IEC 62271-100

Edition 3.1 2024-08
CONSOLIDATED VERSION

# INTERNATIONAL STANDARD

colour inside

## High-voltage switchgear and controlgear –
## Part 100: Alternating-current circuit-breakers



IEC 62271-100:2021-07+AMD1:2024-08 CSV(en)

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# HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

## Part 100: Alternating-current circuit-breakers

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**This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.**

**IEC 62271-100 edition 3.1 contains the third edition (2021-07) [documents 17A/1299/FDIS and 17A/1305/RVD], its corrigendum 1 (2021-12 (applies only to the French version), its corrigendum 2 (2022-07), its corrigendum 3 (2024-01), and its amendment 1 (2024-08) [documents 17A/1406/FDIS and 17A/1410/RVD].**

**In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.**

International Standard IEC 62271-100 has been prepared by subcommittee 17A: Switching devices, of IEC technical committee 17: High-voltage switchgear and controlgear.

This third edition cancels and replaces the second edition published in 2008, Amendment 1:2012 and Amendment 2:2017. This edition constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

– the document has been updated to IEC 62271-1:2017;
– Amendments 1 and 2 have been included;
– the definitions have been updated, terms not used have been removed;
– Subclauses 7.102 through 7.108 have been restructured.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

This document is to be read in conjunction with IEC 62271-1, second edition, published in 2017, to which it refers and which is applicable unless otherwise specified. In order to simplify the indication of corresponding requirements, the same numbering of clauses and subclauses is used as in IEC 62271-1. Amendments to these clauses and subclauses are given under the same references whilst additional subclauses are numbered from 101.

A list of all parts of IEC 62271 series, under the general title *High-voltage switchgear and controlgear* can be found on the IEC website.

The committee has decided that the contents of this document and its amendment will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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# INTRODUCTION to Amendment 1

This amendment includes the following significant changes:

In IEC 62271-100:2021 there is a slight difference for the calculation of $u_c$ for T10 in Table 20 and Table 21. The $u_c$ value for T10 shall be the same for $k_{pp}$ 1,3 and $k_{pp}$ 1,5 because both conditions also cover transformer limited faults. For voltage ratings higher than 170 kV $u_c$ also covers cases of three-phase line faults with effectively earthed neutral systems. See also the notes in Table 20 and Table 21. By increasing the $k_{af}$ from 1,76 to 1,765 the $u_c$ values are practically the same again for $k_{pp}$ 1,3 and $k_{pp}$ 1,5.

Furthermore:

– The definition of terminal fault has been updated.
– The description of the time parameters for the rated operated sequence has been updated (the parameters remained the same).
– Rated voltages 15,5; 27 and 40,5 kV added to Table 1.
– Additional criteria for dielectric test added.
– It has been made explicit that partial discharge test only is applicable to GIS and dead-tank circuit-breakers.
– Voltage test as condition check as per 7.2.12.103 added to 7.2.12.101.
– The $t_2$ for T60 are corrected to the $t_2$ values of T100.
– TRV values in Table 16, Table 17, Table 18, Table 19, Table 20, Table 22, Table 23, Table 24, Table 25, Table 30 and Table F.1 have been recalculated and updated.
– Requirement on having inrush making current in the same phase as minimum arcing times during three-phase back-to-back capacitor bank current tests.
– Requirement to perform mechanical operating tests on all releases added.
– Existing tolerance for single-phase and double-earth fault added to Table B.1.
– Tolerance for breaking current $L_{75}$ updated in Table B.1.

# HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

## Part 100: Alternating-current circuit-breakers

## 1 Scope

This part of IEC 62271 is applicable to three-phase AC circuit-breakers designed for indoor or outdoor installation and for operation at frequencies of 50 Hz and/or 60 Hz on systems having voltages above 1 000 V. This document includes only direct testing methods for making-breaking tests. For synthetic testing methods refer to IEC 62271-101.

NOTE In a direct testing method one source is used to supply the voltage and current during the making and breaking tests.

This part of IEC 62271 is not applicable to:

– circuit-breakers with a closing mechanism for dependent manual operation;
– circuit-breakers intended for use on motive power units of electrical traction equipment; these are covered by IEC 60077 (all parts) [1][1];
– generator circuit-breakers installed between generator and step-up transformer; these are covered by the IEC 62271-37-013 [2];
– self-tripping circuit-breakers with tripping devices that cannot be made inoperative during testing. Tests on automatic circuit reclosers are covered by IEC 62271-111 [3];
– tests to prove the performance under abnormal conditions that are not described in this document are subject to agreement between manufacturer and user. Such abnormal conditions are, for example, cases where the voltage is higher than the rated voltage of the circuit-breaker, conditions which can occur due to sudden loss of load on long lines or cables.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-151:2001, *International Electrotechnical Vocabulary (IEV) – Part 151: Electrical and magnetic devices*
IEC 60050-151:2001/AMD1:2013
IEC 60050-151:2001/AMD2:2014
IEC 60050-151:2001/AMD3:2019
IEC 60050-151:2001/AMD4:2020

IEC 60050-441:1984, *International Electrotechnical Vocabulary (IEV) – Part 441: Switchgear, controlgear and fuses*
IEC 60050-441:1984/AMD1:2000



[1] Numbers in square brackets refer to the bibliography.

IEC 60050-442:1998, *International Electrotechnical Vocabulary (IEV) – Part 442: Electrical accessories*
IEC 60050-442:1998/AMD1:2015
IEC 60050-442:1998/AMD2:2015
IEC 60050-442:1998/AMD3:2019

IEC 60050-461:2008, *International Electrotechnical Vocabulary (IEV) – Part 461: Electric cables*

IEC 60050-601:1985, *International Electrotechnical Vocabulary (IEV) – Part 601: Generation, transmission and distribution of electricity – General*
IEC 60050-601:1985/AMD1:1998
IEC 60050-601:1985/AMD2:2020

IEC 60050-614:2016, *International Electrotechnical Vocabulary (IEV) – Part 614: Generation, transmission and distribution of electricity – Operation*

IEC 60059, *IEC standard current ratings*

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60255-151:2009, *Measuring relays and protection equipment – Part 151: Functional requirements for over/under current protection*

IEC 60270, *High-voltage test techniques – Partial discharge measurements*

IEC 62271-1:2017, *High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear*

IEC 62271-101, *High-voltage switchgear and controlgear – Part 101: Synthetic testing*

IEC 62271-102:2018, *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

IEC 62271-200:20—[2], *High-voltage switchgear and controlgear – Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

IEC 62271-203, *High-voltage switchgear and controlgear – Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-151, IEC 60050-441, IEC 60050-442, IEC 60050-461, IEC 60050-601 and IEC 60050-614, some of which are recalled hereunder, and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

2 Under preparation. Stage at the time of publication: IEC RFDIS 62271-200:2021.

NOTE Terms and definitions are classified in accordance with IEC 60050-441. Reference from other parts than IEC 60050-441 are classified so as to be aligned with the classification used in IEC 60050-441.

### 3.1 General terms and definitions

**3.1.101**
**switchgear and controlgear**
general term covering switching devices intended to be installed indoor or outdoor and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures

[SOURCE: IEC 60050-441:1984, 441-11-01, modified – The definition has been rephrased.]

**3.1.102**
**short-circuit current**
overcurrent resulting from a short-circuit due to a fault or an incorrect connection in an electric circuit

[SOURCE: IEC 60050-441:1984, 441-11-07]

**3.1.103**
**isolated neutral system**
system where the neutral point is not intentionally connected to earth, except for high impedance connections for protection or measurement purposes

[SOURCE: IEC 60050-601:1985, 601-02-24]

**3.1.104**
**solidly earthed (neutral) system**
system whose neutral point(s) is (are) earthed directly

[SOURCE: IEC 60050-601:1985, 601-02-25]

**3.1.105**
**impedance earthed (neutral) system**
system whose neutral point(s) is (are) earthed through impedances to limit earth fault currents

[SOURCE: IEC 60050-601:1985, 601-02-26]

**3.1.106**
**resonant earthed (neutral) system,**
**arc-suppression-coil-earth (neutral) system**
system in which one or more neutral points are connected to earth through reactances which approximately compensate the capacitive component of a single-phase-to-earth fault current

[SOURCE: IEC 60050-601:1985, 601-02-27]

**3.1.107**
**effectively earthed (neutral) system**
system earthed through a sufficiently low impedance such that for all system conditions the ratio of the zero-sequence reactance to the positive-sequence reactance ($X_0/X_1$) is positive and less than 3, and the ratio of the zero-sequence resistance to the positive-sequence reactance ($R_0/X_1$) is positive and less than 1

Note 1 to entry: Normally such systems are solidly earthed (neutral) systems or low impedance earthed (neutral) systems.

Note 2 to entry: The earthing conditions depend not only on the physical earthing conditions around the relevant location but also on the total system.

**3.1.108**
**non-effectively earthed (neutral) system**
system other than effectively earthed neutral system, not meeting the conditions given in 3.1.107

Note 1 to entry: Normally such systems are isolated neutral systems, high impedance earthed (neutral) systems or resonant earthed (neutral) systems.

Note 2 to entry: The earthing conditions depend not only on the physical earthing conditions around the relevant location but also on the total system.

**3.1.109**
**ambient air temperature**
temperature, determined under prescribed conditions, of the air surrounding the complete switching device or fuse

Note 1 to entry: For switching devices or fuses installed inside an enclosure, it is the temperature of the air outside the enclosure.

[SOURCE: IEC 60050-441:1984, 441-11-13]

**3.1.110**
**temperature rise** <of a part of a circuit-breaker>
difference between the temperature of the part under consideration and the ambient air temperature

**3.1.111**
**single capacitor bank**
bank of shunt capacitors in which the inrush current is limited by the inductance of the supply system and the capacitance of the bank of capacitors being energised, there being no other capacitors connected in parallel to the system sufficiently close to increase the inrush current appreciably

**3.1.112**
**back-to-back capacitor bank**
bank of shunt capacitors or capacitor assemblies each of them switched independently to the supply system, the inrush current of one capacitor or capacitor assembly being appreciably increased by the capacitors already connected to the supply

**3.1.113**
**overvoltage** <in an electric power system>
voltage:

– between one line conductor and earth or across a longitudinal insulation having a peak value exceeding the corresponding peak of the highest voltage of the system divided by √3
– between phase conductors having a peak value exceeding the amplitude of the highest voltage of the system

[SOURCE: IEC 60050-614:2016, 614-03-10]

**3.1.114**
**out-of-phase conditions**
abnormal circuit conditions of loss or lack of synchronism between the parts of an electrical system on either side of a circuit-breaker in which, at the instant of operation of the circuit-breaker, the phase angle between rotating vectors, representing the generated voltages on either side, exceeds the normal value

Note 1 to entry: The requirements of this document cater for the great majority of applications of circuit-breakers intended for making and breaking during out-of-phase conditions. Out-of-phase angles corresponding to the specified power frequency recovery voltages are given in 7.110.3. For extreme service conditions see 9.103.3.

**3.1.115**
**out-of-phase** <as prefix to a characteristic quantity>
qualifying term indicating that the characteristic quantity is applicable to operation of the circuit-breaker in out-of-phase conditions

**3.1.116**
**unit test**
test made on a making and breaking unit or group of making and breaking units at the making current or the breaking current, specified for the test on the complete pole of a circuit-breaker and at the appropriate fraction of the applied voltage, or the recovery voltage, specified for the test on the complete pole of the circuit-breaker

**3.1.117**
**loop**
part of the wave of the current embraced by two successive current zero crossings

Note 1 to entry: A distinction is made between a major loop and a minor loop depending on the time interval between two successive current zero crossings being longer or shorter than the half-period of the alternating component of the current.

**3.1.118**
**short-line fault**
**SLF**
short-circuit on an overhead line at a short, but significant, distance from the terminals of the circuit-breaker

Note 1 to entry: As a rule this distance is not more than a few kilometres.

**3.1.119**
**power factor** <of a circuit>
ratio of the resistance to the impedance at power frequency of an equivalent circuit supposed to be formed by a reactance and a resistance in series

**3.1.120**
**external insulation**
distances in atmospheric air, and along the surfaces in contact with atmospheric air of solid insulation of the equipment which are subject to dielectric stresses and to the effects of atmospheric and other environmental conditions from the site

Note 1 to entry: Examples of environmental conditions are pollution, humidity, vermin, etc.

[SOURCE: IEC 60050-614:2016, 614-03-02]

**3.1.121**
**internal insulation**
internal distances of the solid, liquid or gaseous insulation of equipment which are protected from the effects of atmospheric and other external conditions

[SOURCE: IEC 60050-614:2016, 614-03-03]

**3.1.122**
**disruptive discharge**
phenomenon associated with the failure of insulation under electrical stress which includes a collapse of voltage and the passage of current

Note 1 to entry: The term applies to electric breakdown in solid, liquid and gaseous dielectrics and combination of these.

Note 2 to entry: A disruptive discharge in a solid dielectric produces permanent loss of dielectric strength; in a liquid or gaseous dielectric the loss can be temporary only.

[SOURCE: IEC 60050-614:2016, 614-03-16]

**3.1.123**
**non-sustained disruptive discharge**
**NSDD**
disruptive discharge associated with current breaking, that does not result in the resumption of power frequency current or, in the case of capacitive current breaking does not result in current in the load circuit

Note 1 to entry: Oscillations following NSDDs are associated with the parasitic capacitance and inductance local to or of the circuit-breaker itself. NSDDs can also involve the stray capacitance to ground of nearby equipment.

**3.1.124**
**restrike performance**
expected probability of restrike during capacitive current breaking as demonstrated by specified type tests

Note 1 to entry: Specific numeric probabilities cannot be applied throughout a circuit-breaker service life.

**3.1.125**
**re-ignition** <of an AC mechanical switching device>
resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of less than a quarter cycle of power frequency

[SOURCE: IEC 60050-441:1984, 441-17-45]

**3.1.126**
**restrike** <of an AC mechanical switching device>
resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of a quarter cycle of power frequency or longer

[SOURCE: IEC 60050-441:1984, 441-17-46]

**3.1.127**
**current chopping**
current breaking prior to the natural power frequency current zero of the circuit connected

**3.1.128**
**belted cable**
multiconductor cable in which part of the insulation is applied to each conductor individually, and the remainder is applied over the assembled cores

[SOURCE: IEC 60050-461:2008, 461-06-11]

**3.1.129**
**individually screened cable**
**radial field cable**
cable in which each core is covered with an individual screen

[SOURCE: IEC 60050-461:2008, 461-06-12]

### 3.2 Assemblies

No definitions.

### 3.3 Parts of assemblies

No definitions.

### 3.4 Switching devices

**3.4.101**
**switching device**
device designed to make or break the current in one or more electric circuits

[SOURCE: IEC 60050-441:1984, 441-14-01]

**3.4.102**
**mechanical switching device**
switching device designed to close and open one or more electric circuits by means of separable contacts

Note 1 to entry: Any mechanical switching device can be designated according to the medium in which its contacts open and close, for example, air, $SF_6$, oil.

[SOURCE: IEC 60050-441:1984, 441-14-02]

**3.4.103**
**circuit-breaker**
mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short-circuit

[SOURCE: IEC 60050-441:1984, 441-14-20]

**3.4.104**
**dead tank circuit-breaker**
circuit-breaker in which the making and breaking units are housed in an earthed metal tank

[SOURCE: IEC 60050-441:1984, 441-14-25, modified – "interrupters" replaced with "making and breaking units".]

**3.4.105**
**live tank circuit-breaker**
circuit-breaker in which the making and breaking units are housed in a tank insulated from earth

[SOURCE: IEC 60050-441:1984, 441-14-26, modified – "interrupters" replaced with "making and breaking units".]

**3.4.106**
**air circuit-breaker**
circuit-breaker in which the contacts open and close in air at atmospheric pressure

[SOURCE: IEC 60050-441:1984, 441-14-27]

**3.4.107**
**oil circuit-breaker**
circuit-breaker in which the contacts open and close in oil

Note 1 to entry: Typical examples of oil circuit-breakers are live tank minimum oil circuit-breakers and dead tank bulk oil circuit-breakers

[SOURCE: IEC 60050-441:1984, 441-14-28]

**3.4.108**
**vacuum circuit-breaker**
circuit-breaker in which the contacts open and close within a highly evacuated envelope

[SOURCE: IEC 60050-441:1984, 441-14-29]

**3.4.109**
**sealed-for-life circuit-breaker**
circuit-breaker having its making and breaking unit(s) in a sealed pressure system

**3.4.110**
**gas-blast circuit-breaker**
circuit-breaker in which the arc develops in a blast of gas

Note 1 to entry: Where the gas is moved by a difference in pressure established by mechanical means during the opening operation of the circuit-breaker, it is termed a single pressure gas-blast circuit-breaker. Where the gas is moved by a difference in pressure established before the opening operation of the circuit-breaker, it is termed a double pressure gas-blast circuit-breaker.

[SOURCE: IEC 60050-441:1984, 441-14-30]

**3.4.111**
**sulphur hexafluoride circuit-breaker**
**$SF_6$ circuit-breaker**
circuit-breaker in which the contacts open and close in sulphur hexafluoride

[SOURCE: IEC 60050-441:1984, 441-14-31]

**3.4.112**
**air-blast circuit-breaker**
gas-blast circuit-breaker in which the gas used is air

[SOURCE: IEC 60050-441:1984, 441-14-32]

**3.4.113**
**self-tripping circuit-breaker**
circuit-breaker which is tripped by a current in the main circuit without the aid of any form of auxiliary power

### 3.5 Parts of circuit-breakers

**3.5.101**
**pole**
portion of a switching device associated exclusively with one electrically separated conducting path of its main circuit and excluding those portions which provide a means for mounting and operating all poles together

Note 1 to entry: A switching device is called single-pole if it has only one pole. If it has more than one pole, it can be called multipole (two-pole, three-pole, etc.) provided the poles are or can be coupled in such a manner as to operate together.

[SOURCE: IEC 60050-441:1984, 441-15-01]

**3.5.102**
**main circuit** <of a switching device>
all the conductive parts of a switching device included in the circuit which it is designed to close or open

[SOURCE: IEC 60050-441:1984, 441-15-02]

**3.5.103**
**control circuit** <of a switching device>
all the conductive parts (other than the main circuit) of a switching device which are included in a circuit used for the closing operation or opening operation, or both, of the device

[SOURCE: IEC 60050-441:1984, 441-15-03]

**3.5.104**
**auxiliary circuit** <of a switching device>
all the conductive parts of a switching device which are intended to be included in a circuit other than the main circuit and the control circuits of the device

Note 1 to entry: Some auxiliary circuits fulfil supplementary functions such as signalling, interlocking etc., and, as such, they can be part of the control circuit of another switching device

[SOURCE: IEC 60050-441:1984, 441-15-04]

**3.5.105**
**contact** <of a mechanical switching device>
conductive parts designed to establish circuit continuity when they touch and which, due to their relative motion during an operation, open or close a circuit, or in the case of hinged or sliding contacts, maintain circuit continuity

[SOURCE: IEC 60050-441:1984, 441-15-05]

**3.5.106**
**main contact**
contact included in the main circuit of a mechanical switching device, intended to carry, in the closed position, the current of the main circuit

[SOURCE: IEC 60050-441:1984, 441-15-07]

**3.5.107**
**arcing contact**
contact on which the arc is intended to be established

Note 1 to entry: An arcing contact can serve as a main contact; it can be a separate contact so designed that it opens after and closes before another contact which it is intended to protect from injury.

[SOURCE: IEC 60050-441:1984, 441-15-08]

**3.5.108**
**control contact**
contact included in a control circuit of a mechanical switching device and mechanically operated by this device

[SOURCE: IEC 60050-441:1984, 441-15-09]

**3.5.109**
**auxiliary contact**
contact included in an auxiliary circuit and mechanically operated by the switching device

[SOURCE: IEC 60050-441:1984, 441-15-10]

**3.5.110**
**auxiliary switch** <of a mechanical switching device>
switch containing one or more control and/or auxiliary contacts mechanically operated by a switching device

[SOURCE: IEC 60050-441:1984, 441-15-11]

**3.5.111**
**"a" contact**
**make contact**
control or auxiliary contact which is closed when the main contacts of the mechanical switching device are closed and open when they are open

[SOURCE: IEC 60050-441:1984, 441-15-12]

**3.5.112**
**"b" contact**
**break contact**
control or auxiliary contact which is open when the main contacts of a mechanical switching device are closed and closed when they are open

[SOURCE: IEC 60050-441:1984, 441-15-13]

**3.5.113**
**butt contact**
contact in which relative movement of the contact pieces is substantially in a direction perpendicular to the contact surface

[SOURCE: IEC 60050-441:1984, 441-15-14]

**3.5.114**
**release** <of a mechanical switching device>
device, mechanically connected to a mechanical switching device, which releases the holding means and permits the opening or the closing of the switching device

[SOURCE: IEC 60050-441:1984, 441-15-17]

**3.5.115**
**overcurrent release**
release which permits a mechanical switching device to open with or without time-delay when the current in the release exceeds a predetermined value

Note 1 to entry: This value can in some cases depend upon the rate-of-rise of current.

[SOURCE: IEC 60050-441:1984, 441-16-33, modified – Replacement of "may" with "can".]

**3.5.116**
**inverse time-delay overcurrent release**
overcurrent release which operates after a time-delay inversely dependent upon the value of the overcurrent

Note 1 to entry: Such a release may be designed so that the time-delay approaches a definite minimum value for high values of overcurrent.

[SOURCE: IEC 60050-441:1984, 441-16-35]

**3.5.117**
**direct overcurrent release**
overcurrent release directly energised by the current in the main circuit of a mechanical switching device

[SOURCE: IEC 60050-441:1984, 441-16-36]

**3.5.118**
**shunt release**
release energised by a source of voltage

Note 1 to entry: The source of voltage can be independent of the voltage of the main circuit.

[SOURCE: IEC 60050-441:1984, 441-16-41]

**3.5.119**
**under-voltage release**
shunt release which permits a mechanical switching device to open or close, with or without time-delay, when the voltage across the terminals of the release falls below a predetermined value

[SOURCE: IEC 60050-441:1984, 441-16-42]

**3.5.120**
**anti-pumping device**
device which prevents reclosing after a close-open operation as long as the device initiating closing is maintained in the position for closing

[SOURCE: IEC 60050-441:1984, 441-16-48]

**3.5.121**
**interlocking device**
device which makes the operation of a switching device dependent upon the position or operation of one or more other pieces of equipment

[SOURCE: IEC 60050-441:1984, 441-16-49]

**3.5.122**
**circuit-breaker with lock-out preventing closing**
circuit-breaker in which none of the moving contacts can make current if the closing command is initiated while the conditions which should cause the opening operation remain established

[SOURCE: IEC 60050-441:1984, 441-14-23]

**3.5.123**
**arc control device**
device, surrounding the arcing contacts of a mechanical switching device, designed to confine the arc and to assist in its extinction

[SOURCE: IEC 60050-441:1984, 441-15-18]

**3.5.124**
**connection** <bolted or equivalent>
two or more conductors designed to ensure permanent circuit continuity when forced together by means of screws, bolts or the equivalent

**3.5.125**
**terminal**
conductive part of a device, electric circuit or electric network, provided for connecting that device, electric circuit or electric network to one or more external conductors

Note 1 to entry: The term "terminal" is also used for a connection point in circuit theory.

[SOURCE: IEC 60050-151:2001, 151-12-12]

**3.5.126**
**making and breaking unit**
part of a circuit-breaker within which the flow of current is initiated and interrupted

**3.5.127**
**enclosure** <of an assembly>
part of an assembly providing a specified degree of protection of equipment against external influences and a specified degree of protection against approach to or contact with live parts and against contact with moving parts

[SOURCE: IEC 60050-441:1984, 441-13-01]

**3.5.128**
**operating mechanism**
part of the circuit-breaker that actuates the main contacts

**3.5.129**
**power kinematic chain**
mechanical connecting system from and including the operating mechanism up to and including the moving contacts

**3.5.130**
**alternative operating mechanism**
~~alternative operating mechanism is obtained when a~~ change in the power kinematic chain of the original operating mechanism or ~~the~~ use of ~~an entirely~~ a different operating mechanism ~~leads to~~ which retains the same mechanical characteristics

Note 1 to entry: An alternative operating mechanism can utilise an operating principle different from the original one (for example the alternative mechanism can be spring-operated and the original hydraulic).

**3.5.131**
**resistor switch**
contacts intended for switching of a resistive element

**3.5.132**
**vacuum interrupter**
contacts in a highly evacuated, hermetically sealed envelope

## 3.6 Operational characteristics

**3.6.101**
**operation** <of a mechanical switching device>
transfer of the moving contact(s) from one position to an adjacent position

Note 1 to entry: For a circuit-breaker, this can be a closing operation or an opening operation.

Note 2 to entry: If distinction is necessary, an operation in the electrical sense, for example make or break, is referred to as a switching operation, and an operation in the mechanical sense, for example close or open, is referred to as a mechanical operation.

[SOURCE: IEC 60050-441:1984, 441-16-01]

**3.6.102**
**operating cycle** <of a mechanical switching device>
succession of operations from one position to another and back to the first position through all other positions, if any

[SOURCE: IEC 60050-441:1984, 441-16-02]

**3.6.103**
**operating sequence** <of a mechanical switching device>
succession of specified operations with specified time intervals

[SOURCE: IEC 60050-441:1984, 441-16-03]

**3.6.104**
**switching**
closing and/or opening of one or more electrical circuits

**3.6.105**
**closing operation** <of a mechanical switching device>
operation by which the device is brought from the open position to the closed position

[SOURCE: IEC 60050-441:1984, 441-16-08]

**3.6.106**
**opening operation** <of a mechanical switching device>
operation by which the device is brought from the closed position to the open position

[SOURCE: IEC 60050-441:1984, 441-16-09]

**3.6.107**
**auto-reclosing** <of a mechanical switching device>
operating sequence of a mechanical switching device whereby, following its opening, it closes automatically after a predetermined time

[SOURCE: IEC 60050-441:1984, 441-16-10]

**3.6.108**
**dependent manual operation** <of a mechanical switching device>
operation solely by means of directly applied manual energy, such that the speed and force of the operation are dependent upon the action of the operator

[SOURCE: IEC 60050-441:1984 441-16-13]

**3.6.109**
**dependent power operation** <of a mechanical switching device>
operation by means of energy other than manual, where the completion of the operation is dependent upon the continuity of the power supply (to solenoids, electric or pneumatic motors, etc.)

[SOURCE: IEC 60050-441:1984, 441-16-14]

**3.6.110**
**stored energy operation**
operation by means of energy stored in the mechanism itself prior to the completion of the operation and sufficient to complete it under predetermined conditions

Note 1 to entry: This kind of operation can be subdivided according to:

a) The manner of storing the energy (spring, weight, etc.);

b) The origin of the energy (manual, electric, etc.);

c) The manner of releasing the energy (manual, electric, etc.).

SOURCE: IEC 60050-441:1984, 441-16-15]

**3.6.111**
**closed position** <of a mechanical switching device>
position in which the predetermined continuity of the main circuit of the device is secured

[SOURCE: IEC 60050-441:1984, 441-16-22]

**3.6.112**
**open position** <of a mechanical switching device>
position in which the predetermined clearance between open contacts in the main circuit of the device is secured

[SOURCE: IEC 60050-441:1984, 441-16-23]

**3.6.113**
**operating current** <of an overcurrent release>
current value at and above which the release can operate

[SOURCE: IEC 60050-441:1984, 441-16-45]

**3.6.114**
**current setting** <of an overcurrent release>
value of the operating current for which the release is adjusted and in accordance with which its operating conditions are defined

[SOURCE: IEC 60050-441:1984, 441-16-46]

**3.6.115**
**current setting range** <of an overcurrent release>
range between the minimum and maximum values over which the current setting of the release can be adjusted

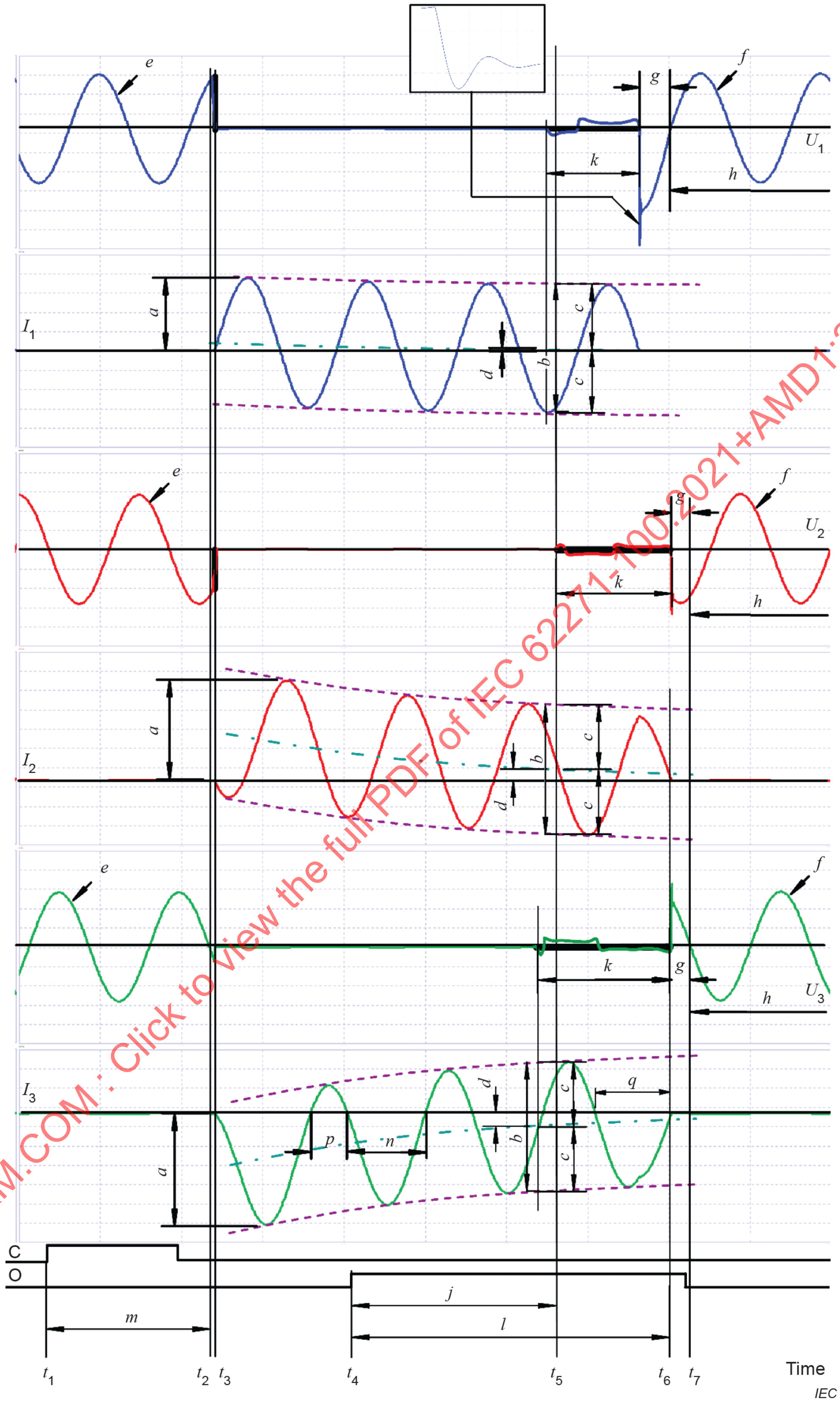
[SOURCE: IEC 60050-441:1984, 441-16-47]

### 3.7 Characteristic quantities

Figure 1 through Figure 7 illustrate some definitions of this subclause.

Time quantities, see definitions 3.7.131 to 3.7.143, are expressed in milliseconds or in cycles. When expressed in cycles, the power frequency should be stated in brackets. In the case of circuit-breakers incorporating switching resistors, a distinction is made, where applicable, between time quantities associated with the contacts switching the full current and the contacts switching the current limited by switching resistors.

Unless otherwise stated, the time quantities referred to are associated with the contacts switching the full current.


e
f
g
k
h
$U_1$
$I_1$
a
b
c
d
$U_2$
$I_2$
$U_3$
$I_3$
p
n
q
C
O
m
j
l
$t_1$
$t_2$
$t_3$
$t_4$
$t_5$
$t_6$
$t_7$
Time
IEC

**Key to** Figure 1**:**

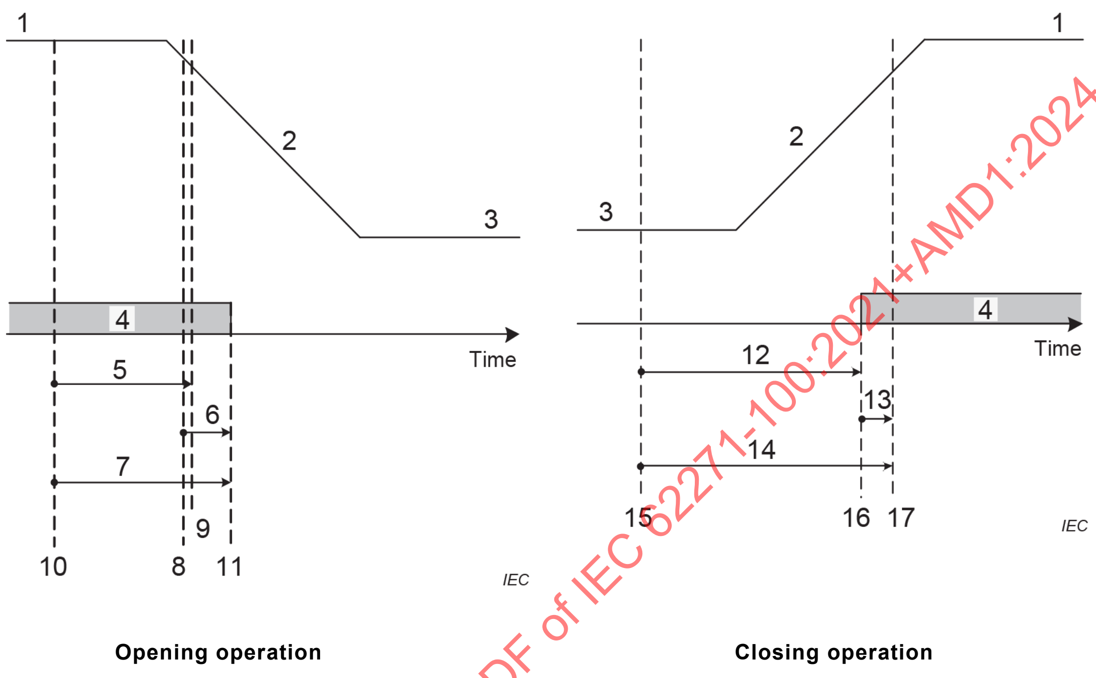
| | |
|---|---|
| $U_1$ | voltage across the terminals of the first-pole-to-clear |
| $I_1$ | current in the first-pole-to-clear |
| $U_2$, $U_3$ | voltage across the terminals of the two other poles |
| $I_2$, $I_3$ | current in the two other poles |
| C | closing command, for example voltage across the terminals of the closing circuit |
| O | opening command, for example voltage across the terminals of the opening release |
| $t_1$ | initiation of the closing operation |
| $t_2$ | instant of the voltage breakdown |
| $t_3$ | instant when the current is established in all poles |
| $t_4$ | initiation of the opening operation |
| $t_5$ | instant when the arcing contacts have separated (or instant of initiation of the arc) in all poles |
| $t_6$ | instant of final arc extinction in all poles |
| $t_7$ | instant when the transient voltage phenomena have subsided in the last pole to clear |
| *a* | (peak) making current |
| *b* | peak-to-peak value of the breaking current |
| *c* | peak value of the alternating component |
| *d* | direct current (DC) component |
| *e* | applied voltage |
| *f* | recovery voltage |
| *g* | TRV |
| *h* | power frequency recovery voltage |
| *j* | opening time |
| *k* | arcing time |
| *l* | break-time |
| *m* | make time |
| *n* | major loop |
| *p* | minor loop |
| *q* | major extended loop |

**Figure 1 – Typical oscillogram of a three-phase short-circuit make-break cycle**

**Notes to the following Figure 2 to Figure 7:**

NOTE 1 In practice, there will be a time spread between the travel of the contacts of the three poles. For clarity the travel of the contacts in the figures is indicated with a single line for all three poles.

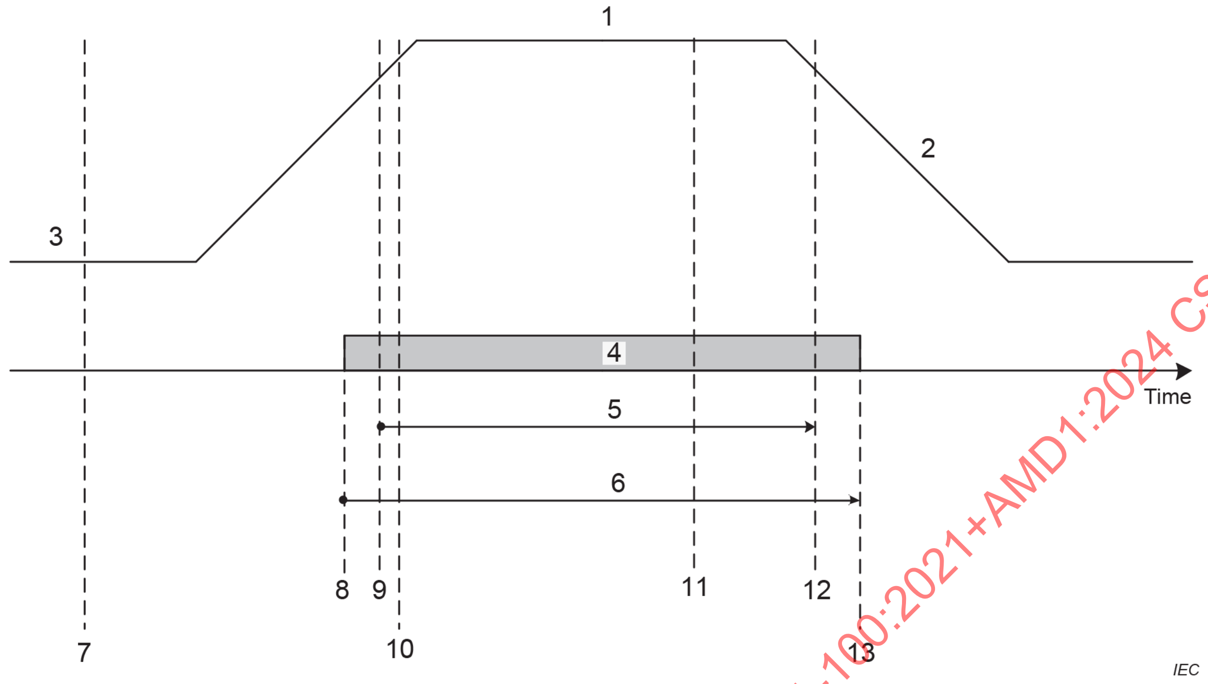
NOTE 2 In practice, there will be a time spread between both the start and end of current flow in the three poles. For clarity, both the start and end of current flow in the figures is indicated with a single line for all three poles.




**Key**

| | | | |
|---|---|---|---|
| 1 | Closed position | 10 | Initiation of opening operation, 3.7.153 |
| 2 | Contact travel | 11 | Instant of final arc extinction in all poles |
| 3 | Open position | 12 | Make time, 3.7.135 |
| 4 | Current flow | 13 | Pre-arcing time, 3.7.136 |
| 5 | Opening time, 3.7.131 | 14 | Closing time, 3.7.134 |
| 6 | Total arcing time, 3.7.154 | 15 | Initiation of closing operation, 3.7.153 |
| 7 | Break-time, 3.7.133 | 16 | Instant of start of current flow in the first pole |
| 8 | Instant of separation of arcing contacts in first opening pole | 17 | Instant of contact touch in all poles |
| 9 | Instant of separation of arcing contacts in all poles | | |

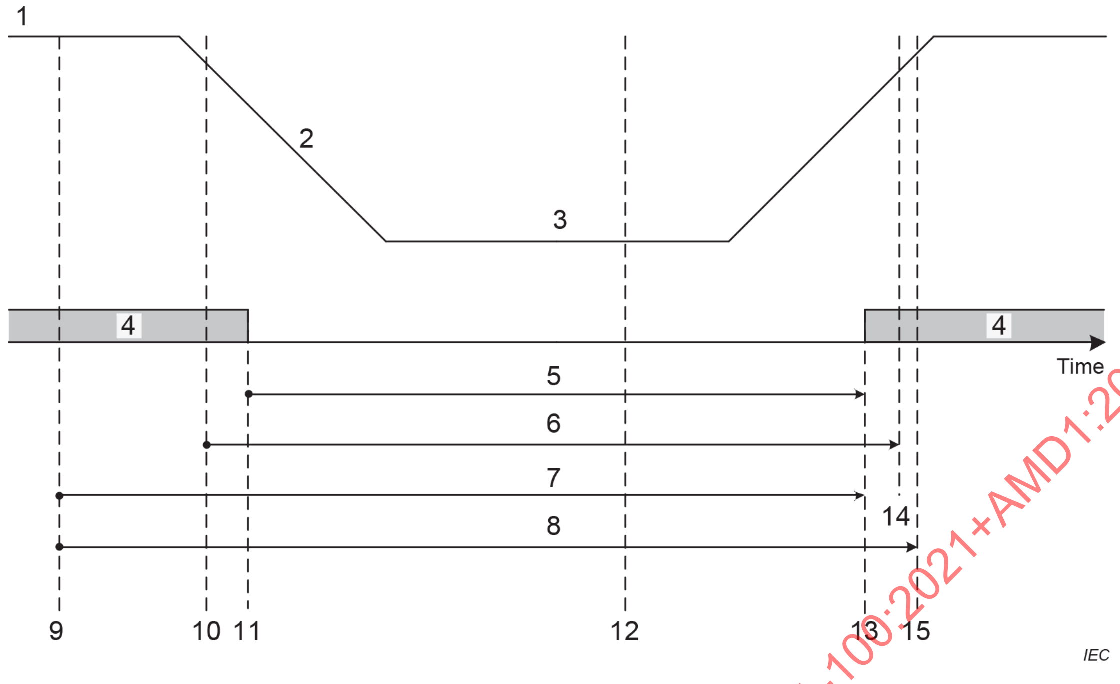
**Figure 2 – Circuit-breaker without switching resistors – Opening and closing operations**




**Key**

1 Closed position
2 Contact travel
3 Open position
4 Current flow
5 Close-open time, 3.7.141
6 Make-break time, 3.7.142
7 Initiation of closing operation, 3.7.153
8 Instant of start of current flow in the first pole
9 Instant of contact touch in the first closing pole
10 Instant of contact touch in all poles
11 Initiation of opening operation, 3.7.153
12 Instant of separation of arcing contacts in all poles
13 Instant of arc extinction in all poles

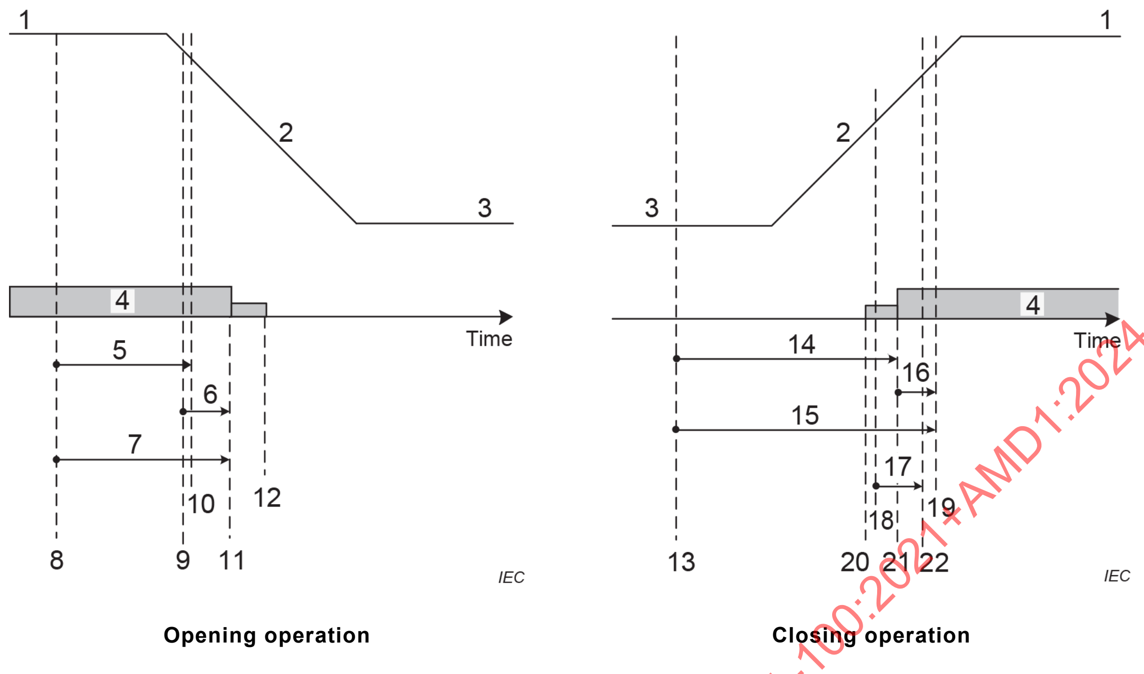
**Figure 3 – Circuit breaker without switching resistors – Close-open cycle**




**Key**

| | | | |
|---|---|---|---|
| 1 | Closed position | 9 | Initiation of opening operation, 3.7.153 |
| 2 | Contact travel | 10 | Instant of separation of arcing contacts in all poles |
| 3 | Open position | 11 | Instant of final arc extinction in all poles |
| 4 | Current flow | 12 | Initiation of closing operation, 3.7.153 |
| 5 | Dead time, 3.7.138 | 13 | Instant of start of current flow in the first closing pole |
| 6 | Open-close time, 3.7.137 | 14 | Instant of contact touch in first pole |
| 7 | Re-make time, 3.7.140 | 15 | Instant of contact touch in all poles |
| 8 | Reclosing time, 3.7.139 | | |

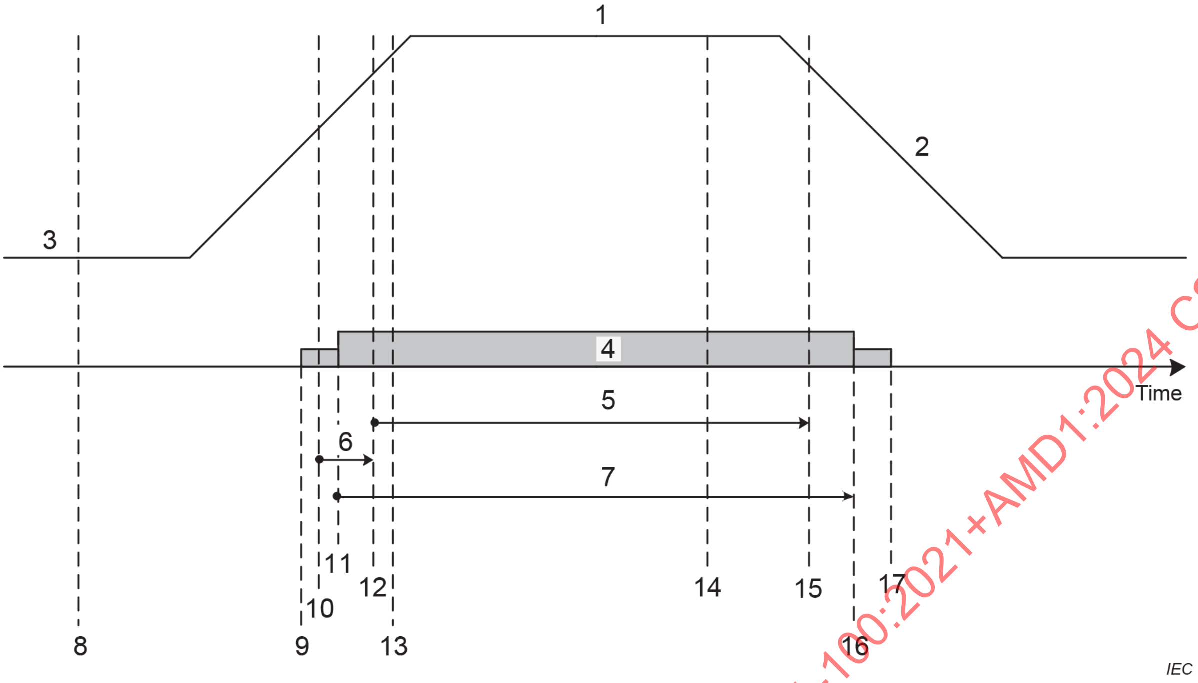
**Figure 4 – Circuit-breaker without switching resistors – Reclosing (auto-reclosing)**




**Key**

| | |
|---|---|
| 1 | Closed position |
| 2 | Contact travel |
| 3 | Open position |
| 4 | Current flow |
| 5 | Opening time, 3.7.131 |
| 6 | Total arcing time, 3.7.154 |
| 7 | Break-time, 3.7.133 |
| 8 | Initiation of opening operation, 3.7.153 |
| 9 | Instant of separation of arcing contacts in first opening pole |
| 10 | Instant of separation of arcing contacts in all poles |
| 11 | Instant of arc extinction in all poles – Full current |
| 12 | Instant of arc extinction in all poles – Resistor current |
| 13 | Initiation of the closing operation, 3.7.153 |
| 14 | Make time, 3.7.135 |
| 15 | Closing time, 3.7.134 |
| 16 | Pre-arcing time, 3.7.136 |
| 17 | Pre-insertion time, 3.7.143 |
| 18 | Instant of contact touch in the closing resistor of any one pole |
| 19 | Instant of contact touch in all poles |
| 20 | Instant of start of current flow in the first pole – Resistor current |
| 21 | Instant of the start of current flow in the first pole – Full current |
| 22 | Instant of contact touch in the making and breaking unit of the same pole as regarded for the resistor |

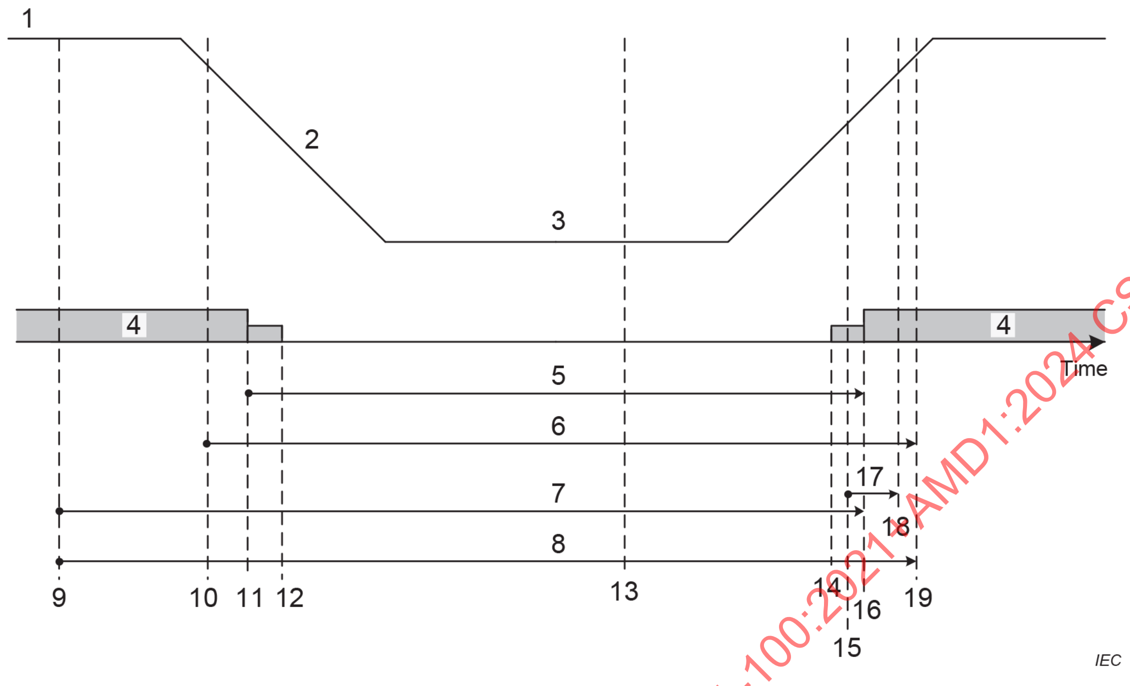
**Figure 5 – Circuit-breaker with switching resistors – Opening and closing operations**




**Key**

| | | | |
|---|---|---|---|
| 1 | Closed position | 10 | Instant of contact touch in the closing resistor of any one pole |
| 2 | Contact travel | 11 | Instant of start of current flow in the first pole – Full current |
| 3 | Open position | 12 | Instant of contact touch in the making and breaking unit of the same pole as regarded for the resistor |
| 4 | Current flow | 13 | Instant of contact touch in all poles |
| 5 | Close-open time, 3.7.141 | 14 | Initiation of opening operation, 3.7.153 |
| 6 | Pre-insertion time, 3.7.143 | 15 | Instant of separation of arcing contacts in all poles |
| 7 | Make-break time, 3.7.142 | 16 | Instant of arc extinction in all poles – Full current |
| 8 | Initiation of closing operation, 3.7.153 | 17 | Instant of arc extinction in all poles – Resistor current |
| 9 | Instant of start of current flow in the first pole – Resistor current | | |

**Figure 6 – Circuit-breaker with switching resistors – Close-open cycle**




**Key**

| | | | |
|---|---|---|---|
| 1 | Closed position | 11 | Instant of arc extinction in all poles – Full current |
| 2 | Contact travel | 12 | Instant of arc extinction in all poles – Resistor current |
| 3 | Open position | 13 | Initiation of closing operation, 3.7.153 |
| 4 | Current flow | 14 | Resistor current |
| 5 | Dead time, 3.7.138 | 15 | Instant of contact touch in the closing resistor of any one pole |
| 6 | Open-close time, 3.7.137 | 16 | Instant of start of current flow in the first pole – Full current |
| 7 | Re-make time, 3.7.140 | 17 | Pre-insertion time, 3.7.143 |
| 8 | Reclosing time, 3.7.139 | 18 | Instant of contact touch in the breaking unit of the same pole as regarded for the resistor |
| 9 | Initiation of opening operation, 3.7.153 | 19 | Instant of contact touch in all poles |
| 10 | Instant of separation of arcing contacts in all poles | | |

**Figure 7 – Circuit-breaker with switching resistors – Reclosing (auto-reclosing)**

**3.7.101**
**rated value**
quantity value assigned, generally by the manufacturer, for a specified operating condition of a component, device or equipment

Note 1 to entry: Examples of rated value usually stated for fuses: voltage, current, breaking capacity.

[SOURCE: IEC 60050-441:2000, 441-18-35]

**3.7.102**
**prospective current** <of a circuit and with respect to a switching device or a fuse>
current that would flow in the circuit if each pole of the switching device or the fuse were replaced by a conductor of negligible impedance

Note 1 to entry: The method to be used to evaluate and to express the prospective current is specified in the relevant publications.

[SOURCE: IEC 60050-441:1984, 441-17-01]

**3.7.103**
**prospective peak current**
peak value of the first major loop of the prospective current during the transient period following initiation

Note 1 to entry: The definition assumes that the current is made by an ideal circuit-breaker, i.e. with instantaneous and simultaneous transition of its impedance across the terminals of each pole from infinity to zero. The peak value can differ from one pole to another; it depends on the instant of current initiation relative to the voltage wave across the terminals of each pole.

**3.7.104**
**peak current**
peak value of the first major loop of current during the transient period following initiation

**3.7.105**
**prospective symmetrical current** <of an AC circuit>
prospective current when it is initiated at such an instant that no transient phenomenon follows the initiation

Note 1 to entry: For polyphase circuits, the condition of non-transient period can only be satisfied for the current in one pole at a time.

Note 2 to entry: The prospective symmetrical current is expressed by its RMS value.

[SOURCE: IEC 60050-441:1984, 441-17-03]

**3.7.106**
**maximum prospective peak current** <of an AC circuit>
prospective peak current when initiation of the current takes place at the instant which leads to the highest possible value

Note 1 to entry: For a multiple device in a polyphase circuit, the maximum prospective peak current refers to a single pole only.

[SOURCE: IEC 60050-441:1984, 441-17-04]

**3.7.107**
**prospective making current** <for a pole of a switching device>
prospective current when initiated under specified conditions

Note 1 to entry: The specified conditions can relate to the method of initiation, for example by an ideal switching device, or to the instant of initiation, for example leading to the maximum prospective peak current in an AC circuit, or to the highest rate of rise. The specification of these conditions is found in the relevant publications.

[SOURCE: IEC 60050-441:1984, 441-17-05]

**3.7.108**
**making current**
peak value of the first major loop of the current in a pole of a circuit-breaker during the transient period following the initiation of current during a making operation

Note 1 to entry: The peak value can differ from one pole to another and from one operation to another as it depends on the instant of current initiation relative to the wave of the applied voltage.

Note 2 to entry: Where, for a polyphase circuit, a single value of (peak) making current is referred to, this is, unless otherwise stated, the highest value in any phase.

**3.7.109**
**prospective breaking current** <for a pole of a switching device>
prospective current evaluated at a time corresponding to the instant of the initiation of the breaking process

Note 1 to entry: Specifications concerning the instant of the initiation of the breaking process can be found in the relevant publications. For mechanical switching devices or fuses, it is usually defined as the moment of initiation of the arc during the breaking process.

[SOURCE: IEC 60050-441:1984, 441-17-06]

**3.7.110**
**breaking current** <of a switching device or a fuse>
current in a pole of a switching device or in a fuse at the instant of initiation of the arc during a breaking process

[SOURCE: IEC 60050-441:1984, 441-17-07]

**3.7.111**
**making and breaking test**
test during which the circuit-breaker is closed (to make) and opened (to break)

**3.7.112**
**terminal fault**
short-circuit on at least one of the terminals of the circuit-breaker

Note 1 to entry: The terminal fault current has contributions from the source side only.

**3.7.113**
**critical (breaking) current**
value of breaking current, less than rated short-circuit breaking current, at which the arcing time is a maximum and is significantly longer than that of the rated short-circuit breaking current

**3.7.114**
**breaking capacity** <of a switching device or a fuse>
value of prospective current that a switching device or a fuse is capable of breaking at a stated voltage under prescribed conditions of use and behaviour

Note 1 to entry: The voltage to be stated and the conditions to be prescribed are dealt with in the relevant publications.

Note 2 to entry: For switching devices, the breaking capacity can be termed according to the kind of current included in the prescribed conditions, for example line-charging breaking capacity, cable charging breaking capacity, single capacitor bank breaking capacity, etc.

[SOURCE: IEC 60050-441:1984, 441-17-08]

**3.7.115**
**no-load line-charging breaking capacity**
breaking capacity for which the specified conditions of use and behaviour include the opening of an overhead line operating at no-load

**3.7.116**
**no-load cable-charging breaking capacity**
breaking capacity for which the specified conditions of use and behaviour include the opening of an insulated cable operating at no-load

**3.7.117**
**capacitor bank breaking capacity**
breaking capacity for which the specified conditions of use and behaviour include the opening of a capacitor bank

**3.7.118**
**making capacity** <of a switching device or a fuse>
value of prospective making current that a switching device is capable of making at a stated voltage under prescribed conditions of use and behaviour

Note 1 to entry: The voltage to be stated and the conditions to be prescribed are dealt with in the relevant specifications.

[SOURCE: IEC 60050-441:1984, 441-17-09]

**3.7.119**
**capacitor bank inrush making capacity**
making capacity for which the specified conditions of use and behaviour include the closing onto a capacitor bank

**3.7.120**
**out-of-phase (making or breaking) capacity**
making or breaking capacity for which the specified conditions of use and behaviour include the loss or the lack of synchronism between the parts of an electrical system on either side of the circuit-breaker

**3.7.121**
**short-circuit making capacity**
making capacity for which the prescribed conditions include a short-circuit at the terminals of the switching device

[SOURCE: IEC 60050-441:1984, 441-17-10]

**3.7.122**
**short-circuit breaking capacity**
breaking capacity for which the prescribed conditions include a short-circuit at the terminals of the switching device

[SOURCE: IEC 60050-441:1984, 441-17-11]

**3.7.123**
**short-time withstand current**
current that a circuit or a switching device in the closed position can carry during a specified short time under prescribed conditions of use and behaviour

[SOURCE: IEC 60050-441:1984, 441-17-17]

**3.7.124**
**peak withstand current**
value of peak current that a circuit or a switching device in the closed position can withstand under prescribed conditions of use and behaviour

[SOURCE: IEC 60050-441:1984, 441-17-18]

**3.7.125**
**applied voltage** <for a switching device>
voltage which exists across the terminals of a pole of a switching device just before the making of the current

[SOURCE: IEC 60050-441:1984, 441-17-24]

**3.7.126**
**recovery voltage**
voltage which appears across the terminals of a pole of a switching device or a fuse after the breaking of the current

Note 1 to entry: This voltage can be considered in two successive intervals of time, one during which a transient voltage exists, followed by a second one during which the power frequency or the steady-state recovery voltage alone exists.

[SOURCE: IEC 60050-441:1984, 441-17-25]

**3.7.127**
**transient recovery voltage**
**TRV**
recovery voltage during the time in which it has a significant transient character

Note 1 to entry: The transient recovery voltage can be oscillatory or non-oscillatory or a combination of these depending on the characteristics of the circuit and the switching device. It includes the voltage shift of the neutral of a polyphase circuit.

Note 2 to entry: The transient recovery voltages in three-phase circuits is, unless otherwise stated, that across the first pole to clear, because this voltage is generally higher than that which appears across each of the other two poles.

[SOURCE: IEC 60050-441:1984, 441-17-26]

**3.7.128**
**prospective transient recovery voltage** <of a circuit>
transient recovery voltage following the breaking of the prospective symmetrical current by an ideal switching device

Note 1 to entry: The definition assumes that the switching device or the fuse, for which the prospective transient recovery voltage is sought, is replaced by an ideal switching device, i.e. having instantaneous transition from zero to infinite impedance at the very instant of zero current, i.e. at the "natural" zero. For circuits where the current can follow several different paths, for example a polyphase circuit, the definition further assumes that the breaking of the current by the ideal switching device takes place only in the pole considered.

[SOURCE: IEC 60050-441:1984, 441-17-29]

**3.7.129**
**power frequency recovery voltage**
recovery voltage after the transient voltage phenomena have subsided

[SOURCE: IEC 60050-441:1984, 441-17-27]

**3.7.130**
**clearance**
distance between two conductive parts along a string stretched the shortest way between these conductive parts

[SOURCE: IEC 60050-441:1984, 441-17-31]

**3.7.131**
**opening time** <of a mechanical switching device>
interval of time between the specified instant of initiation of the opening operation and the instant when the arcing contacts have separated in all poles

Note 1 to entry: The instant of initiation of the opening operation, i.e. the application of the opening command (for example energizing the release, etc.) is given in the relevant specifications.

[SOURCE: IEC 60050-441:1984, 441-17-36]

**3.7.132**
**arcing time** <of a pole or a fuse>
interval of time between the instant of the initiation of the arc in a pole or a fuse and the instant of final arc extinction in that pole or that fuse

[SOURCE: IEC 60050-441:1984, 441-17-37]

**3.7.133**
**break-time**
interval of time between the beginning of the opening time of a mechanical switching device (or the pre-arcing time of a fuse) and the end of the arcing time

[SOURCE: IEC 60050-441:1984, 441-17-39]

**3.7.134**
**closing time**
interval of time between the initiation of the closing operation and the instant when the contacts touch in all poles

[SOURCE: IEC 60050-441:1984, 441-17-41]

**3.7.135**
**make-time**
interval of time between the initiation of the closing operation and the instant when the current begins to flow in the main circuit

[SOURCE: IEC 60050-441:1984, 441-17-40]

**3.7.136**
**pre-arcing time** <of a circuit-breaker>
interval of time between the initiation of current flow in the first pole during a closing operation and the instant when the contacts touch in all poles for three-phase conditions and the instant when the contacts touch in the arcing pole for single-phase conditions

Note 1 to entry: The pre-arcing time depends on the instantaneous value of the applied voltage during a specific closing operation and therefore can vary considerably.

Note 2 to entry: The definition of pre-arcing time of a circuit-breaker is different from that of a fuse.

**3.7.137**
**open-close time** <during auto-reclosing>
interval of time between the instant when the arcing contacts have separated in all poles and the instant when the contacts touch in the first pole during a reclosing cycle

**3.7.138**
**dead time** <during auto-reclosing>
interval of time between final arc extinction in all poles on the opening operation and the first reestablishment of current in any pole on the subsequent closing operation

[SOURCE: IEC 60050-441:1984, 441-17-44]

**3.7.139**
**reclosing time**
interval of time between the beginning of the opening time and the instant when the contacts touch in all poles during a reclosing cycle

**3.7.140**
**re-make time** <during reclosing>
interval of time between the beginning of the opening time and the first re-establishment of current in any pole in the subsequent closing operation

Note 1 to entry: The re-make time can vary, for example due to the variation of the pre-arcing time.

**3.7.141**
**close-open time**
interval of time between the instant when the contacts touch in the first pole during a closing operation and the instant when the arcing contacts have separated in all poles during the subsequent opening operation

[SOURCE: IEC 60050-441:1984, 441-17-42]

**3.7.142**
**make-break time**
interval of time between the instant when the current begins to flow in a pole and the instant of final arc extinction in all poles, with the opening release energised at the instant when current begins to flow in the main circuit

[SOURCE: IEC 60050-441:1984, 441-17-43]

**3.7.143**
**pre-insertion time** <of a closing resistor>
interval of time during which the resistor remains in the main circuit during a no-load operation

**3.7.144**
**continuous current**
current that the main circuit of a circuit-breaker is capable of carrying continuously under specified conditions of use and behaviour

**3.7.145**
**peak factor**
ratio of the maximum absolute value of an alternating quantity to its RMS value

Note 1 to entry: For an alternating quantity $x$, the peak factor is equal to $x_{max} / X_{eff}$.

**3.7.146**
**first-pole-to-clear factor** <in a three-phase system>
$k_{\mathbf{pp}}$
when breaking any symmetrical three-phase current, the first-pole-to-clear factor is the ratio of the power frequency voltage across the first interrupting pole before current breaking in the other poles, to the power frequency voltage occurring across the pole or the poles after breaking in all three poles

**3.7.147**
**amplitude factor**
$k_{\mathbf{af}}$
ratio between the maximum excursion of the TRV to the crest value of the power frequency recovery voltage

**3.7.148**
**insulation level**
set of withstand voltages specified which characterise the dielectric strength of the insulation

[SOURCE: IEC 60050-614:2016, 614-03-23]

**3.7.149**
**power frequency withstand voltage**
RMS value of sinusoidal power frequency voltage that the insulation of the given equipment can withstand during tests made under specified conditions and for a specified duration

[SOURCE: IEC 60050-614:2016, 614-03-22]

**3.7.150**
**impulse withstand voltage**
highest peak value of impulse voltage of prescribed form and polarity which does not cause breakdown of insulation under specified conditions

[SOURCE: IEC 60050-442:2014, 442-09-18]

**3.7.151**
**minimum clearing time**
sum of the minimum opening time, minimum relay time (0,5 cycle), and the shortest arcing time of a minor loop breaking in the phase with intermediate asymmetry that starts with a minor loop at short-circuit current initiation

**3.7.152**
**insertion time** <of an opening resistor>
interval of time during an opening operation between the instant of separation of the arcing contacts in the making and breaking units of any one pole and the instant of contact separation in the resistor switch in that pole

**3.7.153**
**initiation of (opening or closing) operation**
instant of receipt of command for operation at the control circuit

**3.7.154**
**total arcing time**
interval of time between the instant of the first initiation of an arc in a pole and the instant of arc extinction in all poles

**3.7.155**
**direct connection to an overhead line**
connection between a circuit-breaker and an overhead line having a capacitance less than 5 nF

## 3.8 Index of definitions

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S

# 4 Normal and special service conditions

Clause 4 of IEC 62271-1:2017 is applicable.

# 5 Ratings

## 5.1 General

Subclause 5.1 of IEC 62271-1:2017 is applicable with the following additional items.

k) rated short-circuit breaking current;

l) rated first-pole-to-clear factor;

m) rated short-circuit making current;

n) rated operating sequence.

*Optional rated characteristics*

o) rated out-of-phase making and breaking current;

p) rated line-charging breaking current;

q) rated cable-charging breaking current;

r) rated single capacitor bank breaking current;

s) rated back-to-back capacitor bank breaking current;

t) rated back-to-back capacitor bank inrush making current.

### 5.2 Rated voltage ($U_r$)

Subclause 5.2 of IEC 62271-1:2017 is applicable.

### 5.3 Rated insulation level ($U_d$, $U_p$, $U_s$)

Subclause 5.3 of IEC 62271-1:2017 is applicable with the following addition:

The standard values of rated withstand voltages across the open circuit-breaker are given in Tables 1, 2, 3 and 4 of IEC 62271-1:2017.

### 5.4 Rated frequency ($f_r$)

Subclause 5.4 of IEC 62271-1:2017 is applicable with the following modification:

The standard values for the rated frequency of high-voltage circuit-breakers are 50 Hz and 60 Hz.

### 5.5 Rated continuous current ($I_r$)

Subclause 5.5 of IEC 62271-1:2017 is applicable with the following addition:

If the circuit-breaker is fitted with a series connected accessory, such as a direct overcurrent release, the rated continuous current of the accessory is the RMS value of the current which the accessory shall be able to carry continuously without deterioration at its rated frequency, with a temperature rise not exceeding the values specified in Table 14 of IEC 62271-1:2017.

### 5.6 Rated short-time withstand current ($I_k$)

Subclause 5.6 of IEC 62271-1:2017 is applicable with the following addition:

The rated short-time withstand current is equal to the rated short-circuit breaking current (see 5.101).

### 5.7 Rated peak withstand current ($I_p$)

Subclause 5.7 of IEC 62271-1:2017 is applicable.

### 5.8 Rated duration of short-circuit ($t_k$)

Subclause 5.8 of IEC 62271-1:2017 is applicable.

### 5.9 Rated supply voltage of auxiliary and control circuits ($U_a$)

Subclause 5.9 of IEC 62271-1:2017 is applicable.

### 5.10 Rated supply frequency of auxiliary and control circuits

Subclause 5.10 of IEC 62271-1:2017 is applicable.

### 5.11 Rated pressure of compressed gas supply for controlled pressure systems

Subclause 5.11 of IEC 62271-1:2017 is applicable.

**5.101 Rated short-circuit breaking current ($I_{sc}$)**

**5.101.1 General**

A circuit-breaker shall be capable of breaking its rated short-circuit breaking current at voltages equal to and lower than its rated voltage. The rated short-circuit breaking current is the highest short-circuit current which the circuit-breaker shall be capable of breaking under the conditions of use and behaviour required in this document.

The rated short-circuit breaking current is characterised by two values:

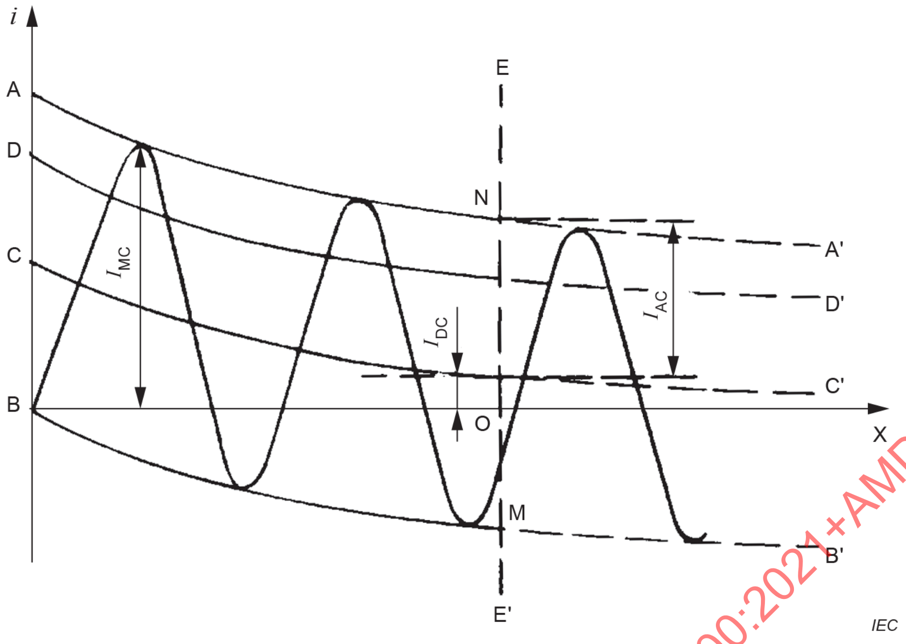
– the RMS value of its AC component;

– the DC time constant of the rated short-circuit breaking current.

If the level of asymmetry expressed in terms of the DC component at contact separation does not exceed 20 %, the rated short-circuit breaking current is considered symmetrical and characterised only by the RMS value of its AC component.

For determination of the AC component and the percentage of DC component at any time following current initiation, see Figure 8.

Circuit-breakers directly connected to overhead lines can be exposed to short-line faults. Further information regarding applicability and testing is given in 3.7.155, 6.107.3 and 7.109.




| | |
|---|---|
| AA'<br>BB' | envelope of current-wave |
| BX | normal zero line |
| CC' | displacement of current-wave zero-line at any instant |
| DD' | RMS value of the AC component of current at any instant, measured from CC' |
| EE' | instant of contact separation (initiation of the arc) |
| $I_{MC}$ | making current |
| $I_{AC}$ | peak value of AC component of current at instant EE' |
| $\frac{I_{AC}}{\sqrt{2}}$ | RMS value of the AC component of current at instant EE' |
| $I_{DC}$ | DC component of current at instant EE' |
| $\frac{I_{DC}}{I_{AC}}\times 100=\frac{\overline{ON}-\overline{OM}}{\overline{MN}}\times 100=\left(\frac{2\times\overline{ON}}{\overline{MN}}-1\right)\times 100$ | percentage value of the DC component |

**Figure 8 – Determination of short-circuit making and breaking currents, and of percentage DC component**

### 5.101.2 AC component of the rated short-circuit breaking current

The standard value of the AC component of the rated short-circuit breaking current shall be selected from the R10 series specified in IEC 60059.

NOTE The R10 series comprises the numbers 1 – 1,25 – 1,6 – 2 – 2,5 – 3,15 – 4 – 5 – 6,3 – 8 and their products by $10^n$.

**5.101.3 DC time constant of the rated short-circuit breaking current**

a) For circuit-breakers with rated voltages up to and including 800 kV

The standard DC time constant is 45 ms. The following are special case DC time constants, related to the rated voltage of the circuit-breaker:

– 120 ms for rated voltages up to and including 52 kV;

– 60 ms for rated voltages from 72,5 kV up to and including 420 kV;

– 75 ms for rated voltages 550 kV and 800 kV.

These special case time constants recognise that the standard value may be inadequate in some systems. They are provided as unified values for such special system needs, taking into account the characteristics of the different ranges of the rated voltage, for example their particular system structures, the design of lines, etc.

In addition, some applications may require even higher values, for example if a circuit-breaker is close to generators. In these circumstances the required DC time constant and any additional test requirements should be specified in the inquiry.

NOTE 1 More detailed information on the use of the standard time constant and the special case time constants is given in the IEC TR 62271-306 [4][3]. The percentage of DC component against time for different time constants is shown in Figure 9.

NOTE 2 The percentage of DC component at contact separation as used in former editions of IEC 62271-100 can be derived by using the equation given in 7.107.6. The concept of percentage of DC component at contact separation for symmetrical test-duties is still used in this edition. For the asymmetrical test-duty T100a, such concept has been changed (see IEC TR 62271-306 [4]).

b) For circuit-breakers with rated voltages higher than 800 kV

The standard DC time constant is 120 ms. Note 2 is also applicable in this case.

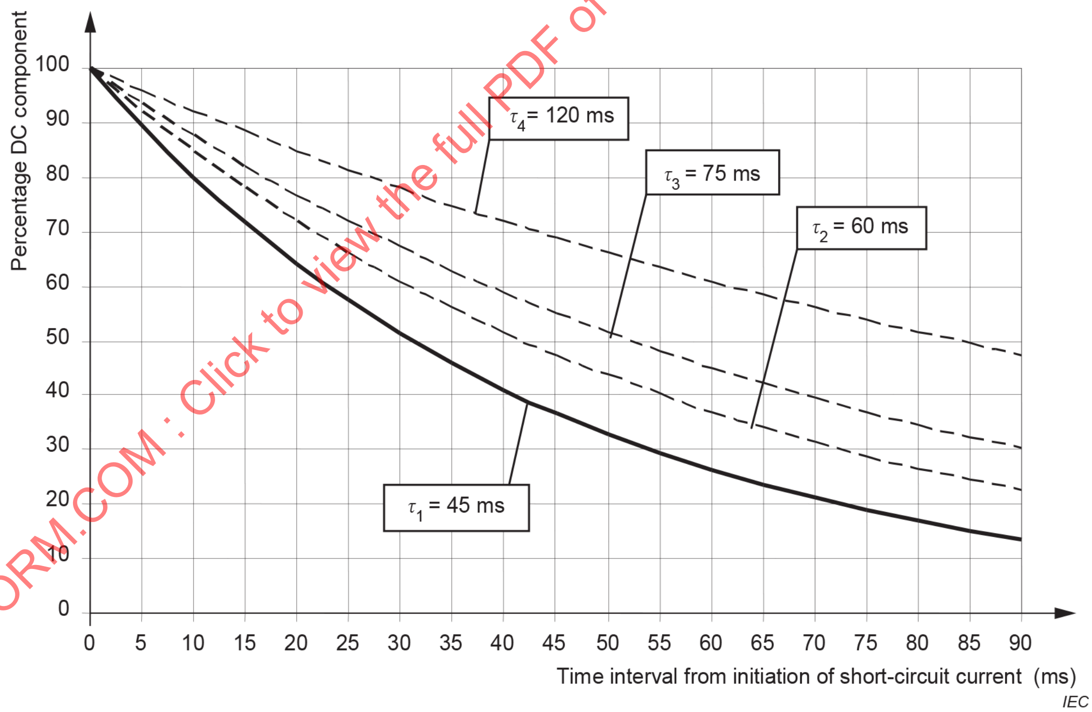



**Figure 9 – Percentage DC component in relation to the time interval from the initiation of the short-circuit for the different time constants**

[3] Numbers in square brackets refer to the Bibliography.

### 5.102 Rated first-pole-to-clear factor ($k_{pp}$)

The ability of the circuit-breaker to operate in networks having different earthing conditions of the system neutral is expressed in terms of $k_{pp}$. The rated values of $k_{pp}$ are:

– 1,2 for circuit-breakers with rated voltages higher than 800 kV in effectively earthed neutral systems;
– 1,3 for circuit-breakers for rated voltages up to and including 800 kV in effectively earthed neutral systems;
– 1,5 for circuit-breakers for rated voltages up to and including 170 kV in non-effectively earthed neutral systems.

NOTE 1 In this document, it is considered that systems with voltages up to and including 170 kV can have either effectively earthed neutrals or non-effectively earthed neutrals. Systems with voltages higher than 170 kV have an effectively-earthed neutral.

NOTE 2 The rated first-pole-to-clear factors given here are associated with terminal faults. For other switching conditions other first-pole-to-clear factors apply. As an example, the following $k_{pp}$ applies to out-of-phase conditions:

– 2,0 for breaking in out-of-phase conditions in systems with effectively earthed neutral;
– 2,5 for breaking in out-of-phase conditions in systems with non-effectively earthed neutral.

### 5.103 Rated short-circuit making current

The rated short-circuit making current is obtained by multiplying the RMS value of the AC component of the rated short-circuit breaking current (see 5.101) with the peak factor given in Table 5 of IEC 62271-1:2017.

### 5.104 Rated operating sequence

The rated operating sequence is O – $t$ – CO – $t'$ – CO, where

O represents an opening operation;

CO represents a close-open operating cycle with the shortest possible close-open time such that the circuit-breaker reaches the fully closed and latched position prior to opening;.

~~$t$ = 3 min for circuit-breakers for auto-reclosing. Alternative values of 15 s and 1 min can be used;~~

~~$t$ = 0,3 s for circuit-breakers for rapid auto-reclosing;~~

~~$t'$ = 3 min. Alternative values of 15 s and 1 min can be used.~~

~~For some applications circuit-breakers can be used without auto-reclosing. For convenience of testing these types of circuit-breakers can be tested with the operating sequence specified for auto-reclosing.~~

The time parameters are as follows:

– circuit-breaker for auto-reclosing: $t$ = 3 min and $t'$= 3 min (alternative values for $t$ and $t'$ may be used, for example 15 s or 1 min);
– circuit-breaker for rapid auto-reclosing: $t$ = 0,3 s and $t'$ = 3 min (alternative values for $t'$ may be used, for example 15 s or 1 min);
– circuit-breaker not for auto-reclosing: $t$ > 3 min and $t'$ > 3 min (values for $t$ and $t'$ to be specified by the manufacturer).

### 5.105 Rated out-of-phase making and breaking current

The rated out-of-phase breaking current is the maximum out-of-phase current that the circuit-breaker shall be capable of breaking under the conditions of use and behaviour required in this document in a circuit having a recovery voltage as specified in 7.110.

If a rated out-of-phase breaking current is assigned, the rated out-of-phase breaking current shall be 25 % of the rated short-circuit breaking current and the rated out-of-phase making current shall be the crest value of the rated out-of-phase breaking current.

The standard conditions of use with respect to the rated out-of-phase making and breaking current are as follows:

– opening and closing operations carried out in conformity with the instructions given by the manufacturer for the operation and proper use of the circuit-breaker and its auxiliary equipment;
– earthing condition of the neutral for the power system corresponding to that for which the circuit-breaker has been tested;
– absence of a fault on either side of the circuit-breaker.

### 5.106 Rated capacitive currents

#### 5.106.1 General

Switching of capacitive loads can comprise part or all of the operating duty of a circuit-breaker such as the charging current of an unloaded transmission line or cable or the load current of a shunt capacitor bank.

NOTE The classes associated with making and breaking of capacitive currents are explained in 6.107.4.

The rating of a circuit-breaker for capacitive currents shall include, where applicable:

– rated line-charging breaking current;
– rated cable-charging breaking current;
– rated single capacitor bank breaking current;
– rated back-to-back capacitor bank breaking current;
– rated back-to-back capacitor bank inrush making current.

Preferred values of rated capacitive currents are given in Table 1.

**Table 1 – Preferred values of rated capacitive currents**

| | Line | Cable | Single capacitor bank | Back-to-back capacitor bank | |
|---|---|---|---|---|---|
| **Rated voltage** $U_r$ kV | **Rated line-charging breaking current** $I_l$ A | **Rated cable-charging breaking current** $I_c$ A | **Rated single capacitor bank breaking current** $I_{sb}$ A | **Rated back-to-back capacitor bank breaking current** $I_{bb}$ A | **Rated back-to-back capacitor bank inrush making current** $I_{bi}$ kA |
| 3,6 | 10 | 10 | 400 | 400 | 20 |
| 4,76 | 10 | 10 | 400 | 400 | 20 |
| 7,2 | 10 | 10 | 400 | 400 | 20 |
| 8,25 | 10 | 10 | 400 | 400 | 20 |
| 12 | 10 | 25 | 400 | 400 | 20 |
| 15 | 10 | 25 | 400 | 400 | 20 |
| 15,5 | 10 | 25 | 400 | 400 | 20 |
| 17,5 | 10 | 31,5 | 400 | 400 | 20 |
| 24 | 10 | 31,5 | 400 | 400 | 20 |
| 25,8 | 10 | 31,5 | 400 | 400 | 20 |
| 27 | 10 | 31,5 | 400 | 400 | 20 |
| 36 | 10 | 50 | 400 | 400 | 20 |
| 38 | 10 | 50 | 400 | 400 | 20 |
| 40,5 | 10 | 50 | 400 | 400 | 20 |
| 48,3 | 10 | 80 | 400 | 400 | 20 |
| 52 | 10 | 80 | 400 | 400 | 20 |
| 72,5 | 10 | 125 | 400 | 400 | 20 |
| 100 | 20 | 125 | 400 | 400 | 20 |
| 123 | 31,5 | 140 | 400 | 400 | 20 |
| 145 | 50 | 160 | 400 | 400 | 20 |
| 170 | 63 | 160 | 400 | 400 | 20 |
| 245 | 125 | 250 | 400 | 400 | 20 |
| 300 | 200 | 315 | 400 | 400 | 20 |
| 362 | 315 | 355 | 400 | 400 | 20 |
| 420 | 400 | 400 | 400 | 400 | 20 |
| 550 | 500 | 500 | 400 | 400 | 20 |
| 800 | 900 | - | - | - | - |
| 1 100 | 1 200 | - | - | - | - |
| 1 200 | 1 300 | - | - | - | - |

NOTE 1 The values given in this table are chosen for standardization purposes. They are preferred values and cover the majority of typical applications. If different values are ~~needed~~ applicable, any appropriate value can be specified as rated value.

NOTE 2 For actual cases, the inrush currents can be calculated based on IEC TR 62271-306 [4].

NOTE 3 The peak of the inrush current can be higher or lower than the preferred values stated in this table depending on system conditions, for example whether or not current limiting reactors are used.

NOTE 4 Preferred values for rated voltages 1 100 kV and 1 200 kV are based on applications at 50 Hz. Higher values of current could be possible in the future in systems operated at 60 Hz, however experience shows that these higher currents would not lead to a higher stress for the circuit-breaker as the recovery voltage is generally the dominant factor for breaking.

#### 5.106.2 Rated line-charging breaking current

The rated line-charging breaking current is the line-charging current the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour required in this document. The associated restrike class (C1 or C2) shall be assigned when a line-charging breaking current is assigned.

#### 5.106.3 Rated cable-charging breaking current

The rated cable-charging breaking current is the cable-charging current the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour required in this document. The associated restrike class (C1 or C2) shall be assigned when a cable-charging breaking current is assigned.

#### 5.106.4 Rated single capacitor bank breaking current

The rated single capacitor bank breaking current is the single capacitor bank breaking current the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour required in this document. This breaking current refers to the switching of a shunt capacitor bank where no shunt capacitors are connected to the source side of the circuit-breaker. The associated restrike class (C1 or C2) shall be assigned when a single capacitor bank breaking current is assigned.

#### 5.106.5 Rated back-to-back capacitor bank breaking current

The rated back-to-back capacitor bank breaking current is the back-to-back capacitor current the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour required in this document. The associated restrike class (C1 or C2) shall be assigned when a back-to-back capacitor bank breaking current is assigned.

This breaking current refers to the switching of a shunt capacitor bank where one or several shunt capacitor banks are connected to the source side of the circuit-breaker giving an inrush making current equal to the rated back-to-back capacitor bank inrush making current.

NOTE Similar conditions could apply for switching in substations with cables.

#### 5.106.6 Rated back-to-back capacitor bank inrush making current

The rated back-to-back capacitor bank inrush making current is the peak value of the current that the circuit-breaker shall be capable of making at its rated voltage and with a frequency of the inrush current during a simultaneous three-phase making operation (see Table 1 and 7.111.5.3).

## 6 Design and construction

### 6.1 Requirements for liquids

Subclause 6.1 of IEC 62271-1:2017 is applicable.

### 6.2 Requirements for gases

Subclause 6.2 of IEC 62271-1:2017 is applicable.

### 6.3 Earthing

Subclause 6.3 of IEC 62271-1:2017 is applicable.

### 6.4 Auxiliary and control equipment and circuits

Subclause 6.4 of IEC 62271-1:2017 is applicable with the following additions:

- where shunt opening and closing releases are used, appropriate measures shall be taken in order to avoid damage on the releases when permanent orders for closing or opening are applied. For example, those measures can be the use of series control contacts arranged so that when the circuit-breaker is closed, the close release control contact ("b" contact or break contact) is open and the open release control contact ("a" contact or make contact) is closed, and when the circuit-breaker is open, the open release control contact is open and the close release control contact is closed;
- where auxiliary switches are used as position indicators, they shall indicate the end position of the circuit-breaker at rest, open or closed. The signalling shall be sustained;
- connections shall withstand the stresses imposed by the circuit-breaker, especially those due to mechanical forces during operations;
- where special items of control equipment are used, they shall operate within the limits specified for supply voltages of auxiliary and control circuits, making and breaking and/or insulating and operating media, and be able to switch the loads which are stated by the circuit-breaker manufacturer;
- special items of auxiliary equipment such as liquid indicators, pressure indicators, relief valves, filling and draining equipment, heating and interlock contacts shall operate within the limits specified for supply voltages of auxiliary and control circuits and/or within the limits of use of making and breaking and/or insulating and operating media;
- where anti-pumping devices are part of the circuit-breaker control scheme, they shall act on each control circuit, if more than one is installed;
- where a control scheme of pole discrepancy is part of the circuit-breaker, the position of the poles shall be supervised, open or closed.

### 6.5 Dependent power operation

Subclause 6.5 of IEC 62271-1:2017 is applicable with the following addition:

A circuit-breaker arranged for dependent power closing with external energy supply shall also be capable of opening immediately following the closing.

### 6.6 Stored energy operation

Subclause 6.6 of IEC 62271-1:2017 is applicable with the following addition to the first paragraph.

A circuit-breaker arranged for stored energy closing shall also be capable of opening immediately following the closing operation.

### 6.7 Independent unlatched operation (independent manual or power operation)

Subclause 6.7 of IEC 62271-1:2017 is applicable with the exception of the last paragraph and Note 2.

### 6.8 Manually operated actuators

Subclause 6.8 of IEC 62271-1:2017 is applicable.

### 6.9 Operation of releases

Subclause 6.9 of IEC 62271-1:2017 is applicable with the following additions.

### 6.9.101 Overcurrent release

#### 6.9.101.1 Operating current

An overcurrent release shall be marked with its rated continuous current and its current setting range.

Within the current setting range, the overcurrent release shall always operate at currents of 110 % and above of the current setting and shall never operate at currents of 90 % and below of this current setting.

#### 6.9.101.2 Operating time

The manufacturer shall provide tables or curves, each with the applicable tolerances, showing the operating time as a function of current, between twice and six times the operating current. These tables or curves shall be provided for extreme current settings together with extreme settings of time delay.

For an inverse time delay overcurrent release, the operating time shall be measured from the instant at which the overcurrent is established until the instant the tripping is initiated.

#### 6.9.101.3 Resetting current

If the current in the main circuit falls below a certain value, before the time delay of the overcurrent release has expired, the release shall not complete its operation and shall reset to its initial position.

The relevant information shall be given by the manufacturer.

### 6.9.102 Multiple releases

If a circuit-breaker is fitted with more than one release for the same function, a defect in one release shall not disturb the function in the others. Releases used for the same function shall be physically separated, i.e. magnetically decoupled.

### 6.9.103 Power consumption of releases

The power consumption of shunt closing or opening releases of a three-pole circuit-breaker should not exceed 1 200 VA. For certain circuit-breaker designs higher values may be required.

### 6.9.104 Integrated relays for self-tripping circuit-breakers

When an integrated relay is used for self-tripping circuit-breakers, it shall comply with IEC 60255-151:2009. The input energising quantity is the current through the main contacts.

## 6.10 Pressure/level indication

### 6.10.1 Gas pressure

Subclause 6.10.1 of IEC 62271-1:2017 is applicable with the following addition:

All circuit-breakers having an energy storage in gas receivers or hydraulic accumulators (see 6.6.2 of IEC 62271-1:2017) and all circuit-breakers except sealed pressure devices, using compressed gas for making and breaking (see 6.103) shall be fitted with a locking device set to operate at, or within, the appropriate limits of pressure stated by the manufacturer.

### 6.10.2 Liquid level

Subclause 6.10.2 of IEC 62271-1:2017 is applicable.

### 6.11 Nameplates

Subclause 6.11 of IEC 62271-1:2017 is applicable with the following additions: the nameplates of a circuit-breaker and its operating devices shall be marked in accordance with Table 2.

Coils of operating devices shall have a reference mark permitting the complete data to be obtained from the manufacturer.

Releases shall bear the appropriate data.

With the exception of removable circuit-breakers, the nameplate shall be visible in the position of normal service and installation. For removable circuit-breakers 6.11 of IEC 62271-200:20— applies.

**Table 2 – Nameplate information**

| | Abbrevi-ation | Unit | Circuit-breaker | Operating device | Condition: Marking only required if |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Manufacturer | | | X | X | |
| Type designation and serial number | | | X | X | |
| Rated voltage | $U_r$ | kV | X | | |
| Rated short-duration power frequency withstand voltage | $U_d$ | kV | X | | |
| Rated lightning impulse withstand voltage | $U_p$ | kV | X | | |
| Rated switching impulse withstand voltage | $U_s$ | kV | y | | Rated voltage 300 kV and above |
| Rated frequency | $f_r$ | Hz | X | | |
| Rated continuous current | $I_r$ | A | X | | |
| Rated duration of short-circuit | $t_k$ | s | y | | Different from 1 s |
| Rated short-circuit breaking current | $I_{sc}$ | kA | X | | |
| DC time constant of the rated short-circuit breaking current | $\tau$ | ms | y | | Different from 45 ms |
| Rated first pole-to-clear factor | $k_{pp}$ | | X | | |
| Short-line fault breaking current | $I_{SLF}$ | kA | (X) | | |
| Rated out-of-phase breaking current | $I_d$ | kA | (X) | | |
| Rated line-charging breaking current | $I_l$ | A | (X) | | |
| Rated cable-charging breaking current | $I_c$ | A | (X) | | |
| Rated single capacitor bank-breaking current | $I_{sb}$ | A | (X) | | |
| Rated back-to-back capacitor bank-breaking current | $I_{bb}$ | A | (X) | | |
| Rated back-to-back capacitor bank inrush making current | $I_{bi}$ | kA | (X) | | |
| Filling pressure for operation | $p_{rm}$ | MPa | | (X) | |
| Filling pressure for making and breaking | $p_{re}$ | MPa | (X) | | |
| Rated supply voltage of auxiliary and control circuits<br>Specify DC/AC (with rated frequency) | $U_a$ | V<br>Hz | | (X) | |
| Mass (including oil for oil circuit-breakers) | $M$ | kg | y | y | More than 300 kg |
| Type and mass of fluid (liquid or gas) for insulation | $M_f$ | kg | y | | If contains fluid |
| Rated operating sequence | | | X | | |
| Year of manufacture | | | X | | |
| Minimum and maximum ambient air temperature | | | y | y | Different from –5 °C and/or 40 °C |

| | Abbrevi-ation | Unit | Circuit-breaker | Operating device | Condition: Marking only required if |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Classification | | | y | | If different from C1, E1, M1, S1 for rated voltages less than 100 kV<br>If different from C1, M1 for rated voltages 100 kV and above |
| Reference to this document | | | X | X | |
| X = the marking of these values is mandatory; blanks indicate the value zero.<br>(X) = the marking of these values is optional.<br>y = the marking of these values to the conditions in column 6. | | | | | |
| The abbreviation in column 2 can be used instead of the terms in column 1. When terms in column 1 are used, the word “rated“ need not appear. | | | | | |



### 6.12 Locking devices

Subclause 6.12 of IEC 62271-1:2017 is applicable.

### 6.13 Position indication

Subclause 6.13 of IEC 62271-1:2017 is applicable.

### 6.14 Degrees of protection provided by enclosures

Subclause 6.14 of IEC 62271-1:2017 is applicable.

### 6.15 Creepage distances for outdoor insulators

Subclause 6.15 of IEC 62271-1:2017 is applicable.

### 6.16 Gas and vacuum tightness

Subclause 6.16 of IEC 62271-1:2017 is applicable.

### 6.17 Tightness for liquid systems

Subclause 6.17 of IEC 62271-1:2017 is applicable.

### 6.18 Fire hazard (flammability)

Subclause 6.18 of IEC 62271-1:2017 is applicable.

### 6.19 Electromagnetic compatibility (EMC)

Subclause 6.19 of IEC 62271-1:2017 is applicable.

### 6.20 X-ray emission

Subclause 6.20 of IEC 62271-1:2017 is applicable

### 6.21 Corrosion

Subclause 6.21 of IEC 62271-1:2017 is applicable.

### 6.22 Filling levels for insulation, switching and/or operation

Subclause 6.22 of IEC 62271-1:2017 is applicable.

### 6.101 Requirements for simultaneity of poles during single closing and single opening operations

The following requirements are applicable under rated conditions of the auxiliary and control voltage and pressure for operation:

– The maximum difference between the instants of contacts touching in the individual poles during closing shall not exceed 1/4 of a cycle of rated frequency. If one pole consists of more than one making and breaking unit connected in series, the maximum difference between the instants of contacts touching within these series connected making and breaking units shall not exceed 1/6 of a cycle of rated frequency. Where closing resistors are used, the maximum difference between the instants of contacts touching during closing in the individual closing resistors shall not exceed 1/2 cycle of rated frequency. If on one pole more than one individual closing resistor is used, each assigned to one of the making and breaking units which are connected in series, the maximum difference between the instants of contacts touching within these series connected closing resistors shall not exceed 1/3 of a cycle of rated frequency;
– The maximum difference between the instants of contacts separating in the individual poles during opening shall not exceed 1/6 of a cycle of rated frequency. If one pole consists of more than one making and breaking unit connected in series, the maximum difference between the instants of contact separation within these series connected making and breaking units shall not exceed 1/8 of a cycle of rated frequency.

Circuit-breakers intended for controlled switching are covered by IEC TR 62271-302 [10].

NOTE For a circuit-breaker having separate poles, the requirement is applicable when these operate in the same conditions; after a single-pole reclosing operation, the conditions of operation for the three mechanisms is not the same.

### 6.102 General requirement for operation

A circuit-breaker, including its operating devices, shall be capable of completing its rated operating sequence 5.104 in accordance with the relevant provisions of 6.5 to 6.10 and 6.103 for the whole range of ambient temperatures within its minimum and maximum air temperature as defined in Clause 4 of IEC 62271-1:2017.

This requirement is not applicable to auxiliary manual operating devices; where provided, these shall be used only for maintenance and for emergency operation on a dead circuit.

Circuit-breakers provided with heaters shall be designed to permit an opening operation at the minimum ambient air temperature when the heaters are not operational for a minimum time of 2 h.

### 6.103 Pressure limits of fluids for operation

The manufacturer shall state the maximum and minimum pressures of the fluid for operation at which the circuit-breaker is capable of performing according to its ratings and at which the appropriate low- and high-pressure interlocking devices shall be set (see 6.10).

The manufacturer can specify pressure limits at which the circuit-breaker is capable of each of the following performances:

– an “O” operation;
– a “CO” operating cycle;

– for circuit-breakers intended for rapid auto-reclosing an "O – $t$ – CO" operating sequence.

The circuit-breakers shall be provided with energy storage of sufficient capacity for satisfactory performance of the appropriate operations at the corresponding minimum pressures stated.

### 6.104 Vent outlets

Vent outlets are devices which allow a deliberate release of pressure in a circuit-breaker during operation.

NOTE This is applicable to air, air-blast and oil circuit-breakers.

Vent outlets of circuit-breakers shall be so situated that a discharge of oil or gas or both will not cause electrical breakdown and is directed away from any location where persons can be present. The necessary safety distance shall be stated by the manufacturer.

The construction shall be such that gas cannot collect at any point where ignition can be caused, during or after operation, by sparks arising from normal operation of the circuit-breaker or its auxiliary equipment.

### 6.105 Time quantities

Refer to Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7.

Values can be assigned to the following time quantities:

– opening time (no-load);
– closing time (no-load);
– open-close time (no-load);
– reclosing time (no-load);
– close-open time (no-load);
– pre-insertion time (no-load).

Time quantities are based on

– rated supply voltages of closing and opening devices and of auxiliary and control circuits (see 5.9);
– rated supply frequency of closing and opening devices and of auxiliary circuits (see 5.10);
– filling pressure for controlled pressure systems (see 5.11);
– filling levels for insulation and/or operation (see 6.22);
– an ambient air temperature of 20 °C ± 5 °C.

NOTE 1 It is not practical to assign a value of make-time or of make-break time due to the variation of the arcing time and the pre-arcing time.

NOTE 2 The break-time is determined using the calculation method given in IEC TR 62271-306 [4].

### 6.106 Mechanical loads

#### 6.106.1 General

Circuit-breakers shall be designed to withstand static forces such as those from connected conductors, wind, etc. and dynamic forces (for example caused by short-circuit current and operation of the circuit-breaker).

These forces can occur simultaneously.

#### 6.106.2 Static mechanical loads

This capability is demonstrated by calculation.

When calculating the stresses resulting from ice and wind, the ice coating and wind pressure shall be in accordance with 4.1.3 of IEC 62271-1:2017.

Some examples of static forces due to wind, ice and weight on flexible and tubular connected conductors are given as a guidance in Table 3.

The tensile force due to the connected conductors is assumed to act at the outermost end of the circuit-breaker terminal.

**Table 3 – Examples of static horizontal and vertical forces for static terminal load**

| Rated voltage range | Rated current range | Static horizontal force $F_{th}$ | | Static vertical force |
|---|---|---|---|---|
| $U_r$<br>kV | $I_r$<br>A | Longitudinal $F_{thA}$<br>N | Transversal $F_{thB}$<br>N | $F_{tv}$<br>N |
| < 100 | 800 to 1 250 | 500 | 400 | 500 |
| < 100 | 1 600 to 2 500 | 750 | 500 | 750 |
| 100 to 170 | 1 250 to 2 000 | 1 000 | 750 | 750 |
| 100 to 170 | 2 500 to 4 000 | 1 250 | 750 | 1 000 |
| 245 to 362 | 1 600 to 4 000 | 1 250 | 1 000 | 1 250 |
| 420 to 800 | 2 000 to 4 000 | 1 750 | 1 250 | 1 500 |
| 1 100 to 1 200 | 4 000 to 6 300 | 3 500 | 3 000 | 2 500 |

#### 6.106.3 Dynamic loads

This capability is demonstrated by calculation.

NOTE A calculation method of the effects of short-circuit current on rigid and flexible conductors is given in IEC 60865-1:2011.

### 6.107 Circuit-breaker classification

#### 6.107.1 General

Circuit-breakers can be classified according to their application according to the following:

– classification for number of mechanical operations (mechanical endurance);
– classification related to the connection to the network;
– classification for capacitive currents;
– classification for electrical endurance.

### 6.107.2 Classification for number of mechanical operations

The following classes are specified with respect to the number of mechanical operations of a circuit-breaker:

– Class M1 circuit-breaker

  A class M1 circuit-breaker shall perform the number of operations given in Table 4, following the programme of maintenance specified by the manufacturer and tested according to 7.101.2.3;

– Class M2 circuit-breaker

  A class M2 circuit-breaker shall perform the number of operations given in Table 4, following the programme of maintenance specified by the manufacturer and tested according to 7.101.2.4.

**Table 4 – Number of mechanical operations**

| | |
|---|---|
| Circuit-breaker class M1 | 2 000 operating cycles (see NOTE) |
| Circuit-breaker class M2 | 10 000 operating cycles (see NOTE) |
| NOTE For more details regarding the operating cycles, see Table 8. | |

### 6.107.3 Classification related to the connection to the network

The following classes are specified related to the connection of a circuit-breaker to the network:

– Class S1 circuit-breaker

  Circuit-breaker having a rated voltage higher than 1 kV and less than 100 kV and where the total length of cable (including when present the equivalent length provided by the capacitance of capacitors and/or insulated bus) connected to the supply side of a circuit-breaker is at least 100 m.

  NOTE 1 Circuit-breakers of indoor substations with cable connection are generally of class S1.

– Class S2 circuit-breaker

  Circuit-breaker having a rated voltage higher than 1 kV and less than 100 kV without a cable connected on the supply side of the circuit-breaker or in which the total length of cable (including when present the equivalent length provided by the capacitance of capacitors and/or insulated bus) on the supply side of a circuit-breaker is less than 100 m.

  NOTE 2 Applications where a circuit-breaker is connected to an overhead line through a busbar (without intervening cable connections) are typical examples of class S2 circuit-breakers.

### 6.107.4 Classification for capacitive currents

The following two classes are specified with respect to capacitive load switching:

– Class C1 circuit-breaker

  Circuit-breaker with low probability of restrike during capacitive current breaking as demonstrated by specific type tests described both in 7.111.9.2 and 7.111.9.3;

– Class C2 circuit-breaker

  Circuit-breaker with very low probability of restrike during capacitive current breaking as demonstrated by specific type tests described both in 7.111.9.2 and 7.111.9.4.

A circuit-breaker can be of class C2 for one kind of application and of class C1 for another kind of application where the recovery voltage stress is more severe.

#### 6.107.5 Classification for electrical endurance

The following classes are specified with respect to the electrical endurance capability of a circuit-breaker:

– Class E1 circuit-breaker

  Circuit-breaker tested in accordance with 7.107.

– Class E2 circuit-breaker

  Circuit-breaker having a rated voltage up to and including 52 kV designed so as not to require maintenance of the making and breaking units of the main circuit during its expected operating life.

  Class E2 circuit-breakers not for auto-reclosing duty are tested in accordance to 7.112.1.

  Class E2 circuit-breakers for auto-reclosing duty or rapid auto-reclosing duty, are tested in accordance to 7.112.2.

  NOTE For circuit-breakers of rated voltages exceeding 52 kV guidance is given in IEC TR 62271-310 [6].

# 7 Type tests

## 7.1 General

### 7.1.1 Basics

Subclause 7.1.1 of 62271-1:2017 is applicable with the following additions:

The type tests for circuit-breakers are listed in Table 5.

Tolerances on test quantities are given in Annex B.

A new or refurbished circuit-breaker can be used for each of the tests specified in Table 5.

The responsibility of the manufacturer is limited to the declared values and not to those values achieved during the type tests.

The expanded uncertainty of a complete measuring system for determination of the ratings (for example short-circuit current, applied voltage and recovery voltage) shall be ≤ 5 %, evaluated with a coverage probability of 95 % corresponding to a coverage factor $k$ = 2 under the assumption of a normal distribution.

NOTE Procedures for the determination of the uncertainty of measurements are given in ISO/IEC Guide 98-3 [7].

If the circuit-breaker can be equipped with different operating mechanisms, complete type tests according to Table 5 shall be performed on circuit-breakers equipped with one type of operating mechanism. The other operating mechanisms are considered being alternative operating mechanisms as defined in 3.5.130, provided they fulfil the related requirements as defined in 7.102.7. Tests to be repeated for alternative mechanisms are defined in 7.1.102.

A change in the secondary equipment does not constitute an alternative operating mechanism. However, it shall be checked that changes in the opening time/minimum clearing time does not entail different requirements for test-duty T100a (see 7.104.2.2).

**Table 5 – Type tests**

| Mandatory type tests [a] | Subclauses |
|---|---|
| Dielectric tests | 7.2 |
| Resistance measurement | 7.4 |
| Continuous current tests | 7.5 |
| Short-time withstand current and peak withstand current tests | 7.6 |
| Additional tests on auxiliary and control circuits | 7.10 |
| Mechanical operation test at ambient temperature (class M1) | 7.101.2.1 to 7.101.2.3 |
| Terminal fault tests | 7.102 to 7.107 |

| Type tests depending on requirements | Condition requiring type test | Subclauses |
|---|---|---|
| Radio interference voltage (RIV) tests | $U_r$ ≥ 245 kV | 7.3 |
| Verification of the protection | Assigned IP and IK class | 7.7 |
| Tightness test | Controlled, sealed or closed pressure systems | 7.8 |
| EMC tests | Electronic equipment or components are included in the secondary system | 7.9 |
| X-ray radiation test | Vacuum circuit-breaker | 7.11 |
| Extended mechanical endurance tests on circuit-breakers for special service conditions | Class M2 rating assigned | 7.101.2.4 |
| Low and high temperature tests | If ambient air temperature is different from -5 °C and/or +40 °C | 7.101.3 |
| Humidity test | Insulation subject to voltage stress and condensation | 7.101.4 |
| Critical current tests | Circuit-breaker performance against conditions in 7.108.1 | 7.108.1 |
| Short-line fault tests | $U_r$ ≥ 15 kV and $I_{sc}$ > 12,5 kA, in case of direct connection to overhead lines | 7.109 |
| Out-of-phase making and breaking tests | Out-of-phase rating assigned | 7.110 |
| Electrical endurance tests (only for $U_r$ ≤ 52 kV) | Class E2 rating assigned | 7.112 |
| Test to prove operation under severe ice conditions | Outdoor circuit-breakers with moving external parts | 7.101.5 |
| Single-phase fault test | Effectively earthed neutral systems | 7.108.2 |
| Double-earth fault test | Non-effectively earthed neutral systems | |
| Capacitive current tests:<br>– line-charging current breaking tests<br>– cable-charging current breaking tests<br>– single capacitor bank making and breaking tests<br>– back-to-back capacitor bank making and breaking tests | Relevant rating and classification (C1 or C2) assigned | 7.111 |

[a] Mandatory type tests, shown in the upper part of the table, are required for all circuit-breakers regardless of rated voltage, design or intended use. Other type tests, shown in the lower part of the table, are required for all circuit-breakers where the associated rating is specified, for example out-of-phase making and breaking, or where a specific condition is met, for example RIV is required only for rated voltages of 245 kV and above.

### 7.1.2 Information for identification of test objects

Subclause 7.1.2 of IEC 62271-1:2017 is applicable.

### 7.1.3 Information to be included in type-test reports

Subclause 7.1.3 of IEC 62271-1:2017 is applicable with the following addition:

Further details relating to records and reports of type tests for making, breaking and short-time current performance are given in Annex C.

#### 7.1.101 Invalid tests

In the case of an invalid test, it may become necessary to perform a greater number of tests than required by this document. An invalid test is one where one or more of the test parameters demanded by the standard is not met. This includes, for example in the case of making and breaking tests, current, voltage and time factors as well as point-on-wave requirements (if specified).

The deviation from the standard could make the test less or more severe. Table 6 considers some cases.

The invalid part of the test-duty can be repeated without reconditioning of the circuit-breaker. However, in the case of a failure of the circuit-breaker during such additional tests, or at the discretion of the manufacturer, the circuit-breaker can be reconditioned and the complete test-duty repeated. In the case where the circuit-breaker has not been reconditioned, the test report shall include reference to the invalid part of the test.

In a rapid auto-reclosing duty cycle, the O – $t$ – CO is regarded as one part, and an ensuing CO is regarded as another part.

A class E2 circuit-breaker can be reconditioned during class E2 tests, but in this event the entire test series (see 7.112) shall be repeated.

If any record of an individual operation cannot be produced for technical reasons, this individual operation is not considered invalid, provided that evidence can be given in another manner that the circuit-breaker did not fail and the required testing values were fulfilled.

**Table 6 – Invalid tests**

| Test conditions related to standard | Circuit-breaker | |
|---|---|---|
| | Passes | Fails |
| More severe | Test valid, result accepted | Test to be repeated with correct parameters |
| Less severe | Test to be repeated with correct parameters | Circuit-breaker failed the test. |

#### 7.1.102 Type tests to repeat for circuit-breakers with alternative operating mechanisms

The following type tests shall be repeated on circuit-breakers with alternative operating mechanisms:

- mechanical operation tests at ambient temperature (according to 7.101.2);
- low and high temperature tests (according to 7.101.3);
- short-circuit making and breaking tests (as defined in 7.102.7);
- short-time withstand current and peak withstand current tests on circuit-breakers having main contacts of the butt type (according to 7.6).

### 7.2 Dielectric tests

#### 7.2.1 General

Subclause 7.2.1 of IEC 62271-1:2017 is applicable.

#### 7.2.2 Ambient air conditions during tests

Subclause 7.2.2 of IEC 62271-1:2017 is applicable.

#### 7.2.3 Wet test procedure

Subclause 7.2.3 of IEC 62271-1:2017 is applicable with the following addition:

In the case of dead tank circuit-breakers, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

#### 7.2.4 Arrangement of the equipment

Subclause 7.2.4 of IEC 62271-1:2017 is applicable.

#### 7.2.5 Criteria to pass the test

Subclause 7.2.5 of IEC 62271-1:2017 is applicable with the following addition:

If disruptive discharges occur and evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, the circuit-breaker shall be dismantled and inspected after the completion of the dielectric test series. If damage (for example tracking, puncture, etc.) to non-self-restoring insulation is observed, the circuit-breaker has failed the test.

For metal-enclosed circuit-breakers tested with test bushings that are not part of the circuit-breaker, ~~flashovers~~ disruptive discharges across the test bushings can be disregarded.

#### 7.2.6 Application of test voltage and test conditions

Subclause 7.2.6 of IEC 62271-1:2017 is applicable.

#### 7.2.7 Tests of switchgear and controlgear of $U_r$ ≤ 245 kV

##### 7.2.7.1 General

Subclause 7.2.7.1 of IEC 62271-1:2017 is applicable.

##### 7.2.7.2 Power-frequency voltage tests

Subclause 7.2.7.2 of IEC 62271-1:2017 is applicable with the following addition:

In the case of dead tank circuit-breakers, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

##### 7.2.7.3 Lightning impulse voltage test

Subclause 7.2.7.3 of IEC 62271-1:2017 is applicable.

#### 7.2.8 Tests of switchgear and controlgear of $U_r$ > 245 kV

##### 7.2.8.1 General

Subclause 7.2.8.1 of IEC 62271-1:2017 is applicable.

#### 7.2.8.2 Power-frequency voltage tests

Subclause 7.2.8.2 of IEC 62271-1:2017 is applicable.

#### 7.2.8.3 Switching impulse voltage tests

Subclause 7.2.8.3 of IEC 62271-1:2017 is applicable with the following addition:

For outdoor circuit-breakers dry tests shall be performed using voltage of positive polarity only. With the circuit-breaker closed, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table 10 of IEC 62271-1:2017.

With the circuit-breaker open, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table 10 of IEC 62271-1:2017.

A second test series, with the test voltages according to column (6) of Tables 3 and 4 of IEC 62271-1:2017, shall be performed for circuit-breakers intended for special applications as stated in 9.102.2. For each test condition of Table 12 of IEC 62271-1:2017, one terminal shall be energised with switching impulse voltage and the opposite terminal with power-frequency voltage.

Subject to the manufacturer's approval, the test with the circuit-breaker open can be performed avoiding the use of the power-frequency voltage source. This test series consists of the application, to each terminal in turn, of impulses at a voltage equal to the sum of the switching impulse voltage and the peak value stated in column (6) of Tables 3 and 4 in IEC 62271-1:2017, the opposite terminal being earthed.

Item b) of 7.2.6.3 of IEC 62271-1:2017 can be used. In general, this test is more severe than that following the specified test procedure.

#### 7.2.8.4 Lightning impulse voltage tests

Subclause 7.2.8.4 of IEC 62271-1:2017 is applicable with the following addition:

With the circuit-breaker closed, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table 10 of IEC 62271-1:2017.

With the circuit-breaker open, the test voltage equal to the rated withstand voltage across the open switching device shall be applied for each test condition of Table 12 of IEC 62271-1:2017.

Subject to the manufacturer's approval, the test with the circuit-breaker open can be performed avoiding the use of the power-frequency voltage source. This test series applies to each terminal in turn (or on one terminal if the arrangement of the terminals is symmetrical with respect to the base), 15 consecutive impulses at a voltage equal to the sum of the rated lightning impulse withstand voltage and the peak value stated in column (8) of Tables 3 and column (7) of IEC 62271-1:2017, the opposite terminal being earthed. Item a) and item b) of 7.2.6.3 of IEC 62271-1:2017 can be used. In general, this test is more severe than that following the specified test procedure.

### 7.2.9 Artificial pollution tests for outdoor insulators

Subclause 7.2.9 of IEC 62271-1:2017 is applicable.

### 7.2.10 Partial discharge tests

Subclause 7.2.10 of IEC 62271-1:2017 is applicable with the following addition:

~~Partial discharge tests are not normally required to be performed on the complete circuit-breaker.~~ Normally it is not required to perform partial discharge tests on a complete circuit-breaker. However, in ~~the~~ case of dead-tank and GIS circuit-breakers using components for which a relevant IEC standard exists~~, including~~ that requires partial discharge measurements (for example, bushings, see IEC 60137~~:2017~~ [8]), evidence shall be ~~produced~~ provided by the manufacturer showing that those components have passed the partial discharge tests as ~~laid down in~~ required by the relevant IEC standard.

### 7.2.11 Dielectric tests on auxiliary and control circuits

Subclause 7.2.11 of IEC 62271-1:2017 is applicable.

### 7.2.12 Voltage test as a condition check

Subclause 7.2.12 of IEC 62271-1:2017 is replaced by the following.

#### 7.2.12.101 Condition after mechanical or environmental test

Where after mechanical or environmental tests (see 7.101.1.4) the insulating properties across open contacts of a circuit-breaker cannot be verified by visual inspection with sufficient reliability, a voltage test as condition check ~~test~~ in dry condition across the open circuit-breaker according to 7.2.12 of IEC 62271-1:2017 or 7.2.12.103 of this document shall be ~~performed across the open contacts of the circuit-breaker~~ applied. For metal-enclosed circuit-breakers test conditions refer to Table 7. For multi-unit live tank circuit-breakers with identical units according to 7.102.4.2.~~5~~3 the voltage test as a condition check ~~shall~~ may be performed as unit test ~~on each tested making and breaking unit~~.

#### 7.2.12.102 Condition check after making and breaking test

Where after making and breaking tests (see 7.102.9) a voltage test as a condition check is performed (see 7.2.12.103), the following conditions shall apply:

For circuit-breakers with an asymmetrical current path, the connections shall be reversed. The complete tests shall be carried out once for each arrangement of the connections. For metal-enclosed circuit-breakers having a symmetrical current path, a test to earth is required with the circuit-breaker in closed position. When a test to earth is required, the rated insulation voltages across open contacts and to earth may be different. For such cases, each of the rated values corresponding to the test condition shall be used as the reference value for the determination of the test voltage. These requirements are summarised in Table 7.

**Table 7 – Test requirements for voltage tests as condition check for metal-enclosed circuit-breakers**

| No. of series connected making and breaking units | Arrangement of the current path | Circuit-breaker position | | |
|---|---|---|---|---|
| | | Open (one side) | Open (other side) | Closed |
| Single | Symmetrical | Y | N | Y |
| | Asymmetrical | Y | Y | N |
| Multi | Symmetrical | Y | N | Y |
| | Asymmetrical | Y | Y | Y |
| Y: necessary to apply voltage.<br>N: not necessary to apply voltage. | | | | |

If making and breaking units are placed in an insulating fluid with different characteristics and other than air at atmospheric pressure, that also might withstand the test voltages when replacing the original arc extinguishing medium (for example a vacuum interrupter in an enclosure filled with $SF_6$), the condition checking test may not be adequate to verify the integrity of the vacuum interrupter. In such cases the integrity of the device shall be demonstrated by the following.

An additional short-circuit breaking test shall be performed using a circuit that supplies at least 10 % of the rated short-circuit breaking current and at least 50 % of the rated voltage. If more than one test-duty is carried out without reconditioning this additional test shall be made before or after the no-load tests subsequent to the short-circuit test-duties as follows:

– if a three-phase test is performed in a circuit with effectively or solidly earthed neutral, one opening operation shall be performed with both the source side neutral and the short-circuit point earthed;

– if a three-phase test is performed in a circuit with non-effectively earthed neutral, three opening operations shall be performed. The first-pole-to-clear conditions shall be demonstrated for each pole of the circuit-breaker;

– if a single-phase test is performed, one opening shall be performed. The test shall be repeated on each pole.

A successful breaking in each pole is evidence that the integrity of the making and breaking unit(s) is maintained.

The additional short-circuit breaking test is not required on the poles in which the final test was a successful single-phase breaking.

If the type test is completed with a successful three-phase breaking in a circuit with effectively earthed neutral no additional short-circuit test as condition check is required.

#### 7.2.12.103 Test voltage for the condition check tests

The following test voltages shall be applied:

– Circuit-breakers with $U_r \leq 72,5$ kV

A 1 min power-frequency voltage test shall be performed. The test voltage shall be 80 % of the value in column (2) of Tables 1 or 2 of IEC 62271-1:2017.

– Circuit-breakers with 72,5 kV < $U_r \leq 245$ kV

An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 60 % of the highest relevant value in column (4) of Tables 1 or 2 of IEC 62271-1:2017.

– Circuit-breakers with 300 kV ≤ $U_r$ ≤ 420 kV

An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 80 % of the rated switching impulse withstand voltage given in Tables 3 or 4 of IEC 62271-1:2017, except in the case of GIS circuit-breakers (i.e. circuit-breakers in Gas Insulated Switchgear (GIS)) the crest value of the impulse voltage shall be 80 % of the rated switching impulse withstand voltage given in IEC 62271-203.

– Circuit-breakers with 550 kV ≤ $U_r$ ≤ 800 kV

An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in Tables 3 or 4 of IEC 62271-1:2017, except in the case of GIS circuit-breakers the crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in IEC 62271-203.

– Circuit-breakers with $U_r$ > 800 kV

An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in Table 3 of IEC 62271-1:2017, except in the case of GIS circuit-breakers the crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage. Examples of rated switching impulse withstand voltage values for GIS equipment are given in IEC 62271-203.

Where an impulse voltage test shall be carried out, the waveshape of the impulse voltage shall be either a standard switching impulse or a waveshape according to the TRV specified for terminal fault test-duty T10. Five impulses of each polarity shall be applied. The circuit-breaker shall be considered to have passed the test if no disruptive discharge occurs. In the case that a T10 waveshape is used, timing tolerances on the TRV waveshape of -10 % and +200 % on time $t_3$ are permitted. If the tests are performed using the TRV impulse with a T10 waveshape, equivalence is maintained to the standard switching impulse if the following rules are applied:

– the damping of the TRV should be such that the second peak of the TRV oscillation is not higher than 80 % of the first one;

– the voltage should be in the range of 50 % of its peak value 2,5 ms after time to peak.

NOTE Comparative tests have shown that there are almost no differences in the behaviour of the circuit-breakers, both in new and in worn conditions, when testing is performed with standard switching impulses or with TRV impulses with a waveshape in accordance with terminal fault T10, respectively.

### 7.3 Radio interference voltage (RIV) test

Subclause 7.3 of IEC 62271-1:2017 is applicable with the following addition:

Tests can be performed on one pole of the circuit-breaker in both closed and open position. During the tests the circuit-breaker shall be equipped with all accessories such as grading capacitors, corona rings, HV connectors, etc., which can influence the radio interference voltage performance.

### 7.4 Resistance measurement

Subclauses 7.4.1 to 7.4.3 of IEC 62271-1:2017 are applicable.

Subclause 7.4.4 is replaced by the following.

#### 7.4.4 Resistance measurements of contacts and connections in the main circuit as a condition check

##### 7.4.4.1 Resistance measurement test procedure

Subclause 7.4.4.1 of IEC 62271-1:2017 is applicable with the following modifications.

The resistance across the circuit-breaker contacts shall be measured before the test. The measuring test points shall be the nearest accessible points to and on either side of the contacts in question. An average value of the resistance shall be calculated based on three measurements. If possible, one no-load open and close operation cycle should be made between each of the measurements. If no-load operations cannot be made, the 3 measurements shall be made without no-load operations of the circuit-breaker.

It is recognised that for some tests, it is not practical (for example if gas handling is required between the measurements) nor possible (for example during a continuous current test because of the presence of temperature sensors within the breaking chamber(s)) to make any no-load operations between each of the three resistance measurements.

#### 7.4.4.2 Making and breaking tests

Subclause 7.4.4.2 of IEC 62271-1:2017 is applicable with the following addition:

For circuit-breaker types other than sealed-for-life visual inspection of the contact system is usually sufficient as stated in 7.102.9.2.

#### 7.4.4.3 Other tests

Subclause 7.4.4.3 of IEC 62271-1:2017 is replaced by 7.101.1.4.

### 7.5 Continuous current tests

#### 7.5.1 Condition of the test object

Subclause 7.5.1 of IEC 62271-1:2017 is applicable.

#### 7.5.2 Arrangement of the equipment

Subclause 7.5.2 of IEC 62271-1:2017 is applicable with the following addition:

For a circuit-breaker not fitted with series connected accessories, the test shall be made with the rated continuous current of the circuit-breaker.

For a circuit-breaker fitted with series connected accessories having a range of rated continuous currents, the following tests shall be made:

a) a test of the circuit-breaker fitted with the series connected accessories having a rated continuous current equal to that of the circuit-breaker, and made at the rated continuous current of the circuit-breaker;
b) a series of tests of the circuit-breaker fitted with the intended accessories made with currents equal to the rated continuous current of each accessory.

If the accessories can be removed from the circuit-breaker, and if it is evident that the temperature rise of the circuit-breaker and of the accessories do not appreciably influence each other, test b) above can be replaced by a series of tests on the accessories alone.

#### 7.5.3 Test current and duration

Subclause 7.5.3 of IEC 62271-1:2017 is applicable.

#### 7.5.4 Temperature measurement during the test

Subclause 7.5.4 of IEC 62271-1:2017 is applicable.

#### 7.5.5 Resistance of the main circuit

Subclause 7.5.5 of IEC 62271-1:2017 does not apply. The resistance of the main circuit shall be measured using the procedure given in 7.4.4.

#### 7.5.6 Criteria to pass the test

Subclause 7.5.6 of IEC 62271-1:2017 is applicable.

### 7.6 Short-time withstand current and peak withstand current tests

#### 7.6.1 General

Subclause 7.6.1 of IEC 62271-1:2017 is applicable.

#### 7.6.2 Arrangement of the equipment and of the test circuit

Subclause 7.6.2 of IEC 62271-1:2017 is applicable with the following addition:

The use of making and breaking and/or insulating fluid is not mandatory for short-time withstand current and peak withstand current tests. Air or $N_2$ may be used as an alternative to gases with high global warming potential. There is also no requirement for minimum pressure for insulation and/or making and breaking.

#### 7.6.3 Test current and duration

Subclause 7.6.3 of IEC 62271-1:2017 is applicable.

#### 7.6.4 Conditions of the test object after test

Subclause 7.6.4 of IEC 62271-1:2017 is applicable with the exception of b) and the following addition.

After the tests of self-tripping circuit-breakers, the conditions of the circuit-breaker shall comply with 7.102.9, and it shall be demonstrated that the overcurrent release is still in order to operate correctly. A primary injection test at 110 % of the minimum tripping current and in the conditions (single-phase or three-phase), as declared by the manufacturer, is a satisfactory demonstration.

### 7.7 Verification of the protection

#### 7.7.1 Verification of the IP coding

Subclause 7.7.1 of IEC 62271-1:2017 is applicable.

#### 7.7.2 Verification of the IK coding

Subclause 7.7.2 of IEC 62271-1:2017 is applicable.

### 7.8 Tightness tests

Subclause 7.8 of IEC 62271-1:2017 is applicable.

### 7.9 Electromagnetic compatibility tests (EMC)

Subclause 7.9 of IEC 62271-1:2017 is applicable with the following addition.

#### 7.9.3.2 Ripple on DC input power port immunity test

Subclause 7.9.3.2 of IEC 62271-1:2017 is applicable with the following addition:

If no electronic components are used in the control unit and the mechanical operation test at ambient air temperature in accordance with 7.101.2 is performed on the complete circuit-breaker equipped with its entire control unit, the ripple on DC input power port immunity test according to 7.9.3.2 of IEC 62271-1:2017 is regarded as covered and additional tests shall be omitted. When testing of the complete circuit-breaker is not practicable, component tests in accordance with 7.101.1.2 are acceptable.

Where electronic components are used, tests according to 7.9.3.2 of IEC 62271-1:2017 on the individual components are sufficient.

NOTE This subclause is applicable to both, complete electronic boards (for example control modules) and devices containing at least one electronic component.

### 7.10 Additional tests on auxiliary and control circuits

#### 7.10.1 General

Subclause 7.10.1 of IEC 62271-1:2017 is applicable.

#### 7.10.2 Functional tests

Subclause 7.10.2 of IEC 62271-1:2017 is applicable with the following addition:

If the mechanical operation test at ambient air temperature in accordance with 7.101.2 is performed on the complete circuit-breaker equipped with its entire control unit, the functional tests according to 7.10.2 of IEC 62271-1:2017 are regarded as covered and additional tests shall be omitted. When testing of the complete circuit-breaker is not practicable, component tests in accordance with 7.101.1.2 are acceptable.

#### 7.10.3 Verification of the operational characteristics of the auxiliary contacts

Subclause 7.10.3 of IEC 62271-1:2017 is applicable.

#### 7.10.4 Environmental tests

Subclause 7.10.4 of IEC 62271-1:2017 is applicable with the following addition:

If the mechanical operation test at ambient air temperature in accordance with 7.101.2, the low and high temperature tests in accordance with 7.101.3 and, if applicable, the humidity test in accordance with 7.101.4 are performed on the complete circuit-breaker equipped with its entire control unit or in case of the humidity test on the control equipment respectively, the environmental tests according to 7.10.4 of IEC 62271-1:2017 are regarded as covered and additional tests can be omitted. When testing of the complete circuit-breaker is not practicable, component tests in accordance with 7.101.1.2 are acceptable.

Seismic tests are not covered. If a seismic test is requested, it should be performed in accordance with IEC TR 62271-300 [9] by agreement between manufacturer and user.

#### 7.10.5 Dielectric test

Subclause 7.10.5 of IEC 62271-1:2017 is applicable with the following addition:

The dielectric test shall be performed on the auxiliary and control circuits in new condition.

### 7.11 X-radiation test procedure for vacuum interrupters

Subclause 7.11 of IEC 62271-1:2017 is applicable.

### 7.101 Mechanical and environmental tests

### 7.101.1 Miscellaneous provisions for mechanical and environmental tests

#### 7.101.1.1 Mechanical characteristics

At the beginning of the type tests, the mechanical characteristics of the circuit-breaker shall be established. IEC TR 62271-306 [4] gives examples on how to measure the mechanical characteristics. The mechanical characteristics will serve as the reference for the purpose of characterising the mechanical behaviour of the circuit-breaker. Furthermore, the mechanical characteristics shall be used to confirm that the different test samples used during the mechanical, making and breaking type tests behave mechanically in a similar way. The reference mechanical characteristics are also used to confirm that production units behave mechanically in a similar way compared to the test samples used during type tests.

Following are examples of operating characteristics that can be recorded:

– no-load travel curves;
– closing and opening times.

The mechanical characteristics shall be produced during a no-load test made with a single O operation and a single C operation at rated supply voltage of operating devices and of auxiliary and control circuits, filling pressure for operation and, for convenience of testing, at the minimum functional pressure for making and breaking.

Annex G gives requirements and explanation on the use of mechanical characteristics.

#### 7.101.1.2 Component tests

When testing of a complete circuit-breaker is not practicable, component tests can be accepted as type tests. The manufacturer should determine the components which are suitable for testing.

Components are separate functional sub-assemblies which can be operated independently of the complete circuit-breaker (for example, pole, breaking unit, operating mechanism).

When component tests are made, the manufacturer shall prove that the mechanical and environmental stresses on the component during the tests are not less than those applied to the same component when the complete circuit-breaker is tested. Component tests shall cover all different types of components of the complete circuit-breaker, provided that the particular test is applicable to the component. The conditions for the component type tests shall be the same as those which could be employed for the complete circuit-breaker.

Parts of auxiliary and control equipment which have been manufactured in accordance with relevant standards shall comply with these standards. The proper function of such parts in connection with the function of the other parts of the circuit-breaker shall be verified.

#### 7.101.1.3 Characteristics and settings of the circuit-breaker to be recorded before and after the tests

Before and after the tests, the following operating characteristics or settings shall be recorded and evaluated:

a) closing time;
b) opening time;

c) time spread between making and breaking units of one pole;
d) time spread between poles (if multi-pole tested);
e) recharging time and consumption of the operating device;
f) consumption of the control circuit, if applicable;
g) consumption of the auxiliary circuit;
h) duration of opening and closing command;
i) tightness, if applicable;
j) gas densities or pressures, if applicable;
k) resistance of the main circuit;
l) mechanical travel, if applicable;
m) other important characteristics or settings as specified by the manufacturer.

The above operating characteristics shall be recorded for the conditions below (if applicable) at:

– rated supply voltage and filling pressure for operation;
– maximum supply voltage and filling pressure for operation;
– maximum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and ~~maximum~~ filling pressure for operation.

#### 7.101.1.4 Condition of the circuit-breaker during and after the tests

During and after the tests, the circuit-breaker shall be in such a condition that it is capable of operating normally, carrying its rated continuous current, making and breaking its rated short-circuit current and withstanding the voltage values according to its rated insulation level.

In general, these requirements are fulfilled if

– during the tests, the circuit-breaker operates on command and does not operate without command;
– after the tests, the characteristics measured according to 7.101.1.3 are within the tolerances given by the manufacturer before the tests;
– after the tests, coated contacts are such that a layer of coating material remains at the contact area. If this is not the case, the contacts shall be regarded as bare and the test requirements are fulfilled only if the temperature rise of the contacts during the continuous current test (according to 7.5) does not exceed the value permitted for bare contacts;
– during and after the tests, it shall be possible to fit any defined replacement part according to the manufacturer's instructions;
– after the tests the insulating properties of the circuit-breaker in the open position shall be in essentially the same condition as before the tests. Visual inspection of the circuit-breaker after the tests is usually sufficient for verification of the insulating properties. In the case of sealed-for-life circuit-breakers a voltage test as a condition check in accordance with 7.2.12 replaces this visual inspection;
– for sealed-for-life circuit-breakers, the increase of the resistance of the main circuit shall be less than or equal to 20 %. If the increase in resistance exceeds 20 % then a continuous current test according to 7.5 is applicable to determine if the test object can carry its rated continuous current without exceeding the temperature limits given in Table 14 of IEC 62271-1:2017 by more than 10 K;
– for other circuit-breaker types, the resistance condition check of the test object is satisfactory if the resistance increase for each phase determined in 7.4.4.1 is not greater

than 20 % and that the visual inspection of the contact system does confirm that the contact system complies with the requirements stated in 7.102.9.4. If the resistance increase exceeds 20 % then also a visual inspection shall be performed in order to see if the contact system is complying with the requirements stated in 7.102.9.4.

#### 7.101.1.5 Condition of the auxiliary and control equipment during and after the tests

During and after the tests, the following conditions for the auxiliary and control equipment shall be fulfilled:

- during the tests, care should be taken to prevent undue heating;
- during the tests, a set of contacts (both make and break auxiliary contacts) shall be arranged to switch the current of the circuits to be controlled (see 6.4);
- during and after the tests, the auxiliary and control equipment shall fulfil its functions;
- during and after the tests, insulation capability of the auxiliary circuits, of the auxiliary switches and of the control equipment shall not be impaired. In case of doubt, the dielectric tests according to 7.10.5 of IEC 62271-1:2017 shall be performed;
- during and after the tests, the contact resistance of the auxiliary switches shall not be affected adversely.

### 7.101.2 Mechanical operation test at ambient air temperature

#### 7.101.2.1 General

The mechanical operation test shall be made at the ambient air temperature of the test location. The ambient air temperature shall be recorded in the test report. Auxiliary equipment forming part of the operating devices shall be included.

The mechanical operation test shall consist of 2 000 operating cycles in accordance with 7.101.2.3 for class M1 circuit-breakers and 10 000 operating cycles in accordance with 7.101.2.4 for class M2 circuit-breakers.

Except for circuit-breakers fitted with direct overcurrent releases the test shall be made without voltage on or current in the main circuit.

For circuit-breakers fitted with overcurrent releases, approximately 10 % of the operating cycles shall be performed with the opening device energised by the current in the main circuit. The current shall be the minimum current necessary to operate the overcurrent release. For these tests, the current through overcurrent releases can be supplied from a suitable low-voltage source.

A circuit-breaker design can be fitted with several variants of auxiliary equipment (shunt releases and motors) in order to accommodate the various rated control voltages and frequencies as stated in 5.9 and 5.10. No additional tests are required if the variants are of similar designs and if the resulting no-load mechanical characteristics are within the tolerance given in Annex G.

#### 7.101.2.2 Condition of the circuit-breaker before the test

The circuit-breaker for test shall be mounted on its own support and its operating mechanism shall be operated in the specified manner. It shall be tested according to its type as follows:

A multipole circuit-breaker actuated by a single operating device and/or with all poles mounted on a common frame shall be tested as a complete unit.

Tests shall be conducted at the filling pressure for making and breaking.

A multipole circuit-breaker in which each pole or even each column is actuated by a separate operating device should be tested preferably as a complete multipole circuit-breaker. However, for convenience, or owing to limitations of the dimensions of the test bay, one single-pole unit of the circuit-breaker can be tested, provided that it is equivalent to, or not in a more favourable condition than, the complete multipole circuit-breaker over the range of tests, for example in respect of

– reference mechanical travel characteristics;
– power and strength of closing and opening mechanism;
– rigidity of structure.

#### 7.101.2.3 Operating sequence for class M1 circuit-breakers

The circuit-breaker shall be tested in accordance with Table 8.

**Table 8 – Number of operating sequences**

| Operating sequence | Supply voltage and operating pressure | Number of operating sequences | |
|---|---|---|---|
| | | Circuit-breakers for auto-reclosing | Circuit-breakers not for auto-reclosing |
| $C - t_a - O - t_a$ | Minimum | 500 | 500 |
| | Rated | 500 | 500 |
| | Maximum | 500 | 500 |
| $O - t - CO - t_a - C - t_a$ | Rated | 250 | – |
| $CO - t_a$ | Rated | – | 500 |

– O = opening;
– C = closing;
– CO = close-open operating cycle with the shortest possible close-open time such that the circuit-breaker reaches the fully closed and latched position prior to opening;
– $t_a$ = time between two operations which is necessary to restore the initial conditions and/or to prevent undue heating of parts of the circuit-breaker (this time can be different according to the type of operation);
– $t$ = 0,3 s for circuit-breakers for rapid auto-reclosing;
– $t$ = 3 min for circuit-breakers for auto-reclosing. For testing purposes shorter times for $t$ can also be used.

During the test, lubrication of parts outside of the main circuit is allowed in accordance with the manufacturer's instructions, but no mechanical adjustment or other kind of maintenance is allowed.

#### 7.101.2.4 Operating sequence for class M2 circuit-breakers

The tests shall be made according to 7.101.1, 7.101.2.1, 7.101.2.2 and 7.101.2.3 with the following addition:

– the tests shall consist of 10 000 operating cycles performing five times the relevant test programme specified in Table 8;
– between each series of 2 000 operating cycles specified, some maintenance, such as lubrication and mechanical adjustment, is allowed, and shall be performed in accordance with the manufacturer’s instructions. Only change of parts outside of the main circuit and not being part of the power kinematic chain, that are listed in the program of maintenance, is permitted;
– during a test series of 2 000 operating cycles, lubrication of parts outside of the main circuit is allowed in accordance with the manufacturer's instructions, but no mechanical adjustment or other kind of maintenance is allowed.

#### 7.101.2.5 Acceptance criteria for the mechanical operation tests

The criteria given below apply for mechanical operation tests on class M1 and class M2 circuit-breakers.

a) Before and after the total test programme, the following operations shall be performed:
   - five close-open operating cycles at the rated supply voltage of closing and opening devices and of auxiliary and control circuits and/or the filling pressure for operation;
   - five close-open operating cycles at the minimum supply voltage of closing and opening devices and of auxiliary and control circuits and/or the minimum pressure for operation;
   - five close-open operating cycles at the maximum supply voltage of closing and opening devices and of auxiliary and control circuits and/or the maximum pressure for operation.

   During these operating cycles, the operating characteristics (see 7.101.1.3) shall be recorded. It is not necessary to publish all the oscillograms recorded. However, at least one oscillogram for each set of conditions given above shall be included in the test report.

   In addition, the following checks and measurements shall be performed:

   - measurements of characteristic operating fluid pressures and consumption during operations, if applicable;
   - verification of the rated operating sequence;
   - checks of certain specific operations, if applicable.

   The variation between the mean values of each parameter measured before and after the extended mechanical endurance tests shall be within the tolerances given by the manufacturer.

b) After each series of 2 000 operating sequences, the operating characteristics a), b), c), d), e) and l) in 7.101.1.3 shall be recorded.

c) After the total test programme the condition of the circuit-breaker shall be in accordance with 7.101.1.4.

### 7.101.3 Low and high temperature tests

#### 7.101.3.1 General requirements

~~The two tests shall not be performed in succession, and the order in which they are made is arbitrary.~~ If the minimum ambient air temperature of indoor and outdoor circuit breakers is higher than or equal to -5 °C, no low temperature test is required. If the maximum ambient air temperature is not higher than +40 °C, no high temperature test is required.

The tests may be combined. If a combined sequence is chosen, a failure after either item k) of 7.101.3.4 or u) of 7.101.3.5 will constitute a failure of both tests.

For single enclosure circuit-breakers or multi-enclosure circuit-breakers with a common operating device, three-pole tests shall be made. For multi-enclosure circuit-breakers with independent poles, the testing of one complete pole is permitted.

Multi-enclosure type circuit-breakers can be tested using one or more of the following alternatives provided that the circuit-breaker in its testing arrangement is not in a more favourable condition than normal condition for mechanical operation (see 7.101.2.2):

a) reduced length of phase-to-earth insulation;
b) reduced pole spacing;
c) reduced number of making and breaking units.

If heat sources are required, they shall be in operation.

Liquid or gas supplies for circuit-breaker operation are to be at the test air temperature unless the circuit-breaker design requires a heat source for these supplies.

No maintenance, replacement of parts, lubrication or readjustment of the circuit-breaker is permissible during the tests.

The circuit-breaker has passed the test if the conditions stated in 7.101.1.4 and 7.101.1.5 are fulfilled. Furthermore, the conditions in 7.101.3.4 and 7.101.3.5 shall be fulfilled and the leakage rates recorded shall not exceed the limits given in Table 15 of IEC 62271-1:2017. In the test report the testing conditions and the condition of the circuit-breaker before, during and after the test shall be reported. The recorded quantities shall be presented. To reduce the number of oscillograms in the test report, a single representative oscillogram of every relevant type of operation under each specified testing condition shall be included.

A circuit-breaker design can be fitted with several variants of auxiliary equipment (shunt releases and motors) in order to accommodate the various rated control voltages and frequencies as stated in 5.9 and 5.10. No additional tests are required if the variants are of similar designs and if the resulting no-load mechanical characteristics are within the tolerance given in 7.101.1.1.

The conditions during and after the tests are given in 7.101.1.4.

#### 7.101.3.2 Additional requirements for metal-enclosed outdoor circuit-breakers

For circuit-breakers equipped with tank heater(s) for the purpose of avoiding gas liquefaction during low ambient temperature conditions, the test sequence required in 7.101.3.4 is not sufficient to demonstrate that the gas heating element is properly designed to avoid gas liquefaction during low ambient temperature conditions. For such circuit-breakers, the test sequence required in 7.101.3.4 shall be performed with a simulation of an average wind speed of 10 km/h (±20 %) applied perpendicularly to the longitudinal axis of an outer phase of the circuit-breaker. The wind shall be applied from step c) to j) of the test procedure described in 7.101.3.4.

The wind speed shall be measured by at least 5 positions along the longitudinal axis of the circuit-breaker and at a distance of 0,5 m (±0,1 m) to the outer circuit-breaker tank (see Figure 10). Each measurement shall be spaced by approximately 0,3 m. The number of measurements shall be such that the measurement length exceeds the circuit-breaker length by at least 0,5 m on each end. The wind speed for each of the individual measurements shall not deviate from the average wind value by more than ±50 %.

It is recognised that the wind speed measurements in relatively small climatic room (in relation to the circuit-breaker dimensions) can be difficult and that wind turbulences from the neighbouring test cell walls cannot be avoided. In such cases, greater deviations than required above can be accepted in agreement between manufacturer and user.

The application of a transversal wind can make the measurement of the gas tightness impossible. If this is the case, it is allowed to split the low temperature test procedure in two parts. After having performed the required test sequence with the simulation of the transversal wind, the low temperature test sequence shall be repeated, without transverse wind and without gas heater, at low temperature $T_L$ equal to or lower than the lowest temperature measured during the first test on the circuit-breaker tank surface close to sealing joints. A minimum of ten temperature measuring points shall be used to measure the tank surface temperature close to sealing joints.

Dimensions in metres

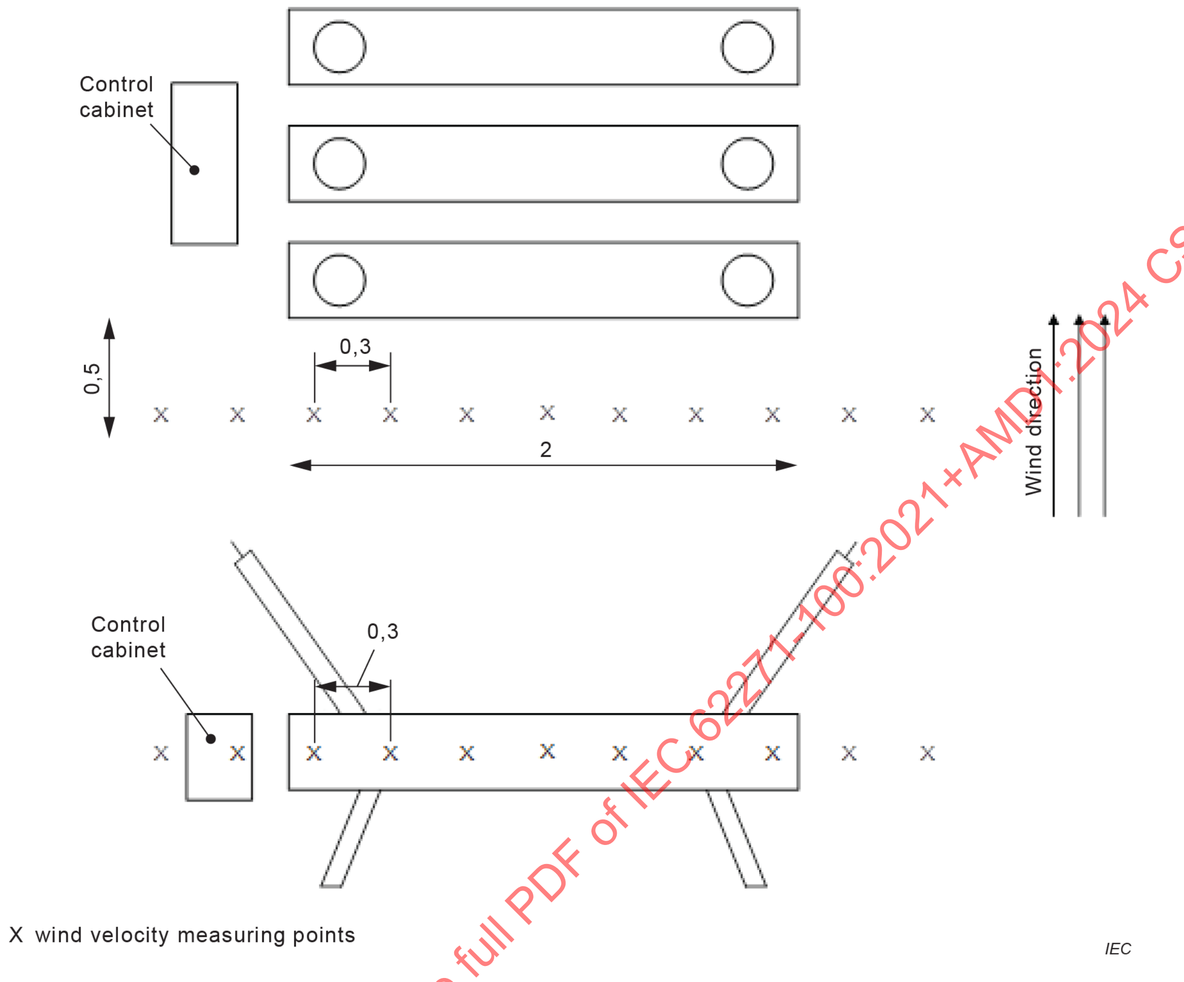





**Figure 10 – Example of wind velocity measurement**

#### 7.101.3.3 Measurement of ambient air temperature

The ambient air temperature of the immediate test environment shall be measured at half the height of the circuit-breaker and at a distance of 1 m from the circuit-breaker.

The maximum temperature deviation over the height of the circuit-breaker shall not exceed 5 K.

#### 7.101.3.4 Low temperature test

The diagram of the test sequences and identification of the application points for the tests specified are given in Figure 11.

If the low temperature test is performed immediately after the high temperature test, the low temperature test can proceed after completion of item u) of the high temperature test in 7.101.3.5. In this case items a) and b) are omitted.

a) The test circuit-breaker shall be prepared and adjusted in accordance with the manufacturer's instructions;

b) Characteristics and settings of the circuit-breaker shall be recorded in accordance with 7.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C ($T_A$). The tightness test (if applicable) shall be performed according to 7.8;

c) With the circuit-breaker in the closed position, the air temperature shall be decreased to the appropriate, minimum ambient air temperature ($T_L$), according to the minimum ambient temperature specified as given in 4.1.2, 4.1.3 and 4.2.4 of IEC 62271-1:2017. The circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at $T_L$;

d) During the 24 h period with the circuit-breaker in the closed position at temperature $T_L$, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017;

e) After 24 h at temperature $T_L$, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances;

f) The low temperature behaviour of the circuit-breaker and its alarms and lock-out systems shall be verified by disconnecting the supply of all heating devices, including also the anti-condensation heating elements, for a duration $t_x$. During this interval, occurrence of an alarm is acceptable but lock-out is not. At the end of the interval $t_x$, an opening order, at rated values of supply voltage and operating pressure, shall be given. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances.

   The manufacturer shall state the value of $t_x$ (not less than 2 h) up to which the circuit-breaker is still operable without auxiliary power to the heaters. In the absence of such a statement, the default value shall be equal to 2 h;

g) The circuit-breaker shall be left in the open position for 24 h;

h) During the 24 h period with the circuit-breaker in the open position at temperature $T_L$, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017;

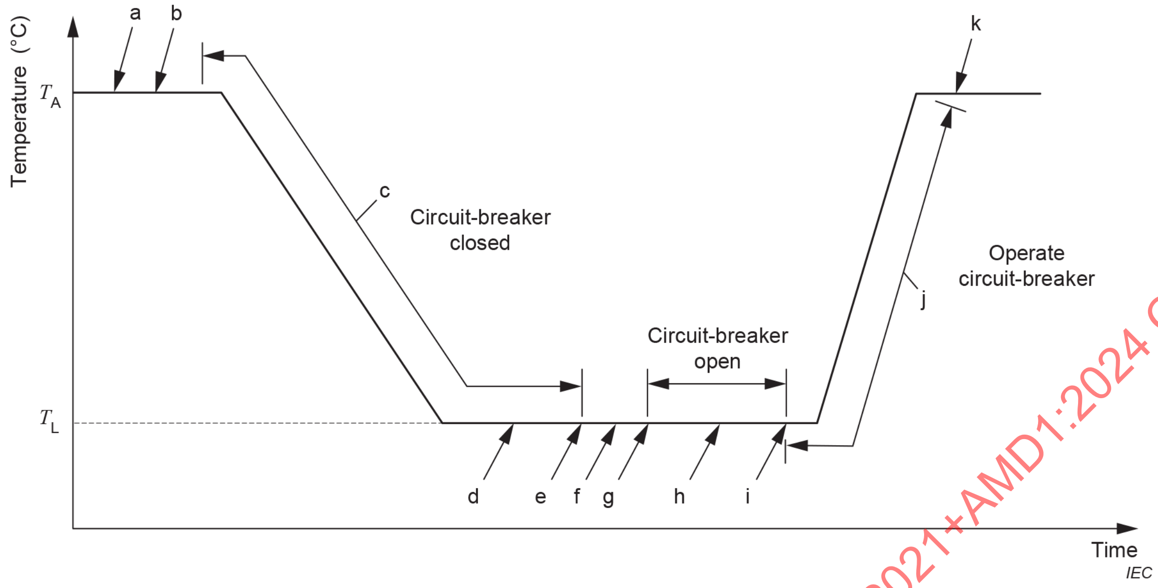
i) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at temperature $T_L$. At least a 3 min interval shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances. Following the first closing operation (C) and the first opening operation (O) three CO operating cycles shall be performed. The additional operations shall be made by performing C – $t_a$ – O – $t_a$ operating sequences ($t_a$ is defined in Table 8);

j) After completing the 50 opening and 50 closing operations, the air temperature shall be increased to ambient air temperature $T_A$ at a rate of change of approximately 10 K per hour;

   During the temperature transition period the circuit-breaker shall be subjected to alternate C – $t_a$ – O – $t_a$ – C and O – $t_a$ – C – $t_a$ – O operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so that the circuit-breaker will be in open and closed positions for 30 min periods between the operating sequences;

k) After the circuit-breaker has stabilised thermally at ambient air temperature $T_A$, a recheck shall be made of the circuit-breaker settings. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances. The tightness test shall be repeated as in item b) and the leakage rate shall remain the limits stated in 7.8.

   The accumulated leakage during the complete low temperature test sequence from item b) to item j) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).




NOTE Letters a through k identify application points of tests specified in 7.101.3.4.

**Figure 11 – Test sequence for low temperature test**

### 7.101.3.5 High temperature test

The diagram of the test sequence and identification of the application points for the tests specified are given in Figure 12.

If the high temperature test is performed immediately after the low temperature test, the high temperature test can proceed after completion of item j) of the low temperature test. In this case, items l) and m) below are omitted.

l) The test circuit-breaker shall be prepared and adjusted in accordance with the manufacturer's instructions;

m) Characteristics and settings of the circuit-breaker shall be recorded in accordance with 7.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C ($T_A$). The tightness test (if applicable) shall be performed according to 7.8;

n) With the circuit-breaker in the closed position, the air temperature shall be increased to the appropriate, maximum ambient air temperature ($T_H$), according to the upper limit of ambient air temperature as given in 4.1.2, 4.1.3 and 4.2.4 of IEC 62271-1:2017. The circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at $T_H$;

o) During the 24 h period with the circuit-breaker in the closed position at the temperature $T_H$, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017;

p) After 24 h at the temperature $T_H$, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances;

q) The circuit-breaker shall be opened and left open for 24 h at the temperature $T_H$;

r) During the 24 h period with the circuit-breaker in the open position at the temperature $T_H$, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017;

s) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at the temperature $T_H$. An interval of at least 3 min shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances;

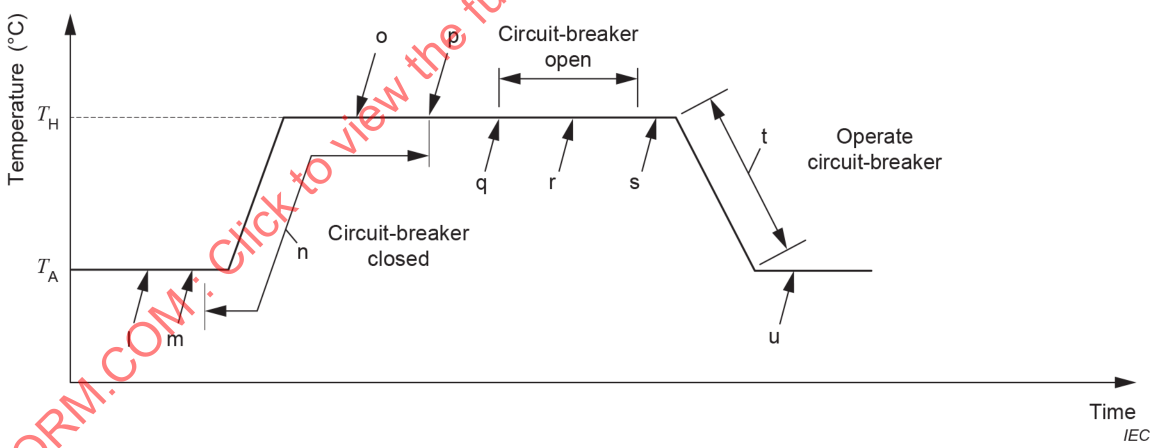
   Following the first closing operation (C) and the first opening operation (O) three CO operation cycles shall be performed. The additional operations shall be made by performing C – $t_a$ – O – $t_a$ operating sequences ($t_a$ is defined in Table 8);

t) After completing the 50 opening and 50 closing operations, the air temperature shall be decreased to ambient air temperature $T_A$, at a rate of change of approximately 10 K/h;

   During the temperature transition period, the circuit-breaker shall be subjected to alternate C – $t_a$ – O – $t_a$ – C and O – $t_a$ – C – $t_a$ – O operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so that the circuit-breaker will be in the open and closed positions for 30 min periods between the operating sequences;

u) After the circuit-breaker has stabilised thermally at ambient air temperature $T_A$, a recheck shall be made of the circuit-breaker settings. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances. The tightness test shall be repeated as in item m) and the leakage rate shall remain within the limits stated in 7.8.

   The accumulated leakage during the complete high temperature test sequence from item l) to item t) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).




NOTE Letters l through u identify application points of tests specified in 7.101.3.5.

**Figure 12 – Test sequence for high temperature test**

#### 7.101.4 Humidity test

##### 7.101.4.1 General

The humidity test does not apply to equipment which is designed to be directly exposed to precipitation, for example primary parts of outdoor circuit-breakers. The test shall be performed on circuit-breakers or circuit-breaker components, where due to sudden changes of the temperature, condensation can occur on insulating surfaces which are continuously stressed by voltage. This is mainly the insulation of the secondary wiring of indoor installed circuit-breakers. The test is not necessary if the circuit breaker is used within a switchgear for which tests on auxiliary and control circuits include environmental tests. It is also not necessary where effective means against condensation are provided, for example control cubicles with anti-condensation heaters.

Applying the test procedure described in 7.101.4.2, the withstand of the test object, primarily circuit-breaker components, to humidity effects, which can produce condensation on the surface of the test object, is determined in an accelerated manner.

##### 7.101.4.2 Test procedure

The test object shall be arranged in a test chamber containing circulating air and in which the temperature and humidity shall follow the cycle given below:

During about half of the cycle the surfaces of the test object shall be wet, and dry during the other half. To obtain this result the test cycle consists of a period $t_4$ with low air temperature ($T_{min}$ = 25 °C ± 3 °C) and a period $t_2$ with high air temperature ($T_{max}$ = 40 °C ± 2 °C) inside the test chamber. Both periods shall be equal in time. The generation of fog shall be maintained for that half of the cycle (see Figure 13) in which the low air temperature is applied.

The beginning of fog generation coincides in principle with the beginning of the low air temperature period. However, to wet the vertical surfaces of materials with a high thermal time constant, it can be necessary to start the fog generation later within the low air temperature period.

The duration of the test cycle depends on the thermal characteristics of the test objects, and shall be sufficiently long, both at high and low temperature, to cause wetting and drying of all insulation surfaces. In order to obtain these conditions, steam should be injected directly into the test chamber or heated water should be atomised; the rise from 25 °C to 40 °C can be obtained with the provision of heat coming from the steam or atomised water or, if necessary, by additional heaters. Preliminary cycles shall be carried out with the test object placed in the test chamber in order to observe and to check these conditions.

For low-voltage components of high-voltage circuit-breakers, usually having time constants smaller than 10 min, the duration of the time intervals given in Figure 13 are: $t_1$ = 10 min, $t_2$ = 20 min, $t_3$ = 10 min and $t_4$ = 20 min.

The fog is obtained by the continuous or periodical atomisation of 0,2 l to 0,4 l of water (with the resistivity characteristics given below) per hour and per cubic metre of test chamber volume. The diameter of the droplets shall be less than 10 µm; such a fog can be obtained by mechanical atomisers. The direction of the spraying shall be such that the surfaces of the test object are not directly sprayed. No water shall drop from the ceiling upon the test object. During the fog generation the test chamber shall be closed and no additional forced air-circulation is permitted.

The water used to create the humidity shall be such that the water collected in the test chamber has a resistivity equal to or greater than 100 Ωm and contains neither salt (NaCl) nor any corrosive element.

The temperature and the relative humidity of the air in the test chamber shall be measured in the immediate vicinity of the test object and shall be recorded for the whole duration of the test. No value of relative humidity is specified during the drop in temperature; however, the humidity shall be above 80 % during the period when the temperature is maintained at 25 °C. The air shall be circulated in order to obtain uniform distribution of the humidity in the test chamber.

The number of cycles shall be 350.

During and after the test, the operating characteristics of the test objects shall not be affected. This is proven by the dielectric withstand test on the auxiliary and control circuits in accordance with 7.2.11. The degree of corrosion, if any, should be indicated in the test report.

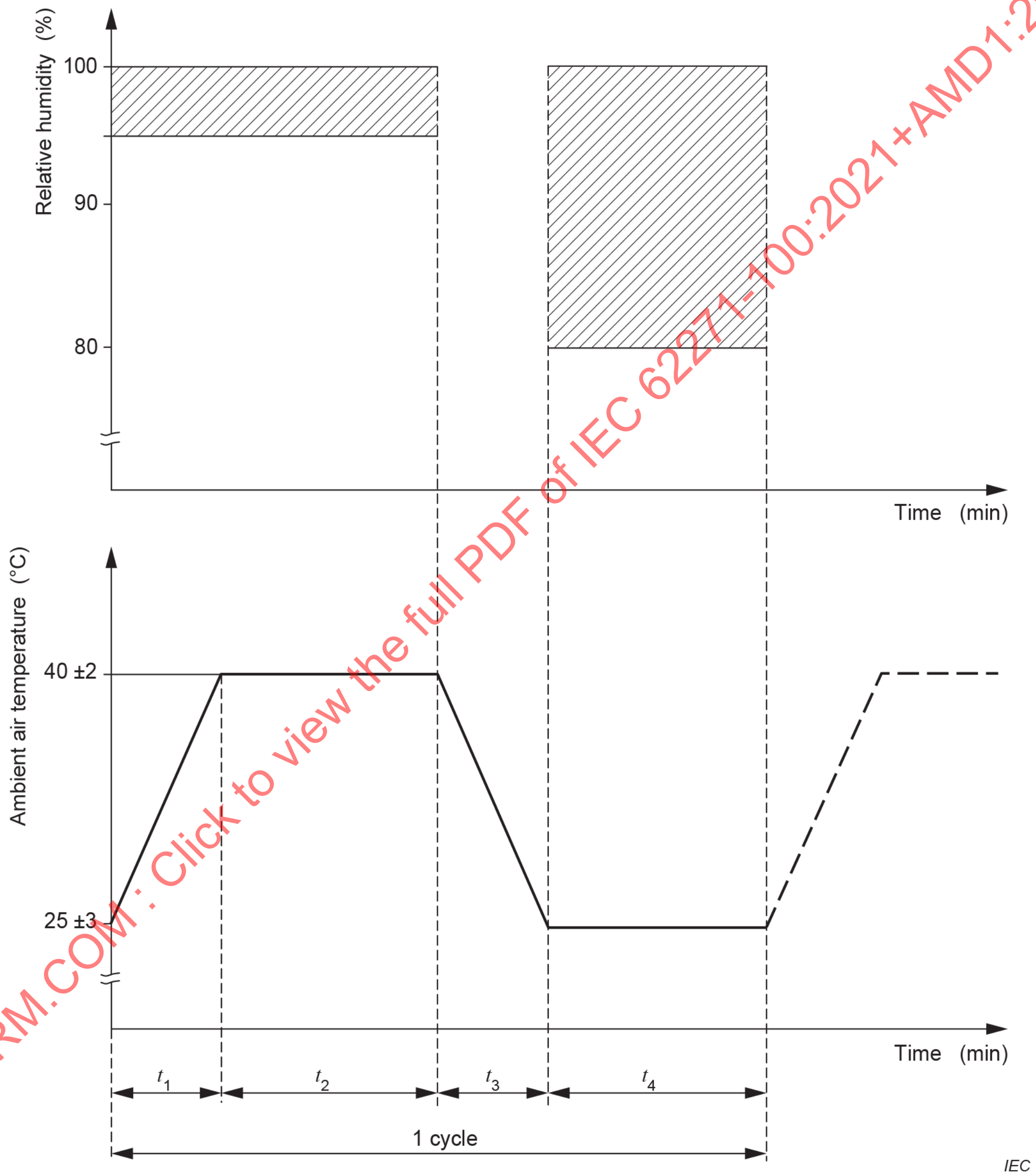



**Figure 13 – Humidity test**

### 7.101.5 Test to prove the operation under severe ice conditions

The test under severe ice conditions is applicable only to outdoor circuit-breakers having moving external parts. The test shall be performed according to IEC 62271-102:2018.

### 7.102 Miscellaneous provisions for making and breaking tests

#### 7.102.1 General

The following subclauses are applicable to all making and breaking tests unless otherwise specified in the relevant clauses.

Circuit-breakers shall be capable of making and breaking all short-circuit currents, symmetrical and asymmetrical, up to and including the rated short-circuit breaking currents: this is demonstrated, when the circuit-breakers make and break the specified three-phase symmetrical and asymmetrical currents between 10 % (or such lower currents as specified in 7.108.1.2 if 7.108.1.1 is applicable) and 100 % of the rated short-circuit breaking current at rated voltage.

In addition, circuit-breakers rated for $k_{pp}$ = 1,2 or 1,3 shall be capable of breaking single-phase short-circuit currents (see 7.108.2). Furthermore, circuit-breakers rated for $k_{pp}$ = 1,5 shall be capable of breaking short-circuit currents in case of double-earth faults (see 7.108.2).

Making and breaking tests according to class S2 cover making and breaking tests according to class S1.

Circuit-breakers to which any capacitive current rating has been assigned shall be capable of making and breaking capacitive currents up to and including the rated capacitive current at a voltage level up to and including that specified (see 7.111.7).

Where applicable, prior to the commencement of the tests, the manufacturer shall declare the values of

– minimum conditions of the operating mechanism guaranteeing the rated operating sequence (for example the minimum pressure for operation in case of a hydraulic operating mechanism);
– minimum conditions of the circuit-breaker guaranteeing the rated operating sequence (for example the minimum pressure for making and breaking in case of an $SF_6$ circuit-breaker).

#### 7.102.2 Additional requirements

The reference test method to prove the making and breaking requirements is using three-phase circuits.

If the tests are carried out in a laboratory, the applied voltage, current, transient and power-frequency recovery voltages can all be obtained from a single power source (direct tests) or from several sources where all of the current, or a major portion of it, is obtained from one source, and the TRV is obtained wholly or in part from one or more separate sources (synthetic tests).

If, due to limitations of the testing facilities, the reference test method cannot be used, several methods employing either direct or synthetic test methods can be used either separate or in combination, depending on the circuit-breaker type:

a) single-phase testing (see 7.102.4.1);
b) unit testing (see 7.102.4.2);
c) multi-part testing (see 7.102.4.3).

#### 7.102.3 Arrangement of circuit-breaker for tests

##### 7.102.3.1 General

The circuit-breaker under test shall be mounted on its own support or on an equivalent support. A circuit-breaker supplied as an integral part of an enclosed unit shall be assembled on its own supporting structure and enclosure, complete with any disconnecting features, with vent outlets forming part of the unit and, where practicable, with main connections and busbars.

Its operating device shall be operated in the manner specified and in particular, if it is electrically or spring operated, closing solenoid or shunt closing releases and shunt opening releases shall be supplied at their respective minimum voltages guaranteeing successful operation (85 % of the rated voltage for the closing solenoid or shunt closing releases, 85 % of the rated voltage if AC or 70 % if DC for the opening release). To facilitate consistent control of the opening and closing operation, the releases shall be supplied at the maximum operating voltage for test-duty T100a, capacitive current tests and the single-phase test specified in 7.108.2. Operating devices having a minimum operating condition (i.e. pressure, energy, etc.) shall be operated at the minimum condition for operation at the commencement of the rated operating sequence, as per 5.104, unless otherwise specified in the relevant clauses. In cases where a test-duty allows for operating sequences consisting of separate O operations, CO and O – $t$ – CO operating sequences, the following procedure applies to pneumatically and hydraulically operating devices:

a) before performing making and breaking tests and starting from the minimum pressure for operation, all the pressures during the rated operating sequence carried out at no-load shall be recorded;
b) the recorded values shall be compared with the minimum values declared by the manufacturer as guaranteeing successful operations as separate O, CO and in case of $t$ = 0,3 s, O – $t$ – CO. For these no-load operations the conditions stated in 7.101.1 apply;
c) tests shall be carried out at the pressure for operation set at the minimum value resulting from a) and b) above, whatever is the lower, for the corresponding operation in the test-duty; the pressure values shall be reported in the test report.

The operating time of some circuit-breakers can vary when the supply voltage to the coils is at the minimum value specified in 6.9 of IEC 62271-1:2017, while the operating times are reasonably constant at their rated supply voltages. Performing a test-duty with correct arcing times can be difficult to achieve in such a case, especially where steps of 18 electrical degrees shall be made to prove the arcing window. Additionally, the scattering of the closing time can prevent the possibility to perform the making test with the rated short-circuit making current.

For circuit-breakers where the operation of the coils does not affect contact travel characteristics, it is permitted to increase the supply voltage of the coils from the minimum value to 110 % of the rated supply voltage. No-load operations performed at the rated and minimum supply voltage shall be included in the test report to show that the contact travel characteristics are not affected by the increased voltage of the coil.

At least one making and one breaking operation shall be performed for test-duty T100s with minimum supply voltage to prove the ability of the circuit-breaker to operate correctly up to its rated short-circuit current under minimum control voltage conditions.

Interlocking devices associated with pressure interlocks shall be made inoperative during the tests, if they interfere with the intent of the test.

It shall be shown that the circuit-breaker will operate satisfactorily under the above conditions at no-load as specified in 7.102.6. The pressure of the compressed gas for making and breaking, if any, shall be set at its minimum functional value.

The circuit-breaker shall be tested according to its type as specified in 7.102.3.2 and 7.102.3.3.

#### 7.102.3.2 Common enclosure type

A three-pole circuit-breaker having all its arcing contacts supported within a common enclosure shall be tested as a complete three-pole circuit-breaker in three-phase circuits, taking Annex H into account.

#### 7.102.3.3 Multi-enclosure type

A three-pole circuit-breaker consisting of three independent single-pole switching devices can be tested single-phase according to 7.102.4.1. The manufacturer shall give testing evidence to show compliance with 6.101.

A three-pole circuit-breaker not having completely independent switching devices should be tested as a complete three-pole circuit-breaker. However, owing to limitation of available testing facilities, one single pole of the circuit-breaker can be tested, provided that it is with regard to the mechanical and electrical conditions applied during the tests equivalent to, or not in a more favourable condition than, the complete three-pole circuit-breaker over the range of tests in respect of:

– mechanical travel characteristics in a making operation (for the evaluation method, see 7.102.4.1);
– mechanical travel characteristics in a breaking operation (for the evaluation method, see 7.102.4.1);
– availability of arc-extinguishing medium;
– power and strength of closing and opening devices;
– rigidity of structure.

#### 7.102.3.4 Self-tripping circuit-breakers

For self-tripping circuit-breakers, subject to the provisions of 7.103.2.3, the overcurrent release shall be inoperative during making and breaking tests and the overcurrent release or the current transformers shall be connected to the live side of the test circuit.

### 7.102.4 General considerations concerning testing methods

#### 7.102.4.1 Single-phase testing of a single pole of a three-pole circuit-breaker

According to this method, a single pole of a three-pole circuit-breaker is tested single-phase, applying to the pole the same current and substantially the same power-frequency voltage which would be impressed upon the most highly stressed pole during three-phase making and breaking by the complete three-pole circuit-breaker under corresponding conditions.

~~In those cases where~~ Depending on the circuit-breaker design this document permits single-pole testing to ~~simulate~~ cover three-phase conditions ~~and~~. In those cases where the circuit-breaker is equipped with one operating mechanism for all three poles, a complete three-pole assembly shall be supplied for the tests.

For short-circuit tests, in order to establish whether ~~the circuit-breaker permits single-phase tests~~ single-pole testing to ~~simulate~~ cover three-phase conditions is permitted, verification tests ~~consisting of an asymmetrical and a symmetrical making operation and a breaking operation~~ for making and breaking shall be performed. Furthermore, it shall be checked that the operating characteristics of the circuit-breaker to be single-phase tested correspond to the provisions of 7.101.1.1.

The verification test for breaking consists of performing a three-phase short-circuit breaking test at the same current level as required for test-duty T100s, without TRV with any convenient test voltage, and with the longest expected arcing time in the last-pole-to-clear.

The verification test for making consists of two three-phase making operations under the same conditions as given in 7.105.2.1. In one making operation full symmetrical current and the maximum pre-arcing time shall be achieved in one pole. In the other making operation the maximum asymmetry shall be achieved in one pole; in this case the making operation can be performed at a convenient reduced voltage.

During the verification test making the circuit-breaker shall reach the fully closed position and the duration of the current shall be at least equal to the time needed for the circuit-breaker to reach the fully closed position.

During these verification tests for making and breaking, the course of the contact travel is recorded. It shall be used as a reference for the following procedure (see Figure 14). The sensor for picking up the course of the contact travel shall be mounted at a suitable location making it possible for providing the course of the contact travel, either directly or indirectly.

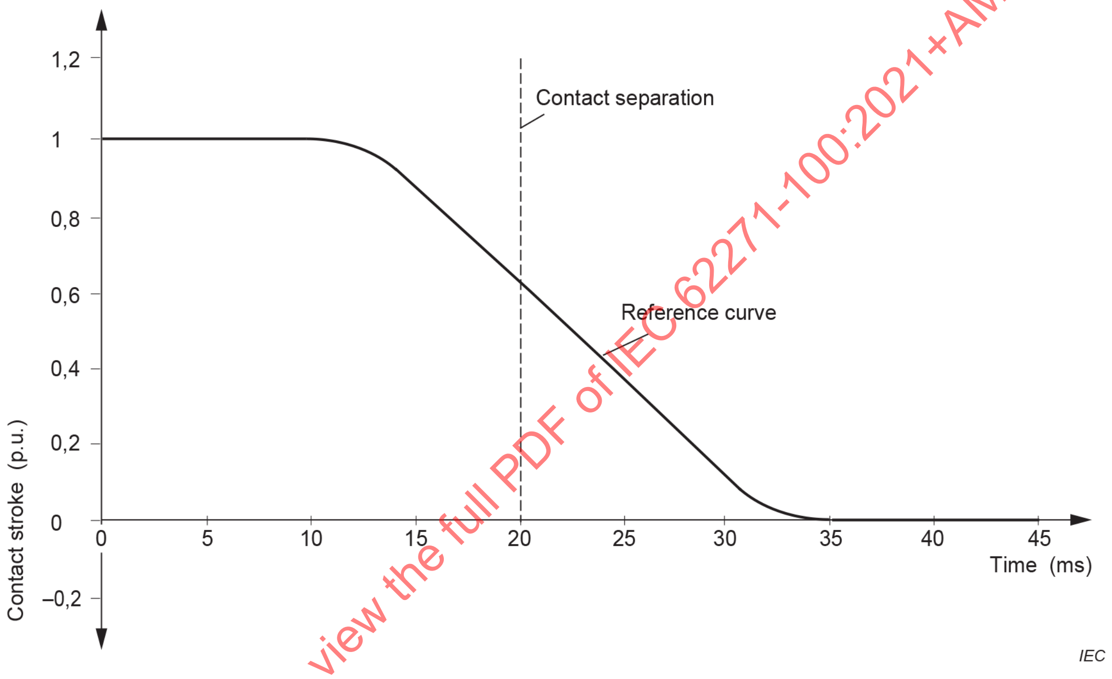



**Figure 14 – Example of reference mechanical characteristics (idealised curve)**

From this reference course, two envelope curves shall be drawn from the instant of contact separation to the end of the contact travel, in the case of a breaking operation, and from the beginning of the contact travel to the instant of contact touch, in the case of a making operation. The distance of the two envelopes from the original course shall be ±5 % of the total travel evaluated from the three-phase verification test (see Figure 15).

During a single-phase test under the same conditions (test-duty T100s with the longest arcing time and the longest pre-arcing time) the course of the contact travel shall be recorded. If the course of the contact travel in the single-phase test is within the envelopes of the mechanical travel characteristics from the instant of contact separation to the end of the contact travel in the case of a breaking operation and from the beginning of the contact travel to the instant of contact touch in the case of a making operation of the three-phase tests, single-phase tests for representing three-phase conditions are valid.

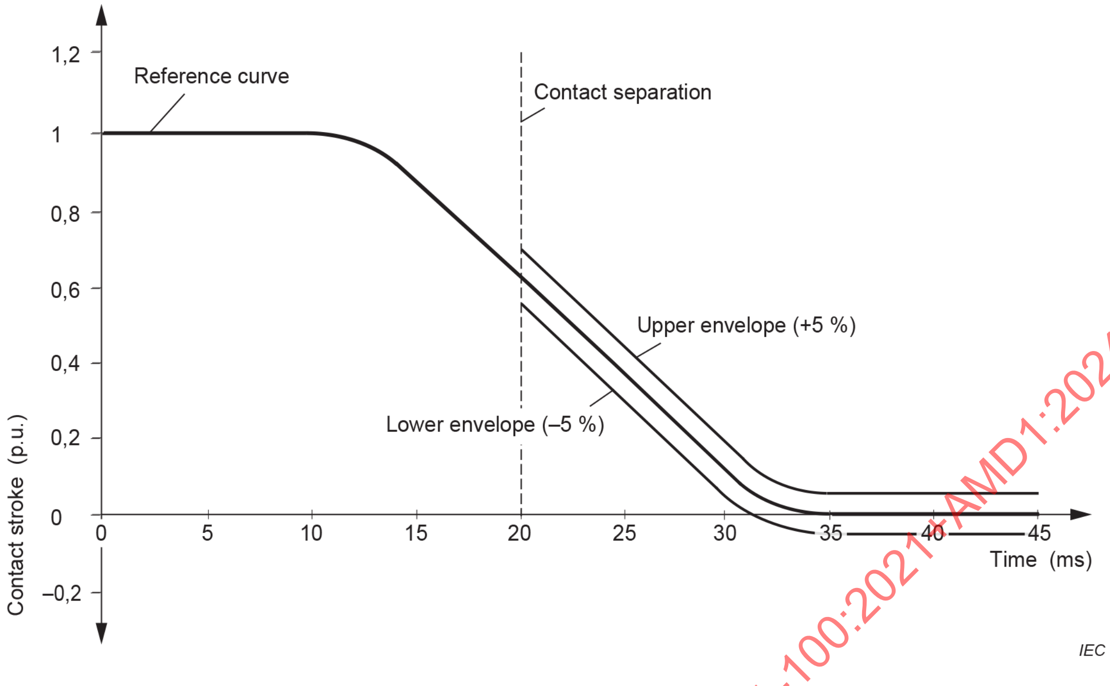



**Figure 15 – Reference mechanical characteristics of Figure 14 with the envelopes centred over the reference curve (+5 %, –5 %)**

The envelopes can be moved in the vertical direction until one of the curves covers the reference curve. This gives maximum tolerances over the reference contact travel curve of –0 %, +10 % and +0 %, –10 % respectively (see Figure 16 and Figure 17). The displacement of the envelope can be done only once for the complete procedure in order to get a maximum total deviation from the reference curve of 10 %.

To achieve the correct contact travel characteristics of the individual poles, depending on the design (single-phase or three-phase operated), it may be necessary to make adjustments, for example by using transfer functions.

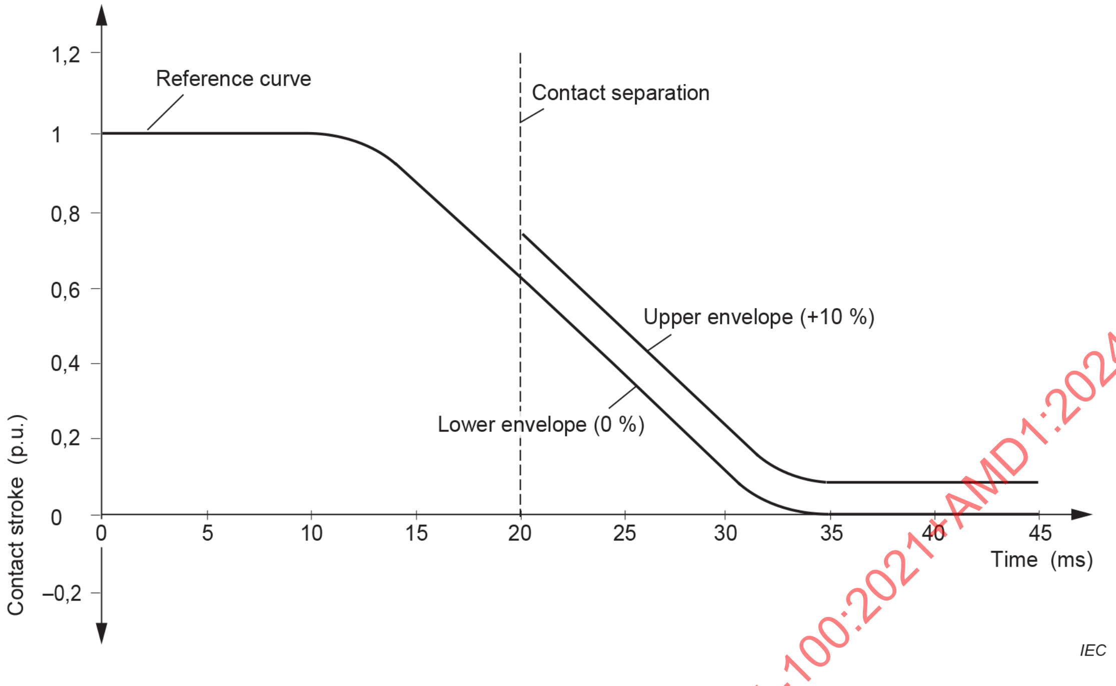



**Figure 16 – Reference mechanical characteristics of Figure 14 with the envelope fully displaced upward from the reference curve (+10 %, –0 %)**

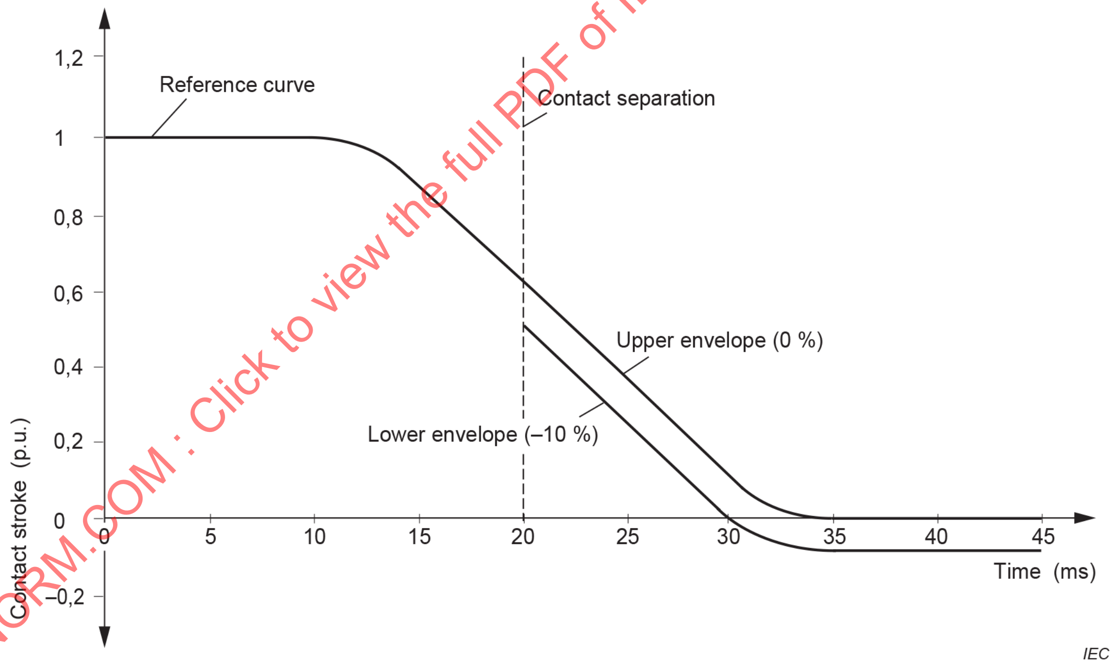



**Figure 17 – Reference mechanical characteristics of Figure 14 with the envelope fully displaced downward from the reference curve (+0 %, –10 %)**

Special attention should be paid to the emission of arc products. If it is considered that such emission would, for example, be likely to impair the insulation distance to adjacent poles, then this shall be checked, using earthed metallic screens (see 7.102.8).

When testing a circuit-breaker for 50 Hz and 60 Hz, verification tests shall only be performed at 50 Hz or 60 Hz, provided the following two conditions are met:

– the arcing time for breaking shall be the longest expected arcing time in the last-pole-to-clear at 50 Hz;
– during the making operation with asymmetrical current the rated short-circuit making current for 60 Hz shall be achieved.

#### 7.102.4.2 Unit testing

##### 7.102.4.2.1 General

Certain circuit-breakers are constructed by assembling identical making and breaking units in series, the voltage distribution between the making and breaking units of each pole often being improved by the use of parallel impedances.

This type of design enables the making and breaking performance of a circuit-breaker to be tested by carrying out tests on one or more making and breaking units.

The requirements of 7.101.1.1, 7.102.3 and 7.102.4.1 also apply for unit testing. Since therefore at least a complete pole assembly shall be made available for the verification tests on one or more making and breaking units, the test results relate only to this specific pole design.

##### 7.102.4.2.2 Configuration and requirements

The following situations can be distinguished:

a) The circuit-breaker pole consists of making and breaking units (or assemblies of making and breaking units) which are separately operated and which have no mutual connections for the arc extinguishing medium.

   In this case unit testing is acceptable. However, the mutual influence through the electrodynamic forces of the current on the making and breaking units and the arc in the making and breaking units should be taken into account (see Figure 18). This can be done by substitution of the second making and breaking unit by a conductor with equivalent shape.

b) The circuit-breaker pole consists of making and breaking units (or assemblies of making and breaking units) which are separately operated but which have a mutual connection for the arc extinguishing medium.

   In this case, unit testing is only acceptable if the making and breaking units not under test arc during the test (for example used as auxiliary circuit-breaker in synthetic tests).

c) The circuit-breaker pole consists of making and breaking units (or assemblies of making and breaking units) which are not separately operated.

   In this case, unit testing is only acceptable if the mechanical characteristics for the unit test and for the full-pole test are the same. The procedure as given in 7.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly. Moreover, the influence of electrodynamic forces (see also item a) above) shall be covered.

   However, if the making and breaking units not under test arc during the test (for example, used as auxiliary circuit-breaker in synthetic tests), the requirements related to the mechanical characteristics are considered to be covered. In this case, the requirement for circuit-breakers, which have mutual connections for the extinguishing medium between making and breaking units (see also item b) above) is covered at the same time.

d) For test currents equal to or less than 60 % of the rated short-circuit current, unit test is permissible if the arc extinguishing medium volume of the single making and breaking unit under test is proportional to the applicable part of one assembly of making and breaking units having the same arc extinguishing medium.

The mechanical characteristics under no-load conditions for unit test and for full-pole testing shall be the same. The procedure for comparison of mechanical characteristics given in 7.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly. The mutual influence through the electrodynamic forces of the current and the arc in the making and breaking units is considered to be negligible for test currents equal or less than 60 % of the rated short-circuit current.

When carrying out unit tests it is essential that the making and breaking units are identical and that the static voltage distribution for the type of test (for example terminal faults, short-line fault, out-of-phase, etc.) is known.

For unit testing of metal-enclosed circuit-breakers, see Annex H.

Pole of a circuit-breaker with two separate making and breaking units in series

Equivalent testing set-up for unit testing; the second making and breaking unit is substituted by a conductor of equivalent shape

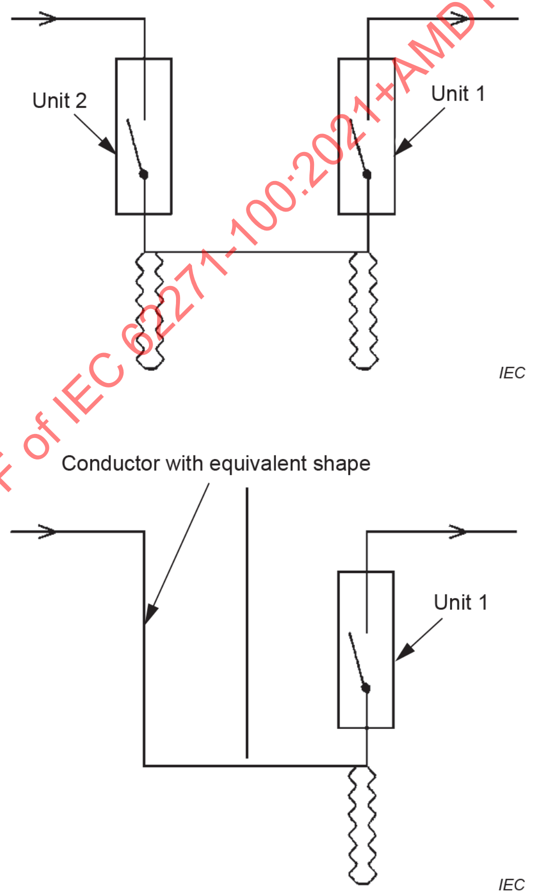



**Figure 18 – Equivalent testing set-up for unit testing of circuit-breakers with more than one separate making and breaking units**



#### 7.102.4.2.3 Identical nature of the making and breaking units

The making and breaking units of the circuit-breaker shall be identical in their shape, in their dimensions and in their operating conditions; only the devices for controlling the voltage distribution among making and breaking units can be different. In particular, the following conditions shall be fulfilled.

a) *Operation of contacts*

The operation of contacts shall be in accordance with 6.101. Rated operating pressures and voltages shall be used.

b) *Supply of the arc-extinguishing medium*

For a circuit-breaker using a supply of arc-extinguishing medium from a source external to the making and breaking units, the supply to each making and breaking unit shall, for all practical purposes, be independent of the supply to the other making and breaking units, and the arrangement of the supply pipes shall be such as to ensure that all making and breaking units are fed essentially together and in an identical manner.

#### 7.102.4.2.4 Voltage distribution

The test voltage is determined by analysing the voltage distribution between the making and breaking units of the pole.

The voltage distribution between making and breaking units of a pole, as affected by the influence of earth, shall be determined for the relevant test conditions laid down for tests on one pole:

– for terminal fault conditions see items c) and d) of 7.103.2.2 and Figure 19a, Figure 19b, Figure 20a and Figure 20b;

NOTE 1 The test circuits shown in Figure 19b and Figure 20b are not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex H and in IEC 62271-101.

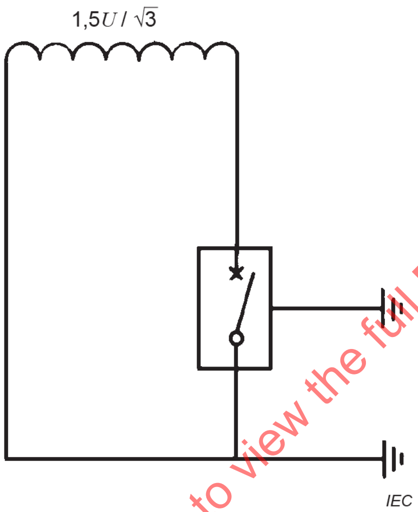



**Figure 19a – Preferred circuit**

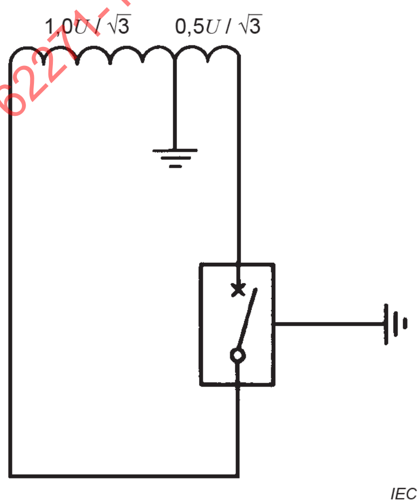



**Figure 19b – Alternative circuit**

**Figure 19 – Earthing of test circuits for single-phase short-circuit tests, $k_{pp}$ = 1,5**

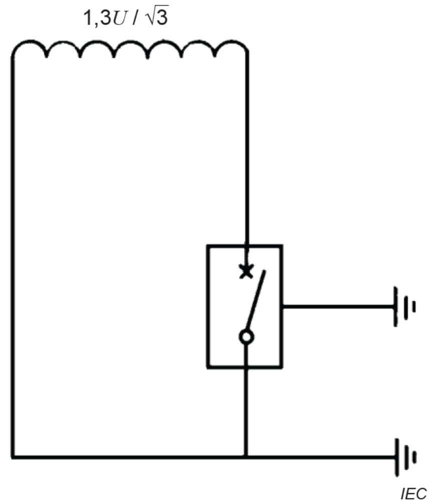



**Figure 20a – Preferred circuit**

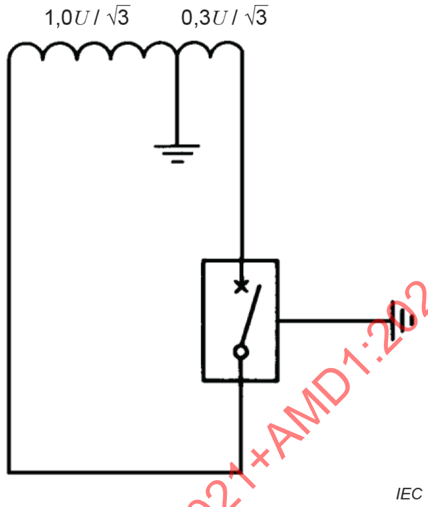
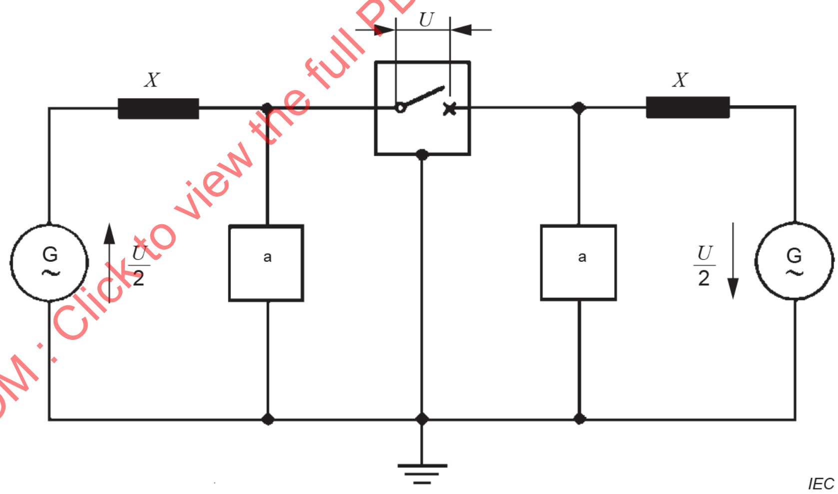



**Figure 20b – Alternative circuit**

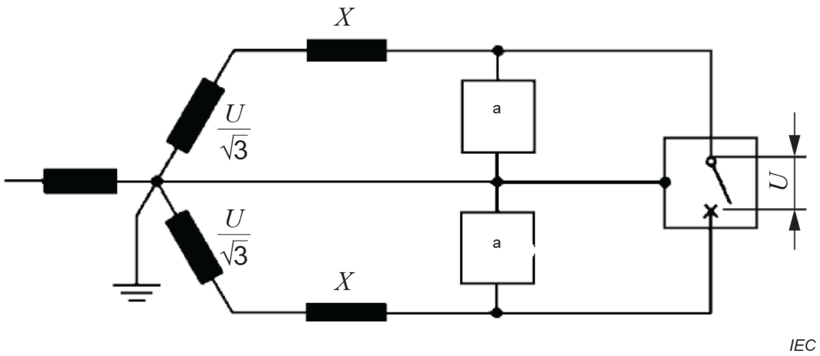
**Figure 20 – Earthing of test circuits for single-phase short-circuit tests, $k_{pp}$ = 1,3**

- for short-line fault conditions see 7.109.3;
- for out-of-phase conditions see 7.110.1 and Figure 21, Figure 22 and Figure 23;
- for capacitive making and breaking conditions see 7.111.3, 7.111.4 and 7.111.5.



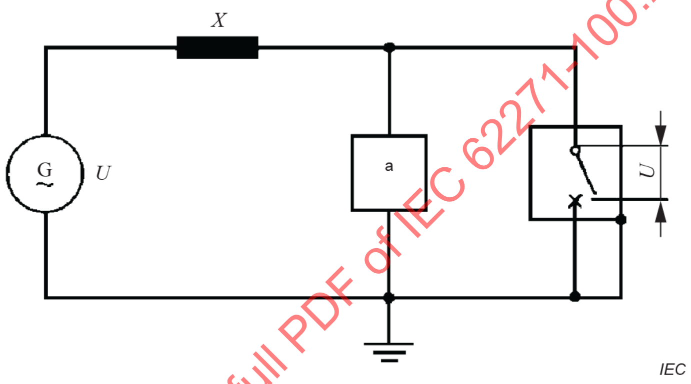

[a] The squares represent TRV control elements.

**Figure 21 – Test circuit for single-phase out-of-phase tests**




[a] The squares represent TRV control elements.

**Figure 22 – Test circuit for out-of-phase tests using two voltages separated by 120 electrical degrees**




[a] The square represents TRV control elements.

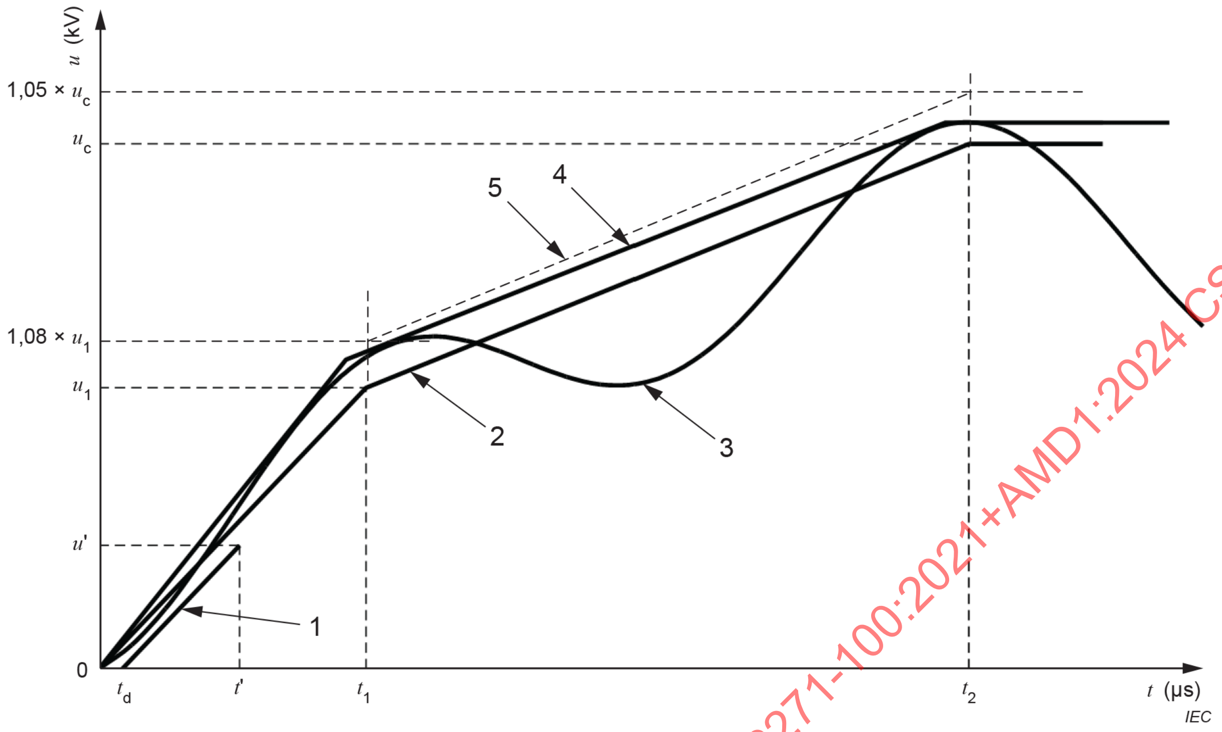
**Figure 23 – Test circuit for out-of-phase tests with one terminal of the circuit-breaker earthed (subject to agreement of the manufacturer)**

Where the making and breaking units are not symmetrically arranged, the voltage distribution shall be determined also with reverse connections.

The voltage distribution is determined either by measurement or by calculation. Values used in the calculations shall be supported by measurements of the stray capacitances of the circuit-breaker. Such calculations and supporting measurements verifying the assumptions used in the calculations are the responsibility of the manufacturer.

If the circuit-breaker is fitted with parallel resistors, the voltage distribution shall be calculated or measured statically at the equivalent frequency involved in the TRV.

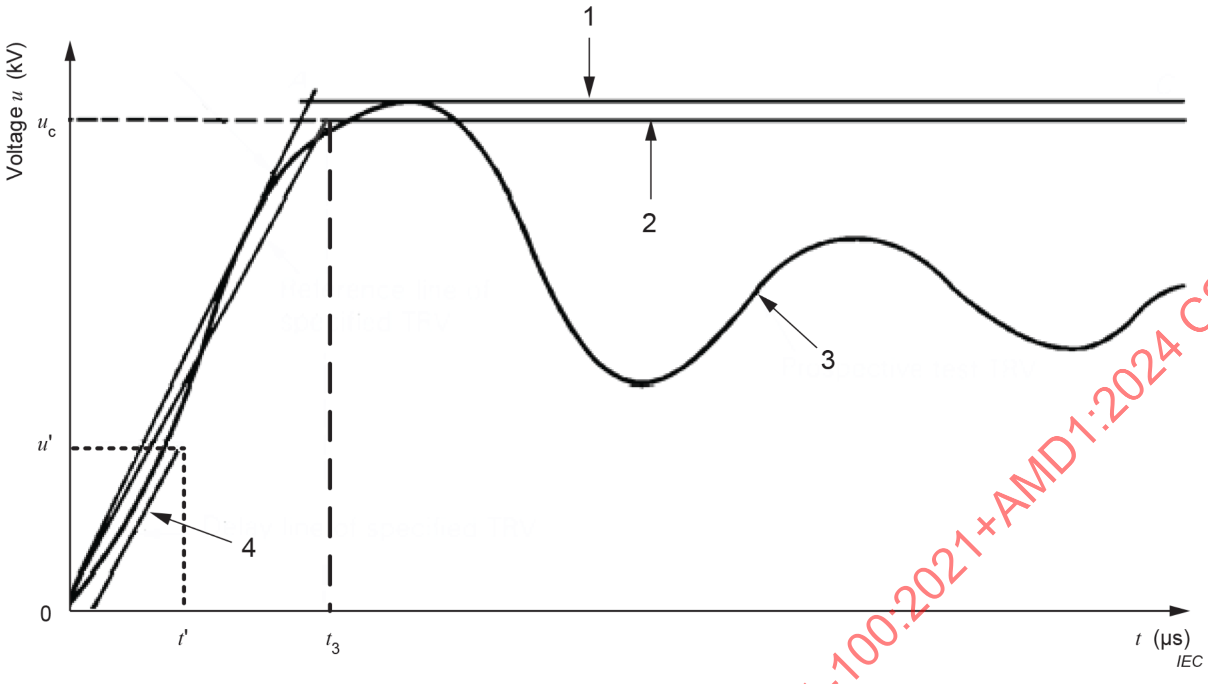
NOTE 2 The equivalent frequency is considered to be $1/(2t_1)$ in the case of four parameters or $1/(2t_3)$ in the case of two parameters (see Figure 24 and Figure 25).




**Key**

| | |
|---|---|
| 1 | Delay line of the specified TRV |
| 2 | Reference line of the specified TRV |
| 3 | Prospective test TRV |
| 4 | Envelope of the prospective test TRV |
| 5 | Upper limit of the envelope of the prospective test TRV |

**Figure 24 – Example of prospective test TRV with four-parameter envelope which satisfies the conditions to be met during type test – Case of specified TRV with four-parameter reference line**




**Key**

1 Envelope of the prospective test TRV

2 Reference line of the specified TRV

3 Prospective test TRV

4 Delay line of the specified TRV

**Figure 25 – Example of prospective test TRV with two-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with two-parameter reference line**

Where short-line fault tests are performed with unit test method, both source and line side TRV shall be determined with the single voltage distribution factor, corresponding to the voltage distribution of the line side TRV.

If only capacitors are used, the voltage distribution can be calculated or measured at power frequency.

The manufacturing tolerances for resistors and capacitors shall be taken into account. The manufacturer shall state the value of these tolerances.

NOTE 3 It can be taken into account that the voltage distribution is more favourable during the out-of-phase and capacitive current breaking tests than during the terminal fault or short-line fault tests. This also applies when, in exceptional cases, tests are performed under the conditions of unearthed faults in effectively earthed neutral systems.

NOTE 4 The influence of pollution is not considered in determining voltage distribution. In some cases, pollution can affect this voltage distribution.

#### 7.102.4.2.5 Additional requirements for unit testing

When testing a single making and breaking unit, the test voltage shall be the voltage of the most highly stressed making and breaking unit of the complete pole of the circuit-breaker, determined in accordance with 7.102.4.2.4. For short-line fault conditions, the making and breaking unit referred to is that most highly stressed at the specified time of the first peak of the line side transient voltage.

When testing a group of making and breaking units, the voltage appearing at the terminals of the most highly stressed making and breaking unit of the group shall be equal to the voltage of the most highly stressed making and breaking unit of the pole, both determined in accordance with 7.102.4.2.4.

Additional guidance is given in Annex H.

#### 7.102.4.3 Multi-part testing

If all recovery voltage requirements for the given test-duty cannot be met simultaneously, the test can be carried out in two successive parts, for example as illustrated in Figure 26.

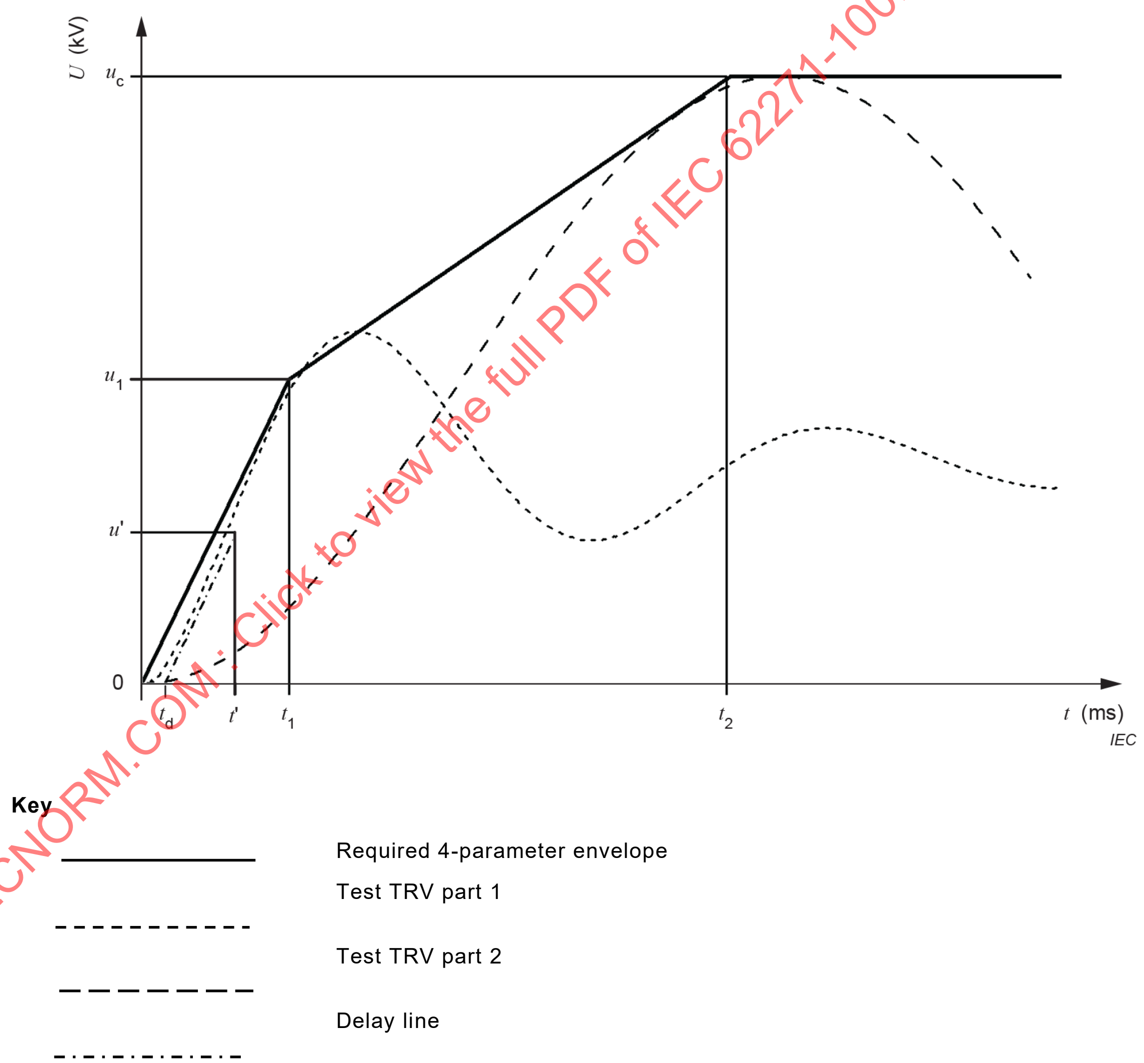



**Figure 26 – Example of prospective test TRV-waves and their combined envelope in two-part test**

In the test circuit used for the first part, the initial portion of the TRV shall not cross the straight line defining the delay time and shall meet the specified reference line up to the voltage $u_1$ and the time $t_1$.

In the test circuit used for the second part, the voltage $u_c$ and the time $t_2$ shall be attained.

Multi-part testing can also be carried out in order to obtain the power frequency recovery voltage of $U_r/\sqrt{3}$ for terminal fault after one half-cycle of rated frequency during single-phase tests in substitution for three-phase tests as specified in 7.103.4.

The number of tests for each part shall be the same as the number required for the test-duty, and the arcing times for each part shall meet the requirements of 7.104. The arcing times in separate tests forming part of one multi-part test shall be the same with a tolerance of ±1 ms. Moreover, if the minimum arcing time in one part differs from that established in the other part by more than 1 ms then the maximum arcing time associated with the longer of the two minimum arcing times shall be used for both parts.

When multi-part testing is used to separately meet the requirements for TRV and for the power frequency recovery voltage, during tests with power frequency recovery voltage it is not necessary to search for the minimum arcing time. Arcing times shall be based on the minimum arcing time obtained during tests with TRV.

The circuit-breaker can be re-conditioned between the parts of the multi-part testing procedure in accordance with 7.102.9.6.

In rare cases, it may be necessary to perform the test in more than two parts. In such cases, the principles stated above shall be applied.

**7.102.5 Synthetic tests**

Synthetic testing methods can be applied for making and breaking tests as required in 7.107 to 7.111. Synthetic testing techniques and methods are described in IEC 62271-101.

**7.102.6 No-load operations before tests**

Before commencing making, breaking tests, C and O operations shall be made and the mechanical characteristics recorded. Details such as closing time and opening time shall be recorded. For these no-load operations, conditions stated in 7.101.1.1 apply. Additional no-load operations can be necessary (see also 7.102.3.1).

In addition, it shall be demonstrated that the mechanical behaviour of the circuit-breaker under test conforms to that of the reference mechanical travel characteristics required in 7.101.1.1. After a change of contacts or any kind of maintenance, these mechanical travel characteristics shall be reconfirmed by repeating these no-load tests.

For a circuit-breaker fitted with a making current release, it shall be shown that this does not operate on no-load.

The pressure of the compressed gas for making and breaking shall be set at the value corresponding to that required for the test-duty to be performed.

For electrically or spring-operated circuit-breakers, operations shall be made with the closing solenoid or shunt-closing releases energised at 100 % and 85 % of the rated supply voltage of the closing device and with the shunt-opening release energised at 100 % and 85 % in the case of AC, and 100 % and 70 % in the case of DC of the rated supply voltage.

#### 7.102.7 Alternative operating mechanisms

In this subclause, it is considered that one version of a circuit-breaker with its operating mechanism is completely type-tested in accordance with this document; this version is referred to as the completely tested circuit-breaker. The other versions, differing in the operating mechanisms (see definition in 3.5.130), are referred to as circuit-breakers with alternative operating mechanisms.

For a circuit-breaker equipped with alternative operating mechanisms, repetition of T100s and T100a (if required in c) below) only is required for the demonstration of the making and breaking capabilities.

Therefore, the tests to be performed on the circuit-breaker equipped with the alternative operating mechanism are as follows:

a) the mechanical characteristics shall be recorded in accordance with 7.101.1.1 and the results of a comparison with the characteristics of the completely tested circuit-breaker shall comply with the requirements given in Annex G;
b) test-duty T100s shall be performed. In addition, the mechanical characteristics during the breaking operations with the longest arcing time shall be compared with the completely tested circuit-breaker according to the method required in 7.101.1.1 and comply with the requirements given in Annex G;
c) in the particular case where the minimum clearing time (see 3.7.151) is falling in a shorter category, test-duty T100a shall be performed.

If requirements a), b) and c) are met, the reference mechanical characteristics of the completely tested circuit-breaker shall apply also for the circuit-breakers equipped with alternative operating mechanisms.

#### 7.102.8 Behaviour of circuit-breaker during tests

During making and breaking tests, the circuit-breaker shall not

– show signs of distress;
– show harmful interaction between poles and to earth;
– show harmful interaction with adjacent laboratory equipment;
– exhibit behaviour which could endanger an operator.

If faults occur which are neither persistent nor due to defect in design, but rather are due to errors in assembly or maintenance, the faults can be rectified and the circuit-breaker subjected to the repeated test-duty concerned. In those cases, the test report shall include reference to the invalid tests.

Resumption of power-frequency current in any pole before one cycle after breaking shall be cleared by the circuit-breaker. A resumption of power frequency current later than one cycle after the first breaking of the short-circuit in all poles is a failure.

NSDDs can occur during the recovery voltage period following a breaking operation. However, their occurrence is not a sign of distress of the switching device under test. Therefore, their number is of no significance to interpreting the performance of the device under test. They shall be reported in the test report in order to differentiate them from restrikes.

It is not the intent to require the installation of special measuring circuits to detect NSDDs. They should only be reported when seen on an oscillogram.

### 7.102.9 Condition of the circuit-breaker after making and breaking tests

#### 7.102.9.1 General

After each short-circuit test-duty, the circuit-breaker shall be capable of making and breaking its rated continuous current at the rated voltage, although its short-circuit making and breaking performance can be impaired. The circuit-breaker shall be inspected after any test-duty or a number of test-duties. Its mechanical parts and insulators shall be in essentially the same condition as before the tests. Visual inspection is usually sufficient for verification of the insulating properties. In some cases as specified in 7.102.9.2, the condition checking test according to 7.2.12 is required to prove the insulation properties.

#### 7.102.9.2 Insulation properties

For sealed-for-life circuit-breakers the voltage test as condition check according to 7.2.12 is mandatory after the tests according to 7.107 through 7.112 and shall be performed as follows:

– in case of a single-phase test, the condition check test shall only be carried out on the pole tested;
– in case of three-phase tests the condition check test shall be carried out on all three poles.

Terminals to which no test voltage is applied shall be earthed during the condition check test.

For other than sealed-for-life circuit-breakers the condition check test shall be performed after test-duty $L_{90}$. If test-duty $L_{90}$ is not required, the condition check shall be carried out after test-duty T100s.

After all other test-duties a visual inspection is sufficient for verification of the insulating properties. There shall be no evidence of puncture, flashover or tracking of the internal parts that contribute to the insulation, except that moderate wear of the parts of arc control devices exposed to the arc is permissible.

~~NOTE In many designs of circuit-breakers "auxiliary" nozzles are included that do not contribute to the insulation but assist the short-circuit breaking process by the release of ablated vapour, leading to material loss and deformation.~~

If, during the capacitive current tests, one or more restrikes occurred, a dielectric condition checking test according to 7.2.12 shall be performed before visual inspection, provided that the tested peak recovery voltage during the capacitive current tests is lower than the peak voltage of the specified dielectric condition checking test. The subsequent visual inspection shall demonstrate that the restrike occurred between the arcing contacts only. There shall be no evidence of puncture, flashover or permanent tracking of internal parts that contribute to the insulation. Wear of the parts of arc control devices exposed to the arc is permissible as long as it does not impair the breaking capability. Moreover, the inspection of the insulating gap between the main contacts, if they are different from the arcing contacts, shall not show any trace of a restrike.

If no restrike occurred during the capacitive current tests visual inspection is sufficient.

#### 7.102.9.3 Integrity of making and breaking units placed in an insulating fluid

If making and breaking units are placed in an insulating fluid with different characteristics and other than air at atmospheric pressure, that also might withstand the test voltages when replacing the original arc extinguishing medium (for example a vacuum interrupter in an enclosure filled with $SF_6$) the integrity check as requested in 7.2.12.102 shall be performed after the short-circuit making and breaking tests. This is not required after a capacitive current test.

#### 7.102.9.4 Continuous current carrying capability

The main contacts shall be in such a condition, in particular with regard to wear, contact area, pressure and freedom of movement, that they are capable of carrying the rated continuous current of the circuit-breaker without their temperature rise exceeding by more than 10 K the values specified for them in Table 14 of IEC 62271-1:2017 with the exception that after capacitive current tests for class C1 the maximum temperature rise does not exceed the values specified in Table 14 of IEC 62271-1:2017.

Contacts shall be considered as "silver-faced" only if there is still a layer of silver at the contact points after any of the short-circuit test-duties; otherwise, they shall be treated as "not silver-faced" (see 7.5.6.2, point 6 of IEC 62271-1:2017).

For other than sealed-for-life ciruit-breakers, visual inspection is usually sufficient for verification of the capability of the circuit-breaker to carry the continuous current and to make and break its rated continuous current at the rated voltage.

For circuit-breakers with sealed-for-life circuit-breakers the following applies:

– a measurement of the resistance as condition check according to 7.4.4 is mandatory for verification of the capability of the circuit-breaker to carry and to make and break the rated continuous current at the rated voltage;
– by-products resulting from arcing can generate a non-conductive layer on contact surfaces, showing high resistance if measured with limited current source. Such value might not be representative of real current carrying capability as this layer might disappear at contact spots under rated continuous current flow;
– if the resistance increase exceeds 100 % it is allowed to repeat the resistance measurement after a maximum of 10 no-load CO operating cycles;
– if the resistance increase still exceeds 100 %, it is allowed to repeat the measurement after applying a current not exceeding the rated continuous current for a maximum duration of 15 min. A cooling time of maximum 30 min is also allowed prior to this resistance measurement;
– if the resistance increase still exceeds 100 % then a continuous current test according to 7.5 is applicable to determine if the test object can carry its rated continuous current;
– the circuit-breaker passed the tests if the maximum temperature rise recorded at the terminals of any making and breaking unit does not exceed by more than 10 K the values specified in Table 14 of IEC 62271-1:2017.

#### 7.102.9.5 No-load tests after a test-duty

No load operations after an individual test-duty are only necessary if change of the contacts or other kinds of maintenance is intended to be performed after the test-duty. The no-load operations shall be compared with the corresponding operations made in accordance with 7.102.6 and shall remain within the tolerances given by the manufacturer.

In order to check the operation of the circuit-breaker after the completion of an entire test series of making and breaking tests, the no-load operating sequence according to 7.102.6 shall be repeated. These no-load tests shall be compared with the corresponding operations made in accordance with 7.102.6. The requirements of 7.101.1.1 and of Annex G shall be fulfilled. The circuit-breaker shall close and latch satisfactorily.

#### 7.102.9.6 Reconditioning during making and breaking tests

For some-circuit breakers it may be necessary to carry out maintenance work after performing a test-duty. After the maintenance work the circuit-breaker shall be in a practically new condition. It is also allowed to exchange the complete circuit-breaker or a big part of the circuit-breaker. Before continuation of the tests on the maintained, reconditioned or new circuit-breaker it shall be demonstrated that the mechanical behaviour of the circuit-breaker under test conforms to that of the reference mechanical travel characteristics required in 7.101.1.1.

It is the responsibility of the manufacturer to specify when the circuit-breaker needs to be maintained, reconditioned or replaced as long as the following requirements are fulfilled:

a) It is not allowed to maintain, recondition or replace the circuit breaker during the specified operating sequence of a terminal fault test-duty, a short-line fault test-duty or an out-of-phase making and breaking test-duty;

b) It is not allowed to maintain, recondition or replace the circuit-breaker during test-duty 1 and test-duty 2 for class C1 and during pre-condition test, test-duty 1 and test-duty 2 for class C2 circuit-breakers. This is also not allowed when combinations of capacitive test-duties for line, cable or capacitor bank charging current tests are made or when reclassification tests are made in accordance with 7.111.11.4;

c) A class E2 circuit-breaker, intended to use without auto-reclosing, shall not be maintained, reconditioned or replaced during the terminal fault test-duties, given in 7.107;

d) A class E2 circuit-breaker, intended to use with auto-reclosing, shall not be maintained, reconditioned or replaced during the test series described in 7.112.2.

## 7.103 General considerations for making and breaking tests

### 7.103.1 General

This subclause describes some general considerations for making and breaking tests. The manufacturer shall specify the values required.

### 7.103.2 Test circuits for short-circuit making and breaking tests

#### 7.103.2.1 Frequency

Circuit-breakers shall be tested at rated frequency with a tolerance of ±8 %.

However, for convenience of testing, some deviations from the above tolerance are allowable; for example, when circuit-breakers rated at 50 Hz are tested at 60 Hz and vice versa, care should be exercised in the interpretation of the results, taking into account all significant facts such as the type of the circuit-breaker and the type of test performed.

#### 7.103.2.2 Earthing of test circuit

The connections to earth of the test circuit for short-circuit making and breaking tests shall be in accordance with the following requirements and shall be indicated in the diagram of the test circuit included in the test report (see item f) of C.2.4).

a) Three-phase tests of a three-pole circuit-breaker, $k_{pp}$ = 1,5:

   The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply isolated and the short-circuit point earthed as shown in Figure 27a, or vice versa as shown in Figure 27b, if the test can only be made in the latter way.

   In accordance with Figure 27a, the neutral of the supply source can be earthed through a resistor, the resistance of which is as high as possible and, expressed in ohms, in no case less than $U$/10, where $U$ is the numerical value in volts of the voltage between lines of the test circuit.

When a test circuit according to Figure 27b is used, it is recognised that in case of an earth fault at one terminal of the test circuit-breaker, the resulting earth current could be dangerous. It is consequently permitted to connect the supply neutral to earth through an appropriate impedance.

b) Three-phase tests of a three-pole circuit-breaker, $k_{pp}$ = 1,3:

The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply connected to earth by an appropriate impedance and the short-circuit point earthed as shown in Figure 28a, or vice versa as shown in Figure 28b, if the test can only be made in the latter way.

The impedance in the neutral connection shall be selected appropriate to a $k_{pp}$ of 1,3. Assuming $Z_0$ = 3,25 × $Z_1$ the appropriate value of the impedance in the neutral connection is 0,75 times the phase impedance.

NOTE 1 The test circuit shown in Figure 28b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex H and in IEC 62271-101.

c) Single-phase tests of a single pole of a three-pole circuit-breaker with $k_{pp}$ = 1,5:

The test circuit and the circuit-breaker structure shall be connected as in Figure 19a, so that the voltage conditions between live parts and the structure after arc extinction are the same as those which would exist in the first-pole-to-clear of a three-pole circuit-breaker if tested in the test circuit shown in Figure 27a.

The preferred test circuit is shown in Figure 19a. Where there are limitations on test station equipment, then the circuit shown in Figure 19b can be used.

NOTE 2 The test circuit shown in Figure 19b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex H and in IEC 62271-101.

d) Single-phase tests of a single pole of a three-pole circuit-breaker with $k_{pp}$ = 1,3:

The test circuit and the circuit-breaker structure shall be connected as in Figure 20a, so that the voltage conditions between live parts and the structure after arc extinction are approximately the same as those that would exist in the first-pole-to-clear of a three-pole circuit-breaker if tested in the test circuit shown in Figure 28a.

The preferred test circuit is shown in Figure 20a. Where there are limitations on test station equipment, then the circuit shown in Figure 20b can be used.

NOTE 3 The test circuit shown in Figure 20b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex H and in IEC 62271-101.

e) Single-phase tests of a single-pole circuit-breaker:

The test circuit and the circuit-breaker structure shall be connected so that the voltage conditions between live parts and earth within the circuit-breaker after arc extinction reproduce the service voltage conditions. The connections used shall be indicated in the test report.

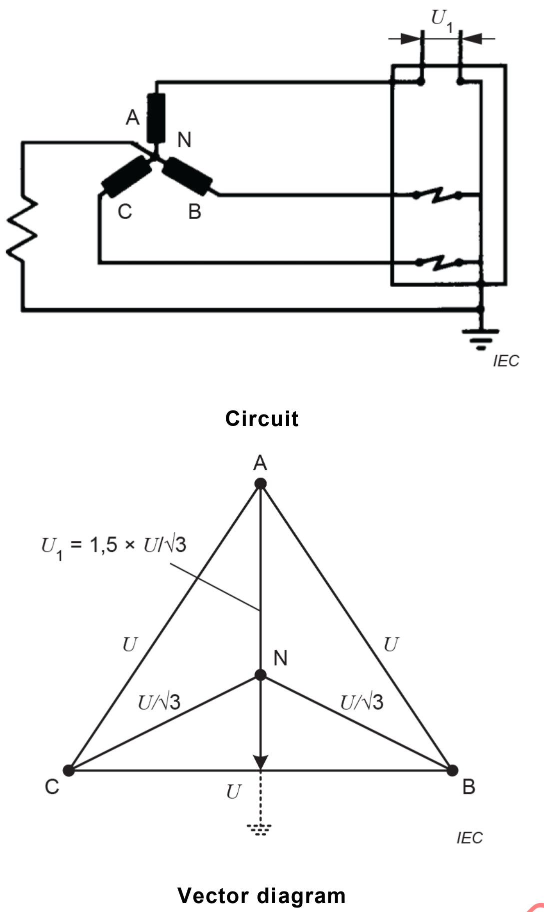



**Figure 27a – Preferred circuit with vector diagram**

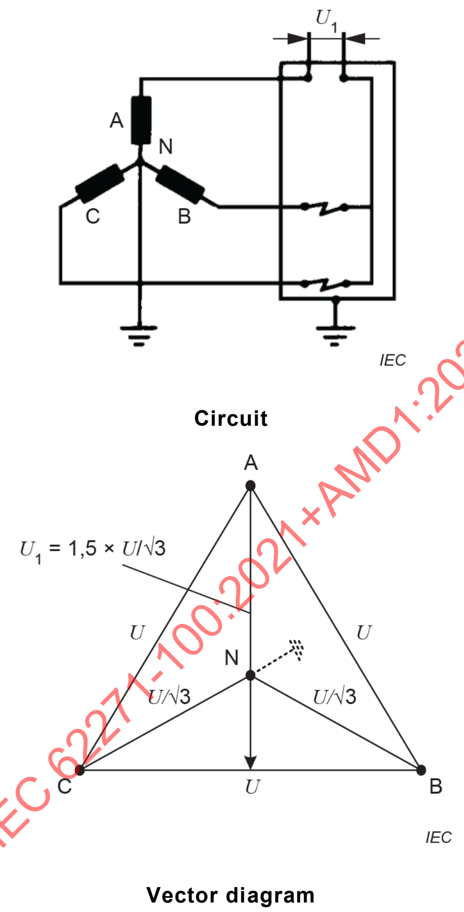
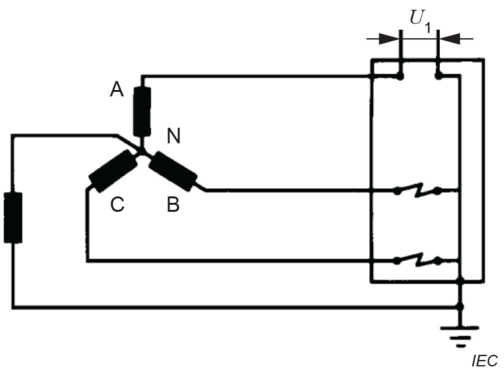
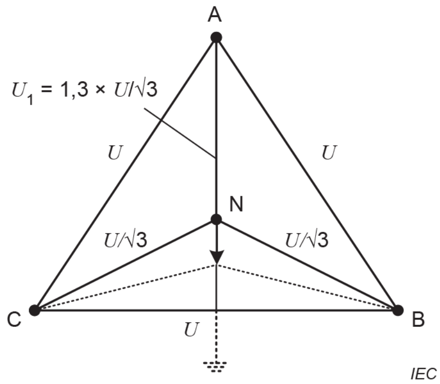



**Figure 27b – Alternative circuit with vector diagram**

**Figure 27 – Earthing of test circuits for three-phase short-circuit tests, $k_{pp}$ = 1,5**

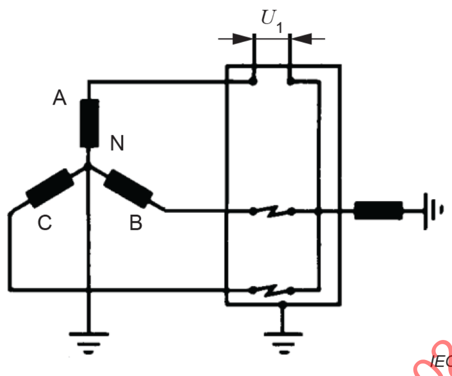



Circuit

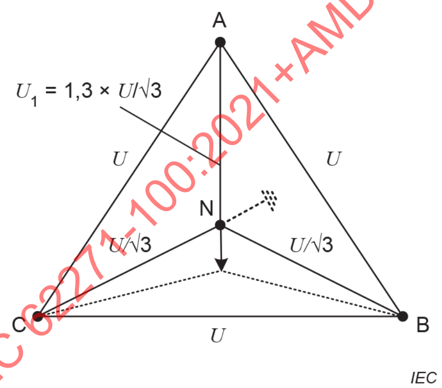



Vector diagram

**Figure 28a – Preferred circuit**




Circuit




Vector diagram

**Figure 28b – Alternative circuit**

**Figure 28 – Earthing of test circuits for three-phase short-circuit tests, $k_{pp}$ = 1,3**

### 7.103.2.3 Connection of test circuit to circuit-breaker

Where the physical arrangement of one side of the circuit-breaker differs from that of the other side, the live side of the test circuit shall be connected for testing to that side of the circuit-breaker which gives the more severe conditions, unless the circuit-breaker is especially designed for feeding from one side only.

Where it cannot be demonstrated satisfactorily which connection gives the more severe conditions, test-duties T10 and T30 shall be made with opposite connections, and likewise for test-duties T100s and T100a. If test-duty T100a is omitted, test-duty T100s shall be made with each of the two connections.

### 7.103.3 Measurement of the TRV during test

During a short-circuit test, the circuit-breaker characteristics such as arc voltage, post-arc conductivity and presence of switching resistors (if any) will affect the TRV. Thus, the test TRV will differ from the prospective TRV-wave of the test circuit upon which the performance requirements are based to a degree depending upon the characteristics of the circuit-breaker.

Methods for the assessment of the TRV characteristics are given in Annex D.

The TRV during the test shall be recorded.

#### 7.103.4 Power frequency recovery voltage

The power frequency recovery voltage of the test circuit can be stated as a percentage of the power frequency recovery voltage specified below. It shall not be less than 95 % of the specified value and shall be maintained for at least 0,3 s.

For synthetic test circuits, details and tolerances are given in IEC 62271-101.

For the terminal fault test-duties of 7.107, the power frequency recovery voltage shall be as follows, subject to the 95 % minimum stated above:

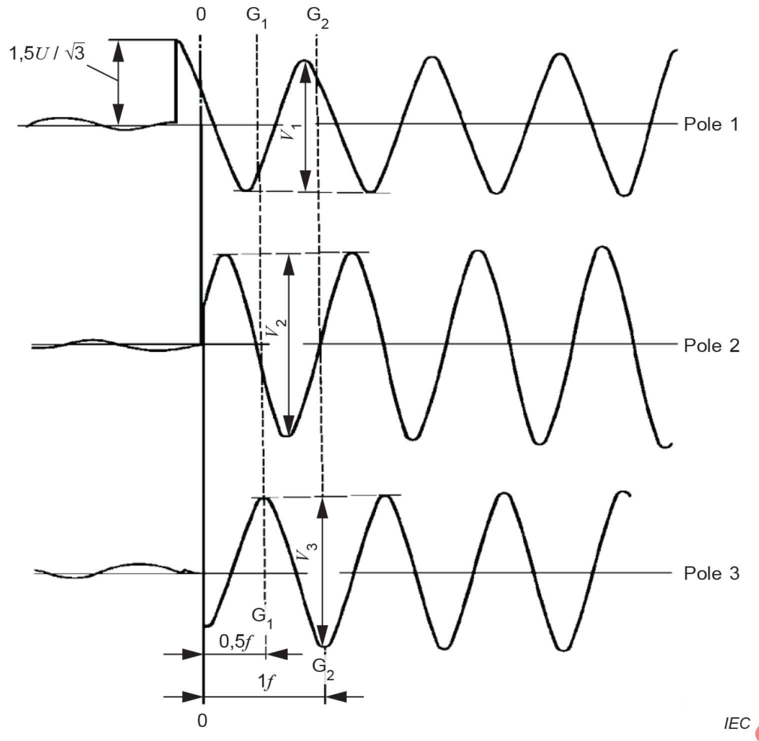
a) For three-phase tests on a three-pole circuit-breaker, the average value of the power frequency recovery voltage shall be equal to the rated voltage $U_r$ of the circuit-breaker divided by √3.

   The power frequency recovery voltage of any pole should not deviate by more than 20 % from the average value at the end of the time for which it is maintained.

   For an effectively earthed neutral system, it shall be proved that the insufficient build-up of dielectric strength in one pole will not lead to prolonged arcing and possible failure. The single-phase test (7.108.2) shall be applied as a demonstration.

b) For single-phase tests on a three-pole circuit-breaker, the power frequency recovery voltage shall be equal to the product of the phase-to-earth value $U_r/\sqrt{3}$ and the first-pole-to-clear factor (1,2, 1,3 or 1,5); the power frequency recovery voltage can be reduced to $U_r/\sqrt{3}$ after an interval of half a cycle of the rated frequency.

The power frequency recovery voltage shall be measured between terminals of a pole in each phase of the test circuit. Its RMS value shall be determined on the oscillogram within the time interval of one half-cycle and one cycle of test frequency after final arc extinction, as indicated in Figure 29. The vertical distance ($V_1$, $V_2$ and $V_3$ respectively) between the peak of the second half-wave and the straight line drawn between the respective peaks of the preceding and succeeding half-waves shall be measured, and this, when divided by $2\sqrt{2}$ and multiplied by the appropriate calibration factor, gives the RMS value of the power frequency recovery voltage recorded.




| | |
|---|---|
| Pole 1 | = first-pole-to clear |
| 00 | = instant of final arc-extinction on all phases |
| $G_1G_1$ | = instant $\frac{1}{2f}$ from 00 |
| $G_2G_2$ | = instant $\frac{1}{f}$ from 00 |
| $f$ | = test frequency |
| $\frac{V_1}{2\sqrt{2}}$ | = value of power frequency recovery voltage of Pole 1 |
| $\frac{V_2}{2\sqrt{2}}$ | = value of power frequency recovery voltage of Pole 2 |
| $\frac{V_3}{2\sqrt{2}}$ | = value of power frequency recovery voltage of Pole 3 |

In Pole 3 a voltage peak occurs exactly at instant $G_1G_1$. In such event measurement is made at later instant $G_1G_1$

Average value of the power frequency recovery voltages of poles 1, 2 and 3

$$= \frac{\frac{V_1}{2\sqrt{2}} + \frac{V_2}{2\sqrt{2}} + \frac{V_3}{2\sqrt{2}}}{3}$$

The example illustrates three voltages obtained during a test of a three-pole circuit-breaker in a three-phase test circuit having one of its neutral points insulated, see Figure 27a or Figure 27b, thus producing momentarily in the first pole-to-clear a 50 % increase in the recovery voltage, as shown in pole 1.

**Figure 29 – Determination of power frequency recovery voltage**

### 7.103.5 Initial transient recovery voltage (ITRV)

Every part of the TRV wave can influence the making and breaking capability of a circuit-breaker. The very beginning of the TRV can be of importance for some types of circuit-breakers. This part of the TRV, called initial TRV (ITRV), is caused by the initial oscillation of small amplitude due to reflections from the first major discontinuity along the busbar. Standard values are given in Table 9. The explanation of the ITRV parameters is given in 7.105.5.1.

**Table 9 – Standard values of ITRV – Rated voltages 100 kV and above**

| Rated voltage | Multiplying factor to determine $u_i$ as function of the RMS value of the short-circuit breaking current $I_{sc}$ [a] | | Time |
|---|---|---|---|
| $U_r$ | $f_i$ | | $t_i$ |
| kV | kV/kA | | µs |
| | 50 Hz | 60 Hz | |
| 100 | 0,046 | 0,055 | 0,4 |
| 123 | 0,046 | 0,055 | 0,4 |
| 145 | 0,046 | 0,055 | 0,4 |
| 170 | 0,058 | 0,069 | 0,5 |
| 245 | 0,069 | 0,083 | 0,6 |
| 300 | 0,081 | 0,097 | 0,7 |
| 362 | 0,092 | 0,111 | 0,8 |
| 420 | 0,092 | 0,111 | 0,8 |
| 550 | 0,116 | 0,139 | 1,0 |
| 800 | 0,159 | 0,191 | 1,1 |
| 1 100 | 0,173 | 0,208 | 1,5 |
| 1 200 | 0,173 | 0,208 | 1,5 |

[a] The actual initial peak voltages are obtained by multiplying the values in these columns by the RMS value of the short-circuit current.

NOTE These values cover both three-phase and single-phase faults and are based on the assumption that the busbar, including the elements connected to it (supports, current and voltage transformers, disconnectors, etc.), can be roughly represented by a resulting surge impedance $Z_i$ of about 260 Ω with the exception of a rated voltage 800 kV for which the resulting surge impedance $Z_i$ is about 325 Ω. The relation between $f_i$ and $t_i$ is then:

$$f_i = t_i \times Z_i \times \omega \times \sqrt{2}$$

where

$\omega = 2\pi f_r$ is the angular frequency corresponding to the rated frequency $f_r$ of the circuit-breaker.



If a circuit-breaker for use in systems with a rated voltage equal to or less than 800 kV has a short-line fault rating, the ITRV requirements are covered if the short-line fault test-duty $L_{90}$ is carried out using a line with a time delay less than 100 ns (see 7.105.5.2 and 7.109.3) unless both terminals are not identical from an electrical point of view (for instance when an additional capacitance is used as mentioned in 7.109.3). When terminals are not identical from an electrical point of view, test circuits which produce an equivalent TRV stress across the circuit-breaker can be used.

For circuit-breakers for use in systems with a rated voltage higher than 800 kV, the ITRV requirements are considered to be covered if the short-line fault test-duty $L_{90}$ is carried out using a line with a time delay less than 100 ns and a surge impedance of 450 Ω unless both terminals are not identical from an electrical point of view (for instance when an additional capacitance is used as mentioned in 7.109.3). When terminals are not identical from an electrical point of view, test circuits which produce an equivalent TRV stress across the circuit-breaker can be used.

Since the ITRV is proportional to the busbar surge impedance and to the current, the ITRV requirements can be neglected for all circuit-breakers with a rated short-circuit breaking current of less than 25 kA and for circuit-breakers with a rated voltage below 100 kV. In addition the ITRV requirements can be neglected for GIS circuit-breakers because of the low surge impedance. ITRV requirements can also be neglected for circuit-breakers directly connected to a busbar with a total source side capacitance of more than 800 pF.

### 7.104 Demonstration of arcing times

#### 7.104.1 General

The requirements described in this subclause are relevant for the adjustment of prospective arcing times. The actual arcing times can vary from the prospective ones. Tests are valid as long as the actual arcing times are within the tolerances given in Annex B.

The terminal fault tests T100a in 7.104.2.2 and 7.104.3.3 consist of three valid breaking operations independent of the rated operating sequence.

NOTE The arcing times required in this subclause are adequate to cover the effect of the unintentional non-simultaneity of the circuit-breaker poles.

Throughout this subclause the following symbols are used:

$T$ is the duration of one cycle of rated frequency;

$t_{a100s}$ in case of a three-phase test $t_{a100s}$ is the minimum of the arcing times of any first-pole-to-clear during the breaking operations of test-duty T100s;

in case of a single-phase test $t_{a100s}$ is the minimum arcing time of terminal fault test-duty T100s;

$d\alpha$ = 18°;

$\tau$ is the DC time constant of the rated short-circuit breaking current;

$\hat{I}$ the p.u. value of peak of the short-circuit current during the last major or major extended loop prior to breaking;

$\Delta t_1$ is the duration of the last major loop of the first-pole-to-clear;

$\Delta t_2$ is the duration of the major extended loop of the last-pole-to-clear for $k_{pp}$ = 1,5;

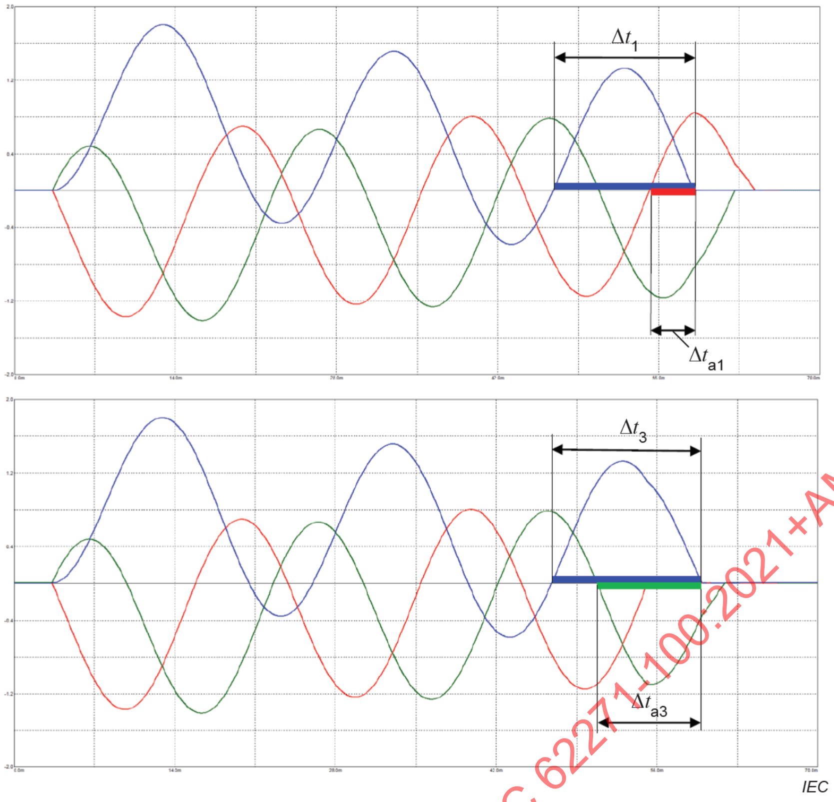
$\Delta t_3$ is the duration of the major extended loop of the second-pole-to-clear for $k_{pp}$ = 1,3 or 1,2;

$\Delta t_{a1}$ is the time interval between the moment of current breaking in the first-pole-to-clear after a major loop with the required asymmetry and the moment of the first preceding current zero;

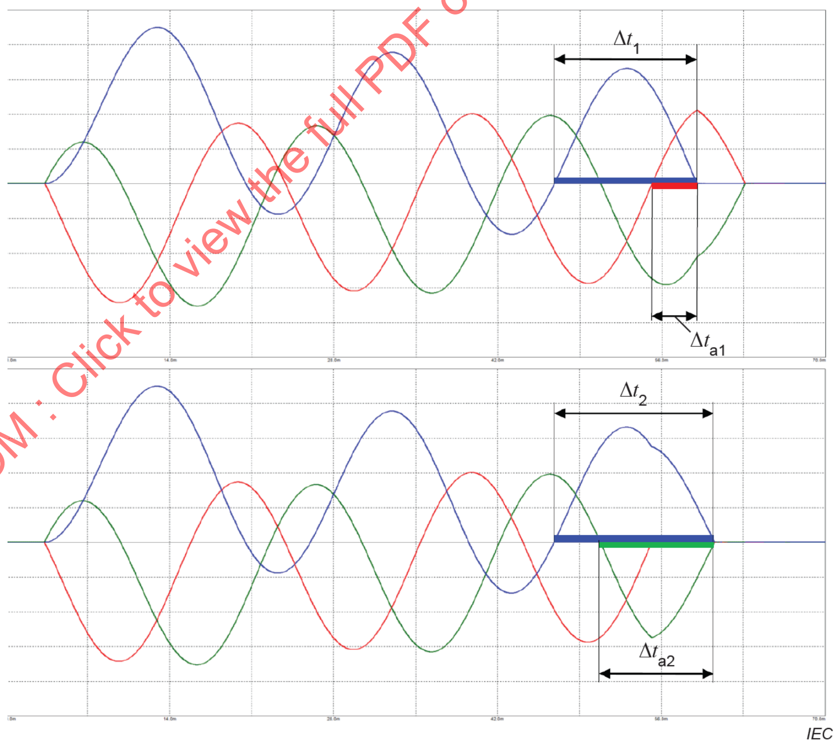
$\Delta t_{a2}$ is the time interval between the moment of current breaking in the last-pole-to-clear after an major extended loop with the required asymmetry for $k_{pp}$ = 1,5 and the moment of the second preceding current zero;

$\Delta t_{a3}$ is the time interval between the moment of current breaking in the second-pole-to-clear after an major extended loop with the required asymmetry for $k_{pp}$ = 1,3 or 1,2 and the moment of the second preceding current zero.

For explanation of $\Delta t_1$, $\Delta t_2$, $\Delta t_3$, $\Delta t_{a1}$, $\Delta t_{a2}$ and $\Delta t_{a3}$ see Figure 30.




**a) Time parameters for $k_{pp}$ = 1,2 or 1,3**




**b) Time parameters for $k_{pp}$ = 1,5**

**Figure 30 – Graphical representation of the time parameters for the demonstration of arcing times in three-phase tests of test-duty T100a**

### 7.104.2 Three-phase tests

#### 7.104.2.1 Test-duty T10, T30, T60, T100s, T100s(b)

For these tests, the tripping command shall be advanced by 40 electrical degrees (40°) between each opening operation. For T100s(b), see 7.107.1.

A graphical representation of an example of the three valid breaking operations for $k_{pp}$ = 1,5 is given in Figure 31 and for $k_{pp}$ = 1,3 or 1,2 in Figure 32.

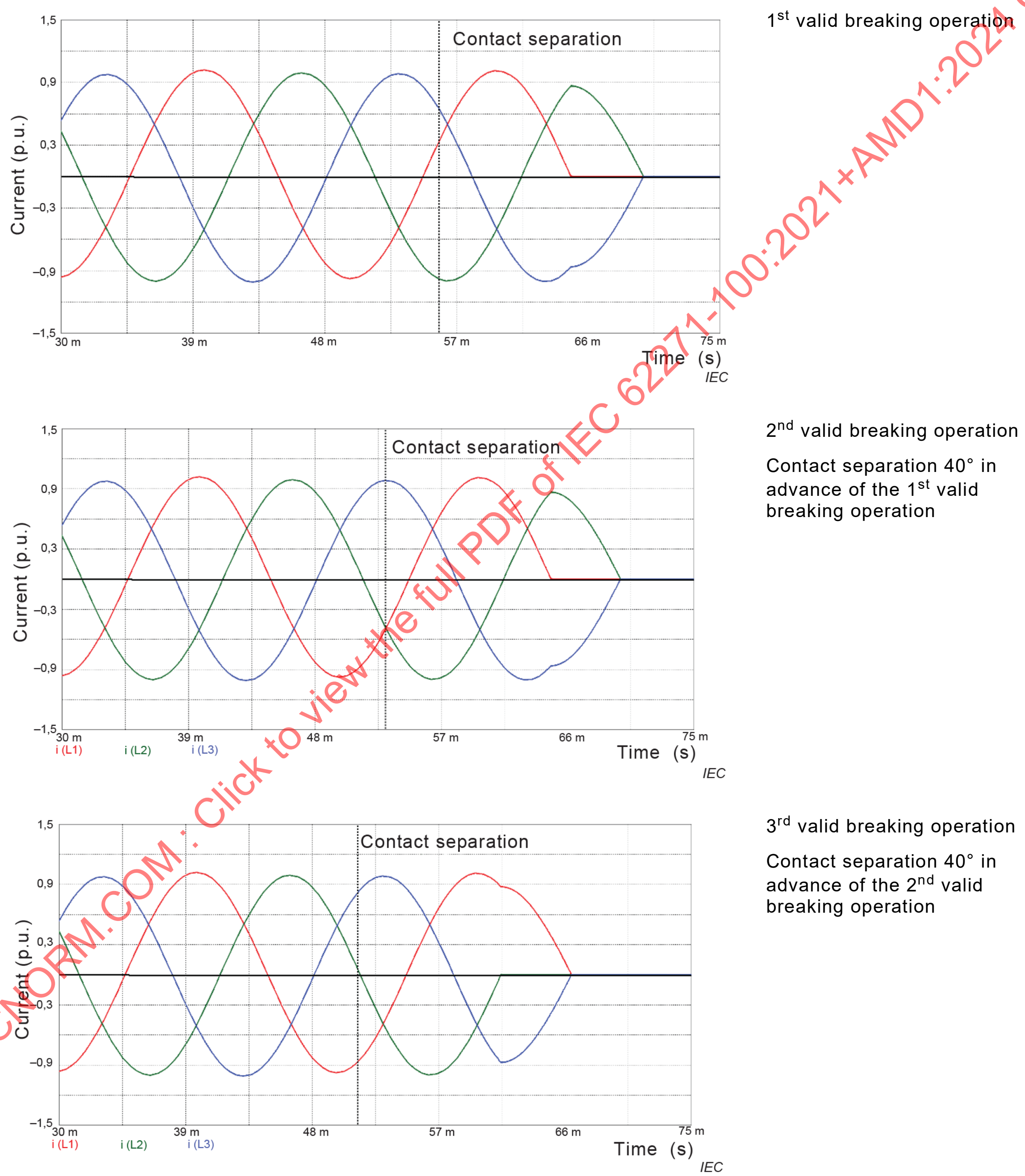



**Figure 31 – Graphical representation of an example of the three valid symmetrical breaking operations for $k_{pp}$ = 1,5**

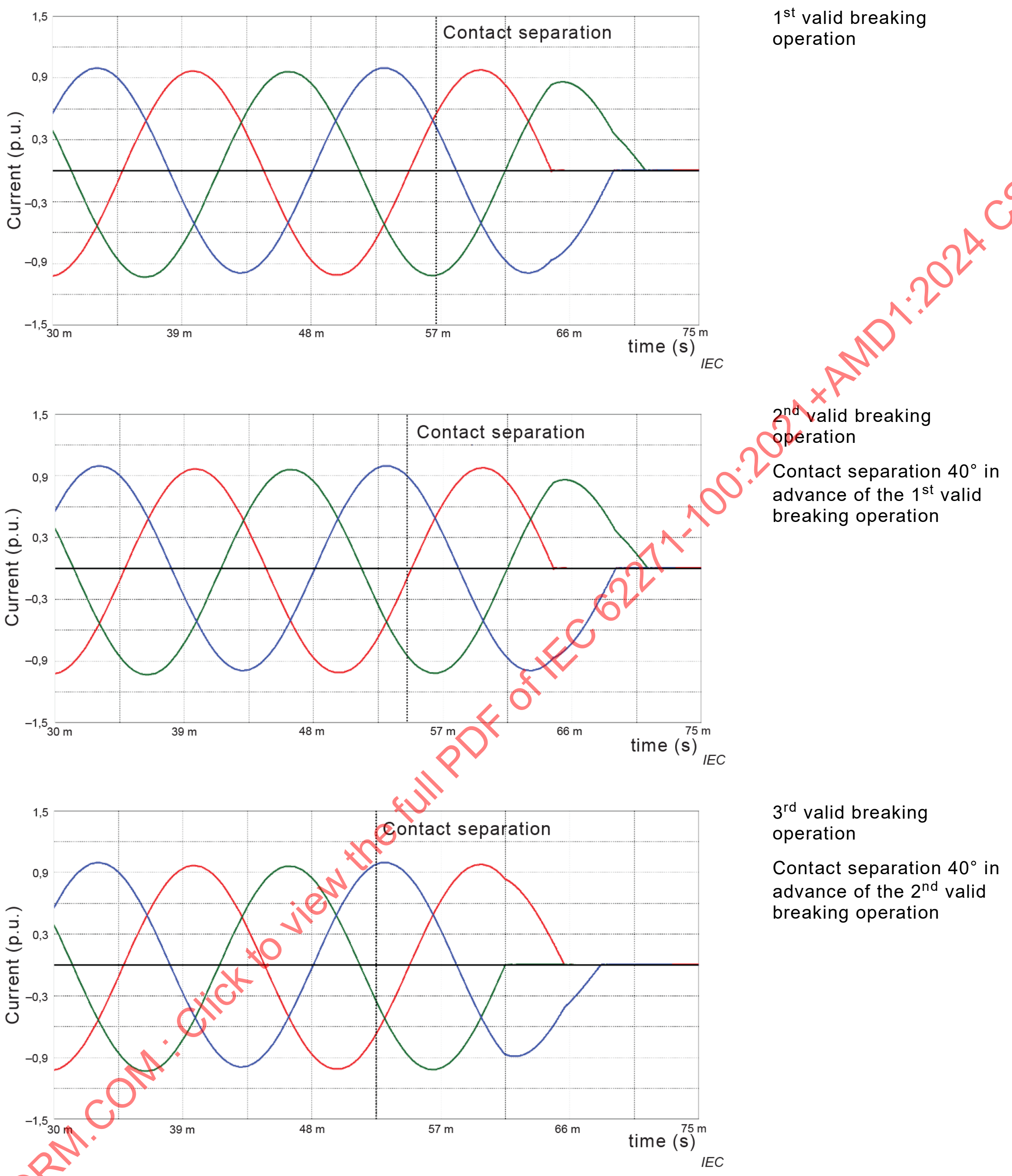



**Figure 32 – Graphical representation of the three valid symmetrical breaking operations for $k_{pp}$ = 1,2 or 1,3**

### 7.104.2.2 Test-duty T100a

The initiation of the short-circuit shall be changed between tests in order to transfer the required asymmetry criteria from phase to phase.

The breaking operations are valid if the prospective current meets the following asymmetry criteria:

– the peak short-circuit current $\hat{I}$ during the last loop prior to breaking is between 90 % and 110 % of the required value; and

– the duration of the short-circuit current loop $\Delta t$ prior to breaking is between 90 % and 110 % of the required value;

– the product "$\hat{I} \times \Delta t$" prior to breaking is between 90 % and 110 % of the required value.

Table 10 and Table 11 give the required prospective values of the peak short-circuit current and loop duration that shall be attained by the last major loop prior to the breaking. In these tables the $k_{pp}$ factors of 1,3 and 1,2 are combined because of very small differences in arcing time requirements.

**Table 10 – Last current loop parameters in three-phase tests and in single-phase tests in substitution for three-phase conditions in relation with short-circuit test-duty T100a – Tests for 50 Hz operation**

| $\tau$ | Minimum clearing time | $\hat{I}$ | $k_{pp}$ = 1,5 , 1,3 or 1,2 | | $k_{pp}$ = 1,5 | | $k_{pp}$ = 1,3 or 1,2 | |
|---|---|---|---|---|---|---|---|---|
| | | | $\Delta t_1$ | $\Delta t_{a1}$ | $\Delta t_2$ | $\Delta t_{a2}$ | $\Delta t_3$ | $\Delta t_{a3}$ |
| ms | ms | p.u. | ms | ms | ms | ms | ms | ms |
| 45 | 10,0 < $t$ ≤ 27,0 | 1,52 | 13,6 | 4,1 | 15,0 | 10,6 | 14,4 | 10,0 |
| | 27,0 < $t$ ≤ 47,5 | 1,33 | 12,2 | 3,8 | 13,7 | 9,8 | 13,1 | 9,1 |
| | 47,5 < $t$ ≤ 68,0 | 1,21 | 11,4 | 3,7 | 12,9 | 9,2 | 12,3 | 8,6 |
| 60 | 10,0 < $t$ ≤ 27,0 | 1,61 | 14,2 | 4,3 | 15,6 | 11,1 | 15,1 | 10,5 |
| | 27,0 < $t$ ≤ 47,5 | 1,44 | 12,9 | 4,0 | 14,3 | 10,2 | 13,8 | 9,6 |
| | 47,5 < $t$ ≤ 67,5 | 1,31 | 12,1 | 3,8 | 13,6 | 9,7 | 12,9 | 9,1 |
| | 67,5 < $t$ ≤ 88,0 | 1,22 | 11,4 | 3,7 | 13,0 | 9,3 | 12,3 | 8,6 |
| 75 | 10,0 < $t$ ≤ 27,0 | 1,67 | 14,8 | 4,4 | 16,1 | 11,3 | 15,6 | 10,8 |
| | 27,0 < $t$ ≤ 47,5 | 1,51 | 13,4 | 4,2 | 14,9 | 10,6 | 14,3 | 10,0 |
| | 47,5 < $t$ ≤ 67,5 | 1,39 | 12,6 | 3,9 | 14,1 | 10,1 | 13,4 | 9,4 |
| | 67,5 < $t$ ≤ 87,5 | 1,30 | 12,0 | 3,8 | 13,5 | 9,7 | 12,8 | 9,0 |
| | 87,5 < $t$ ≤ 108,0 | 1,23 | 11,5 | 3,7 | 13,1 | 9,3 | 12,4 | 8,7 |
| 120 | 10,0 < $t$ ≤ 27,0 | 1,78 | 15,7 | 4,8 | 17,0 | 11,9 | 16,6 | 11,4 |
| | 27,0 < $t$ ≤ 47,0 | 1,66 | 14,6 | 4,4 | 15,9 | 11,3 | 15,3 | 10,8 |
| | 47,0 < $t$ ≤ 67,5 | 1,56 | 13,8 | 4,3 | 15,2 | 10,8 | 14,6 | 10,3 |
| | 67,5 < $t$ ≤ 87,5 | 1,47 | 13,2 | 4,1 | 14,6 | 10,4 | 14,0 | 9,8 |
| | 87,5 < $t$ ≤ 108,0 | 1,40 | 12,6 | 4,0 | 14,1 | 10,1 | 13,5 | 9,5 |

**Table 11 – Last current loop parameters in three-phase tests and in single-phase tests in substitution for three-phase conditions in relation with short-circuit test-duty T100a – Tests for 60 Hz operation**

| $\tau$ | Minimum clearing time | $\hat{I}$ | $k_{pp}$ = 1,5 , 1,3 or 1,2 | | $k_{pp}$ = 1,5 | | $k_{pp}$ = 1,3 or 1,2 | |
|---|---|---|---|---|---|---|---|---|
| | | | $\Delta t_1$ | $\Delta t_{a1}$ | $\Delta t_2$ | $\Delta t_{a2}$ | $\Delta t_3$ | $\Delta t_{a3}$ |
| ms | ms | p.u. | ms | ms | ms | ms | ms | ms |
| 45 | 8,5 < $t$ ≤ 22,5 | 1,58 | 11,6 | 3,5 | 12,8 | 9,1 | 12,4 | 8,6 |
| | 22,5 < $t$ ≤ 39,5 | 1,40 | 10,5 | 3,3 | 11,8 | 8,4 | 11,2 | 7,9 |
| | 39,5 < $t$ ≤ 56,5 | 1,27 | 9,8 | 3,1 | 11,1 | 7,9 | 10,6 | 7,4 |
| | 56,5 < $t$ ≤ 73,0 | 1,19 | 9,3 | 3,0 | 10,7 | 7,6 | 10,1 | 7,1 |
| 60 | 8,5 < $t$ ≤ 22,5 | 1,66 | 12,2 | 3,7 | 13,3 | 9,4 | 12,9 | 9,0 |
| | 22,5 < $t$ ≤ 39,5 | 1,50 | 11,1 | 3,4 | 12,4 | 8,8 | 11,8 | 8,3 |
| | 39,5 < $t$ ≤ 56,5 | 1,38 | 10,4 | 3,3 | 11,7 | 8,3 | 11,2 | 7,8 |
| | 56,5 < $t$ ≤ 73,0 | 1,29 | 9,9 | 3,1 | 11,2 | 8,0 | 10,6 | 7,5 |
| | 73,0 < $t$ ≤ 90,0 | 1,22 | 9,5 | 3,1 | 10,8 | 7,7 | 10,2 | 7,2 |
| 75 | 8,5 < $t$ ≤ 22,5 | 1,72 | 12,6 | 3,8 | 13,7 | 9,6 | 13,3 | 9,2 |
| | 22,5 < $t$ ≤ 39,5 | 1,57 | 11,6 | 3,6 | 12,8 | 9,1 | 12,3 | 8,6 |
| | 39,5 < $t$ ≤ 56,0 | 1,46 | 10,9 | 3,4 | 12,1 | 8,6 | 11,6 | 8,1 |
| | 56,0 < $t$ ≤ 73,0 | 1,37 | 10,3 | 3,2 | 11,6 | 8,3 | 11,1 | 7,8 |
| | 73,0 < $t$ ≤ 90,0 | 1,30 | 9,9 | 3,1 | 11,2 | 8,0 | 10,7 | 7,5 |
| | 90,0 < $t$ ≤ 106,5 | 1,24 | 9,6 | 3,1 | 10,9 | 7,8 | 10,4 | 7,3 |
| 120 | 8,5 < $t$ ≤ 22,5 | 1,81 | 13,4 | 4,1 | 14,4 | 10,1 | 14,1 | 9,7 |
| | 22,5 < $t$ ≤ 39,0 | 1,71 | 12,5 | 3,8 | 13,6 | 9,6 | 13,2 | 9,2 |
| | 39,0 < $t$ ≤ 56,0 | 1,62 | 11,8 | 3,7 | 13,0 | 9,3 | 12,5 | 8,8 |
| | 56,0 < $t$ ≤ 73,0 | 1,54 | 11,3 | 3,5 | 12,5 | 8,9 | 12,0 | 8,5 |
| | 73,0 < $t$ ≤ 89,5 | 1,47 | 10,9 | 3,4 | 12,1 | 8,7 | 11,6 | 8,1 |
| | 89,5 < $t$ ≤ 106,5 | 1,41 | 10,6 | 3,3 | 11,8 | 8,4 | 11,3 | 7,9 |



When the last current loop parameters are within the required tolerances, the resulting deviations on the DC component at current zero, the associated d$i$/d$t$ and the following TRV peak value are within acceptable limits compared to those calculated with rated values.

The intention is to achieve three valid tests and the duty is satisfactory if following conditions are met. There is no preferred order to demonstrate the three valid tests.

a) One operation where arc extinction occurs in the first-pole-to-clear at the end of a major current loop in the phase with the required asymmetry criteria and with the longest possible arcing time.

The longest possible arcing time $t_{arc1}$ for the first-pole-to-clear is achieved, when following condition is met:

$$t_{arc1} = (t_{a100s} - T \times \frac{d\alpha}{360°}) + \Delta t_{a1}$$

b) One operation where arc extinction occurs at the end of an major extended loop in the last-pole-to-clear or in the second-pole-to-clear with the required asymmetry criteria and with the longest possible arcing time.

– The longest possible arcing time $t_{arc2}$ for the last-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,5 is achieved, when following condition is met:

$$t_{arc2} = (t_{a100s} - T \times \frac{d\alpha}{360°}) + \Delta t_{a2}$$

– The longest possible arcing time $t_{arc3}$ for the second-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2 is achieved, when following condition is met:

$$t_{arc3} = (t_{a100s} - T \times \frac{d\alpha}{360°}) + \Delta t_{a3}$$

c) If the required conditions of a) and b) are fulfilled, arc extinction for the third operation can occur at the end

– of a major current loop for first-pole-to-clear conditions, or

– of a major extended loop for last-pole-to-clear conditions for circuit-breakers rated for $k_{pp}$ = 1,5, or

– of a major extended loop for second-pole-to-clear conditions for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2.

There are no further requirements regarding arcing times.

$\Delta t_{a1}$, $\Delta t_{a2}$ and $\Delta t_{a3}$ are the relevant time parameters to be selected from Table 10 and Table 11.

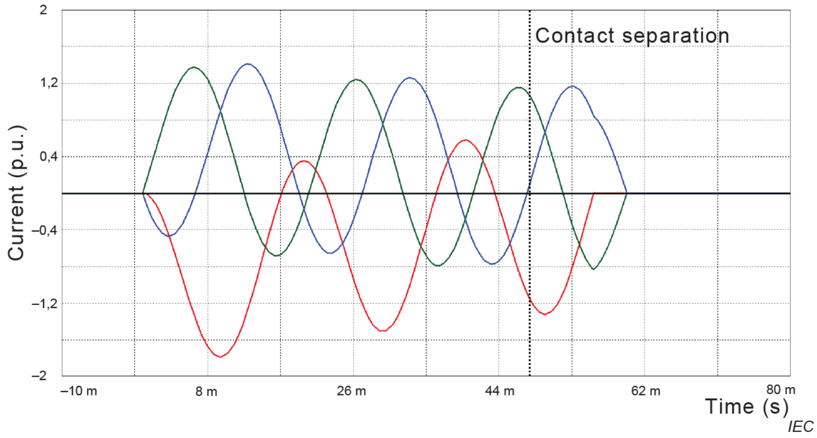
The conditions for current breaking in test-duty T100a for the last-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2 are covered by the tests in test-duty T100s.

Some circuit-breakers will not clear at the end of a major loop or a major extended loop after the required arcing time. However, this test is valid if the circuit-breaker cleared the subsequent minor current loop and it is proven that the longest possible arc-duration was achieved.

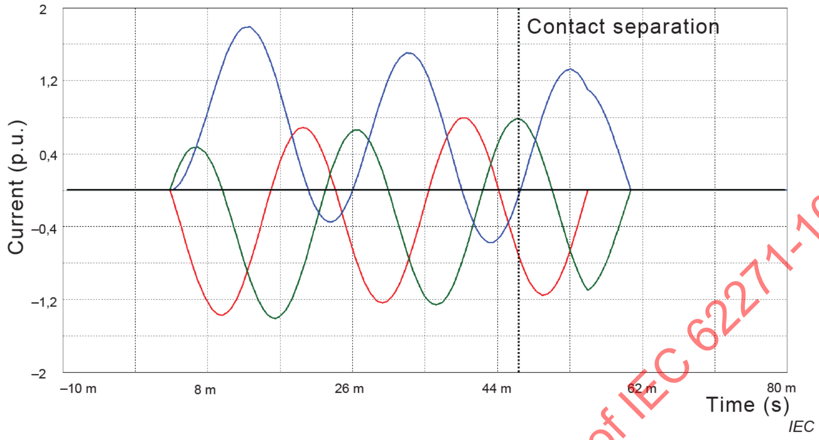
If the behaviour of the circuit-breaker is such that the required conditions of a) and b) are not fulfilled, the test-duty shall be continued by changing the tripping command of the circuit-breaker in steps of 18°. If during tests the required arcing times are not achieved because of minimum arcing times differing from $t_{a100s}$ the maximum achievable arcing times shall be demonstrated. The total number of tests is limited to 6, when attempting to meet the requirements. After these six tests, the test-duty is valid no matter which arcing times have been obtained.

The circuit-breaker can be reconditioned with renewable parts or replaced by a second one before the extended operations (see 7.102.9.6).

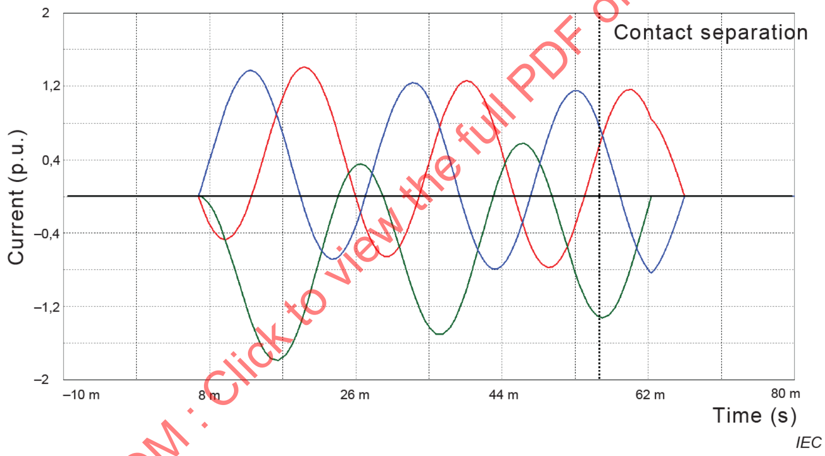
A graphical representation of an example of the three valid breaking operations for $k_{pp}$ = 1,5 is given in Figure 33 and for $k_{pp}$ = 1,3 or 1,2 in Figure 34.



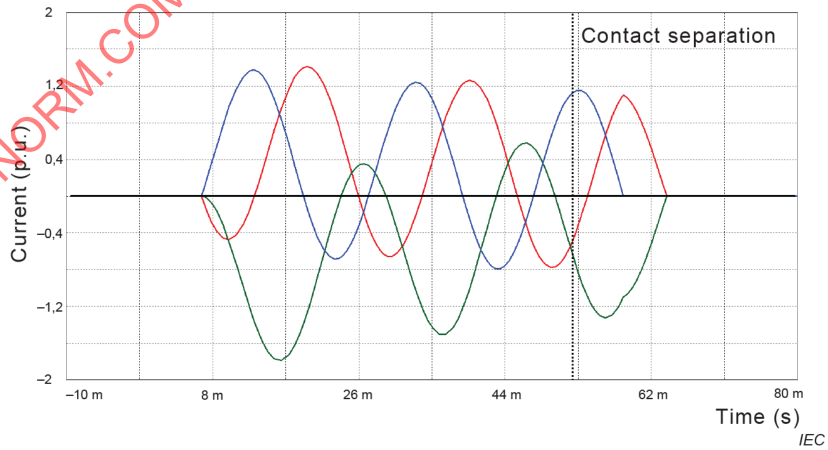

1st valid breaking operation
First-pole-to-clear on a major loop with the required maximum arcing time
(assumption $t_{a100s}$ = 5 ms)




2nd valid breaking operation
Current initiation delayed 60° from that of the first breaking operation
Last-pole-to-clear on an major extended loop with the required maximum arcing time

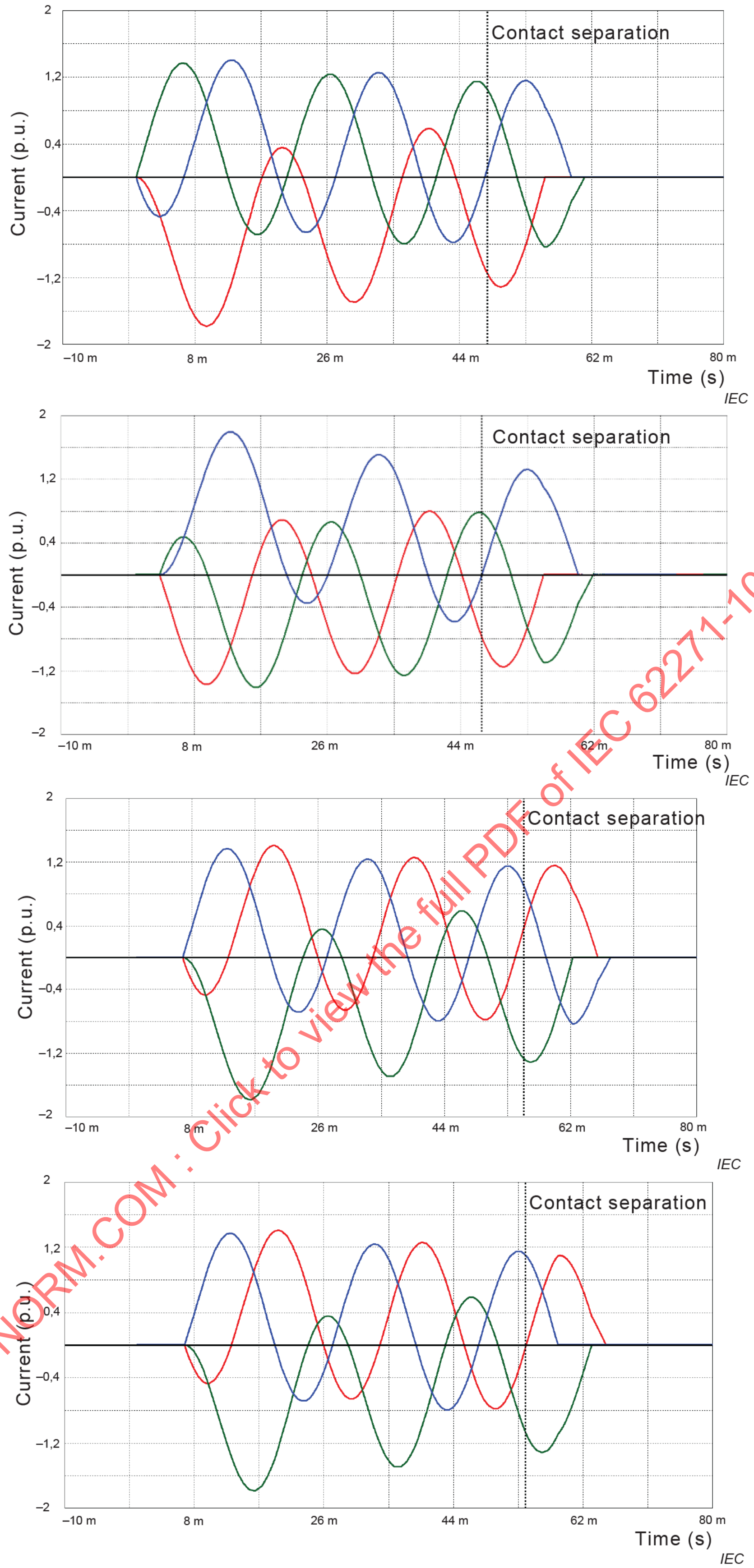



3rd valid breaking operation, option 1
Current initiation delayed 60° from that of the second breaking operation
First-pole-to-clear on a major loop, no requirement regarding arcing time




3rd valid breaking operation, option 2
Current initiation delayed 60° from that of the second breaking operation
Last-pole-to-clear on an major extended loop, no requirement regarding arcing time

**Figure 33 – Graphical representation of an example of the three valid asymmetrical breaking operations for $k_{pp}$ = 1,5**




1st valid breaking operation
First-pole-to-clear on a major loop with the required maximum arcing time
(assumption $t_{a100s}$ = 5 ms)

2nd valid breaking operation
Current initiation delayed 60° from that of the first breaking operation
Second-pole-to-clear on an major extended loop with the required maximum arcing time

3rd valid breaking operation, option 1
Current initiation delayed 60° from that of the second breaking operation
First-pole-to-clear on a major loop, no requirement regarding arcing time

3rd valid breaking operation, option 2
Current initiation delayed 60° from that of the second breaking operation
Second-pole-to-clear on an major extended loop, no requirement regarding arcing time

**Figure 34 – Graphical representation of an example of the three valid asymmetrical breaking operations for $k_{pp}$ = 1,2 or 1,3**

**7.104.2.3 Tests covering the conditions for $k_{pp}$ = 1,3 and $k_{pp}$ = 1,5**

In order to cover the performance for $k_{pp}$ = 1,3 and $k_{pp}$ = 1,5, two separate series of duties with their specific earthing of test circuits as described in 7.103.2.2 should be performed.

If a complete series of test-duties demonstrating the circuit-breaker performance for $k_{pp}$ = 1,5 is already performed, it is not necessary to repeat all terminal fault test-duties required by this document for demonstrating the performance of the circuit-breaker for $k_{pp}$ = 1,3. In that case, test-duties T100s and T100a shall be repeated with a test-circuit simulating $k_{pp}$ = 1,3, see 7.103.2.2.

The repetition of test-duties T100s and T100a with a three-phase circuit for $k_{pp}$ = 1,3 can, as an alternative, be replaced by additional single-phase tests specified below. In this case the three-phase verification test according to 7.102.4.1 is not required. Single-phase tests are allowed for all types of circuit-breakers except for metal-enclosed circuit-breakers with three phases in one enclosure where direct gas dynamic interaction between phases is involved, as per 7.102.3.2 and H.4.1.

The tests shall be carried out with the following parameters:

– a first test shall demonstrate the performance of the second-pole-to-clear under symmetrical fault conditions in an effectively earthed neutral system. The arcing time shall be set to:

$$t_{arc} = t_{a100s} + T \times \frac{119°}{360°}$$

The TRV parameters shall be adjusted in accordance with Table 12.

The test voltage is 1,26 × $U_r/\sqrt{3}$ and can be reduced to $U_r/\sqrt{3}$ after one half cycle of rated frequency after current breaking.

**Table 12 – Prospective TRV parameters for single-phase tests in substitution for three-phase tests to demonstrate the breaking of the second-pole-to-clear for $k_{pp}$ = 1,3**

| $K_{pp}$ | Rated voltage | | | | | |
|---|---|---|---|---|---|---|
| | $U_r$ < 100 kV<br>2-parameter-TRV | | $U_r$ ≥ 100 kV<br>4-parameter-TRV | | | |
| | $u_{c,sp}$ | $t_{3,sp}$ | $u_{1,sp}$ | $t_{1,sp}$ | $u_{c,sp}$ | $t_{2,sp}$ |
| 1,3 | $1{,}26 \times k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $\frac{u_{c,sp}}{\frac{u_c}{t_3} \times 0{,}95}$ | $0{,}95 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $\frac{u_{1,sp}}{\frac{u_1}{t_1} \times 0{,}95}$ | $1{,}26 \times k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | a |
| a 4 × $t_{1,sp}$ for rated voltages from 100 kV up to and including 800 kV. | | | | | | |

– a second test shall demonstrate the performance of the third-pole-to-clear under symmetrical fault conditions in an effectively earthed neutral system. The arcing time shall be set to:

$$t_{arc} = t_{a100s} + T \times \frac{162°}{360°}$$

The TRV-parameters shall be adjusted according to Table 13:

**Table 13 – Prospective TRV parameters for single-phase tests in substitution for three-phase tests to demonstrate the breaking of the third-pole-to-clear for $k_{pp}$ = 1,3**

| $k_{pp}$ | Rated voltage | | | | | |
|---|---|---|---|---|---|---|
| | $U_r$ < 100 kV<br>2-parameter-TRV | | $U_r$ ≥ 100 kV<br>4-parameter-TRV | | | |
| | $u_{c,sp}$ | $t_{3,sp}$ | $u_{1,sp}$ | $t_{1,sp}$ | $u_{c,sp}$ | $t_{2,sp}$ |
| 1,3 | $k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $\frac{u_{c,sp}}{\frac{u_c}{t_3} \times 0{,}7}$ | $0{,}75 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $\frac{u_{1,sp}}{\frac{u_1}{t_1} \times 0{,}7}$ | $k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | a |

[a] 4 × $t_{1,sp}$ for rated voltages from 100 kV up to and including 800 kV, 3 × $t_{1,sp}$ for rated voltages above 800 kV.

The single-phase tests with symmetrical currents can be combined using the prospective TRV peak value required for the second-pole-to-clear with the arcing time required for the third-pole-to-clear.

– an additional single-phase fault test with an asymmetrical current that fulfils the asymmetry criteria as defined in 7.104.2.2 shall be performed. This additional test demonstrates the performance of the second and third-pole-to-clear under asymmetrical fault current on the major extended loop.

The test voltage to be applied is 1,26 × $U_r/\sqrt{3}$ for the verification of $k_{pp}$ = 1,3;

and can be reduced to $U_r/\sqrt{3}$ after one quarter of a cycle of rated frequency after current breaking.

When the last current loop parameters are within the required tolerances, the resulting deviations on the DC component at current zero, the associated d$i$/d$t$ and the following TRV peak value are within acceptable limits compared to those calculated with rated values.

The arcing time shall be the maximum arcing time calculated for a three-phase condition considering the minimum arcing time value found during test-duty T100s performed for $k_{pp}$ = 1,5.

$$t_{arc} = (t_{a100s} - T \times \frac{d\alpha}{360°}) + \Delta t_{a3}$$

where

$\Delta t_{a3}$ is the relevant time parameter to be selected from Table 10 and Table 11.

#### 7.104.3 Single-phase tests in substitution for three-phase conditions, out-of-phase and short-line fault tests

##### 7.104.3.1 General

The procedure for establishing a minimum arcing time might result in a test with maximum arcing time or with an arcing time in excess of the maximum arcing time. The aim of the following single-phase tests is to satisfy the conditions of the first-pole-to-clear, the second-pole-to-clear and the last pole-to-clear for each test-duty in one test circuit.

The following procedures are applicable if all operations of the rated operating sequence fulfil the requirements of 6.101.

##### 7.104.3.2 Test-duties T10, T30, T60, T100s and T100s(b), OP1 and OP2, $L_{90}$, $L_{75}$ and $L_{60}$

Each test-duty shall consist of three valid breaking operations. The order of the breaking operations of each test-duty is not specified.

A valid breaking operation shall demonstrate breaking with an arcing time as small as possible. The resultant arcing time is known as the minimum arcing time ($t_{arc\ min}$). This is established when any extra delay in the contact separation with respect to the current waveform results in breaking at the next current zero. This minimum arcing time is found by changing the setting of the tripping command by steps of 18°.

Another valid breaking operation shall demonstrate breaking with the maximum arcing time. The required maximum arcing time is known as $t_{arc\ max}$ and is determined as follows:

– for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2 and short-line fault tests, by

$$t_{arc\ max} = t_{arc\ min} + T \times \frac{162°}{360°};$$

– for circuit-breakers rated for $k_{pp}$ = 1,5, by

$$t_{arc\ max} = t_{arc\ min} + T \times \frac{132°}{360°};$$

where

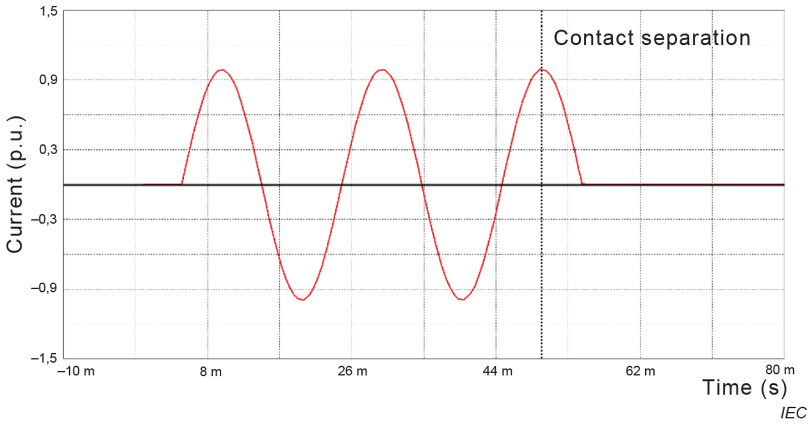
$t_{arc\ min}$ is the minimum arcing time obtained from the first valid operation.

Another valid breaking operation shall demonstrate breaking with an arcing time which is approximately equal to the average value of the minimum arcing time and the required maximum arcing time. This arcing time is known as the medium arcing time ($t_{arc\ med}$) and is determined by

$$t_{arc\ med} = (t_{arc\ max} + t_{arc\ min})/2$$

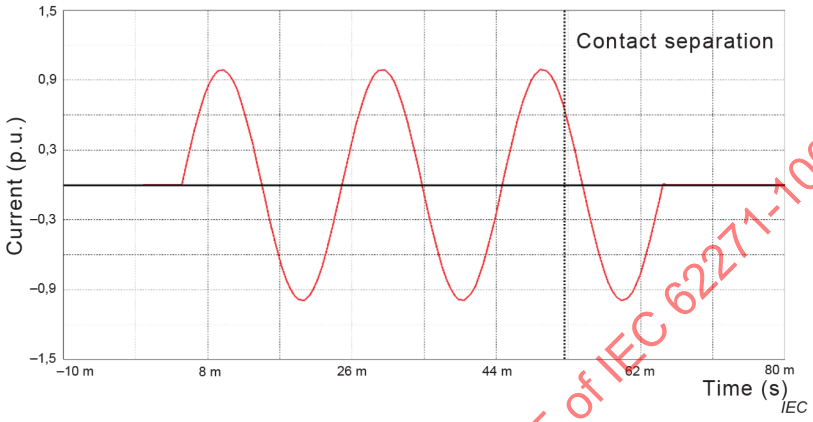
If the circuit-breaker does not interrupt at the expected current zero with medium and/or maximum arcing time but at a subsequent current zero no additional testing is required.

A graphical representation of an example of the three valid breaking operations for $k_{pp}$ = 1,5 is given in Figure 35 and for $k_{pp}$ = 1,3 or 1,2 in Figure 36.



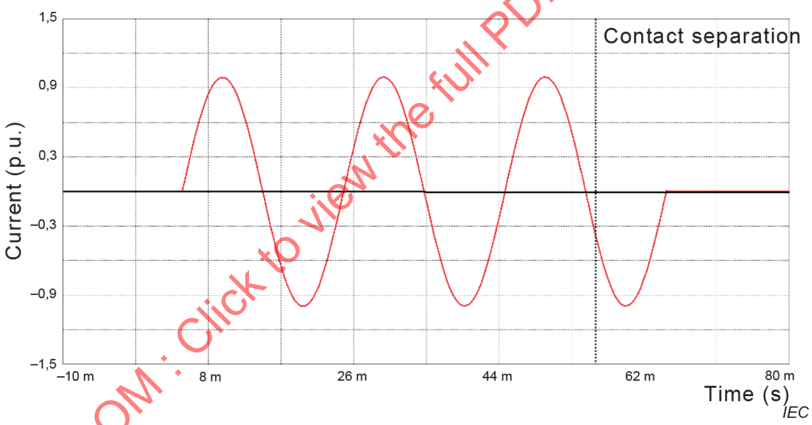

1st valid breaking operation

Minimum arcing time




2nd valid breaking operation

Maximum arcing time




3rd valid breaking operation

Medium arcing time

**Figure 35 – Example of a graphical representation of the three valid symmetrical breaking operations for single-phase tests in substitution of three-phase conditions for $k_{pp}$ = 1,5**

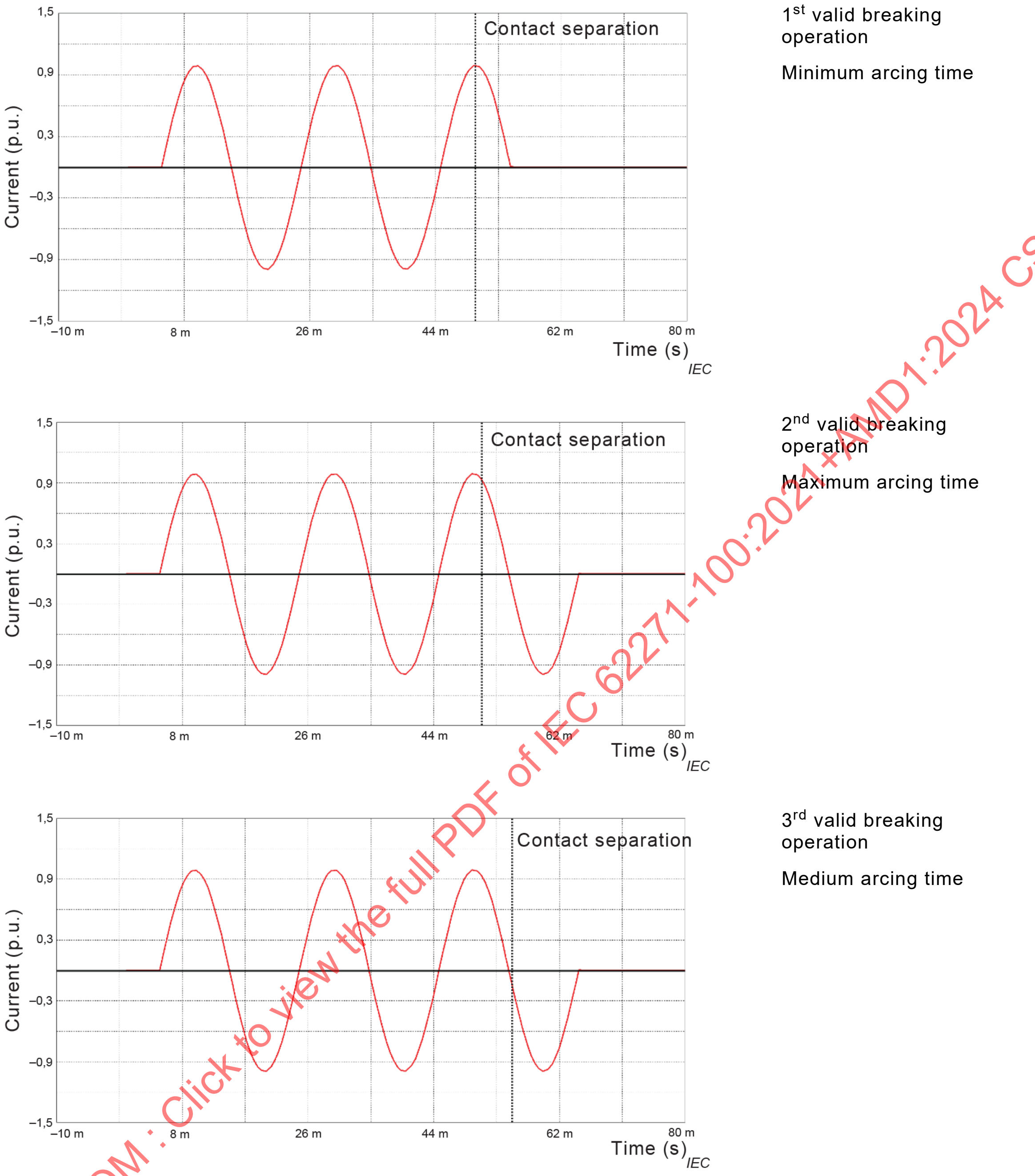



**Figure 36 – Example of a graphical representation of an example of the three valid symmetrical breaking operations for single-phase tests in substitution of three-phase conditions for $k_{pp}$ = 1,2 or 1,3**

### 7.104.3.3 Test-duty T100a

The breaking operations are valid if the prospective current meets the following asymmetry criteria as given in 7.104.2.2.

Table 10 and Table 11 give the required values of the peak short-circuit current and loop duration that shall be attained by the last loop prior to the intended breaking. All tests shall be performed with the current parameters of the first-pole-to-clear.

A breaking operation shall demonstrate breaking at the end of the major loop with an arcing time equivalent to the maximum arcing time under three-phase conditions $t_{arc1}$ of the first-pole-to-clear.

This is achieved, when following condition is met:

$$t_{arc1} = t_{a100s} + \Delta t_{a1} - T \times \frac{d\alpha}{360°}$$

Another breaking operation shall demonstrate breaking at the end of the major loop with an arcing time equivalent to the maximum arcing time of the major extended loop under three-phase conditions

– $t_{arc2}$ for the last-pole-to clear of circuit-breakers rated for $k_{pp}$ = 1,5

  This is achieved, when following condition is met:

$$t_{arc2} = t_{a100s} + \Delta t_{a2} - T \times \frac{d\alpha}{360°}$$

– $t_{arc3}$ for the second-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2.

  This is achieved, when following condition is met:

$$t_{arc3} = t_{a100s} + \Delta t_{a3} - T \times \frac{d\alpha}{360°}$$

$\Delta t_{a1}$, $\Delta t_{a2}$ and $\Delta t_{a3}$ are the relevant time parameters to be selected from Table 10 and Table 11.

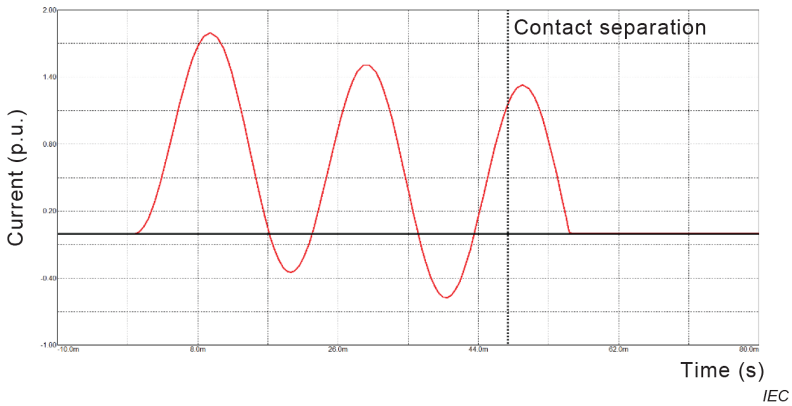
Another breaking operation shall demonstrate the conditions of breaking after a major loop as first-pole-to-clear or after a major extended loop as last-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,5 or after a major extended loop as second-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,2 or 1,3. There are no further requirements regarding arcing times.

If the circuit-breaker fails to interrupt after the required major loop and interrupts after the subsequent minor loop, the required maximum arcing time is extended by the duration of this minor loop.

If the behaviour of the circuit-breaker is such that the required arcing times are not achieved, the test-duty shall be continued by changing the tripping command of the circuit-breaker in steps of 18°. If during tests the required arcing times are not achieved because of minimum arcing times differing from T100s, the maximum achievable arcing times shall be demonstrated. The total number of tests is limited to 6, when attempting to meet the requirements. After 6 tests the test-duty is valid regardless of the arcing times that have been obtained.

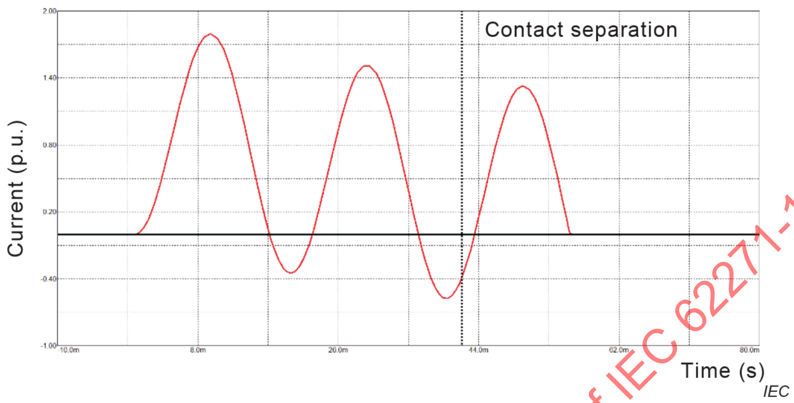
The circuit-breaker can be reconditioned with renewable parts before the extended operations (see 7.102.9.6). Another test sample can also be used for the extended operations.

A graphical representation of an example of the three valid breaking operations for $k_{pp}$ = 1,5 is given in Figure 37 and for $k_{pp}$ = 1,3 and 1,2 in Figure 38.



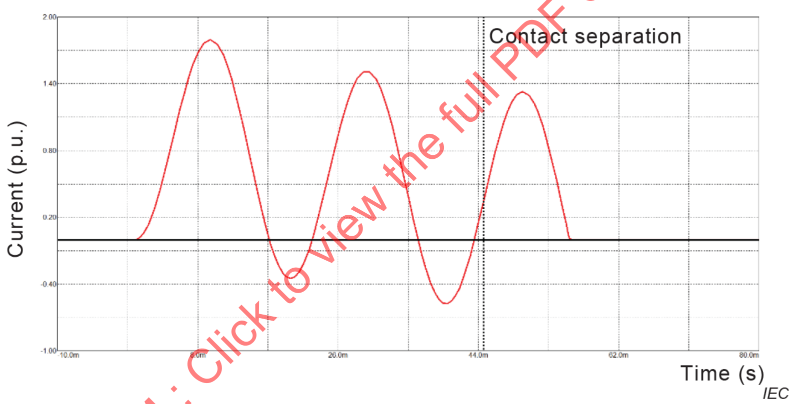

1st valid breaking operation

Demonstration of maximum arcing time for first-pole-to-clear conditions




2nd valid breaking operation

Demonstration of maximum arcing time for last-pole-to-clear conditions




3rd valid breaking operation

**Figure 37 – Example of a graphical representation of an example of the three valid asymmetrical breaking operations for single-phase tests in substitution of three-phase conditions for $k_{pp}$ = 1,5**

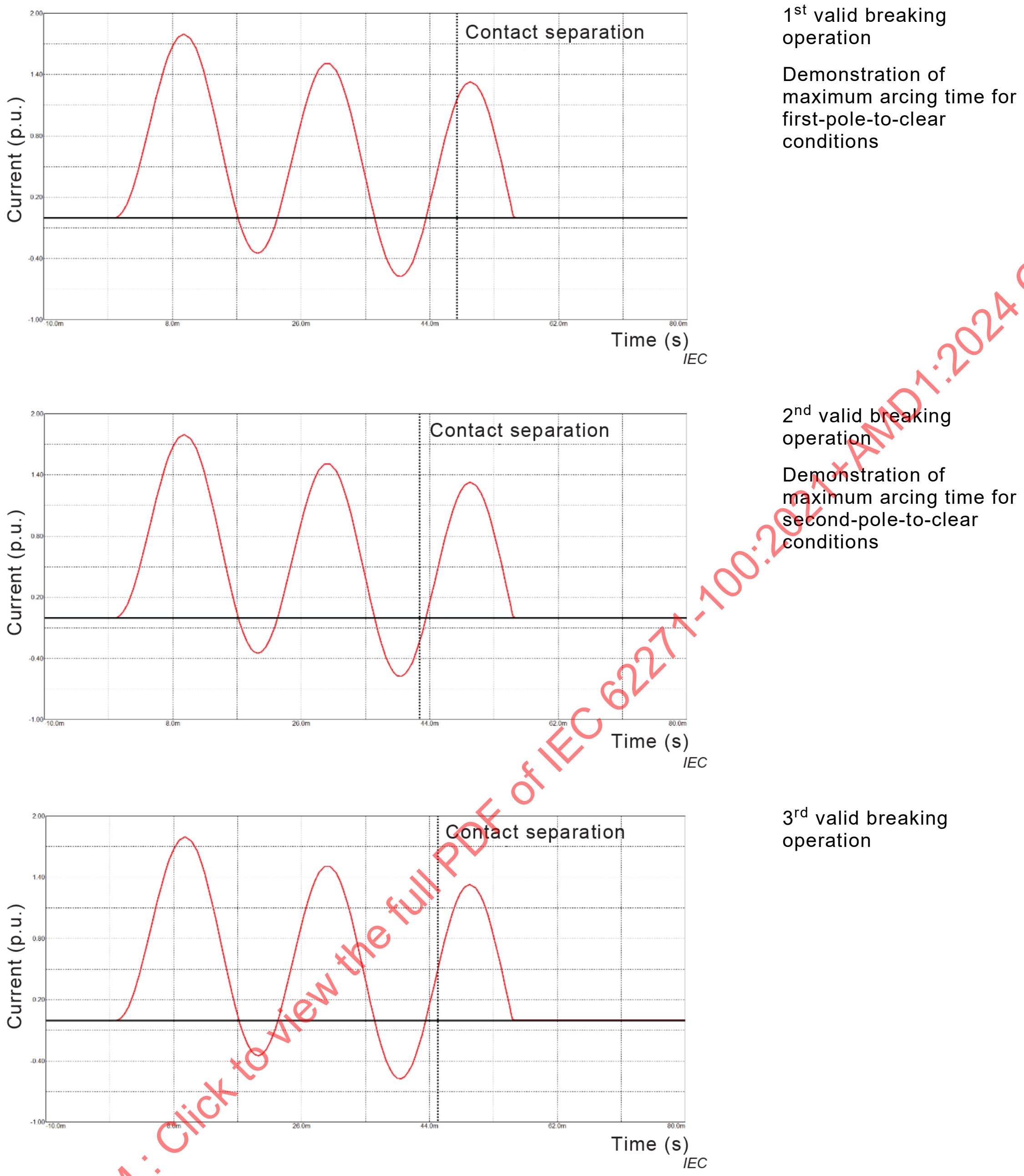



**Figure 38 – Example of a graphical representation of an example of the three valid asymmetrical breaking operations for single-phase tests in substitution of three-phase for $k_{pp}$ = 1,2 and 1,3**

### 7.104.3.4 Tests covering the conditions for $k_{pp}$ = 1,5 and $k_{pp}$ = 1,3

Both conditions, $k_{pp}$ = 1,5 and $k_{pp}$ = 1,3 can be combined in one test series. The transient and power frequency voltages to be used shall be those applicable to a non-effectively earthed neutral system and the arcing times shall be those applicable to an effectively earthed neutral system.

For test-duty T100a the arcing times shall be those applicable to a non-effectively earthed neutral system.

#### 7.104.3.5 Splitting of test-duties in test series taking into account the associated TRV for each pole-to-clear

It is recognised that single-phase tests in substitution of three-phase conditions are more severe than three-phase tests because the arcing time of the last-pole-to-clear is used together with the prospective TRV of the first-pole-to-clear. As an alternative, the manufacturer can choose to split each test-duty into two or three separate test series, each test series demonstrating a successful breaking with the minimum and maximum arcing times for each pole-to-clear with its associated prospective TRV. The standard multipliers for the prospective TRV values for the second and third clearing poles are given in Table 14. They are applicable for test-duties T10, T30, T60, T100s, OP1 and OP2.

**Table 14 – Standard multipliers for TRV values for second and third clearing poles**

| First-pole-to-clear factor $k_{pp}$ | Multipliers | | | |
|---|---|---|---|---|
| | 2nd clearing pole | | 3rd clearing pole | |
| | RRRV | $u_c$ | RRRV | $u_c$ |
| 1,2 (terminal fault)<br>2,0 (out-of-phase) | 0,95 | 0,95 | 0,83 | 0,83 |
| 1,3 (terminal fault)<br>2,0 (out-of-phase) | 0,95 | 0,97 | 0,70 | 0,77 |
| 1,5 (terminal fault)<br>2,5 (out-of-phase) | 0,70 | 0,58 | 0,70 | 0,58 |

Reconditioning of the circuit-breaker is permitted after a minimum of three breakings and shall comply with the requirements of 7.102.9.6.

Assuming that the simultaneity of poles during all operations of the rated operating sequence is within the tolerances of 6.101, for tests with symmetrical current the arcing window for each phase is within the band stated in Table 15, if the instant of breaking for the first clearing pole with the minimum arcing time is taken as reference. A graphical representation of the arcing window and the pole factor $k_p$, determining the TRV of the individual pole, is given for terminal fault in Figure 39 and Figure 40 for systems with a $k_{pp}$ of 1,2 and 1,3 and in Figure 41 for systems with a $k_{pp}$ of 1,5.

**Table 15 – Arcing window for tests with symmetrical current**

| First-pole-to-clear factor | First clearing pole<br>° | Second clearing pole<br>° | Third clearing pole<br>° |
|---|---|---|---|
| 1,5 (Terminal fault)<br>2,5 (Out-of-phase) | 0 to 42 | 90 to 132 | 90 to 132 |
| 1,3 (Terminal fault)<br>2,0 (Out-of-phase) | 0 to 42 | 77 to 119 | 120 to 162 |
| 1,2 (Terminal fault)<br>2,0 (Out-of-phase) | 0 to 42 | 71 to 113 | 120 to 162 |

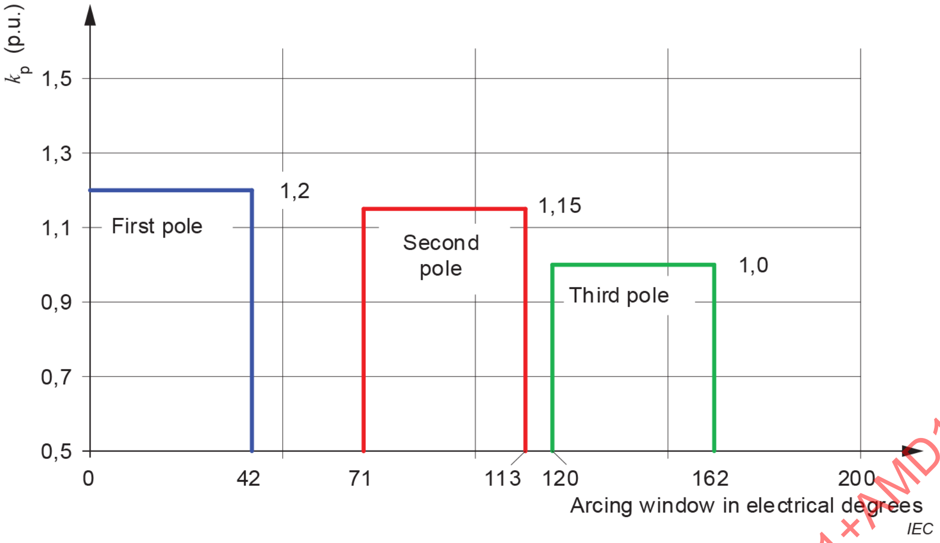



**Figure 39 – Graphical representation of the arcing window and the pole factor $k_p$, determining the TRV of the individual pole, for systems with a $k_{pp}$ of 1,2**

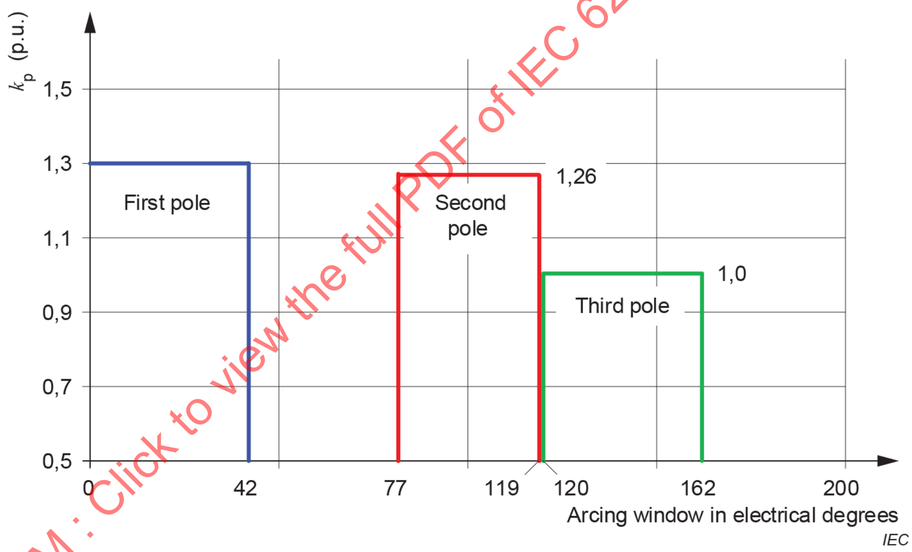



**Figure 40 – Graphical representation of the arcing window and the pole factor $k_p$, determining the TRV of the individual pole, for systems with a $k_{pp}$ of 1,3**

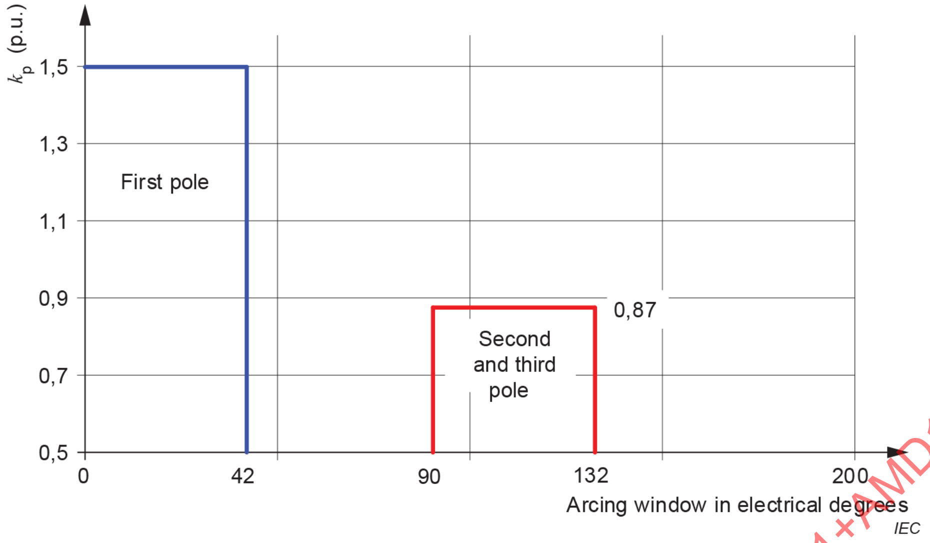



**Figure 41 – Graphical representation of the arcing window and the pole factor $k_p$, determining the TRV of the individual pole, for systems with a $k_{pp}$ of 1,5**



## 7.105 Short-circuit test quantities

### 7.105.1 Applied voltage before short-circuit making tests

For the short-circuit making tests of 7.107, the applied voltage shall be as follows.

a) For three-phase tests on a three-pole circuit-breaker, the average value of the applied voltages phase-to-phase shall not be less than the rated voltage $U_r$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

   The differences between the average value and the applied voltages of each pole shall not exceed 5 %.

b) For single-phase tests on a three-pole circuit-breaker, the applied voltage shall not be less than the phase-to-earth value $U_r/\sqrt{3}$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

   With the manufacturer's consent it is permissible, for convenience of testing, to apply a voltage equal to the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,3 or 1,5) of the circuit-breaker.

   Where the circuit-breaker can be arranged for a single-pole reclosing cycle and the maximum time difference between the contacts touching in a subsequent three-pole closing operation exceeds one-quarter of a cycle of rated frequency (see note of 6.101), the applied voltage shall be the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,3 or 1,5) of the circuit-breaker.

### 7.105.2 Short-circuit making current

#### 7.105.2.1 General

The ability of the circuit-breaker to make the rated short-circuit making current is proven in test-duty T100s (see 7.107.5).

The circuit-breaker shall be able to make the current with pre-strike of the arc occurring at any point on the voltage wave. Two extreme cases are specified as follows (see Figure 1):

– making at the peak of the voltage wave (within the range between –15 ° and +15 °), leading to a symmetrical short-circuit current and the longest pre-striking arc;
– making at the zero of the voltage wave, without pre-striking, leading to a fully asymmetrical short-circuit current.

The test procedure as outlined below aims to demonstrate the ability of the circuit-breaker to fulfil the following two requirements:

a) the circuit-breaker can close against a symmetrical current as a result of the pre-arcing commencing at a peak of the applied voltage. This current shall be the symmetrical component of the rated short-circuit breaking current (see 5.101);
b) the circuit-breaker can close against a fully asymmetrical short-circuit current. This current shall be the rated short-circuit making current (see 5.103).

   A circuit-breaker shall be able to operate at voltages below its rated voltage at which it actually makes with a fully asymmetrical current. The lower limit of voltage, if any, shall be stated by the manufacturer.

Due to unintentional non-simultaneity of poles, the instants of contact touching during making can differ such as to provoke an even higher peak making current in one pole (see also 6.101). This is particularly the case if, in one pole, the current begins to flow about one-quarter of a cycle later than in the other two poles, provided that there is no pre-arcing. Failure of the circuit-breaker during such an event is considered a failure of a circuit-breaker to satisfy the test-duty as long as the prospective making current is within the tolerances given in Table B.1.

~~NOTE For circuit-breakers having a pre-arcing time exceeding 10 ms, more than two making operations can be used to meet the most onerous condition.~~

#### 7.105.2.2 Test procedure

##### 7.105.2.2.1 Three-phase tests

For three-phase tests on a three-pole circuit-breaker it is assumed that the requirements outlined in a) and b) above are adequately demonstrated during the test-duty T100s.

The control of the timing shall be such that at least in one of the two close-open (CO) cycles of test-duty T100s the rated short-circuit making current is obtained.

Where a circuit-breaker exhibits pre-arcing to such an extent that the rated short-circuit making current is not attained during the first CO operating cycle of test-duty T100s and, even after adjustment of the timing, the rated short-circuit making current is not achieved during the second CO operating cycle, further CO operating cycles can be carried out at reduced voltage until the making current is met. Before this operating cycle, the circuit-breaker can be reconditioned.

##### 7.105.2.2.2 Single-phase tests

For single-phase tests, test-duty T100s or T100s(a) shall be carried out in such a way that the requirement outlined in a) of 7.105.2.1 is met in one and that of b) of 7.105.2.1 in the other making operation. The sequence of these operations is not specified. If during test-duty T100s or T100s(a) (see 7.107.1) one of the requirements outlined in a) and b) has not been adequately demonstrated, an additional CO operating cycle is necessary. Before this operating cycle the circuit-breaker can be reconditioned.

The additional CO operating cycle shall, depending on the results obtained during the normal test-duty T100s or T100s(a), demonstrate either

– requirements in a) or b) of 7.105.2.1, or
– evidence that the short-circuit making currents attained are representative of the conditions to be met in service due to the pre-arcing characteristics of the circuit-breaker.

If, during the test-duty T100s or T100s(a), the rated short-circuit making current has not been attained due to the characteristics of the circuit-breaker, further CO operating cycles shall be carried out at reduced voltage until the making current is met.

If during the test-duty T100s or T100s(a) no symmetrical current has been obtained, as required in a) above, the additional CO test can be made at an applied voltage within the tolerances stated in 7.105.1.

#### 7.105.3 Short-circuit breaking current

The short-circuit current to be interrupted by a circuit-breaker shall be determined in accordance with Figure 8 at the instant of contact separation of the last pole to open and shall be stated in terms of the following two values:

– the average of the RMS values of the AC components in all phases;
– the last loop duration and amplitude for test-duty T100a.

The RMS value of the AC component in any phase shall not vary from the average by more than 10 %.

Although the short-circuit breaking current is measured at the instant corresponding to contact separation, the breaking performance of the circuit-breaker is determined, among other factors, by the current which is finally interrupted in the last loop of arcing. The decrement of the AC component of the short-circuit current is therefore very important, particularly when testing those circuit-breakers which arc for several loops of current. To obviate an easement of duty, the decrement of the AC component of the short-circuit current shall be such that at a time corresponding to the final extinction of the current in the last-pole-to-clear, the AC component of the prospective current is not less than 90 % of the appropriate value for the test-duty. This shall be proven by a record of the prospective current before commencing the tests.

If the characteristics of the circuit-breaker are such that it reduces the short-circuit current value below the prospective breaking current, or if the oscillogram is such that the current wave envelope cannot be drawn successfully, the average prospective short-circuit breaking current in all phases shall be used as the short-circuit breaking current and shall be measured from the oscillogram of prospective current at a time corresponding to the instant of contact separation.

The instant of contact separation can be determined according to the experience of the testing station and the type of apparatus under test by various methods, for instance, by recording the contact travel during the test, by recording the arc voltage or by a test on the circuit-breaker at no-load.

#### 7.105.4 DC component of the short-circuit breaking current

For circuit-breakers that prevent the control of the DC component, for example self-tripping circuit-breakers when in a condition for test as set out in 7.102.3, this DC component can be greater than that specified for test-duties T10, T30, T60 and T100s of 7.107.

#### 7.105.5 TRV for short-circuit breaking tests

##### 7.105.5.1 General

The prospective TRV of the test circuits shall be determined by such a method as will produce and measure the TRV wave without significantly influencing it. It shall be measured at the terminals to which the circuit-breaker will be connected with all necessary test-measuring devices, such as voltage dividers, etc. Suitable methods are described in Annex E (see also 7.103.3). In such cases where a measurement is not possible, a calculation of the prospective TRV is allowed. Guidance is given in Annex E.

For three-phase circuits, the prospective TRV refers to the first-pole-to-clear, i.e. the voltage across one open pole with the other two poles closed, with the appropriate test circuit arranged as specified in 7.103.3.

The TRV specified for the test is represented by a reference line, a delay line and ITRV envelope in the same manner as the TRV related to the rated short-circuit breaking current in accordance with 7.103.5 and Figure 42, Figure 43, Figure 44 and Figure 45.

The prospective TRV for the test is represented by its envelope, drawn as shown in Annex D, and by its initial portion.

The special case of circuit-breakers with a connection of low capacitance to a transformer is covered in Annex F.

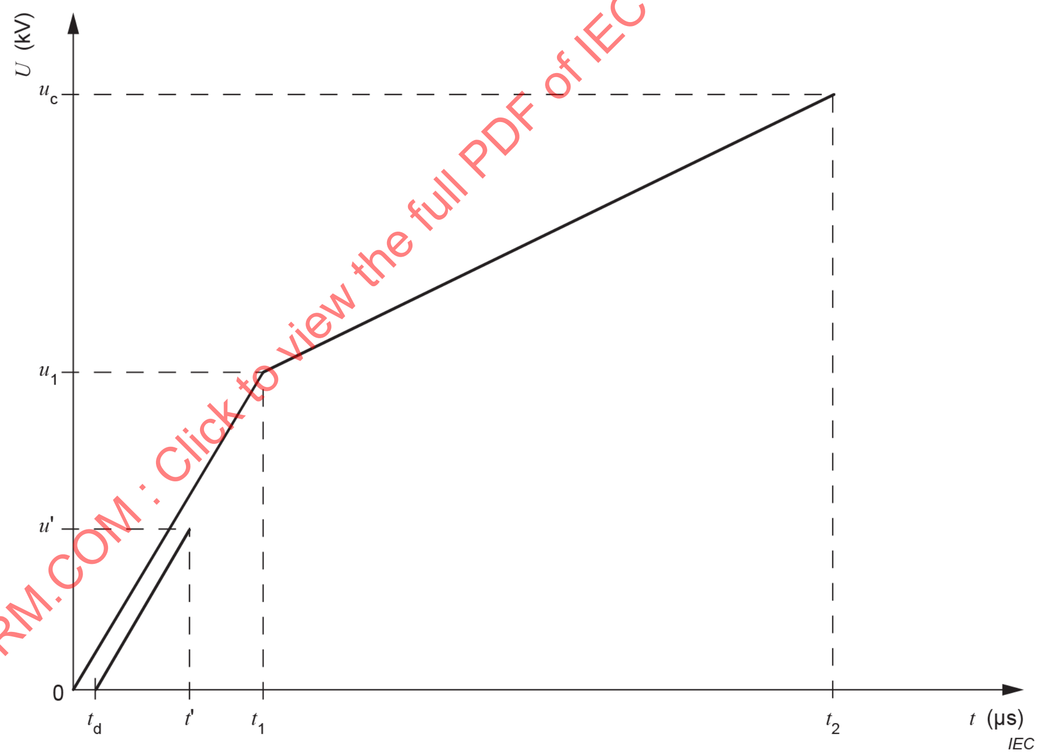



**Figure 42 – Representation of a specified TRV by a 4-parameter reference line and a delay line**

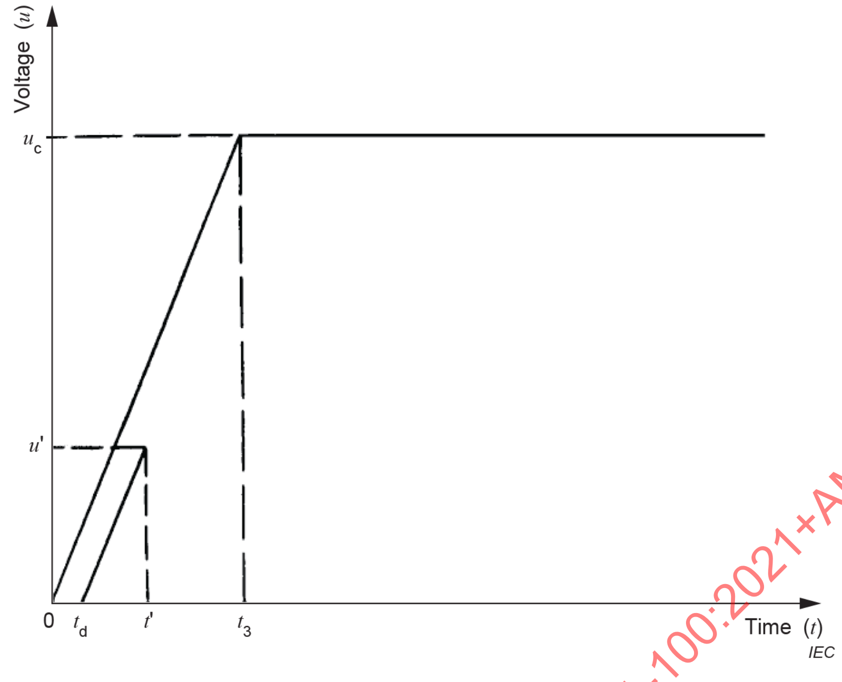
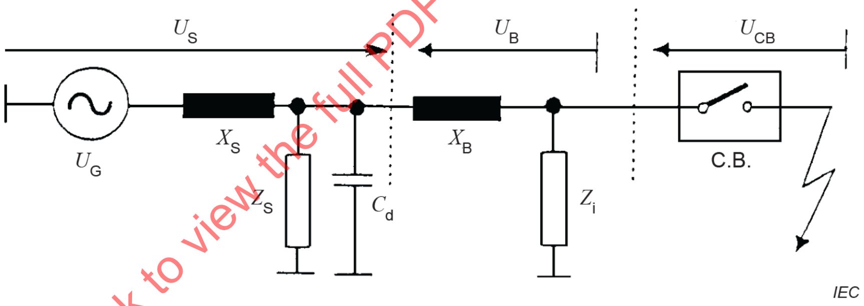


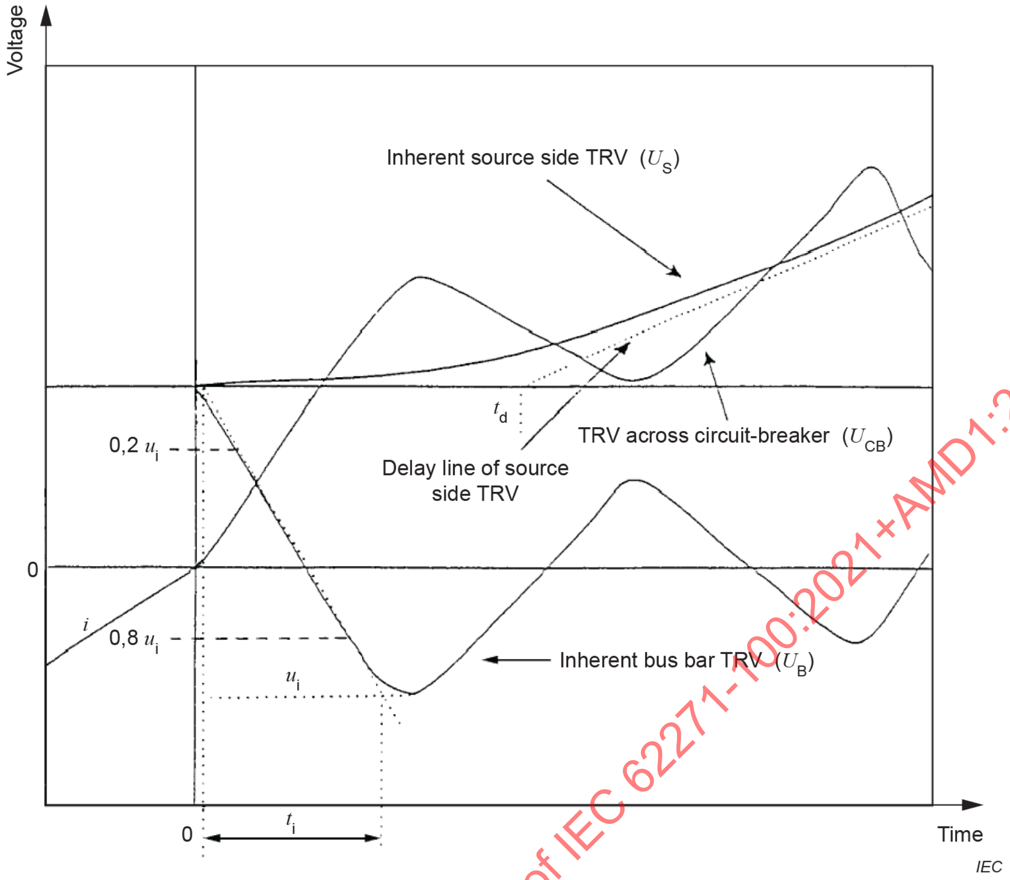

**Figure 43 – Representation of a specified TRV by a two-parameter reference line and a delay line**




| | | | |
|---|---|---|---|
| C.B. | circuit-breaker | $C_d$ | time delaying source side capacitance |
| $U_G$ | supply side voltage | $Z_s$ | source side TRV control components |
| $U_B$ | bus voltage | $Z_i$ | ITRV controlling components |
| $U_{CB}$ | voltage across circuit-breaker | $X_S$ | power frequency source side reactance |
| $U_S$ | source side voltage | $X_B$ | power frequency busbar reactance |

NOTE If a lumped inductance is used as $X_S$, the ITRV controlling components can be connected in parallel to this inductance.

**Figure 44 – Basic circuit for terminal fault with ITRV**




$u_i$ peak voltage of ITRV

$t_i$ time co-ordinate of ITRV

**Figure 45 – Representation of ITRV in relationship to TRV**

TRV parameters are a function of the rated voltage ($U_r$), the rated first-pole-to-clear factor ($k_{pp}$) and the amplitude factor ($k_{af}$). The values of $k_{pp}$ and $k_{af}$ are stated in Table 16 through Table 27. $k_{pp}$ is given in 5.102.

a) *For rated voltages less than 100 kV*

A representation by two parameters of the prospective TRV is used for all test-duties.

– In Table 16 and Table 17, for class S1 circuit-breakers.

TRV peak value $u_c = k_{pp} \times k_{af}\sqrt{(2/3)} \times U_r$ where $k_{af}$ is equal to 1,4 for test-duty T100, 1,5 for test-duty T60, 1,6 for test-duty T30 and 1,7 for test-duty T10, 1,25 for out-of-phase breaking.

Time $t_3$ for test-duty T100 is taken from Table 16 and Table 17. Time $t_3$ for test-duties T60, T30 and T10 is obtained by multiplying the time $t_3$ for test-duty T100 by 0,44 for T60, 0,22 for T30, 0,22 for T10 in Table 16 and 0,25 for T10 in Table 17.

– In Table 18 and Table 19, for class S2 circuit-breakers.

TRV peak value $u_c = k_{pp} \times k_{af}\sqrt{(2/3)} \times U_r$ where $k_{af}$ is equal to 1,54 for test-duty T100 and the supply side circuit for short-line fault, 1,65 for test-duty T60, 1,74 for test-duty T30 and 1,8 for test-duty T10, 1,25 for out-of-phase breaking.

Time $t_3$ for test-duty T100 is taken from Table 18 and Table 19. Time $t_3$ for test-duties T60, T30 and T10 is obtained by multiplying the time $t_3$ for test-duty T100 by 0,67 for T60, 0,40 for T30, 0,40 for T10 in Table 18 and 0,46 for T10 in Table 19.

Time $t_3$ for the supply side circuit of short-line fault is obtained by dividing $t_3$ for test-duty T100 by $k_{pp}$. The ratios $u_c$ / $t_3$ for the supply circuit of SLF is the same as for T100s.

– Time delay $t_d$ for test-duty T100 is 0,15$t_3$ for class S1 circuit-breakers, 0,05$t_3$ for class S2 circuit-breakers, 0,05$t_3$ for the supply side circuit for short-line fault.

– Time delay $t_d$ is 0,15$t_3$ for test-duties T60, T30 and T10 and for out-of-phase breaking.

– Voltage $u' = u_c/3$.

– Time $t'$ is derived from $u'$, $t_3$ and $t_d$ according to Figure 43, $t' = t_d + t_3/3$.

**Table 16 – Values of prospective TRV for class S1 circuit-breakers rated for $k_{pp}$ = 1,5**

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 3,6 | T100 | 1,5 | 1,4 | 6,17 | 40,7 | 6,10 | 2,06 | 19,~~1~~7 | 0,152 |
| | T60 | 1,5 | 1,5 | 6,61 | 17,9 | 2,68 | 2,20 | 8,65 | 0,370 |
| | T30 | 1,5 | 1,6 | 7,05 | 8,95 | 1,34 | 2,35 | 4,32 | 0,788 |
| | T10 | 1,5 | 1,7 | 7,50 | 8,95 | 1,34 | 2,50 | 4,32 | 0,838 |
| 4,76 | T100 | 1,5 | 1,4 | 8,16 | ~~43,7~~44,8 | 6,~~55~~73 | 2,72 | 21,~~1~~7 | 0,~~187~~182 |
| | T60 | 1,5 | 1,5 | 8,74 | 19,~~2~~7 | 2,~~88~~96 | 2,91 | 9,~~29~~54 | 0,~~455~~443 |
| | T30 | 1,5 | 1,6 | 9,33 | 9,~~61~~87 | 1,~~44~~48 | 3,11 | 4,~~65~~77 | 0,~~970~~945 |
| | T10 | 1,5 | 1,7 | 9,91 | 9,~~61~~87 | 1,~~44~~48 | 3,30 | 4,~~65~~77 | 1,~~03~~00 |
| 7,2 | T100 | 1,5 | 1,4 | 12,3 | ~~49,8~~51,5 | 7,~~48~~73 | 4,12 | 24,~~1~~9 | 0,~~248~~240 |
| | T60 | 1,5 | 1,5 | 13,2 | ~~21,9~~22,7 | 3,~~29~~40 | 4,41 | ~~10,6~~11,0 | 0,~~603~~584 |
| | T30 | 1,5 | 1,6 | 14,1 | 11,~~0~~3 | 1,~~64~~70 | 4,70 | 5,~~30~~48 | 1,~~29~~24 |
| | T10 | 1,5 | 1,7 | 15,0 | 11,~~0~~3 | 1,~~64~~70 | 5,00 | 5,~~30~~48 | 1,~~37~~32 |
| 8,25 | T100 | 1,5 | 1,4 | 14,1 | ~~52,4~~54,0 | ~~7,86~~8,09 | 4,72 | ~~25,3~~26,1 | 0,~~270~~262 |
| | T60 | 1,5 | 1,5 | 15,2 | 23,~~1~~7 | 3,~~46~~56 | 5,05 | 11,~~1~~5 | 0,~~657~~638 |
| | T30 | 1,5 | 1,6 | 16,2 | 11,~~5~~9 | 1,~~73~~78 | 5,39 | 5,~~57~~74 | 1,~~40~~36 |
| | T10 | 1,5 | 1,7 | 17,2 | 11,~~5~~9 | 1,~~73~~78 | 5,73 | 5,~~57~~74 | 1,~~49~~45 |
| 12 | T100 | 1,5 | 1,4 | 20,6 | 61,~~2~~8 | 9,~~18~~27 | 6,86 | 29,~~6~~9 | 0,~~336~~333 |
| | T60 | 1,5 | 1,5 | 22,~~1~~0 | ~~26,9~~27,2 | 4,~~04~~08 | 7,35 | 13,~~0~~1 | 0,~~819~~811 |
| | T30 | 1,5 | 1,6 | 23,5 | 13,~~5~~6 | 2,~~02~~04 | 7,84 | 6,~~51~~57 | 1,~~75~~73 |
| | T10 | 1,5 | 1,7 | 25,0 | 13,~~5~~6 | 2,~~02~~04 | 8,33 | 6,~~51~~57 | 1,~~86~~84 |
| 15 | T100 | 1,5 | 1,4 | 25,7 | 67,~~9~~7 | 10,2 | 8,57 | 32,~~8~~7 | 0,~~379~~380 |
| | T60 | 1,5 | 1,5 | 27,6 | 29,~~9~~8 | 4,~~48~~47 | 9,19 | 14,4 | 0,~~923~~925 |
| | T30 | 1,5 | 1,6 | 29,4 | 14,9 | 2,~~24~~23 | 9,80 | 7,~~22~~20 | 1,97 |
| | T10 | 1,5 | 1,7 | 31,2 | 14,9 | 2,~~24~~23 | 10,4 | 7,~~22~~20 | 2,~~09~~10 |
| 15,5 | T100 | 1,5 | 1,4 | 26,6 | 68,~~9~~7 | 10,3 | 8,86 | 33,~~3~~2 | 0,~~386~~387 |
| | T60 | 1,5 | 1,5 | 28,5 | 30,~~3~~2 | 4,~~55~~53 | 9,49 | 14,~~7~~6 | 0,~~939~~943 |
| | T30 | 1,5 | 1,6 | 30,4 | 15,~~2~~1 | 2,27 | 10,1 | 7,~~33~~30 | 2,~~00~~01 |
| | T10 | 1,5 | 1,7 | 32,3 | 15,~~2~~1 | 2,27 | 10,8 | 7,~~33~~30 | 2,~~13~~14 |
| 17,5 | T100 | 1,5 | 1,4 | 30,0 | ~~73,2~~72,5 | ~~11,0~~10,9 | 10,0 | 35,~~4~~0 | 0,~~410~~414 |
| | T60 | 1,5 | 1,5 | 32,1 | ~~32,2~~31,9 | 4,~~83~~79 | 10,7 | 15,~~6~~4 | ~~0,999~~1,00 |
| | T30 | 1,5 | 1,6 | 34,3 | 16,~~1~~0 | 2,~~41~~39 | 11,4 | 7,~~78~~71 | 2,~~13~~15 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| | T10 | 1,5 | 1,7 | 36,4 | 16,~~1~~0 | 2,~~41~~39 | 12,1 | 7,~~78~~71 | 2,~~26~~28 |
| 24 | T100 | 1,5 | 1,4 | 41,2 | ~~86~~85,0 | 12,~~8~~7 | 13,7 | 41,~~6~~1 | 0,~~478~~484 |
| | T60 | 1,5 | 1,5 | 44,1 | 37,~~9~~4 | 5,~~68~~61 | 14,7 | 18,~~3~~1 | 1,~~16~~18 |
| | T30 | 1,5 | 1,6 | 47,0 | 18,~~9~~7 | 2,~~84~~80 | 15,7 | 9,~~15~~04 | 2,~~48~~52 |
| | T10 | 1,5 | 1,7 | 50,0 | 18,~~9~~7 | 2,~~84~~80 | 16,7 | 9,~~15~~04 | 2,~~64~~67 |
| 25,8 | T100 | 1,5 | 1,4 | 44,2 | ~~89~~88,4 | 13,~~4~~3 | 14,7 | ~~43,2~~42,7 | 0,~~495~~500 |
| | T60 | 1,5 | 1,5 | 47,4 | ~~39,3~~38,9 | 5,~~90~~84 | 15,8 | ~~19,0~~18,8 | 1,~~21~~22 |
| | T30 | 1,5 | 1,6 | 50,6 | 19,~~7~~5 | 2,~~95~~92 | 16,9 | 9,~~50~~40 | 2,~~57~~60 |
| | T10 | 1,5 | 1,7 | 53,7 | 19,~~7~~5 | 2,~~95~~92 | 17,9 | 9,~~50~~40 | 2,~~73~~76 |
| 27 | T100 | 1,5 | 1,4 | 46,3 | ~~91,6~~90,7 | 13,~~7~~6 | 15,4 | ~~44,3~~43,8 | 0,~~506~~511 |
| | T60 | 1,5 | 1,5 | 49,6 | ~~40,3~~39,9 | ~~6,04~~5,99 | 16,5 | 19,~~5~~3 | 1,~~23~~24 |
| | T30 | 1,5 | 1,6 | 52,9 | 20,~~1~~0 | ~~3,02~~2,99 | 17,6 | 9,~~74~~64 | 2,~~63~~65 |
| | T10 | 1,5 | 1,7 | 56,2 | 20,~~1~~0 | ~~3,02~~2,99 | 18,7 | 9,~~74~~64 | 2,~~79~~82 |
| 36 | T100 | 1,5 | 1,4 | 61,7 | 107 | 16,1 | 20,6 | 51,~~7~~8 | 0,~~577~~576 |
| | T60 | 1,5 | 1,5 | 66,1 | 47,~~1~~2 | 7,~~06~~07 | 22,0 | 22,8 | 1,40 |
| | T30 | 1,5 | 1,6 | 70,5 | 23,6 | 3,~~53~~54 | 23,5 | 11,4 | ~~3,00~~2,99 |
| | T10 | 1,5 | 1,7 | 75,0 | 23,6 | 3,~~53~~54 | 25,0 | 11,4 | 3,18 |
| 38 | T100 | 1,5 | 1,4 | 65,2 | ~~110~~111 | 16,~~5~~6 | 21,7 | 53,5 | 0,~~591~~589 |
| | T60 | 1,5 | 1,5 | 69,8 | 48,~~5~~7 | 7,~~28~~30 | 23,3 | 23,5 | 1,~~44~~43 |
| | T30 | 1,5 | 1,6 | 74,5 | 24,3 | 3,~~64~~65 | 24,8 | 11,~~7~~8 | 3,~~07~~06 |
| | T10 | 1,5 | 1,7 | 79,1 | 24,3 | 3,~~64~~65 | 26,4 | 11,~~7~~8 | 3,~~26~~25 |
| 40,5 | T100 | 1,5 | 1,4 | 69,4 | ~~114~~115 | 17,~~1~~2 | 23,1 | 55,~~2~~5 | 0,~~608~~605 |
| | T60 | 1,5 | 1,5 | 74,4 | 50,~~3~~5 | 7,~~54~~58 | 24,8 | 24,~~3~~4 | 1,~~48~~47 |
| | T30 | 1,5 | 1,6 | 79,4 | 25,~~1~~3 | 3,~~77~~79 | 26,5 | 12,~~1~~2 | 3,~~16~~14 |
| | T10 | 1,5 | 1,7 | 84,3 | 25,~~1~~3 | 3,~~77~~79 | 28,1 | 12,~~1~~2 | 3,~~36~~34 |
| 48,3 | T100 | 1,5 | 1,4 | 82,8 | ~~126~~127 | ~~18,9~~19,0 | 27,6 | 61,~~1~~4 | 0,~~656~~652 |
| | T60 | 1,5 | 1,5 | 88,7 | 55,~~6~~9 | 8,~~34~~38 | 29,6 | ~~26,9~~27,0 | 1,~~60~~59 |
| | T30 | 1,5 | 1,6 | 94,6 | 27,~~8~~9 | 4,~~17~~19 | 31,5 | 13,~~4~~5 | 3,~~41~~39 |
| | T10 | 1,5 | 1,7 | 101 | 27,~~8~~9 | 4,~~17~~19 | 33,5 | 13,~~4~~5 | 3,~~62~~60 |
| 52 | T100 | 1,5 | 1,4 | 89,2 | 132 | 19,8 | 29,7 | 63,~~8~~9 | 0,~~676~~674 |
| | T60 | 1,5 | 1,5 | 95,5 | 58,~~1~~2 | 8,~~71~~73 | 31,8 | 28,1 | 1,~~65~~64 |
| | T30 | 1,5 | 1,6 | 102 | 29,~~0~~1 | 4,~~35~~37 | 34,0 | 14,~~0~~1 | 3,~~51~~50 |
| | T10 | 1,5 | 1,7 | 108 | 29,~~0~~1 | 4,~~35~~37 | 36,1 | 14,~~0~~1 | 3,~~73~~72 |
| 72,5 | T100 | 1,5 | 1,4 | 124 | ~~164~~166 | 24,~~7~~9 | 41,4 | ~~79,5~~80,1 | 0,~~756~~750 |
| | T60 | 1,5 | 1,5 | 133 | 72,~~4~~9 | 10,9 | 44,4 | 35,~~0~~2 | 1,~~84~~83 |
| | T30 | 1,5 | 1,6 | 142 | 36,~~2~~5 | 5,~~43~~47 | 47,4 | 17,~~5~~6 | 3,~~93~~90 |
| | T10 | 1,5 | 1,7 | 151 | 36,~~2~~5 | 5,~~43~~47 | 50,3 | 17,~~5~~6 | 4,~~17~~14 |

NOTE $k_{pp}$ = 1,5 is specified to cover transformer-limited fault conditions with $X_0/X_1$ higher than 3,0 (for example non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems).

**Table 17 – Values of prospective TRV for class S1 circuit-breakers rated for $k_{pp}$ = 1,3**

| $U_r$<br>kV | Test-duty | $k_{pp}$<br>p.u | $k_{af}$<br>p.u | $u_c$<br>kV | $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 3,6 | T100 | 1,3 | 1,4 | 5,35 | 35,~~3~~2 | 5,29 | 1,78 | 17,0 | 0,152 |
| | T60 | 1,3 | 1,5 | 5,73 | 15,5 | 2,33 | 1,91 | 7,50 | 0,370 |
| | T30 | 1,3 | 1,6 | 6,11 | 7,~~76~~75 | 1,16 | 2,04 | 3,75 | 0,788 |
| | T10 | 1,5 | 1,7 | 7,50 | 8,95 | 1,34 | 2,50 | 4,~~33~~32 | 0,838 |
| 4,76 | T100 | 1,3 | 1,4 | 7,07 | ~~37~~38,9 | 5,~~68~~83 | 2,36 | 18,~~3~~8 | 0,~~187~~182 |
| | T60 | 1,3 | 1,5 | 7,58 | ~~16,7~~17,1 | 2,~~50~~57 | 2,53 | 8,~~05~~27 | 0,~~455~~443 |
| | T30 | 1,3 | 1,6 | 8,08 | 8,~~33~~55 | 1,~~25~~28 | 2,69 | 4,~~03~~13 | 0,~~970~~945 |
| | T10 | 1,5 | 1,7 | 9,91 | 9,~~61~~87 | 1,~~44~~48 | 3,30 | 4,~~65~~77 | 1,~~03~~00 |
| 7,2 | T100 | 1,3 | 1,4 | 10,7 | ~~43,2~~44,6 | 6,~~48~~70 | 3,57 | ~~20,9~~21,6 | 0,~~248~~240 |
| | T60 | 1,3 | 1,5 | 11,5 | 19,~~0~~6 | 2,~~85~~95 | 3,82 | 9,~~19~~49 | 0,~~603~~584 |
| | T30 | 1,3 | 1,6 | 12,2 | 9,~~50~~82 | 1,~~43~~47 | 4,08 | 4,~~59~~75 | 1,~~29~~24 |
| | T10 | 1,5 | 1,7 | 15,0 | 11,~~0~~3 | 1,~~64~~70 | 5,00 | 5,~~30~~48 | 1,~~37~~32 |
| 8,25 | T100 | 1,3 | 1,4 | 12,3 | ~~45,4~~46.8 | ~~6,81~~7,01 | 4,09 | ~~222,0~~22,6 | 0,~~270~~262 |
| | T60 | 1,3 | 1,5 | 13,1 | 20,~~0~~6 | 3,~~00~~09 | 4,38 | 9,~~66~~94 | 0,~~657~~638 |
| | T30 | 1,3 | 1,6 | 14,0 | ~~9,99~~10,3 | 1,~~50~~54 | 4,67 | 4,~~83~~97 | 1,~~40~~36 |
| | T10 | 1,5 | 1,7 | 17,2 | 11,~~5~~9 | 1,~~73~~78 | 5,73 | 5,~~57~~74 | 1,~~49~~45 |
| 12 | T100 | 1,3 | 1,4 | 17,8 | 53,~~0~~6 | ~~7,96~~8,03 | 5,94 | 25,~~6~~9 | 0,~~336~~333 |
| | T60 | 1,3 | 1,5 | 19,1 | 23,~~3~~6 | 3,~~50~~54 | 6,37 | 11,~~3~~4 | 0,~~819~~811 |
| | T30 | 1,3 | 1,6 | 20,4 | 11,~~7~~8 | 1,~~75~~77 | 6,79 | 5,~~64~~70 | 1,~~75~~73 |
| | T10 | 1,5 | 1,7 | 25,0 | 13,~~5~~6 | 2,~~02~~04 | 8,33 | 6,~~51~~57 | 1,~~86~~84 |
| 15 | T100 | 1,3 | 1,4 | 22,3 | ~~57,9~~58,7 | 8,~~82~~80 | 7,43 | 28,4 | 0,~~379~~380 |
| | T60 | 1,3 | 1,5 | 23,9 | 25,~~9~~8 | 3,~~88~~87 | 7,96 | 12,5 | 0,~~923~~925 |
| | T30 | 1,3 | 1,6 | 25,5 | 12,9 | 1,94 | 8,49 | 6,~~25~~24 | 1,97 |
| | T10 | 1,5 | 1,7 | 31,2 | 14,9 | 2,~~24~~23 | 10,4 | 7,~~22~~20 | 2,~~09~~10 |
| 15,5 | T100 | 1,3 | 1,4 | 23,0 | 59,~~7~~5 | 8,~~96~~93 | 7,68 | 28,~~9~~8 | 0,~~386~~387 |
| | T60 | 1,3 | 1,5 | 24,7 | 26,~~3~~2 | 3,~~94~~93 | 8,23 | 12,7 | 0,~~939~~943 |
| | T30 | 1,3 | 1,6 | 26,3 | 13,1 | 1,~~97~~96 | 8,77 | 6,~~35~~33 | 2,~~00~~01 |
| | T10 | 1,5 | 1,7 | 32,3 | 15,~~2~~1 | 2,27 | 10,8 | 7,~~33~~30 | 2,~~13~~14 |
| 17,5 | T100 | 1,3 | 1,4 | 26,0 | ~~63,4~~62.8 | 9,~~51~~43 | 8,67 | 30,~~7~~4 | 0,~~410~~414 |
| | T60 | 1,3 | 1,5 | 27,9 | 27,~~9~~7 | 4,~~18~~15 | 9,29 | 13,~~5~~4 | ~~0,999~~1,01 |
| | T30 | 1,3 | 1,6 | 29,7 | 13,~~9~~8 | 2,~~09~~07 | 9,91 | 6,~~74~~68 | 2,~~13~~15 |
| | T10 | 1,5 | 1,7 | 36,4 | 16,~~1~~0 | 2,~~41~~39 | 12,1 | 7,~~78~~71 | 2,~~26~~28 |
| 24 | T100 | 1,3 | 1,4 | 35,7 | ~~74~~73,6 | 11,~~2~~0 | 11,9 | ~~36,0~~35,6 | 0,~~478~~484 |
| | T60 | 1,3 | 1,5 | 38,2 | 32,~~8~~4 | 4,~~92~~86 | 12,7 | 15,~~9~~7 | 1,~~16~~18 |
| | T30 | 1,3 | 1,6 | 40,8 | 16,~~4~~2 | 2,~~46~~43 | 13,6 | 7,~~93~~83 | 2,~~48~~52 |
| | T10 | 1,5 | 1,7 | 50,0 | 18,~~9~~7 | 2,~~84~~80 | 16,7 | 9,~~15~~04 | 2,~~64~~67 |
| 25,8 | T100 | 1,3 | 1,4 | 38,3 | ~~77,5~~76,6 | 11,~~6~~5 | 12,8 | 37,~~4~~0 | 0,~~495~~500 |
| | T60 | 1,3 | 1,5 | 41,1 | ~~34,1~~33,7 | 5,~~11~~06 | 13,7 | 16,~~5~~3 | 1,~~21~~22 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| | T30 | 1,3 | 1,6 | 43,8 | ~~17,0~~16,9 | 2,~~56~~53 | 14,6 | 8,~~24~~15 | 2,~~57~~60 |
| | T10 | 1,5 | 1,7 | 53,7 | 19,~~7~~5 | 2,~~95~~92 | 17,9 | 9,~~5~~4 | 2,~~73~~76 |
| 27 | T100 | 1,3 | 1,4 | 40,1 | ~~79,4~~78,6 | 11,~~9~~8 | 13,4 | 38,~~4~~0 | 0,~~506~~511 |
| | T60 | 1,3 | 1,5 | 43,0 | 34,~~9~~6 | 5,~~24~~19 | 14,3 | 16,~~9~~7 | 1,~~23~~24 |
| | T30 | 1,3 | 1,6 | 45,9 | 17,~~5~~3 | 2,~~62~~59 | 15,3 | 8,~~44~~36 | 2,~~63~~65 |
| | T10 | 1,5 | 1,7 | 56,2 | 20,~~1~~0 | ~~3,02~~2,99 | 18,7 | 9,~~74~~64 | 2,~~79~~82 |
| 36 | T100 | 1,3 | 1,4 | 53,5 | 92,~~8~~9 | 13,9 | 17,8 | 44,~~8~~9 | 0,~~577~~576 |
| | T60 | 1,3 | 1,5 | 57,3 | 40,~~8~~9 | 6,~~12~~13 | 19,1 | 19,~~7~~8 | 1,40 |
| | T30 | 1,3 | 1,6 | 61,1 | 20,4 | 3,~~06~~07 | 20,4 | 9,~~86~~88 | ~~3,00~~2,99 |
| | T10 | 1,5 | 1,7 | 75,0 | 23,6 | 3,~~53~~54 | 25,0 | 11,4 | 3,18 |
| 38 | T100 | 1,3 | 1,4 | 56,5 | 95,~~6~~9 | 14,~~3~~4 | 18,8 | 46,~~2~~4 | 0,~~591~~589 |
| | T60 | 1,3 | 1,5 | 60,5 | 42,~~1~~2 | 6,~~31~~33 | 20,2 | 20,~~3~~4 | 1,~~44~~43 |
| | T30 | 1,3 | 1,6 | 64,5 | 21,~~0~~1 | 3,~~15~~16 | 21,5 | 10,2 | 3,~~07~~06 |
| | T10 | 1,5 | 1,7 | 79,1 | 24,3 | 3,~~64~~65 | 26,4 | 11,~~7~~8 | 3,~~26~~25 |
| 40,5 | T100 | 1,3 | 1,4 | 60,2 | 99,~~0~~5 | 14,9 | 20,1 | ~~47,9~~48,1 | 0,~~608~~605 |
| | T60 | 1,3 | 1,5 | 64,5 | 43,~~6~~8 | 6,~~54~~57 | 21,5 | 21,~~1~~2 | 1,~~48~~47 |
| | T30 | 1,3 | 1,6 | 68,8 | 21,~~8~~9 | 3,~~27~~28 | 22,9 | 10,~~5~~6 | 3,~~16~~14 |
| | T10 | 1,5 | 1,7 | 84,3 | 25,~~1~~3 | 3,~~77~~79 | 28,1 | 12,~~1~~2 | 3,~~36~~34 |
| 48,3 | T100 | 1,3 | 1,4 | 71,8 | ~~109~~110 | 16,~~4~~5 | 23,9 | ~~52,9~~53,2 | 0,~~656~~652 |
| | T60 | 1,3 | 1,5 | 76,9 | 48,~~2~~4 | 7,~~23~~26 | 25,6 | 23,~~3~~4 | 1,~~60~~59 |
| | T30 | 1,3 | 1,6 | 82,0 | 24,~~1~~2 | 3,~~61~~63 | 27,3 | 11,~~6~~7 | 3,~~41~~39 |
| | T10 | 1,5 | 1,7 | 101 | 27,~~8~~9 | 4,~~17~~19 | 33,5 | 13,~~4~~5 | 3,~~62~~60 |
| 52 | T100 | 1,3 | 1,4 | 77,3 | ~~114~~115 | 17,2 | 25,8 | 55,~~3~~4 | 0,~~676~~674 |
| | T60 | 1,3 | 1,5 | 82,8 | 50,~~3~~4 | 7,~~55~~57 | 27,6 | 24,~~3~~4 | 1,~~65~~64 |
| | T30 | 1,3 | 1,6 | 88,3 | 25,2 | 3,~~77~~78 | 29,4 | 12,2 | 3,~~51~~50 |
| | T10 | 1,5 | 1,7 | 108 | 29,~~0~~1 | 4,~~35~~37 | 36,1 | 14,~~0~~1 | 3,~~73~~72 |
| 72,5 | T100 | 1,3 | 1,4 | 108 | ~~143~~144 | 21,~~4~~6 | 35,9 | ~~68,9~~69,4 | 0,~~756~~750 |
| | T60 | 1,3 | 1,5 | 115 | 62,~~7~~2 | 9,~~41~~48 | 38,5 | 30,~~3~~5 | 1,~~84~~83 |
| | T30 | 1,3 | 1,6 | 123 | 31,~~4~~6 | 4,~~70~~74 | 41,0 | 15,~~2~~3 | 3,~~93~~90 |
| | T10 | 1,5 | 1,7 | 151 | 36,~~2~~5 | 5,~~43~~47 | 50,3 | 17,~~5~~6 | 4,~~17~~14 |

NOTE $k_{pp}$ = 1,5 is specified to cover transformer-limited fault conditions with $X_0/X_1$ higher than 3,0 (for example non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems). ~~The TRV specified covers also cases of 3-phase line faults with effectively earthed neutral systems ($k_{pp}$ = 1,3) where coupling between phases can lead to an amplitude factor of 1,76.~~

**Table 18 – Values of prospective TRV for class S2 circuit-breakers rated for $k_{pp}$ = 1,5**

| $U_r$ kV | Test-duty | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 3,6 | T100 | 1,5 | 1,54 | 6,79 | 11,~~4~~5 | 0,57 ~~(1,71)~~ | 2,26 | 4,~~37 (5,51)~~40 | 0,~~596~~591 |
| | T60 | 1,5 | 1,65 | 7,27 | 7,~~64~~70 | 1,~~2~~15 | 2,42 | 3,~~69~~72 | 0,~~953~~945 |
| | T30 | 1,5 | 1,74 | 7,67 | 4,~~56~~59 | 0,~~684~~689 | 2,56 | 2,~~20~~22 | 1,~~68~~67 |
| | T10 | 1,5 | 1,80 | 7,94 | 4,~~56~~59 | 0,~~684~~689 | 2,65 | 2,~~20~~22 | 1,~~74~~73 |
| 4,76 | T100 | 1,5 | 1,54 | 8,98 | 13,9 | 0,~~693 (2,08)~~697 | 2,99 | 5,~~31 (6,70)~~35 | 0,~~648~~644 |
| | T60 | 1,5 | 1,65 | 9,62 | 9,~~29~~34 | 1,~~4~~40 | 3,21 | 4,~~49~~52 | 1,~~04~~03 |
| | T30 | 1,5 | 1,74 | 10,1 | 5,~~54~~58 | 0,~~832~~837 | 3,38 | 2,~~68~~70 | 1,~~83~~82 |
| | T10 | 1,5 | 1,80 | 10,5 | 5,~~54~~58 | 0,~~832~~837 | 3,50 | 2,~~68~~70 | 1,~~89~~88 |
| 7,2 | T100 | 1,5 | 1,54 | 13,6 | 18,~~5~~6 | 0,~~926 (2,78)~~930 | 4,53 | 7,~~10 (8,95)~~13 | 0,~~733~~730 |
| | T60 | 1,5 | 1,65 | 14,6 | 12,~~4~~5 | 1,~~86~~87 | 4,85 | 6,~~00~~02 | 1,17 |
| | T30 | 1,5 | 1,74 | 15,3 | 7,~~41~~44 | 1,~~11~~12 | 5,11 | 3,~~58~~59 | 2,~~07~~06 |
| | T10 | 1,5 | 1,80 | 15,9 | 7,~~41~~44 | 1,~~11~~12 | 5,29 | 3,~~58~~59 | 2,~~14~~13 |
| 8,25 | T100 | 1,5 | 1,54 | 15,6 | 20,4 | 1,02 ~~(3,06)~~ | 5,19 | ~~7,81 (9,85)~~ 7,83 | 0,~~764~~761 |
| | T60 | 1,5 | 1,65 | 16,7 | 13,7 | 2,05 | 5,56 | 6,~~60~~62 | 1,22 |
| | T30 | 1,5 | 1,74 | 17,6 | 8,~~15~~18 | 1,~~22~~23 | 5,86 | 3,~~94~~95 | 2,~~16~~15 |
| | T10 | 1,5 | 1,80 | 18,2 | 8,~~15~~18 | 1,~~22~~23 | 6,06 | 3,~~94~~95 | 2,~~23~~22 |
| 12 | T100 | 1,5 | 1,54 | 22,6 | 26,5 | ~~1,32 (3,97)~~ 1,33 | 7,54 | 10,2 ~~(12,8)~~ | 0,~~855~~854 |
| | T60 | 1,5 | 1,65 | 24,3 | 17,~~7~~8 | 2,~~66~~67 | 8,08 | 8,~~57~~59 | 1,~~37~~36 |
| | T30 | 1,5 | 1,74 | 25,6 | 10,6 | 1,59 | 8.52 | 5,~~12~~13 | 2,~~42~~41 |
| | T10 | 1,5 | 1,80 | 26,5 | 10,6 | 1,59 | 8,82 | 5,~~12~~13 | 2,~~50~~49 |
| 15 | T100 | 1,5 | 1,54 | 28,3 | 31,0 | 1,55 (4,64) | 9,43 | 11,9 (15,0) | 0,914 |
| | T60 | 1,5 | 1,65 | 30,3 | 20,7 | 3,11 | 10,1 | 10,0 | 1,46 |
| | T30 | 1,5 | 1,74 | 32,0 | 12,4 | 1,86 | 10,7 | 5,~~98~~99 | 2,58 |
| | T10 | 1,5 | 1,80 | 33,1 | 12,4 | 1,86 | 11,0 | 5,~~98~~99 | 2,67 |
| 15,5 | T100 | 1,5 | 1,54 | 29,2 | 31,7 | 1,58 (4,75) | 9,74 | 12,1 (15,3) | 0,923 |
| | T60 | 1,5 | 1,65 | 31,3 | 21,2 | 3,18 | 10,4 | 10,3 | 1,48 |
| | T30 | 1,5 | 1,74 | 33,0 | 12,7 | 1,90 | 11,0 | 6,12 | 2,61 |
| | T10 | 1,5 | 1,80 | 34,2 | 12,7 | 1,90 | 11,4 | 6,12 | 2,70 |
| 17,5 | T100 | 1,5 | 1,54 | 33,0 | 34,5 | 1,72 (5,17) | 11,0 | 13,2 (16,7) | 0,~~957~~958 |
| | T60 | 1,5 | 1,65 | 35,4 | 23,1 | 3,~~47~~46 | 11,8 | 11,2 | 1,53 |
| | T30 | 1,5 | 1,74 | 37,3 | 13,8 | 2,07 | 12,4 | 6,~~67~~66 | 2,70 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| | T10 | 1,5 | 1,880 | 38,6 | 13,8 | 2,07 | 12,9 | 6,6766 | 2,80 |
| 24 | T100 | 1,5 | 1,54 | 45,3 | 43,04 2,9 | 2,15 (6,4544) | 15,1 | 16,5 (20,87) | 1,05 |
| | T60 | 1,5 | 1,65 | 48,5 | 28,8 | 4,3231 | 16,2 | 13,9 | 1,6869 |
| | T30 | 1,5 | 1,74 | 51,21 | 17,2 | 2,58 | 17,10 | 8,32 | 2,9798 |
| | T10 | 1,5 | 1,8 | 52,9 | 17,2 | 2,58 | 17,6 | 8,32 | 3,08 |
| 25,8 | T100 | 1,5 | 1,54 | 48,7 | 45,21 | 2,26 (6,7977) | 16,2 | 17,3 (21,98) | 1,08 |
| | T60 | 1,5 | 1,65 | 52,1 | 30,32 | 4,5554 | 17,4 | 14,6 | 1,72 |
| | T30 | 1,5 | 1,74 | 55,0 | 18,1 | 2,71 | 18,3 | 8,7573 | 3,04 |
| | T10 | 1,5 | 1,880 | 56,9 | 18,1 | 2,71 | 19,0 | 8,7573 | 3,1415 |
| 27 | T100 | 1,5 | 1,54 | 50,9 | 46,76 | 2,34 (7,0133 (6,99) | 17,0 | 17,9 (22,95) | 1,09 |
| | T60 | 1,5 | 1,65 | 54,6 | 31,32 | 4,6968 | 18,2 | 15,1 | 1,7475 |
| | T30 | 1,5 | 1,74 | 57,5 | 18,76 | 2,80 | 19,2 | 9,0301 | 3,0809 |
| | T10 | 1,5 | 1,880 | 59,5 | 18,76 | 2,80 | 19,8 | 9,0301 | 3,19 |
| 36 | T100 | 1,5 | 1,54 | 67,9 | 57,15 6,9 | 2,8685 (8,5754) | 22,6 | 21,98 (27,65) | 1,19 |
| | T60 | 1,5 | 1,65 | 72,8 | 38,31 | 5,7472 | 24,3 | 18,54 | 1,9091 |
| | T30 | 1,5 | 1,74 | 76,7 | 22,98 | 3,4341 | 25,6 | 11,10 | 3,3637 |
| | T10 | 1,5 | 1,880 | 79,4 | 22,98 | 3,4341 | 26,5 | 11,10 | 3,4749 |
| 38 | T100 | 1,5 | 1,54 | 71,7 | 59,31 | 2,9795 (8,90) | 23,9 | 22,76 (28,7) | 1,21 |
| | T60 | 1,5 | 1,65 | 76,8 | 39,86 | 5,9694 | 25,6 | 19,21 | 1,9394 |
| | T30 | 1,5 | 1,74 | 81,0 | 23,76 | 3,5654 | 27,0 | 11,54 | 3,4143 |
| | T10 | 1,5 | 1,880 | 83,8 | 23,76 | 3,5654 | 27,9 | 11,54 | 3,5354 |
| 40,5 | T100 | 1,5 | 1,54 | 76,4 | 62,06 1,8 | 3,1009 (9,3126) | 25,5 | 23,7 (29,8 (30,0) | 1,2324 |
| | T60 | 1,5 | 1,65 | 81,8 | 41,64 | 6,2421 | 27,3 | 20,10 | 1,9798 |
| | T30 | 1,5 | 1,74 | 86,3 | 24,87 | 3,7271 | 28,8 | 12,011,9 | 3,4849 |
| | T10 | 1,5 | 1,880 | 89,3 | 24,87 | 3,7271 | 29,8 | 12,011,9 | 3,6061 |
| 48,3 | T100 | 1,5 | 1,54 | 91,1 | 70,26 9,8 | 3,5149 (10,5) | 30,4 | 26,98 (33,97) | 1,3031 |
| | T60 | 1,5 | 1,65 | 97,6 | 47,04 6,8 | 7,0501 | 32,5 | 22,76 | 2,0809 |
| | T30 | 1,5 | 1,74 | 103 | 28,12 7,9 | 4,2119 | 34,3 | 13,65 | 3,6769 |
| | T10 | 1,5 | 1,880 | 106 | 28,12 7,9 | 4,2119 | 35,5 | 13,65 | 3,7981 |
| 52 | T100 | 1,5 | 1,54 | 98,1 | 73,95 | 3,7067 (11,10) | 32,7 | 28,32 (35,75) | 1,33 |
| | T60 | 1,5 | 1,65 | 105 | 49,52 | 7,4338 | 35,0 | 23,98 | 2,1213 |
| | T30 | 1,5 | 1,74 | 111 | 29,64 | 4,4341 | 36,9 | 14,32 | 3,7577 |
| | T10 | 1,5 | 1,880 | 115 | 29,64 | 4,4341 | 38,2 | 14,32 | 3,8890 |
| 72,5 | T100 | 1,5 | 1,54 | 137 | 93,39 2,6 | 4,66 (14,063 (13,9) | 45,6 | 35,8 (45,15 (44,7) | 1,48 |
| | T60 | 1,5 | 1,65 | 146147 | 62,50 | 9,3730 | 48,8 | 30,20 | 2,3536 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| | T30 | 1,5 | 1,74 | 155 | 37,~~3~~0 | 5,~~60~~55 | 51,5 | ~~18,0~~17,9 | 4,~~14~~17 |
| | T10 | 1,5 | 1,~~8~~80 | 160 | 37,~~3~~0 | 5,~~60~~55 | 53,3 | ~~18,0~~17,9 | 4,~~29~~32 |

NOTE Where two values of times $t_d$ and $t'$ are given for test-duty T100 separated by brackets, the time $t_d$ in brackets is the upper limit of the time delay $t_d$ that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at $t'$ given in brackets. If this is not the case, the lower values of $t_d$ and $t'$ apply.

**Table 19 – Values of prospective TRV for class S2 circuit-breakers rated for $k_{pp}$ = 1,3**

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 3,6 | T100 | 1,3 | 1,54 | 5,88 | 9,~~88~~95 | 0,~~494~~<br>~~(1,48)~~498 | 1,96 | 3,~~79~~<br>~~(4,77)~~82 | 0,~~596~~591 |
| | T60 | 1,3 | 1,65 | 6,30 | 6,~~62~~67 | ~~0,993~~1,00 | 2,10 | 3,~~20~~22 | 0,~~953~~945 |
| | T30 | 1,3 | 1,74 | 6,65 | 3,~~95~~98 | 0,~~593~~597 | 2,22 | 1,~~91~~92 | 1,~~68~~67 |
| | T10 | 1,5 | 1,80 | 7,94 | 4,~~56~~59 | 0,~~684~~689 | 2,65 | 2,~~20~~22 | 1,~~74~~73 |
| 4,76 | T100 | 1,3 | 1,54 | 7,78 | 12,~~0~~1 | 0,~~601~~<br>~~(1,80)~~604 | 2,59 | 4,~~60~~<br>~~(5,81)~~63 | 0,~~648~~644 |
| | T60 | 1,3 | 1,65 | 8,34 | 8,~~05~~10 | 1,21 | 2,78 | 3,~~89~~91 | 1,~~04~~03 |
| | T30 | 1,3 | 1,74 | 8,79 | 4,~~80~~83 | 0,~~721~~725 | 2,93 | 2,~~32~~34 | 1,~~83~~82 |
| | T10 | 1,5 | 1,80 | 10,5 | 5,~~54~~58 | 0,~~832~~837 | 3,50 | 2,~~68~~70 | 1,~~89~~88 |
| 7,2 | T100 | 1,3 | 1,54 | 11,8 | 16,1 | 0,~~802~~<br>~~(2,41)~~806 | 3,92 | 6,~~15~~<br>~~(7,76)~~18 | 0,~~733~~730 |
| | T60 | 1,3 | 1,65 | 12,6 | 10,8 | 1,~~61~~62 | 4,20 | 5,~~20~~22 | 1,17 |
| | T30 | 1,3 | 1,74 | 13,3 | 6,~~42~~45 | 0,~~963~~967 | 4,43 | 3,~~10~~12 | 2,~~07~~06 |
| | T10 | 1,5 | 1,80 | 15,9 | 7,~~41~~44 | 1,~~11~~12 | 5,29 | 3,~~58~~59 | 2,~~14~~13 |
| 8,25 | T100 | 1,3 | 1,54 | 13,5 | 17,7 | 0,~~883~~<br>~~(2,65)~~886 | 4,50 | 6,~~77~~<br>~~(8,53)~~79 | 0,~~764~~761 |
| | T60 | 1,3 | 1,65 | 14,5 | 11,~~8~~9 | 1,~~77~~78 | 4,82 | 5,~~72~~74 | 1,22 |
| | T30 | 1,3 | 1,74 | 15,2 | 7,~~06~~09 | 1,06 | 5,08 | 3,~~41~~42 | 2,~~16~~15 |
| | T10 | 1,5 | 1,80 | 18,2 | 8,~~15~~18 | 1,~~22~~23 | 6,06 | 3,~~94~~95 | 2,~~23~~22 |
| 12 | T100 | 1,3 | 1,54 | 19,6 | 23,0 | 1,15 ~~(3,44)~~ | 6,54 | 8,~~80~~<br>~~(11,1)~~81 | 0,~~855~~854 |
| | T60 | 1,3 | 1,65 | 21,0 | 15,4 | 2,31 | 7,01 | 7,~~43~~44 | 1,~~37~~36 |
| | T30 | 1,3 | 1,74 | 22,2 | 9,~~18~~19 | 1,38 | 7.39 | 4,44 | 2,~~42~~41 |
| | T10 | 1,5 | 1,80 | 26,5 | 10,6 | 1,59 | 8,82 | 5,~~12~~13 | 2,~~50~~49 |
| 15 | T100 | 1,3 | 1,54 | 24,5 | 26,8 | 1,34<br>(4,~~02~~03) | 8,17 | 10,3 (13,0) | 0,914 |
| | T60 | 1,3 | 1,65 | 26,3 | 18,0 | 2,70 | 8,76 | 8,69 | 1,46 |
| | T30 | 1,3 | 1,74 | 27,7 | 10,7 | 1,61 | 9,23 | 5,19 | 2,58 |
| | T10 | 1,5 | 1,80 | 33,1 | 12,4 | 1,86 | 11,0 | 5,~~98~~99 | 2,67 |
| 15,5 | T100 | 1,3 | 1,54 | 25,3 | 27,~~4~~5 | 1,37 (4,12) | 8,45 | 10,5 (13,3) | 0,923 |
| | T60 | 1,3 | 1,65 | 27,2 | 18,4 | 2,76 | 9,05 | 8,89 | 1,48 |
| | T30 | 1,3 | 1,74 | 28,6 | 11,0 | 1,65 | 9,54 | 5,31 | 2,61 |

| $U_r$<br>kV | Test-duty | $k_{pp}$<br>p.u | $k_{af}$<br>p.u | $u_c$<br>kV | $t_3$<br>μs | $t_d$<br>μs | $u'$<br>kV | $t'$<br>μs | $u_c/t_3$<br>kV/μs |
|---|---|---|---|---|---|---|---|---|---|
| | T10 | 1,5 | 1,80 | 34,2 | 12,7 | 1,90 | 11,4 | 6,12 | 2,70 |
| 17,5 | T100 | 1,3 | 1,54 | 28,6 | 29,9 | 1,49 (4,48) | 9,54 | 11,5 (14,4) | 0,957958 |
| | T60 | 1,3 | 1,65 | 30,76 | 20,0 | 3,00 | 10,2 | 9,6867 | 1,53 |
| | T30 | 1,3 | 1,74 | 32,3 | 12,011,9 | 1,79 | 10,8 | 5,78 | 2,70 |
| | T10 | 1,5 | 1,880 | 38,6 | 13,8 | 2,07 | 12,9 | 6,6766 | 2,80 |
| 24 | T100 | 1,3 | 1,54 | 39,2 | 37,32 | 1,86 (5,5958) | 13,1 | 14,3 (18,0) | 1,05 |
| | T60 | 1,3 | 1,65 | 42,0 | 25,024,9 | 3,7574 | 14,0 | 12,0 | 1,6869 |
| | T30 | 1,3 | 1,74 | 44,3 | 14,9 | 2,2423 | 14,8 | 7,2119 | 2,9798 |
| | T10 | 1,5 | 1,880 | 52,9 | 17,2 | 2,58 | 17,6 | 8,32 | 3,08 |
| 25,8 | T100 | 1,3 | 1,54 | 42,2 | 39,21 | 1,96 (5,8887) | 14,1 | 15,0 (19,018,9) | 1,08 |
| | T60 | 1,3 | 1,65 | 45,2 | 26,32 | 3,9493 | 15,1 | 12,7 | 1,72 |
| | T30 | 1,3 | 1,74 | 47,7 | 15,76 | 2,35 | 15,9 | 7,5856 | 3,04 |
| | T10 | 1,5 | 1,880 | 56,9 | 18,1 | 2,71 | 19,0 | 8,7573 | 3,1415 |
| 27 | T100 | 1,3 | 1,54 | 44,1 | 40,54 | 2,02 (6,0706) | 14,7 | 15,5 (19,65) | 1,09 |
| | T60 | 1,3 | 1,65 | 47,3 | 27,1 | 4,0706 | 15,8 | 13,1 | 1,7475 |
| | T30 | 1,3 | 1,74 | 49,9 | 16,2 | 2,4342 | 16,6 | 7,83 | 3,0809 |
| | T10 | 1,5 | 1,880 | 59,5 | 18,76 | 2,80 | 19,8 | 9,0301 | 3,19 |
| 36 | T100 | 1,3 | 1,54 | 58,98 | 49,53 | 2,4847 (7,4340) | 19,6 | 19,018,9 (23,98) | 1,19 |
| | T60 | 1,3 | 1,65 | 63,1 | 33,20 | 4,9896 | 21,0 | 16,0 | 1,9091 |
| | T30 | 1,3 | 1,74 | 66,5 | 19,87 | 2,9796 | 22,2 | 9,5753 | 3,3637 |
| | T10 | 1,5 | 1,880 | 79,4 | 22,98 | 3,4341 | 26,54 | 11,10 | 3,4749 |
| 38 | T100 | 1,3 | 1,54 | 62,1 | 51,42 | 2,5756 (7,7168) | 20,7 | 19,76 (24,98) | 1,21 |
| | T60 | 1,3 | 1,65 | 66,6 | 34,53 | 5,1715 | 22,2 | 16,76 | 1,9394 |
| | T30 | 1,3 | 1,74 | 70,2 | 20,65 | 3,0907 | 23,4 | 9,9490 | 3,4143 |
| | T10 | 1,5 | 1,880 | 83,8 | 23,76 | 3,5654 | 27,9 | 11,54 | 3,5354 |
| 40,5 | T100 | 1,3 | 1,54 | 66,2 | 53,85 | 2,6968 (8,0703) | 22,1 | 20,6 (26,05 (25,9) | 1,2324 |
| | T60 | 1,3 | 1,65 | 70,9 | 36,035,9 | 5,4038 | 23,6 | 17,43 | 1,9798 |
| | T30 | 1,3 | 1,74 | 74,8 | 21,54 | 3,2321 | 24,9 | 10,43 | 3,4849 |
| | T10 | 1,5 | 1,880 | 89,3 | 24,87 | 3,7271 | 29,8 | 12,011,9 | 3,6061 |
| 48,3 | T100 | 1,3 | 1,54 | 79,0 | 60,85 | 3,0402 (9,1207) | 26,3 | 23,32 (29,42) | 1,3031 |
| | T60 | 1,3 | 1,65 | 84,6 | 40,85 | 6,1108 | 28,2 | 19,76 | 2,0809 |
| | T30 | 1,3 | 1,74 | 89,2 | 24,32 | 3,6563 | 29,7 | 11,87 | 3,6769 |
| | T10 | 1,5 | 1,880 | 106 | 28,127,9 | 4,2119 | 35,5 | 13,65 | 3,7981 |
| 52 | T100 | 1,3 | 1,54 | 85,0 | 64,163,7 | 3,2018 (9,6155) | 28,3 | 24,6 (31,04 (30,8) | 1,33 |
| | T60 | 1,3 | 1,65 | 91,1 | 42,97 | 6,4440 | 30,4 | 20,76 | 2,1213 |
| | T30 | 1,3 | 1,74 | 96,0 | 25,65 | 3,8482 | 32,0 | 12,43 | 3,7577 |
| | T10 | 1,5 | 1,880 | 115 | 29,64 | 4,4341 | 38,2 | 14,32 | 3,8890 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 72,5 | T100 | 1,3 | 1,54 | 119 | 80,~~8~~2 | 4,~~04~~01 (12,~~1~~0) | 39,5 | 30,~~0 (39,1~~8 (38,8) | 1,~~47~~48 |
| | T60 | 1,3 | 1,65 | 127 | ~~54,2~~53,7 | 8,~~12~~06 | 42,3 | 26,~~2~~0 | 2,~~35~~36 |
| | T30 | 1,3 | 1,74 | 134 | 32,~~3~~1 | 4,~~85~~81 | 44,6 | 15,~~6~~5 | 4,~~14~~17 |
| | T10 | 1,5 | 1,~~8~~80 | 160 | 37,~~3~~0 | 5,~~60~~55 | 53,3 | ~~18,0~~17,9 | 4,~~29~~32 |

NOTE Where two values of times $t_d$ and $t'$ are given for test-duty T100 separated by brackets, the time $t_d$ in brackets is the upper limit of the time delay $t_d$ that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at $t'$ given in brackets. If this is not the case, the lower values of $t_d$ and $t'$ apply.

b) *For rated voltages from 100 kV to 800 kV*

A representation by four parameters of the prospective TRV is used for test-duties T100 and T60, and the supply circuit of SLF for test-duties $L_{90}$ and $L_{75}$ and for out-of-phase test-duties OP1 and OP2 and by two parameters for test-duties T30 and T10.

– First reference voltage $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$

– Time $t_1$ for terminal fault test-duties is derived from $u_1$ and the specified value of the rate of rise $u_1/t_1$. For test-duties OP1 and OP2, $t_1$ is two times $t_1$ for test-duty T100 and the rate of rise is derived from $u_1$ and $t_1$. For the supply side circuit of short-line fault, time $t_1$ is derived from $u_1$ and the specified value of the rate of rise $u_1/t_1$ which is the same as for test-duty T100.

– TRV peak value $u_c = k_{pp} \times k_{af} \times U_r \times \sqrt{\frac{2}{3}}$

where $k_{af}$ is equal to 1,4 for test-duty T100 and for the supply side circuit for SLF, 1,5 for test-duty T60, 1,54 for test-duty T30, 1,~~76~~765 for test-duty T10 in case of $k_{pp}$ is 1,3, 1,53 (0,9 × 1,7) for test-duty T10 in the case of $k_{pp}$ is 1,5, and 1,25 for out-of-phase breaking.

– Time $t_2$ is equal to $4t_1$ for test-duty T100 and for the supply side circuit for short-line fault and between $t_2$ (for T100) and $2t_2$ (for T100) for out-of-phase breaking. Time $t_2$ is equal to $6t_1$ for T60.

– For test-duties T30 and T10, time $t_3$ is derived from $u_c$ and the specified value of the rate of rise $u_c/t_3$.

– Time delay $t_d$ is 2 µs for test-duty T100, between 2 µs and $0{,}3t_1$ for test-duty T60, between 2 µs and $0{,}1t_1$ for test-duties OP1 and OP2. Time delay is 0,15 $t_3$ for test-duties T30 and T10. For the supply side circuit for short-line fault the time delay is equal to 2 µs. When short-line fault tests are performed, the time delay $t_d$ for test-duty T100 can be extended up to 0,28 $t_1$. The relevant value of $t_d$ to be used for testing is given in 7.105.5.2 to 7.105.5.5.

– Voltage $u'$ = $u_1/2$ for test-duties T100 and T60 and the supply side for SLF and out-of-phase breaking, and $u_c/3$ for test-duties T30 and T10.

– Time $t'$ is derived from $u'$, $u_1/t_1$ and $t_d$ for test-duties T100, T60 and the supply circuit for SLF and out-of-phase breaking, and according to Figure 42; and from $u'$, $u_c/t_3$ and $t_d$ for test-duties T30 and T10 according to Figure 43.

c) *For rated voltages higher than 800 kV*

A representation by four parameters of the prospective TRV is used for test-duties T100 and T60, and the supply circuit of SLF for test-duties $L_{90}$ and $L_{75}$ and by two parameters for test-duties T30, T10 and for out-of-phase test-duties OP1 and OP2.

– First reference voltage $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$

– Time $t_1$ for terminal fault test-duties is derived from $u_1$ and the specified value of the rate of rise $u_1/t_1$. For the supply side circuit of short-line fault, time $t_1$ is derived from $u_1$ and the specified value of the rate of rise $u_1/t_1$ which is the same as for test-duty T100.

– Time $t_3$ for out-of-phase test-duties OP1 and OP2 is derived from $u_c$ and the specified value of the rate of rise.

– TRV peak value $u_c = k_{pp} \times k_{af} \times U_r \times \sqrt{\frac{2}{3}}$

where $k_{af}$ is equal to 1,5 for test-duty T100 and for the supply side circuit for SLF, 1,5 for test-duty T60, 1,54 for test-duty T30, 1,~~76~~765 for test-duty T10, and 1,25 for out-of-phase breaking.

– Time $t_2$ is equal to 3 $t_1$ for test-duty T100 and for the supply side circuit for short-line fault. Time $t_2$ is equal to 4,5 $t_1$ for T60.

– For test-duties T30 and T10, time $t_3$ is derived from $u_c$ and the specified value of the rate of rise $u_c/t_3$.

– Time delay $t_d$ is 2 µs for test-duty T100, between 2 µs and 0,3 $t_1$ for test-duty T60. Time delay is 0,15 $t_3$ for test-duties T30 and T10, 0,05 $t_3$ for test-duties OP1 and OP2. For the supply side circuit for short-line fault the time delay is equal to 2 µs. When short-line fault tests are performed, the time delay $t_d$ for test-duty T100 can be extended up to 0,28 $t_1$. The relevant value of $t_d$ to be used for testing is given in 7.105.5.2 to 7.105.5.5.

– Voltage $u'$ = $u_1/2$ for test-duties T100 and T60 and the supply side for SLF, and $u_c/3$ for test-duties T30, T10 and out-of-phase test-duties.

– Time $t'$ is derived from $u'$, $u_1/t_1$ and $t_d$ for test-duties T100, T60 and the supply circuit for SLF, and according to Figure 42; and from $u'$, $u_c/t_3$ and $t_d$ for test-duties T30, T10 and out-of-phase test-duties according to Figure 43.

For rated voltages of 100 kV and above, the specified values are given in Table 20 and Table 21.

**Table 20 – Values of prospective TRV for circuit-breakers rated for $k_{pp}$ = 1,2 or 1,3 – Rated voltages of 100 kV and above**

| $U_r$<br>kV | Test-duty | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_1$<br>kV | $t_1$<br>µs | $u_c$<br>kV | $t_2$ or $t_3$<br>µs | $t_d$ [a]<br>µs | $u'$<br>kV | $t'$ [a]<br>µs | $u_1/t_1$<br>$u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | T100 | 1,3 | 1,40 | 80 | 40 | 149 | 160 | 2 (11) | 40 | 22 (31) | 2 |
| | T60 | 1,3 | 1,50 | 80 | 27 | 159 | ~~162~~160 | 2-8 | 40 | 15-21 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 163 | 33 | 5 | 54 | 16 | 5 |
| | T10 | 1,3 | 1,~~76~~765 | - | - | 187 | 27 | 4 | 62 | 13 | 7 |
| 123 | T100 | 1,3 | 1,40 | 98 | 49 | 183 | 196 | 2 (14) | 49 | 26 (38) | 2 |
| | T60 | 1,3 | 1,50 | 98 | 33 | 196 | ~~198~~196 | 2-10 | 49 | 18-26 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 201 | 40 | 6 | 67 | 19 | 5 |

| $U_r$<br>kV | Test-duty | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_1$<br>kV | $t_1$<br>µs | $u_c$<br>kV | $t_2$ or $t_3$<br>µs | $t_d$ [a]<br>µs | $u'$<br>kV | $t'$ [a]<br>µs | $u_1/t_1$<br>$u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | T10 | 1,3 | 1,~~76~~765 | - | - | 230 | 33 | 5 | 77 | 16 | 7 |
| 145 | T100 | 1,3 | 1,40 | 115 | 58 | 215 | 232 | 2 (16) | 58 | 31 (45) | 2 |
| | T60 | 1,3 | 1,50 | 115 | 38 | 231 | ~~228~~232 | 2-12 | 58 | 21-31 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 237 | 47 | 7 | 79 | 23 | 5 |
| | T10 | 1,3 | 1,~~76~~765 | - | - | 272 | 39 | 6 | 91 | 19 | 7 |
| 170 | T100 | 1,3 | 1,40 | 135 | 68 | 253 | 272 | 2 (19) | 68 | 36 (53) | 2 |
| | T60 | 1,3 | 1,50 | 135 | 45 | 271 | ~~270~~272 | 2-14 | 68 | 25-36 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 278 | 56 | 8 | 93 | 27 | 5 |
| | T10 | 1,3 | 1,~~76~~765 | - | - | 319 | 46 | 7 | 106 | 22 | 7 |
| 245 | T100 | 1,3 | 1,40 | 195 | 98 | 364 | 392 | 2 (27) | 98 | 51 (76) | 2 |
| | T60 | 1,3 | 1,50 | 195 | 65 | 390 | ~~390~~392 | 2-20 | 98 | 35-52 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 400 | 80 | 12 | 133 | 39 | 5 |
| | T10 | 1,3 | 1,~~76~~765 | - | - | 459 | 66 | 10 | 153 | 32 | 7 |
| 300 | T100 | 1,3 | 1,40 | 239 | 119 | 446 | 476 | 2 (33) | 119 | 62 (93) | 2 |
| | T60 | 1,3 | 1,50 | 239 | 80 | 478 | ~~480~~476 | 2-24 | 119 | 42-64 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 490 | 98 | 15 | 163 | 47 | 5 |
| | T10 | 1,3 | 1,~~76~~765 | - | - | 562 | 80 | 12 | 187 | 39 | 7 |
| 362 | T100 | 1,3 | 1,40 | 288 | 144 | 538 | 576 | 2 (40) | 144 | 74 (112) | 2 |
| | T60 | 1,3 | 1,50 | 288 | 96 | 576 | 576 | 2-29 | 144 | 50-77 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 592 | 118 | 18 | 197 | 57 | 5 |
| | T10 | 1,3 | 1,~~76~~765 | - | - | 678 | 97 | 15 | 226 | 47 | 7 |
| 420 | T100 | 1,3 | 1,40 | 334 | 167 | 624 | 668 | 2 (47) | 167 | 86 (130) | 2 |
| | T60 | 1,3 | 1,50 | 334 | 111 | 669 | ~~666~~668 | 2-33 | 167 | 58-89 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 687 | 137 | 21 | 229 | 66 | 5 |
| | T10 | 1,3 | 1,~~76~~765 | - | - | 787 | 112 | 17 | 262 | 54 | 7 |
| 550 | T100 | 1,3 | 1,40 | 438 | 219 | 817 | 876 | 2 (61) | 219 | 111 (171) | 2 |
| | T60 | 1,3 | 1,50 | 438 | 146 | 876 | 876 | 2-44 | 219 | 75-117 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 899 | 180 | 27 | 300 | 87 | 5 |
| | T10 | 1,3 | 1,~~76~~765 | - | - | 1 031 | 147 | 22 | 344 | 71 | 7 |
| 800 | T100 | 1,3 | 1,40 | 637 | 318 | 1 189 | 1 272 | 2 (89) | 318 | 161 (248) | 2 |
| | T60 | 1,3 | 1,50 | 637 | 212 | 1 274 | 1 272 | 2-64 | 318 | 108-170 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 1 308 | 262 | 39 | 436 | 126 | 5 |
| | T10 | 1,3 | 1,~~76~~765 | - | - | 1 499 | 214 | 32 | 500 | 103 | 7 |
| 1 100 | T100 | 1,2 | 1,50 | 808 | 404 | 1 617 | 1 212 | 2 (113) | 404 | 204 (315) | 2 |
| | T60 | 1,2 | 1,50 | 808 | 269 | 1 617 | 1 212 | 2-81 | 404 | 137-216 | 3 |
| | T30 | 1,2 | 1,54 | - | - | 1 660 | 332 | 50 | 553 | 161 | 5 |
| | T10 | 1,2 | 1,~~76~~765 | - | - | 1 ~~897~~902 | 271 | 41 | ~~632~~634 | 131 | 7 |
| 1 200 | T100 | 1,2 | 1,50 | 882 | 441 | 1 764 | 1 323 | 2 (123) | 441 | 222 (343) | 2 |

| $U_r$<br>kV | Test-duty | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_1$<br>kV | $t_1$<br>µs | $u_c$<br>kV | $t_2$ or $t_3$<br>µs | $t_d$ [a]<br>µs | $u'$<br>kV | $t'$ [a]<br>µs | $u_1/t_1$<br>$u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | T60 | 1,2 | 1,50 | 882 | 294 | 1 764 | 1 323 | 2-88 | 441 | 149-235 | 3 |
| | T30 | 1,2 | 1,54 | - | - | 1 811 | 362 | 54 | 604 | 175 | 5 |
| | T10 | 1,2 | 1,~~76~~765 | - | - | 2 ~~069~~075 | 296 | 44 | ~~690~~692 | 143 | 7 |

NOTE Test-duty T10 covers transformer-limited fault conditions with $X_0/X_1$ higher than 3,0 (for example non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems). For rated voltages higher than 170 kV the TRV specified covers also cases of three-phase line faults with effectively earthed neutral systems where coupling between phases can lead to an amplitude factor of 1,~~76~~765.

[a] Where two values of times $t_d$ and $t'$ are given for terminal fault test-duty T60, those indicate the lower and upper limits which should be used for testing. The time delay $t_d$ and the time $t'$ during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.

[b] Where two values of times $t_d$ and $t'$ are given for test-duty T100~~,~~ separated by brackets, the time $t_d$ in brackets is the upper limit of the time delay $t_d$ that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at $t'$ given in brackets. If this is not the case, the lower values of $t_d$ and $t'$ apply.

**Table 21 – Values of prospective TRV for circuit-breakers rated for $k_{pp}$ = 1,5 – Rated voltages of 100 kV to 170 kV**

| $U_r$ kV | Test-duty | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_1$ kV | $t_1$ µs | $u_c$ kV | $t_2$ or $t_3$ µs | $t_d$ [a] µs | $u'$ kV | $t'$ [a] µs | $u_1/t_1$ $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | T100 | 1,5 | 1,40 | 92 | 46 | 171 | 184 | 2 (13) | 46 | 25 (36) | 2 |
| | T60 | 1,5 | 1,50 | 92 | 31 | 184 | 186 | 2-8 | 46 | 15-21 | 3 |
| | T30 | 1,5 | 1,54 | - | - | 189 | 38 | 5 | 63 | 16 | 5 |
| | T10 | 1,5 | 1,53 | - | - | 187 | 27 | 4 | 62 | 13 | 7 |
| 123 | T100 | 1,5 | 1,40 | 113 | 56 | 211 | 224 | 2 (16) | 56 | 30 (44) | 2 |
| | T60 | 1,5 | 1,50 | 113 | 38 | 226 | 228 | 2-10 | 56 | 18-26 | 3 |
| | T30 | 1,5 | 1,54 | - | - | 232 | 46 | 6 | 77 | 19 | 5 |
| | T10 | 1,5 | 1,53 | - | - | 230 | 33 | 5 | 77 | 16 | 7 |
| 145 | T100 | 1,5 | 1,40 | 133 | 67 | 249 | 268 | 2 (19) | 67 | 35 (52) | 2 |
| | T60 | 1,5 | 1,50 | 133 | 44 | 266 | 264 | 2-12 | 67 | 21-31 | 3 |
| | T30 | 1,5 | 1,54 | - | - | 273 | 55 | 7 | 91 | 23 | 5 |
| | T10 | 1,5 | 1,53 | - | - | 272 | 39 | 6 | 91 | 19 | 7 |
| 170 | T100 | 1,5 | 1,40 | 156 | 78 | 291 | 312 | 2 (22) | 78 | 41 (61) | 2 |
| | T60 | 1,5 | 1,50 | 156 | 52 | 312 | 312 | 2-14 | 78 | 25-36 | 3 |
| | T30 | 1,5 | 1,54 | - | - | 321 | 64 | 8 | 107 | 27 | 5 |
| | T10 | 1,5 | 1,53 | - | - | 319 | 46 | 7 | 106 | 22 | 7 |

[a] Where two values of times $t_d$ and $t'$ are given for terminal fault test-duty T60, those indicate the lower and upper limits which should be used for testing. The time delay $t_d$ and the time $t'$ during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.

Where two values of times $t_d$ and $t'$ are given for test-duty T100, separated by brackets, the time $t_d$ in brackets is the upper limit of the time delay $t_d$ that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at $t'$ given in brackets. If this is not the case, the lower values of $t_d$ and $t'$ apply.

NOTE Test-duty T10 covers transformer-limited fault conditions with $X_0/X_1$ higher than 3,0 (for example non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems).



The prospective TRV wave of the test circuit shall comply with the following two requirements:

– Requirement a)

Its envelope shall at no time be below the specified reference line.

It is stressed that the extent by which the envelope can exceed the specified reference line requires the consent of the manufacturer (see 7.105); this is of particular importance in the case of two-parameter envelopes when four-parameter reference lines are specified, and in the case of four-parameter envelopes when two-parameter reference lines are specified.

For convenience of testing it is allowed to carry out test-duties for which a four parameter TRV is specified with a two parameter TRV, provided that the rate-of-rise of recovery voltage corresponds to the standard value $u_1/t_1$ and the peak value to the standard value $u_c$. This procedure requires the consent of the manufacturer.

– Requirement b)

Its initial portion shall fulfil the specified ITRV requirements. The ITRV shall be handled like a short-line fault. Consequently, it is necessary to measure the ITRV circuit independently of the source side in an inherent way. The ITRV is defined by the peak value $u_i$ and the time coordinate $t_i$ (Figure 45). The inherent waveshape shall mostly follow a straight line reference line drawn from the beginning of the ITRV to the point defined by $u_i$ and $t_i$. The inherent ITRV waveshape shall follow this reference line from 20 % to 80 % of the required ITRV peak value. Deviations from the reference line are permitted for the ITRV amplitude below 20 % and above 80 % of the specified ITRV peak value. It shall not be significantly higher than the above-mentioned reference line. If the 80 % value cannot be reached without significant increase of the rate of rise of the ITRV, it is preferred to raise the peak value $u_i$ above the specified value in order to reach the 80 % point. The rate of rise of the ITRV shall not be increased, because this would be connected to a change of the impedance and thus to an essential change of the severity of the test.

Testing under ITRV conditions is necessary for T100a, T100s and $L_{90}$. However, if a circuit-breaker with rated voltage equal or less than 800 kV has a short-line fault rating, the ITRV requirements are considered to be covered if $L_{90}$ is carried out using a line with a time delay less than 100 ns (see also 7.105.5.2).

If a circuit-breaker with rated voltage higher than 800 kV has a short-line fault rating, the ITRV requirements are covered if $L_{90}$ is carried out using a line with a time delay less than 100 ns and a surge impedance of 450 Ω (see also 7.105.5.2 and 7.109.3).

#### 7.105.5.2 Test-duties T100s and T100a

For rated voltages less than 100 kV, the specified values are given in

– Table 16 and Table 17 for class S1 circuit-breakers,
– Table 18 and Table 19 for class S2 circuit-breakers.

The specific reference lines, delay lines and ITRV are given by the values in Table 9, Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21.

With reference to ITRV, if a test is made with a TRV following the straight reference line specified in requirement a) and b) of 7.105.5.1 and shown in Figure 45, it is assumed that the effect on the circuit-breaker is similar to that of any ITRV defined in requirement b) of 7.105.5.1 and Figure 45.

Owing to limitations of the testing station, it may not be feasible to comply with the requirement of item b) of 7.105.5.1 with respect to the time delay $t_d$ as specified in Table 16 through Table 21.

Where short-line fault duties are also to be performed, any such deficiency of the TRV of the supply circuit shall be compensated by an increase of the voltage excursion to the first peak of the line-side voltage (see 7.109.3). The time delay of the supply circuit shall be as small as possible, but shall in any case not exceed the values given in brackets in Table 18, Table 19, Table 20 or Table 21.

Where short-line fault duties are also to be performed, it may be convenient to combine the ITRV and $L_{90}$ requirements in the line-side circuit. When the ITRV is combined with the transient voltage of a short line having a time delay $t_{dL}$ as specified in 7.109.3 the total stress is, for practical considerations, equal or covered by the stress of a short line with a time delay less than 100 ns and a surge impedance of 450 Ω. Therefore the ITRV requirements for test-duties T100s and T100a are considered to be covered when $L_{90}$ is performed using a line with a time delay less than 100 ns and a surge impedance of 450 Ω.

Where short-line fault test-duty $L_{90}$ with a time delay less than 100 ns is used to cover ITRV requirements, the initial part of the line side transient voltage up to 0,2 $u_L$* shall not cross the 20 % to 80 % $L_{90}$ reference except if the time delay as defined in Figure 46 is less than 100 ns.

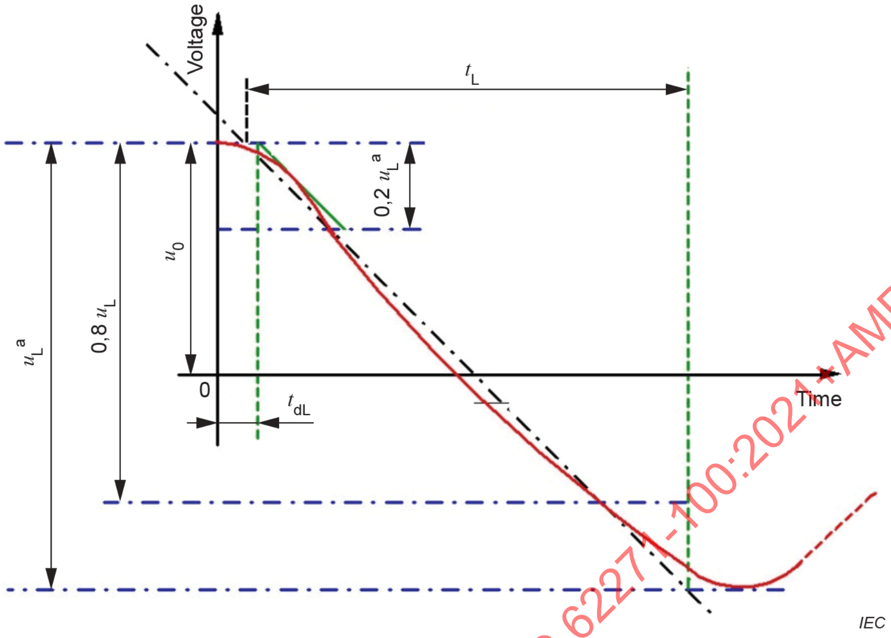



**Figure 46 – Example of line transient voltage with time delay with non-linear rate of rise**

### 7.105.5.3 Test-duty T60

For rated voltages less than 100 kV, the specified values are given in

– Table 16 and Table 17 for class S1 circuit-breakers,
– Table 18 and Table 19 for class S2 circuit-breakers.

For rated voltages of 100 kV and above, the specified standard values are given in Table 20 and Table 21.

### 7.105.5.4 Test-duty T30

a) For rated voltages less than 100 kV, the specified values are given in
   – Table 16 and Table 17 for class S1 circuit-breakers,
   – Table 18 and Table 19 for class S2 circuit-breakers.
b) For rated voltages of 100 kV and above, the specified standard values are given in Table 20 and Table 21.

In case that small values of time $t_3$ cannot be met, the shortest time that can be met shall be used. The values used shall be stated in the test report.

NOTE The contribution of transformers to the short-circuit current is relatively larger at smaller values of short-circuit current as in T30 and T10 conditions. However, most systems have effectively earthed neutrals at ratings of 100 kV up to 800 kV. With the system and transformer neutrals effectively earthed, a $k_{pp}$ of 1,3 is applicable for all test-duties except for T10, where in general a $k_{pp}$ of 1,5 is used in order to take also transformer fed faults into account. For rated voltages higher than 800 kV, a $k_{pp}$ of 1,2 is applicable for all test-duties.

In some systems for rated voltages of 100 kV up to and including 170 kV, transformers with non-effectively earthed neutrals are in service, even though the rest of the system can have effectively earthed neutrals. Such systems are considered special cases and are covered in Table 21 where the TRVs specified for all test-duties are based on a $k_{pp}$ of 1,5. For rated voltages above 170 kV, all systems and their transformers are considered to have effectively earthed neutrals.

#### 7.105.5.5 Test-duty T10

a) For rated voltages less than 100 kV, the specified values are given in
   – Table 16 and Table 17 for class S1 circuit-breakers,
   – Table 18 and Table 19 for class S2 circuit-breakers.

b) For rated voltages of 100 kV and above, the specified standard values are given in Table 20 and Table 21. The time $t_3$ is a function of the natural frequency of transformers.

In case that small values of time $t_3$ cannot be met, the shortest time that can be met shall be used. The values used shall be stated in the test report.

#### 7.105.5.6 Test-duties OP1 and OP2

For rated voltages up to and including 72,5 kV, the specified values are given in the following Tables.

– Table 22 for class S1 circuit-breakers for use in non-effectively earthed neutral systems;
– Table 23 for class S1 circuit-breakers for use in effectively earthed neutral systems;
– Table 24 for class S2 circuit-breakers for use in non-effectively earthed neutral systems;
– Table 25 for class S2 circuit-breakers for use in effectively earthed neutral systems.

For rated voltages of 100 kV and above, the specified values are given in Table 26 and Table 27.

**Table 22 – Values of prospective TRV for out-of-phase tests on class S1 circuit-breakers for $k_{pp}$ = 2,5**

| $U_r$<br>kV | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_c$<br>kV | $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|
| 3,6 | 2,5 | 1,25 | 9,19 | 81,~~4~~3 | 12,2 | 3,06 | 39,3 | 0,113 |
| 4,76 | 2,5 | 1,25 | 12,1 | ~~87,4~~89,7 | 13,~~1~~5 | 4,05 | ~~42,2~~43,4 | 0,~~139~~135 |
| 7,2 | 2,5 | 1,25 | 18,4 | ~~99,7~~103 | 15,~~0~~5 | 6,12 | ~~48,2~~49,8 | 0,~~184~~178 |
| 8,25 | 2,5 | 1,25 | 21,1 | ~~105~~108 | ~~15,7~~16,2 | 7,02 | ~~50,7~~52,3 | 0,~~201~~195 |
| 12 | 2,5 | 1,25 | 30,6 | ~~122~~124 | 18,~~4~~5 | 10,2 | 59,~~2~~7 | 0,~~250~~248 |
| 15 | 2,5 | 1,25 | 38,3 | ~~136~~135 | 20,~~4~~3 | 12,8 | 65,~~6~~4 | 0,~~282~~283 |
| 15,5 | 2,5 | 1,25 | 39,5 | ~~138~~137 | 20,~~7~~6 | 13,2 | ~~68,6~~66,4 | 0,~~287~~288 |
| 17,5 | 2,5 | 1,25 | 44,7 | ~~146~~145 | ~~22,0~~21,8 | 14,9 | 70,~~7~~1 | 0,~~305~~308 |
| 24 | 2,5 | 1,25 | 61,2 | ~~172~~170 | 25,~~8~~5 | 20,4 | ~~83,2~~82,1 | 0,~~356~~360 |
| 25,8 | 2,5 | 1,25 | 65,8 | ~~179~~177 | 26,~~8~~5 | 21,9 | ~~86,4~~85,5 | 0,~~368~~372 |
| 27 | 2,5 | 1,25 | 68,9 | ~~183~~181 | 27,~~5~~2 | 23,0 | ~~88,5~~87,7 | 0,~~376~~380 |
| 36 | 2,5 | 1,25 | 91,9 | 214 | 32,~~1~~2 | 30,6 | ~~103~~104 | 0,~~429~~428 |
| 38 | 2,5 | 1,25 | 97,0 | 221 | 33,~~1~~2 | 32,3 | 107 | 0,~~440~~438 |
| 40,5 | 2,5 | 1,25 | 103 | 229 | 34,~~3~~5 | 34,~~5~~4 | ~~110~~111 | 0,~~452~~450 |
| 48,3 | 2,5 | 1,25 | 123 | ~~253~~254 | ~~37,9~~38,1 | 41,1 | ~~122~~123 | 0,~~488~~485 |
| 52 | 2,5 | 1,25 | 133 | ~~264~~265 | 39,~~6~~7 | 44,2 | 128 | 0,~~503~~502 |
| 72,5 | 2,5 | 1,25 | 185 | ~~329~~332 | 49,~~3~~7 | 61,7 | ~~159~~160 | 0,~~562~~558 |

**Table 23 – Values of prospective TRV for out-of-phase tests on class S1 circuit-breakers for $k_{pp}$ = 2,0**

| $U_r$<br>kV | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_c$<br>kV | $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|
| 3,6 | 2,0 | 1,25 | 7,35 | 65,1 | 9,~~83~~76 | 2,45 | 31,~~6~~5 | 0,113 |
| 4,76 | 2,0 | 1,25 | 9,72 | ~~69,9~~71,8 | 10,~~5~~8 | 3,24 | ~~33,8~~34,7 | 0,~~139~~135 |
| 7,2 | 2,0 | 1,25 | 14,7 | ~~79,7~~82,4 | 12,~~0~~4 | 4,90 | ~~38,5~~39,8 | 0,~~184~~178 |
| 8,25 | 2,0 | 1,25 | 16,8 | ~~83,9~~86,3 | 12,~~6~~9 | 5,61 | ~~40,5~~41,7 | 0,~~201~~195 |
| 12 | 2,0 | 1,25 | 24,5 | ~~97~~98,9 | 14,~~7~~8 | 8,16 | 47,~~3~~8 | 0,250 |
| 15 | 2,0 | 1,25 | 30,6 | ~~109~~108 | 16,~~3~~2 | 10,2 | 52,~~5~~3 | 0,~~282~~283 |
| 15,5 | 2,0 | 1,25 | 31,6 | 110 | 16,5 | 10,6 | 53,~~3~~1 | 0,~~287~~288 |
| 17,5 | 2,0 | 1,25 | 35,7 | ~~117~~116 | 17,~~6~~4 | 11,9 | 56,~~6~~1 | 0,~~305~~308 |
| 24 | 2,0 | 1,25 | 49,0 | ~~138~~136 | 20,~~6~~4 | 16,3 | ~~66,4~~65,7 | 0,~~356~~360 |
| 25,8 | 2,0 | 1,25 | 52,7 | ~~143~~141 | 21,~~5~~2 | 17,6 | ~~69,1~~68,4 | 0,~~368~~372 |
| 27 | 2,0 | 1,25 | 55,1 | ~~143~~145 | ~~22,0~~21,8 | 18,4 | 70,~~8~~1 | 0,~~376~~380 |
| 36 | 2,0 | 1,25 | 73,5 | ~~171~~172 | 25,7 | 24,5 | 82,~~8~~9 | 0,~~429~~428 |
| 38 | 2,0 | 1,25 | 77,6 | ~~176~~177 | 26,~~5~~6 | 25,9 | 85,~~3~~6 | 0,~~440~~438 |
| 40,5 | 2,0 | 1,25 | 82,7 | ~~183~~184 | 27,~~4~~6 | 27,6 | 88,~~4~~8 | 0,~~452~~450 |
| 48,3 | 2,0 | 1,25 | 98,6 | ~~202~~203 | 30,~~3~~5 | 32,9 | ~~97,7~~98,2 | 0,~~488~~485 |
| 52 | 2,0 | 1,25 | 106 | ~~211~~212 | 31,~~7~~8 | 35,4 | 102 | 0,~~503~~502 |
| 72,5 | 2,0 | 1,25 | 148 | ~~263~~265 | 39,~~6~~8 | 49,3 | ~~127~~128 | 0,~~563~~558 |

**Table 24 – Values of prospective TRV for out-of-phase tests on class S2 circuit-breakers for $k_{pp}$ = 2,5**

| $U_r$<br>kV | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_c$<br>kV | $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|
| 3,6 | 2,5 | 1,25 | 9,19 | ~~22,8~~23,0 | 3,~~42~~45 | 3,06 | 11,~~0~~1 | 0,~~403~~400 |
| 4,76 | 2,5 | 1,25 | 12,~~6~~1 | 27,~~7~~9 | 4,~~16~~18 | 4,05 | 13,~~4~~5 | 0,~~438~~435 |
| 7,2 | 2,5 | 1,25 | 18,4 | 37,~~0~~2 | 5,~~56~~58 | 6,12 | ~~17,9~~18,0 | 0,~~496~~494 |
| 8,25 | 2,5 | 1,25 | 21,1 | 40,~~7~~9 | 6,~~11~~13 | 7,02 | 19,~~7~~8 | 0,~~517~~515 |
| 12 | 2,5 | 1,25 | 30,6 | 53,0 | 7,~~94~~96 | 10,2 | 25,6 | 0,~~578~~577 |
| 15 | 2,5 | 1,25 | 38,3 | 61,9 | 9,29 | 12,8 | 29,9 | 0,618 |
| 15,5 | 2,5 | 1,25 | 39,5 | 63,4 | 9,50 | 13,2 | 30,6 | 0,624 |
| 17,5 | 2,5 | 1,25 | 44,7 | ~~69,0~~68,9 | 10,3 | 14,9 | 33,3 | 0,~~647~~648 |
| 24 | 2,5 | 1,25 | 61,2 | ~~86,0~~85,9 | 12,9 | 20,4 | 41,~~6~~5 | 0,~~712~~713 |
| 25,8 | 2,5 | 1,25 | 65,8 | 90,~~5~~3 | 13,~~6~~5 | 21,9 | 43,~~7~~6 | 0,~~727~~729 |
| 27 | 2,5 | 1,25 | 68,9 | 93,~~4~~2 | 14,0 | 23,0 | 45,~~2~~0 | 0,~~737~~739 |
| 36 | 2,5 | 1,25 | 91,9 | 114 | 17,1 | 30,6 | 55,~~2~~0 | 0,~~804~~807 |
| 38 | 2,5 | 1,25 | 97,0 | ~~119~~118 | 17,~~8~~7 | 32,3 | 57,~~4~~1 | 0,~~817~~821 |
| 40,5 | 2,5 | 1,25 | 103 | 124 | 18,~~6~~5 | 34,5 | ~~60,0~~59,7 | 0,~~833~~837 |
| 48,3 | 2,5 | 1,25 | 123 | 140 | 21,0 | 41,1 | 67,~~8~~5 | 0,~~878~~883 |
| 52 | 2,5 | 1,25 | 133 | ~~148~~147 | 22,~~2~~0 | 44,2 | 71,~~4~~0 | 0,~~898~~903 |
| 72,5 | 2,5 | 1,25 | 185 | ~~187~~185 | ~~28,0~~27,8 | 61,7 | ~~90,2~~89,5 | 0,~~992~~999 |

**Table 25 – Values of prospective TRV for out-of-phase tests on class S2 circuit-breakers for $k_{pp}$ = 2,0**

| $U_r$ kV | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|
| 3,6 | 2,0 | 1,25 | 7,35 | 18,~~2~~4 | 2,~~74~~76 | 2,45 | 8,~~82~~88 | 0,~~403~~400 |
| 4,76 | 2,0 | 1,25 | 9,72 | 22,~~2~~3 | 3,~~33~~35 | 3,24 | 10,~~7~~8 | 0,~~438~~435 |
| 7,2 | 2,0 | 1,25 | 14,7 | 29,~~6~~7 | 4,~~44~~46 | 4,90 | 14,~~3~~4 | 0,~~496~~494 |
| 8,25 | 2,0 | 1,25 | 16,8 | 32,~~6~~7 | 4,~~89~~91 | 5,61 | 15,8 | 0,~~517~~515 |
| 12 | 2,0 | 1,25 | 24,5 | 42,4 | 6,~~35~~36 | 8,16 | 20,5 | 0,~~578~~577 |
| 15 | 2,0 | 1,25 | 30,6 | 49,5 | 7,43 | 10,2 | 23,9 | 0,618 |
| 15,5 | 2,0 | 1,25 | 31,6 | 50,7 | 7,60 | 10,6 | 24,5 | 0,624 |
| 17,5 | 2,0 | 1,25 | 35,7 | 55,~~2~~1 | 8,~~28~~27 | 11,9 | 26,7 | 0,648 |
| 24 | 2,0 | 1,25 | 49,0 | 68,~~8~~7 | 10,3 | 16,3 | 33,~~3~~2 | 0,~~712~~713 |
| 25,8 | 2,0 | 1,25 | 52,7 | 72,~~4~~2 | 10,~~9~~8 | 17,6 | ~~35,0~~34,9 | 0,~~728~~729 |
| 27 | 2,0 | 1,25 | 55,1 | 74,~~4~~5 | 11,2 | 18,4 | 36,~~1~~0 | 0,~~737~~739 |
| 36 | 2,0 | 1,25 | 73,5 | 91,~~4~~0 | 13,7 | 24,5 | 44,~~2~~0 | 0,~~804~~807 |
| 38 | 2,0 | 1,25 | 77,6 | 94,~~9~~5 | 14,2 | 25,9 | 45,~~9~~7 | 0,~~817~~821 |
| 40,5 | 2,0 | 1,25 | 82,7 | ~~99,3~~98,8 | 14,~~9~~8 | 27,6 | ~~48,0~~47,8 | 0,~~833~~834 |
| 48,3 | 2,0 | 1,25 | 98,6 | 112 | 16,8 | 32,9 | 54,~~3~~0 | 0,~~878~~883 |
| 52 | 2,0 | 1,25 | 106 | 118 | 17,~~7~~6 | 35,4 | ~~57,2~~56,8 | 0,~~898~~903 |
| 72,5 | 2,0 | 1,25 | 148 | ~~149~~148 | 22,~~4~~2 | 49,3 | ~~72,1~~71,6 | 0,~~992~~999 |

**Table 26 – Values of prospective TRV for out-of-phase tests on circuit-breakers rated for $k_{pp}$ = 2,5 – Rated voltages of 100 kV to 170 kV**

| $U_r$ kV | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_1$ kV | $t_1$ µs | $u_c$ kV | $t_2$ or $t_3$ [a] µs | $t_d$ [a] µs | $u'$ kV | $t'$ [a] µs | $u_1/t_1$ $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 2,5 | 1,25 | 153 | 92 | 255 | 184-368 | 2-8 | 77 | 42-48 | 1,67 |
| 123 | 2,5 | 1,25 | 188 | 112 | 314 | 224-448 | 2-10 | 94 | 51-59 | 1,67 |
| 145 | 2,5 | 1,25 | 222 | 134 | 370 | 268-536 | 2-12 | 111 | 60-70 | 1,67 |
| 170 | 2,5 | 1,25 | 260 | 156 | 434 | 312-624 | 2-14 | 130 | 70-82 | 1,67 |

[a] The values of times $t_2$, $t_d$ and $t'$ indicate the lower and upper limits which should be used for testing. The time delay $t_d$ and the time $t'$ during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.

**Table 27 – Values of prospective TRV for out-of-phase tests on circuit-breakers rated for $k_{pp}$ = 2,0 – Rated voltages of 100 kV and above**

| $U_r$ kV | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_1$ kV | $t_1$ µs | $u_c$ kV | $t_2$ or $t_3$ [a] µs | $t_d$ [a] µs | $u'$ kV | $t'$ [a] µs | $u_1/t_1$ $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 2 | 1,25 | 122 | 80 | 204 | 160-320 | 2-8 | 61 | 42-48 | 1,54 |
| 123 | 2 | 1,25 | 151 | 98 | 251 | 196-392 | 2-10 | 75 | 51-59 | 1,54 |
| 145 | 2 | 1,25 | 178 | 116 | 296 | 232-464 | 2-12 | 89 | 60-70 | 1,54 |
| 170 | 2 | 1,25 | 208 | 136 | 347 | 272-544 | 2-14 | 104 | 70-82 | 1,54 |
| 245 | 2 | 1,25 | 300 | 196 | 500 | 392-784 | 2-20 | 150 | 99-117 | 1,54 |
| 300 | 2 | 1,25 | 367 | 238 | 612 | 476-952 | 2-24 | 184 | 121-143 | 1,54 |
| 362 | 2 | 1,25 | 443 | 288 | 739 | 576-1 152 | 2-29 | 222 | 146-173 | 1,54 |
| 420 | 2 | 1,25 | 514 | 334 | 857 | 668-1 336 | 2-33 | 257 | 169-200 | 1,54 |
| 550 | 2 | 1,25 | 674 | 438 | 1 123 | 876-1 752 | 2-44 | 337 | 221-263 | 1,54 |
| 800 | 2 | 1,25 | 980 | 636 | 1 633 | 1 272- 2 544 | 2-64 | 490 | 320-382 | 1,54 |
| 1 100 | 2 | 1,25 | - | - | 2 245 | 1 458 | 2-73 | 748 | 488-559 | 1,54 |
| 1 200 | 2 | 1,25 | - | - | 2 449 | 1 590 | 2-80 | 816 | 532-610 | 1,54 |

[a] The values of times $t_2$, $t_d$ and $t'$ indicate the lower and upper limits which should be used for testing. The time delay $t_d$ and the time $t'$ during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.



### 7.105.6 Multipliers for TRV for second and third clearing poles

The TRV is defined for the first-pole-to-clear. In order to obtain the values of RRRV and $u_c$ for the second and third clearing poles, a multiplier shall be applied to the values of RRRV and $u_c$ of the first clearing pole at the relevant first-pole-to-clear factor. The values of these multipliers are given in Table 14.

The multipliers of Table 14 have been calculated with the assumptions given in IEC TR 62271-306 [4].

For three-phase testing the test circuit shall be designed to achieve the prospective $u_c$ values for the second and third clearing poles. It is not necessary to meet the prospective RRRV values for the second and third clearing poles. The actual values shall be stated in the test report.

## 7.106 Short-circuit test procedure

### 7.106.1 Time interval between tests

The time intervals between individual operations of a test sequence shall be the time intervals of the rated operating sequence of the circuit-breaker, given in 5.104. For the make-break tests 7.106.3 applies. If, due to test plant limitations, the rated operating sequence cannot be achieved, the following applies:

a) The test shall be performed with the shortest achievable time interval $t'$. The time interval achieved shall be stated in the report. For time intervals longer than 10 min the reason for the delay shall be stated in the report;

b) For different time intervals $t$ the following applies:

   1) $t$ = 0,3 s: the time interval is mandatory;

2) $t \geq 15$ s, procedure a) applies.

Prolonged time intervals shall not be due to faulty operation of the circuit-breaker.

### 7.106.2 Application of auxiliary power to the opening release – Breaking tests

Auxiliary power shall be applied to the opening release after the initiation of the short-circuit, but when due to test plant limitations this is impracticable the power can be applied before the initiation of the short-circuit (with the limitation that contacts shall not start to move before the initiation of the short-circuit).

### 7.106.3 Application of auxiliary power to the opening release – Make-break tests

In make-break tests the auxiliary power shall not be applied to the opening release before the circuit-breaker has reached the closed position. In the close-open operations of the short-circuit test-duties the power shall not be applied until at least one half-cycle has elapsed from the instant of contact touch. The close-open time shall remain as close as possible to the minimum close-open time declared by the manufacturer, but it is permissible to delay the circuit-breaker opening such that the level of asymmetry is within the permissible limit.

### 7.106.4 Latching on short-circuit

A circuit-breaker is latched when the main current-carrying contacts have achieved a stationary, fully engaged position at closing and this position is maintained until intentionally released, either mechanically or electrically. Unless the circuit-breaker is fitted with a making current release, or equivalent device, it shall be verified that it latches satisfactorily without undue hesitation when there is negligible decrement of the AC component of the current during the closing period.

The ability of the circuit-breaker to latch on short-circuit making current can be verified in test-duty T100s (see 7.107.5) or in the verification test for making (see 7.102.4.1). During this test the following applies:

– for three-phase tests on a three-pole circuit-breaker, the closing angle should be chosen in order to stress the pole most remote from the drive with the peak making current;
– if a single-phase test is carried out, care should be taken to stress the pole most remote from the mechanism in the same way as during a three-phase test in respect to applied voltage across the pole and current through the pole.

If the characteristics of the test plant are such that it is impossible to carry out test-duty T100s within the specified limits of the applied voltage stated in 7.105.1, the test shall be repeated at reduced voltage using a test circuit which gives the rated short-circuit making current, with negligible decrement of the AC component.

Several methods can be used to establish whether a circuit-breaker has closed and latched, for example:

– by recording of the auxiliary contacts or the contact travel;
– by visually checking the latching position after the performance of the making test;
– by recording the action of the device in order to detect latching (for example a micro-switch suitably fitted to the mechanism).

The method employed to prove satisfactory latching shall be recorded in the test report.

### 7.107 Terminal fault tests

#### 7.107.1 General

The terminal fault tests shall consist of test-duties T10, T30, T60, T100s and T100a, as specified below. Tests carried out with rapid auto-reclosing sequence cover testing without rapid auto-reclosing.

In the cases explained in 7.106.4, it can be necessary to separate the making and breaking tests of test-duty T100s. In this case, the part consisting of the making operations is designated T100s(a) and the part consisting of the breaking operations is designated T100s(b).

The peak short-circuit current during the breaking-current tests of test-duties T100s, T100s(b) and T100a shall not exceed 110 % of the rated short-circuit making current of the circuit-breaker.

For convenience of testing the making operations of test-duties T10, T30 and T60 can be performed as no-load operations. The time intervals between the individual breaking operations, shall be the time intervals of the rated operating sequence of the circuit-breaker (see 7.106.1).

#### 7.107.2 Test-duty T10

Test-duty T10 consists of the rated operating sequence at 10 % of the rated short-circuit breaking current with a DC component at contact separation not exceeding 20 % and a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.5 (see also Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21).

#### 7.107.3 Test-duty T30

Test-duty T30 consists of the rated operating sequence at 30 % of the rated short-circuit breaking current with a DC component at contact separation not exceeding 20 % and a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.4 (see also Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21).

#### 7.107.4 Test-duty T60

Test-duty T60 consists of the rated operating sequence at 60 % of the rated short-circuit breaking current with a DC component at contact separation not exceeding 20 % and a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.3 (see also Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21).

#### 7.107.5 Test-duty T100s

##### 7.107.5.1 General

Test-duty T100s consists of the rated operating sequence at 100 % of the rated short-circuit breaking current taking account of 7.105.3, and with a transient and power frequency recovery voltage as specified in 7.103.4, 7.105.1 and 7.105.2 (see also Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21) and 100 % of the rated short-circuit making current taking account of 7.105.2 and an applied voltage as specified in 7.105.1.

For this test-duty, the percentage of the DC component at contact separation shall not exceed 20 % of the AC component.

When making single-phase tests on one pole of a three-pole circuit-breaker, or when the characteristics of the test plant are such that it is impossible to carry out test-duty T100s within the specified limits of applied voltage in 7.105.1, making current in 7.105.2, breaking current in 7.105.3 and transient and power frequency recovery voltages in 7.103.4 and 7.105.5.2 taking account also of 7.106.3 and 7.106.4 the making and breaking tests in test-duty T100s can be made separately. The short-circuit current in the separate making operations shall be maintained for an interval of at least 100 ms.

#### 7.107.5.2 Time constant of the DC component of the test circuit equal to the specified value

Where the time constant of the DC component of the test circuit is equal to the specified value as defined by 5.101.3, the alternative for performing test-duty T100s described above is as follows:

a) making tests, test-duty T100s(a)

The sequence C – $t'$ – C shall be carried with one making operation against a symmetrical current equal to the rated short-circuit breaking current and the other making operation against the rated short-circuit making current according to 7.105.2. The making operation against symmetrical current shall be carried out at the applied voltage specified in 7.105.1;

b) breaking tests, test-duty T100s(b)

These making operations detailed in a) shall be followed by O – $t$ – CO – $t'$ – CO at 100 % of the rated short-circuit breaking current and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2.

During this test sequence, the following applies:

– no maintenance is allowed between a) and b);

– the second making operation of a) can be omitted, provided that during b) one of the making operations is such that the rated short-circuit making current is achieved;

#### 7.107.5.3 Time constant of the DC component of the test circuit less than the specified value

Where the time constant of the DC component of the test circuit is less than the specified value as defined by 5.101.3, the alternative for performing test-duty T100s described above is as follows:

a) making tests, test-duty T100s(a)

A single closing operation against the rated short-circuit making current according to 7.105.2 shall be performed. This making operation can be performed at reduced voltage with the limitations stated in 7.105.2;

b) breaking tests, test-duty T100s(b)

This making operation shall be followed by O – $t$ – CO – $t'$ – CO at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 7.105.1 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. In this second part, one of the making operations shall be such that it closes against a symmetrical current equal to the rated short-circuit breaking current.

NOTE Due to the smaller time constant of the DC component of the test circuit with respect to the specified value used for the rated short-circuit breaking current, the symmetrical value of the current during a) will need to be greater than the rated value. During b), for the same reason, the current peak, already demonstrated during a), will be smaller than the rated short-circuit making current.

During this test sequence the following applies:

– no maintenance is allowed between a) and b);

– for synthetic testing IEC 62271-101 applies.

#### 7.107.5.4 Time constant of the DC component of the test circuit greater than the specified value

Where the time constant of the DC component of the test circuit is greater than the specified value as defined by 5.101.3, the alternative for performing test-duty T100s described above is as follows:

a) Making tests, test-duty T100s(a)

   A single making operation against the rated short-circuit making current according to 7.105.2 shall be performed. This making operation can be performed at reduced voltage with the limitations stated in 7.105.2;

b) The sequence O – $t$ – CO – $t'$ – CO shall be carried out at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 7.105.1 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. During this sequence, one of the making operations shall be such that the circuit-breaker closes against a symmetrical current equal to the rated short-circuit breaking current, and the other against a full asymmetrical current. Due to the larger time constant of the DC component of the test circuit with respect to the specified value as per 5.101.3, the current peak during the asymmetrical making will be larger than the rated short-circuit making current. Therefore, the making operation can be controlled by use of point-on-wave control to obtain the required rated short-circuit making current. The performance of the test procedure a) is, however, subject to the consent of the manufacturer;

   NOTE 1 Because of the larger peak of the current during the asymmetrical making, a separate closing operation against the rated short-circuit making current according to 7.105.2 is not required.

c) Alternatively sequence b) can be performed with the first making operation against a symmetrical current equal to the rated short-circuit breaking current and the second making operation at no load, i.e. O – $t$ – CO – $t'$ – O at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 7.105.1 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2.

   In this case evidence of the ability of the circuit-breaker to perform the rated operating sequence will be demonstrated by repeating the test sequence b), with relevant requirements, and with a symmetrical current smaller than the rated short-circuit breaking current in such a manner that the rated short-circuit making current is obtained in one of the making operations. During this repeated duty, the making operations can be performed at reduced voltage with the limitations stated in 7.105.2.

   NOTE 2 Since the ability of the circuit-breaker to close against the rated short-circuit making current is proven during the repeated duty, a separate making operation against the rated short-circuit making current according to 7.105.2 is not required.

During this test sequence the following applies:

– where sequence c) is adopted, maintenance before repetition of the rated operating sequence is permitted;

#### 7.107.5.5 Significant decay of the AC component of the test circuit

Where the decay of the AC component of the test circuit is significant, it may be impossible to test the rated operating sequence without overstressing the circuit-breaker extensively. In such cases it is permitted to split the making and the breaking tests in test-duty T100s as follows, provided that the time constant of the AC component of the test circuit, corresponding to the decay of the AC component, is at least three times longer than the specified DC time constant of the system the circuit-breaker under test is intended to be used for:

a) Making tests, test-duty T100s(a)

   C – $t'$ – C

   with the making current as specified in 7.105.2 and the applied voltage as specified in 7.105.1. For the time interval between the individual tests 7.106.1 applies.

b) Breaking tests, test-duty T100s(b)

- The making operations of test-duty T100s(a) shall be followed by the testing sequence O – $t$ – CO – $t'$ – CO at 100 % of the rated short-circuit breaking current as specified in 7.105.3 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. For the time interval between the individual tests 7.106.1 applies.

  The operating sequence O – $t$ – CO can be demonstrated by two tests. In this case the following applies:

  In the first test the first breaking operation shall be tested at 100 % of the rated short-circuit breaking current as specified in 7.105.3 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. The subsequent making and breaking operations shall be tested with making current and applied voltage or breaking current and transient and power frequency recovery voltage respectively as close as possible to the values specified for test-duty T100s.

  In the second test an additional CO operating cycle shall be performed with the breaking operation at 100 % of the rated short-circuit current as specified in 7.105.3 and with the transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. This CO operating cycle shall be preceded by a no-load opening operation to complete the operating sequence O – $t$ – CO. For the C operation the provisions of 7.105.1 and 7.105.2 may be omitted, however, the making current and the applied voltage shall meet the specified values as close as possible.

  The operating cycle CO is demonstrated by another CO operating cycle where the breaking operation shall be performed at 100 % of the rated short-circuit current as specified in 7.105.3 and with the transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. For the making operation the provisions of 7.105.1 and 7.105.2 may be omitted, however, the making current and the applied voltage shall meet the specified values as close as possible.

- Where a making operation in test-duty T100s(b) fulfils the requirements given in a) above, the respective making operation in test-duty T100s(a) may be omitted. In order to not overstress the circuit-breaker controlled closing can be necessary in test-duty T100s(b). Where needed an auxiliary circuit-breaker can be used. If due to inconsistency of the opening or the closing time the specified test values cannot be met, it is allowed to supply the releases at their maximum operating voltage; in this case the provisions of 7.102.3.1 as to the supply voltage of closing and opening devices are omitted.

No maintenance is allowed between the test-duties T100s(a) and T100s(b). When this testing procedure results in actual stresses exceeding the limits specified in Table B.1 the consent of the manufacturer is necessary.

### 7.107.6 Test-duty T100a

Test-duty T100a is only applicable when the minimum opening time $T_{op}$ of the circuit-breaker, as stated by the manufacturer, plus the relay time is such that the DC component at the instant of contact separation is higher than 20 %. The DC component at contact separation is determined by the following equation:

$$\%\ DC = 100 \times e^{\frac{-(T_{op}+T_r)}{\tau}}$$

where

% DC percentage of DC component at contact separation;

$T_{op}$ minimum opening time declared by the manufacturer;

$T_r$ relay time (0,5 cycle; 10 ms for 50 Hz and 8,3 ms for 60 Hz);

$\tau$ DC time constant of the rated short-circuit current (45 ms, 60 ms, 75 ms or 120 ms, see 5.101.3).

Test-duty T100a consists of three valid breaking operations at 100 % of the rated short-circuit breaking current with the required asymmetry criteria regarding the peak and duration of the last major loop and the related arcing time conditions given in 7.104 and a transient and prospective power frequency recovery voltage under symmetrical conditions as specified in 7.103.4 and 7.105.5.2.

The change of an opening or a closing release does not constitute an alternative operating mechanism. If the opening time of the circuit-breaker is reduced, due exclusively to the use of a faster acting release, it should be checked whether the range of the minimum clearing time, as stated in Table 10 and Table 11 for this release, is still covered by tests performed with the initial release. If the circuit-breaker falls into a range with shorter minimum clearing times, it is sufficient to repeat test-duty T100a only for that range, the rest of the type tests remains valid, provided the release is tested to the relevant subclauses and standards.

## 7.108 Additional short-circuit tests

### 7.108.1 Critical current tests

#### 7.108.1.1 Applicability

These tests are short-circuit tests additional to the terminal fault test-duties covered by 7.107 and are applicable only to circuit-breakers which have a critical current. It shall be assumed that this is the case if the minimum arcing times in any of the test-duties T10, T30 or T60 is one half-cycle or more longer than the minimum arcing times in the adjacent test-duties. For three-phase tests the arcing times of all three phases shall be taken into account.

#### 7.108.1.2 Test current

Where applicable, the behaviour of the circuit-breaker with respect to the critical current shall be tested in two test-duties.

The test currents for these two test-duties shall be equal to the average of the breaking current corresponding to the test-duty in which the prolonged arcing times occurred (see 7.108.1.1) and:

a) the breaking current corresponding to the next higher breaking current for one test-duty; and
b) the breaking current corresponding to the next lower breaking current for the other test-duty.

In the case of prolonged arcing times in test-duty T10, the critical current tests shall be performed at a current of 20 % of the rated short-circuit breaking current for one test-duty and at a current of 5 % of the rated short-circuit breaking current for the other one.

#### 7.108.1.3 Critical current test-duty

The critical current test-duty consists of the rated operating sequence at the current according to 7.108.1.2 with a DC component at contact separation not exceeding 20 %. The transient and power frequency recovery voltage shall be that associated with the terminal fault test-duty having the breaking current the next higher to the critical current.

The critical current test-duty can be performed on a reconditioned circuit-breaker.

### 7.108.2 Single-phase and double-earth fault tests

#### 7.108.2.1 Applicability

Circuit-breakers shall be capable of clearing single-phase short-circuit currents which can occur in two different cases:

– in effectively earthed neutral systems in case of single-phase faults or,

– in non-effectively earthed neutral systems in case of double-earth faults, i.e. earth faults on two different phases, one of which occurs on one side of the circuit-breaker and the other one on the other side.

Depending on the neutral earthing condition of the system in which the circuit-breaker is intended to be used, on the circuit-breaker operating mechanism design (single-pole or three-pole operated) and on whether the circuit-breaker was tested single-phase or three-phase in test-duty T100s, additional single-phase breaking tests may be necessary (see Figure 47).

These tests are intended to demonstrate

– that the circuit-breaker is able to clear a single-phase fault current at relevant parameters;

– for circuit-breakers having a common operating mechanism for all three poles and being fitted with a common opening release, that the operation of the circuit-breaker is not adversely affected by unbalanced forces produced in the case of a single-phase fault current.

The test for single-phase fault shall be performed on an outer pole resulting in the maximum stress on the interpole coupling mechanism, while the test for double-earth fault can be performed on any pole.

NOTE If two single-phase tests are carried out on a circuit-breaker with a three-pole common operating mechanism, the test can be carried out on two different poles to prevent overstressing of one pole.

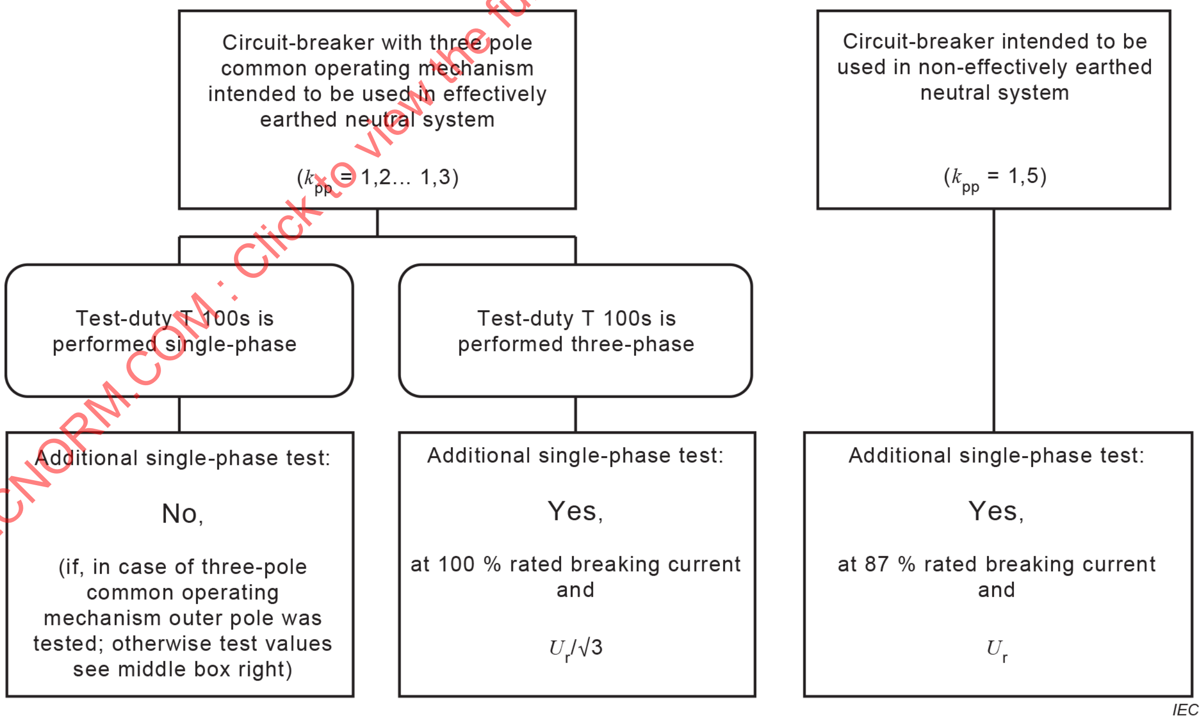



**Figure 47 – Necessity of additional single-phase tests and requirements for testing**

#### 7.108.2.2 Test current and recovery voltage

The breaking current and the recovery voltage for the additional single-phase breaking tests are as shown in Figure 47.

The DC component of the breaking current at contact separation shall not exceed 20 % of the AC component. The TRV shall meet the requirements of Items a), b) and c) of 7.105.5.1 with standard values derived from Table 16, Table 17, Table 18, Table 19, Table 20, and Table 21. The values to be used for single-phase and double-earth fault tests are given in Table 28 marked by the index (sp).

**Table 28 – Prospective TRV parameters for single-phase and double-earth fault tests**

| System neutral | Rated voltage | | | | | |
|---|---|---|---|---|---|---|
| | $U_r$ < 100 kV<br>2-parameter-TRV | | $U_r$ ≥ 100 kV<br>4-parameter-TRV | | | |
| | $u_{c,sp}$ | $t_{3,sp}$ | $u_{1,sp}$ | $t_{1,sp}$ | $u_{c,sp}$ | $t_{2,sp}$ |
| Effectively earthed | $k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $t_3 \times u_{c,sp} / u_c$ | $0{,}75 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $t_1 \times u_{1,sp} / u_1$ | $k_{af} \times u_{1,sp} / 0{,}75$ | [a] |
| Non-effectively earthed | $k_{af} \times \sqrt{2} \times U_r$ | | $0{,}75 \times \sqrt{2} \times U_r$ | | | |

[a] 4 × $t_{1,\ sp}$ for rated voltages from 100 kV up to and including 800 kV, 3 × $t_{1,\ sp}$ for rated voltages above 800 kV.

The other parameters are related to $u_{1,sp}$, $u_{c,sp}$, $t_{1,sp}$ and $t_{3,sp}$ as defined in 7.105.5.1 for test-duty T100. Where necessary, advantage can be taken of the provisions of 7.105.5.2 concerning test plant limitations.

#### 7.108.2.3 Test-duty

The test-duty for each of the two specified fault cases shall consist of one single breaking operation.

The arcing time during the breaking operation shall not be shorter than the following value $t_a$:

$$t_a \geq t_{a100s} + 0{,}7 \times T/2$$

where

$t_{a100s}$ – is the minimum of the arcing times of first-poles-to-clear during the three breaking operations of test-duty T100s, if terminal fault test-duty T100s is tested in three-phase;

– is the minimum arcing time of terminal fault test-duty T100s, if terminal fault test-duty T100s is tested in single-phase.

$T$ is the duration of one cycle of rated frequency.

If the minimum arcing time under the conditions of single-phase or double-earth fault tests is shorter than the minimum arcing time of terminal fault test-duty T100s by more than 0,1 × $T$, the test can be carried out at a shorter arcing time based on the following equation:

$$t_a \geq t_{a\ min\ single\text{-}phase} + 0{,}9 \times T/2$$

where

$t_{a\ min\ single\text{-}phase}$ is the minimum arcing time under the conditions of single-phase or double-earth fault tests.

NOTE It is not necessary to determine the minimum arcing time for single-phase or double-earth fault breaking tests. However, the manufacturer can show that under these conditions a shorter minimum arcing time than for T100s is achievable. Then testing can be done, as shown above, with this shorter minimum arcing time.

To reduce the amount of testing, it is allowed to replace the two applicable tests by one test, provided that both test conditions are met simultaneously. This allowance is permitted only with the consent of the manufacturer.

### 7.109 Short-line fault tests

#### 7.109.1 Applicability

A short-line fault breaking capability is required for circuit-breakers intended for direct connection to overhead lines, having a rated voltage equal to or higher than 15 kV and a rated short-circuit breaking current exceeding 12,5 kA.

Short-line fault tests are short-circuit tests additional to the terminal fault test-duties covered by 7.107. These tests shall be made to determine the ability of a circuit-breaker to break short-circuit currents under short-line fault conditions characterised by a TRV as a combination of the source and the line side components.

The short-line fault current is the maximum current that the circuit-breaker shall be capable of breaking under the conditions of use and behaviour required in this document in a circuit having a recovery voltage as specified in 7.109.

#### 7.109.2 Test current

The test current shall take into account the source and line side impedances. The source side impedance shall be that corresponding to approximately 100 % rated short-circuit breaking current $I_{sc}$ and the phase-to-earth value of the rated voltage $U_r$.

Standard values of the line side impedance are specified corresponding to a reduction of the AC component of the rated short-circuit breaking current to:

– 90 % ($L_{90}$) and 75 % ($L_{75}$) for circuit-breakers with a rated voltage higher than 52 kV;
– 75 % ($L_{75}$) for circuit-breakers with a rated voltage of 15 kV up to and including 52 kV.

In a test, the line length represented on the line side of a circuit-breaker can differ from the length of the line corresponding to currents equal to 90 % and 75 % of the rated short-circuit breaking current.

For rated voltages higher than 52 kV, tolerances on these standardised lengths are –20 % and 0 % for tests at 90 % of the rated short-circuit breaking current and ±20 % for tests at 75 % of the rated short-circuit breaking current.

For rated voltages higher than 12 kV and up to and including 52 kV, tolerances on these standardised lengths are 0 % and –20 % for tests at 75 % of the rated short-circuit breaking current.

These tolerances for the line lengths give the following deviations of the short-circuit currents:

- $L_{90}$ at 0 % deviation: $I_L$ = 90 % of $I_{sc}$;
- $L_{90}$ at –20 % deviation: $I_L$ = 92 % of $I_{sc}$;
- $L_{75}$ at +20 % deviation: $I_L$ = 71 % of $I_{sc}$;
- $L_{75}$ at 0 % deviation: $I_L$ = 75 % of $I_{sc}$;
- $L_{75}$ at –20 % deviation: $I_L$ = 79 % of $I_{sc}$.

For the case stated in 7.109.4, item c) another test ($L_{60}$) at 60 % of the rated short-circuit breaking current is required. The tolerance on the corresponding standardised line length is ±20 %. This results in the following deviations of the short-circuit current:

- $L_{60}$ at +20 % deviation: $I_L$ = 55 % of $I_{sc}$;
- $L_{60}$ at –20 % deviation: $I_L$ = 65 % of $I_{sc}$.

For further information see IEC TR 62271-306.

### 7.109.3 Test circuit

The test circuit shall be single-phase and consists of a supply circuit and a line circuit (see Figure 48, Figure 49 and Figure 50). The source side TRV shall be based on a $k_{pp}$ of 1,0. The values of line characteristics are given in Table 29. The basic requirements are:

- values of the RRRV factor, based on the line surge impedance $Z$, the peak factor $k$ and the line side time delay $t_{dL}$ are given in Table 29. For determination of the line side time delay and the rate-of-rise of the line side voltage, see Figure 46 and Figure 51;
- the method for calculation of TRVs from the characteristics is given in Annex A.

**Table 29 – Values of line characteristics for short-line faults**

| Rated voltage | Surge impedance | Peak factor | RRRV factor 50 Hz | RRRV factor 60 Hz | Time delay |
|---|---|---|---|---|---|
| $U_r$<br>kV | $Z$<br>Ω | $k$ | $s$[b]<br>kV/μskA | | $t_{dL}$<br>μs |
| 15 ≤ $U_r$ ≤ 48,3 | 450 | 1,6 | 0,200 | 0,240 | 0,1 |
| 52 ≤ $U_r$ ≤ 170 | 450 | 1,6 | 0,200 | 0,240 | 0,2 |
| 245 ≤ $U_r$ ≤ 800 | 450 | 1,6 | 0,200 | 0,240 | 0,5 |
| $U_r$ > 800 | 330 [a] | 1,6 | 0,147 | 0,176 | 0,5 |

[a] A value of 450 Ω can be used during testing to cover ITRV requirements.

[b] For the RRRV factor $s$, see Annex A.

NOTE These values cover the short-line faults dealt with in this document. For very short lines ($t_L$ < 5$t_{dL}$) not all requirements as given in the table can be met. The procedures for approaching very short lines are given in IEC TR 62271-306 [4].

Regarding the time delays on the source side and on the line side and the ITRV (see 7.105.5), two main requirements are specified and shall be distinguished:

a) source side: with time delay ($t_d$) and without ITRV;

line side: with time delay ($t_{dL}$);

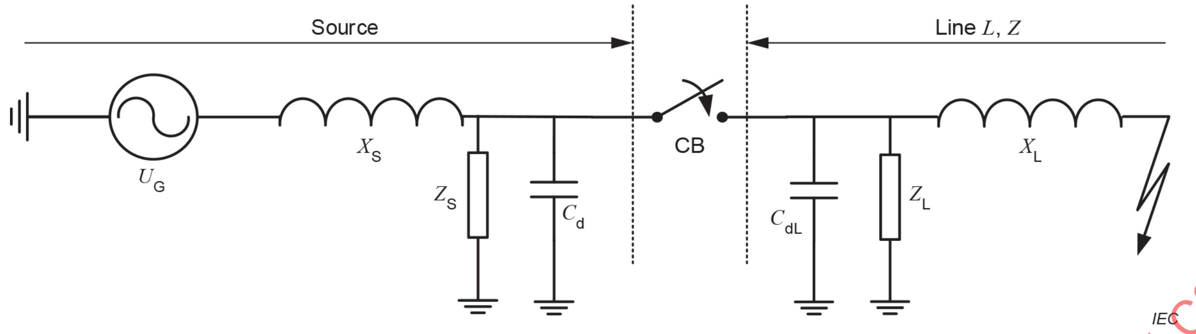
b1) source side: with ITRV;

line side: with time delay ($t_{dL}$);

b2) source side: with time delay ($t_d$);

line side: with a time delay less than 100 ns ($t_{dL}$).

The representation of the ITRV on the source side can be neglected if a line side oscillation with a time delay less than 100 ns is used.




| | | | |
|---|---|---|---|
| $U_G$ | Supply voltage, phase to earth value | $X_L$ | Power frequency line side reactance |
| $X_S$ | Power frequency source side reactance | $Z_L$ | Line side TRV controlling components |
| $Z_S$ | Source side TRV controlling components | $C_{dL}$ | Time delaying line side capacitance |
| $C_d$ | Time delaying source side capacitance | $Z$ | Surge impedance of line |
| CB | Circuit-breaker | $L$ | Length of line to fault |

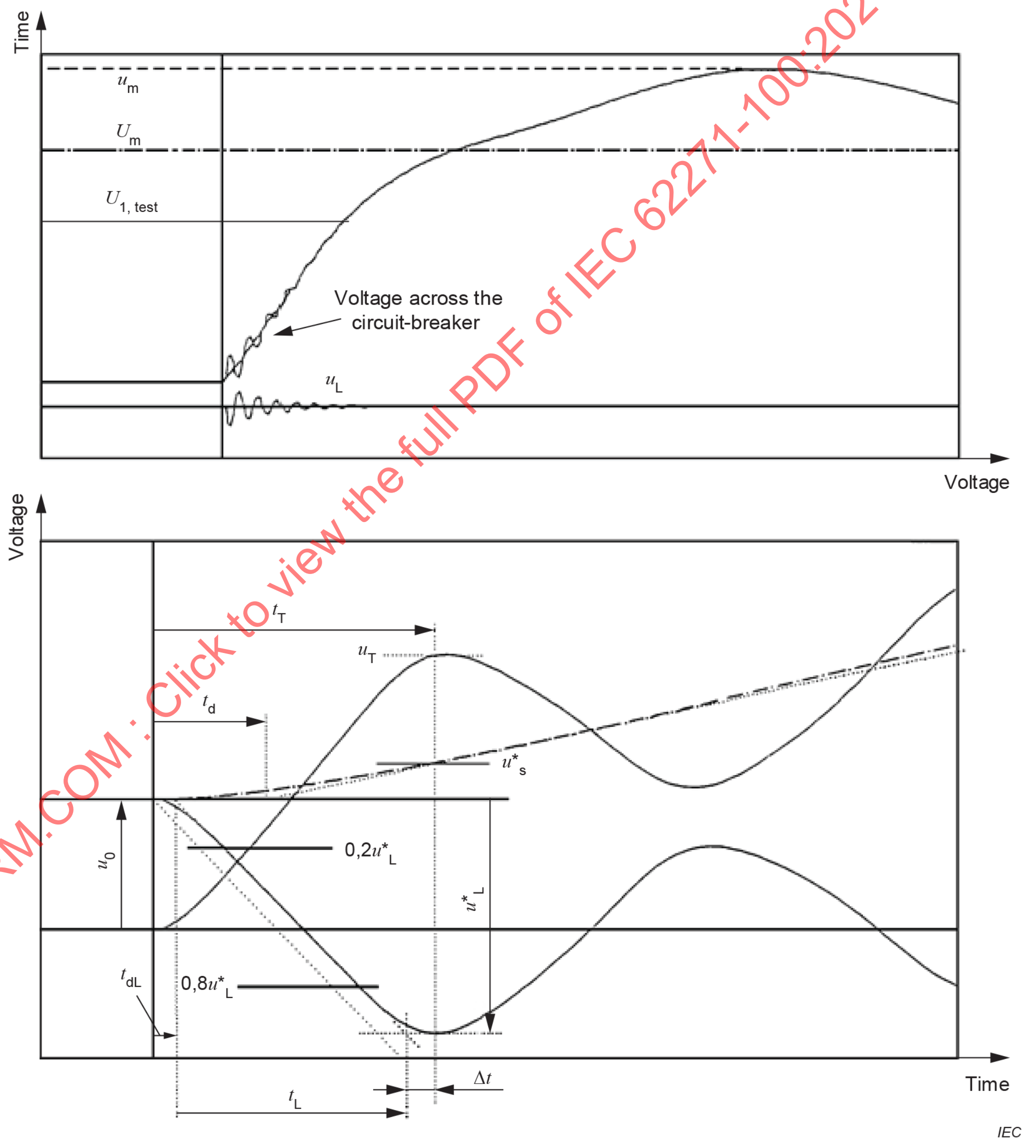
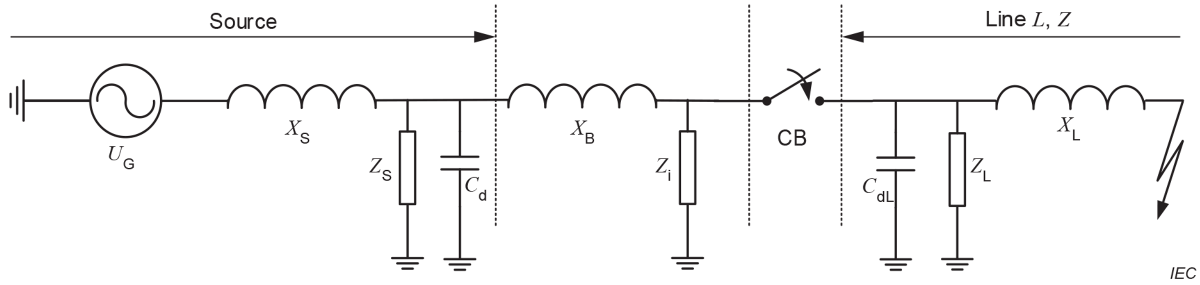



**Figure 48 – Basic circuit arrangement for short-line fault testing and prospective TRV-circuit-type a) according to 7.109.3: Source side and line side with time delay**




| | | | |
|---|---|---|---|
| $U_G$ | Supply voltage, phase to earth value | $Z_i$ | ITRV controlling components |
| $X_S$ | Power frequency source side reactance | $X_L$ | Power frequency line side reactance |
| $Z_S$ | Source side TRV controlling components | $Z_L$ | Line side TRV controlling components |
| $C_d$ | Time delaying source side capacitance | $C_{dL}$ | Time delaying line side capacitance |
| CB | Circuit-breaker | $Z$ | Surge impedance of line |
| $X_B$ | Power frequency busbar reactance | $L$ | Length of line to fault |

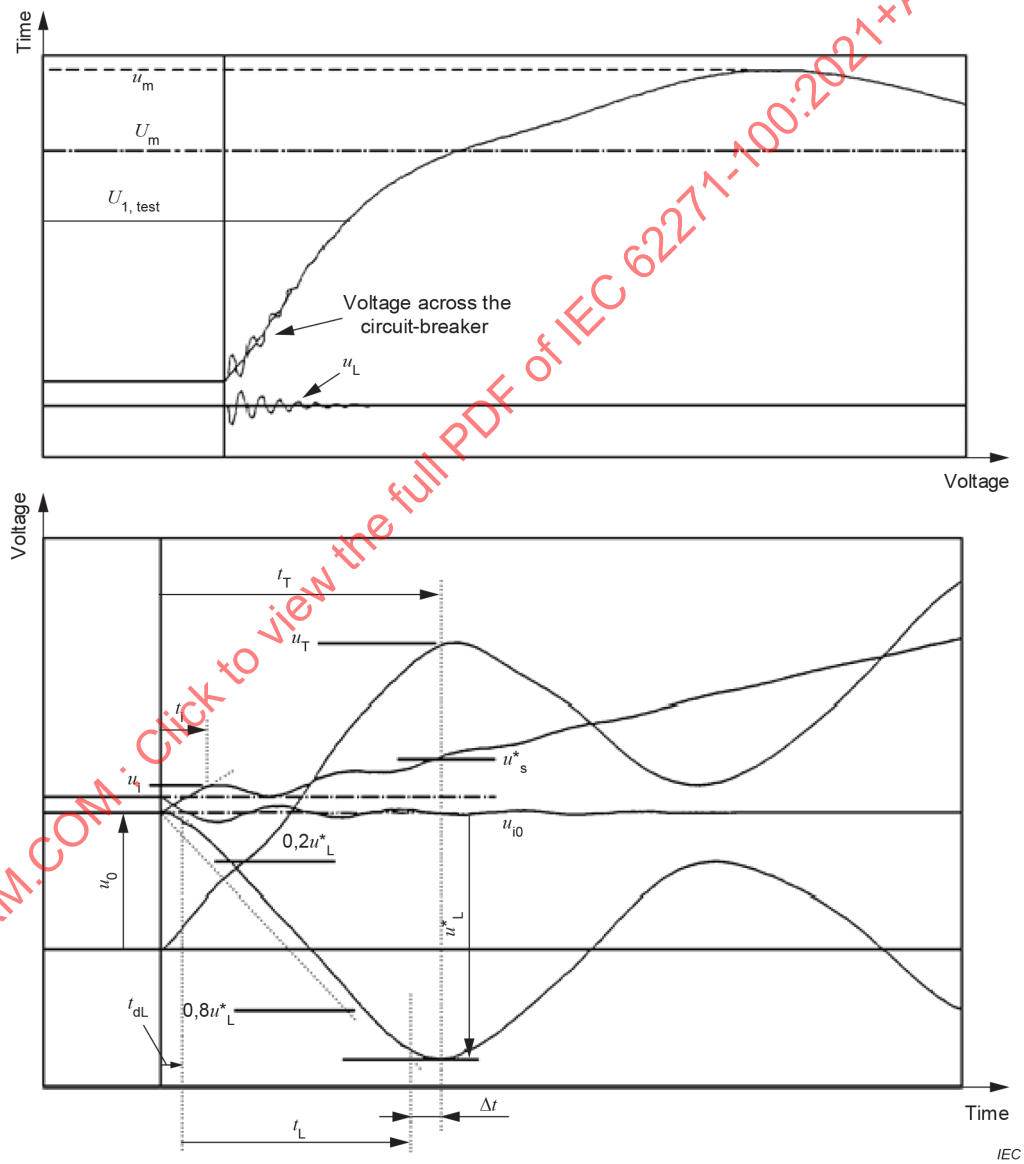
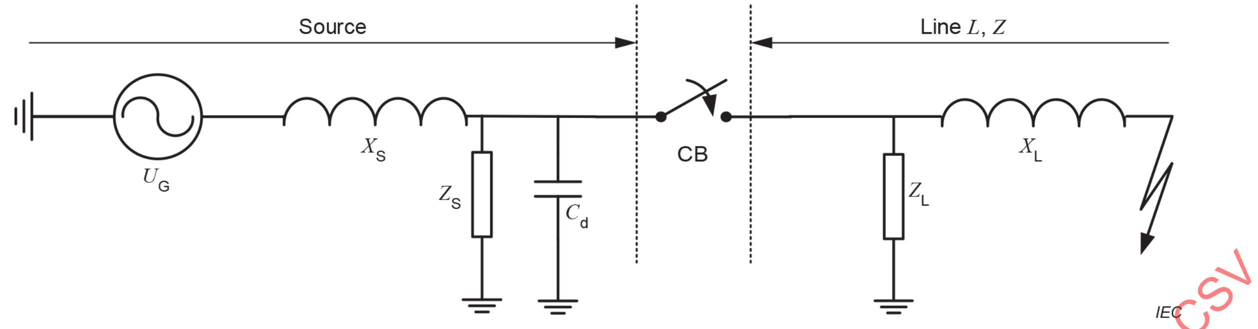



**Figure 49 – Basic circuit arrangement for short-line fault testing – circuit type b1) according to 7.109.3: Source side with ITRV and line side with time delay**




| | | | |
|---|---|---|---|
| $U_G$ | Supply voltage, phase to earth value | $X_L$ | Power frequency line side reactance |
| $X_S$ | Power frequency source side reactance | $Z_L$ | Line side TRV controlling components |
| $Z_S$ | Source side TRV controlling components | $Z$ | Surge impedance of line |
| $C_d$ | Time delaying source side capacitance | $L$ | Length of line to fault |
| CB | Circuit-breaker | | |

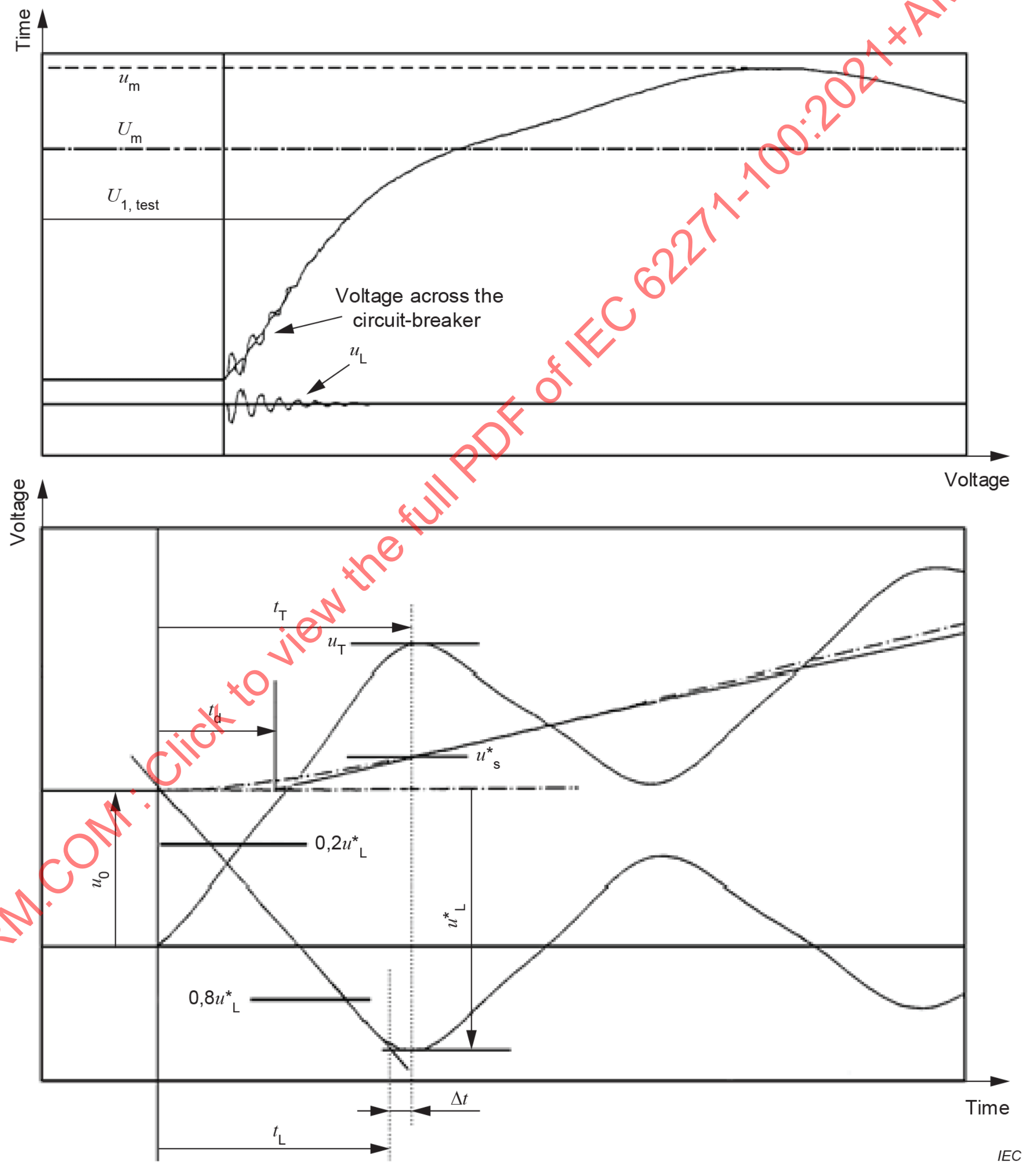



**Figure 50 – Basic circuit arrangement for short-line fault testing – circuit type b2) according to 7.109.3: Source side with time delay and line side without time delay**

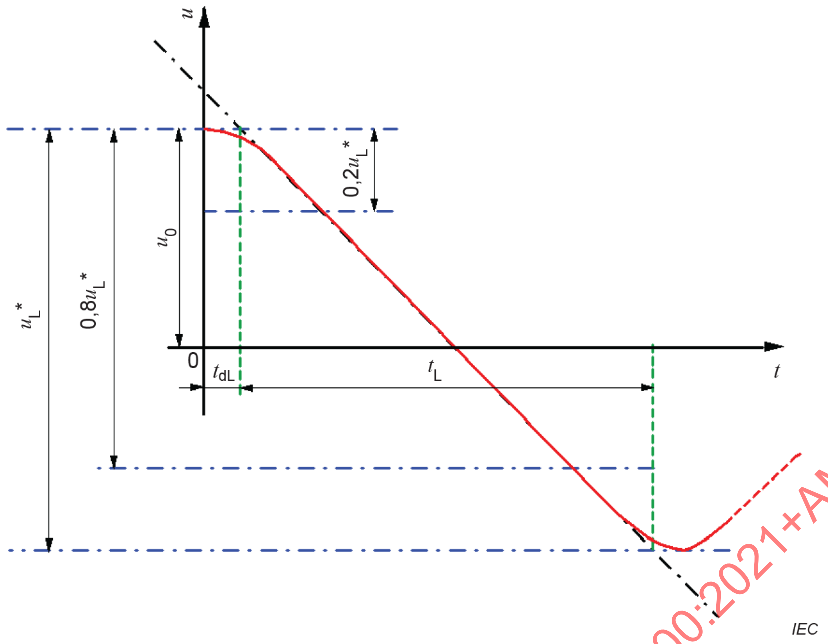



**Figure 51 – Example of a line side transient voltage with time delay**

Figure 46 shows the determination of the line side time delay in case of a non-linear rate of rise.

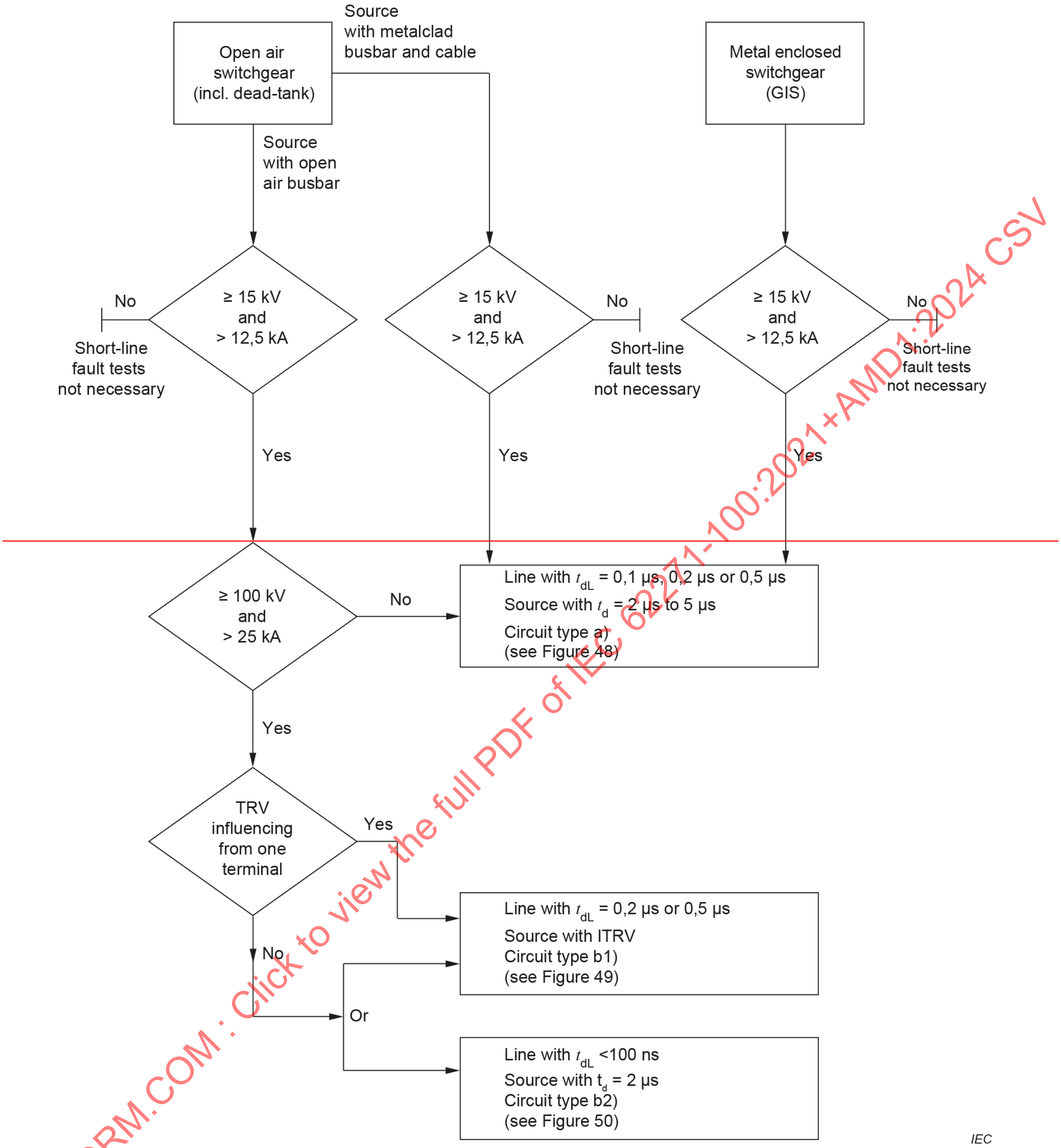
The line side time delay is defined as the time between the origin and the point where the tangent of the straight line drawn through $0,2u_L$ and $0,8u_L$ crosses the zero line (see Figure 51). See also 7.3.1.1 of IEC TR 62271-306:2012.

Taking this into account, three types of test circuits characterised by their time delays are applicable for testing:

- circuit SLF a): source side with time delay ($t_d$) and line side with time delay ($t_{dL}$) (see A.4.2); circuit shown in Figure 48;
- circuit SLF b1): source side with ITRV and line side with time delay ($t_{dL}$) (see A.4.3); circuit shown in Figure 49;
- circuit SLF b2): source side with time delay ($t_d$) and line side with a time delay less than 100 ns ($t_{dL}$); circuit shown in Figure 50.

Circuit a) shall only be used in the case where no ITRV requirements apply. Circuit b2) can be used as a substitute for the circuit b1) unless both terminals are not identical from an electrical point of view.

For the choice of test circuit, see flow chart diagram, Figure 52.


Open air
switchgear
(incl. dead-tank)
Source
with metalclad
busbar and cable
Metal enclosed
switchgear
(GIS)
Source
with open
air busbar
≥ 15 kV
and
> 12,5 kA
No
Short-line
fault tests
not necessary
Yes
≥ 100 kV
and
> 25 kA
Line with $t_{dL}$ = 0,1 µs, 0,2 µs or 0,5 µs
Source with $t_d$ = 2 µs to 5 µs
Circuit type a)
(see Figure 48)
TRV
influencing
from one
terminal
Line with $t_{dL}$ = 0,2 µs or 0,5 µs
Source with ITRV
Circuit type b1)
(see Figure 49)
Or
Line with $t_{dL}$ <100 ns
Source with $t_d$ = 2 µs
Circuit type b2)
(see Figure 50)
IEC

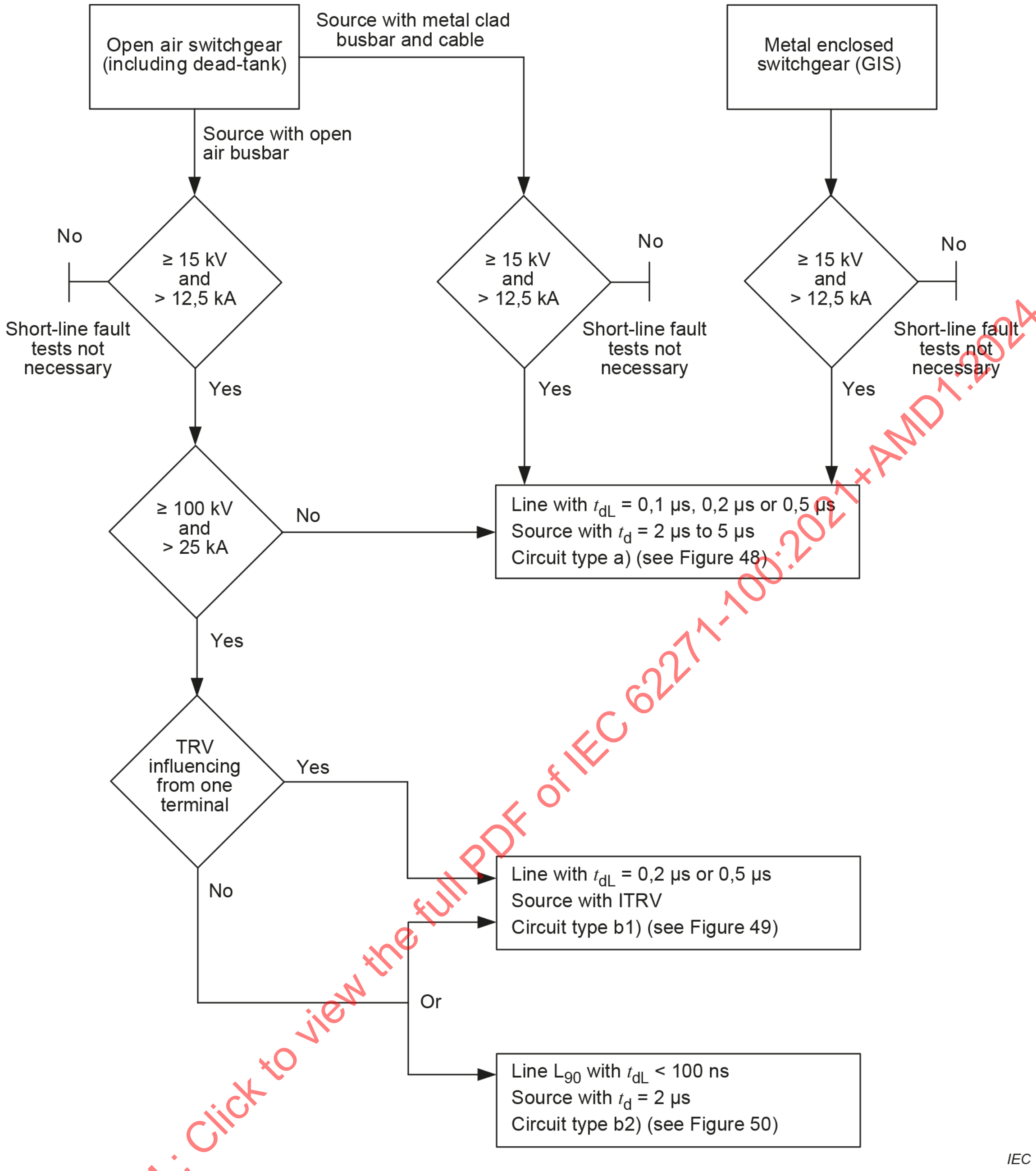



**Figure 52 – Flow chart for the choice of short-line fault test circuits**

Other characteristics of the source side and the line side of the test circuit shall be in line with the explanations and calculations given in Annex A.

Where applicable, a circuit-breaker with rated voltage higher than 800 kV can be tested with a line having a time delay less than 100 ns and a surge impedance of 450 Ω (see 7.105.5.1). If the circuit-breaker fails during this test procedure after a time corresponding to the first peak of ITRV, the test can be repeated with the required test circuit having the specified ITRV and a line having a surge impedance of 330 Ω and the specified time delay ($t_{dL}$). For both cases it is not required to perform T100s and T100a with circuits reproducing the rated ITRV.

If the TRV requirements of the source side cannot be met due to testing station limitations, a deficiency of the time delay of the source side TRV can be compensated by an increase of the excursion of the line side voltage. The increased value $u_{L,mod}{}^*$ is calculated as follows (see also Figure 46, Figure 51 and Figure 53):

$$t_d < t'_d \le t_L \quad u_{L,mod}{}^* = u_L{}^* + L_f \times RRRV \times (t'_d - t_d)$$

$$t_d < t_L \le t'_d \quad u_{L,mod}{}^* = u_L{}^* + L_f \times RRRV \times (t_L - t_d)$$

where

$RRRV$ is the required rate of rise of recovery voltage of the source side (kV/µs);

$L_f$ is the SLF current factor $I_L/I_{sc}$ (0,9 or 0,75 or 0,6);

$t_d$ is the required time delay of the source side (µs);

$t'_d$ is the actual time delay of the source side (µs);

$t_L$ is the time to the peak voltage $u_L{}^*$ of the line side transient voltage (µs);

$u_L{}^*$ is the required peak voltage across the line (kV);

$u_{L,mod}{}^*$ is the adjusted peak voltage across the line (kV).

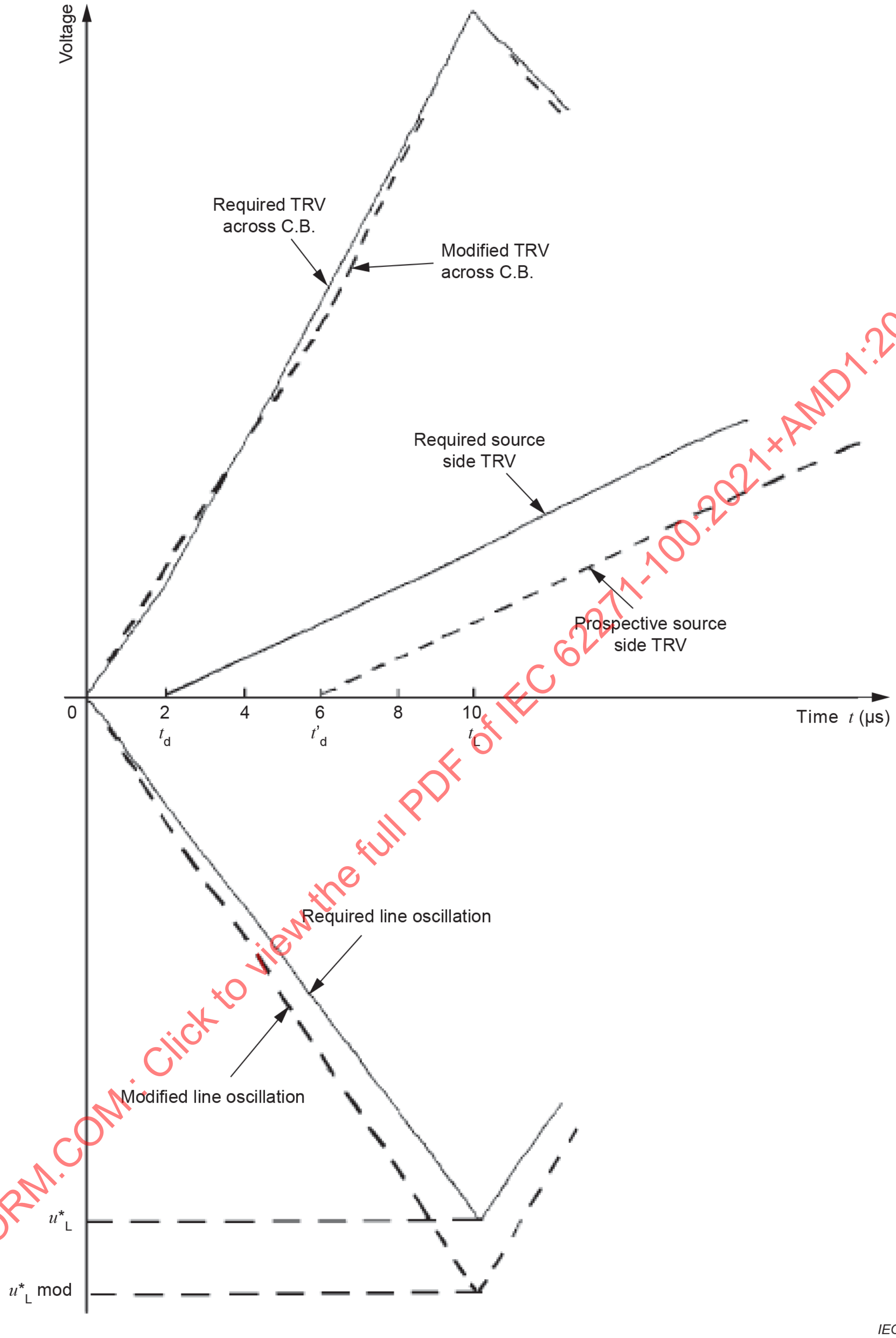





**Figure 53 – Compensation of deficiency of the source side time delay by an increase of the excursion of the line side voltage**

If the tests are carried out on a circuit-breaker with one terminal earthed, as may be the case during synthetic testing, measurements or calculations of voltage distribution factors of line and source side oscillations shall be carried out. The higher stressed making and breaking unit from the line side oscillation is the lower stressed making and breaking unit from the source side oscillation. It is recognised that the more significant stress is due to the line. The voltage distribution factors shall be as follows:

– unit tests: factors calculated or measured on the line side making and breaking unit;
– multi-unit tests: factors calculated or measured on the multi-making and breaking unit next to the line-side. Attention should be paid that the factors to be applied do not overstress the circuit-breaker because of the voltage distribution within the multi-making and breaking unit. A new measurement or calculation can be required for the portion to be tested.

The measurement of the prospective TRV shall be carried out with the line connected to the actual circuit in order to take into account all the effects due to voltage dividers, stray capacitances and inductances of the test circuit.

An extra capacitance can be applied at the line side or at the source side of the circuit-breaker or across the circuit-breaker in order to adjust the time delays of the individual sections of the test circuit.

NOTE 2 The term “actual” is used as distinct from the nominal value (90 %, 75 % or 60 %); the use of prospective short-circuit breaking current in accordance with 7.105.3 is not precluded.

NOTE 3 If an extra capacitance is applied in order to adjust the time delay of the line to the standard value given in Table 29 the rate of rise of the line side TRV will reach its standard value ($du_L/dt = -s \times I_L$) after the decay of the delaying effect of this extra capacitance.

Where the breaking capability of the circuit-breaker is not sufficient to interrupt a short-line fault, an additional capacitance at the line side of the circuit-breaker or parallel to the making and breaking unit(s) can be used, both during the test and in service. In this way, the stress on the circuit-breaker is facilitated. The value and the location of this additional capacitance used during the tests shall be stated in the test report.

For a large additional capacitance, the surge impedance of the line and the line side time delay may seem to be reduced, caused by the effect of this additional capacitance. However, the correct value of the surge impedance of the line itself (in advance adjusted in accordance with the standard values given in Table 29) remains unchanged. Since the period of the decay of the delaying effect of the additional capacitance can be longer than the time to the first peak of the line side TRV, the lower rate of rise at the rising slope of the TRV may be misinterpreted as a decreased surge impedance of the line. Therefore, the values of the time delay and the surge impedance evaluated for the line in connection with the additional capacitance are not relevant to the test.

The test report should show the specified TRV appropriate to the rating of the circuit-breaker, and, for comparative purposes, the prospective TRV of the test circuit used.

#### 7.109.4 Test-duties

The short-line fault tests shall be single-phase tests. The series of test-duties is specified below. Each test-duty consists of the rated operating sequence. For convenience of testing, the making operations can be performed as no-load operations.

The test circuit shall be in accordance with 7.109.3.

The prospective TRV of the supply circuit shall be in accordance with Table 30.

**Table 30 – Values of prospective TRV for the supply circuit of short-line fault tests**

| $U_r$<br>kV | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_1$<br>kV | $t_1$<br>µs | $u_c$<br>kV | $t_2$ or $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_1/t_1$<br>$u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 1 | 1,54 | - | - | 18,9 | 20,6 | 1,03 | 6,29 | 7,91 | 0,914 |
| 15,5 | 1 | 1,54 | - | - | 19,5 | 21,1 | 1,06 | 6,50 | 8,~~09~~10 | 0,923 |
| 17,5 | 1 | 1,54 | - | - | 22,0 | 23,0 | 1,15 | 7,33 | 8,81 | 0,~~957~~958 |
| 24 | 1 | 1,54 | - | - | 30,2 | 28,~~7~~6 | 1,43 | 10,1 | 11,0 | 1,05 |
| 25,8 | 1 | 1,54 | - | - | 32,4 | 30,~~2~~1 | 1,~~51~~50 | 10,8 | 11,~~6~~5 | 1,08 |
| 27 | 1 | 1,54 | - | - | 34,0 | 31,1 | 1,~~56~~55 | 11,3 | 11,9 | 1,09 |
| 36 | 1 | 1,54 | - | - | 45,3 | ~~38,1~~37,9 | 1,90 | 15,1 | 14,~~6~~5 | 1,19 |
| 38 | 1 | 1,54 | - | - | 47,8 | 39,~~6~~4 | 1,~~98~~97 | 15,9 | 15,~~2~~1 | 1,21 |
| 40,5 | 1 | 1,54 | - | - | 50,9 | 41,~~4~~2 | 2,~~07~~06 | 17,0 | 15,~~9~~8 | 1,~~23~~24 |
| 48,3 | 1 | 1,54 | - | - | 60,7 | 46,~~8~~5 | 2,~~34~~33 | 20,2 | 17,~~9~~8 | 1,~~30~~31 |
| 52 | 1 | 1,54 | - | - | 65,4 | 49,~~3~~0 | 2,~~46~~45 | 21,8 | 18,~~9~~8 | 1,33 |
| 72,5 | 1 | 1,54 | - | - | 91,2 | ~~62,2~~61,7 | 3,~~11~~09 | 30,4 | 23,~~8~~7 | 1,~~47~~48 |
| 100 | 1 | 1,40 | 61 | 31 | 114 | 124 | 2 | 31 | 17 | 2 |
| 123 | 1 | 1,40 | 75 | 38 | 141 | 152 | 2 | 38 | 21 | 2 |
| 145 | 1 | 1,40 | 89 | 44 | 166 | 176 | 2 | 44 | 24 | 2 |
| 170 | 1 | 1,40 | 104 | 52 | 194 | 208 | 2 | 52 | 28 | 2 |
| 245 | 1 | 1,40 | 150 | 75 | 280 | 300 | 2 | 75 | 40 | 2 |
| 300 | 1 | 1,40 | 184 | 92 | 343 | 368 | 2 | 92 | 48 | 2 |
| 362 | 1 | 1,40 | 222 | 111 | 414 | 444 | 2 | 111 | 57 | 2 |
| 420 | 1 | 1,40 | 257 | 129 | 480 | 516 | 2 | 129 | 66 | 2 |
| 550 | 1 | 1,40 | 337 | 168 | 629 | 672 | 2 | 168 | 86 | 2 |
| 800 | 1 | 1,40 | 490 | 245 | 914 | 980 | 2 | 245 | 124 | 2 |
| 1 100 | 1 | 1,50 | 674 | 337 | 1 347 | 1 011 | 2 | 337 | 170 | 2 |
| 1 200 | 1 | 1,50 | 735 | 367 | 1 470 | 1 101 | 2 | 367 | 186 | 2 |

For these test-duties, the percentage DC component at the instant of contact separation shall not exceed 20 % of the AC component.

The test-duties related to test currents according to 7.109.2 are as follows:

Test-duty $L_{90}$

a) At the current for $L_{90}$ given in 7.109.2 and the appropriate prospective TRV.

This test-duty is only mandatory for circuit-breakers with a rated voltage higher than 52 kV.

b) Test-duty $L_{75}$

At the current for $L_{75}$ given in 7.109.2 and the appropriate prospective TRV.

c) Test-duty $L_{60}$

At the current for $L_{60}$ given in 7.109.2 and the appropriate prospective TRV.

This test-duty is mandatory only for circuit-breakers with a rated voltage higher than 52 kV and only if the minimum arcing time obtained during test-duty $L_{75}$ is a quarter of a cycle or more longer than the minimum arcing time determined during test-duty $L_{90}$.

#### 7.109.5 Short-line fault tests with a test supply of limited power

When the maximum short-circuit power available at a testing plant is not sufficient to make the short-line fault tests on a complete pole of a circuit-breaker, it is possible to make unit tests (see 7.102.4.2).

Short-line fault tests can also be made at reduced power frequency voltage, the provisions of 7.109.3 being relaxed. These provisions shall be met as well as possible and, for the TRV at least up to three times the specified time of the first line side peak. This method is used if the terminal fault tests in 7.107 have been satisfactory, it being assumed that the dielectric strength of the circuit-breaker near the peak value of TRV is independent of stresses applied immediately after current zero. The test method can also be used in combination with unit tests.

If short-line fault tests are performed at reduced power frequency voltage and in any one short-line fault test-duty the maximum arcing time according to 7.104.3.2 is more than 2 ms longer than the maximum arcing time achieved in test-duty T100s, a single opening operation with the maximum arcing time achieved in the short-line fault tests shall be performed, applying the test conditions of terminal fault T100s. The TRV parameters for this additional operation can be reduced to values corresponding to a $k_{pp}$ of 1,0, as usual for short-line fault testing. The circuit-breaker is considered to have passed the short-line fault test only, if the current is interrupted successfully in this additional opening operation.

### 7.110 Out-of-phase making and breaking tests

#### 7.110.1 Test circuit

Usually the tests are carried out in a single-phase test circuit. This subclause therefore concerns single-phase test procedures only.

Instead of single-phase tests, three-phase tests are permissible. Where three-phase tests are performed, the test procedure should be agreed upon between the manufacturer and user.

The test circuit should be so arranged that approximately one half of the applied voltage and of the recovery voltage is on each side of the circuit-breaker (see Figure 21).

If it is not practicable to use this circuit in the testing station, it is permissible, with the agreement of the manufacturer, to use two identical voltages separated in phase by 120° instead of 180°, provided that the total voltage across the circuit-breaker is as stated in 7.110.2 (see Figure 22).

Tests with one terminal of the circuit-breaker earthed are permissible, with the agreement of the manufacturer (see Figure 23).

#### 7.110.2 Test voltage

For the test voltages used during making and breaking operations the following applies:

a) for circuit-breakers intended to be used in effectively earthed neutral systems the applied voltage and the power frequency recovery voltage shall have a value of $2,0/\sqrt{3}$ times the rated voltage;

b) for circuit-breakers intended to be used in non-effectively earthed neutral systems the applied voltage during the making operation shall have a value of $2,0/\sqrt{3}$ times the rated voltage and the power frequency recovery voltage shall have a value of $2,5/\sqrt{3}$ times the rated voltage.

The TRV shall be in accordance with 7.105.5.6.

### 7.110.3 Test-duties

The test-duties to be made are indicated in Table 31. For arcing times see 7.104.3.

**Table 31 – Test-duties to demonstrate the out-of-phase rating**

| Test-duty | Operating sequence | Breaking current in per cent of the rated out-of-phase breaking current |
|---|---|---|
| OP1 | O – O – O | 30 |
| OP2 | CO – O – O<br>or alternatively<br>C* – C**O – O – O<br><br>C* = C at full voltage<br>C** = C at no-load | 100 |

NOTE 1 For circuit-breakers fitted with closing resistors, the thermal capability of the closing resistors can be tested separately on agreement between manufacturer and user.

NOTE 2 Test-duty OP1 can be omitted for those circuit-breakers for which the T10 current is not a critical current as per 7.108.1.



For the breaking operation of each test-duty, the DC component of the breaking current at contact separation shall not exceed 20 % of the AC component.

For the making operation of the close-open cycle of test-duty OP2:

a) the applied voltage shall be $2U_r/\sqrt{3}$; for convenience of testing the applied voltage for circuit-breakers intended to be used in non-effectively earthed neutral systems can be increased with the agreement of the manufacturer to $2,5U_r/\sqrt{3}$.

   NOTE 1 A power frequency voltage of 2,0 p.u. is specified for making as it is the highest value the first-pole-to-close (which is stressed by the longest pre-arcing time) is normally exposed to.

   NOTE 2 Power frequency recovery voltages corresponding to out-of-phase voltage factors of 2,0 p.u. and 2,5 p.u. are specified for breaking, in effectively earthed neutral systems and non-effectively earthed neutral systems, respectively, as they cater to the great majority of applications of circuit-breakers intended for making and breaking during out-of-phase conditions (see 9.103.3). The out-of-phase angle corresponding to 2,0 p.u. in effectively earthed neutral systems is approximately 105° for rated voltages up to 800 kV and approximately 115° for rated voltages higher than 800 kV. The out-of-phase angle corresponding to 2,5 p.u. in non-effectively earthed neutral systems is approximately 115°. However higher values of angle are covered when considering other factors such as the non-simultaneity of voltage peaks, lower $k_{pp}$ (see IEC TR 62271-306 [4]).

b) the making shall occur within ± 15° of the peak of the applied voltage.

c) the making shall produce a symmetrical current with the longest pre-arcing time. The making current shall be equal to the rated out-of-phase making current.

   If the pre-arcing time when making at the peak of the applied voltage is shorter than or equal to half a cycle of the rated frequency, then the making current can be reduced to any smaller value, but not less than 1 kA;

   If the pre-arcing time when making at the peak of the applied voltage does not exceed ¼ cycle of power frequency with a tolerance of 20 %, due to possible limitations of the testing facilities it is allowed to replace the CO operating cycle of OP2 by the following sequence:

   – C at full voltage;

   – CO with C at no load.

### 7.111 Capacitive current tests

#### 7.111.1 General

This subclause describes capacitive current test procedures for the different ratings defined in 5.106 and their associated restrike class.

Ratings and class demonstrated for back-to-back capacitor bank are also valid for single capacitor bank application for the same earthing conditions.

Tests at 60 Hz cover tests for 50 Hz for same class of probability of restrike.

Tests at 50 Hz cover tests for 60 Hz, provided that the voltage across the circuit-breaker is not less during the first 8,3 ms than it would be during a test at 60 Hz. This test method requires the consent of the manufacturer.

#### 7.111.2 Applicability

Capacitive current tests are applicable to all circuit-breakers to which one or more of the following ratings have been assigned:

– rated line-charging breaking current;

– rated cable-charging breaking current;

– rated single-capacitor bank breaking current;

– rated back-to-back capacitor bank breaking and inrush making current.

Preferred values of rated capacitive currents are given in Table 1.

Tests specified for these ratings are individual type tests, each comprising a tests series with two test-duties.

NOTE 1 The determination of overvoltages when switching capacitive loads is not covered by this document.

NOTE 2 Explanatory notes on switching of capacitive loads are given in IEC TR 62271-306 [4].

When point-on-wave energising is used for back-to-back capacitor bank making, IEC TR 62271-302 [10] applies.

#### 7.111.3 Characteristics of supply circuits

In laboratory tests the lines and cables can be partly or fully replaced by artificial circuits with lumped elements of capacitors, reactors or resistors.

The test circuit shall fulfil the following requirements:

a) the characteristics of the test circuit should be such that the power frequency voltage variation, when breaking, should be less than 2 % for test-duty 1 (LC1, CC1 and BC1) and less than 5 % for test-duty 2 (LC2, CC2 and BC2). Where the voltage variation is higher than the values specified, it is alternatively permissible to perform tests with the specified recovery voltage (7.111.10) or synthetic tests;

b) the impedance of the supply circuit shall not be so low that its short-circuit current exceeds the rated short-circuit current of the circuit-breaker.

For line-charging, cable-charging and single capacitor bank current tests the prospective TRV of the supply circuit shall not be more severe than the TRV specified for test-duty T100s in 7.105.5.2.

For back-to-back capacitor bank making and breaking tests, the capacitance of the supply circuit and the impedance between the capacitors on the supply and load sides shall be such as to give the rated back-to-back capacitor bank inrush making current when testing with 100 % of the rated back-to-back capacitor bank breaking current.

For back-to-back capacitor bank making and breaking tests where separate making tests are performed, a lower capacitance of the supply circuit can be chosen for the breaking tests. The capacitance should, however, not be so low that the prospective TRV of the supply side exceeds that specified for short-circuit in 7.105.5.2.

The test circuit frequency shall be the rated frequency with a tolerance of ± 2 %.

### 7.111.4 Earthing of the test circuit

#### 7.111.4.1 Supply circuit

For single-phase laboratory tests, either terminal of the single-phase supply circuit can be earthed. However, when it is necessary to ensure that the correct voltage distribution exists between the making and breaking units of the circuit-breaker, another point of the supply circuit can be connected to earth.

For three-phase tests, the earthing of the supply circuit shall be as follows:

a) for capacitor bank making and breaking tests, the neutral of the supply circuit shall be earthed. For capacitor banks with effectively earthed neutral, the zero-sequence impedance shall not be more than three times its positive sequence impedance. For capacitor banks with isolated neutral this ratio is not relevant. For the purpose of switching of capacitive loads the high impedance neutral system is considered to fall under effectively earthed neutral systems;

   NOTE The condition for high impedance neutral systems applies to the switching of capacitive loads only.

b) for line-charging and cable-charging current tests, the earthing of the supply circuit should correspond to the earthing conditions in circuits for which the circuit-breaker is to be used:
   – for three-phase tests of a circuit-breaker intended for use in effectively earthed neutral systems, the neutral point of the supply circuit shall be earthed and its zero-sequence impedance shall be no more than three times its positive sequence impedance;
   – for three-phase tests of a circuit-breaker intended for use in non-effectively earthed neutral systems, the neutral point of the supply side shall be isolated.

For convenience of testing, an alternative test circuit can be used as long as the equivalent values of the recovery voltage as given in Table H.1 and Table H.2 will be obtained.

Attention should be given to the influence of TRV control capacitors on the values of the recovery voltage especially for low capacitive currents. Table 32 gives values of the required recovery voltage.

**Table 32 – Specified values of $u_1$, $t_1$, $u_c$ and $t_2$**

<table>
<tr><th rowspan="2">Test-duties</th><th colspan="2">Recovery voltage values of Figure 54 in relation to the peak value of the test voltage</th><th colspan="2">Time values of Figure 54</th></tr>
<tr><th>$u_c$<br>p.u.</th><th>$u_1$<br>p.u.</th><th>$t_1$</th><th>$t_2$</th></tr>
<tr><td>1</td><td>≥ 1,98</td><td>≤ 0,02$k_{af}$ [a]</td><td rowspan="2">≥ $t_1$ or $t_3$ in 7.105.5.1 for terminal fault</td><td rowspan="2">8,7 ms for 50 Hz<br>7,3 ms for 60 Hz</td></tr>
<tr><td>2</td><td>≥ 1,95</td><td>≤ 0,05$k_{af}$ [a]</td></tr>
<tr><td colspan="5">[a] $k_{af}$ = 1,4 (see Table 16, Table 17, Table 20 and Table 21) for class S1 circuit-breakers and for circuit-breakers with rated voltage of 100 kV up to and including 800 kV.<br>$k_{af}$ = 1,5 (see Table 20) for circuit-breakers with rated voltage higher than 800 kV.<br>$k_{af}$ = 1,54 (see Table 18 and Table 19) for class S2 circuit-breakers.</td></tr>
<tr><td colspan="5">NOTE For tests with specified recovery voltage the prospective recovery voltage is calculated based on the test voltage of the corresponding single-phase direct test.</td></tr>
</table>

#### 7.111.4.2 Load circuit for three-phase capacitor bank current tests

Tests performed with an isolated capacitor bank neutral do cover the switching performance of capacitor banks having an earthed neutral. However, tests performed with an earthed supply and an earthed capacitor bank neutral are not valid for demonstrating the switching performance of capacitor banks with isolated neutral.

### 7.111.5 Characteristics of the capacitive circuit to be switched

#### 7.111.5.1 General

There are three possibilities:

a) three-phase tests, where in case of line- or cable-charging current tests it is permissible to use parallel lines or cables respectively or to partly, or fully, replace the real three-phase line or cable with concentrated capacitor banks. The resulting positive sequence capacitance shall be twice the zero-sequence capacitance for tests representing three-core belted cables for rated voltages higher than 72,5 kV, and three times the zero-sequence capacitance for rated voltages up to and including 72,5 kV;

b) single-phase tests in a three-phase test circuit with two phases of the capacitive circuit connected directly to the three-phase supply circuit and one phase connected to the supply circuit through the circuit-breaker pole to be tested;

c) single-phase laboratory tests, where in case of line- or cable-charging current tests it is allowed to replace partly or fully the real lines or cables respectively by concentrated capacitor banks and to use any parallel connection of the conductors in the individual phases with the return current through earth or through a conductor.

The characteristics of the capacitive circuit shall, with all necessary measuring devices such as voltage dividers included, be such that the decay of the voltage at load side does not exceed 10 % at the end of an interval of 0,3 s after final arc extinction, except for test-duty LC1 and/or CC1 as the withstand capability during an interval of 0,3 s is demonstrated by any test-duty 2.

In laboratory tests the lines and cables can be partly or fully replaced by artificial circuits with lumped elements of capacitors, reactors or resistors.

#### 7.111.5.2 Line-charging and cable-charging current tests

When capacitors are used to simulate overhead lines or cables, a non-inductive resistor of a maximum value of 5 % of the capacitive impedance can be inserted in series with the capacitors. Higher values can unduly influence the recovery voltage. If, with this resistor connected, the peak inrush current is still unacceptably high, then an alternative impedance (for example LR) can be used instead of the resistor.

Caution is needed when using such alternative impedances, since this impedance can generate an overvoltage after re-ignition, which can lead to further re-ignitions or restrikes.

#### 7.111.5.3 Capacitor bank current making and breaking tests

The back-to-back capacitor bank making performance is covered when:

– the prospective peak inrush making current is equal to or greater than the rated value;
– the frequency of the inrush current used during tests is 4 250 Hz with the tolerance given in Table B.1.

The prospective damping factor for the inrush current during back-to-back making, i.e. the ratio between the second peak and the first peak of the same polarity, shall be equal to or greater than 0,75 for circuit-breakers having a rated voltage up to and including 72,5 kV and equal to or greater than 0,85 for circuit-breakers having a rated voltage higher than 72,5 kV.

A non-inductive resistor of a maximum value of 5 % of the capacitive impedance can be inserted in series with the capacitors for testing single-capacitor bank current making and breaking and for back-to-back capacitor bank current breaking. Higher values can unduly influence the recovery voltage and the inrush making current.

#### 7.111.6 Waveform of the current

The waveform of the current to be interrupted should, as nearly as possible, be sinusoidal. This condition is considered to be complied with if the ratio of the RMS value of the current to the RMS value of the fundamental component does not exceed 1,2.

The current to be interrupted shall not go through zero more than once per half-cycle of power frequency.

#### 7.111.7 Test voltage

For direct three-phase tests and for single-phase tests with the capacitive circuit to be switched according to the arrangement in item b) of 7.111.5.1, the test voltage measured between the phases across the capacitive load circuit immediately prior to opening shall be not less than the rated voltage $U_r$ of the circuit-breaker.

For direct single-phase laboratory tests, the test voltage measured at the circuit-breaker location immediately prior to opening shall be not less than the product of $U_r/\sqrt{3}$ and the following capacitive voltage factor $k_c$:

a) $\boldsymbol{k_c}$ **= 1,0** for tests corresponding to normal service in effectively earthed neutral systems without significant mutual influence of adjacent phases of the capacitive circuit, typically capacitor banks with earthed neutral and individually screened cables;

b) $\boldsymbol{k_c}$ **= 1,2** for tests on belted cables and for line-charging current tests according to item c) of 7.111.5.1 corresponding to normal service conditions in effectively earthed neutral systems for rated voltages higher than 72,5 kV. This condition is also applicable to high impedance neutral systems;

NOTE 1 The condition for high impedance neutral systems applies to switching of capacitive loads only.

NOTE 2 Selection of the neutral impedance for high impedance neutral systems is determined such that protection relays can work in a short time to detect single-phase earth faults. The value of impedance is normally around several hundred Ohms. For further details see [11].

c) $k_c$ **= 1,4** for tests corresponding to

– breaking during normal service conditions in non-effectively earthed neutral systems;

– breaking of capacitor banks with isolated neutral.

Moreover, the $k_c$ = 1,4 is applicable for tests on belted cables and overhead lines according to item c) of 7.111.5.1 corresponding to normal service conditions in effectively earthed neutral systems for rated voltages up to and including 72,5 kV.

For unit tests, the test voltage shall be chosen to correspond to the most stressed making and breaking unit of the pole of the circuit-breaker.

The power frequency test voltage and the DC voltage resulting from the trapped charge on the capacitive circuit shall be maintained for a period of at least 0,3 s after breaking.

NOTE 3 The voltage factors in b) and c) above are applicable to single circuit line construction. Test requirements for multiple circuit overhead line constructions can be greater than these factors.

Making and breaking of capacitive currents under earth fault conditions is treated in Annex J.

### 7.111.8 Test current

The test currents for the various test-duties can be derived using Table 33.

**Table 33 – Common requirements for test-duties**

| Test-duty | Operating voltage of the releases | Pressure for operation and making and breaking | Test current as percentage of the rated capacitive breaking current<br>% | Type of operation or operating sequence |
|---|---|---|---|---|
| LC1, CC1 and BC1 | Maximum voltage | Minimum functional pressure | 10 to 40 | O |
| LC2, CC2 and BC2 | Maximum voltage | Filling pressure [a] | Not less than 100 | O and CO<br>or<br>CO |

[a] For vacuum circuit-breakers in sealed pressure systems the test shall be performed at minimum functional pressure.

NOTE 1 The tests are performed at maximum operating voltage of the releases in order to facilitate consistent control during operation.

NOTE 2 For convenience of testing, CO operating cycles can be performed in test-duty 1 (LC1, CC1 and BC1).



### 7.111.9 Test-duties

#### 7.111.9.1 General

The two test-duties for LC, CC or BC shall be performed on one test object without any maintenance. The following abbreviations apply:

– line-charging current, test-duty 1 LC1;

– line-charging current, test-duty 2 LC2;

– cable-charging current, test-duty 1 CC1;

– cable-charging current, test-duty 2 CC2;
– capacitor bank current, test-duty 1 BC1;
– capacitor bank current, test-duty 2 BC2.

If back-to-back capacitor bank switching tests are performed, single capacitor bank switching tests are not required.

These test-duties can be combined for the same class of restrike performance in order to demonstrate the performance of a circuit-breaker for covering several ratings (for example LC and/or CC and/or BC). If such combination method is used, the following applies:

– a test-duty 2, covering all test-duties 2 of the combination, with a current not less than 100 % of the highest capacitive current rating to be demonstrated;
– a test-duty 1 with a current between 10 % and 40 % of the highest capacitive current rating to be demonstrated;
– a test-duty 1 for each lower capacitive current rating if the range of 10 % to 40 % of that rating is not covered by a previous test-duty 1;
– all other requirements for the individual test-duties shall also be met (for example type, order and number of operations, pressure conditions and test circuits). Where CO operations are specified for one application and O operations for a different one, CO operations are considered to cover O operations if the testing conditions are the same.

NOTE IEC TR 62271-306 [4] provides examples of the application of the rules for combining test-duties.

#### 7.111.9.2 Common test conditions for class C1 and C2 performance

For the make-break tests, the contacts of the circuit-breaker shall not be separated until the transient currents have subsided. To achieve this, the time between the closing and opening operations can be adjusted but shall remain as close as possible to the close-open time as defined in 3.7.141.

Common requirements for capacitive current test-duties are given in Table 33.

For vacuum circuit-breakers the pressure conditions for making and breaking are not applicable.

No appreciable charge shall remain on the capacitive circuits before the making operations.

In case of three-phase back-to-back capacitor bank current making and breaking tests with non-effectively earthed neutral on supply side and/or load side, the making operation is considered to be valid if the following conditions are met:

– the target phase was involved in two-phase making where the making shall occur within ±25° of the peak value of the phase-to-phase voltage of these two phases, or
– the making in the target phase shall occur within ±25° of the peak value of the applied voltage in case of a three-phase simultaneous making.

For single-phase back-to-back making operations, the making shall occur within ±25° of the peak value of the applied voltage and evenly distributed in both polarities.

For line-charging and cable-charging current tests the C operations can be no-load operations. For the C operations in single capacitor bank tests the making current provided by the test circuit is considered to be sufficient.

Where in case of back-to-back capacitor bank making and breaking tests it is not possible to comply with the requirements during the CO operating cycles, then it is permitted to perform the requirements of test-duty 2 (BC2) as a series of separate making tests followed by a series of CO tests.

It is also permitted to perform these split tests not in two subsequent blocks (i.e. one consisting of all C operations and one of all CO operations), but to mix C and CO operations provided that the number of making operations is larger than or equal to the number of breaking operations at any time during this test. The remaining breaking operations after 80 valid making operations can be performed as CO tests, where the C operations can be no-load operations.

The separate making tests of this test series shall comprise the following:

– the same number of operations, when testing back-to-back capacitor bank making and breaking the prospective inrush making current shall be at least equal to the rated back-to-back capacitor bank inrush making current;
– the target phase was involved in two-phase making where the making shall occur within ±25° of the peak value of the phase-to-phase voltage of these two phases, or
– the making in the target phase shall occur within ±25° of the peak value of the applied voltage in case of a three-phase simultaneous making.

The test voltage shall be the phase-to-earth voltage.

After the separate making operations, the CO operations shall be performed with no-load conditions on the closing. The CO operations shall be carried out on the same pole without intermediate re-conditioning.

When making and breaking capacitive currents, the opening operation in a CO operating cycle is not influenced by the pre-arc of the preceding closing operation but can be impacted by the actual behaviour of the fluid for making and breaking caused by the closing operation (for example local differences in density, turbulence, fluid motion). Therefore, the closing and opening operations can be separated as mentioned above with regard to the electrical stress but not with regard to the motion conditions of the fluid for making and breaking. A no-load closing operation prior to the opening operation is necessary for these reasons.

For opening operations, the minimum arcing time is determined by changing the setting of the contact separation on opening by steps of approximately 6°. Using this method, several tests can be necessary to demonstrate the minimum arcing time.

If a different arcing time is obtained instead of an expected minimum arcing time, this is a valid test and shall be included in the count for the total requirement. In such an event the following will be necessary:

– advance the setting of the control of the tripping command by 6° and repeat the test. The new setting shall be kept for other tests at minimum arcing time;
– make one less opening operation to retain the overall total count of tests.

A re-ignition followed by breaking at a later current zero shall be treated as a breaking operation with a long arcing time.

The specified arcing times generally refer to the first pole-to-clear. No arcing times are specified for the additional tests.

All required minimum arcing times shall be obtained on the same phase. In case of back-to-back capacitor bank current making the inrush current shall be achieved also in that phase. Within each test-duty, the order of the operations as written in 7.111.9.3.2, 7.111.9.3.3 and 7.111.9.4.2 to 7.111.9.4.5 is not mandatory.

For circuit-breakers with a non-symmetrical current path, the terminal connections shall be reversed between test-duty 1 (LC1, CC1 and BC1) and test-duty 2 (LC2, CC2 and BC2). The test arrangement should be such that no interference with the circuit-breaker between the test-duties is necessary. However, if this is not possible, it is allowed to decrease the pressure in the circuit-breaker, in this case the circuit-breaker shall be refilled with at least 50 % of the used gas.

#### 7.111.9.3 Class C1 test-duties

##### 7.111.9.3.1 General

If the behaviour of the circuit-breaker prevents accurate control, the total number of tests is limited to 36 for each test-duty.

There is no preferred order for the following tests:

– capacitive current, test-duty 1 (LC1 or CC1 or BC1);
– capacitive current, test-duty 2 (LC2 or CC2 or BC2).

##### 7.111.9.3.2 Three-phase capacitive current tests

Test-duty 1 (LC1, CC1 and BC1) shall comprise a total of 24 O tests. Test-duty 2 (LC2, CC2 and BC2) shall comprise a total of 24 CO tests.

*Test-duty 1 (LC1, CC1 and BC1):*

– 6 O, distributed on one polarity (step: 10°);
– 3 O at minimum arcing time on one polarity;
– 6 O, distributed on the other polarity (step: 10°);
– 3 O at minimum arcing time on the other polarity;
– additional tests to achieve 24 O, distributed.

*Test-duty 2 (LC2, CC2 and BC2):*

– 6 CO, distributed on one polarity (step: 10°);
– 3 CO at minimum arcing time on one polarity;
– 6 CO, distributed on the other polarity (step: 10°);
– 3 CO at minimum arcing time on the other polarity;
– additional tests to achieve 24 CO, distributed.

##### 7.111.9.3.3 Single-phase capacitive current tests

Test-duty 1 (LC1, CC1 and BC1) shall comprise a total of 24 O tests. Test-duty 2 (LC2, CC2 and BC2) shall comprise a total of 24 CO tests.

*Test-duty 1 (LC1, CC1 and BC1):*

– 6 O, distributed on one polarity (step: 30°);
– 3 O at minimum arcing time on one polarity;
– 6 O, distributed on the other polarity (step: 30°);
– 3 O at minimum arcing time on the other polarity;
– additional tests to achieve 24 O, distributed.

*Test-duty 2 (LC2, CC2 and BC2):*

– 6 CO, distributed on one polarity (step: 30°);
– 3 CO at minimum arcing time on one polarity;
– 6 CO, distributed on the other polarity (step: 30°);
– 3 CO at minimum arcing time on the other polarity;
– additional tests to achieve 24 CO, distributed.

**7.111.9.4 Class C2 test-duties**

**7.111.9.4.1 General**

Capacitive current tests for class C2 circuit-breakers shall be made after performing test-duty T60 as a preconditioning test (T60 is related to the AC component of the rated short-circuit breaking current).

As an alternative, the preconditioning can be performed at reduced voltage under the following conditions:

– same current as test-duty T60;
– reduced voltage and no specified TRV;
– three breaking operations;
– arcing times: as for test-duty T60 given by the manufacturer;
– filling or minimum pressure for operation and making and breaking.

NOTE For practical reasons the manufacturer can choose to add other test-duties to the T60 preconditioning tests.

If several capacitive current tests, for instance line-charging, cable-charging and capacitor bank current tests, are performed with the same circuit-breaker without reconditioning, the T60 preconditioning tests shall be performed only once at the beginning of the capacitive current tests.

For the line-charging or cable-charging current tests, there is no preferred order between test-duty 1 and test-duty 2.

The mandatory order for capacitor bank (single or back-to-back) making and breaking tests is as follows:

– capacitive current, test-duty 2 (BC2);
– capacitive current, test-duty 1 (BC1).

**7.111.9.4.2 Three-phase line-charging and cable-charging current tests**

Each test-duty shall comprise a total of 24 operations or operating cycles as follows:

*Test-duty 1 (LC1 and CC1):*

– 4 O, distributed on one polarity (step: 15°);
– 6 O at minimum arcing time on one polarity;
– 4 O, distributed on the other polarity (step: 15°);
– 6 O at minimum arcing time on the other polarity;
– additional tests to achieve 24 O, distributed.

*Test-duty 2 (LC2 and CC2):*

– 4 CO, distributed on one polarity (step: 15°);
– 6 CO at minimum arcing time on one polarity;
– 4 CO, distributed on the other polarity (step: 15°);
– 6 CO at minimum arcing time on the other polarity;
– additional tests to achieve 24 CO, distributed.

If the behaviour of the circuit-breaker prevents accurate control, the total number of tests is limited to 36 for each test-duty independent from arcing times obtained.

#### 7.111.9.4.3 Single-phase line-charging and cable-charging current tests

Each test-duty shall comprise a total requirement of 48 operations or operating cycles as follows:

*Test-duty 1 (LC1 and CC1):*

– 12 O, distributed on one polarity (step: 15°);
– 6 O at minimum arcing time on one polarity;
– 12 O, distributed on the other polarity (step: 15°);
– 6 O at minimum arcing time on the other polarity;
– additional tests to achieve 48 O, distributed.

If the behaviour of the circuit-breaker prevents accurate control, the total number of tests is limited to 72 independent from arcing times obtained.

*Test-duty 2 (LC2 and CC2):*

– 6 O and 6 CO, distributed on one polarity (step 30°);
– 3 O and 3 CO at minimum arcing time on one polarity;
– 6 O and 6 CO, distributed on the other polarity (step: 30°);
– 3 O and 3 CO at minimum arcing time on the other polarity;
– additional tests to achieve 24 O and 24 CO, distributed.

If the behaviour of the circuit-breaker prevents accurate control, the total number of tests is limited to 36 O and 36 CO independent from arcing times obtained.

#### 7.111.9.4.4 Three-phase capacitor bank (single or back-to-back) making and breaking tests

Test-duty 1 (BC1) shall comprise a total of 24 O tests. Test-duty 2 (BC2) shall comprise a total of 80 CO tests as follows:

*Test-duty 1 (BC1):*

– 4 O, distributed on one polarity (step:15°);
– 6 O at minimum arcing time on one polarity;
– 4 O, distributed on the other polarity (step: 15°);
– 6 O at minimum arcing time on the other polarity;
– additional tests to achieve 24 O, distributed.

If the behaviour of the circuit-breaker prevents accurate control, the total number of tests is limited to 36 independent from arcing times obtained.

*Test-duty 2 (BC2):*

– 4 CO, distributed on one polarity (step 15°);
– 32 CO at minimum arcing time on one polarity;
– 4 CO, distributed on the other polarity (step: 15°);
– 32 CO at minimum arcing time on the other polarity;
– additional tests to achieve 80 CO, distributed.

If the behaviour of the circuit-breaker prevents accurate control, the total number of tests is limited to 100 independent from arcing times and making conditions obtained.

**7.111.9.4.5 Single-phase capacitor bank (single or back-to-back) making and breaking tests**

Test-duty 1 (BC1) shall comprise a total of 48 O tests. Test-duty 2 (BC2) shall comprise a total of 80 CO tests at minimum arcing time with making at applied voltage and 40 CO tests, where the C operations can be no-load operations. For back-to-back making and breaking tests the making shall occur within ±25° of the peak value of the applied voltage.

*Test-duty 1 (BC1):*

– 12 O, distributed on one polarity (step: 15°);
– 6 O at minimum arcing time on one polarity;
– 12 O, distributed on the other polarity (step: 15°);
– 6 O at minimum arcing time on the other polarity;
– additional tests to achieve 48 O, distributed.

If the behaviour of the circuit-breaker prevents accurate control, the total number of tests is limited to 72 independent of arcing times obtained.

*Test-duty 2 (BC2):*

– 12 CO, distributed on one polarity (step: 15°);
– 40 CO at minimum arcing time on one polarity;
– 12 CO, distributed on the other polarity (step: 15°);
– 40 CO at minimum arcing time on the other polarity;
– Additional tests to achieve 120 CO, distributed (step: 15°).

If the behaviour of the circuit-breaker prevents accurate control, the total number of tests to meet the requirement for making angle is limited to 100 and the total number of tests is limited to 158 independent of the arcing times obtained.

**7.111.10 Tests with specified recovery voltage**

As an alternative to using the test circuits defined in 7.111.3 through 7.111.5, tests can be performed in circuits which fulfil the following requirements for the prospective recovery voltage:

– with the envelope of the prospective test recovery voltage defined as (see Figure 54)

  $u'_c \geq u_c$

  $t'_2 \leq t_2$;

– in addition the initial part of the prospective recovery voltage shall remain below the line from the origin to the point defined by $u_1$ and $t_1$;

– care should be taken in order to assure that the actual recovery voltage shall not exceed the theoretical test voltage of the corresponding single-phase direct test (1-cos curve) by more than 6 % of the peak value of the test voltage (i.e. approximately 3 % of the peak recovery voltage $u_c$ shown in Figure 54).

NOTE The use of a series resistor (7.111.5.2 and 7.111.5.3) in the load circuit causes a phase shift which can lead to the above given limit be exceeded. In those cases the value of the resistor can be decreased or an appropriate LR circuit can be used instead (7.111.5.2 and 7.111.5.3).

Specified values of $u_1$, $t_1$, $u_c$ and $t_2$ for single-phase testing are given in Table 32.

For three-phase testing the same principle is used to define the initial part of the recovery voltage for the first-pole-to-clear.

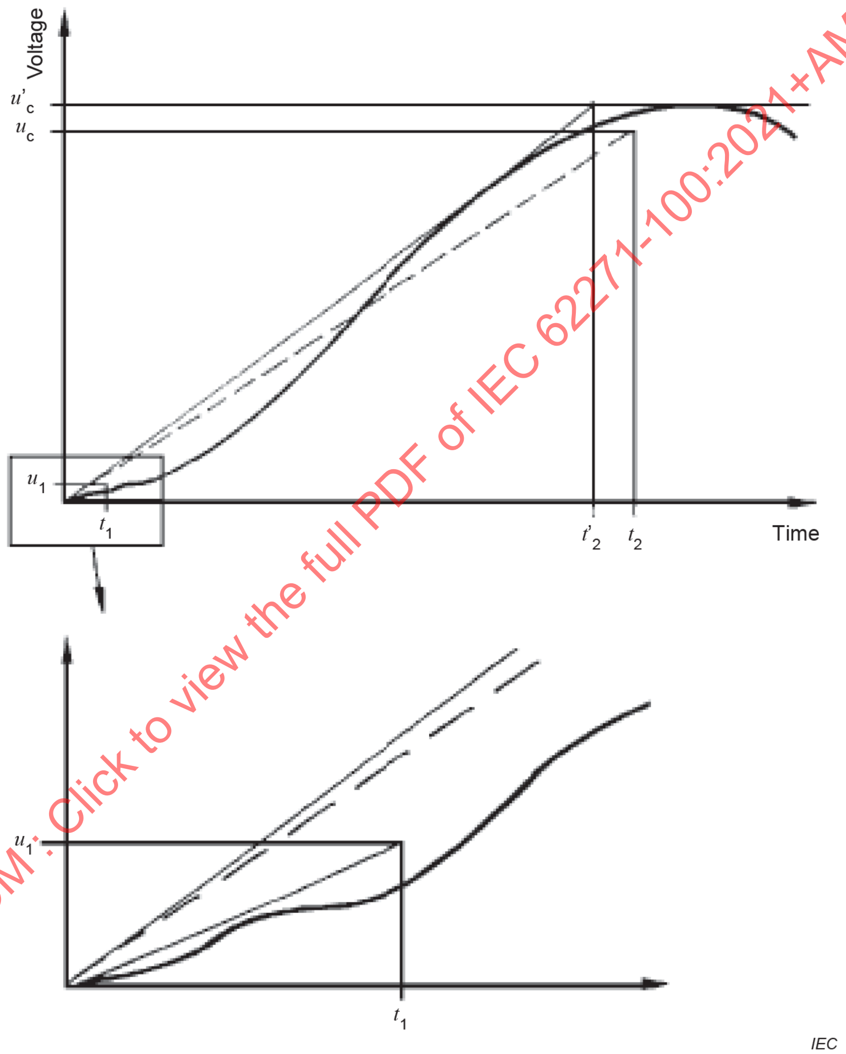



**Figure 54 – Recovery voltage for capacitive current breaking tests**

#### 7.111.11 Criteria to pass the test

##### 7.111.11.1 General

The circuit-breakers of the individual classes shall have successfully passed the tests if the following conditions are fulfilled:

a) the behaviour of the circuit-breaker during making and breaking of the capacitive currents in all required test-duties fulfils the conditions given in 7.102.8;
b) the condition of the circuit-breaker after the tests corresponds to the conditions given in 7.102.9.2. If no restrike occurred during test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2), visual inspection is sufficient.

Where combined testing in accordance with 7.111.9.1 is carried out, the criteria to pass the test apply to each combination of test-duties 1 and 2 relevant to cover the rating the tests have been carried out for.

##### 7.111.11.2 Class C1 performance

The circuit-breaker has successfully passed the tests if up to one restrike occurred during the complete test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2).

If two restrikes occurred during the complete test-duties 1 and 2 for LC, CC or BC, then both test-duties shall be repeated on the same apparatus without any maintenance. If no more than one additional restrike happens during this extended series of tests, the circuit-breaker has successfully passed the tests. External flashover and phase-to-ground flashover shall not take place.

In the case of combined testing according to 7.111.9.1, the circuit-breaker shall have passed the test for those ratings for which both, a test-duty 2 and a matching test-duty 1 were carried out with less than two restrikes in total. Where due to restrikes test-duties shall be repeated, the affected set of matching test-duties (test-duty 1 and test-duty 2) shall be repeated. If in more than one test-duty 1 restrikes occurred, each of them shall be repeated together with one single test-duty 2. If restrikes occurred only in test-duty 2, this one and any one of the test-duties 1 shall be repeated.

##### 7.111.11.3 Class C2 performance

The circuit-breaker has successfully passed the tests if no restrike occurred during the complete test-duties 1 and 2 for LC, CC or BC.

If one restrike occurred during the complete test-duties 1 (LC1 or CC1 or BC1) and 2 (LC2 or CC2 or BC2), then both test-duties shall be repeated on the same apparatus without any maintenance. If no additional restrike occurs during this extended series of tests, the circuit-breaker has successfully passed the tests. External flashover and phase-to-ground flashover shall not take place.

In the case of combined testing according to 7.111.9.1, the circuit-breaker has passed the test for those applications or ratings for which both a test-duty 2 and a matching test-duty 1 were carried out without restrike. Where due to restrikes test-duties shall be repeated, the affected set of matching test-duties (test-duty 1 and test-duty 2) shall be repeated. If in more than one test-duty 1 one restrike occurred, each of them shall be repeated together with one single test-duty 2. If one restrike occurred in test-duty 2, this one and any one of the test-duties 1 shall be repeated.

##### 7.111.11.4 Criteria for reclassification from class C2 performance to class C1

A circuit-breaker which has met the requirements for class C2 performance for a particular test-duty (LC, CC, BC) can be class C1 for the same duty without further testing.

A circuit-breaker tested in accordance with the class C2 test procedure but which has failed to pass class C2 performance can be qualified for class C1 performance if the requirements of 7.111.11.1 are fulfilled and if the following condition is met:

a) Line- or cable-charging current tests

   The total number of restrikes during line-charging current tests (LC1 and LC2) or cable-charging current tests (CC1 and CC2) does not exceed two in the first series of test operations i.e. 96 in case of single-phase tests and 48 in case of three-phase tests, see 7.111.9.4.2 or 7.111.9.4.3 respectively. In the event of a single restrike during the first series of test operations a repetition series can be carried out in accordance with 7.111.11.3. The behaviour of the circuit-breaker during the repetition series is not relevant for the purpose of reclassification. If during this repetition series a restrike occurs no further testing is required.

b) Capacitor bank current tests

   The total number of restrikes during capacitor bank current tests (BC1 and BC2) does not exceed five in the first series of operations, i.e. 168 in case of single-phase tests and 104 in case of three-phase tests, see 7.111.9.4.4 or 7.111.9.4.5 respectively. In the event of a single restrike during the first series of test operations a repetition series can be carried out in accordance with 7.111.11.3. The behaviour of the circuit-breaker during the repetition series is not relevant for the purpose of reclassification. If during this repetition series a restrike occurs no further testing is required.

The reclassification procedure is shown in Figure 55 and Figure 56.



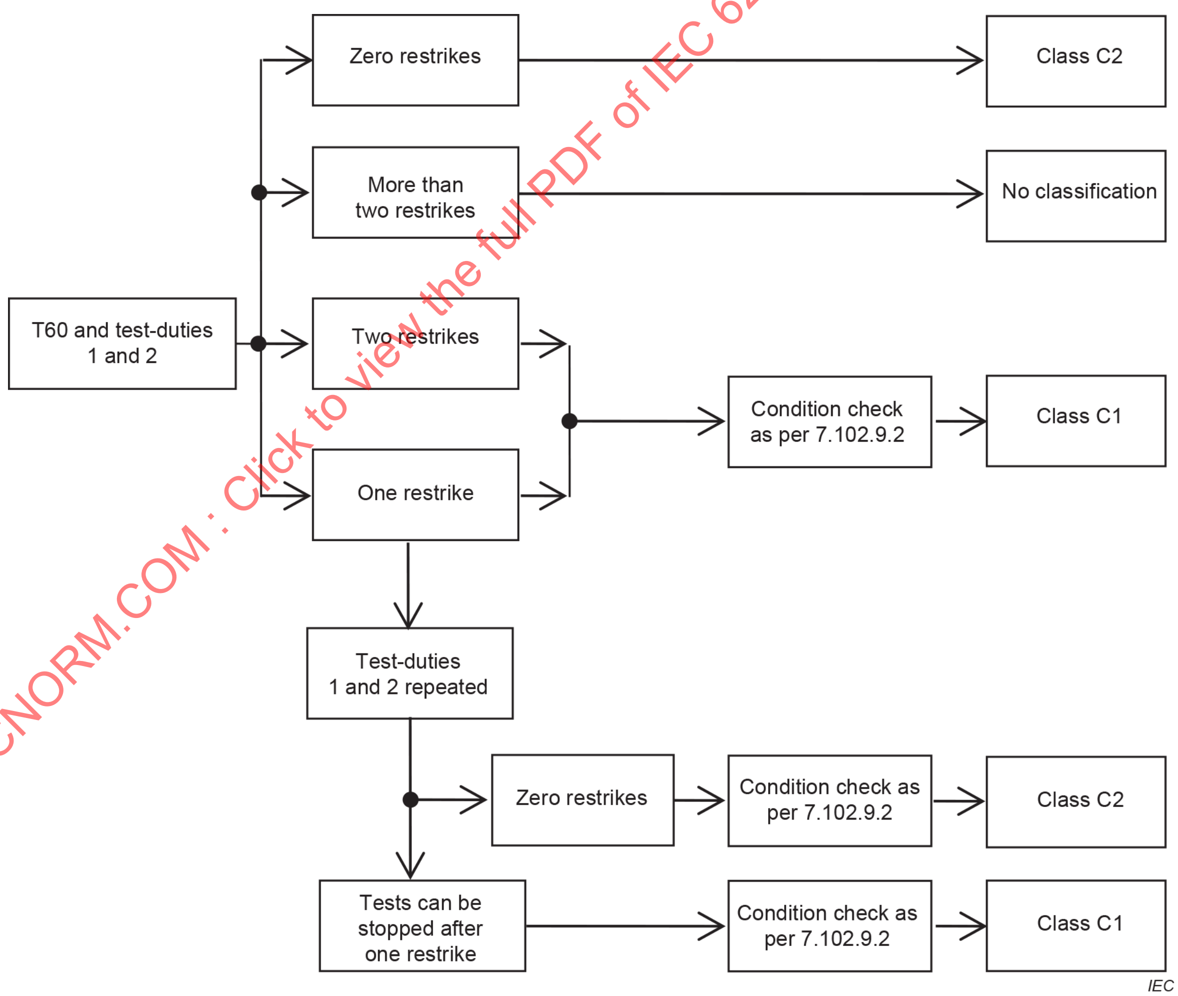



**Figure 55 – Reclassification procedure for line and cable-charging current tests**

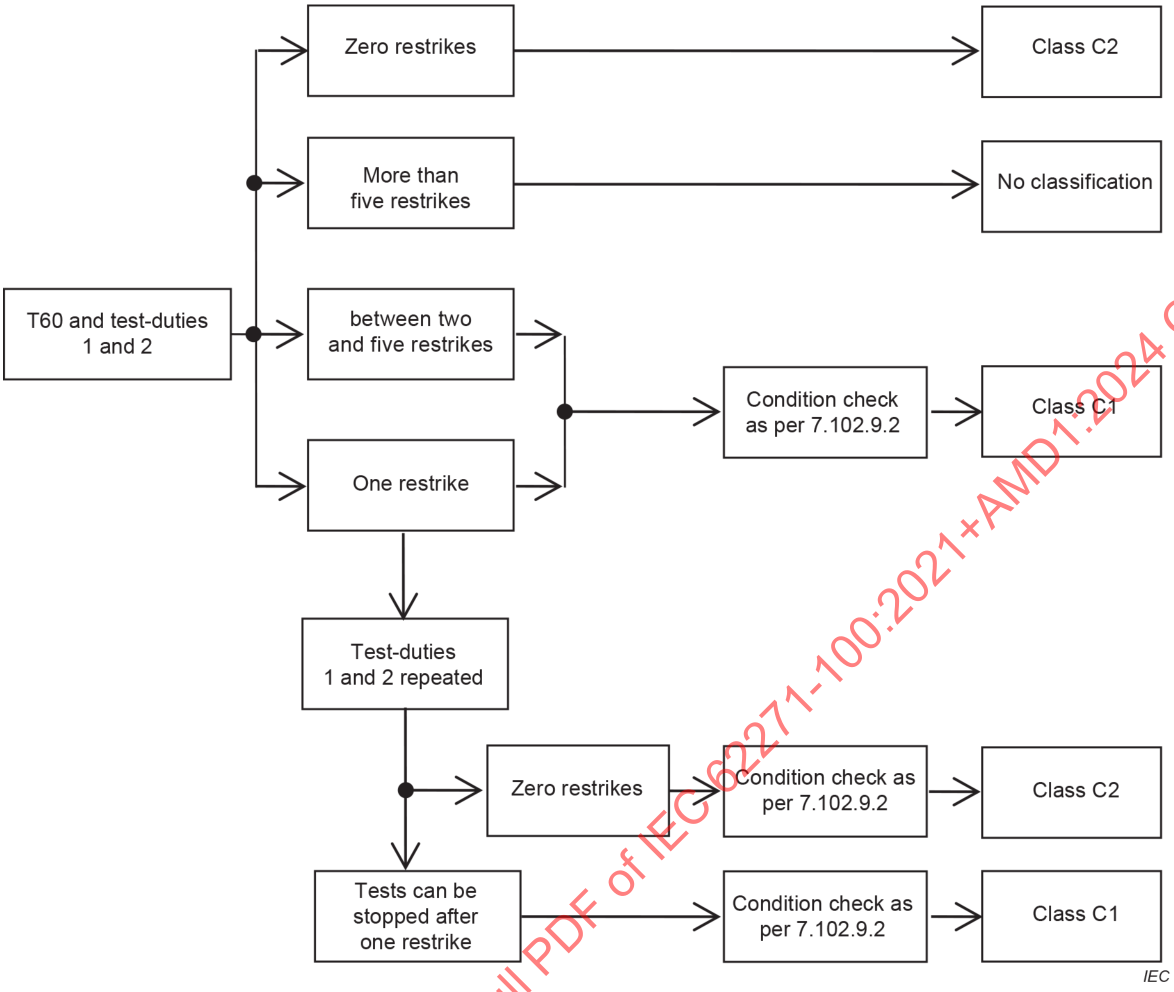



**Figure 56 – Reclassification procedure for capacitor bank current tests**

### 7.112 Requirements for making and breaking tests on class E2 circuit-breakers having a rated voltage above 1 kV up to and including 52 kV

#### 7.112.1 Class E2 circuit-breakers not for auto-reclosing

The electrical endurance capability of circuit-breakers, that are not for auto-reclosing duty, is demonstrated by performing the terminal fault test-duties of 7.107 without intermediate maintenance. Additional tests are not required.

#### 7.112.2 Class E2 circuit-breakers for auto-reclosing

The test shall be performed in accordance with, and in the order specified in, Table 34.

The test shall be carried out on a circuit-breaker, that is in clean and new condition and identical to that which has been submitted to the terminal fault tests, given in 7.107. No intermediate maintenance shall be carried out during the tests specified in Table 34. The test parameters shall be in accordance with 7.107 except as follows:

a) the test shall be made at the rated supply voltage of closing and opening devices and of auxiliary and control circuits and at the filling pressure for operation;

b) the test shall be made at the filling pressure for insulation and/or making and breaking;

c) the values of $t'$ shall be chosen for convenience of testing;

d) the minimum time interval between operating sequences should be stated by the manufacturer.

Arcing times shall be at random for the 10 % and 30 % tests. Adjustment of the trip command shall be made in accordance with 7.104 for the 60 % and 100 % tests.

The condition of the circuit-breaker after the test shall comply with 7.102.9.

If a circuit-breaker already has been tested for $k_{pp}$ = 1,3 and $k_{pp}$ = 1,5, a class E2 test performed with either $k_{pp}$ = 1,3 or $k_{pp}$ = 1,5 covers both conditions.

**Table 34 – Operating sequence for electrical endurance test on class E2 circuit-breakers for auto-reclosing duty**

| Testing current (percentage of rated short-circuit breaking current) % | Operating sequences | Number of operating sequences (list 1) [a] | Number of operating sequences (list 2) [a] | Number of operating sequences (list 3) [a] |
|---|---|---|---|---|
| 10 | O | 84 | 12 | - |
| | O – $t$ – CO | 14 | 6 | - |
| | O – $t$ – CO – $t'$ – CO | 6 [b] | 4 [b] | 1 [b] |
| 30 | O | 84 | 12 | - |
| | O – $t$ – CO | 14 | 6 | - |
| | O – $t$ – CO – $t'$ – CO | 6 [b] | 4 [b] | 1 [b] |
| 60 | O | 2 | 8 | 15 |
| | O – $t$ – CO – $t'$ – CO | 2 [b] | 8 [b] | 15 [b] |
| 100 % (symmetrical) | O – $t$ – CO – $t'$ – CO | 2 [b] | 4 [b] | 2 [b] |

[a] List 1 is preferred. List 2 can be used as an alternative to list 1 for circuit-breakers used for effectively earthed neutral systems. Calculations have been carried out on the basis of publication [12]. These calculations are applicable for certain circuit-breaker types (single-pressure $SF_6$ and vacuum circuit-breakers). Calculation results can be different for other types of circuit-breakers. Using these calculations and setting the wear generated by list 1 at 100 %, list 2 results in 125 % and list 3 in 134 %. Therefore, list 3 can be used as an alternative to list 1 and to list 2 to reduce the number of different test circuits.

[b] When no reconditioning is made on the sample during and after the terminal fault tests, the test already carried out can be taken into account in determining the number of additional tests required to satisfy the requirements of Table 34. In practice, this means reducing these numbers marked [b] by 1.

# 8 Routine tests

Clause 8 of IEC 62271-1:2017 is applicable with the following addition.

## 8.1 General

Subclause 8.1 of IEC 62271-1:2017 is applicable.

## 8.2 Dielectric test on the main circuit

Subclause 8.2 of IEC 62271-1:2017 is applicable with the following addition:

In the case of circuit-breakers constructed by assembling identical making and breaking units in series, the test voltage to be applied across each single making and breaking unit, when open, shall be the higher fraction of the total withstand voltage resulting from actual power-frequency voltage distribution with the circuit-breaker fully open and one terminal earthed.

With reference to Figure 2 of IEC 62271-1:2017, which shows a diagram of a three-pole circuit-breaker, the test voltage shall be applied, according to Table 35.

**Table 35 – Application of voltage for dielectric test on the main circuit**

| Test condition N° | Circuit-breaker | Voltage applied to | Earth connected to |
|---|---|---|---|
| 1 | Open | ABC | abcF |
| 2 | Closed | AaCc | BbF |
| 3 | Closed | Bb | AaCcF |
| The tests in closed position are only required for metal-enclosed circuit-breakers.<br><br>NOTE If the insulation between poles is air at atmospheric pressure, test conditions n° 2 and 3 can be combined, the test voltage being applied between all parts of the main circuit connected together and the frame. | | | |

For circuit-breakers using compressed gas for insulation the gas pressure during the dielectric test on the main circuit shall be set at the minimum functional pressure for making and breaking and insulation. For sealed pressure systems, the gas pressure shall be the filling pressure for making and breaking and insulation.

In case of circuit-breakers using a gas mixture such as $SF_6/CF_4$ or $SF_6/N_2$, the test can be performed using the declared gas mixture at the minimum functional pressure for making and breaking and insulation or pure $SF_6$ at a total absolute pressure not exceeding the equivalent gas pressure ($P_{test}$) as calculated by the following equations (see Figure 4.1 of CIGRE Technical Brochure 163 [13]):

– for circuit-breakers using a $SF_6/N_2$ mixture: $P_{test} = P_{SF6} + 0{,}7 \times P_{add\ N_2}$ . The equation is valid for mixtures having at least 30 % of $SF_6$ gas volume (see Note);

– for circuit-breakers using a $SF_6/CF_4$ mixture: $P_{test} = P_{SF6} + 0{,}45 \times P_{add\ CF4}$ .

where

$P_{test}$ is the total absolute $SF_6$ pressure at $T$ = 20 °C during routine dielectric test on the main circuit;

$P_{SF6}$ is the partial pressure of $SF_6$ at $T$ = 20 °C at the minimum functional pressure for making and breaking and insulation according to the declared gas mixture;

$P_{add}$ is the partial pressure of $CF_4$ or $N_2$ at $T$ = 20 °C at the minimum functional pressure for making and breaking and insulation according to the declared gas mixture.

NOTE See CIGRE Technical Brochure 163 [13] for mixtures having less than 30 % $SF_6$.

### 8.2.101 Partial discharge measurement

For dead-tank circuit-breakers with rated voltage higher than 52 kV using solid insulating material to earth, a measurement of partial discharges shall be performed to detect possible material and manufacturing defects within these solid insulating parts.

The measurement of partial discharges should be preferably performed on the complete circuit-breaker. In this case, the measurement of partial discharges shall be performed during the dielectric test (8.2) and preferably after mechanical operating routine tests (8.101).

If a test on the complete circuit-breaker is impractical, it is allowed to replace the test on the complete circuit-breaker by partial discharge measurements on individual components, before assembly, such as bushings, insulators, partitions, insulated operating rods, etc. For partial discharge tests on bushings, 9.5 of IEC 60137:2017[8] is applicable.

The measurement shall be made in accordance with IEC 60270.

The applied power-frequency voltage shall be raised to a pre-stress value which is identical to the power-frequency withstand voltage test and maintained at that value for 1 min. Partial discharges occurring during this period shall be disregarded. Then, the voltage shall be decreased to the value defined in Table 36.

The extinction voltage shall be recorded during the reduction of the applied test voltage specified in Table 36.

**Table 36 – Test voltage for partial discharge test**

| | Circuit-breaker rated for $k_{pp}$ = 1,2 or 1,3 | | Circuit-breaker rated for $k_{pp}$ = 1,5 | |
|---|---|---|---|---|
| | **Pre-stress voltage** $U_{ps}$ (1 min) | **Test voltage for PD measurement** $U_{pd}$ (> 1 min) | **Pre-stress voltage** $U_{ps}$ (1 min) | **Test voltage for PD measurement** $U_{pd}$ (> 1 min) |
| Single-phase enclosure designs (phase-to-earth voltage) | $U_d$ | 1,2 × $U_r/\sqrt{3}$ | $U_d$ | 1,2 × $U_r$ |
| Three-phase enclosure designs | $U_d$ | $U_{pd, pe}$ = 1,2 × $U_r/\sqrt{3}$<br>$U_{pd, pp}$ = 1,2 × $U_r$ | $U_d$ | $U_{pd, pe}$ = 1,2 × $U_r$ |

$U_r$ voltage for equipment.

$U_d$ power-frequency withstand test voltage as per Tables 1, 2, 3 or 4 of IEC 62271-1:2017 for dead-tank circuit-breakers.

$U_{ps}$ pre-stress voltage.

$U_{pd}$ test voltage for PD measurement.

$U_{pd, pe}$ test voltage for PD measurement, phase-to-earth.

$U_{pd, pp}$ test voltage for PD measurement, phase-to-phase.

The maximum permissible partial discharge level shall not exceed 10 pC for dead-tank circuit-breakers at the test voltage specified in Table 36.

### 8.3 Tests on auxiliary and control circuits

Subclause 8.3 of IEC 62271-1:2017 is applicable.

### 8.4 Measurement of the resistance of the main circuit

Subclause 8.4 of IEC 62271-1:2017 is applicable.

### 8.5 Tightness test

Subclause 8.5 of IEC 62271-1:2017 is applicable.

### 8.6 Design and visual checks

Subclause 8.6 of IEC 62271-1:2017 is applicable with the following addition:

The following items shall be checked as applicable:

- the language and data on the nameplates;
- identification of any auxiliary equipment;
- the colour and quality of paint and corrosion protection of metallic surfaces;
- the values of the resistors and capacitors connected to the main circuit.

### 8.101 Mechanical operating tests

Mechanical operating tests shall be performed on all releases and shall include the following:

a) at maximum supply voltage of operating devices and of auxiliary and control circuits and maximum pressure for operation (if applicable):
   - five closing operations;
   - five opening operations.

b) at specified minimum supply voltage of operating devices and of auxiliary and control circuits and minimum functional pressure for operation (if applicable):
   - five closing operations;
   - five opening operations.

c) at rated supply voltage of operating devices and of auxiliary and control circuits and filling pressure for operation (if applicable):
   - five close-open operating cycles with the ~~tripping mechanism energised by the closing of the main contacts~~ the shortest possible CO time such that the circuit-breaker reaches the fully closed and latched position prior to opening;
   - moreover, for circuit-breakers intended for rapid auto-reclosing (see 5.104), five open-close operating cycles O – $t$ – C where $t$ shall be not more than the time interval specified for the rated operating sequence.

Mechanical operating tests should be made on the complete circuit-breaker. However, when circuit-breakers are assembled and shipped as separate making and breaking units, routine tests can be performed on components according to 7.101.1.2. In such cases, the manufacturer shall produce a programme of commissioning tests for use at site to confirm the compatibility of such separate making and breaking units and components when assembled as a circuit-breaker. A guidance for commissioning tests is given in 11.3.101.

For all required operating sequences the following shall be performed and records made of the closing and opening operations:

– measurement of operating times;
– where applicable, measurement of fluid consumption during operations, for example pressure difference.

Proof shall be given that the mechanical behaviour conforms to that of the test object used for type testing. For example, a no-load operating cycle, as described in 7.101.1.1, can be performed to record the no-load travel curves at the end of the routine tests. Where this is done, the curve shall be within the required envelope of the reference mechanical travel characteristic, as defined in 7.101.1.1, from the instant of contact separation to the end of the contact travel for an opening operation and from start of movement to contact touch for a closing operation.

Where the mechanical routine tests are performed on sub-assemblies, the reference mechanical travel characteristics shall be confirmed to be correct, as above, at the end of the commissioning tests on site.

If the measurement is performed on site, the manufacturer shall state the preferred measuring procedure. If other procedures are used, the results can be different and the comparison of the instantaneous contact stroke can be impossible to achieve.

The mechanical travel characteristics can be recorded directly, using a travel transducer or similar device on the circuit-breaker contact system or at other convenient locations on the drive to the contact system where there is a direct connection, and a representative image of the contact stroke can be achieved. The mechanical travel characteristics shall be preferably a continuous curve as shown in Figure 14. Where the measurements are taken on site, other methods can be applied which record points of travel during the operating period.

In these circumstances, the number of points recorded shall be sufficient to derive the time to, and contact speed at, contact touch and contact separation, together with the total travel time.

After completion of the required operating sequences, the following tests and inspections shall be performed (if applicable):

– connections shall be checked;
– the control and/or auxiliary switches shall correctly indicate the open and closed positions of the circuit-breaker;
– all auxiliary equipment shall operate correctly at the limits of supply voltage of operating devices and of auxiliary and control circuits and/or pressures for operation.

Furthermore the following tests and inspections shall be made (if applicable):

– measurement of the resistance of heaters (if fitted) and of the control coils;
– inspections of the wiring of the control, heater and auxiliary equipment circuits and checking of the number of auxiliary contacts, in accordance with the order specification;
– inspection of control cubicle (electrical, mechanical, pneumatic and hydraulic systems);
– recharging duration(s);
– functional performance of pressure relief valve of the operating mechanism;
– operation of electrical, mechanical, pneumatic or hydraulic interlocks and signalling devices;
– operation of anti-pumping device;
– general performance of equipment within the required tolerance of the supply voltage;
– inspection of earthing terminals of the circuit-breaker.

For self-tripping circuit-breakers, the releases or the relays shall be set at the minimum calibration mark on the scale of current settings.

It shall be shown that the overcurrent releases or relays correctly initiate the opening of the circuit-breaker with the current through the main circuit not exceeding 110 % of the minimum tripping current corresponding to the value set on the scale of current settings. A secondary injection test can be used as an alternative.

For these tests, the current through overcurrent releases, or through current transformers, can be supplied from a suitable low-voltage source.

For circuit-breakers fitted with under-voltage opening releases, it shall be shown that the circuit-breaker opens and can be closed when voltages within the specified limits are applied to the releases (see 6.9.5 of IEC 62271-1:2017).

If adjustments are required during the mechanical operating tests, the complete test sequence shall be repeated following the adjustments.

# 9 Guide to the selection of switchgear and controlgear (informative)

Clause 9 of IEC 62271-1:2017 is applicable with the following addition.

## 9.101 General

A circuit-breaker suitable for a given duty in service is best selected by considering the individual rated values required by load conditions and fault conditions.

The complete list of rated characteristics is given in Clause 5. The following individual ratings are dealt with in this clause.

| *Type of rating and characteristic* | *Subclause* |
|---|---|
| Rated voltage | 9.102.1 |
| Rated insulation level | 9.102.2 |
| Rated frequency | 9.102.3 |
| Rated continuous current | 9.102.4 |
| Rated short-circuit breaking current | 9.103.1 |
| Rated first-pole-to-clear factor | 9.103.2 |
| Rated out-of-phase making and breaking current | 9.103.3 |
| Rated short-circuit making current | 9.103.4 |
| Rated operating sequence | 9.103.5 |
| Rated duration of short-circuit | 9.103.6 |
| Classification as for electrical endurance (class E1 or E2 (with/without auto-reclosing duty)), where applicable | 9.104 |

For rated characteristics not dealt with in Clause 9, reference should, if applicable, be made to Clause 5 as follows:

| *Type of rating and characteristic* | *Subclause* |
|---|---|
| Rated short-time withstand current | 5.6 |
| Rated peak withstand current | 5.7 |
| Rated supply voltage of auxiliary and control circuits | 5.9 |
| Rated supply frequency of auxiliary circuits | 5.10 |
| Pressures of compressed gas supply for controlled pressure systems | 5.11 |
| Restrike performance (class C1 or C2) | 6.107.4 |
| Short-line fault current | 7.109 |
| Characteristics as for switching of capacitive loads (for example earthing conditions, type of capacitive load, etc.) | 5.106 |
| Rated line-charging breaking current | 5.106.2 |
| Rated cable-charging breaking current | 5.106.3 |
| Rated single capacitor bank breaking current | 5.106.4 |
| Rated back-to-back capacitor bank breaking current | 5.106.5 |
| Rated back-to-back capacitor bank inrush making current | 5.106.6 |
| Number of mechanical operations (class M1 or M2) | 6.107.2 |

Other parameters to be considered when selecting a circuit-breaker are, for example:

| | |
|---|---|
| Local atmospheric and climatic conditions | 9.102.5 |
| Use at high altitudes | 9.102.6 |
| Opening time | 9.103.1 |

The duty imposed by the fault conditions that a circuit-breaker is required to meet should be determined by calculating the fault currents at the place where the circuit-breaker is to be located in the system, in accordance with some recognised method of calculation.

When selecting a circuit-breaker, due allowance should be made for the likely future development of the system as a whole, so that the circuit-breaker may be suitable not merely for immediate needs but also for the requirements of the future.

Circuit-breakers which have satisfactorily completed type tests for a combination of rated values (i.e. voltage, continuous current, making and/or breaking current) are suitable for any lower rated values (with the exception of rated frequency) without further testing. Switching of inductive loads (magnetising currents of transformers, high-voltage motors and shunt reactors) is specified in IEC 62271-110 [14].

NOTE Some fault conditions such as evolving faults and some service conditions such as switching of arc furnaces are not dealt with in this document and are considered as special conditions subject to agreement between manufacturer and user.

The same is applicable to circuit-breakers used for any operation leading to a power-frequency recovery voltage higher than that corresponding to the rated voltage of the circuit-breaker, which can be the case at certain points of the system and, in particular, at the end of long lines. In this particular case, the value of current to be interrupted at the highest voltage which can occur across the terminals of the circuit-breaker when opening are subject to a similar agreement.

### 9.102 Selection of rated values for service conditions

#### 9.102.1 Selection of rated voltage

The rated voltage of the circuit-breaker should be chosen so as to be at least equal to the highest voltage of the system at the point where the circuit-breaker is to be installed.

The rated voltage of a circuit-breaker should be selected from the standard values given in 5.2 of IEC 62271-1:2017.

In selecting the rated voltage the corresponding insulation levels specified in 5.2 should also be taken into account (see also 9.102.2).

#### 9.102.2 Insulation coordination

The rated insulation level of a circuit-breaker should be selected according to 5.3.

The values in the tables stated there apply to both indoor and outdoor circuit-breakers. It should be specified in the enquiry whether the circuit-breaker is to be of indoor or outdoor type.

The insulation coordination in an electrical system serves to minimise damage to the electrical equipment due to overvoltages and tends to confine flashovers (when these cannot be economically avoided) to points where they will cause no damage.

Precautions should be taken to limit the overvoltages on the terminals of the circuit-breaker to stated values below the insulation level (see IEC 60071-2).

Where a circuit-breaker is required for a position necessitating a higher insulation level, this should be specified in the enquiry (see 10.2).

For circuit-breakers with $U_r$ > 245 kV for use in synchronisation operations simultaneously with a substantial transient or temporary overvoltage, the insulation of a standard circuit-breaker may be insufficient. In such cases it is suggested to use a standard circuit-breaker having a higher rated voltage or to use a special circuit-breaker, increasing the severity of the test with the circuit-breaker open. The test procedure for this test is described in 7.2.6.3 of IEC 62271-1:2017. The standard values of rated power frequency and rated switching impulse withstand voltage across the open switching device are given in columns (3) and (6) of Tables 3 and 4 of IEC 62271-1:2017.

When selecting circuit-breakers for service, it is also necessary to take into account their characteristics in respect of transient phenomena and overvoltages. Experience shows that the unfavourable effects of transient phenomena and the risk of overvoltages for certain critical cases of application can be minimised by

– appropriate selection of the type of circuit-breaker;
– changes in the system or the use of additional equipment for damping and limiting transient phenomena (RC circuits, overvoltage arresters, non-linear resistances, etc.).

These precautions shall be discussed with the manufacturer for individual cases. Special tests can be agreed for evaluating the selected solution.

#### 9.102.3 Rated frequency

The manufacturer should be consulted if a circuit-breaker is to be used at any frequency other than its rated frequency (see 5.4 of IEC 62271-1:2017).

When circuit-breakers rated 50 Hz are tested at 60 Hz and vice versa, care should be exercised in the interpretation of the test results, taking into account all significant facts such as the type of circuit-breaker and the type of test performed.

### 9.102.4 Selection of rated continuous current

The rated continuous current of a circuit-breaker should be selected from the standard values given in 5.5.

It should be noted that circuit-breakers have no specified continuous overcurrent capability. When selecting a circuit-breaker therefore, the rated continuous current should be such as to make it suitable for any load current that can occur in service. Where intermittent overcurrents are expected to be frequent and severe, the manufacturer should be consulted.

### 9.102.5 Local atmospheric and climatic conditions

The normal atmospheric and climatic conditions for circuit-breakers are given in Clause 4.

For outdoor circuit-breakers, the atmospheric conditions in certain areas are unfavourable on account of smoke, chemical fumes, salt-laden spray and the like. Where such adverse conditions are known to exist, special consideration should be given to the design of those parts of the circuit-breaker, especially the insulators, normally exposed to the atmosphere.

The performance of an insulator in such atmospheres also depends on the frequency of washing or cleaning operations and on the frequency of natural washing by rain. Since the performance of an insulator under such conditions is dependent on so many factors, it is not possible to give precise definitions of normal and heavily polluted atmospheres. Experience in the area where the insulator is to be used is the best guide.

The manufacturer should be consulted when the circuit-breaker is to be located where the wind speed exceeds 34 m/s.

If a circuit-breaker is to be located where an ice-coating exceeding 20 mm is expected, agreement should be reached between manufacturer and user as to the ability of the circuit-breaker to perform correctly under such conditions.

Where applicable, the seismic qualification level should be specified by the user. Subclause 4.2.5 of IEC 62271-1:2017 should be taken into account.

For indoor installations, the humidity conditions are given in 4.1.2e) of IEC 62271-1:2017. When selecting the circuit-breaker for service, it is recommended to indicate the cases, where the high values of humidity are expected and condensation can occur.

For indoor circuit-breakers, the manufacturer should be consulted for any special service conditions, for example when chemical fumes, aggressive atmosphere, salt laden spray, etc., are present.

### 9.102.6 Use at high altitudes

The normal service conditions specified in Clause 4 of IEC 62271-1:2017 provide for circuit-breakers intended for use at altitudes not exceeding 1 000 m.

For installation at altitudes above 1 000 m, 4.2.2 of IEC 62271-1:2017 is applicable.

## 9.103 Selection of rated values for fault conditions

### 9.103.1 Selection of rated short-circuit breaking current

As stated in 5.101, the rated short-circuit breaking current is expressed by two values:

a) the RMS value of its AC component;

b) the DC time constant.

The rated short-circuit breaking current should be selected from the standard values given in 5.101.2.

The percentage DC component, as shown in Figure 9, varies with time from the incidence of the short-circuit and with the corresponding DC time constant of the rated short-circuit breaking current. The percentage DC component at contact separation can be determined by applying the equation given in 7.107.6. Standard DC time constants are specified in 5.101.3. The corresponding last current loop parameters are defined in Table 10 and Table 11 for the minimum clearing time range. The minimum clearing time is defined in 3.7.151.

The curves in Figure 9 are based on a constant AC component and on a DC time constant $\tau$ = 45 ms (i.e. the standard DC time constant for rated voltages up to and including 800 kV), 60 ms, 75 ms and 120 ms (i.e. the standard DC time constant for rated voltages higher than 800 kV).

A circuit-breaker tested with a higher DC time constant covers application at lower DC time constants.

The terminal fault test-duties, see 7.107, together with the critical current tests, see 7.108.1, and where applicable, short-line fault tests, see 7.109, have been chosen to prove the capability of the circuit-breaker for all values of current up to the rated short-circuit current. Therefore, for situations where the prospective short-circuit current of the network is lower, it is not necessary to perform a short-circuit test series based on a lower rated short-circuit breaking current.

When circuit-breakers are installed in the vicinity of centres of generation, the AC component can decrease more quickly than in the normal case. The short-circuit current may then not have a current zero for a number of cycles. In such circumstances the duty of the circuit-breaker can be eased, for example, by delaying its opening, or by connecting an additional damping device with another circuit-breaker and opening the circuit-breakers in sequence. If the standard or special case DC time constants values cannot be adhered to, the required percentage should be specified in the enquiry and testing should be subject to agreement between manufacturer and user.

NOTE The current zero crossing can be advanced by the effects of the arc voltages of the circuit-breaker and/or the making and breakings of the short-circuit currents in the other phases with earlier current zero crossings. For such circumstances, standard circuit-breakers are applicable subject to careful investigation.

### 9.103.2 Selection of TRV and $k_{pp}$ for terminal fault and characteristics for short-line faults

The prospective TRV of the system should not exceed the reference line representing the TRV specified for the circuit-breaker; it should cross the specified delay line close to zero voltage but should not re-cross it later (see 7.105.5). Standard values are shown in 7.105.5.

NOTE 1 The TRVs which appear when breaking the highest short-circuit currents are not necessarily more severe than those which appear in other cases. For example, the rate-of-rise of TRV can be higher when breaking smaller short-circuit currents.

In the range of rated voltages higher than 1 kV and less than 100 kV, in order to cover all types of networks (distribution, industrial and sub-transmission) and for standardisation purposes, two classes of circuit-breakers are specified depending on their connection to the network (see 6.107.3).

The following considerations should facilitate the choice by the user of the class S1 or S2:

– TRV values specified in IEC 62271-100:2001 and IEC 62271-100:2001/AMD1:2002 can still be required by specifying class S1 (these are given in Table 16 and Table 17);
– to cover applications type S1 and S2, except those mentioned in a), b) and c) below, class S2 of circuit-breakers shall be specified (TRV values are given in Table 18 and Table 19).

NOTE 2 In the special cases where the total length of cable (or equivalent length when capacitors are also present) on the supply side of the circuit-breaker is between 20 m and 100 m, the system is considered as a line system except if a calculation can show that the actual TRV is covered by the envelope defined from Table 16 and Table 17. If the TRV is covered the system is then considered as a cable system.

The TRV values given for rated voltages below 100 kV are applicable to a rated $k_{pp}$ of 1,3 or 1,5. For rated voltages 100 kV to 800 kV, the rated $k_{pp}$ is 1,3 since most systems at 100 kV and above are effectively earthed. For rated voltages 100 kV to 170 kV, the choice of $k_{pp}$ between 1,3 and 1,5 is provided for those special cases with non-effectively earthed neutrals (see also the note in 7.105.5.4). For rated voltages higher than 800 kV the rated $k_{pp}$ is 1,2.

The values of $k_{pp}$ of 1,3 and 1,2 are based on a system with effectively earthed neutral where three-phase faults not involving earth are considered highly improbable. For applications in non-effectively earthed neutral systems, $k_{pp}$ = 1,5 should be used. For applications in systems with effectively-earthed neutral in cases where the probability of three-phase faults not involving earth cannot be disregarded, and for applications in systems other than with effectively-earthed neutral systems, $k_{pp}$ = 1,5 can be necessary.

Generally, it will not be necessary to consider alternative TRV as the standard values specified cover the majority of practical cases.

More severe conditions can occur in some cases, for example:

a) One case is when a short-circuit occurs close to a transformer but on the opposite side to the circuit-breaker and where there is no appreciable additional capacitance between the transformer and the circuit-breaker. In this case both the peak voltage and rate-of-rise of TRV can exceed the values specified in this document.

   Care should also be taken when selecting a circuit-breaker for the primary side of a transformer which may have to interrupt a short-circuit on the secondary side.

   Such cases are covered in Annex F.

b) Circuit-breakers being used next to current-limiting reactors can fail to interrupt due to the high natural frequency of these reactors (see 9.103.7).

c) In the case of a short-circuit on circuit-breakers close to generators, the rate-of-rise of TRV can exceed the values specified in this document.

In such cases it can be necessary for special TRV characteristics to be agreed between manufacturer and user.

When circuit-breakers are required for installations necessitating the assignment of rated characteristics for short-line faults, the line on which they are to be used should have a surge impedance and peak-factor not greater than, and a time delay not less than, the standard values of rated line characteristic given in Table 29. However, if this should not be the case, it is still possible that a standard circuit-breaker is suitable, especially if the short-circuit current of the system is less than the rated short-circuit breaking current of the circuit-breaker. This can be established by calculating the prospective TRV for short-line faults from the rated characteristics by the method given in Annex A and comparing this with the prospective TRV derived from the actual characteristics of the system.

If special characteristics for short-line faults are required, they should be agreed between manufacturer and user.

A higher rate of rise than specified in Table 16 through Table 21 can occur when one circuit-breaker terminal is transformer-connected. Circuit-breakers tested in accordance with this document are considered to comply with this higher rate-of-rise requirement, provided that they have satisfied test-duty T30 of the terminal fault test-duties (see 7.107.3).

### 9.103.3 Selection of out-of-phase characteristics

The out-of-phase requirements of this document cater for the great majority of applications of circuit-breakers intended for out-of-phase conditions. Several circumstances would have to be combined to produce a severity in excess of those covered by the specific tests of the standard and, as out-of-phase conditions are rare, it would be uneconomical to design circuit-breakers for the most extreme conditions.

The actual system conditions should be considered when frequent out-of-phase conditions are expected or where excessive stresses are probable.

A special circuit-breaker, or one rated at a higher voltage, can sometimes be required. As an alternative solution, the severity of out-of-phase duty is reduced in several systems by using relays with coordinated impedance-sensitive elements to control the tripping instant, so that breaking will occur either substantially after or substantially before the instant the phase angle reaches 180°.

In the case of applications of circuit-breakers with rated voltages higher than 800 kV, an out-of-phase angle of approximately 115° is covered by the specific tests of this document; however, higher values of angle are covered when considering other factors such as the non-simultaneity of voltage peaks, lower $k_{pp}$ (see IEC TR 62271-306 [4]).

### 9.103.4 Selection of rated short-circuit making current

As stated in 5.103, the rated short-circuit making current is derived from the rated voltage and is related to the rated frequency and the DC time constant of the rated short-circuit current. For a rated frequency of 50 Hz and based on a time constant $\tau$ = 45 ms, it is 2,5 times (i.e. approximately 1,8√2 times) the AC component of the rated short-circuit breaking current of the circuit-breaker. For a rated frequency of 60 Hz and based on a time constant $\tau$ = 45 ms, it is 2,6 times the AC component of the rated short-circuit breaking current of the circuit-breaker.

If one of the other DC time constants (60 ms, 75 ms or 120 ms) stated in 5.101.3 applies, taking the explanations given in Annex A of IEC TR 62271-306:2012 [4] into account, the rated short-circuit making current is 2,7 times the AC component of the rated short-circuit breaking current of the circuit-breaker, for both 50 Hz and 60 Hz rated frequencies.

The selected circuit-breaker should have a rated short-circuit making current not less than the highest peak value of the short-circuit currents expected at the application point.

In some cases, for example when induction motors are electrically close, the maximum peak value of the fault current can be more than the AC component of the short-circuit current multiplied by the factors given above. In such cases, a special design should be avoided and a standard circuit-breaker having a suitable rated short-circuit making current should be selected.

### 9.103.5 Operating sequence in service

The rated operating sequence of a circuit-breaker is given in 5.104.

When the operating sequence in service is more severe than is provided for in this document, this should be specified by the user in his enquiry and/or order in such a way that the manufacturer can modify the rating of the circuit-breaker appropriately. Examples of circuit-breakers for special duty are those used for controlling arc furnaces, electrode boilers and, in certain cases, rectifiers. Single-pole operation of a multi-pole circuit-breaker, for example with a view to single-phase making and breaking, is also a special duty.

### 9.103.6 Selection of rated duration of short-circuit

The standard value of rated duration of short-circuit (5.8 of IEC 62271-1:2017) is 1 s.

If, however, a lower or higher duration is necessary, the recommended values of 0,5 s, 2 s and 3 s should be selected as the rated value.

For short-circuit durations greater than the rated duration, the relation between current and time, unless otherwise stated by the manufacturer, is in accordance with the equation:

$$I^2 \times t = \text{constant}$$

### 9.103.7 Faults in the presence of current limiting reactors

Due to the very small inherent capacitance of a number of current limiting reactors, the natural frequency of transients involving these reactors can be very high. A circuit-breaker installed immediately in series with such type of reactor will face a high frequency TRV when clearing a terminal fault (reactor at supply side of circuit-breaker) or clearing a fault behind the reactor (reactor at load side of circuit-breaker). The resulting TRV frequency generally exceeds by far the standardised TRV values.

In these cases, it is necessary to take mitigation measures, such as the application of capacitors in parallel to the reactors or connected to earth. The available mitigation measures are very effective and cost efficient. It is strongly recommended to use them, unless it can be demonstrated by tests that a circuit-breaker can successfully clear faults with the required high frequency TRV.

The mitigation method should be such that the rate-of-rise of TRV for the fault current, as limited by the series reactor, is reduced to a value lower than the standard values given in Table 16 through Table 21, depending on the circuit-breaker ratings. It shall be considered that the fault current can be close to 100 % of the rating of the circuit-breaker.

Based on the preceding considerations, no rated values of TRV and no special test-duty are specified for this fault case.

### 9.104 Selection for electrical endurance in networks of rated voltage above 1 kV and up to and including 52 kV

The electrical endurance capability of a class E2 circuit-breaker (see 6.107.5) is demonstrated by performing the short-circuit test-duties of 7.107 without intermediate maintenance. This electrical endurance is considered to be sufficient for circuit-breakers used on cable connected networks, where auto-reclosing ~~is~~ should not ~~required~~ be applied. If intermediate maintenance is permissible, then a circuit-breaker class E1 (see 6.107.5) can be selected.

For the more severe conditions of use on an overhead-line connected network, including auto-reclosing duty, a class E2 circuit-breaker capable of meeting the electrical endurance requirements specified in 7.112 is recommended.

### 9.105 Selection for switching of capacitive loads

Caution is required where capacitor banks are to be installed at substations where cables are already installed, and vice versa, as this can inflict back-to-back making and breaking duties on the controlling circuit-breakers for these circuits. The back-to-back duty can be similar to that detailed in 6.107.4.

## 10 Information to be given with enquiries, tenders and orders (informative)

### 10.1 General

Subclause 10.1 of IEC 62271-1:2017 is applicable.

### 10.2 Information with enquiries and orders

Subclause 10.2 of IEC 62271-1:2017 is applicable with the following edition.

When enquiring for or ordering a circuit-breaker, the following particulars should be supplied by the enquirer:

a) particulars of systems, i.e. nominal and highest voltages, frequency, number of phases and details of neutral earthing;

b) service conditions including minimum and maximum ambient air temperatures, altitude if over 1 000 m and any special conditions likely to exist or arise, for example unusual exposure to water vapour, moisture, fumes, explosive gases, excessive dust or salt air (see 9.102.5 and 9.102.6);

c) characteristics of circuit-breaker.

The following information should be given:

| Type of information | Reference |
|---|---|
| 1) number of poles | |
| 2) indoor or outdoor | 9.102.5 |
| 3) rated voltage | 9.102.1 |
| 4) rated insulation level where a choice exists between different insulation levels corresponding to a given rated voltage, or, if other than standard, the desired insulation level | 9.102.2 |
| 5) rated frequency | 9.102.3 |
| 6) rated continuous current | 9.102.4 |
| 7) rated short-circuit breaking current | 9.103.1 |
| 8) rated first-pole-to-clear factor | 9.103.2 |
| 9) rated operating sequence | 9.103.5 |

| Type of information | Reference |
|---|---|
| 10) the number of mechanical operations (class M1 or M2) | 6.107.2 |
| 11) the type tests specified under special request (for example artificial pollution and radio interference, etc.) | 7.2.9 and 7.3 |
| The following information should be given, if the required performance is other than standard | |
| 12) desired TRV for terminal faults | 9.103.2 |
| 13) desired characteristics for short-line faults | 9.103.2 |
| 14) desired short-circuit making current | 9.103.4 |
| 15) desired duration of short-circuit | 9.103.6 |
| The following information should be given in the case of applicability | |
| 16) short-line fault current | 7.109 |
| 17) rated out-of-phase making and breaking current | 5.105 |
| 18) restrike performance (Class C1 or C2) | 6.107.4 |
| 19) characteristics of the capacitive load (for example, earthing conditions, type of capacitive load etc.) | 5.106 |
| 20) rated line-charging breaking current | 5.106.2 |
| 21) rated cable-charging breaking current | 5.106.3 |
| 22) rated single capacitor bank breaking current | 5.106.4 |
| 23) rated back-to-back capacitor bank breaking current | 5.106.5 |
| 25) rated back-to-back capacitor bank inrush making current | 5.106.6 |
| 26) characteristic for electrical endurance (class E1 or E2 (with/without auto-reclosing duty)) | 6.107.5 |
| 27) any test exceeding the standardised type, routine and commissioning tests | |

d) characteristics of the operating mechanism of circuit-breaker and associated equipment, in particular:
   1) method of operation, whether manual or power;
   2) number and type of spare auxiliary switches;
   3) rated supply voltage and rated supply frequency;
   4) number of releases for tripping, if more than one;
   5) number of releases for closing, if more than one.

e) requirements concerning the use of compressed gas and requirements for design and tests of pressure vessels.

The enquirer should give information of any special conditions not included above, that might influence the tender or order (see also the note in 9.101).

### 10.3 Information to be given with tenders

Subclause 10.3 of IEC 62271-1:2017 is applicable with the following addition:

When the enquirer requests technical particulars of a circuit-breaker, the following information (those which are applicable) should be given by the manufacturer, with the descriptive matter and drawings:

a) rated values and characteristics:

| Type of information | Reference |
|---|---|
| 1) number of poles | |
| 2) indoor or outdoor, temperature, ice-coating | 9.102.5 |
| 3) rated voltage | 9.102.1 |
| 4) rated insulation level | 9.102.2 |
| 5) rated frequency | 9.102.3 |
| 6) rated continuous current | 9.102.4 |
| 7) rated short-circuit breaking current | 9.103.1 |
| 8) rated first-pole-to-clear factor | 9.103.2 |
| 9) rated operating sequence | 9.103.5 |
| 10) opening time, break-time and closing time | 6.105 |
| 11) class M1 or class M2 for mechanical endurance | 6.107.2 |
| 12) the type tests specified under special request (for example artificial pollution and radio interference etc.) | 7.2.9 and 7.3 |
| **The following information should be given, if the required performance is other than standard** | |
| 13) TRV for terminal faults | 9.103.2 |
| 14) characteristics for short-line faults | 9.103.2 |
| 15) rated short-circuit making current | 9.103.4 |
| 16) rated duration of short-circuit | 9.103.6 |
| The following information should be given in the case of applicability | |
| 17) rated out-of-phase making and breaking current | 5.105 |
| 18) restrike performance (class C1 or C2) | 6.107.4 |
| 19) characteristics for capacitive current conditions | 5.106 |
| 20) rated line-charging breaking current | 5.106.2 |
| 21) rated cable-charging breaking current | 5.106.3 |
| 22) rated single capacitor bank breaking current | 5.106.4 |
| 23) rated back-to-back capacitor bank breaking current | 5.106.5 |
| 24) rated back-to-back capacitor bank inrush making current | 5.106.6 |
| 25) class S1, S2 circuit-breakers (circuit-breakers with rated voltage less than 100 kV) | 6.107.3 |
| 26) class E1 or class E2 (with/without auto re-close) for electrical endurance | 6.107.5 |
| 27) any test exceeding the standardised type, routine and commissioning tests | |



b) type tests:

certificate or report on request;

c) constructional features:

The following details are required where they are applicable to the design:

1) mass of complete circuit-breaker without fluids for insulation, making and breaking and operation;
2) mass/volume of fluid for insulation, its quality and operating range, including the minimum functional value;
3) mass/volume of fluid for making and breaking (where different fluid to items 2) and/or 4)), its quality and operating range, including the minimum functional value;

4) mass/volume of fluid for operation (where different fluid to items 2) and/or 3)), its quality and operating range, including the minimum functional value;
5) tightness qualification;
6) mass/volume of fluids per pole to fill to a level sufficient to prevent deterioration of internal components during storage and transportation;
7) number of making and breaking units in series per pole;
8) minimum clearances in air:
   – between poles;
   – to earth;
   – the safety boundaries during a breaking operation, for circuit-breakers with an external exhaust for ionised gasses or flame;
9) any special arrangements (for example heating or cooling) to maintain the rated characteristics of the circuit-breaker at the required temperatures of the ambient air;

d) operating mechanism of circuit-breaker and associated equipment:
   1) type of operating mechanism;
   2) whether the circuit-breaker is suitable for trip-free or fixed trip operation and whether it is provided with lock-out preventing closing;
   3) rated supply voltage and/or pressure of closing mechanism, pressure limits where different to or expanding data required in c) 4) of 10.3;
   4) current required at rated supply voltage to close the circuit-breaker;
   5) energy expended to close the circuit-breaker, for example measured as a fall in pressure;
   6) rated supply voltage of shunt opening release;
   7) current required at rated supply voltage for shunt opening release;
   8) number and type of spare auxiliary switches;
   9) current required at rated supply voltage by other auxiliaries;
   10) setting of high and low pressure interlocking devices;
   11) number of releases for tripping, if more than one;
   12) number of releases for closing, if more than one;

e) overall dimensions and other information:

   The manufacturer should give the necessary information as regards the overall dimensions of the circuit-breaker and details necessary for the design of the foundation.

   General information regarding maintenance of the circuit-breaker and its connections should be given.

# 11 Transport, storage, installation, operation instructions and maintenance

## 11.1 General

Subclause 11.1 of IEC 62271-1:2017 is applicable.

## 11.2 Conditions during transport, storage and installation

Subclause 11.2 of IEC 62271-1:2017 is applicable.

## 11.3 Installation

Subclauses 11.3 of IEC 62271-1:2017 are applicable, with the following addition.

### 11.3.101 Commissioning tests

After a circuit-breaker has been installed and all connections have been completed, commissioning tests are recommended to be performed. The purpose of these tests is to confirm that transportation and storage have not damaged the circuit-breaker. In addition, when a large part of the assembly and/or of the adjustment is performed on site, as identified in 8.101, the tests are required to confirm compatibility of the sub-components and the satisfactory nature of both the site work and the functional characteristics dependent upon it.

In addition to the requirements of 11.3.102, a minimum of 50 no-load operations shall be performed on site on the circuit-breaker where major sub-assemblies are combined at site without previous routine tests on the complete circuit-breaker. These operations shall be performed after assembly, all connections and checks having been made and the programme of commissioning tests having been completed. These operations can include deferred routine test operations forming part of the commissioning programme only where they are made after all site adjustments and tightness checks are complete. The purpose of these tests is to reduce occurrences of maloperation and failure early in the operational life of the circuit-breaker.

The manufacturer shall produce a programme of site commissioning checks and tests. Repetition of the full programme of routine tests, already performed in the factory, shall be avoided as the purpose of commissioning tests is for confirmation of

- absence of damage;
- compatibility of separate making and breaking units;
- correct assembly;
- correct performance of the assembled circuit-breaker.

In general, this is achieved when the commissioning tests include, but are not limited to, the programme given in 11.3.102. The results of the tests shall be recorded in a test report.

### 11.3.102 Commissioning checks and test programme

#### 11.3.102.1 Checks after installation

##### 11.3.102.1.1 General

Subclause 11.3.101 requires the manufacturer to produce a programme of commissioning checks and tests. This should be based on, but is not limited to, the programme of checks and tests given here.

##### 11.3.102.1.2 General checks

- assembly conforms to manufacturer's drawings and instructions;
- tightness of circuit-breaker, its fastenings, fluid systems and control devices;
- external insulation and, where applicable, internal insulation are undamaged and clean;
- paint and other corrosion protection are sound;
- operating devices, especially operating releases, are free from contamination;
- adequacy and integrity of the earth connection up to and including the interface with the substation earthing system;

and, where applicable:

- record the number on the operations counter(s) at delivery;
- record the number on the operations counter(s) at completion of all site testing;
- record the number on the operations counter(s) at first energisation.

#### 11.3.102.1.3 Checks of electrical circuits

- Conformity to the wiring diagram.
- Correct operation of signalling (position, alarms, lockouts, etc.).
- Correct operation of heating and lighting.

#### 11.3.102.1.4 Checks of the insulation and/or extinguishing fluid(s)

| | |
|---|---|
| Oil | Type, dielectric strength (IEC 60296 [16]), level |
| Gas | Filling pressure/density, and quality checks, to confirm the acceptance levels of IEC 60376 [17], IEC 60480 [18] and IEC 62271-4 [19] as applicable. These quality checks are not required on sealed equipment and new gas used from sealed bottles. A dewpoint check and a check of the total impurities shall be carried out to confirm the manufacturer's acceptance levels |
| Gas mixtures | Quality to be confirmed prior to energisation |
| Compressed air | Quality (if applicable) and pressure |

#### 11.3.102.1.5 Checks on operating fluid(s), where filled or added to on site

| | |
|---|---|
| Hydraulic oil | Level and, unless otherwise agreed, confirmation that the moisture content is sufficiently low to prevent internal corrosion or other damage to the hydraulic system |
| Nitrogen | Filling pressure and purity (for example oxygen free or 1 % tracer gas) |

#### 11.3.102.1.6 Site operations

Confirmation shall be given that the programme of commissioning checks and tests required by 8.101 has been completed and, where applicable, extended by the additional 50 operations required by 11.3.101.

### 11.3.102.2 Mechanical tests and measurements

#### 11.3.102.2.1 Measurements of the characteristic insulating and/or making and breaking fluid pressures (where applicable)

The following measurements shall be taken in order to compare them with the values both recorded during the routine tests and guaranteed by the manufacturer. These values serve as the reference for future maintenance and other checks and will enable any drift in operating characteristics to be detected.

The purpose of these measurements is to verify that pre-set pressure (density) levels of pressure or density switches, where applicable, for signalling, alarms and lockouts are within operating tolerances. These measurements shall be performed on rising pressure and/or dropping pressure depending of the manufacturer instructions for checking operating characteristics of pressure (or density) devices. Allowable tolerances from the pre-set pressure (density) level(s) shall be given by the manufacturer.

#### 11.3.102.2.2 Measurements of characteristic operating fluid pressures (if applicable)

##### 11.3.102.2.2.1 General

The following measurements (list to be adapted as necessary) should be taken, in order to compare them with the values both recorded during routine tests and guaranteed by the manufacturer. These values can serve as a reference during later checks (maintenance) and will enable any drift in operating characteristics to be detected.

The measurements involve a check of the operation of the lockout or alarm devices (pressure switches, relays, etc.).

##### 11.3.102.2.2.2 Measurements to be taken

a) On a rise in pressure with the pumping device (pump, compressor, controlled valve, etc.) in service:
   – the reset value of the opening lockout;
   – the reset value of the closing lockout;
   – the reset value of the auto-reclosing lockout (if applicable);
   – disappearance of the low-pressure alarm;
   – cut-off of the pumping device;
   – opening of the safety valve (if applicable).

NOTE The measurements can be combined with the measurements of the recharging time of the operating mechanism (see 11.3.102.2.5.2).

b) On a drop in pressure with the pumping device switched off:
   – closing of the safety valve (if applicable);
   – starting of the pumping device;
   – appearance of the low-pressure alarm;
   – lockout of the auto-reclosing (if applicable);
   – lockout of the closing;
   – lockout of the opening.

In the case of a hydraulic control, the pre-inflation pressure of the accumulators should be indicated together with the ambient air temperature before the tests are performed.

#### 11.3.102.2.3 Measurement of consumption during operations (if applicable)

With the pumping device switched off and the individual reservoir at the cut-in pressure of the pumping device, the consumption during each of the following operations or operating sequences should be evaluated:

– O three-pole;
– C three-pole;
– O – 0,3 s – CO three-pole (if applicable).

The steady-state pressure after each operation or operating sequence should be noted.

#### 11.3.102.2.4 Verification of the rated operating sequence

The ability of the circuit-breaker to perform its specified rated operating sequence should be verified. The tests should be performed with the recharging device in service, with site supply voltage and, if applicable, starting with the cut-in pressure of the pumping device, as in 11.3.102.2.3.

Evidence should be given to demonstrate the coordination between the interlocking device intervention levels and the minimum pressures for operation measured during the rated operating sequence.

The site supply voltage is the on-load voltage available at the circuit-breaker from the normal site supply and should be compatible with the rated supply voltage of auxiliary and control circuits.

#### 11.3.102.2.5 Measurement of time quantities

##### 11.3.102.2.5.1 Characteristic time quantities of the circuit-breaker

a) Closing and opening times, time spread

The following measurements should be made at maximum pressure (cut-off of pumping device) and at the supply voltage of the auxiliary and control circuits, measured at the terminals of the equipment and under typical load conditions of the supply voltage source:

– closing time of each pole, time spread of the poles and when possible time spread of the making and breaking units or groups of making and breaking units of each pole;

– opening time of each pole, time spread of the poles and when possible time spread of the making and breaking units or groups of making and breaking units of each pole.

These measurements should be carried out for separate opening and closing operations and for the individual opening and closing operations of a CO operating cycle, in case of an O – $t$ – CO operating sequence or in case of a circuit-breaker with a rated operating sequence O – $t$ – CO – $t'$ – CO.

In the case of multiple trip coils, all should be tested and the times recorded for each.

The supply voltage before and during the operations should be recorded. Furthermore, the instant at which the three-pole control relay, if any, is energised should also be recorded to enable calculation of the total time in three-pole operation (relay time plus closing or opening time).

When the circuit-breaker is provided with closing or opening resistors, the resistor insertion times should be recorded.

b) Operation of control and auxiliary contacts

The timing of the operation of one of each kind (make and break) of control and auxiliary contacts should be determined in relation to the operation of the main contacts, on closing and on opening of the circuit-breaker.

##### 11.3.102.2.5.2 Recharging time of the operating mechanism

a) Fluid-operated mechanism

The operation time of the pumping device (pump, compressor, control valve, etc.) should be measured:

– between minimum and maximum pressure (cut-in and cut-off of the pumping device);

– during the following operations or operating sequence, starting each time with minimum pressure (cut-in of the pumping device):

  • C three-pole;
  • O three-pole;
  • O – 0,3 s – CO three-pole (if applicable).

b) Spring-operated mechanism

The recharging time of the motor after a closing operation should be measured at the site supply voltage.

#### 11.3.102.2.6 Record of mechanical ~~travel~~ characteristics

As required by 8.101, a record can be made of the mechanical ~~travel~~ characteristics where the circuit-breaker has been assembled as a complete circuit-breaker for the first time on site or where all or part of the routine tests are performed on site. The record shall confirm satisfactory performance by comparison with the reference mechanical ~~travel~~ characteristics obtained during the reference no-load tests detailed in 7.101.1.1.

#### 11.3.102.2.7 Checks of certain specific operations

##### 11.3.102.2.7.1 Auto-reclosing at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered to the lockout value for auto-reclosing and an auto-reclosing operating sequence be carried out (under site conditions it can be necessary to use a separate timing device to initiate reclosure). The test should be conducted at the supply voltage of the equipment with full current flowing. The supply voltage before and during the operations should be recorded. The final pressure should be noted and it should be ensured that there is sufficient safety margin to the minimum functional pressure for operation for opening, as a guard against pressure switch deviation and pressure transients.

In case of doubt, an alternative test to the one described above can be performed, starting with a lower pressure than the minimum functional pressure for operation for auto-reclosing (short-circuited contact). It should then be verified that an opening operation is still possible.

##### 11.3.102.2.7.2 Closing at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered as far as the lockout value for closing and a closing operation be carried out. The test should be conducted at the supply voltage of the equipment with full current flowing. The supply voltage before and during the operations should be recorded. The final pressure should be noted and a sufficient safety margin ensured to the minimum functional pressure for operation for opening.

In case of doubt, an alternative test to the one described above can be performed, starting with a lower pressure than the minimum functional pressure for operation for closing (short-circuited contact). It should then be verified that an opening operation is still possible.

##### 11.3.102.2.7.3 Opening at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered as far as the lockout value for opening and an opening operation be carried out. The test should be conducted at the supply voltage of the equipment with full current flowing. The supply voltage before and during the operations should be recorded. The final pressure should be noted.

##### 11.3.102.2.7.4 Simulation of fault-making operation and check of anti-pumping device

Measurement should be taken of the time during which the circuit-breaker remains closed on a CO operating cycle with the trip circuit energised by the closing of the auxiliary contact.

The test also allows checking of the anti-pumping device operation and the absence of malfunction for any mechanical, hydraulic or pneumatic reasons, caused by the rapid application of the opening command.

The closing command should be maintained for 1 s to 2 s in order that the anti-pumping device can be checked for effective operation.

NOTE A simplified anti-pumping test can also be executed, using the local control. In this case, a closing command is applied and maintained, while a consecutive opening command is applied.

**11.3.102.2.7.5 Behaviour of the circuit-breaker on a closing command while an opening command is already present**

It should be verified that the circuit-breaker meets the technical specifications in the presence of a closing command when previously an opening command is applied and maintained.

**11.3.102.2.7.6 Application of an opening command on both releases simultaneously (if applicable)**

It can happen that both releases (normal and emergency) are energised simultaneously (or virtually simultaneously).

It should be ensured that the operations are not subject to any mechanical, hydraulic or pneumatic interference, particularly if the releases do not operate at the same level.

**11.3.102.2.7.7 Protection against pole discrepancy (if applicable)**

Protection against pole discrepancy should be checked by either of the following tests:

– with the circuit-breaker open, the closing release of one of the poles shall be energised and a check carried out to see that it closes and then opens;
– with the circuit-breaker closed, the opening release of one of the poles shall be energised and a check carried out to see that the other two poles open.

**11.3.102.3 Electrical tests and measurements**

**11.3.102.3.1 Dielectric tests**

Dielectric tests on auxiliary circuits shall be performed to confirm that transportation and storage of the circuit-breaker have not damaged these circuits. However, it is recognised that such circuits contain vulnerable sub-components and the application of the full testing voltage for the full duration can cause damage. In order to avoid this, and to avoid the temporary removal of proven connections, the supplier shall detail the test process that demonstrates that damage has not occurred as well as the method of recording the results from this test process.

For dielectric tests on the main circuit of metal-enclosed switchgear and controlgear, IEC 62271-200 and IEC 62271-203 are applicable.

**11.3.102.3.2 Measurement of the resistance of the main circuit**

Measurement of the resistance of the main circuit shall only be made if making and breaking units have been assembled on site. The measurement shall be made with a direct current in accordance with 8.4 of IEC 62271-1:2017.

NOTE Dynamic resistance measurements (DRM) can be carried out as an additional tool for the assessment of the condition of the circuit-breaker during life time for some designs.

**11.4 Operating instructions**

Subclause 11.4 of IEC 62271-1:2017 is applicable.

**11.5 Maintenance**

Subclause 11.5 of IEC 62271-1:2017 is applicable with the following addition:

In addition, the manufacturer should give information regarding the maintenance of circuit-breakers following:

a) short-circuit operations;

b) operations in normal service.

This information should include the number of operations according to items a) and b) after which the circuit-breaker is to be overhauled.

Subclauses 11.5.1 to 11.5.5 of IEC 62271-1:2017 are applicable. The checks required in 11.3.102.1 apply.

### 11.101 Resistors and capacitors

When checking resistors and capacitors, allowed variations of the values should be given. Users should be aware of the Garton effect that can lead to incorrect values of tanδ, see CIGRE Technical Brochure 368 [15]

## 12 Safety

Clause 12 of IEC 62271-1:2017 is applicable with the following addition:

Any known chemical and environmental impact hazards should be identified in the manufacturer's instruction for use.

## 13 Influence of the product on the environment

Clause 13 of IEC 62271-1:2017 is applicable.

# Annex A
(normative)

# Calculation of TRVs for short-line faults from rated characteristics

## A.1 Basic approach

For rating and testing purposes, it has been decided to consider only a short-line fault occurring from one phase to earth in a system having the neutral earthed and with a first-pole-to-clear factor of 1,0, the severity of this being sufficient to cover other cases, except in special circumstances where the system parameters can be more severe than the standard values.

The simplified single-phase circuit can be represented as shown in Figure 48, Figure 49 and Figure 50.

During the short-circuit, the driving supply voltage $U_G$ is

$$U_G = U_r / \sqrt{3} \tag{A.1}$$

where $U_r$ is the rated voltage of the circuit-breaker.

This voltage $U_G$ drives the current $I_L$ through the circuit consisting of the reactances $X_S$, $X_B$ (if any) and $X_L$ in series.

The reactances with their corresponding inductances are defined as follows:

$X_S$ source side reactance, $L_S = X_S/\omega$ (A.2)

$X_B$ busbar reactance on source side, $L_B = X_B/\omega$ (A.3)

$X_L$ line side reactance, $L_L = X_L/\omega$ (A.4)

The RMS value of the voltage drop on the source side, not considering $X_B$ because of its negligible contribution, is

$$U_S = I_L \times X_S = U_G \frac{I_L}{I_{sc}} \tag{A.5}$$

where

$I_{sc}$ is the rated short-circuit breaking current;

$I_L$ is the short-line fault breaking current.

The RMS value of the voltage drop along the line is

$$U_L = I_L \times X_L = U_G (1 - \frac{I_L}{I_{sc}}) \tag{A.6}$$

At the instant when the current is interrupted, the induced voltage drop across the line inductance is:

$$u_0 = U_L \sqrt{2} = L_L \frac{di}{dt} \tag{A.7}$$

and for a symmetrical current:

$$u_0 = \omega \times L_L \times I_L \sqrt{2} \tag{A.8}$$

This voltage drop returns to zero by a series of travelling waves reflected back and forth along the line between the circuit-breaker and the location of the fault, generating a transient voltage across the line in the form of a decaying saw-tooth oscillation[4].

At the instant when the current is interrupted, the induced voltage drop across the source side inductance is:

$$u_X = U_X \sqrt{2} = L_S \frac{di}{dt} \tag{A.9}$$

and for a symmetrical current:

$$u_X = \omega \times L_S \times I_L \sqrt{2} \tag{A.10}$$

This voltage drop returns to zero by a series of oscillations. It is superimposed to the driving source voltage, both forming the source side voltage $u_S$ of the circuit-breaker.

The crest value $U_m$ of the total induced voltage at the instant of current breaking is:

$$U_m = u_0 + u_X = (L_L + L_S) \frac{di}{dt} \tag{A.11}$$

and for a symmetrical current:

$$U_m = \omega (L_L + L_S) I_L \sqrt{2} = U_G \sqrt{2} = U_r \sqrt{2} / \sqrt{3} \tag{A.12}$$

The voltage at the source side terminals of the circuit-breaker is the difference between the driving supply voltage and the voltage drop across the reactance $X_S$. The resulting specified TRV for short-line faults appearing across the circuit-breaker is the difference between the source side transient voltage $u_S$ and the line side transient voltage $u_L$ as shown in Figure A.1.



4 In practice the saw-tooth waveform is in some degree modified by a time delay, due to lumped capacitances present at the terminals of the circuit-breaker (capacitances of voltage transformers, current transformers, etc.); in addition, the top of the oscillation is slightly rounded.

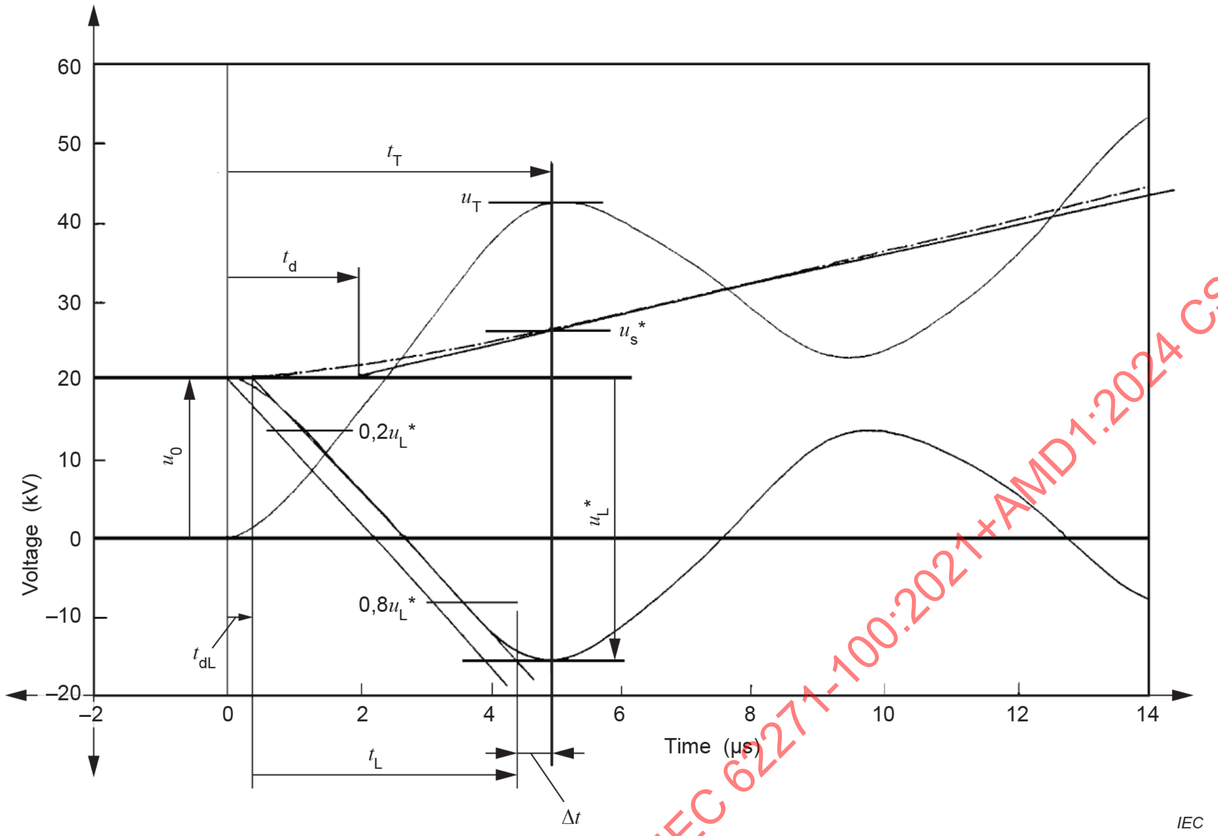



**Figure A.1 – Typical graph of line and source side TRV parameters – Line side and source side with time delay**



The ratio between the voltage $u_0$ at the instant of breaking and the crest value $U_m$ of the driving voltage is determined by the ratio of voltage drops across the line-side inductance and the source-side inductance, hence

$$u_0/U_m = u_0/(u_0 + u_x) = L_L/(L_L + L_S) = 1 - I_L/I_{SC} \qquad \text{(A.13)}$$

This relation is shown in Table A.1 for the standard ratios of short-line fault currents.

**Table A.1 – Ratios of voltage-drop and source-side TRV**

| $U_r$ | $I_L/I_{SC}$ | $u_0/U_m$ | $u_m/U_m$ | $u_{1,test}$ / $u_1$ |
|---|---|---|---|---|
| < 100 kV | 0,90 | 0,10 | 1,49 | - |
| | 0,75 | 0,25 | 1,41 | - |
| | 0,60 | 0,40 | 1,32 | - |
| ≥ 100 kV | 0,90 | 0,10 | 1,36 | 1,033 |
| | 0,75 | 0,25 | 1,30 | 1,083 |
| | 0,60 | 0,40 | 1,24 | 1,133 |

## A.2 Transient voltage on line side

Only separate measurement of the line side prospective TRV can be used to assess that the circuit fulfils the requirements given in this document.

The prospective TRV of the line side circuit shall be measured separately from that of the source side. The resulting rate-of-rise of the line side TRV, $\mathrm{d}u_L/\mathrm{d}t$, $t_{dL}$, $u_L$* and the surge impedance, $Z$, shall be within the tolerances given in Annex B.

The peak value $u_L$* of the first peak of the transient voltage across the line is obtained by multiplying the value $u_0$ by the peak factor $k$.

$$u_L^* = ku_0 = kL_L \frac{\mathrm{d}i}{\mathrm{d}t} \tag{A.14}$$

The time $t_L$ is obtained from the rate-of-rise $\mathrm{d}u_L/\mathrm{d}t$ of the transient voltage $u_L$ across the line and the peak value $u_L$* of the transient voltage across the line:

$$\frac{\mathrm{d}u_L}{\mathrm{d}t} = sI_L = Z\frac{\mathrm{d}i}{\mathrm{d}t} \tag{A.15}$$

then

$$t_L = \frac{u_L^*}{\frac{\mathrm{d}u_L}{\mathrm{d}t}} = \frac{u_L^*}{sI_L} = k\frac{L_L}{Z} \tag{A.16}$$

where

$s$ is the RRRV factor (kV/μs/kA);

$Z$ is the surge impedance of the line;

$f$ is the rated frequency.

The rated line characteristics $Z$, $k$ and $s$ are given in Table 29.

NOTE The approximate length of line corresponding to a given short-line fault can be obtained by the equation:

$$L = c \times t_L/2 \tag{A.17}$$

where $c$ is the speed of the travelling wave propagation assumed to be equal to: $c$ = 0,3 km/μs.

## A.3 Transient voltage on source side

### A.3.1 Rated voltages of 100 kV and above

The course of the source-side transient voltage from the initial value $u_0$ to the peak value $u_m$ can be derived from Table 30. The time coordinates $t_1$, $t_2$, $t_3$ and $t_d$ given in these tables can be used directly. The voltage $u_1$ in Table 30 equalling 0,75 times the induced voltage $U_m$ (instantaneous value of the supply voltage) at the instant of the current breaking results in the higher value $u_{1,test}$:

$$u_{1,\text{test}} = u_1 \times (1 + \frac{1}{3} \times (1 - \frac{I_L}{I_{sc}})) \qquad \text{(A.18)}$$

The actual values of the ratio $u_{1,\text{test}} / u_1$ are given in Table A.1.

The TRV peak value $u_c$ results in a lower value $u_m$:

$$u_m = u_0 + k_{af} u_x \qquad \text{(A.19)}$$

then

$$u_m / U_m = (u_0 + k_{af} u_x) / U_m \qquad \text{(A.20)}$$

and using Equation (A.10)

$$u_m / U_m = 1 + (k_{af} - 1) I_L / I_{sc} \qquad \text{(A.21)}$$

as given in Table A.1.

The actual rate of rise of the source side TRV is lowered related to the standard value of RRRV for short-line fault given in Table 30 using Equation (A.19).

$$RRRV_{SLF} = RRRV \times \frac{I_L}{I_{sc}} \qquad \text{(A.22)}$$

The time to reach the voltage level $U_m$ is

$$t_m = t_1 \times \frac{k_{af}}{k_{af} - 3/4} \qquad \text{(A.23)}$$

The peak value $u_m$ of the source-side TRV is also the peak value of the TRV across the circuit-breaker provided that the voltage oscillation on the line has been damped to zero by the time $t_2$ (or $t_3$), as is generally the case. The resulting course of the TRV of the source side is shown in Figure A.2.

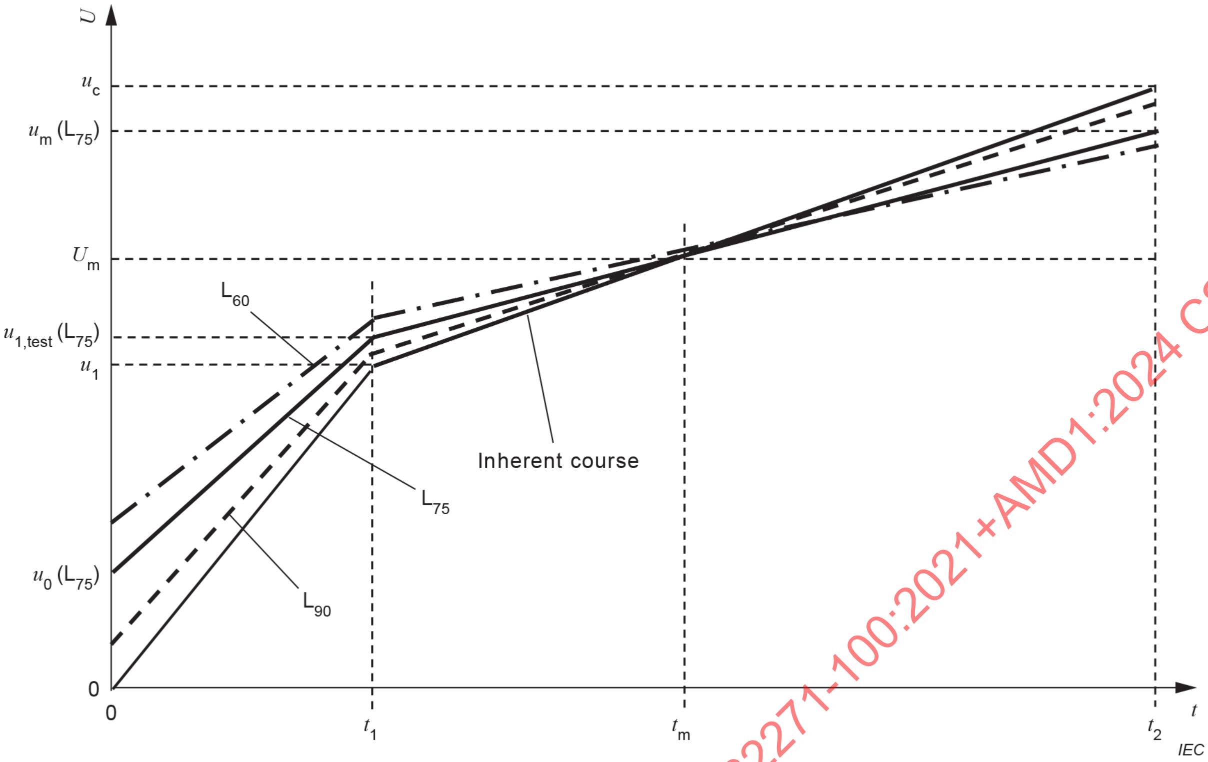



**Figure A.2 – Actual course of the source side TRV for short-line fault $L_{90}$, $L_{75}$ and $L_{60}$**



The most important part of the resulting TRV is up to the first peak value $u_L$* of the transient voltage across the line which is reached at time $t_{dL}$ + $t_L$ + $\Delta t$, where:

$$\Delta t = t_{dL}$$

For a line with a time delay less than 100 ns (see Figure 50), $t_{dL}$ and $\Delta t$ are 0,1 µs for calculation purposes.

NOTE In contrast to the usual procedure for defining TRVs by their envelopes, for the evaluation of the total voltage across the circuit-breaker at the instant, when the line side voltage reaches its first peak $u_L$*, the actual waveshape is used. This modified procedure is applied because the envelope method would result in an intermediate voltage value in the rising slope of the TRV shortly before the peak, but not in the real crest value of the total voltage across the circuit-breaker, which is relevant for the assessment of the testing conditions. The envelope method is quite satisfactory, provided TRVs are not superimposed by two or more components. However, in the present case where the complete TRV is evaluated across the circuit-breaker, the sum of three different components is considered: the source side TRV, the ITRV of the source side and the line side TRV.

For the calculation of the source-side contribution $u_s$* at the time $t_T$ two different cases shall be distinguished:

a) without ITRV requirements (see Figure A.1)

$$u_s^* = RRRV_{SLF} \times (t_{dL} + t_L + \Delta t - t_d) \quad (A.24)$$

The recovery voltage across the circuit-breaker at $t_T$ is the sum of $u_L$* and of $u_s$*.

b) with ITRV requirements (see Figure A.3):

$$u_s^* = u_{i0} + RRRV_{SLF} \times (t_{dL} + t_L + \Delta t - t_d) \quad (A.25)$$

The recovery voltage across the circuit-breaker at $t_T$ is the sum of $u_L$* and of $u_s$*.

For ITRV requirements (as given in Table 9), the following equations apply:

$$u_i = f_i I_L = k_i L_B \frac{di}{dt} \quad (A.26)$$

where

$k_i$ = 1,4 (peak factor);

$f_i$ is the multiplying factor according to Table 9.

Then the busbar voltage drop $u_{i0}$ becomes

$$u_{i0} = u_i / k_i \quad (A.27)$$

and the busbar inductance

$$L_B = u_{i0} / (di / dt) \quad (A.28)$$

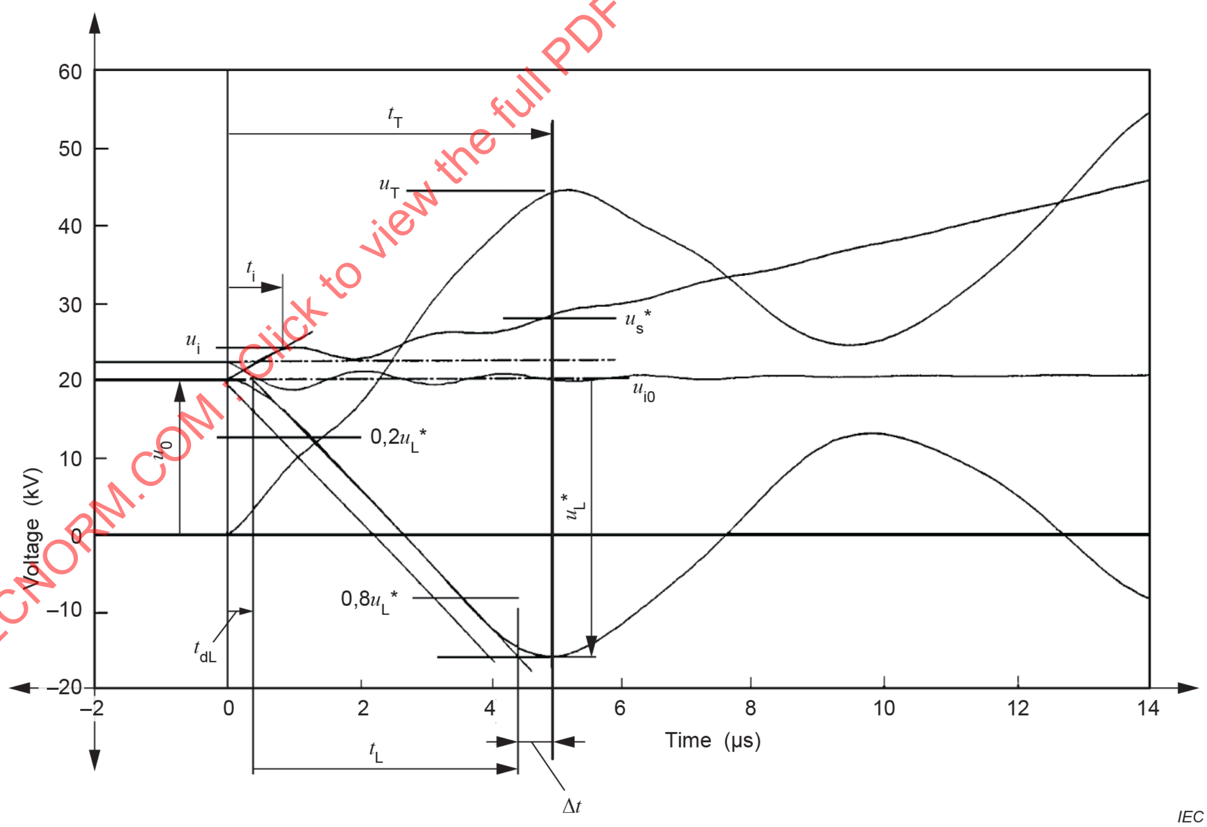



**Figure A.3 – Typical graph of line and source side TRV parameters – Line side and source side with time delay, source side with ITRV**

### A.3.2 Rated voltages equal and higher than 15 kV and below 100 kV

Subclause A.3.1 applies except the following:

The course of the source-side transient voltage from the initial value $u_0$ to the peak value $u_m$ can be derived from Table 18 and Table 19. The time coordinates $t_3$ and $t_d$ given in these tables can be used directly. The TRV peak value $u_c$ results in a lower value $u_m$:

$$u_m = u_0 + k_{af} u_x \tag{A.29}$$

then

$$u_m / U_m = \left(u_0 + k_{af} u_x\right) / U_m \tag{A.30}$$

## A.4 Examples of calculations

### A.4.1 General

As examples of calculations the two basic types of test circuits (see 7.109.3) are calculated. The results are given in A.4.2 and A.4.3 as follows:

– source side and line side with time delay (see A.4.2);

– source side with ITRV and line side with time delay (see A.4.3).

### A.4.2 Test circuit with source side and line side with time delay ($L_{90}$ and $L_{75}$ for 245 kV, 50 kA, 50 Hz)

| Parameters | Equation | Test parameters | | |
|---|---|---|---|---|
| | | Unit | $L_{90}$ | $L_{75}$ |
| Power frequency source side | | | | |
| Rated voltage $U_r$ | --- | kV | 245 | 245 |
| Rated short-circuit current $I_{sc}$ | --- | kA | 50 | 50 |
| Rated frequency $f_r$ | --- | Hz | 50 | 50 |
| Driving supply voltage $U_G$ | (A.1) | kV | 141,5 | 141,5 |
| Source side reactance $X_S$ | --- | Ω | 2,83 | 2,83 |
| Source side inductance $L_S$ | (A.2) | mH | 9,01 | 9,01 |
| Power frequency line side | | | | |
| Specified line setting | --- | % | 90 | 75 |
| Short-line fault breaking current $I_L$ | --- | kA | 45 | 37,5 |
| d$i$/d$t$ at the instant of current breaking | --- | A/µs | 20 | 16,7 |
| Line side voltage $U_L$ | (A.6) | kV | 14,2 | 35,4 |
| Line side reactance $X_L$ | --- | Ω | 0,316 | 0,944 |
| Line side inductance $L_L$ | (A.4) | mH | 1,0 | 3,0 |
| TRV parameters on line side | | | | |
| Voltage at the instant of current breaking $u_0$ | (A.13) | kV | 20 | 50 |
| Peak factor $k$ | --- | p.u. | 1,6 | 1,6 |
| Peak value of first peak of line side TRV $u_L$* | (A.14) | kV | 32 | 80 |
| Time delay $t_{dL}$ | --- | µs | 0,5 | 0,5 |
| Rate-of-rise of line side TRV d$u_L$/d$t$ | (A.15) | kV/µs | 9 | 7,5 |
| Specified line surge impedance $Z$ | --- | Ω | 450 | 450 |
| Rise time $t_L$ | (A.16) | µs | 3,56 | 10,7 |
| TRV parameters on source side | | | | |
| Time delay $t_d$ | --- | µs | 2 | 2 |
| Rate of rise at rated short-circuit breaking current $I_{sc}$ ($RRRV$) | --- | kV/µs | 2 | 2 |
| Rate of rise at short-line fault breaking current $I_L$ ($RRRV_{SLF}$) | (A.22) | kV/µs | 1,8 | 1,5 |
| Voltage at instant of current breaking $u_X$ | (A.11) | kV | 180 | 150 |
| Voltage $u_{1,test}$ at time $t_1$ | (A.18) | kV | 155 | 162,5 |
| Time $t_m$ to reach the voltage level $U_m$ | (A.23) | µs | 162 | 162 |
| Transient peak voltage $u_m$ | (A.19) | kV | 272 | 260 |
| Transient factor $u_m$/$U_m$ | (A.20) | p.u. | 1,36 | 1,3 |

### A.4.3 Circuit with source side with ITRV, line side with time delay ($L_{90}$ for 245 kV, 50 kA, 50 Hz)

| Parameter | Equation | Test parameters | |
|---|---|---|---|
| | | Unit | $L_{90}$ |
| Power frequency source side | Same as in A.4.2 | | |
| Power frequency line side | Same as in A.4.2 | | |
| TRV parameters on line side | Same as in A.4.2 | | |
| TRV parameters on source side | Same as in A.4.2 | | |
| ITRV parameters on source side | | | |
| Time coordinate $t_i$ | Table 9 | µs | 0,6 |
| Multiplying factor $f_i$ | Table 9 | kV/kA | 0,069 |
| Initial peak voltage $u_i$ | (A.26) | kV | 3,1 |
| Busbar voltage drop $u_{i0}$ | (A.27) | kV | 2,21 |
| Bus inductance $L_B$ | (A.28) | µH | 111 |

# Annex B
(normative)

## Tolerances on test quantities during type tests

During type tests, the following types of tolerances can normally be distinguished:

– tolerances on test quantities which directly determine the stress of the test object;
– tolerances concerning features or the behaviour of the test object before and after the test;
– tolerances on test conditions;
– tolerances concerning parameters of measurement devices to be applied.

In the following Table B.1, only tolerances on test quantities are considered.

A tolerance is defined as the range of the test value specified in this document within which the measured test value should lie for a test to be valid. In certain cases (see Table 6) the test can remain valid even if the measured value falls outside the tolerance.

Any deviation of the measured test value and the true test value caused by the uncertainty of the measurement are not taken into account in this respect.

The basic rules for application of tolerances on test quantities during type tests are as follows:

a) testing stations shall aim wherever possible for the test values specified;
b) the tolerances on test quantities specified shall be observed by the testing station. Higher stresses of the circuit-breaker exceeding those tolerances are permitted only with the consent of the manufacturer. Lower stresses render the test invalid;
c) where, for any test quantity, no tolerance is given within this document, or the standard to be applied, the type test shall be performed at values not less severe than specified. The upper stress limits are subject to the consent of the manufacturer;
d) if, for any test quantity, only one limit is given, the other limit shall be considered to be as close as possible to the specified value.

**Table B.1 – Tolerances on test quantities for type tests**

| Subclause | Designation of the test | Test quantity | Specified test value | Test tolerances/ limits of test values | Reference to |
|---|---|---|---|---|---|
| 7.2 | Dielectric tests | | | | |
| 7.2.7.2 and 7.2.8.2 | Power-frequency voltage tests | Test voltage (RMS value) | Rated short-duration power-frequency withstand voltage | ± 1 % | IEC 62271-1, IEC 60060-1 |
| | | Frequency | -- | 45 Hz to 65 Hz | IEC 60060-1 |
| | | Wave shape | Peak value / RMS value = √2 | ± 5 % | |
| 7.2.7.3 and 7.2.8.4 | Lightning impulse voltage tests | Peak value | Rated lightning impulse withstand voltage | ± 3 % | |
| | | Front time | 1,2 µs | ± 30 % | |
| | | Time to half-value | 50 µs | ± 20 % | |
| 7.2.8.3 | Switching impulse voltage tests | Peak value | Rated switch impulse withstand voltage | ± 3 % | |
| | | Time to peak | 250 µs | ± 20 % | |
| | | Time to half-value | 2 500 µs | ± 60 % | |
| 7.2.12 | Voltage test as condition check using standard switching impulse voltage | | | | |
| | | Peak value of switching impulse voltage | See 7.2.12 | ± 3 % | IEC 60060-1 |
| | | Time to peak | 250 µs | ± 20 % | |
| | | Time of half-value | 2 500 µs | ± 60 % | |
| | Using TRV circuit of T10 | Peak value of switching impulse voltage | See 7.2.12 | ± 3 % | |
| | | Time to peak | Standard value for T10 (see Table 20 and Table 21) | $^{+200}_{-10}$ % | |
| 7.3 | Radio interference voltage tests | Test voltage | See 7.3 of IEC 62271-1:2017 | ± 1 % | IEC 60060-1 |
| 7.4 | Measurement of the resistance of the main circuit | DC test current $I_{DC}$ | | 50 A ≤ $I_{DC}$ ≤ rated continuous current | IEC 62271-1 |

| Subclause | Designation of the test | Test quantity | Specified test value | Test tolerances/ limits of test values | Reference to |
|---|---|---|---|---|---|
| 7.5 | Continuous current tests | Ambient air velocity | -- | ≤ 0,5 m/s | IEC 62271-1 |
| | | Test current frequency | Rated frequency | $^{+2}_{-5}$ % | |
| | | Test current | Rated continuous current | $^{+2}_{0}$ % These limits shall be kept only for the last two hours of the testing period. | |
| | | Ambient air temperature $T$ | -- | + 10 °C < $T$ < 40 °C | |
| 7.6 | Short-time withstand current and peak withstand current tests | Test frequency | Rated frequency | ± 10 % at the beginning of the test, $^{+10}_{-20}$ % at the end | IEC 62271-1 |
| | | Peak current (in one of the outer phases) | Rated peak withstand current | $^{+5}_{0}$ % | |
| | | Average of AC component of three-phase test current | Rated short-time withstand current | See tolerances for $I^2t$ in 7.6.3 | |
| | | Ratio of AC component of test current in any phase vs average of the three phases | 1 | ± 10 % | |
| | | Short-circuit current duration | Rated short-circuit duration | Maximum 5 s | |
| | | Value of $I^2t$ | Value $I^2t$ Derived from rated values short-time withstand current and duration | $^{+10}_{0}$ % | |
| 7.101.3 | Low and high temperature tests | Deviation of ambient air temperature over height of test object | -- | ≤ 5 K | |
| | | Ambient air temperature for recording characteristics before test | 20 °C | ± 5 K | |
| | | Minimum and maximum ambient air temperature during tests | According to the service conditions of circuit-breaker (see IEC 62271-1) | ± 3 K | |
| 7.101.3.2 | Low and high temperature tests; General | Perpendicular wind speed, if applicable | Specified average test value | ± 10 % | |
| | | | Limits for any individual measurement from the specified average test value | ± 50 % | |

| Subclause | Designation of the test | Test quantity | Specified test value | Test tolerances/ limits of test values | Reference to |
|---|---|---|---|---|---|
| 7.101.4 | Humidity test | Minimum temperature of a cycle | 25 °C | ± 3 K | |
| | | Maximum temperature of a cycle | 40 °C | ± 2 K | |
| 7.103 | Making and breaking tests | Frequency | Rated frequency | ± 8 % | |
| 7.103.4 | Power frequency recovery voltage (RV) | Power frequency recovery voltage | Specified values | ± 5 % | |
| | | RV of any pole at the end of the time / average | 1 | ± 20 % | |
| 7.104 | Demonstration of arcing times | | | | |
| 7.104.2.2 | Test-duty T100a, three-phase test | $t_{arc1}$: maximum arcing time in T100a for the first-pole-to-clear | $t_{arc1}$ | > ($t_{arc1}$-1 ms) | |
| | | $t_{arc2}$: maximum arcing time in T100a for the last-pole-to-clear for $k_{pp}$ = 1,5 | $t_{arc2}$ | > ($t_{arc2}$-1 ms) | |
| | | $t_{arc3}$: maximum arcing time in T100a for the second-pole-to-clear for $k_{pp}$ = 1,3 or 1,2 | $t_{arc3}$ | > ($t_{arc3}$-1 ms) | |
| 7.104.2.3 | Tests for covering the conditions for $k_{pp}$= 1,3 and $k_{pp}$= 1,5 | $t_{arc}$: maximum possible arcing time calculated for a three-phase condition considering the minimum arcing time value found during T100s test-duty performed for $k_{pp}$ = 1,5. | $t_{arc}$ | > ($t_{arc}$-1 ms) | |
| 7.104.3.2 | Test-duties T10, T30, T60, T100s and T100s(b), OP1 and OP2, $L_{90}$, $L_{75}$ and $L_{60}$, single-phase test | $t_{arc\ max}$ maximum arcing | $t_{arc\ max}$ | > ($t_{arc\ max}$-1 ms) | |
| | | $t_{arc\ med}$ medium arcing time | $t_{arc\ med}$ | > ($t_{arc\ med}$-1 ms) | |
| 7.104.3.3 | Test-duty T100a, single-phase test | $t_{arc1}$: maximum arcing time in T100a for the first-pole-to-clear | $t_{arc1}$ | > ($t_{arc1}$-1 ms) | |
| | | $t_{arc2}$: maximum arcing time in T100a for the last-pole-to-clear for $k_{pp}$= 1,5 | $t_{arc2}$ | > ($t_{arc2}$-1 ms) | |
| | | $t_{arc3}$: maximum arcing time in T100a for the second-pole-to-clear for $k_{pp}$= 1,3 or 1,2 | $t_{arc3}$ | > ($t_{arc3}$-1 ms) | |

| Subclause | Designation of the test | Test quantity | Specified test value | Test tolerances/ limits of test values | Reference to |
|---|---|---|---|---|---|
| 7.104.3.4 | Tests for covering the conditions for $k_{pp}$ = 1,3 and $k_{p\,p}$ = 1,5 | $t_{arc}$: demonstration of the performance of the second-pole-to-clear under symmetrical fault conditions and demonstration of the performance of the third-pole-to-clear under symmetrical fault conditions | $t_{arc}$ | > ($t_{arc}$-1 ms) | |
| | | $t_{arc}$: maximum possible arcing time calculated for a three-phase condition considering the minimum arcing time value found during T100s test-duty performed for $k_{pp}$ = 1,5. | $t_{arc}$ | > ($t_{arc}$-1 ms) | |
| 7.105 | Short-circuit test quantities | | | | |
| 7.105.1 | Applied voltage before short-circuit making tests | Applied voltage | See 7.105.1 | $^{+10}_{\ 0}$ % | |
| | | Applied phase voltage / average (three-phase) | 1 | ± 5 % | |
| 7.105.3 | Short-circuit breaking current | AC component of any phase / average | 1 | ± 10 % | |
| | | AC component of the prospective current at final arc extinction in last-pole-to-clear | Specified breaking current for the relevant test-duty | ≥ 90 % | |
| 7.105.4 | DC component of short-circuit breaking current | DC component in T10, T30, T60, T100s | -- | ≤ 20 % | |
| | | Peak short-circuit current $\hat{I}$ during the last loop prior to breaking for T100a | See Table 10 and Table 11 | ±10 % | |
| | | Duration of the short-circuit current loop $\Delta t$ prior to breaking for T100a | See Table 10 and Table 11 | ±10 % | |

| Subclause | Designation of the test | Test quantity | Specified test value | Test tolerances/ limits of test values | Reference to |
|---|---|---|---|---|---|
| 7.105.5 | TRV for short-circuit breaking tests | Peak value of TRV: | | | |
| | | – for circuit-breakers ≤ 72,5 kV | See Table 16, Table 17 Table 18 and Table 19 | $^{+10}_{0}$ % | |
| | | – for circuit-breakers > 72,5 kV | See Table 20 and Table 21 | $^{+5}_{0}$ % | |
| | | Rate of rise of TRV: | | | |
| | | – for circuit-breakers ≤ 72,5 kV | See Table 16, Table 17 Table 18 and Table 19 | $^{+15}_{0}$ % [a] | |
| | | – for circuit-breakers > 72,5 kV | See Table 20 and Table 21 | $^{+8}_{0}$ % | |
| | | Time delay $t_d$ | See Table 16 through Table 21 | ± 20 % | |
| | | RV of any pole at the end of the time / average | 1 | ± 20 % | |
| 7.107 | Terminal fault tests | Breaking current in T10 | 10 % of rated short-circuit breaking current | ± 20 % | |
| | | Breaking current in T30 | 30 % of rated short-circuit breaking current | ± 20 % | |
| | | Breaking current in T60 | 60 % of rated short-circuit breaking current | ± 10 % | |
| | | Breaking current in T100s | 100 % of rated short-circuit breaking current | $^{+5}_{0}$ % | |
| | | Breaking current in T100a | 100 % of rated short-circuit breaking current | ±10% | |
| | | Making current in T100s | Rated short-circuit making current | $^{+10}_{0}$ % | |
| | | Peak short-circuit current in T100a | Rated peak withstand current | ≤ 110 % | |
| 7.108.1 | Critical current tests | Breaking current | See 7.108.1.2 | ± 20 % | |
| | | DC component of breaking current | ≤ 20 % | Upper limit 25 % | |

| Subclause | Designation of the test | Test quantity | Specified test value | Test tolerances/ limits of test values | Reference to |
|---|---|---|---|---|---|
| 7.108.2 | Single-phase and double-earth fault tests | Breaking current | See Figure 47 | $^{+5}_{0}$ % | |
| | | DC component of breaking current | ≤ 20 % | | |
| | | Peak value of TRV | | | |
| | | – for circuit-breakers ≤ 72,552 kV | See 7.108.2 and Table 16, Table 17, Table 18 and Table 19 | $^{+10}_{0}$ % | |
| | | – for circuit-breakers > 72,552 kV | See Table 20 and Table 21 | $^{+5}_{0}$ % | |
| | | Rate-of-rise of TRV | | | |
| | | – for circuit-breakers ≤ 72,552 kV | See 7.108.2 and Table 16, Table 17 Table 18 and Table 19 | $^{+15}_{0}$ % | |
| | | – for circuit-breakers > 72,552 kV | See Table 20 and Table 21 | $^{+8}_{0}$ % | |
| | | Arcing time | $t_a$ | $t_a \geq t_{a100s}$ + 0,7 × $T/2$ | |
| 7.109 | Short-line fault tests | DC component of breaking current | ≤ 20 % | | |
| | | Breaking current $L_{90}$ | 90 % of rated short-circuit breaking current | 90 % to 92 % | |
| | | Breaking current $L_{75}$ | 75 % of rated short-circuit breaking current | 12 kV < $U_r$ ≤ 52 kV: 7175 % to 79 % | |
| | | | | $U_r$ > 52 kV: 71 % to 79 % | |
| | | Breaking current $L_{60}$ | 60 % of rated short-circuit breaking current | 55 % to 65 % | |
| | | Surge impedance $Z$ | | ± 3 % | See NOTE |
| | | Peak value of line side voltage | | $^{+20}_{0}$ % | |
| | | Rate of rise of line side voltage | See Table 21 Table 29 and Annex A | $^{+5}_{0}$ % | |
| | | Time delay $t_{dL}$ | | $^{0}_{-10}$ % | |

| Subclause | Designation of the test | Test quantity | Specified test value | Test tolerances/ limits of test values | Reference to |
|---|---|---|---|---|---|
| 7.110 | Out-of-phase making and breaking tests | DC component of breaking current | ≤ 20 % | | |
| | | Applied voltage and power frequency recovery voltage | As specified in 7.110.2 | ± 5 % | |
| | | Peak value of TRV: | | | |
| | | – for circuit-breakers ≤ 72,5 kV | See Table 22, Table 23, Table 24 and Table 25 | $^{+10}_{0}$ % | |
| | | – for circuit-breakers > 72,5 kV | See Table 26 and Table 27 | $^{+5}_{0}$ % | |
| | | Rate of rise of TRV: | | | |
| | | – for circuit-breakers ≤ 72,5 kV | See Table 22, Table 23, Table 24 and Table 25 | $^{+15}_{0}$ % | |
| | | – for circuit-breakers > 72,5 kV | See Table 26 and Table 27 | $^{+8}_{0}$ % | |
| | | Instant of closing in OP2 | At crest of applied voltage in one pole | ± 15° | |
| | | Breaking current for OP1 | 30 % of rated out-of-phase breaking current | ± 20 % of specified value | |
| | | Breaking current for OP2 | 100 % of rated out-of-phase breaking current | $^{+10}_{0}$ % | |

| Subclause | Designation of the test | Test quantity | Specified test value | Test tolerances/ limits of test values | Reference to |
|---|---|---|---|---|---|
| 7.111 | Capacitive current tests | Power frequency voltage variation:<br>– for LC1, CC1 and BC1<br>– for LC2, CC2 and BC2 | | <br>≤ 2 %<br>≤ 5 % | |
| | | Voltage decay of recovery voltage 300 ms after arc extinction | | ≤ 10 % | |
| | | RMS value / RMS value of fundamental component | -- | ≤ 1,2 | |
| | | Test voltage | As specified in 7.111.7 | $^{+3}_{0}$ % | |
| | | Frequency of the recovery voltage | Rated frequency | ± 2 % | |
| | | Breaking current / rated capacitive breaking current | LC1, CC1, BC1<br>LC2, CC2, BC2 | 10 % to 40 %<br>≥ 100 % | |
| | | Damping factor of inrush current | Circuit-breakers ≤ 52 kV | ≥ 0,75 | |
| | | | Circuit-breakers > 52 kV | ≥ 0,85 | |
| | | Back-to-back making current: inherent peak value of inrush making current | BC2 | $^{+10}_{0}$ % | |
| | | Back-to-back making current: frequency of inrush making current | BC2 | 3 400 Hz to 6 000 Hz | |
| | Capacitive current breaking tests with specified recovery voltage | Waveshape of the recovery voltage | Theoretical test voltage waveshape of the corresponding single-phase direct test<br>(1-cos curve) | $^{+6}_{0}$ % of the peak value of the test voltage (i.e. approximately 3 % of the peak recovery voltage $u_c$ shown in Figure 54) | |
| Annex F | TRV for T30, for circuit-breakers of rated voltage less than 100 kV intended to be connected to a transformer with a connection of small capacitance | Peak value of TRV | See Table F.1 | $^{+10}_{0}$ % | |
| | | Rate of rise of TRV | | $^{+5}_{-10}$ % | |

[a] If the rate-of-rise of TRV for T10 and T30 ~~the upper limit is exceeded, the smallest value possible shall be used~~ is lower than the specified value due to limitations of the laboratory, the highest attainable value shall be used keeping the TRV peak within the limits given.

NOTE The priority parameter for short-line fault testing is the waveshape of the line side voltage and not the surge impedance of the line.

# Annex C
(normative)

# Records and reports of type tests

## C.1 Information and results to be recorded

All relevant information and results of type tests shall be included in the type test report.

Oscillographic records in accordance with C.2 shall be made of all short-circuit operations, making and breaking operations under out-of-phase conditions, capacitive current operations and no-load operations.

The type test report shall include a statement concerning the uncertainty of the measurement systems used for the tests. This statement shall refer to internal procedures of the laboratory through which traceability of the measuring uncertainty is established.

The type test report shall include a statement of the performance of the circuit-breaker during each test-duty and of the condition of the circuit-breaker after each test-duty, in so far as an examination is made, and at the end of the series of test-duties. The statement shall include the following particulars:

a) condition of circuit-breaker, giving details of any replacements or adjustments made and condition of contacts, arc control devices, oil (including any quantity lost), statement of any damage to arc shields, enclosures, insulators and bushings;
b) description of performance during test-duty, including observations regarding emission of oil, gas or flame.

## C.2 Information to be included in type test reports

### C.2.1 General

a) date of tests;
b) reference of report number;
c) test numbers;
d) oscillogram numbers.

### C.2.2 Apparatus tested

Subclause 7.1.3 and Annex A of IEC 62271-1:2017 are applicable with the following additions:

Reference drawing numbers given in the test report shall indicate the manufacturer's reference number, revision number and corresponding contents.

The reference mechanical travel characteristic, if applicable, shall be included or reference shall be made in the test report by the use of a drawing number or in an equivalent way.

### C.2.3 Rated characteristics of circuit-breaker, including its operating devices and auxiliary equipment

The values of rated characteristics specified in Clause 5 and the minimum opening time shall be given by the manufacturer.

### C.2.4 Test conditions (for each series of tests)

a) number of poles;
b) frequency, in Hz;
c) generator neutral (earthed or isolated);
d) transformer neutral (earthed or isolated);
e) short-circuit point or load side neutral (earthed or isolated);
f) diagram of test circuit including connection(s) to earth;
g) details of connection of circuit-breaker to the test circuit (for example orientation);
h) pressure of fluid for insulation and/or breaking;
i) pressure of fluid for operation.

### C.2.5 Short-circuit making and breaking tests

a) operating sequence and time intervals;
b) applied voltage, in kV;
c) making current (peak value), in kA;
d) breaking current:
   1) RMS value of AC component in kA for each phase and average;
   2) peak current in the last current loop (applicable only to T100a for the phase having the highest DC component);
   3) loop duration of the last current loop (applicable only to T100a for the phase having the highest DC component and first-pole-to-clear; for major extended loop, the prospective loop duration taken from the prospective current calibration test shall be given);
e) power frequency recovery voltage, in kV;
f) prospective TRV;
   1) compliance with requirement a) of 7.105.5.1; voltage and time coordinates can be quoted;
   2) compliance with requirement b) of 7.105.5.1;
g) arcing time, in ms;
h) opening time, in ms;
i) break-time, in ms;

   Where applicable, break-times up to the instant of extinction of the main arc and up to the instant of the breaking of resistance current shall be given.
j) closing time, in ms;
k) make time, in ms;
l) behaviour of circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDDs shall be noted;
m) condition after tests;
n) parts renewed or reconditioned during the tests.

### C.2.6 Short-time withstand current test

a) current
   1) RMS value, in kA,
   2) peak value, in kA;
b) duration, in s;
c) behaviour of circuit-breaker during tests;

d) condition after tests;

e) resistance of the main circuit of the circuit-breaker before and after tests in μΩ.

### C.2.7 No-load operation

a) before making and breaking tests (see 7.102.6);

b) after making and breaking tests (see 7.102.9.5).

### C.2.8 Out-of-phase making and breaking tests

a) breaking current in kA;

b) making current in kA;

c) voltage in kV;

d) prospective TRV;

e) arcing time, in ms;

f) opening time, in ms;

g) break-time, in ms;

h) closing time, in ms;

i) make-time, in ms;

j) duration of resistor current (where applicable), in ms;

k) behaviour of circuit-breaker during tests, including, where applicable, emission of flame, gas, oil, etc.; the occurrence of NSDDs shall be noted;

l) condition after tests.

### C.2.9 Capacitive current tests

a) test voltage, in kV;

b) breaking current in each phase, in A;

c) making current in each phase, in kA;

d) peak values of the voltage between phase and earth, in kV:

   1) supply side of circuit-breaker;

   2) load side of circuit-breaker;

e) number of restrikes (if any); the occurrence of NSDDs (if any) shall be noted;

f) details of point-on-wave setting, arcing time in ms;

g) closing time, in ms;

h) make-time, in ms;

i) behaviour of circuit-breaker during tests;

j) condition after tests.

#### C.2.10 Oscillographic and other records

Oscillograms shall record the whole of the operation. The following quantities shall be recorded. Certain of these quantities can be recorded separately from the oscillograms, and several oscillographs with different time scales can be necessary:

a) applied voltage;
b) current in each pole;
c) recovery voltage (voltages on supply and load side of circuit-breaker for charging current tests);
d) current in closing coil;
e) current in opening coil;
f) amplitude and timing scale appropriate for the required accuracy;
g) mechanical travel characteristics (where applicable).

All cases in which the requirements of this document are not strictly complied with and all deviations shall be explicitly mentioned at the beginning of the test report.

# Annex D
(normative)

# Method of determination of the prospective TRV

## D.1 General

A TRV wave can assume different forms, both oscillatory and non-oscillatory.

The waveform of the TRVs varies according to the arrangement of actual circuits. Two representations of TRV waves are defined, depending on the rated voltage and level of short-circuit current.

a) A two-parameter representation is used for circuit-breakers with rated voltages less than 100 kV and for circuit-breakers with rated voltages higher than 100 kV when the short-circuit current is equal to or lower than 30 % of rated breaking current and for out of phase test for rated voltages higher than 800 kV.

   The two-parameter reference line is shown in Figure 43.

   $u_c$ = reference voltage (TRV peak value), in kV;

   $t_3$ = time in µs.

   The RRRV is $u_c/t_3$.

b) A four-parameter representation is used for circuit-breakers with rated voltages equal to or higher than 100 kV when the short-circuit current is higher than 30 % of rated breaking current and for out of phase condition equal to or higher than 100 kV and lower than or equal to 800 kV.

   The four-parameter reference line is shown on Figure 42.

   $u_1$ = first reference voltage, in kV;

   $t_1$ = time to reach $u_1$, in µs;

   $u_c$ = second reference voltage (TRV peak value), in kV;

   $t_2$ = time to reach $u_c$, in µs.

The RRRV is $u_1/t_1$. The influence of local capacitance on the source side of the circuit-breaker produces a slower rate of rise of the voltage during the first few microseconds of the TRV. This is taken into account by introducing a time delay.

The TRV wave can be defined by means of an envelope made up of three consecutive line segments; when the wave approaches that of a damped oscillation at one single frequency, the envelope resolves itself into two consecutive line segments. In all cases, the envelope should reflect as closely as possible the actual shape of the TRV. The method described here enables this aim to be achieved in the majority of practical cases with sufficient approximation.

NOTE In some cases the chosen circuit can lead to overstressing the circuit-breaker after the first TRV peak.

## D.2 Drawing the envelope

The following method is used for constructing the line segments forming the envelope of the prospective TRV curve.

a) The first line segment passes through the origin O, is tangential to the curve and does not cut the curve (see Figure D.1 to Figure D.3, segment OB and Figure D.4, segment OA).

   In the case of curves whose initial portion is concave towards the left, the point of contact is often in the vicinity of the first peak (see Figure D.1 and Figure D.2, segment OB).

   If the concavity is towards the right, as in the case of an exponential curve, the point of contact is near the origin (see Figure D.3, segment OB).

b) The second line segment is a horizontal line tangential to the curve at its highest peak (see Figure D.1 to Figure D.4, segment AC).

c) The third line segment is tangential to the curve at one or more points situated between the first two points of contact, and does not cut the curve.

   There are three possible cases for drawing this latter line segment.

   1) One single line segment can be drawn touching the curve at two points (or possibly at more than two points).

      In this case, it forms part of the envelope (see Figure D.1, segment BA).

      The four-parameter envelope O, B, A, C, is then obtained.

   2) Several segments can be drawn which touch the curve at two points (or possibly at more than two points) without cutting it.

      In this case, the segment to be used for the envelope is that which touches the curve at one point only, situated so that the areas on either side of this point between the curve and the envelope are approximately equal (see Figure D.2, segment BA).

      The four-parameter envelope O, B, A, C is then obtained.

   3) No segment can be drawn touching the curve at more than one point without cutting it.

      In this case, the following distinction should be made.

      i) The point of contact of the first line segment and the highest peak are comparatively far apart from each other. This is typically the case for an exponential curve or a curve approximating to an exponential.

         In this case, the line segment shall be tangential to the curve at a point such that the areas on either side of this point between the curve and the envelope are approximately equal, as in case c) 2) of D.2 (see Figure D.3, segment BA).

         The four-parameter envelope O, B, A, C is then obtained.

      ii) The point of contact of the first line segment and the highest peak are comparatively close to each other.

         This is the case for a curve representing a damped oscillation of single frequency or a curve of similar shape.

         In this case, a third line segment is not drawn, and representation by two parameters, corresponding to the first two line segments, is adopted (see Figure D.4).

         The two-parameter envelope O, A, C is then obtained.

## D.3 Determination of parameters

The representative parameters are, by definition, the coordinates of the points of intersection of the line segments constituting the envelope.

When the envelope is composed of three line segments, the four parameters $u_1$, $t_1$, $u_c$ and $t_2$ shown in Figure D.1, Figure D.2 and Figure D.3 can be obtained as coordinates of the points of intersection B and A.

When the envelope is composed of two line segments only, the two parameters $u_c$ and $t_3$ shown in Figure D.4 can be obtained as coordinates of the point of intersection A.

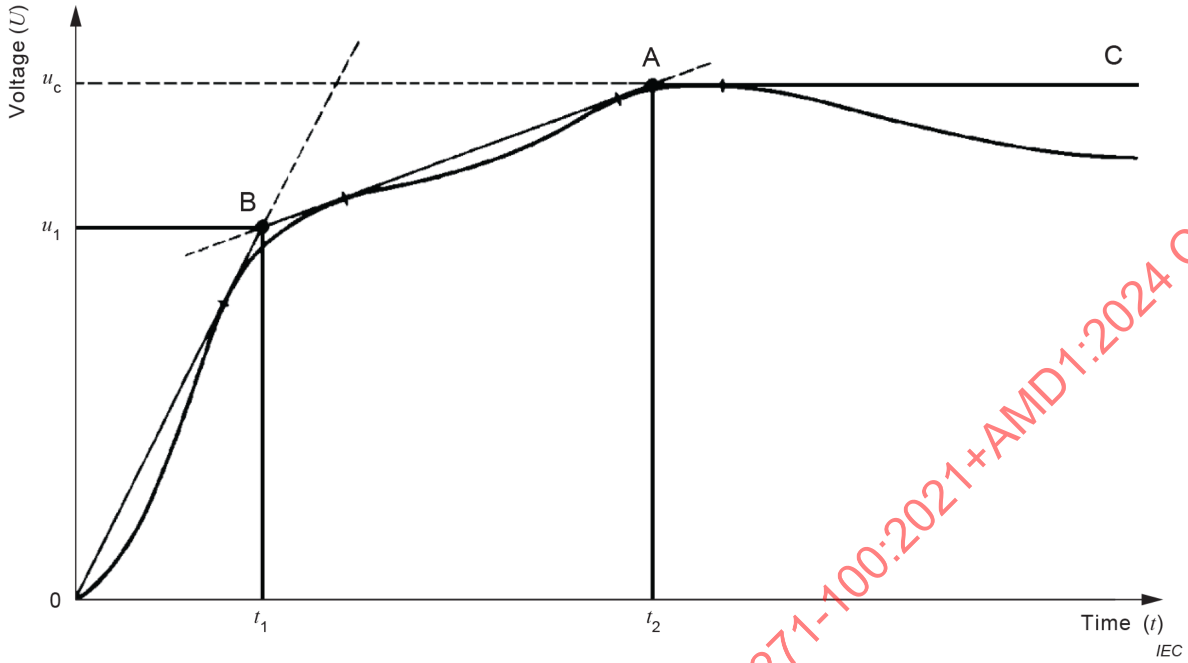



**Figure D.1 – Representation by four parameters of a prospective TRV of a circuit – Case D.2 c) 1)**

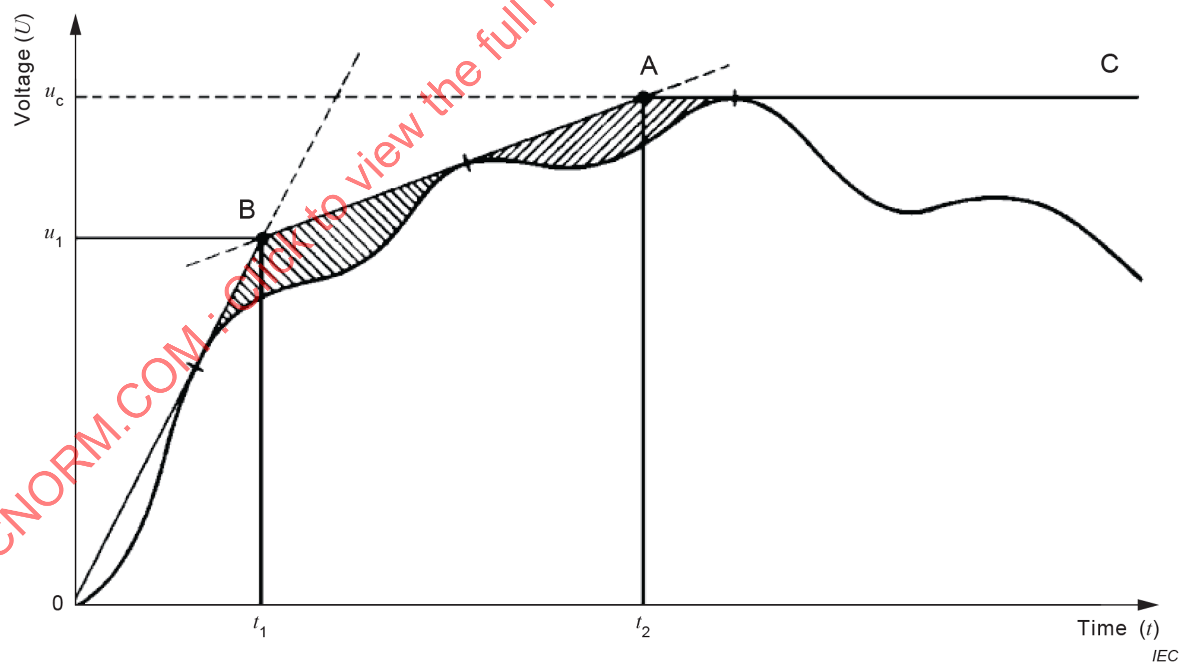



**Figure D.2 – Representation by four parameters of a prospective TRV of a circuit – Case D.2 c) 2)**

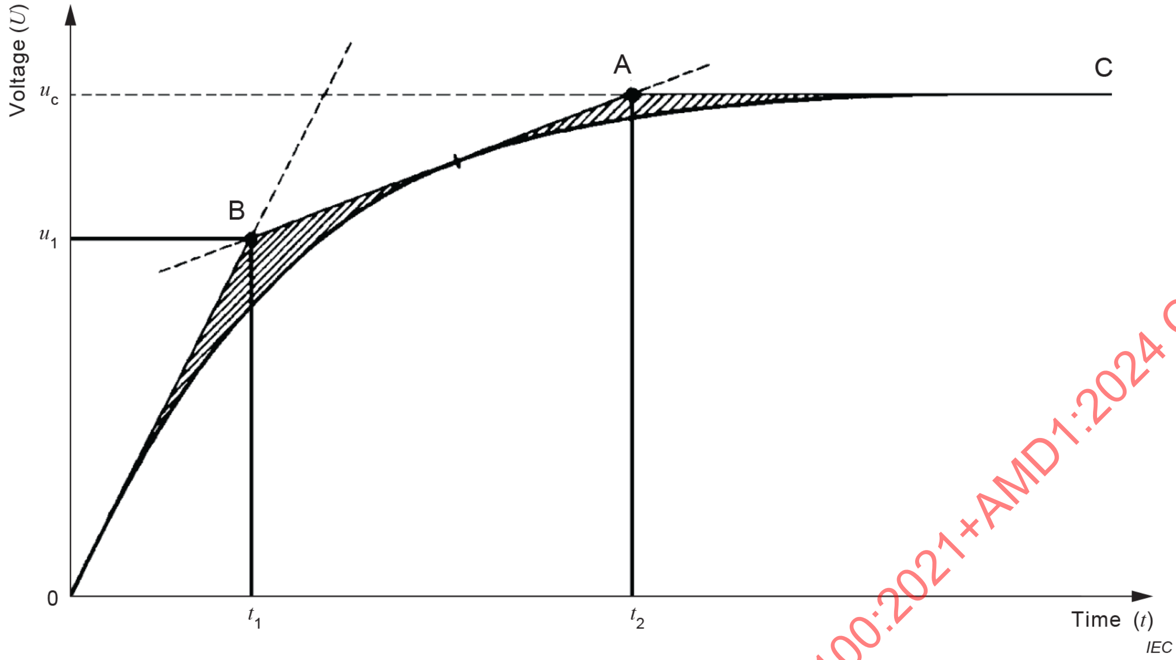



**Figure D.3 – Representation by four parameters of a prospective TRV of a circuit – Case D.2 c) 3) i)**

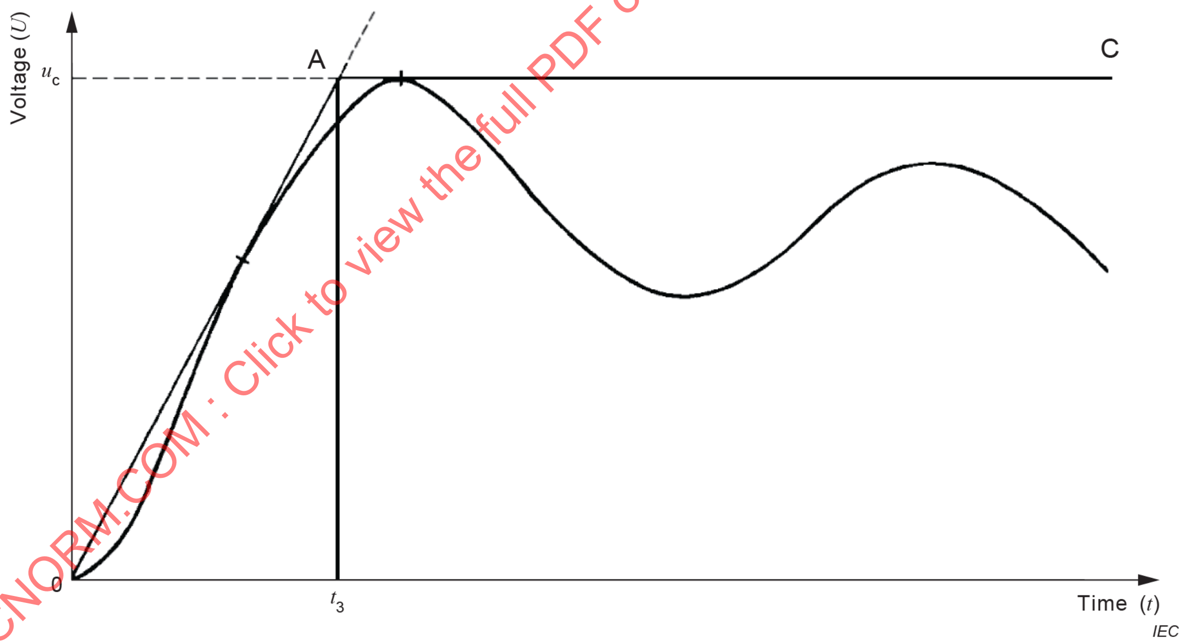



**Figure D.4 – Representation by two parameters of a prospective TRV of a circuit – Case D.2 c) 3) ii)**

# Annex E
(normative)

## Methods of determining prospective TRV waves

### E.1 General

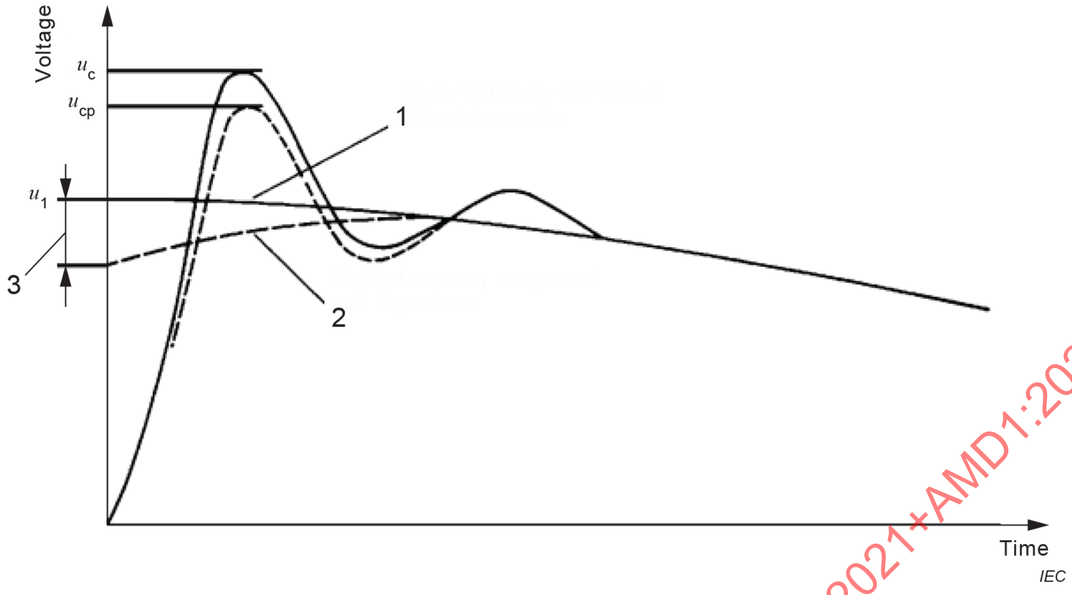
The waveforms of the TRV resulting from the breaking of short-circuit currents depend on two groups of factors, namely: those dependent on the circuit characteristics (inductance, capacitance, resistance, surge impedance, etc.), and those arising from the circuit-breaker characteristics (arc voltage, post-arc conductivity, capacitors and switching resistors, etc.).

Methods are recommended for determining the waveform of the TRV as produced solely by the circuit characteristics, this being the "prospective TRV".

Since any measuring device will have some effect upon the waveform of the prospective TRV, suitable precautions and, possibly, corrections are necessary.

Methods are available for the evaluation of the prospective TRV of both short-circuit test plant circuits and power systems, and the recommended methods are enumerated and briefly described, taking into account the TRV characteristics which are specified for rating and testing.

Experience on testing plants and also on systems has shown that following the breaking of a short-circuit current, not only is a single or multi-frequency oscillation superimposed on the power-frequency voltage wave, but exponential components of substantial size and duration are also present. The latter have time constants which are dependent upon the characteristics of the components of the circuit, for example generators, transformers, lines, etc. These exponential components have the effect of depressing the peak value of the TRV and the rate-of-rise to below those which would have occurred if the oscillatory components alone had been superimposed on the power-frequency voltage. This is shown in Figure E.1 and any method used for measurement should take this effect into account.




**Key**

| | |
|---|---|
| 1 | power-frequency component without depression |
| 2 | power-frequency component with depression |
| 3 | depression |
| $u_c$ | peak value of specified TRV |
| $u_{cp}$ | TRV measured with depression |
| $u_1$ | peak value of power frequency voltage without depression |

**Figure E.1 – Effect of depression on the peak value of the TRV**

Measurements have shown that the inductance of the various circuit components varies with frequency, owing to the screening effects of eddy currents within the conductors, the earth and the magnetic circuits. Together with other factors tending to reduce instantaneous voltages, this introduces a time constant varying from hundreds of microseconds for some generators down to tens of microseconds for transformers, the exact values depending upon the design of the particular equipment and the frequency of the components of the TRV. In some cases, this can result in a depression of the peak value of the TRV by as much as 25 %.

It is therefore important that these factors are taken into account when assessing the prospective TRV of either a test plant or system, and that guidance is given in connection with the recommended methods.

Irrespective of the method used, the actual values measured in the test plant for the prospective TRV shall be in accordance with the values specified in this document.

Where the time $t_2$ of the crest of the TRV exceeds, say, 1 250 µs, then, in addition to the effects described above, the instantaneous power-frequency voltage will, in any case, have decreased by more than 6 % at 50 Hz and more than 10 % at 60 Hz. Consequently, this further effect shall be taken into consideration when using methods for determining the prospective TRV which involve a power-frequency recovery voltage, or where calculations are made using circuit constants.

The instantaneous value of the power-frequency component immediately following current zero is also dependent upon the short-circuit power factor and upon the percentage DC component of the last half-cycle of current, and can be less than the full crest value. For symmetrical currents and short-circuit power factors of 0,15 or less, the reduction is not more than 1,5 %, and so is of little importance on test plant circuits; it can be of significance, however, at higher power factors which can occur in service.

For the TRV for terminal faults (see 7.105.5), a time delay has been introduced to allow for the influence of local capacitance on the source side of the circuit-breaker. Corresponding time delays have also been specified for the relevant test circuits, and the method used for measuring the TRV should be capable of resolving these time delays.

For some circuit-breakers the characteristics for short-line faults are also specified (see 7.109), and during short-line fault tests the corresponding resulting TRV has been specified. Local capacitance between the circuit-breaker and the line will also produce a time delay in the line side TRV component. During testing, it is desirable to measure and record the line side time delay and the method used should be suitable for evaluating this.

## E.2 General summary of the recommended methods

The basic methods for determining prospective TRV waveforms are classified as follows:

- group 1 – Direct short-circuit breaking;
- group 2 – Power-frequency current injection;
- group 3 – Capacitor current injection;
- group 4 – Model networks;
- group 5 – Calculation from circuit parameters;
- group 6 – No-load switching of test circuits including transformers;
- group 7 – Combination of different methods.

Groups 1, 4 and 5 are recommended for power systems.

Groups 2 and 3 can be used for portions of power systems.

Only groups 1 to 3 or a combination of these are suitable for assessing the prospective TRV of circuits used in short-circuit test plants.

When using groups 1, 2, 3, 4, 6 or 7, the voltage recording circuits should be carefully checked to ensure that the overall calibration is constant over the range of TRV frequencies to be recorded, and that time deflections are linear. The transient recorder and any voltage divider should then be calibrated against a known voltage.

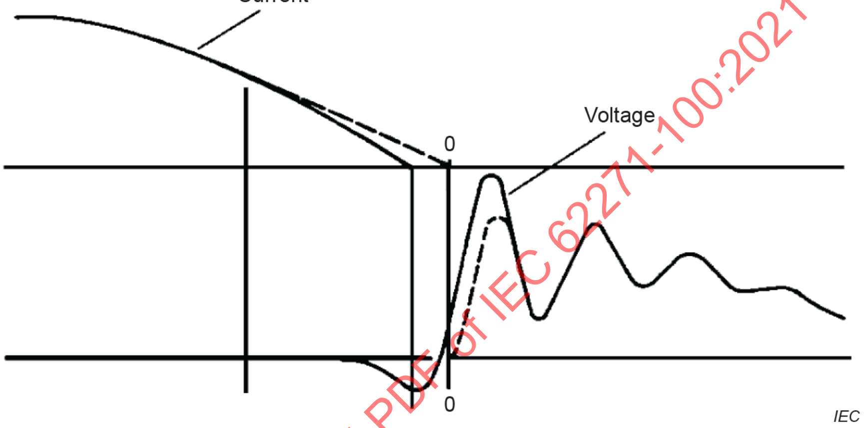
Where applicable, the injected current and the voltage across the circuit under investigation should be recorded using a suitable sampling rate. The TRV should be recorded with suitable sensitivity.

## E.3 Detailed consideration of the recommended methods

### E.3.1 Group 1 – Direct short-circuit breaking

This method involves the breaking of an actual short-circuit current, established by means of a solid metallic connection in the system under investigation and recording the resultant TRV. Ideally, the current broken should be symmetrical, or allowance made for the change in d$i$/d$t$ if there is appreciable asymmetry. With this method, it is essential to allow for the influence of the circuit-breaker. The most important characteristics in this respect are arc voltage and post-arc conductivity.

Due to the voltage of the arc, the voltage across the circuit-breaker contacts may not be zero at the instant of current breaking, and hence the TRV does not rise from zero voltage but from the value of the arc voltage at current zero. The TRV thus begins below the voltage zero axis and then crosses it (see Figure E.2).




NOTE Influence of the arc, of premature current-zero and of post-arc conductivity on the TRV. The chain-dotted lines represent the behaviour following ideal breaking.

**Figure E.2 – Breaking with arc-voltage present**

As a result, the peak voltage is higher than in the case of an ideal circuit-breaker (zero arc voltage) (see Figure E.3). A similar but more pronounced effect results from breaking at a markedly premature current zero (current chopping) which can occur if the current is small (see Figure E.4). Furthermore, if the prospective TRV comprises several oscillatory components, current chopping can produce a waveform which is markedly different from that which would be obtained with an "ideal" circuit-breaker.

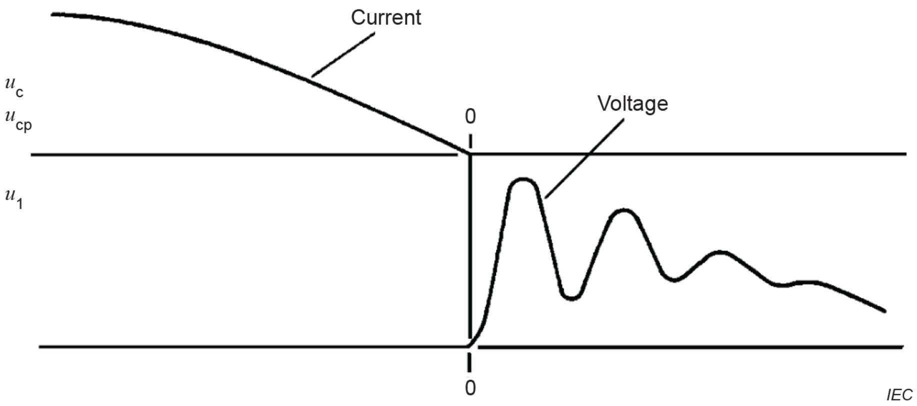
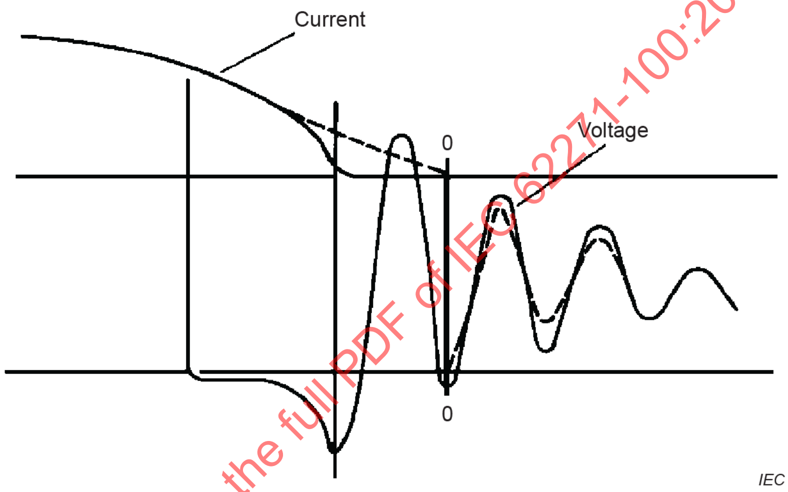



**Figure E.3 – TRV in case of ideal breaking**

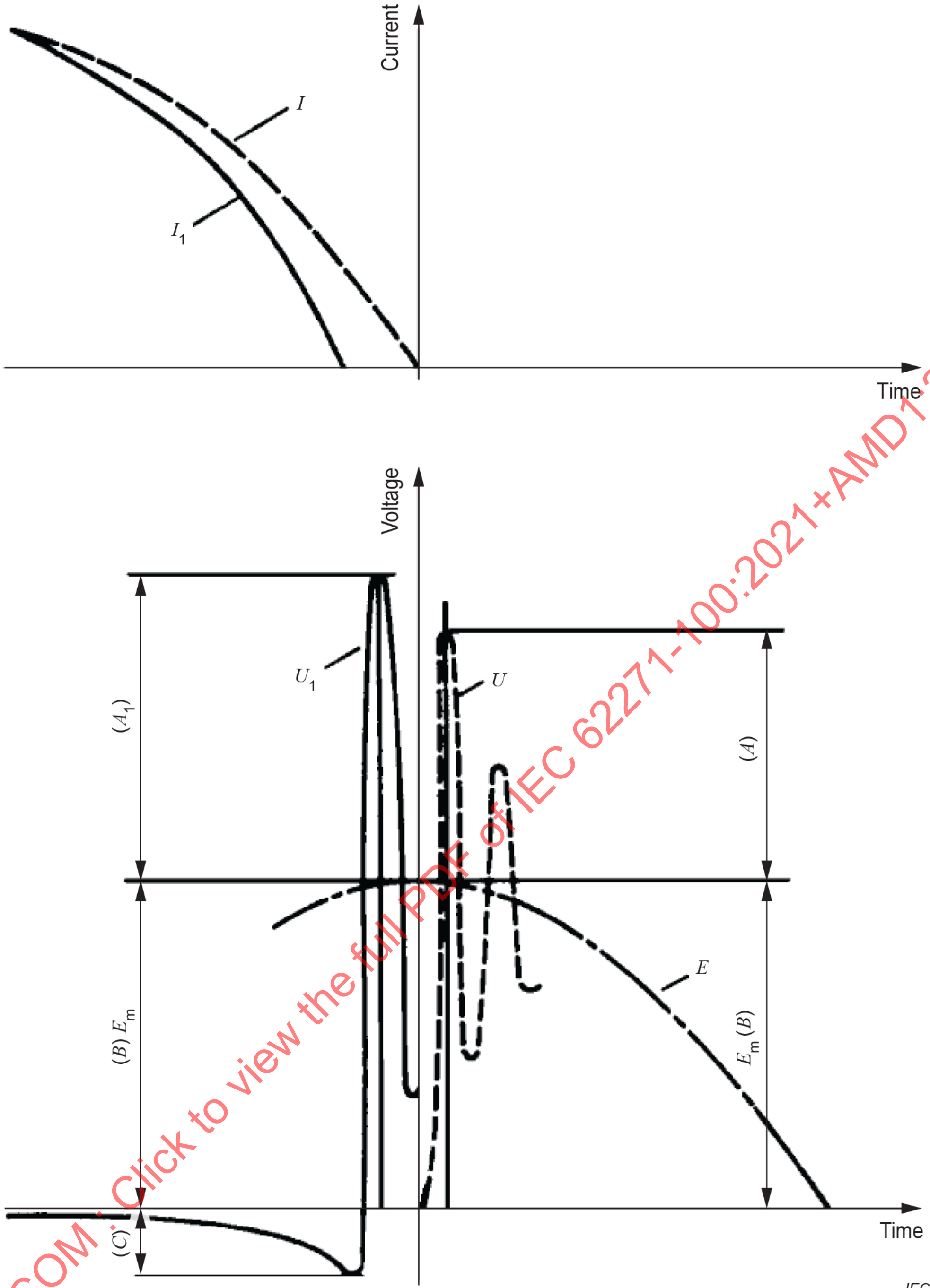



NOTE Influence of the arc, of premature current-zero and of post-arc conductivity on the TRV. The chain-dotted lines represent the behaviour following ideal breaking.

**Figure E.4 – Breaking with pronounced premature current-zero**

Thus a circuit-breaker with a low arc voltage immediately before current zero and which does not exhibit current chopping is the most suitable for use with direct short-circuit breaking.

The influence of the arc voltage can be compensated for as shown in Figure E.5.




| | | |
|---|---|---|
| $I_1$, $U_1$ | = | current and voltage, respectively, obtained in test |
| $I$, $U$ | = | prospective current and voltage, respectively, of system |
| $E$ | = | power frequency recovery voltage |

$A + B = A_1 \frac{B}{B + C} + B =$ peak value of TRV

NOTE Influence of the arc, of premature current-zero and of post-arc conductivity on the TRV. The chain-dotted lines represent the behaviour following ideal breaking.

**Figure E.5 – Relationship between the values of current and TRV occurring in test and those prospective to the system**

In principle, compensation for the arc voltage is only suitable for TRVs having a single-frequency transient component; nevertheless, it can also be used as a good approximation for multi-frequency transients if the amplitude of the main oscillatory component is predominant.

The post-arc current, i.e. the current flowing through the arc-gap during the rise of the TRV, can influence the waveform of the latter by damping, thus reducing its rate-of-rise and peak value (see Figure E.6). A similar effect results from the use of resistors in parallel with the making and breaking units of the circuit-breaker.

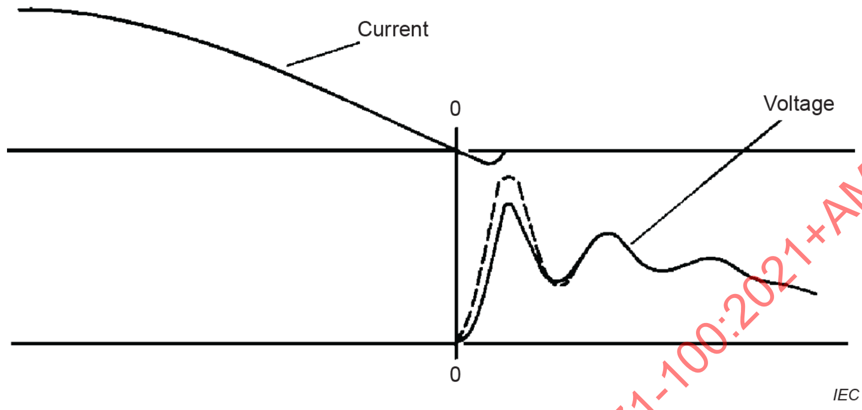



**Figure E.6 – Breaking with post-arc current**

It follows, therefore, that in addition to the requirements relating to low arc voltage and absence of current chopping, any circuit-breaker used for the direct short-circuit breaking method should not be fitted with shunt resistors and should not exhibit significant post-arc conductivity.

Particularly, where the test plant can be operated at a suitably reduced excitation, vacuum interrupters can often be used as nearly "ideal" circuit-breakers. However, it should be ascertained that any device used does not exhibit significant current chopping in the particular circuit under investigation.

The characteristics of circuit-breakers used for direct short-circuit breaking can sometimes be appropriately improved, for example by delaying the instant of contact separation to produce a short arcing time and low arc voltage.

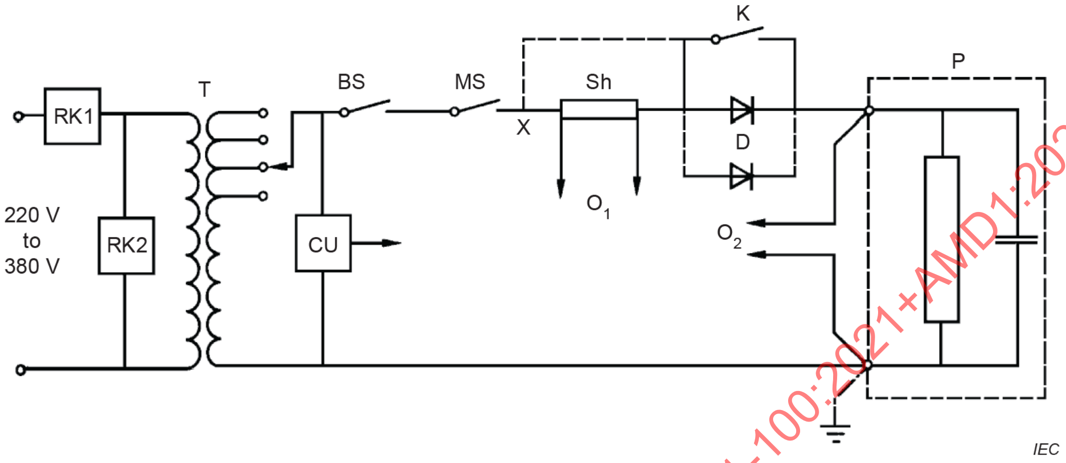
With this method, an actual short-circuit current is broken in the circuit under investigation and the recorded TRV will take into account, more or less, the effects contributing to depression of the recovery voltage. For this reason, the direct short-circuit breaking method can be, depending upon the characteristics of the circuit-breaker, the most suitable means of obtaining an assessment of the prospective TRV, and is frequently used as the basis for checking other methods. However, the direct short-circuit breaking method is less suited for measuring time delays, particularly the time delay of the line-side TRV, in the case of short-line fault.

### E.3.2 Group 2 – Power-frequency current injection

This method is only used with the circuit de-energised and is therefore mainly of use in test plants, or where part of a system can be analysed whilst de-energised. It does not take into account corona or magnetic saturation phenomena.

The basis of this method is the injection of a relatively small current into the circuit and the recording of the response of the circuit when the current is switched off by an ideal switching device, i.e. a device having negligible arc voltage and post-arc current.

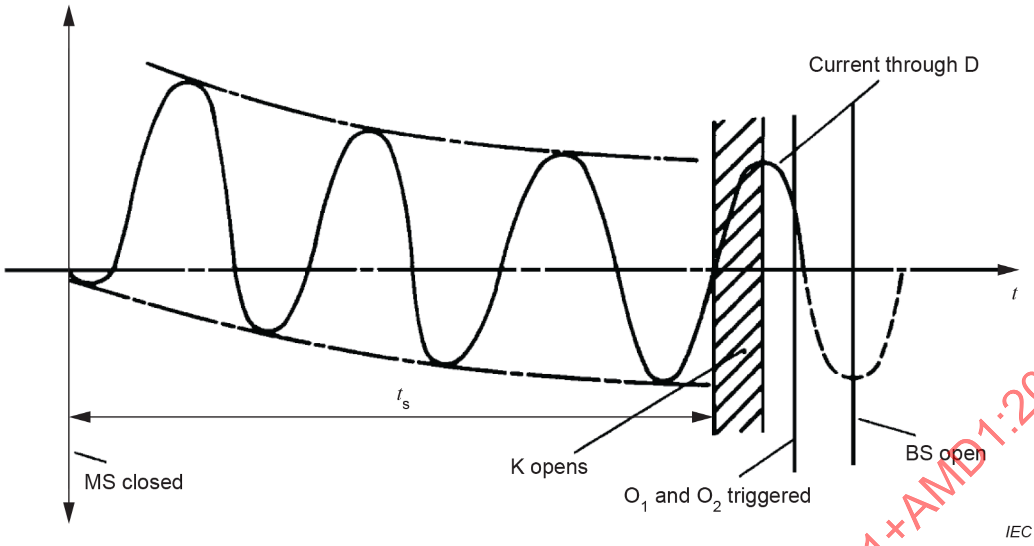
A suitable source of injected current is a single-phase transformer operated from the local low-voltage mains, the secondary giving, for example, a range of currents and voltages between 2 A at 200 V and 300 A at 25 V. This range will cover the impedances of the majority of circuits to be assessed. A schematic diagram as an example of the application of this method is shown in Figure E.7 together with details of the components. Figure E.8 shows the sequence of operation of the scheme.




| | | |
|---|---|---|
| RK1, RK2 | = | where required, series and parallel resonant circuits for harmonic suppression purposes |
| T | = | transformer to isolate injection circuit from supply and to provide an adjustable output voltage |
| BS | = | back-up switch |
| MS | = | making switch |
| K | = | diode by-pass switch |
| X | = | alternative connection for K to permit use of a shunt having relatively low time-current rating |
| D | = | parallel connection of up to five fast silicon switching diodes |
| Sh | = | current measuring shunt |
| $O_1$ | = | transient recorder, trace 1 recording magnitude and linearity of current for checking the diode operation |
| $O_2$ | = | transient recorder, trace 2 recording the response of the circuit |
| P | = | circuit the prospective TRV of which shall be measured |
| CU | = | control unit to provide the sequence of operation given in Figure E.8 |

NOTE The measurement of the injected current can equally be made at earth potential.

**Figure E.7 – Schematic diagram of power-frequency current injection apparatus**




Quiescent state: BS and K closed, MS open.

$t_s$ = duration of current flow prior to operation of switch K

Typical values lie between 10 and 20 cycles of injected current.

The main criterion is that the DC component of current, if any, shall have decayed to a value of 20 % or less of the AC component.

**Figure E.8 – Sequence of operation of power-frequency current injection apparatus**

Care should be taken to ensure that the inherent capacitances of the supply and measuring devices do not influence the results.

The voltage response should be measured at the input terminals of the circuit and, when applicable, one terminal of the circuit should be earthed. In those cases where the circuit is not earthed at one of its terminals, it is essential that the measuring and injection equipment are completely isolated from earth. This can be achieved by using an auxiliary generator insulated from earth and having negligible capacitance to earth.

The most convenient switching device for this scheme is a semiconductor diode. In general, semiconductor diodes with reverse recovering times not exceeding 100 ns have been found to be suitable. Longer times are acceptable where the TRV has a low equivalent natural frequency. To obtain the correct current-carrying capacity, several diodes can be operated in parallel.

NOTE The characteristics of diodes are dependent on a number of factors, for example the value of the current in the forward direction, the waveform and value of the reverse voltage, and the manufacturer's data which are dependent on the methods employed to determine the characteristics.

To achieve a symmetrical current wave, it can be necessary for the current to flow for a duration of up to 20 cycles. During most of this time, the diodes will be by-passed by a switch which is opened at the end of this time thus allowing the current to pass through the diodes which will interrupt the current at the following current-zero.

To assess the time delay accurately, it is necessary to amplify the voltage and time scales for the initial part of the wave.

The lower speed record of the current shows whether the current was symmetrical when broken, and the high-speed record gives the rate-of-change, d$i$/d$t$, immediately before current-zero. It also shows whether or not there was any appreciable post-arc current to cause damping of the TRV, or appreciable suppression of the current, likely to affect the TRV amplitude.

The TRV record represents the natural transient oscillation of the circuit under investigation and takes into account most of the factors causing voltage depression.

The values can be determined using a voltage calibration in terms of the full power of the circuit. Detailed explanations are given in E.3.4.

### E.3.3 Group 3 – Capacitor current injection

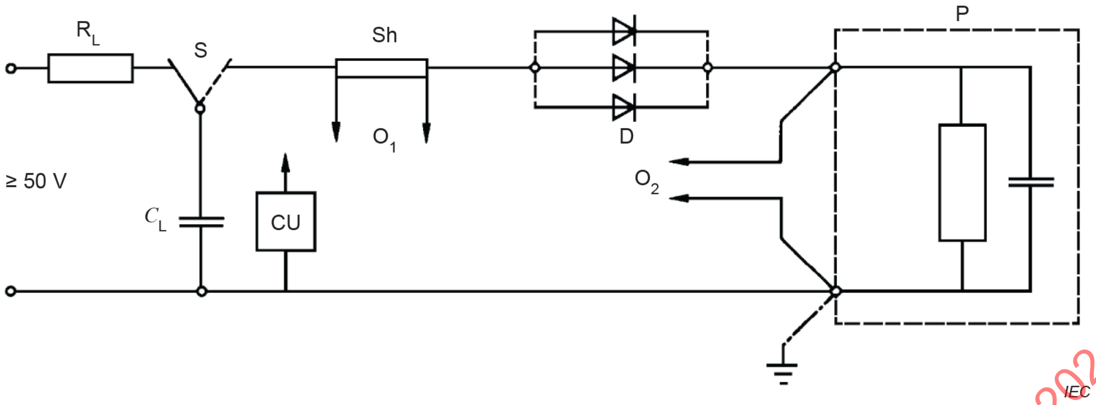
This method is similar to group 2 except that the current through the circuit being considered is obtained from the discharge of a capacitor. Thus, the frequency of the injected current will depend upon the values of the capacitor and the inductance of the circuit.

Since the frequency of the injected current is usually much higher than the power frequency, this method does not take into account the factors causing voltage depression.

As the frequency of the discharge current should be one-eighth of the equivalent natural frequency of the circuit, this means that the method is suitable for measuring the TRV of circuits containing components with high natural frequencies. It is particularly useful for measuring the characteristics of the components on the line side of short-line fault test circuits, the natural frequencies of which are very high, with correspondingly small time delays.

Figure E.9 provides a schematic diagram of an example of a capacitor current injection circuit together with details of the components. Figure E.10 shows the sequence of operation of the schema.

The same precautions and method of calibration are used as for group 2, and these are detailed in E.3.4.




$R_L$ = charging resistor

S = switching relay

$C_L$ = source capacitance

When the charged capacitance $C_L$ is connected to the circuit P via relay S an oscillatory current, of frequency $f_i$, flows. The value of $C_L$ should be adjusted so that:

$$f_i \le \frac{f_e}{8}\text{, where } f_e \text{ is the natural frequency of circuit P, } f_e = \frac{1}{2T_e / 2}$$

$f_i$ shall be such that the superimposed current oscillations will have disappeared before the instant of current zero.

Sh = current measuring shunt

$O_1$ = transient recorder, trace 1 recording magnitude and linearity of the current and checking the diode operation

$O_2$ = transient recorder, trace 2 recording the response of the circuit

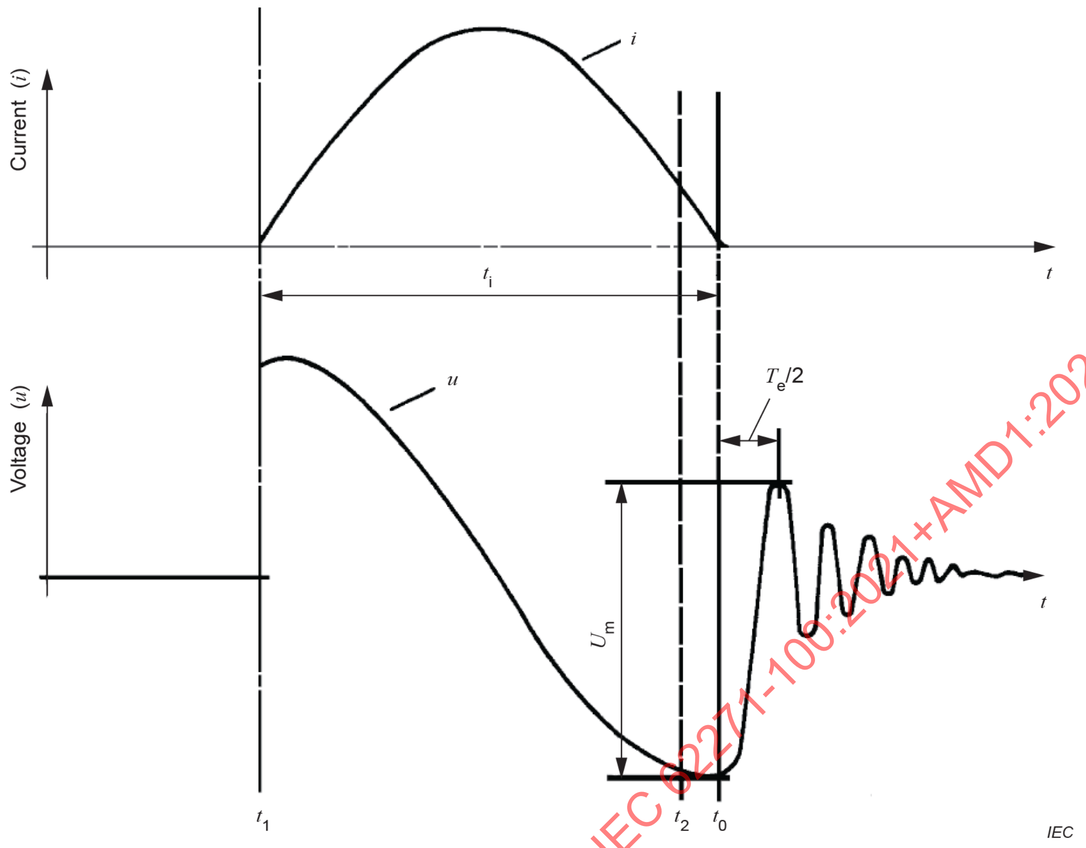
D = parallel connection of up to 100 fast silicon switching diodes

P = circuit the prospective TRV of which is to be measured

CU = control unit to provide the sequence of operation given in Figure E.10

NOTE The measurement of the injected current can equally be made at earth potential.

**Figure E.9 – Schematic diagram of capacitance injection apparatus**




$t_1$ = switching of S

$t_2$ = tripping of the cathode-ray oscillograph

$u$ = voltage curve across the terminals of the circuit P

$i$ = waveform of the injected current

$U_m$ = maximum voltage stressing of the diodes

$t_0$ = time where current passes through zero (beginning of the TRV oscillation)

$t_i$ = duration of current through diode D, $f_i = \frac{1}{2t_i}$

$\frac{T_e}{2}$ = duration of half-cycle of TRV

**Figure E.10 – Sequence of operation of capacitor-injection apparatus**

### E.3.4 Groups 2 and 3 – Methods of calibration

From the measured value of the rate-of-change, $di/dt$, of the injected current immediately before zero, calculate the equivalent RMS value of the injected current $I_i$.

$$I_i = \frac{\frac{di_i}{dt}}{2\pi f_i \sqrt{2}}$$

where $f_i$ is the frequency of the injected current.

In this calculation, it is assumed that:

$$i_i = I_i\sqrt{2}\sin(2\pi f_i t) \cong I_i\sqrt{2} \times 2\pi f_i t$$

This is approximately valid when $t_2$ < 1 250 μs (or when $t_2$ < 1 000 μs on a 60 Hz basis).

On the basis of the above approximations, the following rule can be derived:

The frequency of the injected current should be ≤ 1/8th of the equivalent natural frequency of the circuit being measured. For cases where the coordinate $t_2$ of the prospective TRV is greater than 1 250 μs (1 000 μs for 60 Hz), the frequency of the injected current should equal the rated power frequency.

NOTE If the factor is 1/8, during the interval ($t_2 - t_0$) a maximum deviation of the slope of the injection current from a straight line of 15 % would occur. A factor 1/14 would give a maximum deviation of 5 %.

If the RMS value of the maximum short-circuit current of the circuit is $I_{sc}$, then the voltage calibration $V_{sc}$ for the TRV corresponding to $I_{sc}$ will be:

$$V_{sc} = V_i \times (I_{sc}/I_i) \times (f_{sc}/f_i)$$

where $f_{sc}$ is the frequency of the short-circuit current.

Subject to the provisions given above concerning prospective TRV with long times $t_2$, for those cases where the deviation of the curve of the current from the sinusoidal, symmetrical form is too significant to be neglected, the following basic equation should be used:

$$V_{sc} = V_i \frac{\left(\frac{di_{sc}}{dt}\right)_{i_{sc}\to 0}}{\left(\frac{di_i}{dt}\right)_{i_i\to 0}}$$

where $\left(\frac{di_{sc}}{dt}\right)_{i_{sc}\to 0}$ is the rate-of-change of the power frequency short-circuit current at current zero, with the current function:

$$i_{sc} = I_{sc}\sqrt{2}\sin(2\pi f_{sc} t) \cong I_{sc}\sqrt{2} \times (2\pi f_{sc} t)$$

This equation applies particularly to the method of capacitor current injection where the current is of a slightly damped oscillatory form.

To determine the calibration for short-line fault tests, the following method is suitable:

From the high-speed recording measure:

$\frac{du_i}{dt}$ = RRRV of the TRV at zero of the injected current;

$u_i$ = first voltage peak caused by the injected current;

$\left(\frac{\mathrm{d}i_\mathrm{i}}{\mathrm{d}t}\right)_{i_\mathrm{i}\to 0}$ = rate-of-change of the injected current at its zero.

The value of the surge impedance $Z$ is then obtained by the following calculation:

$$Z = \frac{\dfrac{\mathrm{d}u_\mathrm{i}}{\mathrm{d}t}}{\left(\dfrac{\mathrm{d}i_\mathrm{i}}{\mathrm{d}t}\right)_{i_\mathrm{i}\to 0}}$$

### E.3.5 Group 4 – Model networks

In this method, a model network is assembled from units which shall be true representations of the components of the full-scale circuit. It is usually necessary to imitate the components of the full-scale circuit which have distributed parameters by model units having lumped parameters. In addition, it is essential that the impedance (especially reactance and resistance) characteristics of the model units shall be, as near as possible, a true imitation of those characteristics of the full-scale components at frequencies up to at least that corresponding to the TRV under consideration.

The accuracy of this method depends upon having exact data for the parameters of the circuit to be imitated, and these are frequently difficult to obtain and to simulate on a small model component.

This applies particularly to parameters which vary with frequency, so that this method in general does not directly take into account the depression of the TRV and tends to give values which are somewhat higher than those obtained with direct short-circuits on a full-scale system.

The method is mainly useful for investigating power systems since it does not require the system to be taken out of service and will give useful guidance provided that its limitations are recognised.

### E.3.6 Group 5 – Calculation from circuit parameters

When the data concerning the parameters of the components of the circuit are known, as for group 4, it is often convenient to calculate the waveform of the TRV, particularly if the circuit is not too complex.

In general, the method does not take into account depression effects, although some allowance can be made for these if the relevant data for the circuit are available; similarly, the decrement of the power-frequency component for those TRV where the time $t_2$ exceeds 1 250 µs (1 000 µs for 60 Hz), can be taken into account.

The method is subject to the limitations of group 4, plus the errors inherent in calculations unless experience has been gained in checking results with actual TRV obtained from tests using the techniques of groups 1, 2, 3 or 6.

### E.3.7 Group 6 – No-load switching of test circuits including transformers

This method consists of connecting the test transformer on the open circuit and recording, by oscillograms, the behaviour of the transient voltage at the open gap of the secondary circuit.

The method is very useful in those test stations where the short-circuit current is obtained by generators. However, the circuit-breaker used for the switching shall have no shunt resistance, be free of any appreciable pre-striking and be located in close proximity to the circuit-breaker under test. Furthermore, this method has a limited application to those circuits producing single frequency TRV and does not reproduce the exponential component which is related to eddy currents.

#### E.3.8 Group 7 – Combination of different methods

Depending on the test circuit a combination of the proposed methods can be necessary. This is always the case, if the TRV is superimposed by the outputs of different sources (up to three different sources are usual). For example, in a voltage injection test circuit, it is possible to check the TRV from the current source separated from the TRV from the voltage injection circuit. This means that each of the separate circuits can be checked by one of the proposed methods. For the different circuits, different methods can be applied. The overall TRV (sum of the TRVs from the different circuits), can be constructed by mathematical methods. If digital recording equipment is used, it is also possible to construct the overall TRV by combining the digital data obtained by the different methods.

In the case of a combined use of the proposed methods, the specific limits of the methods, given in Table E.1, shall be taken into account.

### E.4 Comparison of methods

The various methods are listed in Table E.1, with their characteristics, advantages and disadvantages.

**Table E.1 – Methods for determination of prospective TRV**

| Method | Theoretical limitations | Practical limitations |
|---|---|---|
| E.1.1 Full scale tests with an ideal circuit-breaker | None. All phenomena are correctly represented | Non-existence of an ideal circuit-breaker to cover the full range of requirements |
| E.1.2 Power-frequency tests at full voltage with a limited current disturbance. (Either an ideal circuit-breaker test or a "close" test is feasible) | Does not account for non-linearities which can exist in the test circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements) | Non-existence of an ideal circuit-breaker to cover the full range of requirements. Extraction of the TRV requires sophisticated measurement techniques: otherwise, it is difficult to interpret results in the presence of a large power-frequency voltage component<br>For making tests, the most suitable current limiting device is a perfect inductance; otherwise an element of the test circuit can be used where it is available (for example resistor or capacitor)<br>Elements used are likely to be bulky and expensive |
| E.1.3 Power-frequency tests at reduced voltage with an ideal circuit-breaker on an otherwise unmodified test circuit (i.e. low excitation tests) | Does not account for non-linearities which can exist in the test circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements) | Whilst ideal circuit-breakers to cover the whole range are not yet available, the selection of the ideal circuit-breaker to be used is limited<br>With circuits employing more than one generator, synchronization can be difficult to achieve<br>Excitation should be sufficiently high to avoid waveform distortion<br>Generally not possible in a network station |
| E.1.4 Full scale tests with a conventional circuit-breaker | Difficulty of separating the circuit-breaker effects from the TRV characteristics recorded during test | Choice of suitable circuit-breakers having a low arc-voltage producing negligible current distortion at current zero, negligible post-arc current and no shunt impedances.<br>In cases where the above cannot be made, errors are introduced and there is the possibility of lack of uniformity between testing stations due to the use of circuit-breakers having different characteristics |

| Method | Theoretical limitations | Practical limitations |
|---|---|---|
| E.2 Ideal circuit-breaker tests on a "dead" circuit with power frequency current injection | Does not account for non-linearities which can exist in the circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements) | In a network-fed testing station, only applicable on "dead" circuit elements, for example short-line fault components, or where the impedance of the network is negligible compared with the remainder of the circuit impedance<br>Generators shall be at rest to avoid remanent voltages<br>Position of rotor can be important if there is a considerable difference between direct and quadrature reactances.<br>The reverse recovery time of switching diodes as used instead of an ideal circuit-breaker, capable of carrying the necessary injected power-frequency current, can affect the TRV where this contains high frequency components, for example in short-line fault test circuits.<br>Interference from external sources induced in the "dead" circuit can affect the TRV where the measuring voltage is relatively small due to very low circuit reactance, for example as associated with short-line faults |
| E.3.2 Power frequency current injection | Does not account for non-linearities which can exist in the circuit.<br>Does not give power frequency impedance directly.<br>Gives correct waveform and values for the TRV of single and multi-frequency circuits from zero to the first maximum only, provided that the injection frequency is above power frequency and well below the frequency of the TRV. It is not possible to evaluate amplitude factor correctly | In a network-fed testing station, only applicable on "dead" circuit elements, for example short-line fault components, or where the impedance of the network is negligible compared with the remainder of the test circuit impedance.<br>Generators shall be at rest to avoid remanent voltages.<br>Position of rotor can be important if there is a considerable difference between phase and quadrature reactances |
| E.3.5 Model networks | Precise information on non-linear and frequency-dependent characteristics of the network is not always available<br>Exact knowledge of circuit components and their stray parameters is necessary | Adequate representation of circuit components in the transient network analyser elements, including their non-linear and lime-dependent characteristics, is necessary |
| E.3.6 Calculation from circuit parameters | Precise information on non-linear and frequency-dependent characteristics of the network is not always available<br>Exact knowledge of circuit components and their stray parameters is necessary | Where the network impedance is not negligible compared with the test station impedance, complete knowledge of the relevant momentary network conditions is necessary<br>Accurate or adequate representation of the circuit components, including their non-linear and time-dependent characteristics and particularly the stray parameters |

| Method | Theoretical limitations | Practical limitations |
|---|---|---|
| E.3.7 No-load switching of testing transformers | Corrections necessary for TRV peak value unless the transformers are energised at or near the peak of the voltage wave | Requires actual short-circuit test circuits.<br>Applicable only for single-frequency circuits.<br>Cannot be used for the determination of the TRV time delay. Generally, with this method, the time delay is overestimated (e.g. longer than the real value). |

# Annex F
(informative)

# Requirements for breaking of transformer-limited faults by circuit-breakers with rated voltage higher than 1 kV

## F.1 General

Figure F.1 and Figure F.2 illustrate the two typical cases of transformer-limited faults. These types of faults can be subdivided into

– transformer-fed faults (Figure F.1);
– transformer-secondary faults (Figure F.2).

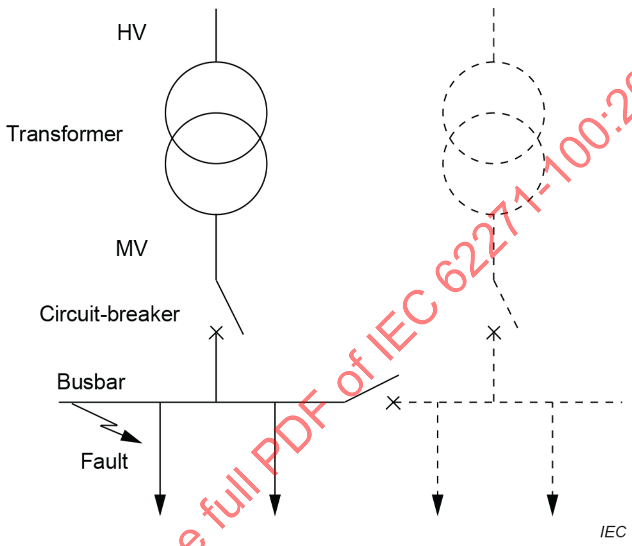



**Figure F.1 – First example of transformer-limited fault (also called transformer-fed fault)**

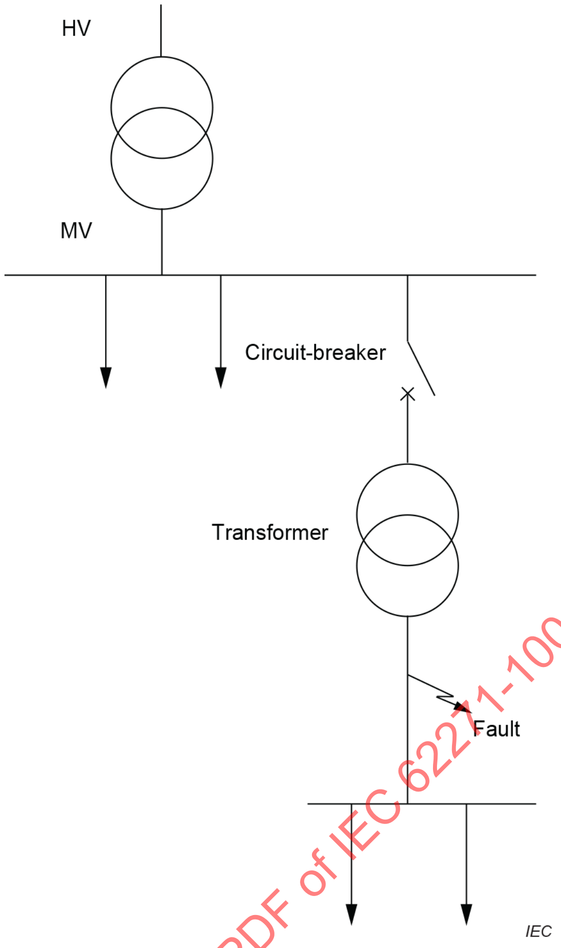



**Figure F.2 – Second example of transformer-limited fault (also called transformer-secondary fault)**

## F.2 Circuit-breakers with rated voltage less than 100 kV

As most substations have more than one transformer, the breaking current for the transformer breaker is only a fraction of the total short-circuit current of the substation. In general, the same breaking capacity is specified for transformer breakers and outgoing feeders even if the necessary breaking capacity is very different. There are two reasons for this over-dimensioning: the uniformity of all breakers in the station and the fact, that high rated continuous currents, as necessary for transformer breakers, the standard coordination of rated values can imply rated short-circuit breaking capability higher than necessary. Therefore, for standardization purposes, test-duty T30 is specified to prove the capability of a circuit-breaker to interrupt transformer-limited faults.

Two cases of application shall be considered:

a) in cases where there is sufficient capacitance to earth between transformer and circuit-breaker, transformer-limited faults are covered by performing T30 with TRV parameter values as given in Table 16 and Table 17 for circuit-breakers class S1 or Table 18 and Table 19 for circuit-breakers class S2. Where cables or insulated busbars are used, the capacitance to earth of the connection between transformer and circuit-breaker generally exceed the required value.

Calculations show that the additional capacitance necessary to reduce the transformer's natural frequency to the TRV frequency specified for T30 in Table 16, Table 17, Table 18 and Table 19 is independent of the rated voltage and proportional to the rated short-circuit current. The additional capacitance to earth should be at least

$$C_0 = 0{,}6 \times I_{30} \text{ (50 Hz) or } 0{,}7 \times I_{30} \text{ (60 Hz)}$$

where

$I_{30}$ is 30 % of the rated short-circuit current in kA;

$C_0$ is in nF.

Typical cables (0,3 nF/m to 0,5 nF/m) easily provide the values of necessary additional capacitance.

For example, in the case of a circuit-breaker with a rated short-circuit breaking current of 31,5 kA – 50 Hz the minimum length of cable for which type test T30 covers the breaking of transformer-limited faults is $\frac{0{,}6 \times 0{,}3 \times 31{,}5}{0{,}3} = 19 \text{ m}$, assuming that the capacitance is 0,3 nF/m.

b) In the special case where the capacitance of the connection between the transformer and the circuit-breaker is lower than the value $C_0$ defined in a) above, a special test-duty T30 can be specified to circuit-breakers with a TRV defined in Table F.1. For applications in effectively-earthed neutral systems and if this test duty T30 is performed three-phase, an additional single-phase test should be performed with $k_{pp}$ = 1,5 and arcing time = 0,7 times half period at power frequency.

Alternatively, a capacitance should be added to allow the use of a circuit-breaker class S1 or S2.

NOTE Particular cases of application can exist where the substation is fed by only one transformer and with the short-circuit current of the transformer breaker equal to its rated short-circuit current. In such cases, the breaking capability can be demonstrated by performing test-duty T100, when the connection has sufficient capacitance as explained in a) above, or alternatively a capacitance can be added in order to obtain TRV parameters covered by the values in Table 16, Table 17, Table 18 and Table 19.

**Table F.1 – Required values of prospective TRV for T30, for circuit-breakers intended to be connected to a transformer with a connection of small capacitance – Rated voltage higher than 1 kV and less than 100 kV for non-effectively earthed neutral systems**

| $U_r$<br>kV | Test-duty | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_c$<br>kV | $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 3,6 | T30 | 1,5 | 1,6 | 7,05 | 4,47 | 0,671 | 2,35 | 2,16 | 1,58 |
| 4,76 | T30 | 1,5 | 1,6 | 9,33 | 4,~~81~~93 | 0,~~721~~740 | 3,11 | 2,~~32~~38 | 1,~~94~~89 |
| 7,2 | T30 | 1,5 | 1,6 | 14,1 | 5,~~48~~67 | 0,~~822~~850 | 4,70 | 2,~~65~~74 | 2,~~57~~49 |
| 8,25 | T30 | 1,5 | 1,6 | 16,2 | 5,~~76~~93 | 0,~~865~~890 | 5,39 | 2,~~79~~87 | 2,~~80~~72 |
| 12 | T30 | 1,5 | 1,6 | 23,5 | 6,~~73~~80 | 1,~~01~~02 | 7,84 | 3,~~25~~26 | 3,~~49~~46 |
| 15 | T30 | 1,5 | 1,6 | 29,4 | 7,~~46~~45 | 1,12 | 9,80 | 3,~~61~~60 | 3,~~94~~95 |
| 15,5 | T30 | 1,5 | 1,6 | 30,4 | 7,~~58~~55 | 1,~~14~~13 | 10,1 | 3,~~67~~65 | 4,~~01~~02 |
| 17,5 | T30 | 1,5 | 1,6 | 34,3 | ~~8,05~~7,98 | 1,~~21~~20 | 11,4 | 3,~~89~~86 | 4,~~26~~30 |
| 24 | T30 | 1,5 | 1,6 | 47,0 | 9,~~46~~35 | 1,~~42~~40 | 15,7 | 4,~~57~~52 | ~~4,97~~5,03 |
| 25,8 | T30 | 1,5 | 1,6 | 50,6 | 9,~~83~~73 | 1,~~47~~46 | 16,9 | 4,~~75~~70 | 5,14 |
| 27 | T30 | 1,5 | 1,6 | 52,9 | ~~10,1~~9,98 | 1,~~51~~50 | 17,6 | 4,~~87~~82 | 5,~~25~~30 |
| 36 | T30 | 1,5 | 1,6 | 70,6 | 11,8 | 1,77 | 23,5 | 5,~~69~~70 | 5,~~99~~98 |
| 38 | T30 | 1,5 | 1,6 | 74,5 | 12,~~1~~2 | 1,~~82~~83 | 24,8 | 5,~~86~~88 | 6,~~14~~12 |
| 40,5 | T30 | 1,5 | 1,6 | 79,4 | 12,6 | 1,~~89~~90 | 26,5 | 6,~~07~~11 | 6,~~31~~28 |
| 48,3 | T30 | 1,5 | 1,6 | 94,~~7~~6 | ~~13,9~~14,0 | 2,~~08~~10 | 31,5 | 6,~~72~~75 | 6,~~81~~78 |
| 52 | T30 | 1,5 | 1,6 | 102 | 14,~~5~~6 | 2,18 | 34,0 | 7,~~01~~03 | 7,~~02~~00 |
| 72,5 | T30 | 1,5 | 1,6 | 142 | 18,~~1~~2 | 2,~~71~~73 | 47,4 | 8,~~74~~81 | 7,~~85~~79 |

## F.3 Circuit-breakers with rated voltage from 100 kV to 800 kV

Standard values of prospective TRV are under consideration by CIGRE, therefore no test requirements are specified.

## F.4 Circuit-breakers with rated voltage higher than 800 kV

Severe TRV conditions can occur when short-circuit occurs immediately after a transformer without any appreciable capacitance between the transformer and the circuit breaker. In such cases, the RRRV exceeds the values specified for terminal fault test-duties. This is due to the fact that the capacitances to earth of transformers are relatively small i.e. 9 000 pF for applications at voltages above 800 kV. The corresponding natural frequency of the transformer leads to a TRV having a rate-of-rise that is approximately two times the value for T10.

The system TRV can be modified by a capacitance and then be within the standard TRV capability envelope. As an alternative, the user can choose to specify a transformer limited fault (TLF) current breaking capability.

The TLF breaking current is selected from the R10 series in order to limit the number of testing values possible. For applications at voltages above 800 kV, preferred values are 10 kA and 12,5 kA.

TRV parameters (see Table F.2) are calculated from the TLF current, the rated voltage and a capacitance of the transformer of 9 nF. The first-pole-to clear factor corresponding to this type of fault is 1,2. Pending further studies, conservative values are taken for the amplitude factor and the voltage drop across the transformer. They are equal to 1,7 and 0,9, respectively.

**Table F.2 – Required values of prospective TRV for circuit-breakers with rated voltages higher than 800 kV intended to be connected to a transformer with a connection of low capacitance**

| $U_r$<br>kV | TLF current<br>kA | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_c$<br>kV | $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 1 100 | 10 | 1,2 | 1,7 × 0,9 | 1 649 | 107 | 16 | 550 | 51 | 15,4 |
| 1 100 | 12,5 | 1,2 | 1,7 × 0,9 | 1 649 | 96 | 14 | 550 | 46 | 17,2 |
| 1 200 | 10 | 1,2 | 1,7 × 0,9 | 1 799 | 112 | 17 | 600 | 54 | 16,1 |
| 1 200 | 12,5 | 1,2 | 1,7 × 0,9 | 1 799 | 100 | 15 | 600 | 48 | 18,0 |

# Annex G
(normative)

## Use of mechanical characteristics and related requirements

At the beginning of the type tests, the mechanical characteristics of the circuit-breaker shall be established, for example, by recording no-load travel curves and/or by defining additional characteristic parameters, such as, if applicable, momentary speed at a certain stroke, closing and opening times, damping time, etc. The tolerances applicable to these additional parameters shall also be defined and declared by the manufacturer. The mechanical characteristics will serve as the reference for the purpose of characterising the mechanical behaviour of the circuit-breaker.

The mechanical characteristics shall be used to confirm that the different test objects used during the mechanical, making and breaking tests behave mechanically in a similar way. All test objects used for mechanical, making and breaking type tests shall have their respective no-load contact travel curves within the following described envelopes. Care should be exercised in the interpretation of the curves when, due to variable measuring methods at different laboratories, a direct comparison between the envelopes cannot be made.

The reference mechanical characteristics are also used to confirm that production units behave mechanically in a similar way as the test objects used during type tests.

The type and location of the sensor used for the record of the mechanical characteristics shall be stated in the test report. The mechanical characteristic curve which can be measured at any part of the power kinematic chain can be recorded continuously or discretely. In case of discrete measurement, at least 20 discrete values should be given for the complete stroke.

The no-load contact travel curves shall be used for determining the limits of the allowable deviations over or under this reference curve. From this reference curve, two envelope curves shall be drawn from the instant of contact separation to the end of the contact travel for the opening operation and from the beginning of the contact travel to the instant of contact touch for the closing operation. The distance of the two envelopes from the original course shall be ±5 % of the total stroke as shown in Figure 15. In case of circuit-breakers with a total stroke of 40 mm or less the distance of the two envelopes from the original course shall be ±2 mm. It is recognised that for some designs of circuit-breakers, these methods can be unsuitable, as for example for vacuum circuit-breakers or for some circuit-breakers rated 1 kV up to and including 52 kV. In such cases the manufacturer shall define an appropriate method to verify the proper operation of the circuit-breaker.

If mechanical characteristics other than no-load contact travel curves are used, the manufacturer shall define the alternative method and the tolerances used.

The series of Figure 14 through Figure 17 are for illustrative purposes and only illustrate the opening operation. They are idealised, and do not show the variation in profile caused by the friction effect of the contacts or the end of travel damping. In particular, it is important to note that the effects of damping are not shown in these diagrams. The oscillations produced at the end of travel are dependent upon the efficiency of the damping of the drive system. The shape of these oscillations can be a deliberate function of the design and can slightly vary from one specimen to another. Therefore, it is important that any variations in the curve at the end of the stroke, which are outside the tolerance margin given by the envelope, are fully explained and understood before they are rejected or accepted as showing equivalence with the reference curves. In general, all curves should fall within the envelopes for acceptance.

The travel characteristics of all production units shall lie within the 10 % total allowable tolerance around the reference travel characteristic. The reference travel characteristic can lie at any point within the defined tolerance band but the parameters of the 10 % tolerance band, once defined, shall remain unchanged. Figure 16 and Figure 17 show the two extremes of the allowable cases which are –0 %, +10 % and –10 %, +0 % respectively.

# Annex H
(normative)

# Requirements for making and breaking test procedures for metal-enclosed and dead tank circuit-breakers

## H.1 General

This annex contains requirements for test circuits and procedures for type testing relevant to short-circuit making and breaking performance of metal-enclosed and dead tank circuit-breakers. Other methods are not excluded, provided that they supply the correct stresses to the circuit-breaker.

The various test cases are evaluated and test circuits are given, or special precautions required to use test circuits developed for live tank circuit-breakers. The tests described can be made in both direct and synthetic circuits. For synthetic test circuits, see IEC 62271-101.

Metal-enclosed circuit-breakers shall fulfil their duties under conditions that are different from those prevailing for live tank circuit-breakers.

The main features with certain consequences on making and breaking tests are:

a) The making and breaking units are integrated parts of a given substation design. Thus, the surrounding components of a substation shall be considered when defining the test conditions;
b) Several making and breaking units of one pole, or even all three poles, can be placed within a common enclosure. Various components of making and breaking units of the substation as well as other live and earthed parts are in immediate vicinity. This will cause high dielectric stress on the insulating medium and can lead to strong interactions between parts of making and breaking units and the surroundings. It also results in a relatively high capacitance and low inductance of tested and surrounding parts.

   The implications of such interactions shall be considered in determining the test requirements;
c) In metal-enclosed switchgear, the insulating surfaces are exposed to a relatively high dielectric stress and this can make them sensitive to deposits.

## H.2 Reduced number of making and breaking units for testing purposes

Due to limitations of the test facility it may not be possible to perform the tests on a complete circuit-breaker. In these cases alternative procedures can be used if the following instructions are taken into account.

Depending on the alternatives, the following interactions between the tested object and the omitted parts should be analysed:

– between circuit-breaker and surrounding parts of the substation;
– between poles or between poles and the enclosure;
– between different making and breaking units or between making and breaking units and the enclosure.

Two different stresses can be considered, which usually can be treated separately:

– stress of the making and breaking gap;
– stress of insulation between phases, or between phases and the enclosure.

## H.3 Tests for single pole in one enclosure

### H.3.1 General

The conditions of 7.102 shall be fulfilled.

### H.3.2 Terminal fault tests

#### H.3.2.1 General

For short-circuit-currents in excess of 60 % of the short-circuit breaking current the test circuits shall comply with Figure 27a and Figure 28a.

Test circuits given in Figure 27b, and Figure 28b do not stress metal-enclosed and dead tank circuit-breakers in earthed fault conditions correctly but are acceptable for short-circuit currents equal to or less than 60 % of the rated short-circuit breaking current.

#### H.3.2.2 Unit testing

Subclause 7.102.4.2 is applicable with the following additional requirements:

To verify the insulation performance of metal-enclosed circuit-breakers between live parts and enclosures, an additional test shall be performed with:

– the rated short-circuit current interrupted by all making and breaking units under condition of maximum arcing time;
– the corresponding voltage applied between the incoming terminal and the tank for both duties T100s and T100a.

A single breaking operation is sufficient to demonstrate this performance. The circuit-breaker can be reconditioned before this additional test.

### H.3.3 Capacitive current tests

#### H.3.3.1 General

The testing procedure shall be in agreement with 7.111.

Table H.1 gives the source-side and load-side voltages and the recovery voltages during three-phase capacitive current breaking in actual service conditions and shall be used for three-phase tests.

Table H.2 gives the corresponding values of the source-side, load-side, and recovery voltages during single-phase capacitive current breaking tests.

**Table H.1 – Three-phase capacitive current breaking in service conditions: voltages on the source-side, load-side, and recovery voltages**

| Voltage at circuit-breaker terminal | Values of the voltages for effectively earthed neutral systems | | | Values of the voltages for non-effectively earthed neutral systems |
|---|---|---|---|---|
| | Unearthed capacitors | Earthed capacitor banks and screened cables | Lines | In all cases |
| $U_{CE}$ | $U_r\sqrt{2}/\sqrt{3}$ | $U_r\sqrt{2}/\sqrt{3}$ | $U_r\sqrt{2}/\sqrt{3}$ | $U_r\sqrt{2}/\sqrt{3}$ |
| $U_{C'E}$ | $1{,}5\times U_r\sqrt{2}/\sqrt{3}$ | $U_r\sqrt{2}/\sqrt{3}$ | $1{,}2\times U_r\sqrt{2}/\sqrt{3}$ | $1{,}5\times U_r\sqrt{2}/\sqrt{3}$ |
| $U_{C/C'}$ | $2{,}5\times U_r\sqrt{2}/\sqrt{3}$ | $2\times U_r\sqrt{2}/\sqrt{3}$ | $2{,}2\times U_r\sqrt{2}/\sqrt{3}$ | $2{,}5\times U_r\sqrt{2}/\sqrt{3}$ |

Pole C is assumed to be the first-pole-to-clear.

C: source side

C': load side

C/C': across the open contacts

$U_r$ = rated voltage

$U_{CE}$ = voltage between source-side terminal and earth

$U_{C'E}$ = voltage between load-side terminal and earth

$U_{C/C'}$ = voltage across the open contacts

NOTE 1 The designation of the poles is illustrated in Figure H.1.

NOTE 2 The values given do not consider the voltage drop at the supply side after breaking.

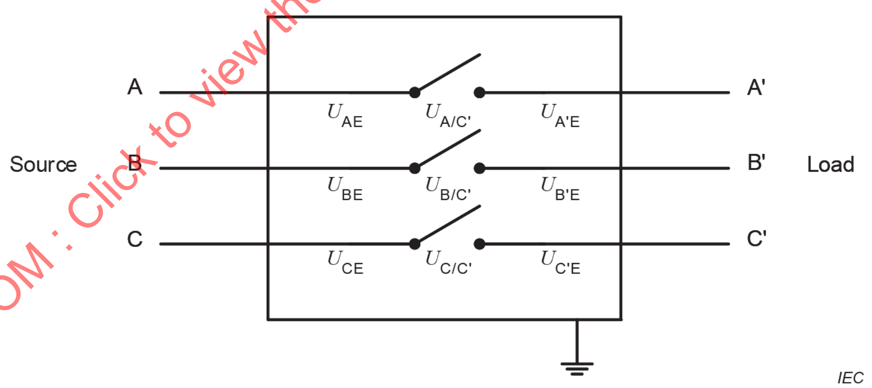



**Figure H.1 – Test configuration considered in Table H.1, Table H.2 and Table H.3**

**Table H.2 – Corresponding capacitive current-breaking tests in accordance with 7.111.7 for single-phase laboratory tests. Values of voltages on the source-side, load-side, and recovery voltages**

| Voltage at circuit-breaker terminal | Values of the voltages for effectively earthed neutral systems | | | Values of the voltages for non-effectively earthed neutral systems |
|---|---|---|---|---|
| | Unearthed capacitors | Earthed capacitor banks and screened cables | Lines | In all cases |
| $U_{CE}$ | $1{,}3 \times U_r \sqrt{2} / \sqrt{3}$ | $U_r \sqrt{2} / \sqrt{3}$ | $1{,}2 \times U_r \sqrt{2} / \sqrt{3}$ | $1{,}3 \times U_r \sqrt{2} / \sqrt{3}$ |
| $U_{C'E}$ | $1{,}5 \times U_r \sqrt{2} / \sqrt{3}$ | $U_r \sqrt{2} / \sqrt{3}$ | $1{,}2 \times U_r \sqrt{2} / \sqrt{3}$ | $1{,}5 \times U_r \sqrt{2} / \sqrt{3}$ |
| $U_{C/C'}$ | $2{,}8 \times U_r \sqrt{2} / \sqrt{3}$ | $2 \times U_r \sqrt{2} / \sqrt{3}$ | $2{,}4 \times U_r \sqrt{2} / \sqrt{3}$ | $2{,}8 \times U_r \sqrt{2} / \sqrt{3}$ |

Pole C is assumed to be the first-pole-to-clear.

C: source side

C': load side

C/C': across the open contacts

$U_r$ = rated voltage

$U_{CE}$ = voltage between source-side terminal and earth

$U_{C'E}$ = voltage between load-side terminal and earth

$U_{C/C'}$ = voltage across the open contacts

NOTE 1 The designation of the poles is illustrated in Figure H.1.

NOTE 2 The values given do not consider the voltage drop at the supply side after breaking.



### H.3.3.2 Single-pole testing of three-pole circuit-breakers

In some test circuits, both voltages are combined at one terminal of the circuit-breaker, the other terminal being earthed.

This condition is more severe for the insulation to earth and can affect the severity of the test across the circuit-breaker.

For single-phase tests performed to prove three-phase switching of capacitor banks with unearthed neutral or switching in non-effectively earthed neutral systems, the dielectric withstand can be demonstrated by one of the following test methods:

a) Making and breaking tests with an intermediate earth point in the source-side or in the load-side resulting in a voltage between the live parts on the source side and the enclosure of $1{,}5 \times U_r \sqrt{2} / \sqrt{3}$ and a recovery voltage of $2{,}8 \times U_r \sqrt{2} / \sqrt{3}$;

b) Subject to agreement of the manufacturer, tests can be performed with a supply circuit having an earthed neutral and a supply voltage of $1{,}5 \times U_r \sqrt{2} / \sqrt{3}$.

If for single-phase tests, according to 7.111.7, the dielectric stress between the live part and the enclosure is not correctly reproduced, additional dielectric tests shall be performed applying the load side dielectric stresses to the enclosure according to Table H.2. The load side voltage shall be applied, with both polarities, on each terminal of the circuit-breaker and maintained for 0,3 s.

In addition to the conditions of Table H.1 and Table H.2, the following paragraphs give information concerning switching of capacitive loads in the presence of earth faults (see Annex J).

With the neutral of the supply effectively earthed and in presence of single- or two-phase earth faults, the voltages in the healthy phases can reach up to $1{,}4 \times U_r \sqrt{2} / \sqrt{3}$ .The precise value depends on the zero-sequence impedances. In that case, the values of the voltages on source-side and load-side terminals to earth which shall be achieved are:

– $U_{C/E} = U_{C'/E} = 1{,}4 \times U_r \sqrt{2} / \sqrt{3}$

– $U_{C/C'} = 2{,}8 \times U_r \sqrt{2} / \sqrt{3}$ (recovery voltage)

With the neutral of the supply not effectively earthed and in presence of single- or two-phase earth faults, the voltages in the healthy phases can reach up to $1{,}7 \times U_r \sqrt{2} / \sqrt{3}$ .

In that case, the values of the voltages on source-side and load-side terminals to earth which shall be achieved are:

– $U_{C/E} = U_{C'/E} = 1{,}7 \times U_r \sqrt{2} / \sqrt{3}$

– $U_{C/C'} = 3{,}4 \times U_r \sqrt{2} / \sqrt{3}$ (recovery voltage)

#### H.3.3.3 Unit testing

Unit testing is only acceptable if the voltage to earth at one terminal is equal to the load side voltage to earth during full-pole testing. This condition can be met by:

– energizing the enclosure of the circuit-breaker, insulated from earth, with a proper voltage, or

– in the case of two series connected making and breaking units per pole, performing half-pole testing with both voltages (AC and DC) superimposed at one terminal and the other terminal of that half-pole being earthed.

## H.4 Tests for three poles in one enclosure

### H.4.1 Terminal fault tests

For short-circuit-currents in excess of 60 % of the short-circuit breaking current the test circuits shall comply with Figure 27a or Figure 28a.Test circuits given in Figure 27b and Figure 28b do not stress metal-enclosed and dead tank circuit-breakers in earthed fault conditions correctly but are acceptable for short-circuit testing equal to or less than 60 % of the rated short-circuit breaking current.

### H.4.2 Capacitive current tests

In case of single-phase testing, the dielectric stresses between the insulation to earth and between poles are not reproduced correctly and additional dielectric test are necessary. If not otherwise verified, the stresses stated in Table H.3 shall be verified by applying them at both polarities and for a duration of at least 0,3 s in case of DC voltages and for a duration of at least 0,3 s in case of AC voltages. In case of DC voltages on two terminals these voltages shall have opposite polarity. For voltage distribution of the AC and DC voltages, see Table H.1. All terminals not being part of the testing shall be earthed.

Depending on configuration of the circuit-breaker (for example, symmetry between poles and/or enclosure), some tests are redundant and shall not be performed.

It is sufficient to verify the dielectric stresses between the insulation to earth and between poles only once for a certain design of circuit-breaker. If different capacitive ratings shall be covered, the dielectric stresses related to the highest recovery voltage shall be applied. If the intent is to cover class C2, a T60 preconditioning test according to 7.111.9.4.1 shall be performed prior to the verification of the dielectric stresses.

**Table H.3 – Capacitive current breaking in actual service conditions: maximum typical voltage values**

| Voltage between terminal | Effectively earthed neutral systems | | | Non-effectively earthed neutral systems |
|---|---|---|---|---|
| | Unearthed capacitor banks<br>p.u. | Earthed capacitor banks<br>p.u. | Lines<br>p.u. | p.u. |
| A-earth | 1,0 | 1,0 | 1,0 | 1,5 |
| A'-earth | 1,5 | 1,0 | 1,2 | 1,0 |
| A-A' | 2,5 | 2,0 | 2,2 | 2,5 |
| A'-B' | ≤ 1,73 | ≤ 1,73 | ≤ 1,73 | ≤ 1,73 |
| A'-C' | 2,37 | 2,0 | 2,1 | 2,37 |
| B'-C' | ≤ 1,73 | 2,0 | 1,9 | ≤ 1,73 |
| A-B' | 1,87 | 2,0 | 2,0 | 1,87 |
| A-C' | 1,87 | 2,0 | 1,9 | 1,87 |
| B-A' | 2,5 | 2,0 | 2,2 | 2,5 |
| B-C' | 1,87 | 2,0 | 1,9 | 1,87 |
| C-A' | 2,5 | 2,0 | 2,2 | 2,5 |
| C-B' | 1,87 | 2,0 | 2,0 | 1,87 |

A-A' First-pole-to-clear A = Source side A' = Load side

NOTE 1 The indicated values for non-effectively earthed neutral systems apply if the source-side zero-sequence capacitance is negligible compared to that of the load side.

NOTE 2 1 p.u. = $U_r \sqrt{2} / \sqrt{3}$

NOTE 3 Poles B and C clear at the first current zeros after the clearance of pole A.

NOTE 4 The voltage values for A-B, A-C and B-C are in all cases equal to $U_r \sqrt{2}$.

NOTE 5 The voltages B-earth, B'-earth, B-B' and C-earth, C'-earth and C-C' are not incorporated in the table, because their values are lower than those for pole A.

# Annex I
(normative)

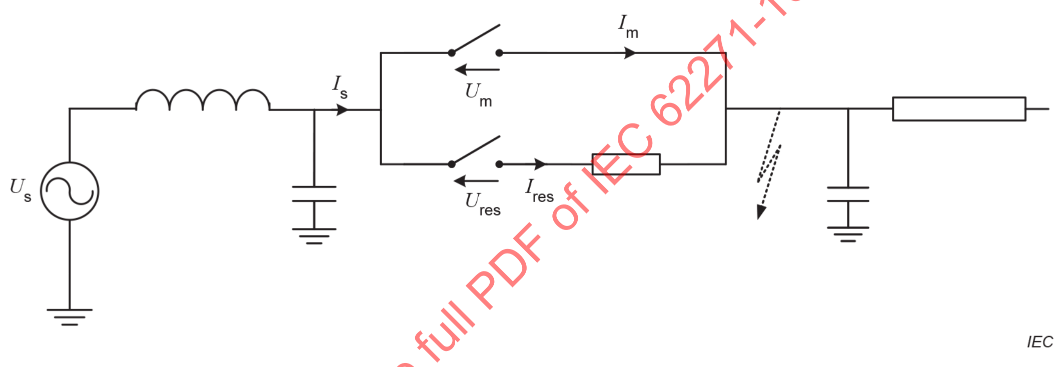
# Requirements for circuit-breakers with opening resistors

## I.1 General

This annex is applicable to circuit-breakers in which a resistor is inserted in series with the circuit to be interrupted. This resistor is connected in parallel to the making and breaking unit at least for breaking operations. During the breaking process, the making and breaking unit transfers the current to the resistor and then the resistor switch connected in series to the resistor break the remaining current.

Circuit-breakers with opening resistors shall meet all requirements of the main text of this document. This annex supplements the main text and defines specific design and testing requirements which take into account the presence of the opening resistors.

A typical system configuration is given in Figure I.1.




**Key**

| | | | |
|---|---|---|---|
| $I_m$ | Current through the making and breaking unit | $U_m$ | Voltage across the making and breaking unit |
| $I_{res}$ | Current through the resistor switch | $U_{res}$ | Voltage across the resistor switch |
| $I_s$ | Source side current | $U_s$ | Source side voltage |

**Figure I.1 – Typical system configuration for breaking by a circuit-breaker with opening resistors**

## I.2 Switching performance to be verified

### I.2.1 General

The switching performance of the circuit-breaker with opening resistors is adequately verified if a direct test method is used. In case of limitations in testing facilities, synthetic test methods shall be used, refer to IEC 62271-101.

Appropriate timing of mechanical and electrical operation including pre-arcing time and arcing times for both making and breaking unit and resistor switch shall be achieved.

NOTE 1 The number of consecutive operations during tests and in service is limited by the thermal capacity of the resistor and by its cooling time constant.

Tests should be performed preferably with opening resistor. Alternatively, the tests can also be performed without opening resistor provided that breaking by the making and breaking unit is not affected by or affecting the resistor switch. The resistor is taken into account by applying modified current and voltage parameters as calculated under breaking conditions.

If the tests are performed without the opening resistor, modified TRV values should be calculated on a case-by-case basis, depending on the operating conditions such as short-circuit current and ohmic resistance value of the opening resistor. TRV calculations can be performed using transient calculation programs. Modified TRV values should be specified by the system designer in this case.

Modified TRV parameters can also be obtained by calculating the influence of the resistor on the circuits with lumped elements that generates the uninfluenced TRV.

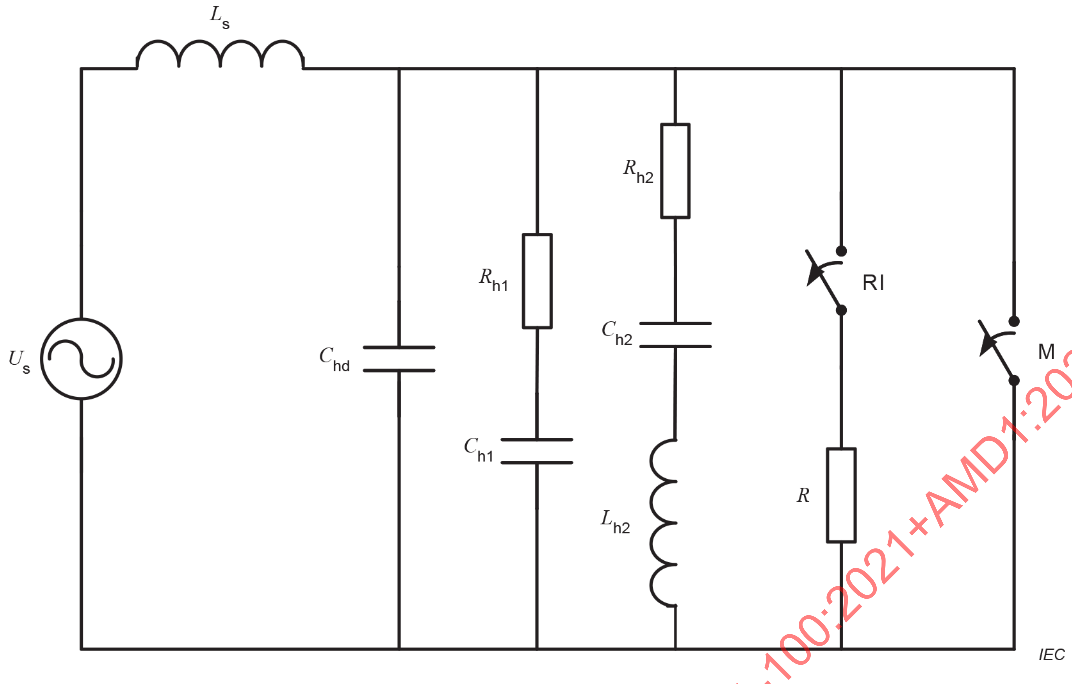
NOTE 2 It is common that making and breaking tests are performed without the opening resistor and the test parameters are adjusted considering the effects of the resistor on the current to be interrupted and on the following recovery voltage for both making and breaking unit and resistor switch.

NOTE 3 When tests are performed without the opening resistor, it is essential that the operation and performances of the making and breaking unit and of the resistor switch are not mutually affected during operations for example influence of hot gases.

### I.2.2 Tests of the making and breaking unit

#### I.2.2.1 Short-circuit making and breaking tests

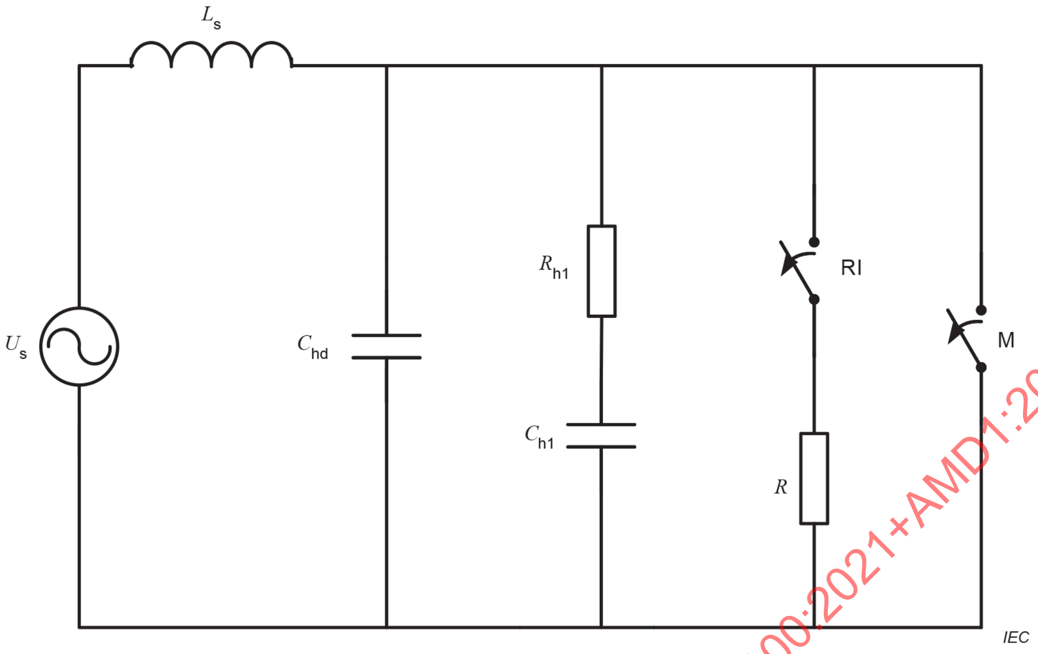
An example of a test circuit for test-duties T60 and T100 is given in Figure I.2. An example of a test circuit for test-duties T10, T30 and OP2 is given in Figure I.3.




**Key**

| | | | |
|---|---|---|---|
| $U_s$ | Source voltage | $C_{h2}$ | TRV capacitance part 2 |
| $L_s$ | Source inductance | $L_{h2}$ | TRV inductance |
| $C_{hd}$ | Capacitance for time delay | RI | Resistor switch |
| $R_{h1}$ | TRV resistance part 1 | $R$ | Resistance |
| $C_{h1}$ | TRV capacitance part 1 | M | Main contacts |
| $R_{h2}$ | TRV resistance part 2 | | |

**Figure I.2 – Test circuit for test-duties T60 and T100**




**Key**

| | | | |
|---|---|---|---|
| $U_s$ | Source voltage | $C_{h1}$ | TRV capacitance |
| $L_s$ | Source inductance | RI | Resistor switch |
| $C_{hd}$ | Capacitance for time delay | $R$ | Resistance |
| $R_{h1}$ | TRV resistance | M | Main contacts |

**Figure I.3 – Test circuit for test-duties T10, T30 and OP2**



Calculation of parameters:

$U_s = k_{pp} \times U_r/\sqrt{3}$

$L_s = (U_s/I_s)/\omega$

Calculation of the TRV components for T100:

$R_{h1} \approx (\mathrm{d}u/\mathrm{d}t)/(\mathrm{d}i/\mathrm{d}t)$

$C_{h1} \approx 0{,}31 \times L_s/R_{h1}^2$

$R_{h2} \approx 0{,}32 \times R_{h1}$

$C_{h2} \approx 0{,}7 \times C_{h1}$

$L_{h2} \approx 1{,}15 \times L_s$

$C_{hd} \approx t_d/R_{h1}$

Calculation of the TRV components for T60:

$R_{h1} \approx 0,9 \times (du/dt)/(di/dt)$

$C_{h1} \approx 0,3 \times L_s/R_{h1}^2$

$R_{h2} \approx 0,1 \times R_{h1}$

$C_{h2} \approx 1,16 \times C_{h1}$

$L_{h2} \approx 1,38 \times L_s$

$C_{hd} \approx t_d/R_{h1}$

Calculation of the TRV components for T30:

$R_{h1} \approx (du/dt)/(di/dt)$

$C_{h1} \approx 0,42 \times L_s/R_{h1}^2$

$C_{hd} \approx t_d/R_{h1}$

Calculation of the TRV components for T10:

$R_{h1} \approx 1,3 \times (du/dt)/ (di/dt)$

$C_{h1} \approx 0,42 \times L_s/R_{h1}^2$

$C_{hd} \approx t_d/R_{h1}$

Calculation of the TRV components for OP2:

$R_{h1} \approx 1,85 \times (du/dt)/(di/dt)$

$C_{h1} \approx 2,55 \times L_s/R_{h1}^2$

$C_{hd} \approx t_d/R_{h1}$

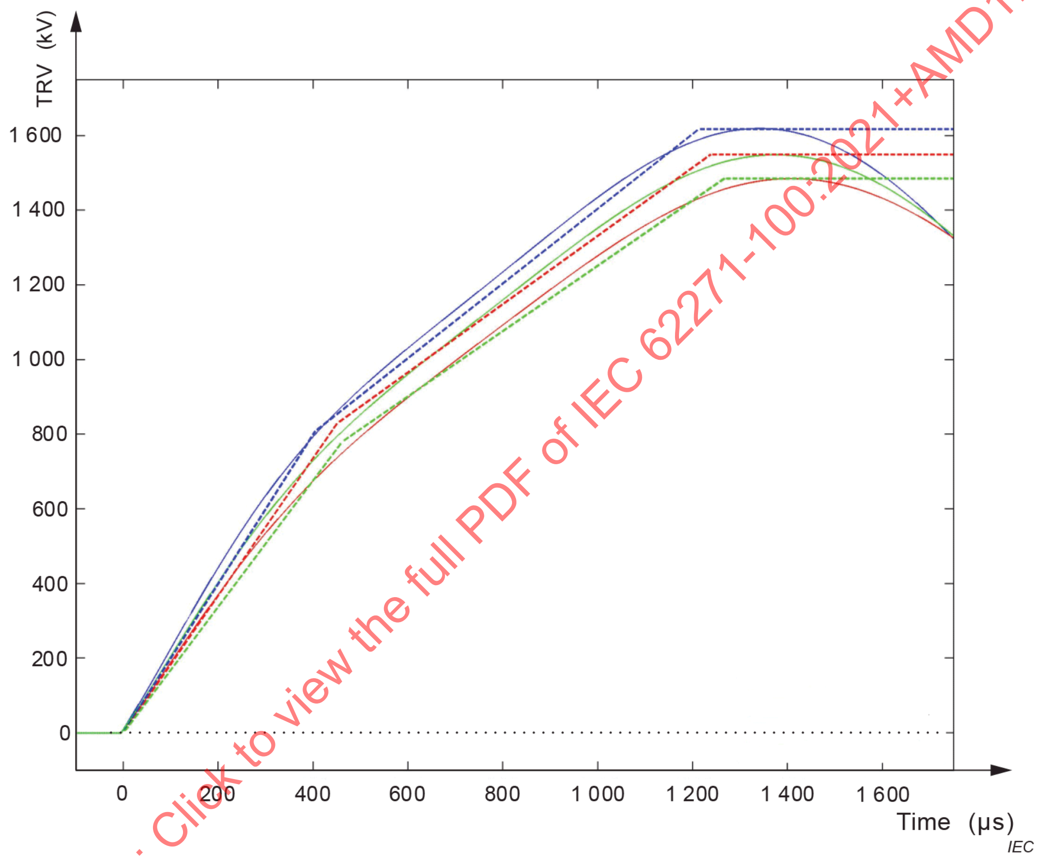
Table I.1 lists the results of calculations done using the two circuits. The reduction of the $TRV_{peak}$ is listed under $u_{cred}$.

**Table I.1 – Results of the TRV calculation for terminal faults and out-of-phase**

| $U_r$ kV | $I_{sc}$ kA | $f$ Hz | Duty | $R$ Ω | $u_1$ kV | $t_1$ µs | $u_c$ kV | $t_2$ or $t_3$ µs | $u_{cred}$ % | Result |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 100 | 50 | 50 | T100s(b) | ∞ | 808 | 404 | 1 617 | 1 212 | 0 | - |
| 1 100 | 50 | 50 | T100s(b) | 1 000 | 830 | 451 | 1 549 | 1 238 | -4 | Underdamped |
| 1 100 | 50 | 50 | T100s(b) | 500 | 780 | 461 | 1 485 | 1 267 | -8 | Underdamped |
| 1 100 | 50 | 50 | T60 | ∞ | 808 | 269 | 1 617 | 1 212 | 0 | - |
| 1 100 | 50 | 50 | T60 | 1 000 | 740 | 320 | 1 508 | 1 210 | -7 | Underdamped |
| 1 100 | 50 | 50 | T60 | 500 | 660 | 340 | 1 410 | 1 237 | -13 | Underdamped |
| 1 100 | 50 | 50 | T30 | ∞ | - | - | 1 660 | 332 | 0 | - |
| 1 100 | 50 | 50 | T30 | 1 000 | - | - | 1 163 | 407 | -30 | Underdamped |
| 1 100 | 50 | 50 | T30 | 500 | - | - | 1 036 | 531 | -38 | Overdamped |
| 1 100 | 50 | 50 | T10 | ∞ | - | - | 1 897 | 271 | 0 | - |
| 1 100 | 50 | 50 | T10 | 1 000 | - | - | 971 | 624 | -49 | Overdamped |

| $U_r$ kV | $I_{sc}$ kA | $f$ Hz | Duty | $R$ Ω | $u_1$ kV | $t_1$ µs | $u_c$ kV | $t_2$ or $t_3$ µs | $u_{cred}$ % | Result |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 100 | 50 | 50 | T10 | 500 | - | - | 853 | 935 | -55 | Overdamped |
| 1 100 | 50 | 50 | OP2 | ∞ | - | - | 2 245 | 1 344 | 0 | - |
| 1 100 | 50 | 50 | OP2 | 1 000 | - | - | 1 877 | 1 435 | -16 | Underdamped |
| 1 100 | 50 | 50 | OP2 | 500 | - | - | 1 639 | 1 502 | -27 | Overdamped |

Figure I.4 and Figure I.5 show examples of underdamped TRV and overdamped TRV, respectively.



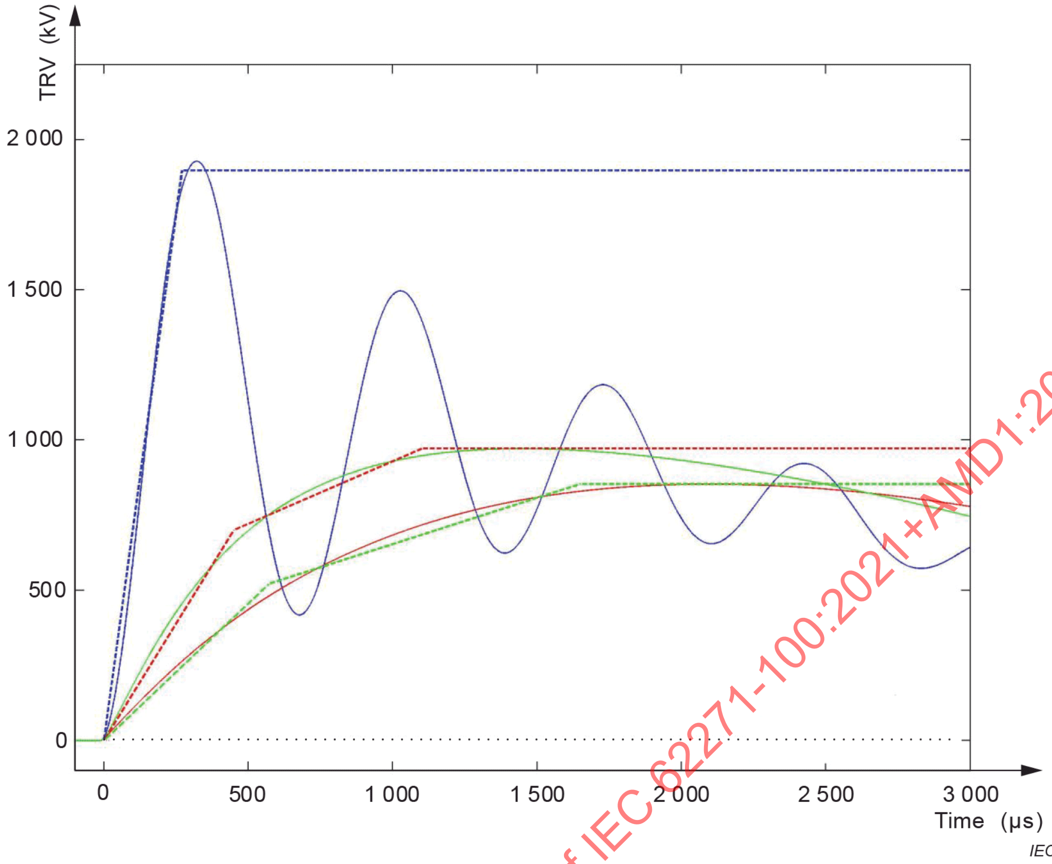

**Key**

Blue line $R = \infty$

Red line $R$ = 1 000 Ω

Green line $R$ = 500 Ω

**Figure I.4 – Example of an underdamped TRV for T100s(b), $U_r$ = 1 100 kV $I_{sc}$ = 50 kA, $f_r$ = 50 Hz**




**Key**

Blue line $R = \infty$

Red line $R$ = 1 000 Ω

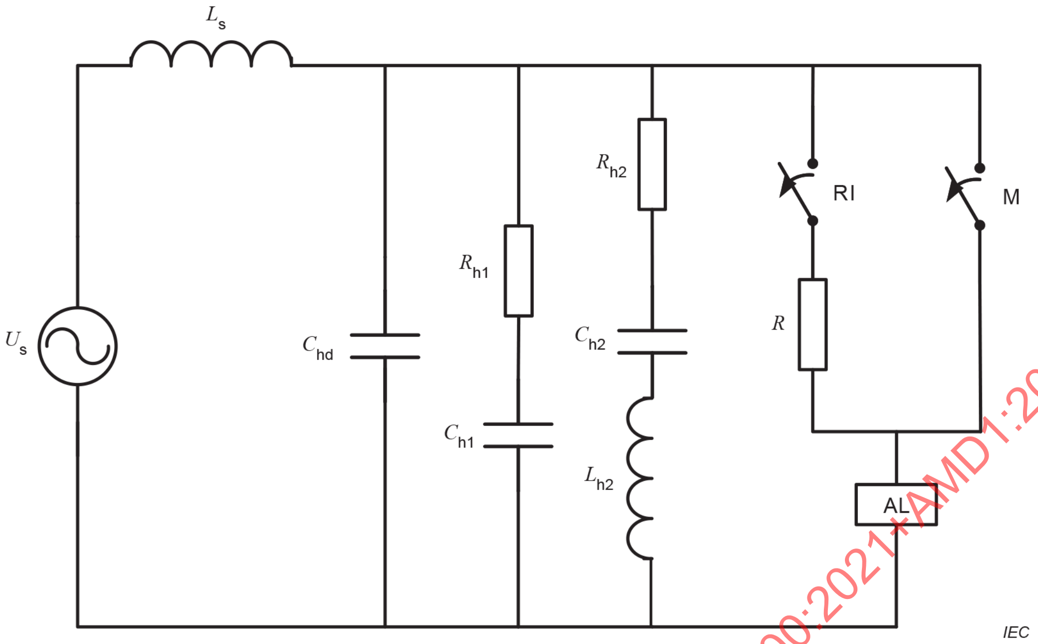
Green line $R$ = 500 Ω

**Figure I.5 – Example of an overdamped TRV for T10, $U_r$ = 1 100 kV $I_{sc}$ = 50 kA, $f_r$ = 50 Hz**

### I.2.2.2 Short-line fault tests

An example of a test circuit for test-duty $L_{90}$ is given in Figure I.6.

The equivalent line side TRV shall be calculated by simulation of a line having at least 10 π sections with the specified surge impedance. An example of such a calculation is given in Figure I.7.




**Key**

| | | | |
|---|---|---|---|
| $U_s$ | Source voltage | $C_{h2}$ | TRV capacitance part 2 |
| $L_s$ | Source inductance | $L_{h2}$ | TRV inductance |
| $C_{hd}$ | Capacitance for time delay | RI | Resistor switch |
| $R_{h1}$ | TRV resistance part 1 | $R$ | Resistance |
| $C_{h1}$ | TRV capacitance part 1 | M | Main contacts |
| $R_{h2}$ | TRV resistance part 2 | AL | Artificial line |

**Figure I.6 – Example of a test circuit for short-line fault test-duty $L_{90}$**

Table I.2 lists the results of calculations done using the test circuit shown in Figure I.6. The reduction of the $TRV_{peak}$ is listed under $u_{cred}$ column.

Calculation of the TRV components for $L_{90}$:

– Source side

$R_{h1} \approx (du/dt)/(di/dt)$

$C_{h1} \approx 0{,}31 \times L_s/R_{h1}^2$

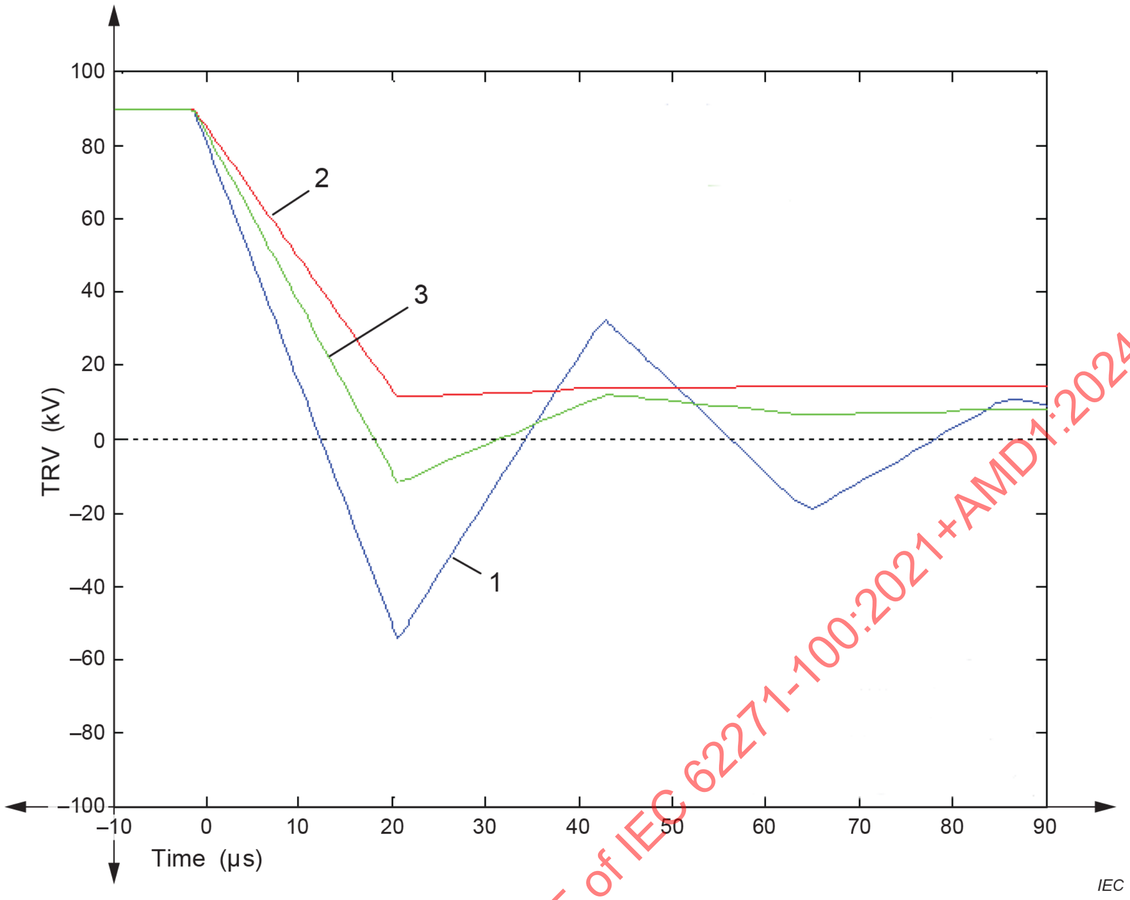
$R_{h2} \approx 0{,}32 \times R_{h1}$

$C_{h2} \approx 0{,}7 \times C_{h1}$

$L_{h2} \approx 1{,}15 \times L_s$

$C_{hd} \approx t_d/R_{h1}$

– Line side by real line simulation as indicated in Figure I.7




**Key**

1 Blue line: IEC 62271-100 ($R$ = ∞): $k$ = 1,6 and $Z$ = 330 Ω

2 Red line: $R$ = 500 Ω: $k$ = 0,87 and $Z$ = 173 Ω

3 Green line: $R$ = 1 000 Ω: $k$ = 1,13 and $Z$ = 224 Ω

**Figure I.7 – Example of real line simulation for short-line fault test-duty $L_{90}$ based on $U_r$ = 1 100 kV, $I_{sc}$ = 50 kA and $f_r$ = 50 Hz**



**Table I.2 – Results of the TRV calculation for test-duty $L_{90}$**

| $U_r$ (kV) | $I_{sc}$ (kA) | $f$ (Hz) | Duty | $R$ (Ω) | $u_1$ (kV) | $t_1$ (us) | $u_c$ (kV) | $t_2$ (us) | $u_{cred}$ (%) | $k$ | $Z$ (Ω) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Source | | | | | Line | |
| 1 100 | 50 | 50 | L90 | ∞ | 674 | 337 | 1 347 | 1 011 | 0 | 1,6 | 330 |
| 1 100 | 50 | 50 | L90 | 1 000 | 635 | 350 | 1 302 | 1 050 | -3 | 1,13 | 224 |
| 1 100 | 50 | 50 | L90 | 500 | 605 | 360 | 1 251 | 1 076 | -7 | 0,87 | 173 |

### I.2.2.3 Capacitive current tests

Application of circuit-breakers with opening resistors is limited to overhead line switching only.

The recovery voltage waveshape during the insertion period is expressed as follows:

$$U(t) = \frac{\sqrt{2}U_\text{s}R}{Z}\left[\cos\varphi \times e^{-(1/RC)t} - \cos(\omega t + \varphi)\right] \quad (\text{I.1})$$

where

$U_\text{s}$ is the source voltage including the capacitive voltage factor $k_\text{c}$ expressed in RMS value (kV);

$C$ is the line side capacitance (F);

$R$ is the value of the opening resistor (Ω);

$Z = \sqrt{R^2 + (1/\omega C)^2}$ ;

$\varphi = \tan^{-1}(1/\omega RC)$.

Line-charging current breaking tests on the making and breaking unit are performed in two parts:

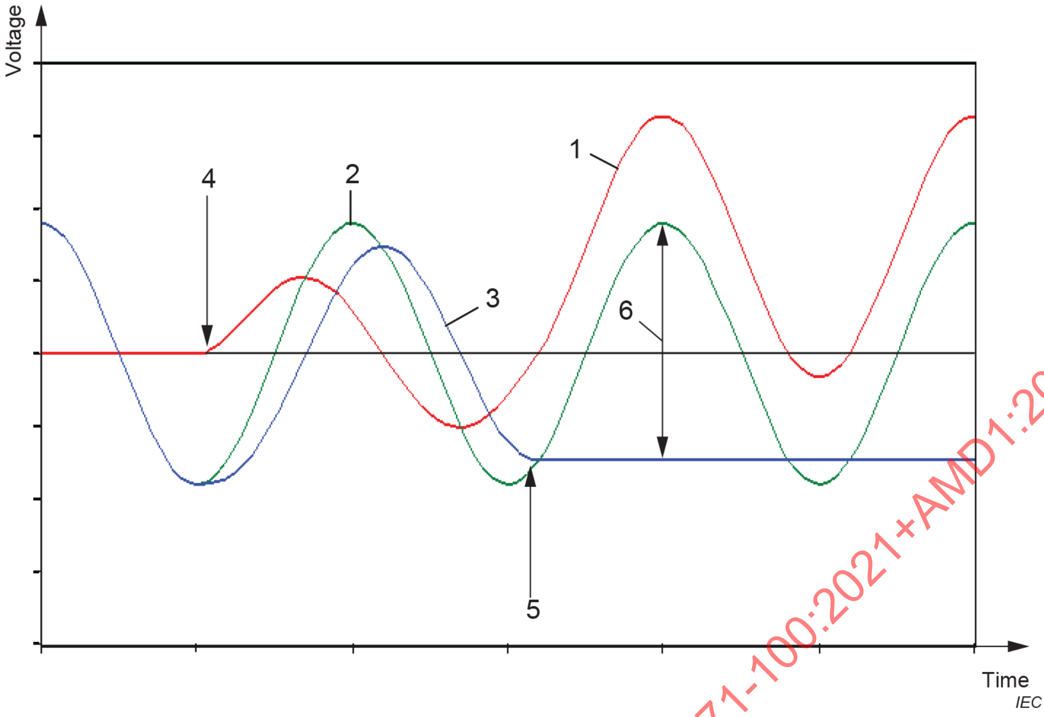
a) Test-duty LC2 with a sinusoidal recovery voltage to verify that there is no restrike or reignition during the resistor insertion period. If a reignition(s) occurs the tests are considered to be invalid and direct tests shall be performed to confirm the adequate behaviour of the making and breaking unit.

b) Test-duty LC1 with a modified "1 – cos" waveshape to verify the voltage withstand for the highest recovery voltage peak. The modified "1 – cos" waveshape shall be applied at a time after current zero equal to or less than the rated opening resistor insertion time.

NOTE The recovery voltage waveshape after insertion period is considered to be without reduction. An alternative way is to conduct the tests with a single test to cover both conditions with same number of tests as described in 7.111.9.

The restrike performance of the making and breaking unit shall be in accordance with 7.111.11.

A typical recovery voltage waveshape for capacitive current breaking is shown in Figure I.8.




**Key**

| | | |
|---|---|---|
| 1 | red line | Voltage across the terminals of the making and breaking unit $U_m$ |
| 2 | green line | Source side voltage $U_s$ |
| 3 | blue line | Load side voltage $U_l$ |
| 4 | | Breaking of making and breaking unit |
| 5 | | Breaking of resistor switch |
| 6 | | Voltage across the terminals of the resistor switch $U_{res}$ |

**Figure I.8 – Typical recovery voltage waveshape of capacitive current breaking on a circuit-breaker equipped with opening resistors**

### I.2.3 Tests on the resistor switch

#### I.2.3.1 Short-circuit making and breaking tests

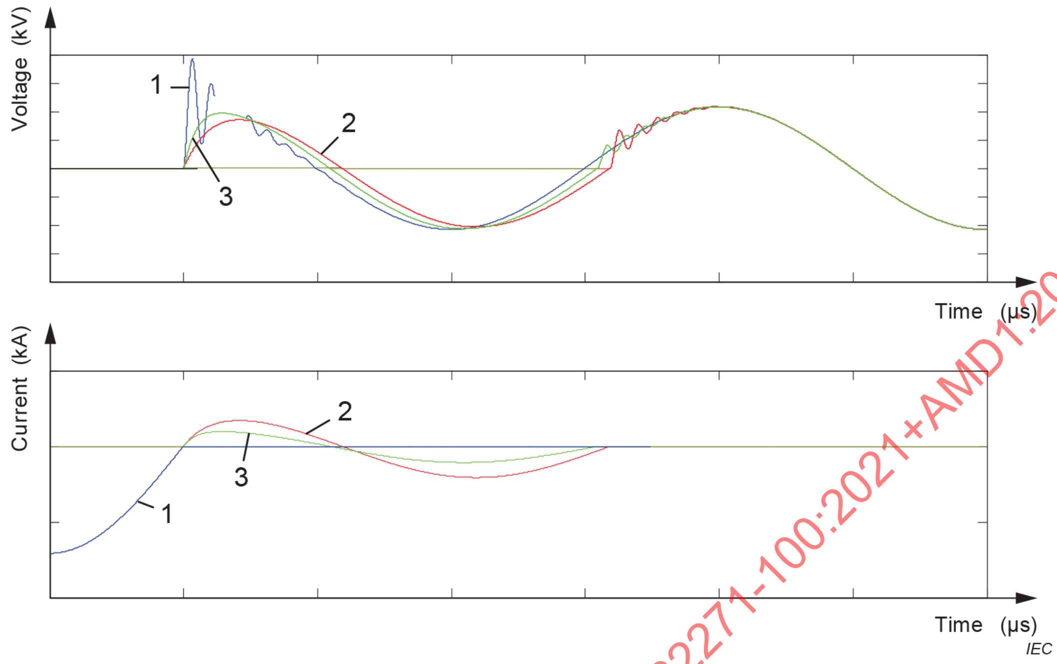
The breaking current value of the resistor switch is generally of the order of 1,5 kA or less even in the case of rated voltages above 800 kV, since the ohmic value of the opening resistor is in the range of 500 Ω to 2 000 Ω. The short-circuit current is assumed to be in the range of 40 kA to 63 kA. Then the current flowing in the resistor switch is in the order of 1 % to 4 % of the rated short-circuit current. Only in the case of out-of-phase the current could be of the order of 3 kA.

As done for the making and breaking unit, modified TRV values shall be calculated for each specific case.

TRV calculations can be conducted using a suitable electromagnetic transient calculation program.

Modified TRV parameters can also be obtained by calculating the influence of the resistor on the circuits with lumped elements. An example of a test circuit is given in Figure I.3.

A typical recovery voltage waveshape and the current through the resistor switch are shown in Figure I.9.




**Key**

1 Blue line: making and breaking unit, $R = \infty$

2 Red line: $R = 500\ \Omega$

3 Green line: $R = 1\ 000\ \Omega$

**Figure I.9 – Typical recovery voltage waveshape of T10 (based on $U_r$ = 1 100 kV, $I_{sc}$ = 50 kA and $f_r$ = 50 Hz) on the resistor switch of a circuit-breaker equipped with opening resistors**



Table I.3 lists the results of calculations done using the circuit as given in Figure I.3.

**Table I.3 – Results of the TRV calculations for test-duty T10**

| $U_r$ kV | $I_{sc}$ kA | $f$ Hz | Duty | $R$ Ω | $U_c$ kV | $t_3$ µs | $I_r$ kA |
|---|---|---|---|---|---|---|---|
| 1 100 | 50 | 50 | T10 | ∞ | | | |
| 1 100 | 50 | 50 | T10 | 1 000 | 408 | 295 | 0,75 |
| 1 100 | 50 | 50 | T10 | 500 | 673 | 287 | 1,46 |

When terminal fault test-duty T10 is performed, it is not necessary to repeat the other terminal fault test-duties on the resistor switch (T30, T60, T100a and T100s).

### I.2.3.2 Short-line fault (SLF) tests

For the breaking current value of the resistor switch, refer to I.2.3.1.

As done for the making and breaking unit, modified TRV values shall be calculated for each specific case.

TRV calculations can be conducted using a suitable electromagnetic transient calculation program.

When terminal fault test-duty T10 is performed, no SLF tests are required on the resistor switch.

### I.2.3.3 Capacitive current tests

Two series of line-charging current breaking tests are required:

a) LC1: using a "1 – cos" waveshape as defined for circuit-breakers not equipped with opening resistors;

b) LC2: with a modified “1 – cos” waveshape on a circuit-breaker equipped with opening resistors. The following equation gives the modified momentary and peak recovery voltage of the resistor switch in a circuit with a resistor $R$ in series:

$$U(t) = \sqrt{2}U_{\mathrm{s}}\left[\cos(\theta) - \cos(\omega t + \theta)\right] \quad \text{(I.2)}$$

where $\theta = \tan^{-1}(\omega CR)$

The restrike performance of the resistor switch shall be in accordance with 7.111.11.

### I.2.4 Tests of the resistor stack

The resistor stack shall withstand the thermal stresses caused by current flow through the resistor during the insertion time. This is tested by performing one T100s breaking operation, followed by one out-of-phase make-break duty (CO operation). Both energy and current levels shall be obtained in the resistor elements during test. Upon agreement with the manufacturer, it is permissible to shorten the current duration during the test if the current used in an actual test is higher than the current flowing in the resistor during an out-of-phase condition. These tests can be conducted with the actual circuit-breaker contacts or with an auxiliary circuit-breaker.

Tests on thermally pro-rated sections containing at least 20 series connected resistor elements can be performed. The pro-rated sections shall simulate thermal and dielectric conditions that are equal to or more severe than those of the complete resistor stack.

Prospective insertion times are considered to be 10 ms for a making operation and 30 ms for a breaking operation.

NOTE Different insertion time(s) can be used if the assigned insertion time(s) are different than mentioned above.

The duration between two rated energy injections shall be stated by the manufacturer.

To verify the thermal capacity of resistor stacks, a second test-duty after the required duration of cooling shall be performed. The cooling of the resistor assembly in between the two test-duties shall not be more favourable than service conditions. No significant deterioration shall be observed on the resistor elements after the second test-duty.

Measurement of the ohmic values of the resistor assembly and each individual resistor element shall be such that the ohmic values after test, and after a sufficient cooling time, does not vary by more than 2,5 % from the values measured before test.

## I.3 Insertion time of the resistor

The resistor shall be inserted in the circuit during breaking operations for a certain period of time. The mechanical insertion time of the resistor shall be longer than the maximum arcing time of the making and breaking unit and a value around 30 ms is generally sufficient (the arcing time of the resistor switch shall also be considered).

Depending on the design, the same resistor and resistor switch assembly can be used for closing and opening. The resistor shall be inserted in the circuit during the pre-insertion time defined in 3.7.143, taking the pre-arcing of resistor and making and breaking units into consideration.

## I.4 Current carrying performance

The resistor shall be capable of carrying its current for a specified period without any abnormalities such as arcing, flashover to the adjacent parts, cracks, or any mechanical damages. Their electrical contact surfaces shall not show any signs of arcing such as burning marks.

Insulating material supporting resistor elements, if any, shall withstand the thermal and electrical stresses caused by current through the resistors during making and breaking operations.

## I.5 Dielectric performance

See 7.2.

## I.6 Mechanical performance

The mechanical operation test (see 7.101.2) shall be conducted on a pole or poles of circuit-breaker fully equipped with making and breaking unit and resistor switch and resistor assembly.

The resistor elements shall fulfil the conditions stated in 7.101.1.4 during and after a mechanical test. In addition, the resistor elements shall not show any damages such as chips, cracks, etc. The ohmic resistance of resistor assembly measured after tests shall not differ by more than 2,5 % from the value measured before tests.

## I.7 Requirements for the specification of opening resistors

For circuit-breakers equipped with opening resistors, the following items shall be specified:

– resistor value;
– insertion time for resistors;
– duty cycle.

  The time between two consecutive duty cycles identified in I.2.3 (one duty cycle being one O under terminal fault and one CO under out-of-phase) shall be stated by the manufacturer.

## I.8 Examples of recovery voltage waveshapes

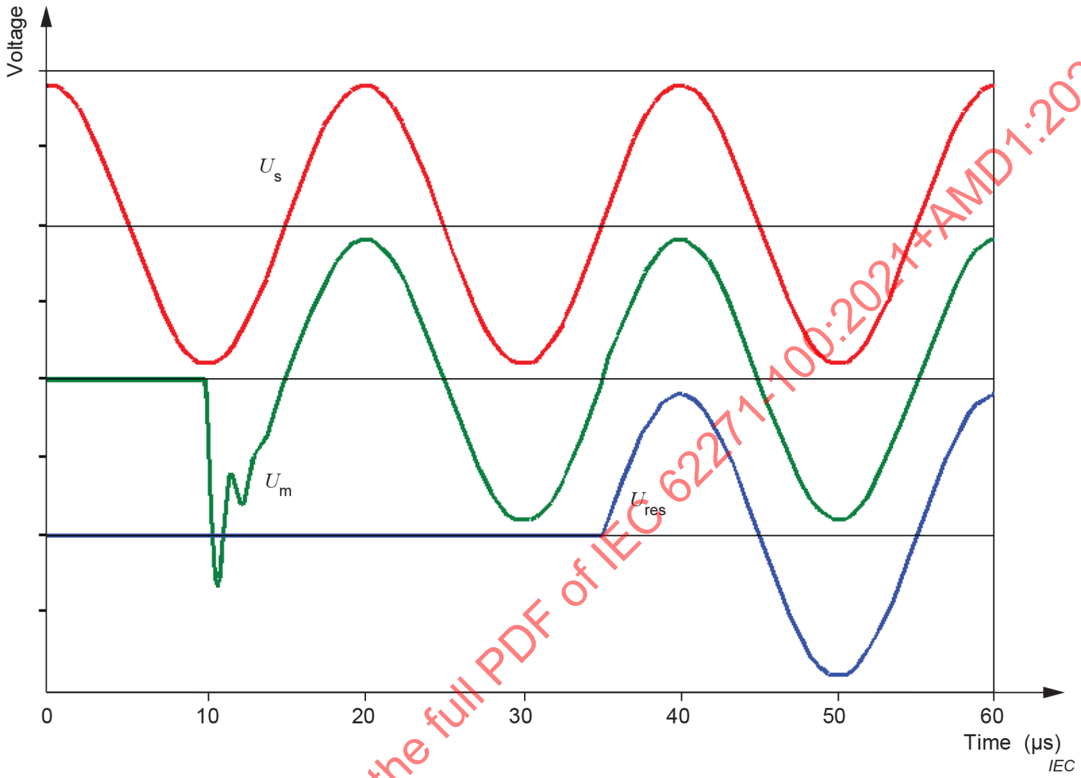
### I.8.1 General

Figure I.10 to Figure I.15 give the waveshapes for various making and breaking conditions. The aim is to show a graphical representation and to illustrate the effects of an opening resistor.

### I.8.2 Terminal faults

Typical examples of waveshapes for making and breaking unit and resistor switch in case of breaking high short-circuit currents such as T100s are given in Figure I.10 and corresponding currents are shown in Figure I.11.

In case of rather low short-circuit currents such as T30 and T10, the TRV waveshapes are shown in Figure I.12 and current shapes are illustrated in Figure I.13.



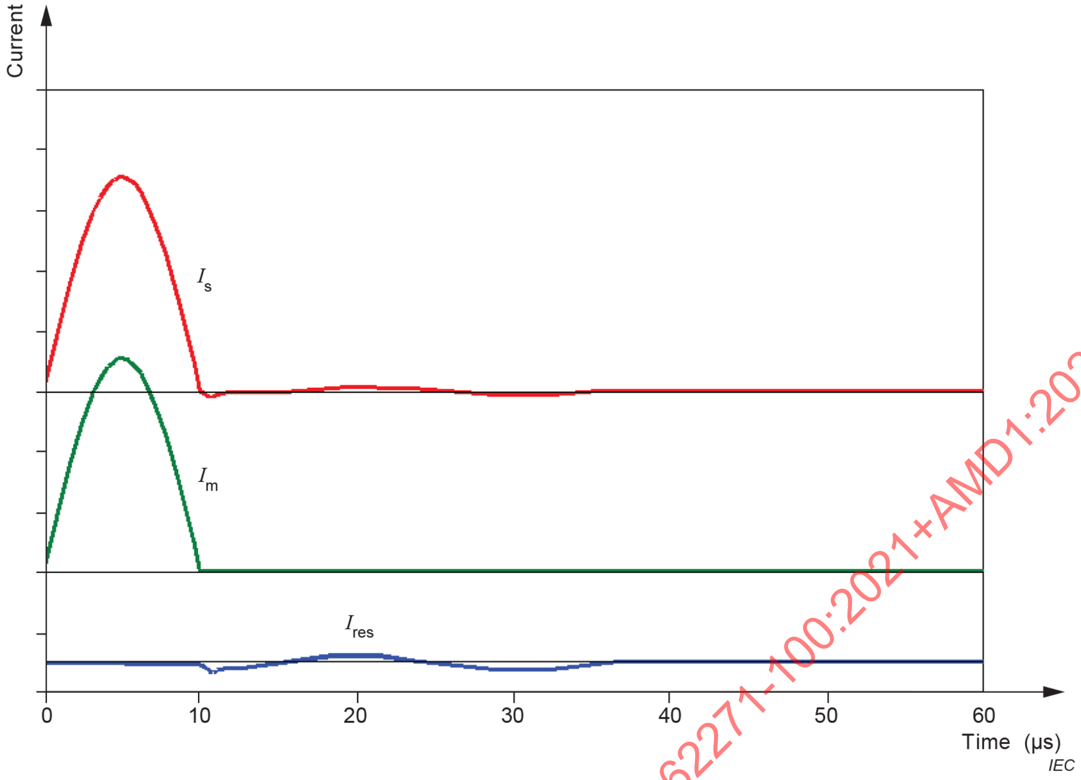

**Key**

$U_m$ Voltage across making and breaking unit

$U_{res}$ Voltage across resistor switch

$U_s$ Source voltage

**Figure I.10 – TRV waveshapes for high short-circuit current breaking operation**



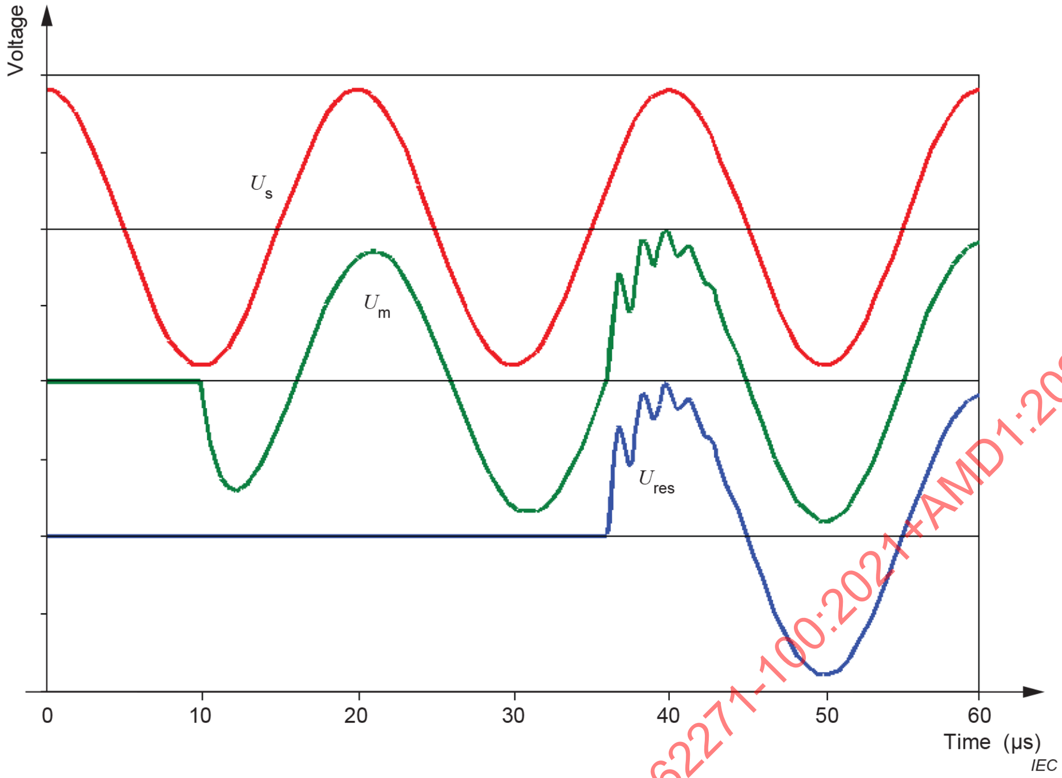

**Key**

$I_m$ Current through making and breaking unit

$I_{res}$ Current through resistor switch

$I_s$ Source current

**Figure I.11 – Currents in case of high short-circuit current breaking operation**



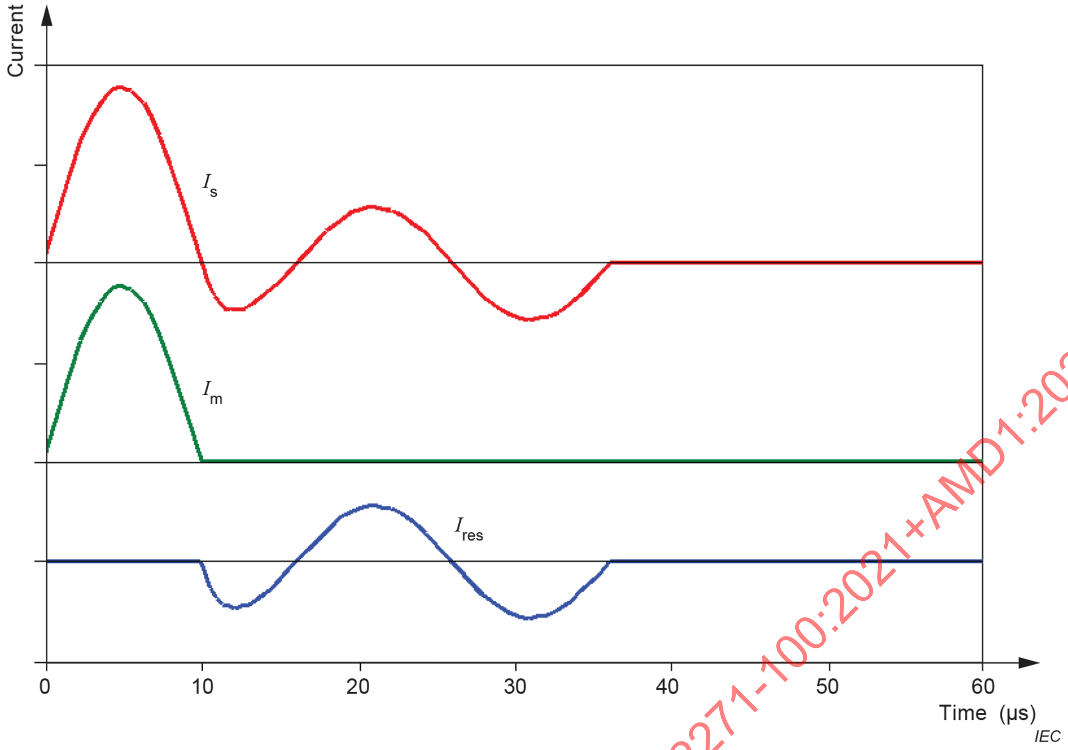

**Key**

$U_m$ Voltage across making and breaking unit

$U_{res}$ Voltage across resistor switch

$U_s$ Source voltage

**Figure I.12 – TRV shapes for low short-circuit current breaking operation**




**Key**

$I_m$ Current through making and breaking unit

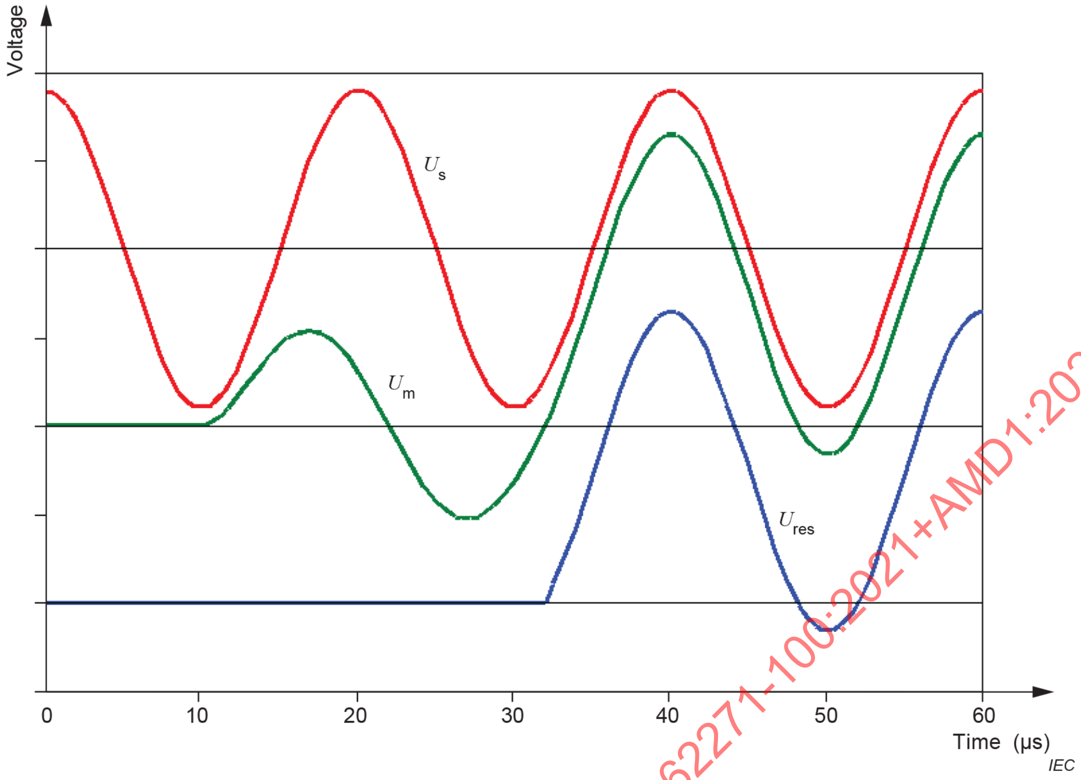
$I_{res}$ Current through resistor switch

$I_s$ Source current

**Figure I.13 – Currents in case of low short-circuit current breaking operation**

### I.8.3 Line-charging current breaking

Typical recovery voltage waveshapes for line-charging current breaking operations are given in Figure I.14, current waveshapes are shown in Figure I.15.



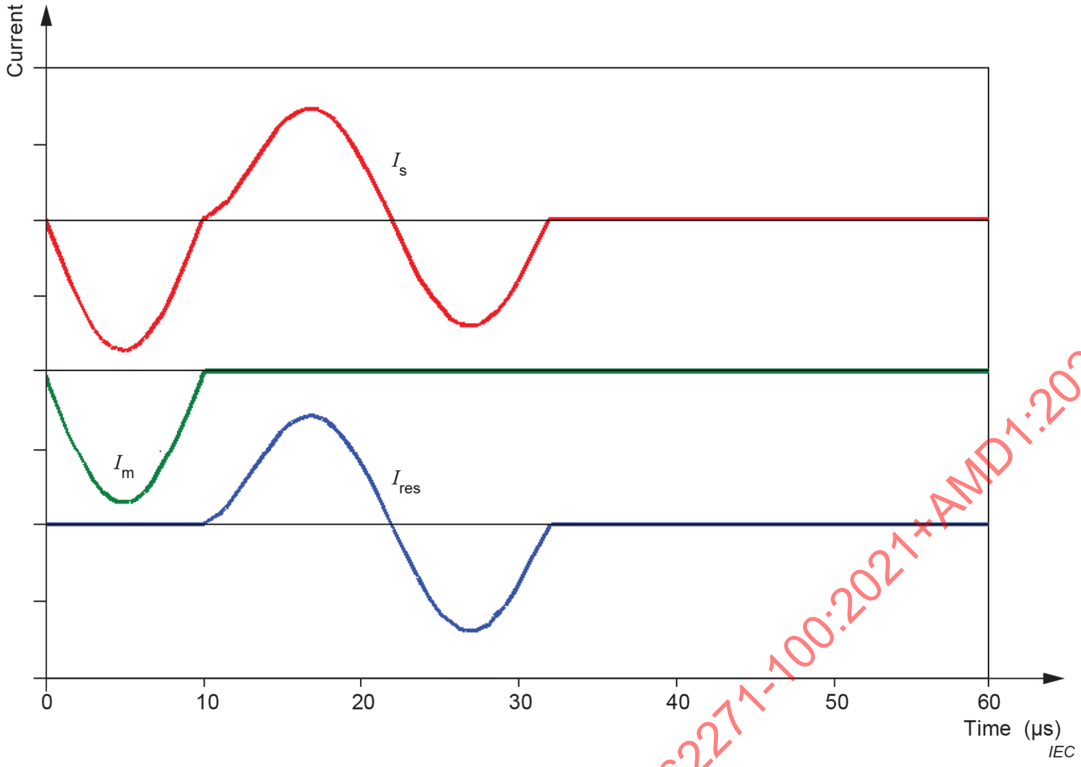

**Key**

$U_m$ Voltage across making and breaking unit

$U_{res}$ Voltage across resistor switch

$U_s$ Source voltage

**Figure I.14 – Voltage waveshapes for line-charging current breaking operation**




**Key**

$I_m$ Current through making and breaking unit

$I_{res}$ Current through resistor switch

$I_s$ Source current

**Figure I.15 – Current waveshapes for line-charging current breaking operation**

# Annex J
(normative)

# Verification of capacitive current breaking in presence of single or two-phase earth faults

## J.1 General

In case of single or two-phase earth faults higher voltages across open circuit-breaker and to earth will appear on the healthy phases. Those values are not covered with type tests according to 7.111.

This annex is applicable in case breaking of capacitive currents in the presence of single or two-phase earth faults is required by a user. A test procedure based on class C1 is considered to be sufficient because of the low probability of occurrence.

If during tests according to 7.111.9, the requirements regarding test voltage, test current and number of tests of this annex are fulfilled no further testing is required for verification of capacitive current breaking in presence of single or two-phase earth faults.

Only a limited number of single-phase laboratory tests as per J.4 shall be made with a test voltage as given in J.2 and a capacitive current as given in J.3. A preconditioning test is not required.

Subclauses 7.111.1 to 7.111.3, 7.111.5 and 7.111.6 apply to tests according to this annex.

## J.2 Test voltage

The test voltage measured at the circuit-breaker location immediately prior to opening shall be not less than the product of $U_r/\sqrt{3}$ and the following capacitive voltage factor $k_c$:

– **1,4** for tests corresponding to breaking in the presence of single or two-phase earth faults in effectively earthed neutral systems;
– **1,7** for tests corresponding to breaking in non-effectively earthed neutral systems in the presence of single or two-phase earth faults.

For unit tests, the test voltage shall be chosen to correspond to the most stressed making and breaking unit of the pole of the circuit-breaker.

The power frequency test voltage and the DC voltage resulting from the trapped charge on the capacitive circuit shall be maintained for a period of at least 0,3 s after breaking.

For testing of metal-enclosed circuit-breakers refer also to Annex H.

## J.3 Test current

For capacitive current breaking in the presence of earth faults, the test current shall be:

– 1,25 times the rated capacitive breaking current in effectively earthed neutral systems;
– 1,7 times the rated capacitive breaking current in non-effectively earthed neutral systems.

## J.4 Test-duty

Subclauses 7.111.9.1 and 7.111.9.2 are applicable but restricted to test-duty 2. For line-charging, cable-charging and single capacitor bank current tests the making operations can be carried out as no-load operations. For back-to-back capacitor bank current tests the making operations can be carried out separately at phase-to-earth voltage.

– 6 CO, distributed on one polarity (step: 30°);
– 3 CO at minimum arcing time on one polarity;
– 6 CO, distributed on the other polarity (step: 30°);
– 3 CO at minimum arcing time on the other polarity;
– additional tests to achieve 24 CO.

If the behaviour of the circuit-breaker prevents accurate control, the total number of tests is limited to 36.

## J.5 Criteria to pass the tests

The circuit-breaker has successfully passed the tests based on the following criterion:

One restrike is permitted to occur without additional testing. If two restrikes occur then the test-duty shall be repeated on the same apparatus without any maintenance. If no more additional restrike happens during this repetition of tests, the circuit-breaker shall have successfully passed the tests.

The behaviour during test and the condition after test shall comply with 7.102.8 and 7.102.9.

# Bibliography

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[10] IEC TR 62271-302, *High-voltage switchgear and controlgear – Part 302: Alternating current circuit-breakers with intentionally non-simultaneous pole operation*

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5 This publication was withdrawn and replaced by IEC 62271-100:2001.

[17] IEC 60376, *Specification of technical grade sulphur hexafluoride ($SF_6$) and complementary gases to be used in its mixtures for use in electrical equipment*

[18] IEC 60480, *Specifications for the re-use of sulphur hexafluoride ($SF_6$) and its mixtures in electrical equipment*

[19] IEC 62271-4, *High-voltage switchgear and controlgear – Part 4: Handling procedures for sulphur hexafluoride ($SF_6$) and its mixtures*

[20] IEC 60865-1:2011, *Short-circuit currents – Calculation of effects – Part 1: Definitions and calculation methods*

**Other documents providing additional information:**

IEC 60050-441:1984, *International Electrotechnical Vocabulary (IEV) – Part 441: Switchgear, controlgear and fuses*

IEC 60071-1, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60071-2, *Insulation co-ordination – Part 2: Application guidelines*

IEC 60099-4, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC 60143-2, *Series capacitors for power systems – Part 2: Protective equipment for series capacitor banks*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 61869 (all parts), *Instrument transformers*

IEC 61869-1, *Instrument transformers – Part 1: General requirements*

IEC 61869-3, *Instrument transformers – Part 3: Additional requirements for inductive voltage transformers*

IEC 62262, *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)*

IEC 62271-100:2001[6], *High-voltage switchgear and controlgear – Part 100: High-voltage alternating-current circuit-breakers*
IEC 62271-100:2001/AMD:2002
IEC 62271-100:2001/AMD:2006

IEC 62271-109, *High-voltage switchgear and controlgear – Part 109: Alternating-current series capacitor by-pass switches*

ANSI/IEEE C37.013-1997, *Standard for AC High-Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis*



6 This publication was withdrawn.

ANSI/IEEE, C37.09-1999, *Test procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*

IEEE 100, *The authoritative dictionary of IEEE standards terms*, 7th edition, 2000

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

# HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

## Part 100: Alternating-current circuit-breakers

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**This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.**

**IEC 62271-100 edition 3.1 contains the third edition (2021-07) [documents 17A/1299/FDIS and 17A/1305/RVD], its corrigendum 1 (2021-12 (applies only to the French version), its corrigendum 2 (2022-07), its corrigendum 3 (2024-01), and its amendment 1 (2024-08) [documents 17A/1406/FDIS and 17A/1410/RVD].**

**This Final version does not show where the technical content is modified by amendment 1. A separate Redline version with all changes highlighted is available in this publication.**

International Standard IEC 62271-100 has been prepared by subcommittee 17A: Switching devices, of IEC technical committee 17: High-voltage switchgear and controlgear.

This third edition cancels and replaces the second edition published in 2008, Amendment 1:2012 and Amendment 2:2017. This edition constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

– the document has been updated to IEC 62271-1:2017;
– Amendments 1 and 2 have been included;
– the definitions have been updated, terms not used have been removed;
– Subclauses 7.102 through 7.108 have been restructured.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

This document is to be read in conjunction with IEC 62271-1, second edition, published in 2017, to which it refers and which is applicable unless otherwise specified. In order to simplify the indication of corresponding requirements, the same numbering of clauses and subclauses is used as in IEC 62271-1. Amendments to these clauses and subclauses are given under the same references whilst additional subclauses are numbered from 101.

A list of all parts of IEC 62271 series, under the general title *High-voltage switchgear and controlgear* can be found on the IEC website.

The committee has decided that the contents of this document and its amendment will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

**IMPORTANT – The *'colour inside'* logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.**

# INTRODUCTION to Amendment 1

This amendment includes the following significant changes:

In IEC 62271-100:2021 there is a slight difference for the calculation of $u_c$ for T10 in Table 20 and Table 21. The $u_c$ value for T10 shall be the same for $k_{pp}$ 1,3 and $k_{pp}$ 1,5 because both conditions also cover transformer limited faults. For voltage ratings higher than 170 kV $u_c$ also covers cases of three-phase line faults with effectively earthed neutral systems. See also the notes in Table 20 and Table 21. By increasing the $k_{af}$ from 1,76 to 1,765 the $u_c$ values are practically the same again for $k_{pp}$ 1,3 and $k_{pp}$ 1,5.

Furthermore:

- The definition of terminal fault has been updated.
- The description of the time parameters for the rated operated sequence has been updated (the parameters remained the same).
- Rated voltages 15,5; 27 and 40,5 kV added to Table 1.
- Additional criteria for dielectric test added.
- It has been made explicit that partial discharge test only is applicable to GIS and dead-tank circuit-breakers.
- Voltage test as condition check as per 7.2.12.103 added to 7.2.12.101.
- The $t_2$ for T60 are corrected to the $t_2$ values of T100.
- TRV values in Table 16, Table 17, Table 18, Table 19, Table 20, Table 22, Table 23, Table 24, Table 25, Table 30 and Table F.1 have been recalculated and updated.
- Requirement on having inrush making current in the same phase as minimum arcing times during three-phase back-to-back capacitor bank current tests.
- Requirement to perform mechanical operating tests on all releases added.
- Existing tolerance for single-phase and double-earth fault added to Table B.1.
- Tolerance for breaking current $L_{75}$ updated in Table B.1.

# HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

## Part 100: Alternating-current circuit-breakers

## 1 Scope

This part of IEC 62271 is applicable to three-phase AC circuit-breakers designed for indoor or outdoor installation and for operation at frequencies of 50 Hz and/or 60 Hz on systems having voltages above 1 000 V. This document includes only direct testing methods for making-breaking tests. For synthetic testing methods refer to IEC 62271-101.

NOTE In a direct testing method one source is used to supply the voltage and current during the making and breaking tests.

This part of IEC 62271 is not applicable to:

– circuit-breakers with a closing mechanism for dependent manual operation;
– circuit-breakers intended for use on motive power units of electrical traction equipment; these are covered by IEC 60077 (all parts) [1][1];
– generator circuit-breakers installed between generator and step-up transformer; these are covered by the IEC 62271-37-013 [2];
– self-tripping circuit-breakers with tripping devices that cannot be made inoperative during testing. Tests on automatic circuit reclosers are covered by IEC 62271-111 [3];
– tests to prove the performance under abnormal conditions that are not described in this document are subject to agreement between manufacturer and user. Such abnormal conditions are, for example, cases where the voltage is higher than the rated voltage of the circuit-breaker, conditions which can occur due to sudden loss of load on long lines or cables.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-151:2001, *International Electrotechnical Vocabulary (IEV) – Part 151: Electrical and magnetic devices*
IEC 60050-151:2001/AMD1:2013
IEC 60050-151:2001/AMD2:2014
IEC 60050-151:2001/AMD3:2019
IEC 60050-151:2001/AMD4:2020

IEC 60050-441:1984, *International Electrotechnical Vocabulary (IEV) – Part 441: Switchgear, controlgear and fuses*
IEC 60050-441:1984/AMD1:2000

[1] Numbers in square brackets refer to the bibliography.

IEC 60050-442:1998, *International Electrotechnical Vocabulary (IEV) – Part 442: Electrical accessories*
IEC 60050-442:1998/AMD1:2015
IEC 60050-442:1998/AMD2:2015
IEC 60050-442:1998/AMD3:2019

IEC 60050-461:2008, *International Electrotechnical Vocabulary (IEV) – Part 461: Electric cables*

IEC 60050-601:1985, *International Electrotechnical Vocabulary (IEV) – Part 601: Generation, transmission and distribution of electricity – General*
IEC 60050-601:1985/AMD1:1998
IEC 60050-601:1985/AMD2:2020

IEC 60050-614:2016, *International Electrotechnical Vocabulary (IEV) – Part 614: Generation, transmission and distribution of electricity – Operation*

IEC 60059, *IEC standard current ratings*

IEC 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60255-151:2009, *Measuring relays and protection equipment – Part 151: Functional requirements for over/under current protection*

IEC 60270, *High-voltage test techniques – Partial discharge measurements*

IEC 62271-1:2017, *High-voltage switchgear and controlgear – Part 1: Common specifications for alternating current switchgear and controlgear*

IEC 62271-101, *High-voltage switchgear and controlgear – Part 101: Synthetic testing*

IEC 62271-102:2018, *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

IEC 62271-200:20—[2], *High-voltage switchgear and controlgear – Part 200: AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV*

IEC 62271-203, *High-voltage switchgear and controlgear – Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-151, IEC 60050-441, IEC 60050-442, IEC 60050-461, IEC 60050-601 and IEC 60050-614, some of which are recalled hereunder, and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp



[2] Under preparation. Stage at the time of publication: IEC RFDIS 62271-200:2021.

NOTE Terms and definitions are classified in accordance with IEC 60050-441. Reference from other parts than IEC 60050-441 are classified so as to be aligned with the classification used in IEC 60050-441.

### 3.1 General terms and definitions

**3.1.101**
**switchgear and controlgear**
general term covering switching devices intended to be installed indoor or outdoor and their combination with associated control, measuring, protective and regulating equipment, also assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures

[SOURCE: IEC 60050-441:1984, 441-11-01, modified – The definition has been rephrased.]

**3.1.102**
**short-circuit current**
overcurrent resulting from a short-circuit due to a fault or an incorrect connection in an electric circuit

[SOURCE: IEC 60050-441:1984, 441-11-07]

**3.1.103**
**isolated neutral system**
system where the neutral point is not intentionally connected to earth, except for high impedance connections for protection or measurement purposes

[SOURCE: IEC 60050-601:1985, 601-02-24]

**3.1.104**
**solidly earthed (neutral) system**
system whose neutral point(s) is (are) earthed directly

[SOURCE: IEC 60050-601:1985, 601-02-25]

**3.1.105**
**impedance earthed (neutral) system**
system whose neutral point(s) is (are) earthed through impedances to limit earth fault currents

[SOURCE: IEC 60050-601:1985, 601-02-26]

**3.1.106**
**resonant earthed (neutral) system,**
**arc-suppression-coil-earth (neutral) system**
system in which one or more neutral points are connected to earth through reactances which approximately compensate the capacitive component of a single-phase-to-earth fault current

[SOURCE: IEC 60050-601:1985, 601-02-27]

**3.1.107**
**effectively earthed (neutral) system**
system earthed through a sufficiently low impedance such that for all system conditions the ratio of the zero-sequence reactance to the positive-sequence reactance ($X_0/X_1$) is positive and less than 3, and the ratio of the zero-sequence resistance to the positive-sequence reactance ($R_0/X_1$) is positive and less than 1

Note 1 to entry: Normally such systems are solidly earthed (neutral) systems or low impedance earthed (neutral) systems.

Note 2 to entry: The earthing conditions depend not only on the physical earthing conditions around the relevant location but also on the total system.

**3.1.108**
**non-effectively earthed (neutral) system**
system other than effectively earthed neutral system, not meeting the conditions given in 3.1.107

Note 1 to entry: Normally such systems are isolated neutral systems, high impedance earthed (neutral) systems or resonant earthed (neutral) systems.

Note 2 to entry: The earthing conditions depend not only on the physical earthing conditions around the relevant location but also on the total system.

**3.1.109**
**ambient air temperature**
temperature, determined under prescribed conditions, of the air surrounding the complete switching device or fuse

Note 1 to entry: For switching devices or fuses installed inside an enclosure, it is the temperature of the air outside the enclosure.

[SOURCE: IEC 60050-441:1984, 441-11-13]

**3.1.110**
**temperature rise** <of a part of a circuit-breaker>
difference between the temperature of the part under consideration and the ambient air temperature

**3.1.111**
**single capacitor bank**
bank of shunt capacitors in which the inrush current is limited by the inductance of the supply system and the capacitance of the bank of capacitors being energised, there being no other capacitors connected in parallel to the system sufficiently close to increase the inrush current appreciably

**3.1.112**
**back-to-back capacitor bank**
bank of shunt capacitors or capacitor assemblies each of them switched independently to the supply system, the inrush current of one capacitor or capacitor assembly being appreciably increased by the capacitors already connected to the supply

**3.1.113**
**overvoltage** <in an electric power system>
voltage:

– between one line conductor and earth or across a longitudinal insulation having a peak value exceeding the corresponding peak of the highest voltage of the system divided by √3
– between phase conductors having a peak value exceeding the amplitude of the highest voltage of the system

[SOURCE: IEC 60050-614:2016, 614-03-10]

**3.1.114**
**out-of-phase conditions**
abnormal circuit conditions of loss or lack of synchronism between the parts of an electrical system on either side of a circuit-breaker in which, at the instant of operation of the circuit-breaker, the phase angle between rotating vectors, representing the generated voltages on either side, exceeds the normal value

Note 1 to entry: The requirements of this document cater for the great majority of applications of circuit-breakers intended for making and breaking during out-of-phase conditions. Out-of-phase angles corresponding to the specified power frequency recovery voltages are given in 7.110.3. For extreme service conditions see 9.103.3.

**3.1.115**
**out-of-phase** <as prefix to a characteristic quantity>
qualifying term indicating that the characteristic quantity is applicable to operation of the circuit-breaker in out-of-phase conditions

**3.1.116**
**unit test**
test made on a making and breaking unit or group of making and breaking units at the making current or the breaking current, specified for the test on the complete pole of a circuit-breaker and at the appropriate fraction of the applied voltage, or the recovery voltage, specified for the test on the complete pole of the circuit-breaker

**3.1.117**
**loop**
part of the wave of the current embraced by two successive current zero crossings

Note 1 to entry: A distinction is made between a major loop and a minor loop depending on the time interval between two successive current zero crossings being longer or shorter than the half-period of the alternating component of the current.

**3.1.118**
**short-line fault**
**SLF**
short-circuit on an overhead line at a short, but significant, distance from the terminals of the circuit-breaker

Note 1 to entry: As a rule this distance is not more than a few kilometres.

**3.1.119**
**power factor** <of a circuit>
ratio of the resistance to the impedance at power frequency of an equivalent circuit supposed to be formed by a reactance and a resistance in series

**3.1.120**
**external insulation**
distances in atmospheric air, and along the surfaces in contact with atmospheric air of solid insulation of the equipment which are subject to dielectric stresses and to the effects of atmospheric and other environmental conditions from the site

Note 1 to entry: Examples of environmental conditions are pollution, humidity, vermin, etc.

[SOURCE: IEC 60050-614:2016, 614-03-02]

**3.1.121**
**internal insulation**
internal distances of the solid, liquid or gaseous insulation of equipment which are protected from the effects of atmospheric and other external conditions

[SOURCE: IEC 60050-614:2016, 614-03-03]

**3.1.122**
**disruptive discharge**
phenomenon associated with the failure of insulation under electrical stress which includes a collapse of voltage and the passage of current

Note 1 to entry: The term applies to electric breakdown in solid, liquid and gaseous dielectrics and combination of these.

Note 2 to entry: A disruptive discharge in a solid dielectric produces permanent loss of dielectric strength; in a liquid or gaseous dielectric the loss can be temporary only.

[SOURCE: IEC 60050-614:2016, 614-03-16]

**3.1.123**
**non-sustained disruptive discharge**
**NSDD**
disruptive discharge associated with current breaking, that does not result in the resumption of power frequency current or, in the case of capacitive current breaking does not result in current in the load circuit

Note 1 to entry: Oscillations following NSDDs are associated with the parasitic capacitance and inductance local to or of the circuit-breaker itself. NSDDs can also involve the stray capacitance to ground of nearby equipment.

**3.1.124**
**restrike performance**
expected probability of restrike during capacitive current breaking as demonstrated by specified type tests

Note 1 to entry: Specific numeric probabilities cannot be applied throughout a circuit-breaker service life.

**3.1.125**
**re-ignition** <of an AC mechanical switching device>
resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of less than a quarter cycle of power frequency

[SOURCE: IEC 60050-441:1984, 441-17-45]

**3.1.126**
**restrike** <of an AC mechanical switching device>
resumption of current between the contacts of a mechanical switching device during a breaking operation with an interval of zero current of a quarter cycle of power frequency or longer

[SOURCE: IEC 60050-441:1984, 441-17-46]

**3.1.127**
**current chopping**
current breaking prior to the natural power frequency current zero of the circuit connected

**3.1.128**
**belted cable**
multiconductor cable in which part of the insulation is applied to each conductor individually, and the remainder is applied over the assembled cores

[SOURCE: IEC 60050-461:2008, 461-06-11]

**3.1.129**
**individually screened cable**
**radial field cable**
cable in which each core is covered with an individual screen

[SOURCE: IEC 60050-461:2008, 461-06-12]

## 3.2 Assemblies

No definitions.

## 3.3 Parts of assemblies

No definitions.

## 3.4 Switching devices

**3.4.101**
**switching device**
device designed to make or break the current in one or more electric circuits

[SOURCE: IEC 60050-441:1984, 441-14-01]

**3.4.102**
**mechanical switching device**
switching device designed to close and open one or more electric circuits by means of separable contacts

Note 1 to entry: Any mechanical switching device can be designated according to the medium in which its contacts open and close, for example, air, $SF_6$, oil.

[SOURCE: IEC 60050-441:1984, 441-14-02]

**3.4.103**
**circuit-breaker**
mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short-circuit

[SOURCE: IEC 60050-441:1984, 441-14-20]

**3.4.104**
**dead tank circuit-breaker**
circuit-breaker in which the making and breaking units are housed in an earthed metal tank

[SOURCE: IEC 60050-441:1984, 441-14-25, modified – "interrupters" replaced with "making and breaking units".]

**3.4.105**
**live tank circuit-breaker**
circuit-breaker in which the making and breaking units are housed in a tank insulated from earth

[SOURCE: IEC 60050-441:1984, 441-14-26, modified – "interrupters" replaced with "making and breaking units".]

**3.4.106**
**air circuit-breaker**
circuit-breaker in which the contacts open and close in air at atmospheric pressure

[SOURCE: IEC 60050-441:1984, 441-14-27]

**3.4.107**
**oil circuit-breaker**
circuit-breaker in which the contacts open and close in oil

Note 1 to entry: Typical examples of oil circuit-breakers are live tank minimum oil circuit-breakers and dead tank bulk oil circuit-breakers

[SOURCE: IEC 60050-441:1984, 441-14-28]

**3.4.108**
**vacuum circuit-breaker**
circuit-breaker in which the contacts open and close within a highly evacuated envelope

[SOURCE: IEC 60050-441:1984, 441-14-29]

**3.4.109**
**sealed-for-life circuit-breaker**
circuit-breaker having its making and breaking unit(s) in a sealed pressure system

**3.4.110**
**gas-blast circuit-breaker**
circuit-breaker in which the arc develops in a blast of gas

Note 1 to entry: Where the gas is moved by a difference in pressure established by mechanical means during the opening operation of the circuit-breaker, it is termed a single pressure gas-blast circuit-breaker. Where the gas is moved by a difference in pressure established before the opening operation of the circuit-breaker, it is termed a double pressure gas-blast circuit-breaker.

[SOURCE: IEC 60050-441:1984, 441-14-30]

**3.4.111**
**sulphur hexafluoride circuit-breaker**
**$SF_6$ circuit-breaker**
circuit-breaker in which the contacts open and close in sulphur hexafluoride

[SOURCE: IEC 60050-441:1984, 441-14-31]

**3.4.112**
**air-blast circuit-breaker**
gas-blast circuit-breaker in which the gas used is air

[SOURCE: IEC 60050-441:1984, 441-14-32]

**3.4.113**
**self-tripping circuit-breaker**
circuit-breaker which is tripped by a current in the main circuit without the aid of any form of auxiliary power

### 3.5 Parts of circuit-breakers

**3.5.101**
**pole**
portion of a switching device associated exclusively with one electrically separated conducting path of its main circuit and excluding those portions which provide a means for mounting and operating all poles together

Note 1 to entry: A switching device is called single-pole if it has only one pole. If it has more than one pole, it can be called multipole (two-pole, three-pole, etc.) provided the poles are or can be coupled in such a manner as to operate together.

[SOURCE: IEC 60050-441:1984, 441-15-01]

**3.5.102**
**main circuit** <of a switching device>
all the conductive parts of a switching device included in the circuit which it is designed to close or open

[SOURCE: IEC 60050-441:1984, 441-15-02]

**3.5.103**
**control circuit** <of a switching device>
all the conductive parts (other than the main circuit) of a switching device which are included in a circuit used for the closing operation or opening operation, or both, of the device

[SOURCE: IEC 60050-441:1984, 441-15-03]

**3.5.104**
**auxiliary circuit** <of a switching device>
all the conductive parts of a switching device which are intended to be included in a circuit other than the main circuit and the control circuits of the device

Note 1 to entry: Some auxiliary circuits fulfil supplementary functions such as signalling, interlocking etc., and, as such, they can be part of the control circuit of another switching device

[SOURCE: IEC 60050-441:1984, 441-15-04]

**3.5.105**
**contact** <of a mechanical switching device>
conductive parts designed to establish circuit continuity when they touch and which, due to their relative motion during an operation, open or close a circuit, or in the case of hinged or sliding contacts, maintain circuit continuity

[SOURCE: IEC 60050-441:1984, 441-15-05]

**3.5.106**
**main contact**
contact included in the main circuit of a mechanical switching device, intended to carry, in the closed position, the current of the main circuit

[SOURCE: IEC 60050-441:1984, 441-15-07]

**3.5.107**
**arcing contact**
contact on which the arc is intended to be established

Note 1 to entry: An arcing contact can serve as a main contact; it can be a separate contact so designed that it opens after and closes before another contact which it is intended to protect from injury.

[SOURCE: IEC 60050-441:1984, 441-15-08]

**3.5.108**
**control contact**
contact included in a control circuit of a mechanical switching device and mechanically operated by this device

[SOURCE: IEC 60050-441:1984, 441-15-09]

**3.5.109**
**auxiliary contact**
contact included in an auxiliary circuit and mechanically operated by the switching device

[SOURCE: IEC 60050-441:1984, 441-15-10]

**3.5.110**
**auxiliary switch** <of a mechanical switching device>
switch containing one or more control and/or auxiliary contacts mechanically operated by a switching device

[SOURCE: IEC 60050-441:1984, 441-15-11]

**3.5.111**
**"a" contact**
**make contact**
control or auxiliary contact which is closed when the main contacts of the mechanical switching device are closed and open when they are open

[SOURCE: IEC 60050-441:1984, 441-15-12]

**3.5.112**
**"b" contact**
**break contact**
control or auxiliary contact which is open when the main contacts of a mechanical switching device are closed and closed when they are open

[SOURCE: IEC 60050-441:1984, 441-15-13]

**3.5.113**
**butt contact**
contact in which relative movement of the contact pieces is substantially in a direction perpendicular to the contact surface

[SOURCE: IEC 60050-441:1984, 441-15-14]

**3.5.114**
**release** <of a mechanical switching device>
device, mechanically connected to a mechanical switching device, which releases the holding means and permits the opening or the closing of the switching device

[SOURCE: IEC 60050-441:1984, 441-15-17]

**3.5.115**
**overcurrent release**
release which permits a mechanical switching device to open with or without time-delay when the current in the release exceeds a predetermined value

Note 1 to entry: This value can in some cases depend upon the rate-of-rise of current.

[SOURCE: IEC 60050-441:1984, 441-16-33, modified – Replacement of "may" with "can".]

**3.5.116**
**inverse time-delay overcurrent release**
overcurrent release which operates after a time-delay inversely dependent upon the value of the overcurrent

Note 1 to entry: Such a release may be designed so that the time-delay approaches a definite minimum value for high values of overcurrent.

[SOURCE: IEC 60050-441:1984, 441-16-35]

**3.5.117**
**direct overcurrent release**
overcurrent release directly energised by the current in the main circuit of a mechanical switching device

[SOURCE: IEC 60050-441:1984, 441-16-36]

**3.5.118**
**shunt release**
release energised by a source of voltage

Note 1 to entry: The source of voltage can be independent of the voltage of the main circuit.

[SOURCE: IEC 60050-441:1984, 441-16-41]

**3.5.119**
**under-voltage release**
shunt release which permits a mechanical switching device to open or close, with or without time-delay, when the voltage across the terminals of the release falls below a predetermined value

[SOURCE: IEC 60050-441:1984, 441-16-42]

**3.5.120**
**anti-pumping device**
device which prevents reclosing after a close-open operation as long as the device initiating closing is maintained in the position for closing

[SOURCE: IEC 60050-441:1984, 441-16-48]

**3.5.121**
**interlocking device**
device which makes the operation of a switching device dependent upon the position or operation of one or more other pieces of equipment

[SOURCE: IEC 60050-441:1984, 441-16-49]

**3.5.122**
**circuit-breaker with lock-out preventing closing**
circuit-breaker in which none of the moving contacts can make current if the closing command is initiated while the conditions which should cause the opening operation remain established

[SOURCE: IEC 60050-441:1984, 441-14-23]

**3.5.123**
**arc control device**
device, surrounding the arcing contacts of a mechanical switching device, designed to confine the arc and to assist in its extinction

[SOURCE: IEC 60050-441:1984, 441-15-18]

**3.5.124**
**connection** <bolted or equivalent>
two or more conductors designed to ensure permanent circuit continuity when forced together by means of screws, bolts or the equivalent

**3.5.125**
**terminal**
conductive part of a device, electric circuit or electric network, provided for connecting that device, electric circuit or electric network to one or more external conductors

Note 1 to entry: The term "terminal" is also used for a connection point in circuit theory.

[SOURCE: IEC 60050-151:2001, 151-12-12]

**3.5.126**
**making and breaking unit**
part of a circuit-breaker within which the flow of current is initiated and interrupted

**3.5.127**
**enclosure** <of an assembly>
part of an assembly providing a specified degree of protection of equipment against external influences and a specified degree of protection against approach to or contact with live parts and against contact with moving parts

[SOURCE: IEC 60050-441:1984, 441-13-01]

**3.5.128**
**operating mechanism**
part of the circuit-breaker that actuates the main contacts

**3.5.129**
**power kinematic chain**
mechanical connecting system from and including the operating mechanism up to and including the moving contacts

**3.5.130**
**alternative operating mechanism**
change in the power kinematic chain of the original operating mechanism or use of a different operating mechanism which retains the same mechanical characteristics

Note 1 to entry: An alternative operating mechanism can utilise an operating principle different from the original one (for example the alternative mechanism can be spring-operated and the original hydraulic).

**3.5.131**
**resistor switch**
contacts intended for switching of a resistive element

**3.5.132**
**vacuum interrupter**
contacts in a highly evacuated, hermetically sealed envelope

## 3.6 Operational characteristics

**3.6.101**
**operation** <of a mechanical switching device>
transfer of the moving contact(s) from one position to an adjacent position

Note 1 to entry: For a circuit-breaker, this can be a closing operation or an opening operation.

Note 2 to entry: If distinction is necessary, an operation in the electrical sense, for example make or break, is referred to as a switching operation, and an operation in the mechanical sense, for example close or open, is referred to as a mechanical operation.

[SOURCE: IEC 60050-441:1984, 441-16-01]

**3.6.102**
**operating cycle** <of a mechanical switching device>
succession of operations from one position to another and back to the first position through all other positions, if any

[SOURCE: IEC 60050-441:1984, 441-16-02]

**3.6.103**
**operating sequence** <of a mechanical switching device>
succession of specified operations with specified time intervals

[SOURCE: IEC 60050-441:1984, 441-16-03]

**3.6.104**
**switching**
closing and/or opening of one or more electrical circuits

**3.6.105**
**closing operation** <of a mechanical switching device>
operation by which the device is brought from the open position to the closed position

[SOURCE: IEC 60050-441:1984, 441-16-08]

**3.6.106**
**opening operation** <of a mechanical switching device>
operation by which the device is brought from the closed position to the open position

[SOURCE: IEC 60050-441:1984, 441-16-09]

**3.6.107**
**auto-reclosing** <of a mechanical switching device>
operating sequence of a mechanical switching device whereby, following its opening, it closes automatically after a predetermined time

[SOURCE: IEC 60050-441:1984, 441-16-10]

**3.6.108**
**dependent manual operation** <of a mechanical switching device>
operation solely by means of directly applied manual energy, such that the speed and force of the operation are dependent upon the action of the operator

[SOURCE: IEC 60050-441:1984 441-16-13]

**3.6.109**
**dependent power operation** <of a mechanical switching device>
operation by means of energy other than manual, where the completion of the operation is dependent upon the continuity of the power supply (to solenoids, electric or pneumatic motors, etc.)

[SOURCE: IEC 60050-441:1984, 441-16-14]

**3.6.110**
**stored energy operation**
operation by means of energy stored in the mechanism itself prior to the completion of the operation and sufficient to complete it under predetermined conditions

Note 1 to entry: This kind of operation can be subdivided according to:

a) The manner of storing the energy (spring, weight, etc.);

b) The origin of the energy (manual, electric, etc.);

c) The manner of releasing the energy (manual, electric, etc.).

SOURCE: IEC 60050-441:1984, 441-16-15]

**3.6.111**
**closed position** <of a mechanical switching device>
position in which the predetermined continuity of the main circuit of the device is secured

[SOURCE: IEC 60050-441:1984, 441-16-22]

**3.6.112**
**open position** <of a mechanical switching device>
position in which the predetermined clearance between open contacts in the main circuit of the device is secured

[SOURCE: IEC 60050-441:1984, 441-16-23]

**3.6.113**
**operating current** <of an overcurrent release>
current value at and above which the release can operate

[SOURCE: IEC 60050-441:1984, 441-16-45]

**3.6.114**
**current setting** <of an overcurrent release>
value of the operating current for which the release is adjusted and in accordance with which its operating conditions are defined

[SOURCE: IEC 60050-441:1984, 441-16-46]

**3.6.115**
**current setting range** <of an overcurrent release>
range between the minimum and maximum values over which the current setting of the release can be adjusted

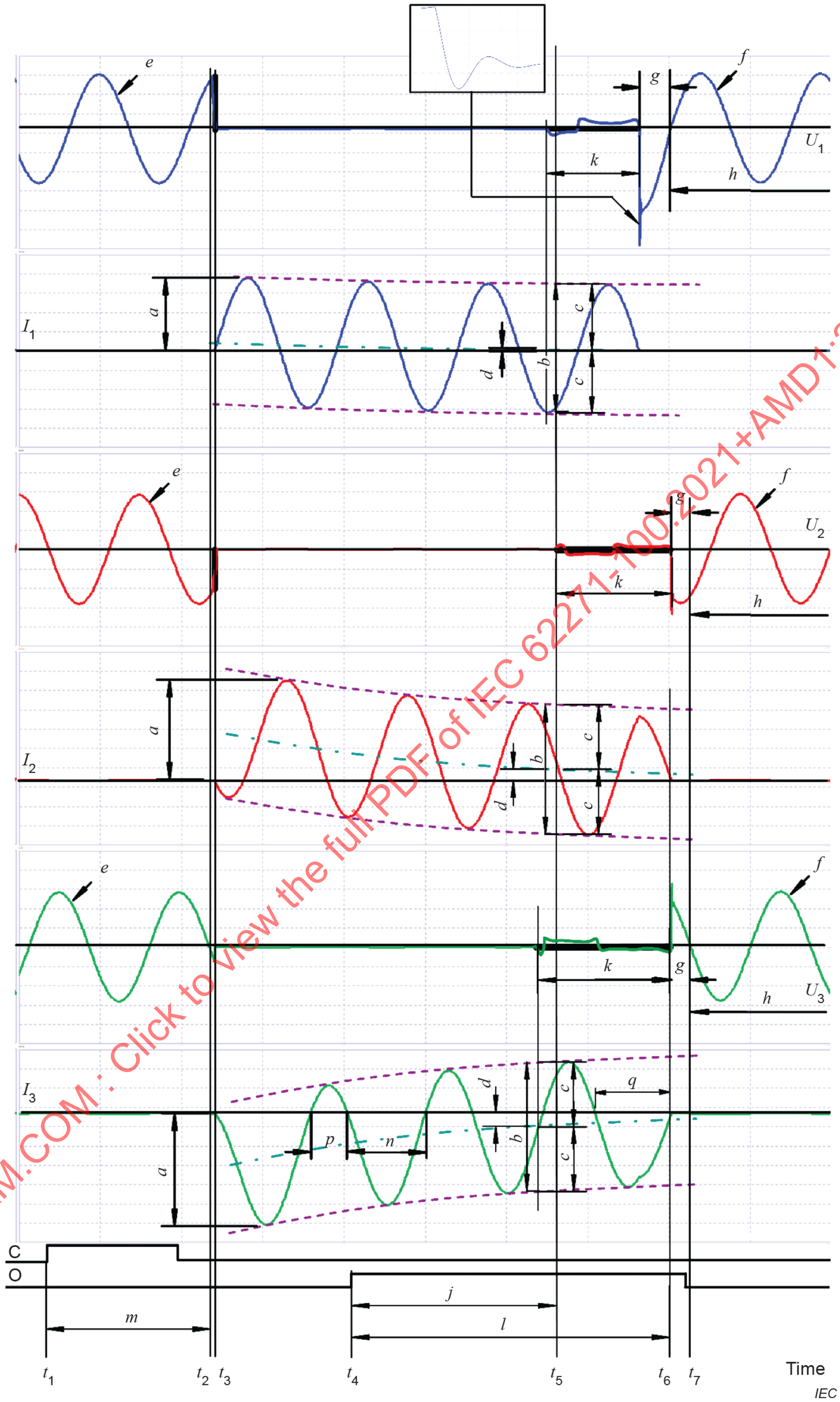
[SOURCE: IEC 60050-441:1984, 441-16-47]

## 3.7 Characteristic quantities

Figure 1 through Figure 7 illustrate some definitions of this subclause.

Time quantities, see definitions 3.7.131 to 3.7.143, are expressed in milliseconds or in cycles. When expressed in cycles, the power frequency should be stated in brackets. In the case of circuit-breakers incorporating switching resistors, a distinction is made, where applicable, between time quantities associated with the contacts switching the full current and the contacts switching the current limited by switching resistors.

Unless otherwise stated, the time quantities referred to are associated with the contacts switching the full current.


e
f
g
k
h
$U_1$
$I_1$
a
b
c
d
$U_2$
$I_2$
$U_3$
$I_3$
p
n
q
C
O
m
j
l
$t_1$
$t_2$
$t_3$
$t_4$
$t_5$
$t_6$
$t_7$
Time
IEC

**Key to** Figure 1**:**

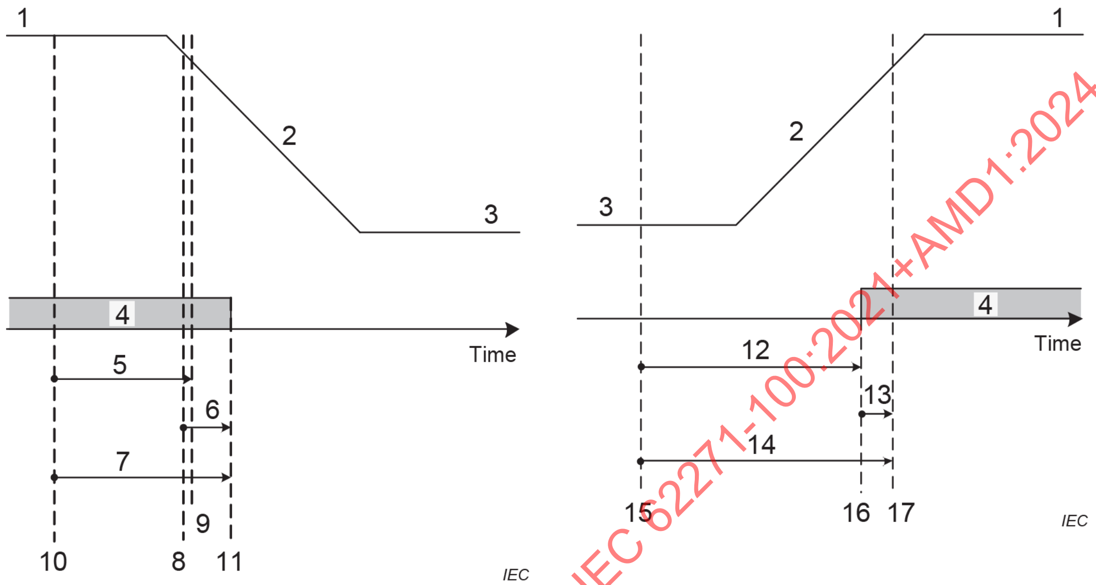
| | | | |
|---|---|---|---|
| $U_1$ | voltage across the terminals of the first-pole-to-clear | *a* | (peak) making current |
| $I_1$ | current in the first-pole-to-clear | *b* | peak-to-peak value of the breaking current |
| $U_2$, $U_3$ | voltage across the terminals of the two other poles | *c* | peak value of the alternating component |
| $I_2$, $I_3$ | current in the two other poles | *d* | direct current (DC) component |
| C | closing command, for example voltage across the terminals of the closing circuit | *e* | applied voltage |
| O | opening command, for example voltage across the terminals of the opening release | *f* | recovery voltage |
| $t_1$ | initiation of the closing operation | *g* | TRV |
| $t_2$ | instant of the voltage breakdown | *h* | power frequency recovery voltage |
| $t_3$ | instant when the current is established in all poles | *j* | opening time |
| $t_4$ | initiation of the opening operation | *k* | arcing time |
| $t_5$ | instant when the arcing contacts have separated (or instant of initiation of the arc) in all poles | *l* | break-time |
| $t_6$ | instant of final arc extinction in all poles | *m* | make time |
| $t_7$ | instant when the transient voltage phenomena have subsided in the last pole to clear | *n* | major loop |
| | | *p* | minor loop |
| | | *q* | major extended loop |

**Figure 1 – Typical oscillogram of a three-phase short-circuit make-break cycle**

**Notes to the following Figure 2 to Figure 7:**

NOTE 1 In practice, there will be a time spread between the travel of the contacts of the three poles. For clarity the travel of the contacts in the figures is indicated with a single line for all three poles.

NOTE 2 In practice, there will be a time spread between both the start and end of current flow in the three poles. For clarity, both the start and end of current flow in the figures is indicated with a single line for all three poles.

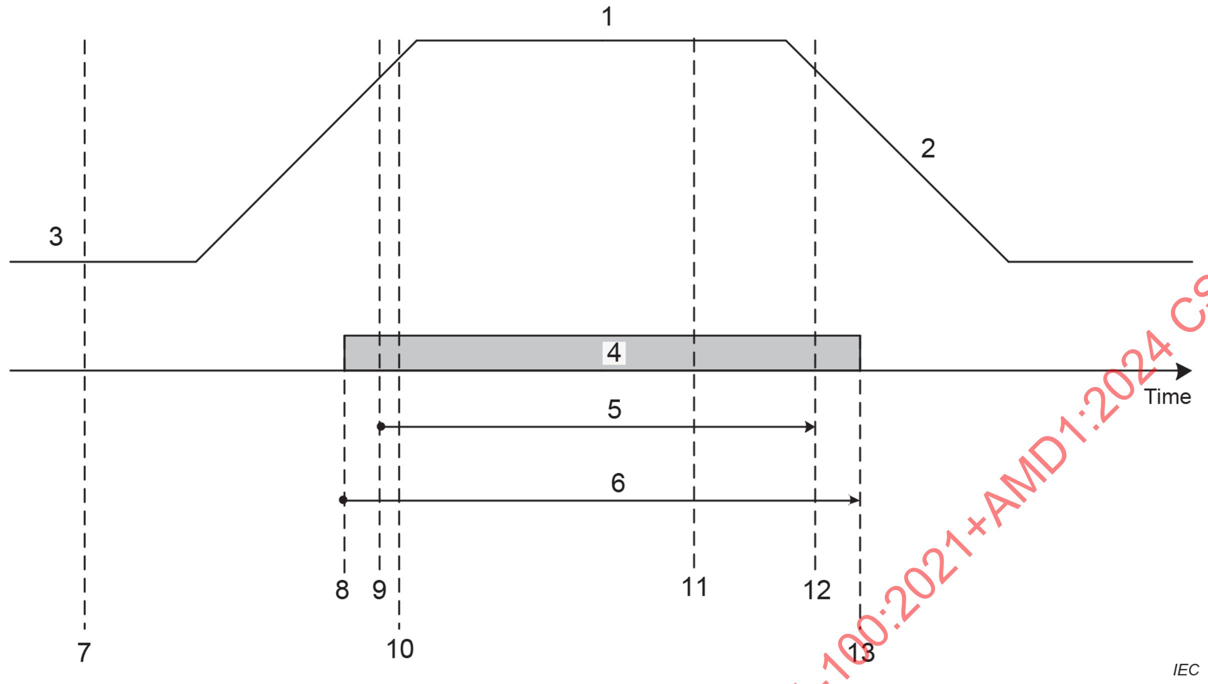



**Opening operation** **Closing operation**

**Key**

| | | | |
|---|---|---|---|
| 1 | Closed position | 10 | Initiation of opening operation, 3.7.153 |
| 2 | Contact travel | 11 | Instant of final arc extinction in all poles |
| 3 | Open position | 12 | Make time, 3.7.135 |
| 4 | Current flow | 13 | Pre-arcing time, 3.7.136 |
| 5 | Opening time, 3.7.131 | 14 | Closing time, 3.7.134 |
| 6 | Total arcing time, 3.7.154 | 15 | Initiation of closing operation, 3.7.153 |
| 7 | Break-time, 3.7.133 | 16 | Instant of start of current flow in the first pole |
| 8 | Instant of separation of arcing contacts in first opening pole | 17 | Instant of contact touch in all poles |
| 9 | Instant of separation of arcing contacts in all poles | | |

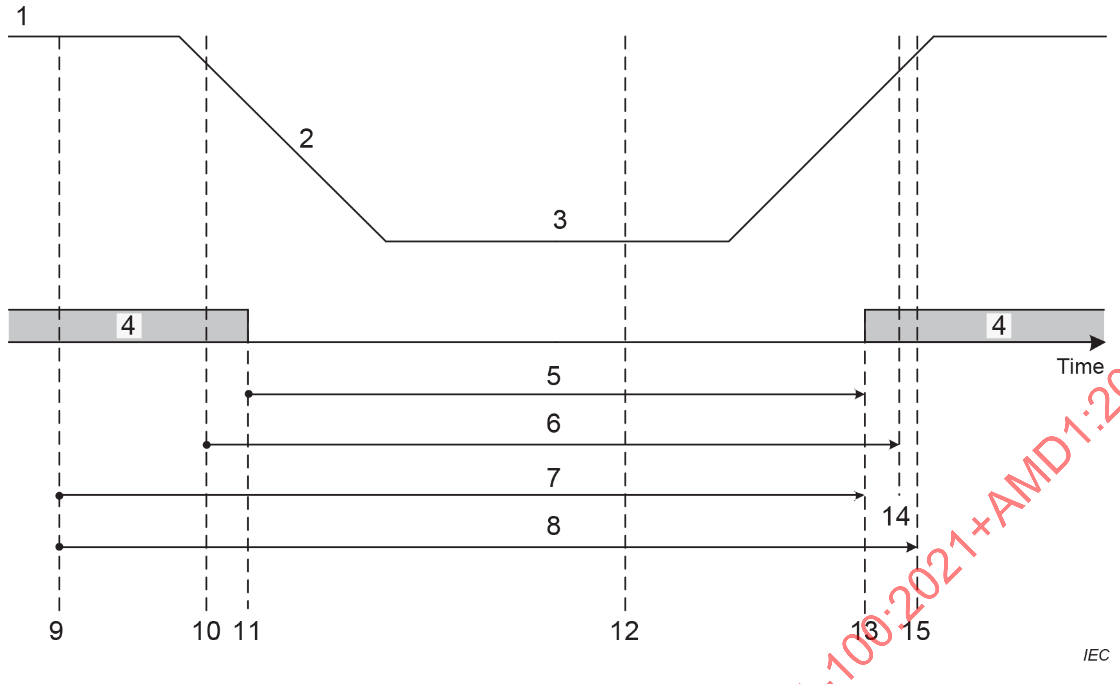
**Figure 2 – Circuit-breaker without switching resistors – Opening and closing operations**




**Key**

1 Closed position
2 Contact travel
3 Open position
4 Current flow
5 Close-open time, 3.7.141
6 Make-break time, 3.7.142
7 Initiation of closing operation, 3.7.153
8 Instant of start of current flow in the first pole
9 Instant of contact touch in the first closing pole
10 Instant of contact touch in all poles
11 Initiation of opening operation, 3.7.153
12 Instant of separation of arcing contacts in all poles
13 Instant of arc extinction in all poles

**Figure 3 – Circuit breaker without switching resistors – Close-open cycle**




**Key**

1 Closed position

2 Contact travel

3 Open position

4 Current flow

5 Dead time, 3.7.138

6 Open-close time, 3.7.137

7 Re-make time, 3.7.140

8 Reclosing time, 3.7.139

9 Initiation of opening operation, 3.7.153

10 Instant of separation of arcing contacts in all poles

11 Instant of final arc extinction in all poles

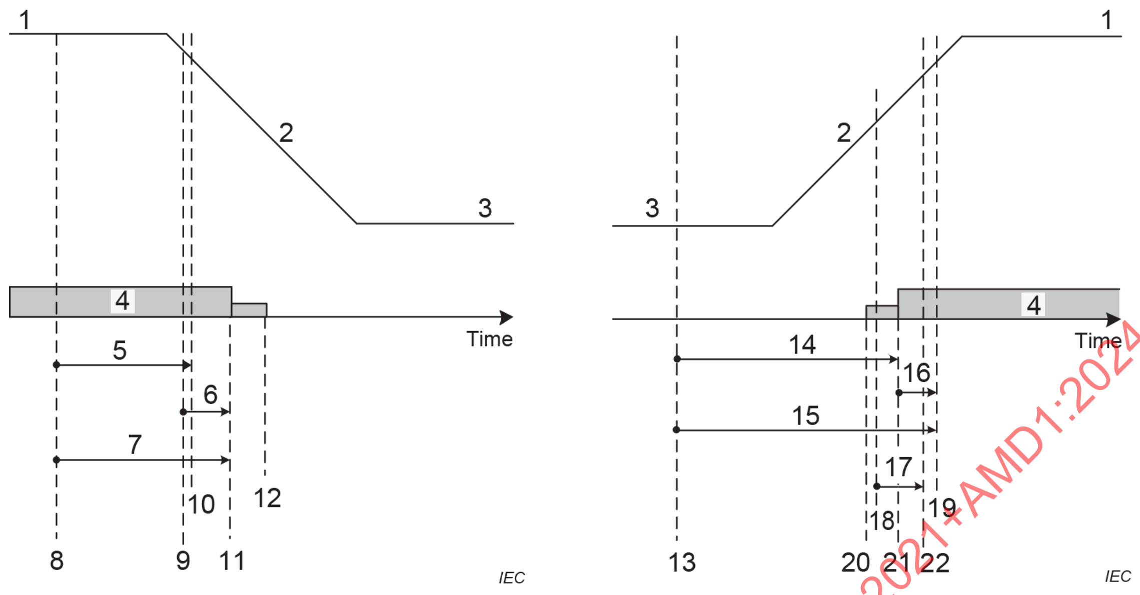
12 Initiation of closing operation, 3.7.153

13 Instant of start of current flow in the first closing pole

14 Instant of contact touch in first pole

15 Instant of contact touch in all poles

**Figure 4 – Circuit-breaker without switching resistors – Reclosing (auto-reclosing)**

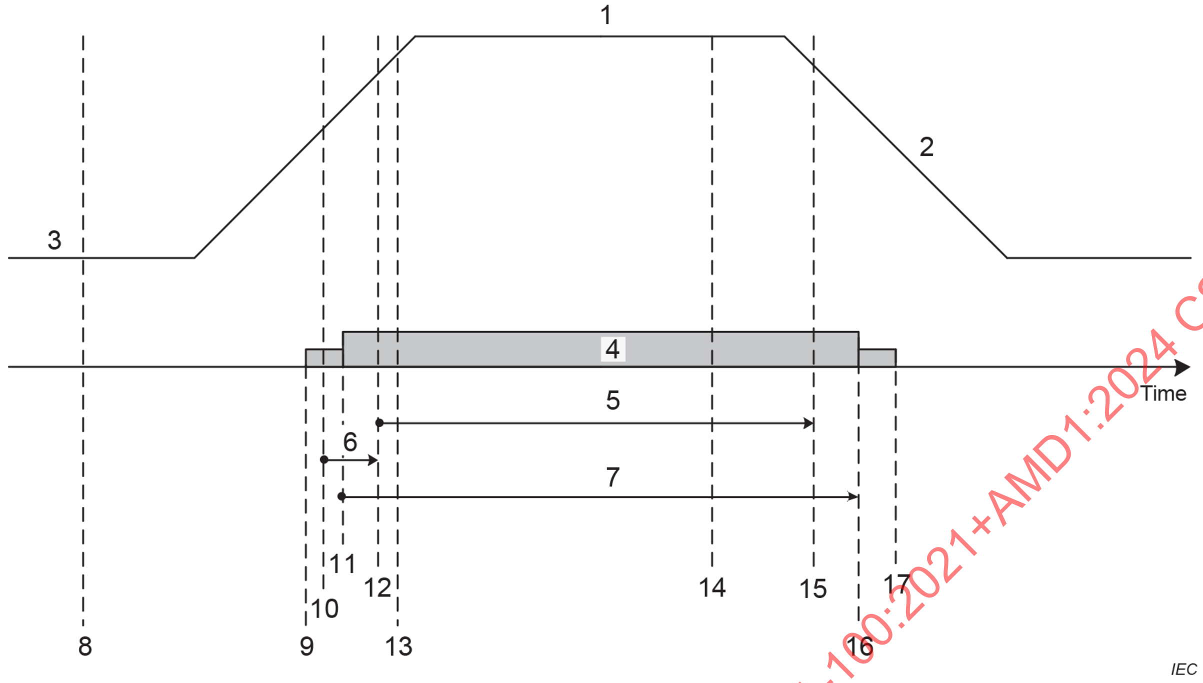



**Opening operation** **Closing operation**

**Key**

| | | | |
|---|---|---|---|
| 1 | Closed position | 12 | Instant of arc extinction in all poles – Resistor current |
| 2 | Contact travel | 13 | Initiation of the closing operation, 3.7.153 |
| 3 | Open position | 14 | Make time, 3.7.135 |
| 4 | Current flow | 15 | Closing time, 3.7.134 |
| 5 | Opening time, 3.7.131 | 16 | Pre-arcing time, 3.7.136 |
| 6 | Total arcing time, 3.7.154 | 17 | Pre-insertion time, 3.7.143 |
| 7 | Break-time, 3.7.133 | 18 | Instant of contact touch in the closing resistor of any one pole |
| 8 | Initiation of opening operation, 3.7.153 | 19 | Instant of contact touch in all poles |
| 9 | Instant of separation of arcing contacts in first opening pole | 20 | Instant of start of current flow in the first pole – Resistor current |
| 10 | Instant of separation of arcing contacts in all poles | 21 | Instant of the start of current flow in the first pole – Full current |
| 11 | Instant of arc extinction in all poles – Full current | 22 | Instant of contact touch in the making and breaking unit of the same pole as regarded for the resistor |

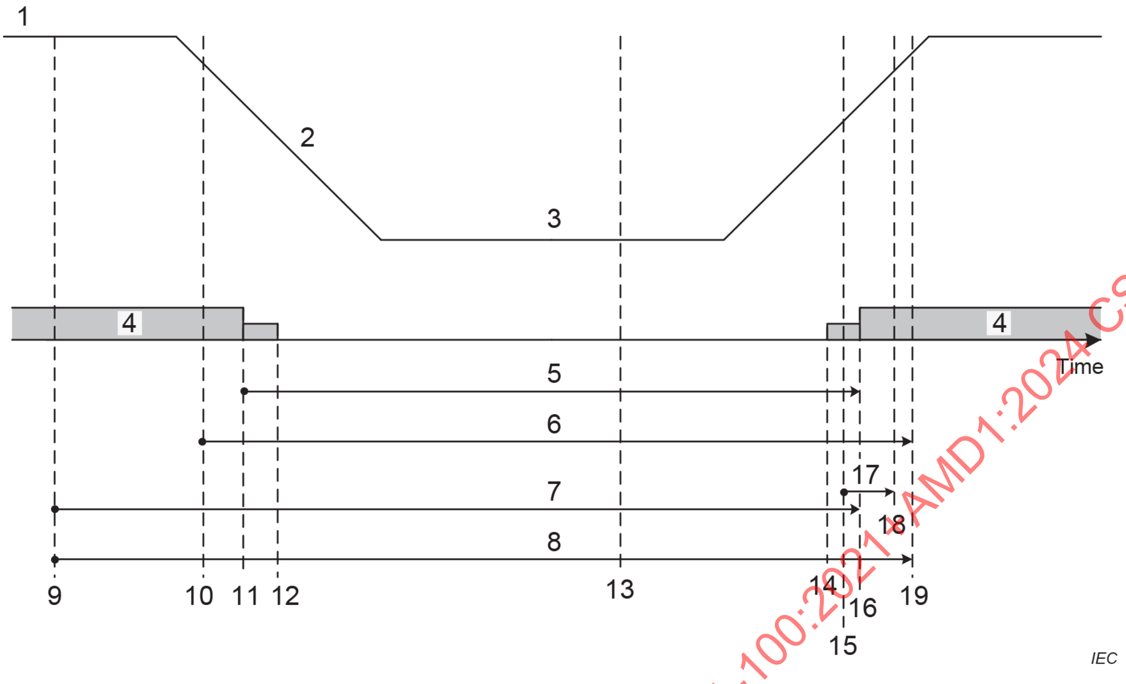
**Figure 5 – Circuit-breaker with switching resistors – Opening and closing operations**




**Key**

| | | | |
|---|---|---|---|
| 1 | Closed position | 10 | Instant of contact touch in the closing resistor of any one pole |
| 2 | Contact travel | 11 | Instant of start of current flow in the first pole – Full current |
| 3 | Open position | 12 | Instant of contact touch in the making and breaking unit of the same pole as regarded for the resistor |
| 4 | Current flow | 13 | Instant of contact touch in all poles |
| 5 | Close-open time, 3.7.141 | 14 | Initiation of opening operation, 3.7.153 |
| 6 | Pre-insertion time, 3.7.143 | 15 | Instant of separation of arcing contacts in all poles |
| 7 | Make-break time, 3.7.142 | 16 | Instant of arc extinction in all poles – Full current |
| 8 | Initiation of closing operation, 3.7.153 | 17 | Instant of arc extinction in all poles – Resistor current |
| 9 | Instant of start of current flow in the first pole – Resistor current | | |

**Figure 6 – Circuit-breaker with switching resistors – Close-open cycle**




**Key**

| | | | |
|---|---|---|---|
| 1 | Closed position | 11 | Instant of arc extinction in all poles – Full current |
| 2 | Contact travel | 12 | Instant of arc extinction in all poles – Resistor current |
| 3 | Open position | 13 | Initiation of closing operation, 3.7.153 |
| 4 | Current flow | 14 | Resistor current |
| 5 | Dead time, 3.7.138 | 15 | Instant of contact touch in the closing resistor of any one pole |
| 6 | Open-close time, 3.7.137 | 16 | Instant of start of current flow in the first pole – Full current |
| 7 | Re-make time, 3.7.140 | 17 | Pre-insertion time, 3.7.143 |
| 8 | Reclosing time, 3.7.139 | 18 | Instant of contact touch in the breaking unit of the same pole as regarded for the resistor |
| 9 | Initiation of opening operation, 3.7.153 | 19 | Instant of contact touch in all poles |
| 10 | Instant of separation of arcing contacts in all poles | | |

**Figure 7 – Circuit-breaker with switching resistors – Reclosing (auto-reclosing)**

**3.7.101**
**rated value**
quantity value assigned, generally by the manufacturer, for a specified operating condition of a component, device or equipment

Note 1 to entry: Examples of rated value usually stated for fuses: voltage, current, breaking capacity.

[SOURCE: IEC 60050-441:2000, 441-18-35]

**3.7.102**
**prospective current** <of a circuit and with respect to a switching device or a fuse>
current that would flow in the circuit if each pole of the switching device or the fuse were replaced by a conductor of negligible impedance

Note 1 to entry: The method to be used to evaluate and to express the prospective current is specified in the relevant publications.

[SOURCE: IEC 60050-441:1984, 441-17-01]

**3.7.103**
**prospective peak current**
peak value of the first major loop of the prospective current during the transient period following initiation

Note 1 to entry: The definition assumes that the current is made by an ideal circuit-breaker, i.e. with instantaneous and simultaneous transition of its impedance across the terminals of each pole from infinity to zero. The peak value can differ from one pole to another; it depends on the instant of current initiation relative to the voltage wave across the terminals of each pole.

**3.7.104**
**peak current**
peak value of the first major loop of current during the transient period following initiation

**3.7.105**
**prospective symmetrical current** <of an AC circuit>
prospective current when it is initiated at such an instant that no transient phenomenon follows the initiation

Note 1 to entry: For polyphase circuits, the condition of non-transient period can only be satisfied for the current in one pole at a time.

Note 2 to entry: The prospective symmetrical current is expressed by its RMS value.

[SOURCE: IEC 60050-441:1984, 441-17-03]

**3.7.106**
**maximum prospective peak current** <of an AC circuit>
prospective peak current when initiation of the current takes place at the instant which leads to the highest possible value

Note 1 to entry: For a multiple device in a polyphase circuit, the maximum prospective peak current refers to a single pole only.

[SOURCE: IEC 60050-441:1984, 441-17-04]

**3.7.107**
**prospective making current** <for a pole of a switching device>
prospective current when initiated under specified conditions

Note 1 to entry: The specified conditions can relate to the method of initiation, for example by an ideal switching device, or to the instant of initiation, for example leading to the maximum prospective peak current in an AC circuit, or to the highest rate of rise. The specification of these conditions is found in the relevant publications.

[SOURCE: IEC 60050-441:1984, 441-17-05]

**3.7.108**
**making current**
peak value of the first major loop of the current in a pole of a circuit-breaker during the transient period following the initiation of current during a making operation

Note 1 to entry: The peak value can differ from one pole to another and from one operation to another as it depends on the instant of current initiation relative to the wave of the applied voltage.

Note 2 to entry: Where, for a polyphase circuit, a single value of (peak) making current is referred to, this is, unless otherwise stated, the highest value in any phase.

**3.7.109**
**prospective breaking current** <for a pole of a switching device>
prospective current evaluated at a time corresponding to the instant of the initiation of the breaking process

Note 1 to entry: Specifications concerning the instant of the initiation of the breaking process can be found in the relevant publications. For mechanical switching devices or fuses, it is usually defined as the moment of initiation of the arc during the breaking process.

[SOURCE: IEC 60050-441:1984, 441-17-06]

**3.7.110**
**breaking current** <of a switching device or a fuse>
current in a pole of a switching device or in a fuse at the instant of initiation of the arc during a breaking process

[SOURCE: IEC 60050-441:1984, 441-17-07]

**3.7.111**
**making and breaking test**
test during which the circuit-breaker is closed (to make) and opened (to break)

**3.7.112**
**terminal fault**
short-circuit on at least one of the terminals of the circuit-breaker

Note 1 to entry: The terminal fault current has contributions from the source side only.

**3.7.113**
**critical (breaking) current**
value of breaking current, less than rated short-circuit breaking current, at which the arcing time is a maximum and is significantly longer than that of the rated short-circuit breaking current

**3.7.114**
**breaking capacity** <of a switching device or a fuse>
value of prospective current that a switching device or a fuse is capable of breaking at a stated voltage under prescribed conditions of use and behaviour

Note 1 to entry: The voltage to be stated and the conditions to be prescribed are dealt with in the relevant publications.

Note 2 to entry: For switching devices, the breaking capacity can be termed according to the kind of current included in the prescribed conditions, for example line-charging breaking capacity, cable charging breaking capacity, single capacitor bank breaking capacity, etc.

[SOURCE: IEC 60050-441:1984, 441-17-08]

**3.7.115**
**no-load line-charging breaking capacity**
breaking capacity for which the specified conditions of use and behaviour include the opening of an overhead line operating at no-load

**3.7.116**
**no-load cable-charging breaking capacity**
breaking capacity for which the specified conditions of use and behaviour include the opening of an insulated cable operating at no-load

**3.7.117**
**capacitor bank breaking capacity**
breaking capacity for which the specified conditions of use and behaviour include the opening of a capacitor bank

**3.7.118**
**making capacity** <of a switching device or a fuse>
value of prospective making current that a switching device is capable of making at a stated voltage under prescribed conditions of use and behaviour

Note 1 to entry: The voltage to be stated and the conditions to be prescribed are dealt with in the relevant specifications.

[SOURCE: IEC 60050-441:1984, 441-17-09]

**3.7.119**
**capacitor bank inrush making capacity**
making capacity for which the specified conditions of use and behaviour include the closing onto a capacitor bank

**3.7.120**
**out-of-phase (making or breaking) capacity**
making or breaking capacity for which the specified conditions of use and behaviour include the loss or the lack of synchronism between the parts of an electrical system on either side of the circuit-breaker

**3.7.121**
**short-circuit making capacity**
making capacity for which the prescribed conditions include a short-circuit at the terminals of the switching device

[SOURCE: IEC 60050-441:1984, 441-17-10]

**3.7.122**
**short-circuit breaking capacity**
breaking capacity for which the prescribed conditions include a short-circuit at the terminals of the switching device

[SOURCE: IEC 60050-441:1984, 441-17-11]

**3.7.123**
**short-time withstand current**
current that a circuit or a switching device in the closed position can carry during a specified short time under prescribed conditions of use and behaviour

[SOURCE: IEC 60050-441:1984, 441-17-17]

**3.7.124**
**peak withstand current**
value of peak current that a circuit or a switching device in the closed position can withstand under prescribed conditions of use and behaviour

[SOURCE: IEC 60050-441:1984, 441-17-18]

**3.7.125**
**applied voltage** <for a switching device>
voltage which exists across the terminals of a pole of a switching device just before the making of the current

[SOURCE: IEC 60050-441:1984, 441-17-24]

**3.7.126**
**recovery voltage**
voltage which appears across the terminals of a pole of a switching device or a fuse after the breaking of the current

Note 1 to entry: This voltage can be considered in two successive intervals of time, one during which a transient voltage exists, followed by a second one during which the power frequency or the steady-state recovery voltage alone exists.

[SOURCE: IEC 60050-441:1984, 441-17-25]

**3.7.127**
**transient recovery voltage**
**TRV**
recovery voltage during the time in which it has a significant transient character

Note 1 to entry: The transient recovery voltage can be oscillatory or non-oscillatory or a combination of these depending on the characteristics of the circuit and the switching device. It includes the voltage shift of the neutral of a polyphase circuit.

Note 2 to entry: The transient recovery voltages in three-phase circuits is, unless otherwise stated, that across the first pole to clear, because this voltage is generally higher than that which appears across each of the other two poles.

[SOURCE: IEC 60050-441:1984, 441-17-26]

**3.7.128**
**prospective transient recovery voltage** <of a circuit>
transient recovery voltage following the breaking of the prospective symmetrical current by an ideal switching device

Note 1 to entry: The definition assumes that the switching device or the fuse, for which the prospective transient recovery voltage is sought, is replaced by an ideal switching device, i.e. having instantaneous transition from zero to infinite impedance at the very instant of zero current, i.e. at the "natural" zero. For circuits where the current can follow several different paths, for example a polyphase circuit, the definition further assumes that the breaking of the current by the ideal switching device takes place only in the pole considered.

[SOURCE: IEC 60050-441:1984, 441-17-29]

**3.7.129**
**power frequency recovery voltage**
recovery voltage after the transient voltage phenomena have subsided

[SOURCE: IEC 60050-441:1984, 441-17-27]

**3.7.130**
**clearance**
distance between two conductive parts along a string stretched the shortest way between these conductive parts

[SOURCE: IEC 60050-441:1984, 441-17-31]

**3.7.131**
**opening time** <of a mechanical switching device>
interval of time between the specified instant of initiation of the opening operation and the instant when the arcing contacts have separated in all poles

Note 1 to entry: The instant of initiation of the opening operation, i.e. the application of the opening command (for example energizing the release, etc.) is given in the relevant specifications.

[SOURCE: IEC 60050-441:1984, 441-17-36]

**3.7.132**
**arcing time** <of a pole or a fuse>
interval of time between the instant of the initiation of the arc in a pole or a fuse and the instant of final arc extinction in that pole or that fuse

[SOURCE: IEC 60050-441:1984, 441-17-37]

**3.7.133**
**break-time**
interval of time between the beginning of the opening time of a mechanical switching device (or the pre-arcing time of a fuse) and the end of the arcing time

[SOURCE: IEC 60050-441:1984, 441-17-39]

**3.7.134**
**closing time**
interval of time between the initiation of the closing operation and the instant when the contacts touch in all poles

[SOURCE: IEC 60050-441:1984, 441-17-41]

**3.7.135**
**make-time**
interval of time between the initiation of the closing operation and the instant when the current begins to flow in the main circuit

[SOURCE: IEC 60050-441:1984, 441-17-40]

**3.7.136**
**pre-arcing time** <of a circuit-breaker>
interval of time between the initiation of current flow in the first pole during a closing operation and the instant when the contacts touch in all poles for three-phase conditions and the instant when the contacts touch in the arcing pole for single-phase conditions

Note 1 to entry: The pre-arcing time depends on the instantaneous value of the applied voltage during a specific closing operation and therefore can vary considerably.

Note 2 to entry: The definition of pre-arcing time of a circuit-breaker is different from that of a fuse.

**3.7.137**
**open-close time** <during auto-reclosing>
interval of time between the instant when the arcing contacts have separated in all poles and the instant when the contacts touch in the first pole during a reclosing cycle

**3.7.138**
**dead time** <during auto-reclosing>
interval of time between final arc extinction in all poles on the opening operation and the first reestablishment of current in any pole on the subsequent closing operation

[SOURCE: IEC 60050-441:1984, 441-17-44]

**3.7.139**
**reclosing time**
interval of time between the beginning of the opening time and the instant when the contacts touch in all poles during a reclosing cycle

**3.7.140**
**re-make time** <during reclosing>
interval of time between the beginning of the opening time and the first re-establishment of current in any pole in the subsequent closing operation

Note 1 to entry: The re-make time can vary, for example due to the variation of the pre-arcing time.

**3.7.141**
**close-open time**
interval of time between the instant when the contacts touch in the first pole during a closing operation and the instant when the arcing contacts have separated in all poles during the subsequent opening operation

[SOURCE: IEC 60050-441:1984, 441-17-42]

**3.7.142**
**make-break time**
interval of time between the instant when the current begins to flow in a pole and the instant of final arc extinction in all poles, with the opening release energised at the instant when current begins to flow in the main circuit

[SOURCE: IEC 60050-441:1984, 441-17-43]

**3.7.143**
**pre-insertion time** <of a closing resistor>
interval of time during which the resistor remains in the main circuit during a no-load operation

**3.7.144**
**continuous current**
current that the main circuit of a circuit-breaker is capable of carrying continuously under specified conditions of use and behaviour

**3.7.145**
**peak factor**
ratio of the maximum absolute value of an alternating quantity to its RMS value

Note 1 to entry: For an alternating quantity $x$, the peak factor is equal to $x_{max} / X_{eff}$.

**3.7.146**
**first-pole-to-clear factor** <in a three-phase system>
$k_{\mathbf{pp}}$
when breaking any symmetrical three-phase current, the first-pole-to-clear factor is the ratio of the power frequency voltage across the first interrupting pole before current breaking in the other poles, to the power frequency voltage occurring across the pole or the poles after breaking in all three poles

**3.7.147**
**amplitude factor**
$k_{\mathbf{af}}$
ratio between the maximum excursion of the TRV to the crest value of the power frequency recovery voltage

**3.7.148**
**insulation level**
set of withstand voltages specified which characterise the dielectric strength of the insulation

[SOURCE: IEC 60050-614:2016, 614-03-23]

**3.7.149**
**power frequency withstand voltage**
RMS value of sinusoidal power frequency voltage that the insulation of the given equipment can withstand during tests made under specified conditions and for a specified duration

[SOURCE: IEC 60050-614:2016, 614-03-22]

**3.7.150**
**impulse withstand voltage**
highest peak value of impulse voltage of prescribed form and polarity which does not cause breakdown of insulation under specified conditions

[SOURCE: IEC 60050-442:2014, 442-09-18]

**3.7.151**
**minimum clearing time**
sum of the minimum opening time, minimum relay time (0,5 cycle), and the shortest arcing time of a minor loop breaking in the phase with intermediate asymmetry that starts with a minor loop at short-circuit current initiation

**3.7.152**
**insertion time** <of an opening resistor>
interval of time during an opening operation between the instant of separation of the arcing contacts in the making and breaking units of any one pole and the instant of contact separation in the resistor switch in that pole

**3.7.153**
**initiation of (opening or closing) operation**
instant of receipt of command for operation at the control circuit

**3.7.154**
**total arcing time**
interval of time between the instant of the first initiation of an arc in a pole and the instant of arc extinction in all poles

**3.7.155**
**direct connection to an overhead line**
connection between a circuit-breaker and an overhead line having a capacitance less than 5 nF

## 3.8 Index of definitions

**L**



**M**



**N**



**O**

**P**



**R**



**S**

# 4 Normal and special service conditions

Clause 4 of IEC 62271-1:2017 is applicable.

# 5 Ratings

## 5.1 General

Subclause 5.1 of IEC 62271-1:2017 is applicable with the following additional items.

k) rated short-circuit breaking current;
l) rated first-pole-to-clear factor;
m) rated short-circuit making current;
n) rated operating sequence.

*Optional rated characteristics*

o) rated out-of-phase making and breaking current;
p) rated line-charging breaking current;
q) rated cable-charging breaking current;
r) rated single capacitor bank breaking current;
s) rated back-to-back capacitor bank breaking current;
t) rated back-to-back capacitor bank inrush making current.

### 5.2 Rated voltage ($U_r$)

Subclause 5.2 of IEC 62271-1:2017 is applicable.

### 5.3 Rated insulation level ($U_d$, $U_p$, $U_s$)

Subclause 5.3 of IEC 62271-1:2017 is applicable with the following addition:

The standard values of rated withstand voltages across the open circuit-breaker are given in Tables 1, 2, 3 and 4 of IEC 62271-1:2017.

### 5.4 Rated frequency ($f_r$)

Subclause 5.4 of IEC 62271-1:2017 is applicable with the following modification:

The standard values for the rated frequency of high-voltage circuit-breakers are 50 Hz and 60 Hz.

### 5.5 Rated continuous current ($I_r$)

Subclause 5.5 of IEC 62271-1:2017 is applicable with the following addition:

If the circuit-breaker is fitted with a series connected accessory, such as a direct overcurrent release, the rated continuous current of the accessory is the RMS value of the current which the accessory shall be able to carry continuously without deterioration at its rated frequency, with a temperature rise not exceeding the values specified in Table 14 of IEC 62271-1:2017.

### 5.6 Rated short-time withstand current ($I_k$)

Subclause 5.6 of IEC 62271-1:2017 is applicable with the following addition:

The rated short-time withstand current is equal to the rated short-circuit breaking current (see 5.101).

### 5.7 Rated peak withstand current ($I_p$)

Subclause 5.7 of IEC 62271-1:2017 is applicable.

### 5.8 Rated duration of short-circuit ($t_k$)

Subclause 5.8 of IEC 62271-1:2017 is applicable.

### 5.9 Rated supply voltage of auxiliary and control circuits ($U_a$)

Subclause 5.9 of IEC 62271-1:2017 is applicable.

### 5.10 Rated supply frequency of auxiliary and control circuits

Subclause 5.10 of IEC 62271-1:2017 is applicable.

### 5.11 Rated pressure of compressed gas supply for controlled pressure systems

Subclause 5.11 of IEC 62271-1:2017 is applicable.

### 5.101 Rated short-circuit breaking current ($I_{sc}$)

#### 5.101.1 General

A circuit-breaker shall be capable of breaking its rated short-circuit breaking current at voltages equal to and lower than its rated voltage. The rated short-circuit breaking current is the highest short-circuit current which the circuit-breaker shall be capable of breaking under the conditions of use and behaviour required in this document.

The rated short-circuit breaking current is characterised by two values:

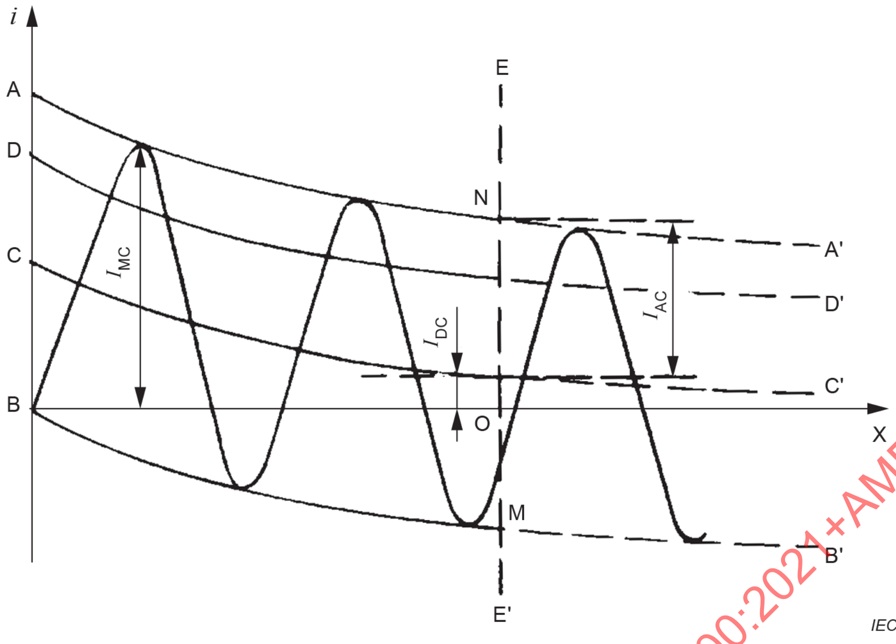
– the RMS value of its AC component;

– the DC time constant of the rated short-circuit breaking current.

If the level of asymmetry expressed in terms of the DC component at contact separation does not exceed 20 %, the rated short-circuit breaking current is considered symmetrical and characterised only by the RMS value of its AC component.

For determination of the AC component and the percentage of DC component at any time following current initiation, see Figure 8.

Circuit-breakers directly connected to overhead lines can be exposed to short-line faults. Further information regarding applicability and testing is given in 3.7.155, 6.107.3 and 7.109.




| | |
|---|---|
| AA' BB' | envelope of current-wave |
| BX | normal zero line |
| CC' | displacement of current-wave zero-line at any instant |
| DD' | RMS value of the AC component of current at any instant, measured from CC' |
| EE' | instant of contact separation (initiation of the arc) |
| $I_{MC}$ | making current |
| $I_{AC}$ | peak value of AC component of current at instant EE' |
| $\frac{I_{AC}}{\sqrt{2}}$ | RMS value of the AC component of current at instant EE' |
| $I_{DC}$ | DC component of current at instant EE' |
| $\frac{I_{DC}}{I_{AC}} \times 100 = \frac{\overline{ON} - \overline{OM}}{\overline{MN}} \times 100 = \left( \frac{2 \times \overline{ON}}{\overline{MN}} - 1 \right) \times 100$ | percentage value of the DC component |

**Figure 8 – Determination of short-circuit making and breaking currents, and of percentage DC component**

### 5.101.2 AC component of the rated short-circuit breaking current

The standard value of the AC component of the rated short-circuit breaking current shall be selected from the R10 series specified in IEC 60059.

NOTE The R10 series comprises the numbers 1 – 1,25 – 1,6 – 2 – 2,5 – 3,15 – 4 – 5 – 6,3 – 8 and their products by $10^n$.

### 5.101.3 DC time constant of the rated short-circuit breaking current

a) For circuit-breakers with rated voltages up to and including 800 kV

The standard DC time constant is 45 ms. The following are special case DC time constants, related to the rated voltage of the circuit-breaker:

– 120 ms for rated voltages up to and including 52 kV;

– 60 ms for rated voltages from 72,5 kV up to and including 420 kV;

– 75 ms for rated voltages 550 kV and 800 kV.

These special case time constants recognise that the standard value may be inadequate in some systems. They are provided as unified values for such special system needs, taking into account the characteristics of the different ranges of the rated voltage, for example their particular system structures, the design of lines, etc.

In addition, some applications may require even higher values, for example if a circuit-breaker is close to generators. In these circumstances the required DC time constant and any additional test requirements should be specified in the inquiry.

NOTE 1 More detailed information on the use of the standard time constant and the special case time constants is given in the IEC TR 62271-306 [4][3]. The percentage of DC component against time for different time constants is shown in Figure 9.

NOTE 2 The percentage of DC component at contact separation as used in former editions of IEC 62271-100 can be derived by using the equation given in 7.107.6. The concept of percentage of DC component at contact separation for symmetrical test-duties is still used in this edition. For the asymmetrical test-duty T100a, such concept has been changed (see IEC TR 62271-306 [4]).

b) For circuit-breakers with rated voltages higher than 800 kV

The standard DC time constant is 120 ms. Note 2 is also applicable in this case.

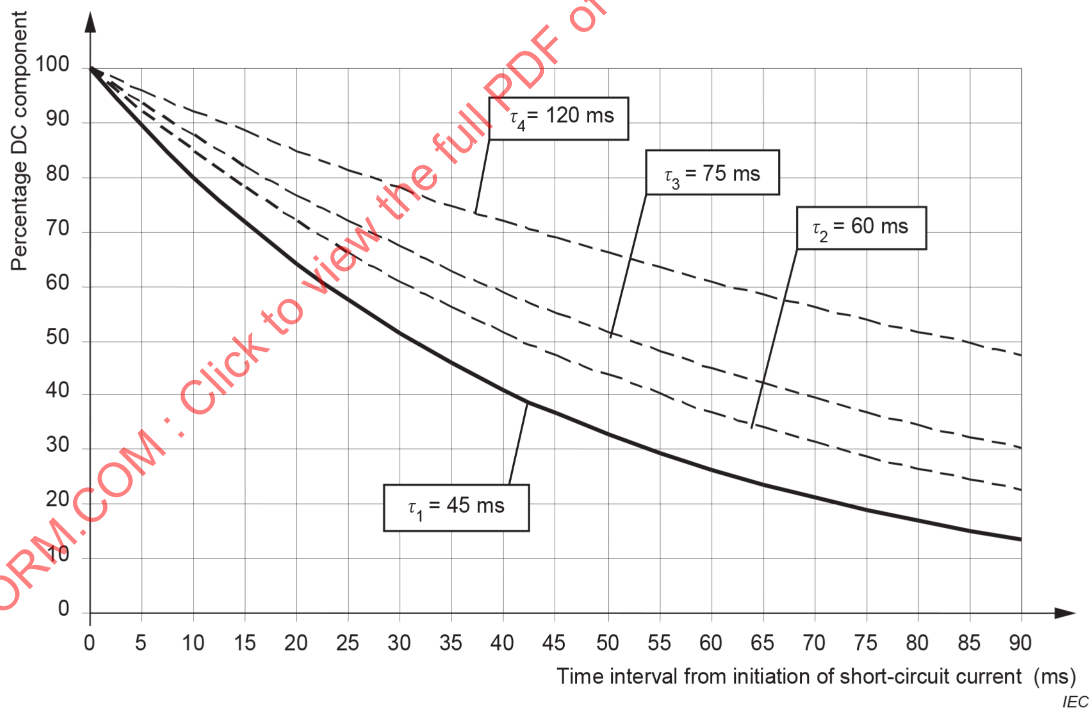



**Figure 9 – Percentage DC component in relation to the time interval from the initiation of the short-circuit for the different time constants**

3 Numbers in square brackets refer to the Bibliography.

### 5.102 Rated first-pole-to-clear factor ($k_{pp}$)

The ability of the circuit-breaker to operate in networks having different earthing conditions of the system neutral is expressed in terms of $k_{pp}$. The rated values of $k_{pp}$ are:

– 1,2 for circuit-breakers with rated voltages higher than 800 kV in effectively earthed neutral systems;
– 1,3 for circuit-breakers for rated voltages up to and including 800 kV in effectively earthed neutral systems;
– 1,5 for circuit-breakers for rated voltages up to and including 170 kV in non-effectively earthed neutral systems.

NOTE 1 In this document, it is considered that systems with voltages up to and including 170 kV can have either effectively earthed neutrals or non-effectively earthed neutrals. Systems with voltages higher than 170 kV have an effectively-earthed neutral.

NOTE 2 The rated first-pole-to-clear factors given here are associated with terminal faults. For other switching conditions other first-pole-to-clear factors apply. As an example, the following $k_{pp}$ applies to out-of-phase conditions:

– 2,0 for breaking in out-of-phase conditions in systems with effectively earthed neutral;
– 2,5 for breaking in out-of-phase conditions in systems with non-effectively earthed neutral.

### 5.103 Rated short-circuit making current

The rated short-circuit making current is obtained by multiplying the RMS value of the AC component of the rated short-circuit breaking current (see 5.101) with the peak factor given in Table 5 of IEC 62271-1:2017.

### 5.104 Rated operating sequence

The rated operating sequence is O – $t$ – CO – $t'$ – CO, where

O represents an opening operation;

CO represents a close-open operating cycle with the shortest possible close-open time such that the circuit-breaker reaches the fully closed and latched position prior to opening.

The time parameters are as follows:

– circuit-breaker for auto-reclosing: $t$ = 3 min and $t'$= 3 min (alternative values for $t$ and $t'$ may be used, for example 15 s or 1 min);
– circuit-breaker for rapid auto-reclosing: $t$ = 0,3 s and $t'$ = 3 min (alternative values for $t'$ may be used, for example 15 s or 1 min);
– circuit-breaker not for auto-reclosing: $t$ > 3 min and $t'$ > 3 min (values for $t$ and $t'$ to be specified by the manufacturer).

### 5.105 Rated out-of-phase making and breaking current

The rated out-of-phase breaking current is the maximum out-of-phase current that the circuit-breaker shall be capable of breaking under the conditions of use and behaviour required in this document in a circuit having a recovery voltage as specified in 7.110.

If a rated out-of-phase breaking current is assigned, the rated out-of-phase breaking current shall be 25 % of the rated short-circuit breaking current and the rated out-of-phase making current shall be the crest value of the rated out-of-phase breaking current.

The standard conditions of use with respect to the rated out-of-phase making and breaking current are as follows:

– opening and closing operations carried out in conformity with the instructions given by the manufacturer for the operation and proper use of the circuit-breaker and its auxiliary equipment;
– earthing condition of the neutral for the power system corresponding to that for which the circuit-breaker has been tested;
– absence of a fault on either side of the circuit-breaker.

### 5.106 Rated capacitive currents

#### 5.106.1 General

Switching of capacitive loads can comprise part or all of the operating duty of a circuit-breaker such as the charging current of an unloaded transmission line or cable or the load current of a shunt capacitor bank.

NOTE The classes associated with making and breaking of capacitive currents are explained in 6.107.4.

The rating of a circuit-breaker for capacitive currents shall include, where applicable:

– rated line-charging breaking current;
– rated cable-charging breaking current;
– rated single capacitor bank breaking current;
– rated back-to-back capacitor bank breaking current;
– rated back-to-back capacitor bank inrush making current.

Preferred values of rated capacitive currents are given in Table 1.

**Table 1 – Preferred values of rated capacitive currents**

| | Line | Cable | Single capacitor bank | Back-to-back capacitor bank | |
|---|---|---|---|---|---|
| Rated voltage<br>$U_r$<br>kV | Rated line-charging breaking current<br>$I_l$<br>A | Rated cable-charging breaking current<br>$I_c$<br>A | Rated single capacitor bank breaking current<br>$I_{sb}$<br>A | Rated back-to-back capacitor bank breaking current<br>$I_{bb}$<br>A | Rated back-to-back capacitor bank inrush making current<br>$I_{bi}$<br>kA |
| 3,6 | 10 | 10 | 400 | 400 | 20 |
| 4,76 | 10 | 10 | 400 | 400 | 20 |
| 7,2 | 10 | 10 | 400 | 400 | 20 |
| 8,25 | 10 | 10 | 400 | 400 | 20 |
| 12 | 10 | 25 | 400 | 400 | 20 |
| 15 | 10 | 25 | 400 | 400 | 20 |
| 15,5 | 10 | 25 | 400 | 400 | 20 |
| 17,5 | 10 | 31,5 | 400 | 400 | 20 |
| 24 | 10 | 31,5 | 400 | 400 | 20 |
| 25,8 | 10 | 31,5 | 400 | 400 | 20 |
| 27 | 10 | 31,5 | 400 | 400 | 20 |
| 36 | 10 | 50 | 400 | 400 | 20 |
| 38 | 10 | 50 | 400 | 400 | 20 |
| 40,5 | 10 | 50 | 400 | 400 | 20 |
| 48,3 | 10 | 80 | 400 | 400 | 20 |
| 52 | 10 | 80 | 400 | 400 | 20 |
| 72,5 | 10 | 125 | 400 | 400 | 20 |
| 100 | 20 | 125 | 400 | 400 | 20 |
| 123 | 31,5 | 140 | 400 | 400 | 20 |
| 145 | 50 | 160 | 400 | 400 | 20 |
| 170 | 63 | 160 | 400 | 400 | 20 |
| 245 | 125 | 250 | 400 | 400 | 20 |
| 300 | 200 | 315 | 400 | 400 | 20 |
| 362 | 315 | 355 | 400 | 400 | 20 |
| 420 | 400 | 400 | 400 | 400 | 20 |
| 550 | 500 | 500 | 400 | 400 | 20 |
| 800 | 900 | - | - | - | - |
| 1 100 | 1 200 | - | - | - | - |
| 1 200 | 1 300 | - | - | - | - |

NOTE 1 The values given in this table are chosen for standardization purposes. They are preferred values and cover the majority of typical applications. If different values are applicable, any appropriate value can be specified as rated value.

NOTE 2 For actual cases, the inrush currents can be calculated based on IEC TR 62271-306 [4].

NOTE 3 The peak of the inrush current can be higher or lower than the preferred values stated in this table depending on system conditions, for example whether or not current limiting reactors are used.

NOTE 4 Preferred values for rated voltages 1 100 kV and 1 200 kV are based on applications at 50 Hz. Higher values of current could be possible in the future in systems operated at 60 Hz, however experience shows that these higher currents would not lead to a higher stress for the circuit-breaker as the recovery voltage is generally the dominant factor for breaking.

#### 5.106.2 Rated line-charging breaking current

The rated line-charging breaking current is the line-charging current the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour required in this document. The associated restrike class (C1 or C2) shall be assigned when a line-charging breaking current is assigned.

#### 5.106.3 Rated cable-charging breaking current

The rated cable-charging breaking current is the cable-charging current the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour required in this document. The associated restrike class (C1 or C2) shall be assigned when a cable-charging breaking current is assigned.

#### 5.106.4 Rated single capacitor bank breaking current

The rated single capacitor bank breaking current is the single capacitor bank breaking current the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour required in this document. This breaking current refers to the switching of a shunt capacitor bank where no shunt capacitors are connected to the source side of the circuit-breaker. The associated restrike class (C1 or C2) shall be assigned when a single capacitor bank breaking current is assigned.

#### 5.106.5 Rated back-to-back capacitor bank breaking current

The rated back-to-back capacitor bank breaking current is the back-to-back capacitor current the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour required in this document. The associated restrike class (C1 or C2) shall be assigned when a back-to-back capacitor bank breaking current is assigned.

This breaking current refers to the switching of a shunt capacitor bank where one or several shunt capacitor banks are connected to the source side of the circuit-breaker giving an inrush making current equal to the rated back-to-back capacitor bank inrush making current.

NOTE Similar conditions could apply for switching in substations with cables.

#### 5.106.6 Rated back-to-back capacitor bank inrush making current

The rated back-to-back capacitor bank inrush making current is the peak value of the current that the circuit-breaker shall be capable of making at its rated voltage and with a frequency of the inrush current during a simultaneous three-phase making operation (see Table 1 and 7.111.5.3).

## 6 Design and construction

### 6.1 Requirements for liquids

Subclause 6.1 of IEC 62271-1:2017 is applicable.

### 6.2 Requirements for gases

Subclause 6.2 of IEC 62271-1:2017 is applicable.

### 6.3 Earthing

Subclause 6.3 of IEC 62271-1:2017 is applicable.

### 6.4 Auxiliary and control equipment and circuits

Subclause 6.4 of IEC 62271-1:2017 is applicable with the following additions:

– where shunt opening and closing releases are used, appropriate measures shall be taken in order to avoid damage on the releases when permanent orders for closing or opening are applied. For example, those measures can be the use of series control contacts arranged so that when the circuit-breaker is closed, the close release control contact ("b" contact or break contact) is open and the open release control contact ("a" contact or make contact) is closed, and when the circuit-breaker is open, the open release control contact is open and the close release control contact is closed;
– where auxiliary switches are used as position indicators, they shall indicate the end position of the circuit-breaker at rest, open or closed. The signalling shall be sustained;
– connections shall withstand the stresses imposed by the circuit-breaker, especially those due to mechanical forces during operations;
– where special items of control equipment are used, they shall operate within the limits specified for supply voltages of auxiliary and control circuits, making and breaking and/or insulating and operating media, and be able to switch the loads which are stated by the circuit-breaker manufacturer;
– special items of auxiliary equipment such as liquid indicators, pressure indicators, relief valves, filling and draining equipment, heating and interlock contacts shall operate within the limits specified for supply voltages of auxiliary and control circuits and/or within the limits of use of making and breaking and/or insulating and operating media;
– where anti-pumping devices are part of the circuit-breaker control scheme, they shall act on each control circuit, if more than one is installed;
– where a control scheme of pole discrepancy is part of the circuit-breaker, the position of the poles shall be supervised, open or closed.

### 6.5 Dependent power operation

Subclause 6.5 of IEC 62271-1:2017 is applicable with the following addition:

A circuit-breaker arranged for dependent power closing with external energy supply shall also be capable of opening immediately following the closing.

### 6.6 Stored energy operation

Subclause 6.6 of IEC 62271-1:2017 is applicable with the following addition to the first paragraph.

A circuit-breaker arranged for stored energy closing shall also be capable of opening immediately following the closing operation.

### 6.7 Independent unlatched operation (independent manual or power operation)

Subclause 6.7 of IEC 62271-1:2017 is applicable with the exception of the last paragraph and Note 2.

### 6.8 Manually operated actuators

Subclause 6.8 of IEC 62271-1:2017 is applicable.

### 6.9 Operation of releases

Subclause 6.9 of IEC 62271-1:2017 is applicable with the following additions.

#### 6.9.101 Overcurrent release

##### 6.9.101.1 Operating current

An overcurrent release shall be marked with its rated continuous current and its current setting range.

Within the current setting range, the overcurrent release shall always operate at currents of 110 % and above of the current setting and shall never operate at currents of 90 % and below of this current setting.

##### 6.9.101.2 Operating time

The manufacturer shall provide tables or curves, each with the applicable tolerances, showing the operating time as a function of current, between twice and six times the operating current. These tables or curves shall be provided for extreme current settings together with extreme settings of time delay.

For an inverse time delay overcurrent release, the operating time shall be measured from the instant at which the overcurrent is established until the instant the tripping is initiated.

##### 6.9.101.3 Resetting current

If the current in the main circuit falls below a certain value, before the time delay of the overcurrent release has expired, the release shall not complete its operation and shall reset to its initial position.

The relevant information shall be given by the manufacturer.

#### 6.9.102 Multiple releases

If a circuit-breaker is fitted with more than one release for the same function, a defect in one release shall not disturb the function in the others. Releases used for the same function shall be physically separated, i.e. magnetically decoupled.

#### 6.9.103 Power consumption of releases

The power consumption of shunt closing or opening releases of a three-pole circuit-breaker should not exceed 1 200 VA. For certain circuit-breaker designs higher values may be required.

#### 6.9.104 Integrated relays for self-tripping circuit-breakers

When an integrated relay is used for self-tripping circuit-breakers, it shall comply with IEC 60255-151:2009. The input energising quantity is the current through the main contacts.

### 6.10 Pressure/level indication

#### 6.10.1 Gas pressure

Subclause 6.10.1 of IEC 62271-1:2017 is applicable with the following addition:

All circuit-breakers having an energy storage in gas receivers or hydraulic accumulators (see 6.6.2 of IEC 62271-1:2017) and all circuit-breakers except sealed pressure devices, using compressed gas for making and breaking (see 6.103) shall be fitted with a locking device set to operate at, or within, the appropriate limits of pressure stated by the manufacturer.

### 6.10.2 Liquid level

Subclause 6.10.2 of IEC 62271-1:2017 is applicable.

### 6.11 Nameplates

Subclause 6.11 of IEC 62271-1:2017 is applicable with the following additions: the nameplates of a circuit-breaker and its operating devices shall be marked in accordance with Table 2.

Coils of operating devices shall have a reference mark permitting the complete data to be obtained from the manufacturer.

Releases shall bear the appropriate data.

With the exception of removable circuit-breakers, the nameplate shall be visible in the position of normal service and installation. For removable circuit-breakers 6.11 of IEC 62271-200:20— applies.

**Table 2 – Nameplate information**

| | Abbrevi-ation | Unit | Circuit-breaker | Operating device | Condition: Marking only required if |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Manufacturer | | | X | X | |
| Type designation and serial number | | | X | X | |
| Rated voltage | $U_r$ | kV | X | | |
| Rated short-duration power frequency withstand voltage | $U_d$ | kV | X | | |
| Rated lightning impulse withstand voltage | $U_p$ | kV | X | | |
| Rated switching impulse withstand voltage | $U_s$ | kV | y | | Rated voltage 300 kV and above |
| Rated frequency | $f_r$ | Hz | X | | |
| Rated continuous current | $I_r$ | A | X | | |
| Rated duration of short-circuit | $t_k$ | s | y | | Different from 1 s |
| Rated short-circuit breaking current | $I_{sc}$ | kA | X | | |
| DC time constant of the rated short-circuit breaking current | $\tau$ | ms | y | | Different from 45 ms |
| Rated first pole-to-clear factor | $k_{pp}$ | | X | | |
| Short-line fault breaking current | $I_{SLF}$ | kA | (X) | | |
| Rated out-of-phase breaking current | $I_d$ | kA | (X) | | |
| Rated line-charging breaking current | $I_l$ | A | (X) | | |
| Rated cable-charging breaking current | $I_c$ | A | (X) | | |
| Rated single capacitor bank-breaking current | $I_{sb}$ | A | (X) | | |
| Rated back-to-back capacitor bank-breaking current | $I_{bb}$ | A | (X) | | |
| Rated back-to-back capacitor bank inrush making current | $I_{bi}$ | kA | (X) | | |
| Filling pressure for operation | $p_{rm}$ | MPa | | (X) | |
| Filling pressure for making and breaking | $p_{re}$ | MPa | (X) | | |
| Rated supply voltage of auxiliary and control circuits<br>Specify DC/AC (with rated frequency) | $U_a$ | V<br>Hz | | (X) | |
| Mass (including oil for oil circuit-breakers) | $M$ | kg | y | y | More than 300 kg |
| Type and mass of fluid (liquid or gas) for insulation | $M_f$ | kg | y | | If contains fluid |
| Rated operating sequence | | | X | | |
| Year of manufacture | | | X | | |
| Minimum and maximum ambient air temperature | | | y | y | Different from –5 °C and/or 40 °C |

| | Abbrevi-ation | Unit | Circuit-breaker | Operating device | Condition: Marking only required if |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Classification | | | y | | If different from C1, E1, M1, S1 for rated voltages less than 100 kV<br>If different from C1, M1 for rated voltages 100 kV and above |
| Reference to this document | | | X | X | |
| X = the marking of these values is mandatory; blanks indicate the value zero.<br>(X) = the marking of these values is optional.<br>y = the marking of these values to the conditions in column 6. | | | | | |
| The abbreviation in column 2 can be used instead of the terms in column 1. When terms in column 1 are used, the word “rated“ need not appear. | | | | | |



### 6.12 Locking devices

Subclause 6.12 of IEC 62271-1:2017 is applicable.

### 6.13 Position indication

Subclause 6.13 of IEC 62271-1:2017 is applicable.

### 6.14 Degrees of protection provided by enclosures

Subclause 6.14 of IEC 62271-1:2017 is applicable.

### 6.15 Creepage distances for outdoor insulators

Subclause 6.15 of IEC 62271-1:2017 is applicable.

### 6.16 Gas and vacuum tightness

Subclause 6.16 of IEC 62271-1:2017 is applicable.

### 6.17 Tightness for liquid systems

Subclause 6.17 of IEC 62271-1:2017 is applicable.

### 6.18 Fire hazard (flammability)

Subclause 6.18 of IEC 62271-1:2017 is applicable.

### 6.19 Electromagnetic compatibility (EMC)

Subclause 6.19 of IEC 62271-1:2017 is applicable.

### 6.20 X-ray emission

Subclause 6.20 of IEC 62271-1:2017 is applicable

### 6.21 Corrosion

Subclause 6.21 of IEC 62271-1:2017 is applicable.

### 6.22 Filling levels for insulation, switching and/or operation

Subclause 6.22 of IEC 62271-1:2017 is applicable.

### 6.101 Requirements for simultaneity of poles during single closing and single opening operations

The following requirements are applicable under rated conditions of the auxiliary and control voltage and pressure for operation:

– The maximum difference between the instants of contacts touching in the individual poles during closing shall not exceed 1/4 of a cycle of rated frequency. If one pole consists of more than one making and breaking unit connected in series, the maximum difference between the instants of contacts touching within these series connected making and breaking units shall not exceed 1/6 of a cycle of rated frequency. Where closing resistors are used, the maximum difference between the instants of contacts touching during closing in the individual closing resistors shall not exceed 1/2 cycle of rated frequency. If on one pole more than one individual closing resistor is used, each assigned to one of the making and breaking units which are connected in series, the maximum difference between the instants of contacts touching within these series connected closing resistors shall not exceed 1/3 of a cycle of rated frequency;
– The maximum difference between the instants of contacts separating in the individual poles during opening shall not exceed 1/6 of a cycle of rated frequency. If one pole consists of more than one making and breaking unit connected in series, the maximum difference between the instants of contact separation within these series connected making and breaking units shall not exceed 1/8 of a cycle of rated frequency.

Circuit-breakers intended for controlled switching are covered by IEC TR 62271-302 [10].

NOTE For a circuit-breaker having separate poles, the requirement is applicable when these operate in the same conditions; after a single-pole reclosing operation, the conditions of operation for the three mechanisms is not the same.

### 6.102 General requirement for operation

A circuit-breaker, including its operating devices, shall be capable of completing its rated operating sequence 5.104 in accordance with the relevant provisions of 6.5 to 6.10 and 6.103 for the whole range of ambient temperatures within its minimum and maximum air temperature as defined in Clause 4 of IEC 62271-1:2017.

This requirement is not applicable to auxiliary manual operating devices; where provided, these shall be used only for maintenance and for emergency operation on a dead circuit.

Circuit-breakers provided with heaters shall be designed to permit an opening operation at the minimum ambient air temperature when the heaters are not operational for a minimum time of 2 h.

### 6.103 Pressure limits of fluids for operation

The manufacturer shall state the maximum and minimum pressures of the fluid for operation at which the circuit-breaker is capable of performing according to its ratings and at which the appropriate low- and high-pressure interlocking devices shall be set (see 6.10).

The manufacturer can specify pressure limits at which the circuit-breaker is capable of each of the following performances:

– an “O” operation;
– a “CO” operating cycle;

– for circuit-breakers intended for rapid auto-reclosing an "O – $t$ – CO" operating sequence.

The circuit-breakers shall be provided with energy storage of sufficient capacity for satisfactory performance of the appropriate operations at the corresponding minimum pressures stated.

### 6.104 Vent outlets

Vent outlets are devices which allow a deliberate release of pressure in a circuit-breaker during operation.

NOTE This is applicable to air, air-blast and oil circuit-breakers.

Vent outlets of circuit-breakers shall be so situated that a discharge of oil or gas or both will not cause electrical breakdown and is directed away from any location where persons can be present. The necessary safety distance shall be stated by the manufacturer.

The construction shall be such that gas cannot collect at any point where ignition can be caused, during or after operation, by sparks arising from normal operation of the circuit-breaker or its auxiliary equipment.

### 6.105 Time quantities

Refer to Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7.

Values can be assigned to the following time quantities:

– opening time (no-load);
– closing time (no-load);
– open-close time (no-load);
– reclosing time (no-load);
– close-open time (no-load);
– pre-insertion time (no-load).

Time quantities are based on

– rated supply voltages of closing and opening devices and of auxiliary and control circuits (see 5.9);
– rated supply frequency of closing and opening devices and of auxiliary circuits (see 5.10);
– filling pressure for controlled pressure systems (see 5.11);
– filling levels for insulation and/or operation (see 6.22);
– an ambient air temperature of 20 °C ± 5 °C.

NOTE 1 It is not practical to assign a value of make-time or of make-break time due to the variation of the arcing time and the pre-arcing time.

NOTE 2 The break-time is determined using the calculation method given in IEC TR 62271-306 [4].

### 6.106 Mechanical loads

#### 6.106.1 General

Circuit-breakers shall be designed to withstand static forces such as those from connected conductors, wind, etc. and dynamic forces (for example caused by short-circuit current and operation of the circuit-breaker).

These forces can occur simultaneously.

#### 6.106.2 Static mechanical loads

This capability is demonstrated by calculation.

When calculating the stresses resulting from ice and wind, the ice coating and wind pressure shall be in accordance with 4.1.3 of IEC 62271-1:2017.

Some examples of static forces due to wind, ice and weight on flexible and tubular connected conductors are given as a guidance in Table 3.

The tensile force due to the connected conductors is assumed to act at the outermost end of the circuit-breaker terminal.

**Table 3 – Examples of static horizontal and vertical forces for static terminal load**

| Rated voltage range | Rated current range | Static horizontal force $F_{th}$ | | Static vertical force |
|---|---|---|---|---|
| $U_r$<br>kV | $I_r$<br>A | Longitudinal $F_{thA}$<br>N | Transversal $F_{thB}$<br>N | $F_{tv}$<br>N |
| < 100 | 800 to 1 250 | 500 | 400 | 500 |
| < 100 | 1 600 to 2 500 | 750 | 500 | 750 |
| 100 to 170 | 1 250 to 2 000 | 1 000 | 750 | 750 |
| 100 to 170 | 2 500 to 4 000 | 1 250 | 750 | 1 000 |
| 245 to 362 | 1 600 to 4 000 | 1 250 | 1 000 | 1 250 |
| 420 to 800 | 2 000 to 4 000 | 1 750 | 1 250 | 1 500 |
| 1 100 to 1 200 | 4 000 to 6 300 | 3 500 | 3 000 | 2 500 |

#### 6.106.3 Dynamic loads

This capability is demonstrated by calculation.

NOTE A calculation method of the effects of short-circuit current on rigid and flexible conductors is given in IEC 60865-1:2011.

### 6.107 Circuit-breaker classification

#### 6.107.1 General

Circuit-breakers can be classified according to their application according to the following:

– classification for number of mechanical operations (mechanical endurance);
– classification related to the connection to the network;
– classification for capacitive currents;
– classification for electrical endurance.

#### 6.107.2 Classification for number of mechanical operations

The following classes are specified with respect to the number of mechanical operations of a circuit-breaker:

– Class M1 circuit-breaker

  A class M1 circuit-breaker shall perform the number of operations given in Table 4, following the programme of maintenance specified by the manufacturer and tested according to 7.101.2.3;

– Class M2 circuit-breaker

  A class M2 circuit-breaker shall perform the number of operations given in Table 4, following the programme of maintenance specified by the manufacturer and tested according to 7.101.2.4.

**Table 4 – Number of mechanical operations**

| | |
|---|---|
| Circuit-breaker class M1 | 2 000 operating cycles (see NOTE) |
| Circuit-breaker class M2 | 10 000 operating cycles (see NOTE) |
| NOTE For more details regarding the operating cycles, see Table 8. | |

#### 6.107.3 Classification related to the connection to the network

The following classes are specified related to the connection of a circuit-breaker to the network:

– Class S1 circuit-breaker

  Circuit-breaker having a rated voltage higher than 1 kV and less than 100 kV and where the total length of cable (including when present the equivalent length provided by the capacitance of capacitors and/or insulated bus) connected to the supply side of a circuit-breaker is at least 100 m.

  NOTE 1 Circuit-breakers of indoor substations with cable connection are generally of class S1.

– Class S2 circuit-breaker

  Circuit-breaker having a rated voltage higher than 1 kV and less than 100 kV without a cable connected on the supply side of the circuit-breaker or in which the total length of cable (including when present the equivalent length provided by the capacitance of capacitors and/or insulated bus) on the supply side of a circuit-breaker is less than 100 m.

  NOTE 2 Applications where a circuit-breaker is connected to an overhead line through a busbar (without intervening cable connections) are typical examples of class S2 circuit-breakers.

#### 6.107.4 Classification for capacitive currents

The following two classes are specified with respect to capacitive load switching:

– Class C1 circuit-breaker

  Circuit-breaker with low probability of restrike during capacitive current breaking as demonstrated by specific type tests described both in 7.111.9.2 and 7.111.9.3;

– Class C2 circuit-breaker

  Circuit-breaker with very low probability of restrike during capacitive current breaking as demonstrated by specific type tests described both in 7.111.9.2 and 7.111.9.4.

A circuit-breaker can be of class C2 for one kind of application and of class C1 for another kind of application where the recovery voltage stress is more severe.

#### 6.107.5 Classification for electrical endurance

The following classes are specified with respect to the electrical endurance capability of a circuit-breaker:

– Class E1 circuit-breaker

Circuit-breaker tested in accordance with 7.107.

– Class E2 circuit-breaker

Circuit-breaker having a rated voltage up to and including 52 kV designed so as not to require maintenance of the making and breaking units of the main circuit during its expected operating life.

Class E2 circuit-breakers not for auto-reclosing duty are tested in accordance to 7.112.1.

Class E2 circuit-breakers for auto-reclosing duty or rapid auto-reclosing duty, are tested in accordance to 7.112.2.

NOTE For circuit-breakers of rated voltages exceeding 52 kV guidance is given in IEC TR 62271-310 [6].

# 7 Type tests

## 7.1 General

### 7.1.1 Basics

Subclause 7.1.1 of 62271-1:2017 is applicable with the following additions:

The type tests for circuit-breakers are listed in Table 5.

Tolerances on test quantities are given in Annex B.

A new or refurbished circuit-breaker can be used for each of the tests specified in Table 5.

The responsibility of the manufacturer is limited to the declared values and not to those values achieved during the type tests.

The expanded uncertainty of a complete measuring system for determination of the ratings (for example short-circuit current, applied voltage and recovery voltage) shall be ≤ 5 %, evaluated with a coverage probability of 95 % corresponding to a coverage factor $k$ = 2 under the assumption of a normal distribution.

NOTE Procedures for the determination of the uncertainty of measurements are given in ISO/IEC Guide 98-3 [7].

If the circuit-breaker can be equipped with different operating mechanisms, complete type tests according to Table 5 shall be performed on circuit-breakers equipped with one type of operating mechanism. The other operating mechanisms are considered being alternative operating mechanisms as defined in 3.5.130, provided they fulfil the related requirements as defined in 7.102.7. Tests to be repeated for alternative mechanisms are defined in 7.1.102.

A change in the secondary equipment does not constitute an alternative operating mechanism. However, it shall be checked that changes in the opening time/minimum clearing time does not entail different requirements for test-duty T100a (see 7.104.2.2).

**Table 5 – Type tests**

| Mandatory type tests [a] | Subclauses |
|---|---|
| Dielectric tests | 7.2 |
| Resistance measurement | 7.4 |
| Continuous current tests | 7.5 |
| Short-time withstand current and peak withstand current tests | 7.6 |
| Additional tests on auxiliary and control circuits | 7.10 |
| Mechanical operation test at ambient temperature (class M1) | 7.101.2.1 to 7.101.2.3 |
| Terminal fault tests | 7.102 to 7.107 |

| Type tests depending on requirements | Condition requiring type test | Subclauses |
|---|---|---|
| Radio interference voltage (RIV) tests | $U_r$ ≥ 245 kV | 7.3 |
| Verification of the protection | Assigned IP and IK class | 7.7 |
| Tightness test | Controlled, sealed or closed pressure systems | 7.8 |
| EMC tests | Electronic equipment or components are included in the secondary system | 7.9 |
| X-ray radiation test | Vacuum circuit-breaker | 7.11 |
| Extended mechanical endurance tests on circuit-breakers for special service conditions | Class M2 rating assigned | 7.101.2.4 |
| Low and high temperature tests | If ambient air temperature is different from -5 °C and/or +40 °C | 7.101.3 |
| Humidity test | Insulation subject to voltage stress and condensation | 7.101.4 |
| Critical current tests | Circuit-breaker performance against conditions in 7.108.1 | 7.108.1 |
| Short-line fault tests | $U_r$ ≥ 15 kV and $I_{sc}$ > 12,5 kA, in case of direct connection to overhead lines | 7.109 |
| Out-of-phase making and breaking tests | Out-of-phase rating assigned | 7.110 |
| Electrical endurance tests (only for $U_r$ ≤ 52 kV) | Class E2 rating assigned | 7.112 |
| Test to prove operation under severe ice conditions | Outdoor circuit-breakers with moving external parts | 7.101.5 |
| Single-phase fault test | Effectively earthed neutral systems | 7.108.2 |
| Double-earth fault test | Non-effectively earthed neutral systems | |
| Capacitive current tests:<br>– line-charging current breaking tests<br>– cable-charging current breaking tests<br>– single capacitor bank making and breaking tests<br>– back-to-back capacitor bank making and breaking tests | Relevant rating and classification (C1 or C2) assigned | 7.111 |

[a] Mandatory type tests, shown in the upper part of the table, are required for all circuit-breakers regardless of rated voltage, design or intended use. Other type tests, shown in the lower part of the table, are required for all circuit-breakers where the associated rating is specified, for example out-of-phase making and breaking, or where a specific condition is met, for example RIV is required only for rated voltages of 245 kV and above.

### 7.1.2 Information for identification of test objects

Subclause 7.1.2 of IEC 62271-1:2017 is applicable.

### 7.1.3 Information to be included in type-test reports

Subclause 7.1.3 of IEC 62271-1:2017 is applicable with the following addition:

Further details relating to records and reports of type tests for making, breaking and short-time current performance are given in Annex C.

#### 7.1.101 Invalid tests

In the case of an invalid test, it may become necessary to perform a greater number of tests than required by this document. An invalid test is one where one or more of the test parameters demanded by the standard is not met. This includes, for example in the case of making and breaking tests, current, voltage and time factors as well as point-on-wave requirements (if specified).

The deviation from the standard could make the test less or more severe. Table 6 considers some cases.

The invalid part of the test-duty can be repeated without reconditioning of the circuit-breaker. However, in the case of a failure of the circuit-breaker during such additional tests, or at the discretion of the manufacturer, the circuit-breaker can be reconditioned and the complete test-duty repeated. In the case where the circuit-breaker has not been reconditioned, the test report shall include reference to the invalid part of the test.

In a rapid auto-reclosing duty cycle, the O – $t$ – CO is regarded as one part, and an ensuing CO is regarded as another part.

A class E2 circuit-breaker can be reconditioned during class E2 tests, but in this event the entire test series (see 7.112) shall be repeated.

If any record of an individual operation cannot be produced for technical reasons, this individual operation is not considered invalid, provided that evidence can be given in another manner that the circuit-breaker did not fail and the required testing values were fulfilled.

**Table 6 – Invalid tests**

| Test conditions related to standard | Circuit-breaker | |
|---|---|---|
| | Passes | Fails |
| More severe | Test valid, result accepted | Test to be repeated with correct parameters |
| Less severe | Test to be repeated with correct parameters | Circuit-breaker failed the test. |

#### 7.1.102 Type tests to repeat for circuit-breakers with alternative operating mechanisms

The following type tests shall be repeated on circuit-breakers with alternative operating mechanisms:

- mechanical operation tests at ambient temperature (according to 7.101.2);
- low and high temperature tests (according to 7.101.3);
- short-circuit making and breaking tests (as defined in 7.102.7);
- short-time withstand current and peak withstand current tests on circuit-breakers having main contacts of the butt type (according to 7.6).

### 7.2 Dielectric tests

#### 7.2.1 General

Subclause 7.2.1 of IEC 62271-1:2017 is applicable.

#### 7.2.2 Ambient air conditions during tests

Subclause 7.2.2 of IEC 62271-1:2017 is applicable.

#### 7.2.3 Wet test procedure

Subclause 7.2.3 of IEC 62271-1:2017 is applicable with the following addition:

In the case of dead tank circuit-breakers, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

#### 7.2.4 Arrangement of the equipment

Subclause 7.2.4 of IEC 62271-1:2017 is applicable.

#### 7.2.5 Criteria to pass the test

Subclause 7.2.5 of IEC 62271-1:2017 is applicable with the following addition:

If disruptive discharges occur and evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, the circuit-breaker shall be dismantled and inspected after the completion of the dielectric test series. If damage (for example tracking, puncture, etc.) to non-self-restoring insulation is observed, the circuit-breaker has failed the test.

For metal-enclosed circuit-breakers tested with test bushings that are not part of the circuit-breaker, disruptive discharges across the test bushings can be disregarded.

#### 7.2.6 Application of test voltage and test conditions

Subclause 7.2.6 of IEC 62271-1:2017 is applicable.

#### 7.2.7 Tests of switchgear and controlgear of $U_r \leq 245$ kV

##### 7.2.7.1 General

Subclause 7.2.7.1 of IEC 62271-1:2017 is applicable.

##### 7.2.7.2 Power-frequency voltage tests

Subclause 7.2.7.2 of IEC 62271-1:2017 is applicable with the following addition:

In the case of dead tank circuit-breakers, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

##### 7.2.7.3 Lightning impulse voltage test

Subclause 7.2.7.3 of IEC 62271-1:2017 is applicable.

#### 7.2.8 Tests of switchgear and controlgear of $U_r > 245$ kV

##### 7.2.8.1 General

Subclause 7.2.8.1 of IEC 62271-1:2017 is applicable.

#### 7.2.8.2 Power-frequency voltage tests

Subclause 7.2.8.2 of IEC 62271-1:2017 is applicable.

#### 7.2.8.3 Switching impulse voltage tests

Subclause 7.2.8.3 of IEC 62271-1:2017 is applicable with the following addition:

For outdoor circuit-breakers dry tests shall be performed using voltage of positive polarity only. With the circuit-breaker closed, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table 10 of IEC 62271-1:2017.

With the circuit-breaker open, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table 10 of IEC 62271-1:2017.

A second test series, with the test voltages according to column (6) of Tables 3 and 4 of IEC 62271-1:2017, shall be performed for circuit-breakers intended for special applications as stated in 9.102.2. For each test condition of Table 12 of IEC 62271-1:2017, one terminal shall be energised with switching impulse voltage and the opposite terminal with power-frequency voltage.

Subject to the manufacturer's approval, the test with the circuit-breaker open can be performed avoiding the use of the power-frequency voltage source. This test series consists of the application, to each terminal in turn, of impulses at a voltage equal to the sum of the switching impulse voltage and the peak value stated in column (6) of Tables 3 and 4 in IEC 62271-1:2017, the opposite terminal being earthed.

Item b) of 7.2.6.3 of IEC 62271-1:2017 can be used. In general, this test is more severe than that following the specified test procedure.

#### 7.2.8.4 Lightning impulse voltage tests

Subclause 7.2.8.4 of IEC 62271-1:2017 is applicable with the following addition:

With the circuit-breaker closed, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table 10 of IEC 62271-1:2017.

With the circuit-breaker open, the test voltage equal to the rated withstand voltage across the open switching device shall be applied for each test condition of Table 12 of IEC 62271-1:2017.

Subject to the manufacturer's approval, the test with the circuit-breaker open can be performed avoiding the use of the power-frequency voltage source. This test series applies to each terminal in turn (or on one terminal if the arrangement of the terminals is symmetrical with respect to the base), 15 consecutive impulses at a voltage equal to the sum of the rated lightning impulse withstand voltage and the peak value stated in column (8) of Tables 3 and column (7) of IEC 62271-1:2017, the opposite terminal being earthed. Item a) and item b) of 7.2.6.3 of IEC 62271-1:2017 can be used. In general, this test is more severe than that following the specified test procedure.

#### 7.2.9 Artificial pollution tests for outdoor insulators

Subclause 7.2.9 of IEC 62271-1:2017 is applicable.

### 7.2.10 Partial discharge tests

Subclause 7.2.10 of IEC 62271-1:2017 is applicable with the following addition:

Normally it is not required to perform partial discharge tests on a complete circuit-breaker. However, in case of dead-tank and GIS circuit-breakers using components for which a relevant IEC standard exists that requires partial discharge measurements (for example, bushings, see IEC 60137 [8]), evidence shall be provided by the manufacturer showing that those components have passed the partial discharge tests as required by the relevant IEC standard.

### 7.2.11 Dielectric tests on auxiliary and control circuits

Subclause 7.2.11 of IEC 62271-1:2017 is applicable.

### 7.2.12 Voltage test as a condition check

Subclause 7.2.12 of IEC 62271-1:2017 is replaced by the following.

#### 7.2.12.101 Condition after mechanical or environmental test

Where after mechanical or environmental tests (see 7.101.1.4) the insulating properties across open contacts of a circuit-breaker cannot be verified by visual inspection with sufficient reliability, a voltage test as condition check in dry condition across the open circuit-breaker according to 7.2.12 of IEC 62271-1:2017 or 7.2.12.103 of this document shall be applied. For metal-enclosed circuit-breakers test conditions refer to Table 7. For multi-unit live tank circuit-breakers with identical units according to 7.102.4.2.3 the voltage test as a condition check may be performed as unit test.

#### 7.2.12.102 Condition check after making and breaking test

Where after making and breaking tests (see 7.102.9) a voltage test as a condition check is performed (see 7.2.12.103), the following conditions shall apply:

For circuit-breakers with an asymmetrical current path, the connections shall be reversed. The complete tests shall be carried out once for each arrangement of the connections. For metal-enclosed circuit-breakers having a symmetrical current path, a test to earth is required with the circuit-breaker in closed position. When a test to earth is required, the rated insulation voltages across open contacts and to earth may be different. For such cases, each of the rated values corresponding to the test condition shall be used as the reference value for the determination of the test voltage. These requirements are summarised in Table 7.

**Table 7 – Test requirements for voltage tests as condition check for metal-enclosed circuit-breakers**

| No. of series connected making and breaking units | Arrangement of the current path | Circuit-breaker position | | |
|---|---|---|---|---|
| | | Open (one side) | Open (other side) | Closed |
| Single | Symmetrical | Y | N | Y |
| | Asymmetrical | Y | Y | N |
| Multi | Symmetrical | Y | N | Y |
| | Asymmetrical | Y | Y | Y |
| Y: necessary to apply voltage.<br>N: not necessary to apply voltage. | | | | |

If making and breaking units are placed in an insulating fluid with different characteristics and other than air at atmospheric pressure, that also might withstand the test voltages when replacing the original arc extinguishing medium (for example a vacuum interrupter in an enclosure filled with $SF_6$), the condition checking test may not be adequate to verify the integrity of the vacuum interrupter. In such cases the integrity of the device shall be demonstrated by the following.

An additional short-circuit breaking test shall be performed using a circuit that supplies at least 10 % of the rated short-circuit breaking current and at least 50 % of the rated voltage. If more than one test-duty is carried out without reconditioning this additional test shall be made before or after the no-load tests subsequent to the short-circuit test-duties as follows:

– if a three-phase test is performed in a circuit with effectively or solidly earthed neutral, one opening operation shall be performed with both the source side neutral and the short-circuit point earthed;

– if a three-phase test is performed in a circuit with non-effectively earthed neutral, three opening operations shall be performed. The first-pole-to-clear conditions shall be demonstrated for each pole of the circuit-breaker;

– if a single-phase test is performed, one opening shall be performed. The test shall be repeated on each pole.

A successful breaking in each pole is evidence that the integrity of the making and breaking unit(s) is maintained.

The additional short-circuit breaking test is not required on the poles in which the final test was a successful single-phase breaking.

If the type test is completed with a successful three-phase breaking in a circuit with effectively earthed neutral no additional short-circuit test as condition check is required.



#### 7.2.12.103 Test voltage for the condition check tests

The following test voltages shall be applied:

– Circuit-breakers with $U_r \leq 72{,}5$ kV

A 1 min power-frequency voltage test shall be performed. The test voltage shall be 80 % of the value in column (2) of Tables 1 or 2 of IEC 62271-1:2017.

– Circuit-breakers with 72,5 kV < $U_r \leq 245$ kV

An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 60 % of the highest relevant value in column (4) of Tables 1 or 2 of IEC 62271-1:2017.

– Circuit-breakers with 300 kV ≤ $U_r$ ≤ 420 kV

  An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 80 % of the rated switching impulse withstand voltage given in Tables 3 or 4 of IEC 62271-1:2017, except in the case of GIS circuit-breakers (i.e. circuit-breakers in Gas Insulated Switchgear (GIS)) the crest value of the impulse voltage shall be 80 % of the rated switching impulse withstand voltage given in IEC 62271-203.

– Circuit-breakers with 550 kV ≤ $U_r$ ≤ 800 kV

  An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in Tables 3 or 4 of IEC 62271-1:2017, except in the case of GIS circuit-breakers the crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in IEC 62271-203.

– Circuit-breakers with $U_r$ > 800 kV

  An impulse voltage test shall be performed. The crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage given in Table 3 of IEC 62271-1:2017, except in the case of GIS circuit-breakers the crest value of the impulse voltage shall be 90 % of the rated switching impulse withstand voltage. Examples of rated switching impulse withstand voltage values for GIS equipment are given in IEC 62271-203.

Where an impulse voltage test shall be carried out, the waveshape of the impulse voltage shall be either a standard switching impulse or a waveshape according to the TRV specified for terminal fault test-duty T10. Five impulses of each polarity shall be applied. The circuit-breaker shall be considered to have passed the test if no disruptive discharge occurs. In the case that a T10 waveshape is used, timing tolerances on the TRV waveshape of -10 % and +200 % on time $t_3$ are permitted. If the tests are performed using the TRV impulse with a T10 waveshape, equivalence is maintained to the standard switching impulse if the following rules are applied:

– the damping of the TRV should be such that the second peak of the TRV oscillation is not higher than 80 % of the first one;

– the voltage should be in the range of 50 % of its peak value 2,5 ms after time to peak.

NOTE Comparative tests have shown that there are almost no differences in the behaviour of the circuit-breakers, both in new and in worn conditions, when testing is performed with standard switching impulses or with TRV impulses with a waveshape in accordance with terminal fault T10, respectively.

### 7.3 Radio interference voltage (RIV) test

Subclause 7.3 of IEC 62271-1:2017 is applicable with the following addition:

Tests can be performed on one pole of the circuit-breaker in both closed and open position. During the tests the circuit-breaker shall be equipped with all accessories such as grading capacitors, corona rings, HV connectors, etc., which can influence the radio interference voltage performance.

### 7.4 Resistance measurement

Subclauses 7.4.1 to 7.4.3 of IEC 62271-1:2017 are applicable.

Subclause 7.4.4 is replaced by the following.

#### 7.4.4 Resistance measurements of contacts and connections in the main circuit as a condition check

##### 7.4.4.1 Resistance measurement test procedure

Subclause 7.4.4.1 of IEC 62271-1:2017 is applicable with the following modifications.

The resistance across the circuit-breaker contacts shall be measured before the test. The measuring test points shall be the nearest accessible points to and on either side of the contacts in question. An average value of the resistance shall be calculated based on three measurements. If possible, one no-load open and close operation cycle should be made between each of the measurements. If no-load operations cannot be made, the 3 measurements shall be made without no-load operations of the circuit-breaker.

It is recognised that for some tests, it is not practical (for example if gas handling is required between the measurements) nor possible (for example during a continuous current test because of the presence of temperature sensors within the breaking chamber(s)) to make any no-load operations between each of the three resistance measurements.

#### 7.4.4.2 Making and breaking tests

Subclause 7.4.4.2 of IEC 62271-1:2017 is applicable with the following addition:

For circuit-breaker types other than sealed-for-life visual inspection of the contact system is usually sufficient as stated in 7.102.9.2.

#### 7.4.4.3 Other tests

Subclause 7.4.4.3 of IEC 62271-1:2017 is replaced by 7.101.1.4.

### 7.5 Continuous current tests

#### 7.5.1 Condition of the test object

Subclause 7.5.1 of IEC 62271-1:2017 is applicable.

#### 7.5.2 Arrangement of the equipment

Subclause 7.5.2 of IEC 62271-1:2017 is applicable with the following addition:

For a circuit-breaker not fitted with series connected accessories, the test shall be made with the rated continuous current of the circuit-breaker.

For a circuit-breaker fitted with series connected accessories having a range of rated continuous currents, the following tests shall be made:

a) a test of the circuit-breaker fitted with the series connected accessories having a rated continuous current equal to that of the circuit-breaker, and made at the rated continuous current of the circuit-breaker;
b) a series of tests of the circuit-breaker fitted with the intended accessories made with currents equal to the rated continuous current of each accessory.

If the accessories can be removed from the circuit-breaker, and if it is evident that the temperature rise of the circuit-breaker and of the accessories do not appreciably influence each other, test b) above can be replaced by a series of tests on the accessories alone.

#### 7.5.3 Test current and duration

Subclause 7.5.3 of IEC 62271-1:2017 is applicable.

#### 7.5.4 Temperature measurement during the test

Subclause 7.5.4 of IEC 62271-1:2017 is applicable.

#### 7.5.5 Resistance of the main circuit

Subclause 7.5.5 of IEC 62271-1:2017 does not apply. The resistance of the main circuit shall be measured using the procedure given in 7.4.4.

#### 7.5.6 Criteria to pass the test

Subclause 7.5.6 of IEC 62271-1:2017 is applicable.

### 7.6 Short-time withstand current and peak withstand current tests

#### 7.6.1 General

Subclause 7.6.1 of IEC 62271-1:2017 is applicable.

#### 7.6.2 Arrangement of the equipment and of the test circuit

Subclause 7.6.2 of IEC 62271-1:2017 is applicable with the following addition:

The use of making and breaking and/or insulating fluid is not mandatory for short-time withstand current and peak withstand current tests. Air or $N_2$ may be used as an alternative to gases with high global warming potential. There is also no requirement for minimum pressure for insulation and/or making and breaking.

#### 7.6.3 Test current and duration

Subclause 7.6.3 of IEC 62271-1:2017 is applicable.

#### 7.6.4 Conditions of the test object after test

Subclause 7.6.4 of IEC 62271-1:2017 is applicable with the exception of b) and the following addition.

After the tests of self-tripping circuit-breakers, the conditions of the circuit-breaker shall comply with 7.102.9, and it shall be demonstrated that the overcurrent release is still in order to operate correctly. A primary injection test at 110 % of the minimum tripping current and in the conditions (single-phase or three-phase), as declared by the manufacturer, is a satisfactory demonstration.

### 7.7 Verification of the protection

#### 7.7.1 Verification of the IP coding

Subclause 7.7.1 of IEC 62271-1:2017 is applicable.

#### 7.7.2 Verification of the IK coding

Subclause 7.7.2 of IEC 62271-1:2017 is applicable.

### 7.8 Tightness tests

Subclause 7.8 of IEC 62271-1:2017 is applicable.

### 7.9 Electromagnetic compatibility tests (EMC)

Subclause 7.9 of IEC 62271-1:2017 is applicable with the following addition.

#### 7.9.3.2 Ripple on DC input power port immunity test

Subclause 7.9.3.2 of IEC 62271-1:2017 is applicable with the following addition:

If no electronic components are used in the control unit and the mechanical operation test at ambient air temperature in accordance with 7.101.2 is performed on the complete circuit-breaker equipped with its entire control unit, the ripple on DC input power port immunity test according to 7.9.3.2 of IEC 62271-1:2017 is regarded as covered and additional tests shall be omitted. When testing of the complete circuit-breaker is not practicable, component tests in accordance with 7.101.1.2 are acceptable.

Where electronic components are used, tests according to 7.9.3.2 of IEC 62271-1:2017 on the individual components are sufficient.

NOTE This subclause is applicable to both, complete electronic boards (for example control modules) and devices containing at least one electronic component.

## 7.10 Additional tests on auxiliary and control circuits

### 7.10.1 General

Subclause 7.10.1 of IEC 62271-1:2017 is applicable.

### 7.10.2 Functional tests

Subclause 7.10.2 of IEC 62271-1:2017 is applicable with the following addition:

If the mechanical operation test at ambient air temperature in accordance with 7.101.2 is performed on the complete circuit-breaker equipped with its entire control unit, the functional tests according to 7.10.2 of IEC 62271-1:2017 are regarded as covered and additional tests shall be omitted. When testing of the complete circuit-breaker is not practicable, component tests in accordance with 7.101.1.2 are acceptable.

### 7.10.3 Verification of the operational characteristics of the auxiliary contacts

Subclause 7.10.3 of IEC 62271-1:2017 is applicable.

### 7.10.4 Environmental tests

Subclause 7.10.4 of IEC 62271-1:2017 is applicable with the following addition:

If the mechanical operation test at ambient air temperature in accordance with 7.101.2, the low and high temperature tests in accordance with 7.101.3 and, if applicable, the humidity test in accordance with 7.101.4 are performed on the complete circuit-breaker equipped with its entire control unit or in case of the humidity test on the control equipment respectively, the environmental tests according to 7.10.4 of IEC 62271-1:2017 are regarded as covered and additional tests can be omitted. When testing of the complete circuit-breaker is not practicable, component tests in accordance with 7.101.1.2 are acceptable.

Seismic tests are not covered. If a seismic test is requested, it should be performed in accordance with IEC TR 62271-300 [9] by agreement between manufacturer and user.

### 7.10.5 Dielectric test

Subclause 7.10.5 of IEC 62271-1:2017 is applicable with the following addition:

The dielectric test shall be performed on the auxiliary and control circuits in new condition.

### 7.11 X-radiation test procedure for vacuum interrupters

Subclause 7.11 of IEC 62271-1:2017 is applicable.

### 7.101 Mechanical and environmental tests

#### 7.101.1 Miscellaneous provisions for mechanical and environmental tests

##### 7.101.1.1 Mechanical characteristics

At the beginning of the type tests, the mechanical characteristics of the circuit-breaker shall be established. IEC TR 62271-306 [4] gives examples on how to measure the mechanical characteristics. The mechanical characteristics will serve as the reference for the purpose of characterising the mechanical behaviour of the circuit-breaker. Furthermore, the mechanical characteristics shall be used to confirm that the different test samples used during the mechanical, making and breaking type tests behave mechanically in a similar way. The reference mechanical characteristics are also used to confirm that production units behave mechanically in a similar way compared to the test samples used during type tests.

Following are examples of operating characteristics that can be recorded:

– no-load travel curves;
– closing and opening times.

The mechanical characteristics shall be produced during a no-load test made with a single O operation and a single C operation at rated supply voltage of operating devices and of auxiliary and control circuits, filling pressure for operation and, for convenience of testing, at the minimum functional pressure for making and breaking.

Annex G gives requirements and explanation on the use of mechanical characteristics.

##### 7.101.1.2 Component tests

When testing of a complete circuit-breaker is not practicable, component tests can be accepted as type tests. The manufacturer should determine the components which are suitable for testing.

Components are separate functional sub-assemblies which can be operated independently of the complete circuit-breaker (for example, pole, breaking unit, operating mechanism).

When component tests are made, the manufacturer shall prove that the mechanical and environmental stresses on the component during the tests are not less than those applied to the same component when the complete circuit-breaker is tested. Component tests shall cover all different types of components of the complete circuit-breaker, provided that the particular test is applicable to the component. The conditions for the component type tests shall be the same as those which could be employed for the complete circuit-breaker.

Parts of auxiliary and control equipment which have been manufactured in accordance with relevant standards shall comply with these standards. The proper function of such parts in connection with the function of the other parts of the circuit-breaker shall be verified.

##### 7.101.1.3 Characteristics and settings of the circuit-breaker to be recorded before and after the tests

Before and after the tests, the following operating characteristics or settings shall be recorded and evaluated:

a) closing time;
b) opening time;

c) time spread between making and breaking units of one pole;
d) time spread between poles (if multi-pole tested);
e) recharging time and consumption of the operating device;
f) consumption of the control circuit, if applicable;
g) consumption of the auxiliary circuit;
h) duration of opening and closing command;
i) tightness, if applicable;
j) gas densities or pressures, if applicable;
k) resistance of the main circuit;
l) mechanical travel, if applicable;
m) other important characteristics or settings as specified by the manufacturer.

The above operating characteristics shall be recorded for the conditions below (if applicable) at:

– rated supply voltage and filling pressure for operation;
– maximum supply voltage and filling pressure for operation;
– maximum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and filling pressure for operation.

**7.101.1.4 Condition of the circuit-breaker during and after the tests**

During and after the tests, the circuit-breaker shall be in such a condition that it is capable of operating normally, carrying its rated continuous current, making and breaking its rated short-circuit current and withstanding the voltage values according to its rated insulation level.

In general, these requirements are fulfilled if

– during the tests, the circuit-breaker operates on command and does not operate without command;
– after the tests, the characteristics measured according to 7.101.1.3 are within the tolerances given by the manufacturer before the tests;
– after the tests, coated contacts are such that a layer of coating material remains at the contact area. If this is not the case, the contacts shall be regarded as bare and the test requirements are fulfilled only if the temperature rise of the contacts during the continuous current test (according to 7.5) does not exceed the value permitted for bare contacts;
– during and after the tests, it shall be possible to fit any defined replacement part according to the manufacturer's instructions;
– after the tests the insulating properties of the circuit-breaker in the open position shall be in essentially the same condition as before the tests. Visual inspection of the circuit-breaker after the tests is usually sufficient for verification of the insulating properties. In the case of sealed-for-life circuit-breakers a voltage test as a condition check in accordance with 7.2.12 replaces this visual inspection;
– for sealed-for-life circuit-breakers, the increase of the resistance of the main circuit shall be less than or equal to 20 %. If the increase in resistance exceeds 20 % then a continuous current test according to 7.5 is applicable to determine if the test object can carry its rated continuous current without exceeding the temperature limits given in Table 14 of IEC 62271-1:2017 by more than 10 K;
– for other circuit-breaker types, the resistance condition check of the test object is satisfactory if the resistance increase for each phase determined in 7.4.4.1 is not greater

than 20 % and that the visual inspection of the contact system does confirm that the contact system complies with the requirements stated in 7.102.9.4. If the resistance increase exceeds 20 % then also a visual inspection shall be performed in order to see if the contact system is complying with the requirements stated in 7.102.9.4.

#### 7.101.1.5 Condition of the auxiliary and control equipment during and after the tests

During and after the tests, the following conditions for the auxiliary and control equipment shall be fulfilled:

– during the tests, care should be taken to prevent undue heating;

– during the tests, a set of contacts (both make and break auxiliary contacts) shall be arranged to switch the current of the circuits to be controlled (see 6.4);

– during and after the tests, the auxiliary and control equipment shall fulfil its functions;

– during and after the tests, insulation capability of the auxiliary circuits, of the auxiliary switches and of the control equipment shall not be impaired. In case of doubt, the dielectric tests according to 7.10.5 of IEC 62271-1:2017 shall be performed;

– during and after the tests, the contact resistance of the auxiliary switches shall not be affected adversely.

### 7.101.2 Mechanical operation test at ambient air temperature

#### 7.101.2.1 General

The mechanical operation test shall be made at the ambient air temperature of the test location. The ambient air temperature shall be recorded in the test report. Auxiliary equipment forming part of the operating devices shall be included.

The mechanical operation test shall consist of 2 000 operating cycles in accordance with 7.101.2.3 for class M1 circuit-breakers and 10 000 operating cycles in accordance with 7.101.2.4 for class M2 circuit-breakers.

Except for circuit-breakers fitted with direct overcurrent releases the test shall be made without voltage on or current in the main circuit.

For circuit-breakers fitted with overcurrent releases, approximately 10 % of the operating cycles shall be performed with the opening device energised by the current in the main circuit. The current shall be the minimum current necessary to operate the overcurrent release. For these tests, the current through overcurrent releases can be supplied from a suitable low-voltage source.

A circuit-breaker design can be fitted with several variants of auxiliary equipment (shunt releases and motors) in order to accommodate the various rated control voltages and frequencies as stated in 5.9 and 5.10. No additional tests are required if the variants are of similar designs and if the resulting no-load mechanical characteristics are within the tolerance given in Annex G.

#### 7.101.2.2 Condition of the circuit-breaker before the test

The circuit-breaker for test shall be mounted on its own support and its operating mechanism shall be operated in the specified manner. It shall be tested according to its type as follows:

A multipole circuit-breaker actuated by a single operating device and/or with all poles mounted on a common frame shall be tested as a complete unit.

Tests shall be conducted at the filling pressure for making and breaking.

A multipole circuit-breaker in which each pole or even each column is actuated by a separate operating device should be tested preferably as a complete multipole circuit-breaker. However, for convenience, or owing to limitations of the dimensions of the test bay, one single-pole unit of the circuit-breaker can be tested, provided that it is equivalent to, or not in a more favourable condition than, the complete multipole circuit-breaker over the range of tests, for example in respect of

– reference mechanical travel characteristics;
– power and strength of closing and opening mechanism;
– rigidity of structure.

#### 7.101.2.3 Operating sequence for class M1 circuit-breakers

The circuit-breaker shall be tested in accordance with Table 8.

**Table 8 – Number of operating sequences**

| Operating sequence | Supply voltage and operating pressure | Number of operating sequences | |
|---|---|---|---|
| | | Circuit-breakers for auto-reclosing | Circuit-breakers not for auto-reclosing |
| $C - t_a - O - t_a$ | Minimum | 500 | 500 |
| | Rated | 500 | 500 |
| | Maximum | 500 | 500 |
| $O - t - CO - t_a - C - t_a$ | Rated | 250 | – |
| $CO - t_a$ | Rated | – | 500 |

– O = opening;
– C = closing;
– CO = close-open operating cycle with the shortest possible close-open time such that the circuit-breaker reaches the fully closed and latched position prior to opening;
– $t_a$ = time between two operations which is necessary to restore the initial conditions and/or to prevent undue heating of parts of the circuit-breaker (this time can be different according to the type of operation);
– $t$ = 0,3 s for circuit-breakers for rapid auto-reclosing;
– $t$ = 3 min for circuit-breakers for auto-reclosing. For testing purposes shorter times for $t$ can also be used.

During the test, lubrication of parts outside of the main circuit is allowed in accordance with the manufacturer's instructions, but no mechanical adjustment or other kind of maintenance is allowed.

#### 7.101.2.4 Operating sequence for class M2 circuit-breakers

The tests shall be made according to 7.101.1, 7.101.2.1, 7.101.2.2 and 7.101.2.3 with the following addition:

– the tests shall consist of 10 000 operating cycles performing five times the relevant test programme specified in Table 8;
– between each series of 2 000 operating cycles specified, some maintenance, such as lubrication and mechanical adjustment, is allowed, and shall be performed in accordance with the manufacturer’s instructions. Only change of parts outside of the main circuit and not being part of the power kinematic chain, that are listed in the program of maintenance, is permitted;
– during a test series of 2 000 operating cycles, lubrication of parts outside of the main circuit is allowed in accordance with the manufacturer's instructions, but no mechanical adjustment or other kind of maintenance is allowed.

#### 7.101.2.5 Acceptance criteria for the mechanical operation tests

The criteria given below apply for mechanical operation tests on class M1 and class M2 circuit-breakers.

a) Before and after the total test programme, the following operations shall be performed:
   - five close-open operating cycles at the rated supply voltage of closing and opening devices and of auxiliary and control circuits and/or the filling pressure for operation;
   - five close-open operating cycles at the minimum supply voltage of closing and opening devices and of auxiliary and control circuits and/or the minimum pressure for operation;
   - five close-open operating cycles at the maximum supply voltage of closing and opening devices and of auxiliary and control circuits and/or the maximum pressure for operation.

   During these operating cycles, the operating characteristics (see 7.101.1.3) shall be recorded. It is not necessary to publish all the oscillograms recorded. However, at least one oscillogram for each set of conditions given above shall be included in the test report.

   In addition, the following checks and measurements shall be performed:

   - measurements of characteristic operating fluid pressures and consumption during operations, if applicable;
   - verification of the rated operating sequence;
   - checks of certain specific operations, if applicable.

   The variation between the mean values of each parameter measured before and after the extended mechanical endurance tests shall be within the tolerances given by the manufacturer.

b) After each series of 2 000 operating sequences, the operating characteristics a), b), c), d), e) and l) in 7.101.1.3 shall be recorded.

c) After the total test programme the condition of the circuit-breaker shall be in accordance with 7.101.1.4.

### 7.101.3 Low and high temperature tests

#### 7.101.3.1 General requirements

If the minimum ambient air temperature of indoor and outdoor circuit breakers is higher than or equal to -5 °C, no low temperature test is required. If the maximum ambient air temperature is not higher than +40 °C, no high temperature test is required.

The tests may be combined. If a combined sequence is chosen, a failure after either item k) of 7.101.3.4 or u) of 7.101.3.5 will constitute a failure of both tests.

For single enclosure circuit-breakers or multi-enclosure circuit-breakers with a common operating device, three-pole tests shall be made. For multi-enclosure circuit-breakers with independent poles, the testing of one complete pole is permitted.

Multi-enclosure type circuit-breakers can be tested using one or more of the following alternatives provided that the circuit-breaker in its testing arrangement is not in a more favourable condition than normal condition for mechanical operation (see 7.101.2.2):

a) reduced length of phase-to-earth insulation;
b) reduced pole spacing;
c) reduced number of making and breaking units.

If heat sources are required, they shall be in operation.

Liquid or gas supplies for circuit-breaker operation are to be at the test air temperature unless the circuit-breaker design requires a heat source for these supplies.

No maintenance, replacement of parts, lubrication or readjustment of the circuit-breaker is permissible during the tests.

The circuit-breaker has passed the test if the conditions stated in 7.101.1.4 and 7.101.1.5 are fulfilled. Furthermore, the conditions in 7.101.3.4 and 7.101.3.5 shall be fulfilled and the leakage rates recorded shall not exceed the limits given in Table 15 of IEC 62271-1:2017. In the test report the testing conditions and the condition of the circuit-breaker before, during and after the test shall be reported. The recorded quantities shall be presented. To reduce the number of oscillograms in the test report, a single representative oscillogram of every relevant type of operation under each specified testing condition shall be included.

A circuit-breaker design can be fitted with several variants of auxiliary equipment (shunt releases and motors) in order to accommodate the various rated control voltages and frequencies as stated in 5.9 and 5.10. No additional tests are required if the variants are of similar designs and if the resulting no-load mechanical characteristics are within the tolerance given in 7.101.1.1.

The conditions during and after the tests are given in 7.101.1.4.

#### 7.101.3.2 Additional requirements for metal-enclosed outdoor circuit-breakers

For circuit-breakers equipped with tank heater(s) for the purpose of avoiding gas liquefaction during low ambient temperature conditions, the test sequence required in 7.101.3.4 is not sufficient to demonstrate that the gas heating element is properly designed to avoid gas liquefaction during low ambient temperature conditions. For such circuit-breakers, the test sequence required in 7.101.3.4 shall be performed with a simulation of an average wind speed of 10 km/h (±20 %) applied perpendicularly to the longitudinal axis of an outer phase of the circuit-breaker. The wind shall be applied from step c) to j) of the test procedure described in 7.101.3.4.

The wind speed shall be measured by at least 5 positions along the longitudinal axis of the circuit-breaker and at a distance of 0,5 m (±0,1 m) to the outer circuit-breaker tank (see Figure 10). Each measurement shall be spaced by approximately 0,3 m. The number of measurements shall be such that the measurement length exceeds the circuit-breaker length by at least 0,5 m on each end. The wind speed for each of the individual measurements shall not deviate from the average wind value by more than ±50 %.

It is recognised that the wind speed measurements in relatively small climatic room (in relation to the circuit-breaker dimensions) can be difficult and that wind turbulences from the neighbouring test cell walls cannot be avoided. In such cases, greater deviations than required above can be accepted in agreement between manufacturer and user.

The application of a transversal wind can make the measurement of the gas tightness impossible. If this is the case, it is allowed to split the low temperature test procedure in two parts. After having performed the required test sequence with the simulation of the transversal wind, the low temperature test sequence shall be repeated, without transverse wind and without gas heater, at low temperature $T_L$ equal to or lower than the lowest temperature measured during the first test on the circuit-breaker tank surface close to sealing joints. A minimum of ten temperature measuring points shall be used to measure the tank surface temperature close to sealing joints.

Dimensions in metres

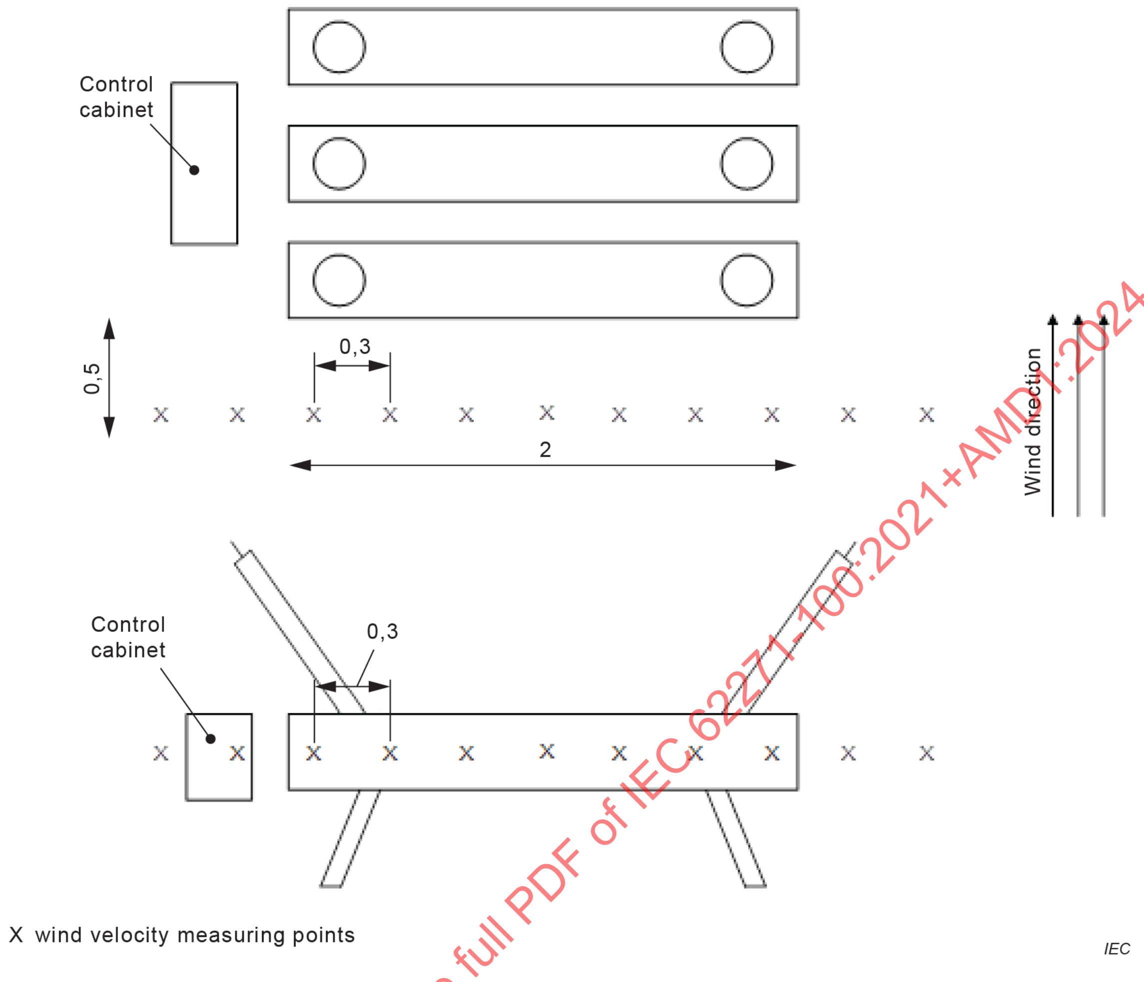



**Figure 10 – Example of wind velocity measurement**



#### 7.101.3.3 Measurement of ambient air temperature

The ambient air temperature of the immediate test environment shall be measured at half the height of the circuit-breaker and at a distance of 1 m from the circuit-breaker.

The maximum temperature deviation over the height of the circuit-breaker shall not exceed 5 K.

#### 7.101.3.4 Low temperature test

The diagram of the test sequences and identification of the application points for the tests specified are given in Figure 11.

If the low temperature test is performed immediately after the high temperature test, the low temperature test can proceed after completion of item u) of the high temperature test in 7.101.3.5. In this case items a) and b) are omitted.

a) The test circuit-breaker shall be prepared and adjusted in accordance with the manufacturer's instructions;

b) Characteristics and settings of the circuit-breaker shall be recorded in accordance with 7.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C ($T_A$). The tightness test (if applicable) shall be performed according to 7.8;

c) With the circuit-breaker in the closed position, the air temperature shall be decreased to the appropriate, minimum ambient air temperature ($T_L$), according to the minimum ambient temperature specified as given in 4.1.2, 4.1.3 and 4.2.4 of IEC 62271-1:2017. The circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at $T_L$;

d) During the 24 h period with the circuit-breaker in the closed position at temperature $T_L$, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017;

e) After 24 h at temperature $T_L$, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances;

f) The low temperature behaviour of the circuit-breaker and its alarms and lock-out systems shall be verified by disconnecting the supply of all heating devices, including also the anti-condensation heating elements, for a duration $t_x$. During this interval, occurrence of an alarm is acceptable but lock-out is not. At the end of the interval $t_x$, an opening order, at rated values of supply voltage and operating pressure, shall be given. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances.

   The manufacturer shall state the value of $t_x$ (not less than 2 h) up to which the circuit-breaker is still operable without auxiliary power to the heaters. In the absence of such a statement, the default value shall be equal to 2 h;

g) The circuit-breaker shall be left in the open position for 24 h;

h) During the 24 h period with the circuit-breaker in the open position at temperature $T_L$, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017;

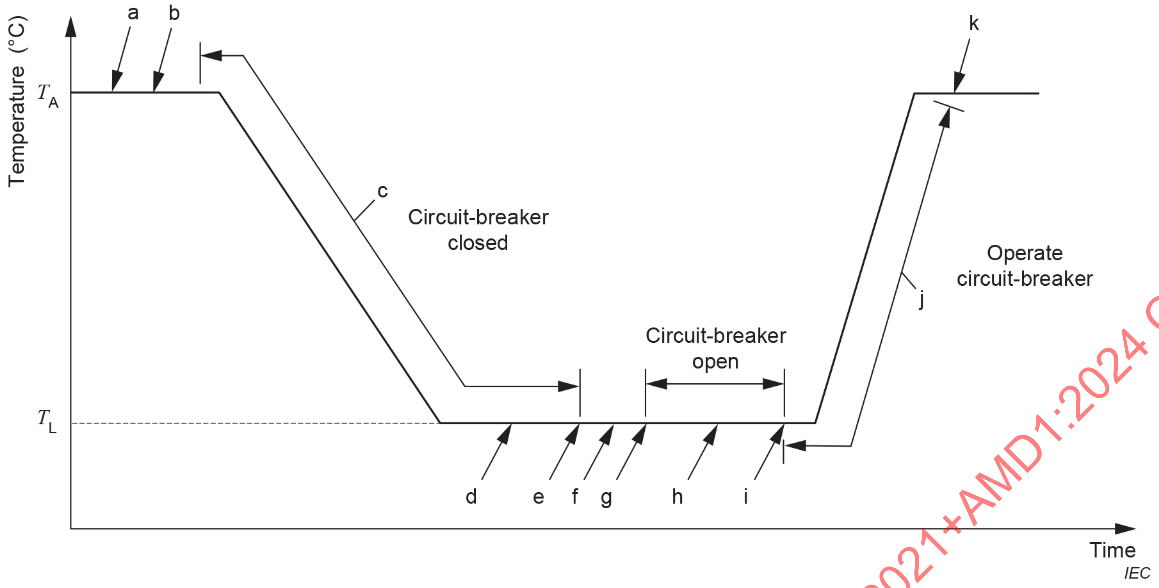
i) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at temperature $T_L$. At least a 3 min interval shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances. Following the first closing operation (C) and the first opening operation (O) three CO operating cycles shall be performed. The additional operations shall be made by performing C – $t_a$ – O – $t_a$ operating sequences ($t_a$ is defined in Table 8);

j) After completing the 50 opening and 50 closing operations, the air temperature shall be increased to ambient air temperature $T_A$ at a rate of change of approximately 10 K per hour;

   During the temperature transition period the circuit-breaker shall be subjected to alternate C – $t_a$ – O – $t_a$ – C and O – $t_a$ – C – $t_a$ – O operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so that the circuit-breaker will be in open and closed positions for 30 min periods between the operating sequences;

k) After the circuit-breaker has stabilised thermally at ambient air temperature $T_A$, a recheck shall be made of the circuit-breaker settings. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances. The tightness test shall be repeated as in item b) and the leakage rate shall remain the limits stated in 7.8.

   The accumulated leakage during the complete low temperature test sequence from item b) to item j) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).




NOTE Letters a through k identify application points of tests specified in 7.101.3.4.

**Figure 11 – Test sequence for low temperature test**



### 7.101.3.5 High temperature test

The diagram of the test sequence and identification of the application points for the tests specified are given in Figure 12.

If the high temperature test is performed immediately after the low temperature test, the high temperature test can proceed after completion of item j) of the low temperature test. In this case, items l) and m) below are omitted.

l) The test circuit-breaker shall be prepared and adjusted in accordance with the manufacturer's instructions;

m) Characteristics and settings of the circuit-breaker shall be recorded in accordance with 7.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C ($T_A$). The tightness test (if applicable) shall be performed according to 7.8;

n) With the circuit-breaker in the closed position, the air temperature shall be increased to the appropriate, maximum ambient air temperature ($T_H$), according to the upper limit of ambient air temperature as given in 4.1.2, 4.1.3 and 4.2.4 of IEC 62271-1:2017. The circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilises at $T_H$;

o) During the 24 h period with the circuit-breaker in the closed position at the temperature $T_H$, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017;

p) After 24 h at the temperature $T_H$, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances;

q) The circuit-breaker shall be opened and left open for 24 h at the temperature $T_H$;

r) During the 24 h period with the circuit-breaker in the open position at the temperature $T_H$, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate shall not exceed the permissible temporary leakage rate of Table 15 of IEC 62271-1:2017;

s) At the end of the 24 h period, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at the temperature $T_H$. An interval of at least 3 min shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances;

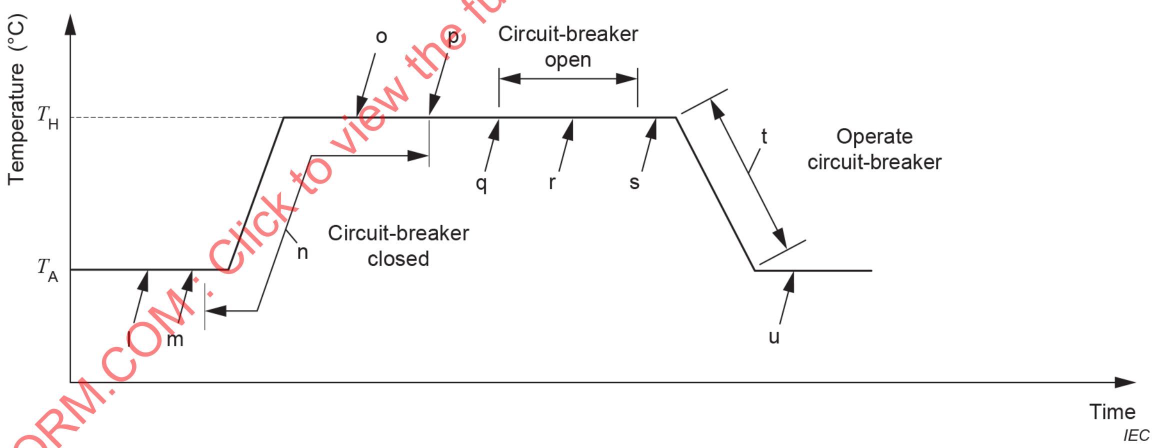
   Following the first closing operation (C) and the first opening operation (O) three CO operation cycles shall be performed. The additional operations shall be made by performing C – $t_a$ – O – $t_a$ operating sequences ($t_a$ is defined in Table 8);

t) After completing the 50 opening and 50 closing operations, the air temperature shall be decreased to ambient air temperature $T_A$, at a rate of change of approximately 10 K/h;

   During the temperature transition period, the circuit-breaker shall be subjected to alternate C – $t_a$ – O – $t_a$ – C and O – $t_a$ – C – $t_a$ – O operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so that the circuit-breaker will be in the open and closed positions for 30 min periods between the operating sequences;

u) After the circuit-breaker has stabilised thermally at ambient air temperature $T_A$, a recheck shall be made of the circuit-breaker settings. The mechanical characteristics shall be recorded and shall be within the manufacturer's specified tolerances. The tightness test shall be repeated as in item m) and the leakage rate shall remain within the limits stated in 7.8.

   The accumulated leakage during the complete high temperature test sequence from item l) to item t) shall not be such that lock-out pressure is reached (reaching alarm pressure is allowed).




NOTE Letters l through u identify application points of tests specified in 7.101.3.5.

**Figure 12 – Test sequence for high temperature test**

#### 7.101.4 Humidity test

##### 7.101.4.1 General

The humidity test does not apply to equipment which is designed to be directly exposed to precipitation, for example primary parts of outdoor circuit-breakers. The test shall be performed on circuit-breakers or circuit-breaker components, where due to sudden changes of the temperature, condensation can occur on insulating surfaces which are continuously stressed by voltage. This is mainly the insulation of the secondary wiring of indoor installed circuit-breakers. The test is not necessary if the circuit breaker is used within a switchgear for which tests on auxiliary and control circuits include environmental tests. It is also not necessary where effective means against condensation are provided, for example control cubicles with anti-condensation heaters.

Applying the test procedure described in 7.101.4.2, the withstand of the test object, primarily circuit-breaker components, to humidity effects, which can produce condensation on the surface of the test object, is determined in an accelerated manner.

##### 7.101.4.2 Test procedure

The test object shall be arranged in a test chamber containing circulating air and in which the temperature and humidity shall follow the cycle given below:

During about half of the cycle the surfaces of the test object shall be wet, and dry during the other half. To obtain this result the test cycle consists of a period $t_4$ with low air temperature ($T_{min}$ = 25 °C ± 3 °C) and a period $t_2$ with high air temperature ($T_{max}$ = 40 °C ± 2 °C) inside the test chamber. Both periods shall be equal in time. The generation of fog shall be maintained for that half of the cycle (see Figure 13) in which the low air temperature is applied.

The beginning of fog generation coincides in principle with the beginning of the low air temperature period. However, to wet the vertical surfaces of materials with a high thermal time constant, it can be necessary to start the fog generation later within the low air temperature period.

The duration of the test cycle depends on the thermal characteristics of the test objects, and shall be sufficiently long, both at high and low temperature, to cause wetting and drying of all insulation surfaces. In order to obtain these conditions, steam should be injected directly into the test chamber or heated water should be atomised; the rise from 25 °C to 40 °C can be obtained with the provision of heat coming from the steam or atomised water or, if necessary, by additional heaters. Preliminary cycles shall be carried out with the test object placed in the test chamber in order to observe and to check these conditions.

For low-voltage components of high-voltage circuit-breakers, usually having time constants smaller than 10 min, the duration of the time intervals given in Figure 13 are: $t_1$ = 10 min, $t_2$ = 20 min, $t_3$ = 10 min and $t_4$ = 20 min.

The fog is obtained by the continuous or periodical atomisation of 0,2 l to 0,4 l of water (with the resistivity characteristics given below) per hour and per cubic metre of test chamber volume. The diameter of the droplets shall be less than 10 µm; such a fog can be obtained by mechanical atomisers. The direction of the spraying shall be such that the surfaces of the test object are not directly sprayed. No water shall drop from the ceiling upon the test object. During the fog generation the test chamber shall be closed and no additional forced air-circulation is permitted.

The water used to create the humidity shall be such that the water collected in the test chamber has a resistivity equal to or greater than 100 Ωm and contains neither salt (NaCl) nor any corrosive element.

The temperature and the relative humidity of the air in the test chamber shall be measured in the immediate vicinity of the test object and shall be recorded for the whole duration of the test. No value of relative humidity is specified during the drop in temperature; however, the humidity shall be above 80 % during the period when the temperature is maintained at 25 °C. The air shall be circulated in order to obtain uniform distribution of the humidity in the test chamber.

The number of cycles shall be 350.

During and after the test, the operating characteristics of the test objects shall not be affected. This is proven by the dielectric withstand test on the auxiliary and control circuits in accordance with 7.2.11. The degree of corrosion, if any, should be indicated in the test report.

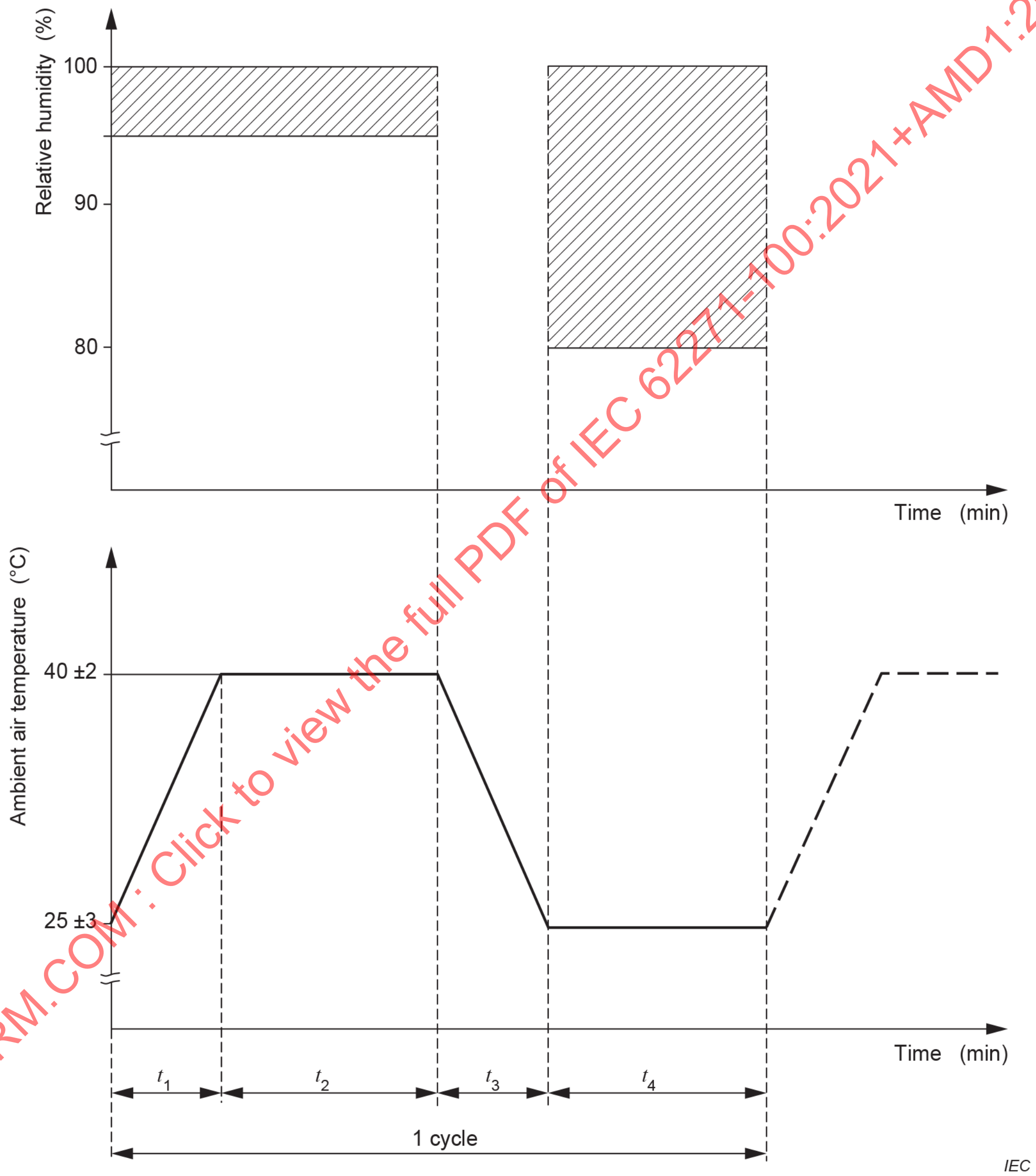



**Figure 13 – Humidity test**



### 7.101.5 Test to prove the operation under severe ice conditions

The test under severe ice conditions is applicable only to outdoor circuit-breakers having moving external parts. The test shall be performed according to IEC 62271-102:2018.

### 7.102 Miscellaneous provisions for making and breaking tests

#### 7.102.1 General

The following subclauses are applicable to all making and breaking tests unless otherwise specified in the relevant clauses.

Circuit-breakers shall be capable of making and breaking all short-circuit currents, symmetrical and asymmetrical, up to and including the rated short-circuit breaking currents: this is demonstrated, when the circuit-breakers make and break the specified three-phase symmetrical and asymmetrical currents between 10 % (or such lower currents as specified in 7.108.1.2 if 7.108.1.1 is applicable) and 100 % of the rated short-circuit breaking current at rated voltage.

In addition, circuit-breakers rated for $k_{pp}$ = 1,2 or 1,3 shall be capable of breaking single-phase short-circuit currents (see 7.108.2). Furthermore, circuit-breakers rated for $k_{pp}$ = 1,5 shall be capable of breaking short-circuit currents in case of double-earth faults (see 7.108.2).

Making and breaking tests according to class S2 cover making and breaking tests according to class S1.

Circuit-breakers to which any capacitive current rating has been assigned shall be capable of making and breaking capacitive currents up to and including the rated capacitive current at a voltage level up to and including that specified (see 7.111.7).

Where applicable, prior to the commencement of the tests, the manufacturer shall declare the values of

– minimum conditions of the operating mechanism guaranteeing the rated operating sequence (for example the minimum pressure for operation in case of a hydraulic operating mechanism);
– minimum conditions of the circuit-breaker guaranteeing the rated operating sequence (for example the minimum pressure for making and breaking in case of an $SF_6$ circuit-breaker).

#### 7.102.2 Additional requirements

The reference test method to prove the making and breaking requirements is using three-phase circuits.

If the tests are carried out in a laboratory, the applied voltage, current, transient and power-frequency recovery voltages can all be obtained from a single power source (direct tests) or from several sources where all of the current, or a major portion of it, is obtained from one source, and the TRV is obtained wholly or in part from one or more separate sources (synthetic tests).

If, due to limitations of the testing facilities, the reference test method cannot be used, several methods employing either direct or synthetic test methods can be used either separate or in combination, depending on the circuit-breaker type:

a) single-phase testing (see 7.102.4.1);
b) unit testing (see 7.102.4.2);
c) multi-part testing (see 7.102.4.3).

#### 7.102.3 Arrangement of circuit-breaker for tests

##### 7.102.3.1 General

The circuit-breaker under test shall be mounted on its own support or on an equivalent support. A circuit-breaker supplied as an integral part of an enclosed unit shall be assembled on its own supporting structure and enclosure, complete with any disconnecting features, with vent outlets forming part of the unit and, where practicable, with main connections and busbars.

Its operating device shall be operated in the manner specified and in particular, if it is electrically or spring operated, closing solenoid or shunt closing releases and shunt opening releases shall be supplied at their respective minimum voltages guaranteeing successful operation (85 % of the rated voltage for the closing solenoid or shunt closing releases, 85 % of the rated voltage if AC or 70 % if DC for the opening release). To facilitate consistent control of the opening and closing operation, the releases shall be supplied at the maximum operating voltage for test-duty T100a, capacitive current tests and the single-phase test specified in 7.108.2. Operating devices having a minimum operating condition (i.e. pressure, energy, etc.) shall be operated at the minimum condition for operation at the commencement of the rated operating sequence, as per 5.104, unless otherwise specified in the relevant clauses. In cases where a test-duty allows for operating sequences consisting of separate O operations, CO and O – $t$ – CO operating sequences, the following procedure applies to pneumatically and hydraulically operating devices:

a) before performing making and breaking tests and starting from the minimum pressure for operation, all the pressures during the rated operating sequence carried out at no-load shall be recorded;
b) the recorded values shall be compared with the minimum values declared by the manufacturer as guaranteeing successful operations as separate O, CO and in case of $t$ = 0,3 s, O – $t$ – CO. For these no-load operations the conditions stated in 7.101.1 apply;
c) tests shall be carried out at the pressure for operation set at the minimum value resulting from a) and b) above, whatever is the lower, for the corresponding operation in the test-duty; the pressure values shall be reported in the test report.

The operating time of some circuit-breakers can vary when the supply voltage to the coils is at the minimum value specified in 6.9 of IEC 62271-1:2017, while the operating times are reasonably constant at their rated supply voltages. Performing a test-duty with correct arcing times can be difficult to achieve in such a case, especially where steps of 18 electrical degrees shall be made to prove the arcing window. Additionally, the scattering of the closing time can prevent the possibility to perform the making test with the rated short-circuit making current.

For circuit-breakers where the operation of the coils does not affect contact travel characteristics, it is permitted to increase the supply voltage of the coils from the minimum value to 110 % of the rated supply voltage. No-load operations performed at the rated and minimum supply voltage shall be included in the test report to show that the contact travel characteristics are not affected by the increased voltage of the coil.

At least one making and one breaking operation shall be performed for test-duty T100s with minimum supply voltage to prove the ability of the circuit-breaker to operate correctly up to its rated short-circuit current under minimum control voltage conditions.

Interlocking devices associated with pressure interlocks shall be made inoperative during the tests, if they interfere with the intent of the test.

It shall be shown that the circuit-breaker will operate satisfactorily under the above conditions at no-load as specified in 7.102.6. The pressure of the compressed gas for making and breaking, if any, shall be set at its minimum functional value.

The circuit-breaker shall be tested according to its type as specified in 7.102.3.2 and 7.102.3.3.

#### 7.102.3.2 Common enclosure type

A three-pole circuit-breaker having all its arcing contacts supported within a common enclosure shall be tested as a complete three-pole circuit-breaker in three-phase circuits, taking Annex H into account.

#### 7.102.3.3 Multi-enclosure type

A three-pole circuit-breaker consisting of three independent single-pole switching devices can be tested single-phase according to 7.102.4.1. The manufacturer shall give testing evidence to show compliance with 6.101.

A three-pole circuit-breaker not having completely independent switching devices should be tested as a complete three-pole circuit-breaker. However, owing to limitation of available testing facilities, one single pole of the circuit-breaker can be tested, provided that it is with regard to the mechanical and electrical conditions applied during the tests equivalent to, or not in a more favourable condition than, the complete three-pole circuit-breaker over the range of tests in respect of:

– mechanical travel characteristics in a making operation (for the evaluation method, see 7.102.4.1);
– mechanical travel characteristics in a breaking operation (for the evaluation method, see 7.102.4.1);
– availability of arc-extinguishing medium;
– power and strength of closing and opening devices;
– rigidity of structure.

#### 7.102.3.4 Self-tripping circuit-breakers

For self-tripping circuit-breakers, subject to the provisions of 7.103.2.3, the overcurrent release shall be inoperative during making and breaking tests and the overcurrent release or the current transformers shall be connected to the live side of the test circuit.

### 7.102.4 General considerations concerning testing methods

#### 7.102.4.1 Single-phase testing of a single pole of a three-pole circuit-breaker

According to this method, a single pole of a three-pole circuit-breaker is tested single-phase, applying to the pole the same current and substantially the same power-frequency voltage which would be impressed upon the most highly stressed pole during three-phase making and breaking by the complete three-pole circuit-breaker under corresponding conditions.

Depending on the circuit-breaker design this document permits single-pole testing to cover three-phase conditions. In those cases where the circuit-breaker is equipped with one operating mechanism for all three poles, a complete three-pole assembly shall be supplied for the tests.

For short-circuit tests, in order to establish whether single-pole testing to cover three-phase conditions is permitted, verification tests for making and breaking shall be performed. Furthermore, it shall be checked that the operating characteristics of the circuit-breaker to be single-phase tested correspond to the provisions of 7.101.1.1.

The verification test for breaking consists of performing a three-phase short-circuit breaking test at the same current level as required for test-duty T100s, without TRV with any convenient test voltage, and with the longest expected arcing time in the last-pole-to-clear.

The verification test for making consists of two three-phase making operations under the same conditions as given in 7.105.2.1. In one making operation full symmetrical current and the maximum pre-arcing time shall be achieved in one pole. In the other making operation the maximum asymmetry shall be achieved in one pole; in this case the making operation can be performed at a convenient reduced voltage.

During the verification test making the circuit-breaker shall reach the fully closed position and the duration of the current shall be at least equal to the time needed for the circuit-breaker to reach the fully closed position.

During these verification tests for making and breaking, the course of the contact travel is recorded. It shall be used as a reference for the following procedure (see Figure 14). The sensor for picking up the course of the contact travel shall be mounted at a suitable location making it possible for providing the course of the contact travel, either directly or indirectly.

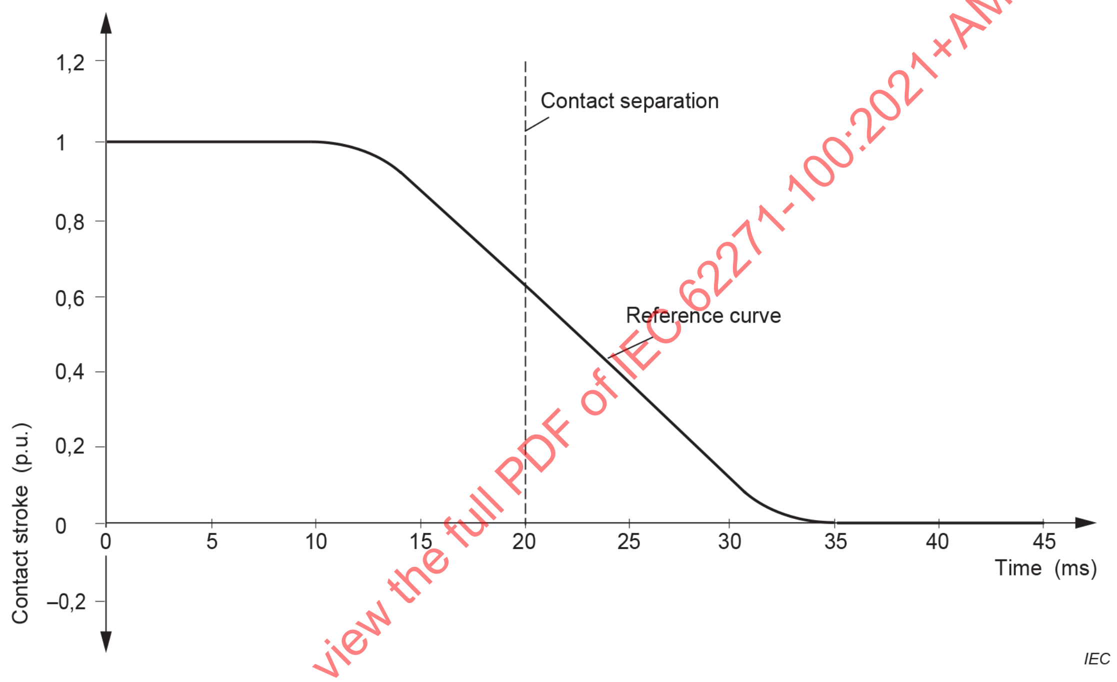



**Figure 14 – Example of reference mechanical characteristics (idealised curve)**

From this reference course, two envelope curves shall be drawn from the instant of contact separation to the end of the contact travel, in the case of a breaking operation, and from the beginning of the contact travel to the instant of contact touch, in the case of a making operation. The distance of the two envelopes from the original course shall be ±5 % of the total travel evaluated from the three-phase verification test (see Figure 15).

During a single-phase test under the same conditions (test-duty T100s with the longest arcing time and the longest pre-arcing time) the course of the contact travel shall be recorded. If the course of the contact travel in the single-phase test is within the envelopes of the mechanical travel characteristics from the instant of contact separation to the end of the contact travel in the case of a breaking operation and from the beginning of the contact travel to the instant of contact touch in the case of a making operation of the three-phase tests, single-phase tests for representing three-phase conditions are valid.

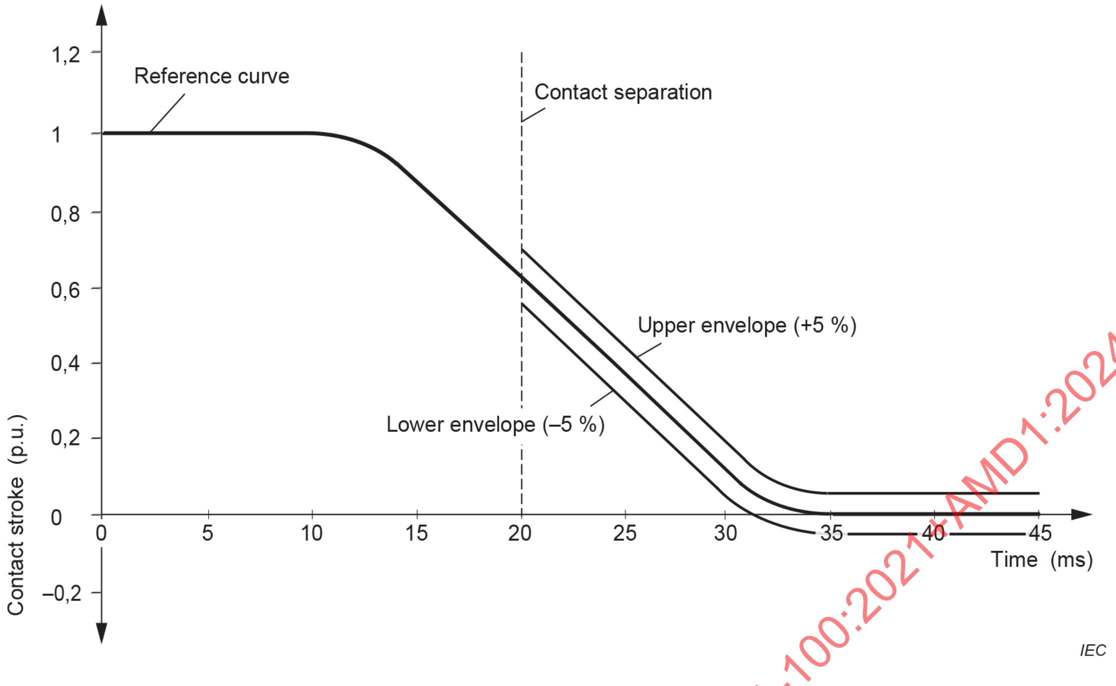



**Figure 15 – Reference mechanical characteristics of Figure 14 with the envelopes centred over the reference curve (+5 %, –5 %)**

The envelopes can be moved in the vertical direction until one of the curves covers the reference curve. This gives maximum tolerances over the reference contact travel curve of –0 %, +10 % and +0 %, –10 % respectively (see Figure 16 and Figure 17). The displacement of the envelope can be done only once for the complete procedure in order to get a maximum total deviation from the reference curve of 10 %.

To achieve the correct contact travel characteristics of the individual poles, depending on the design (single-phase or three-phase operated), it may be necessary to make adjustments, for example by using transfer functions.

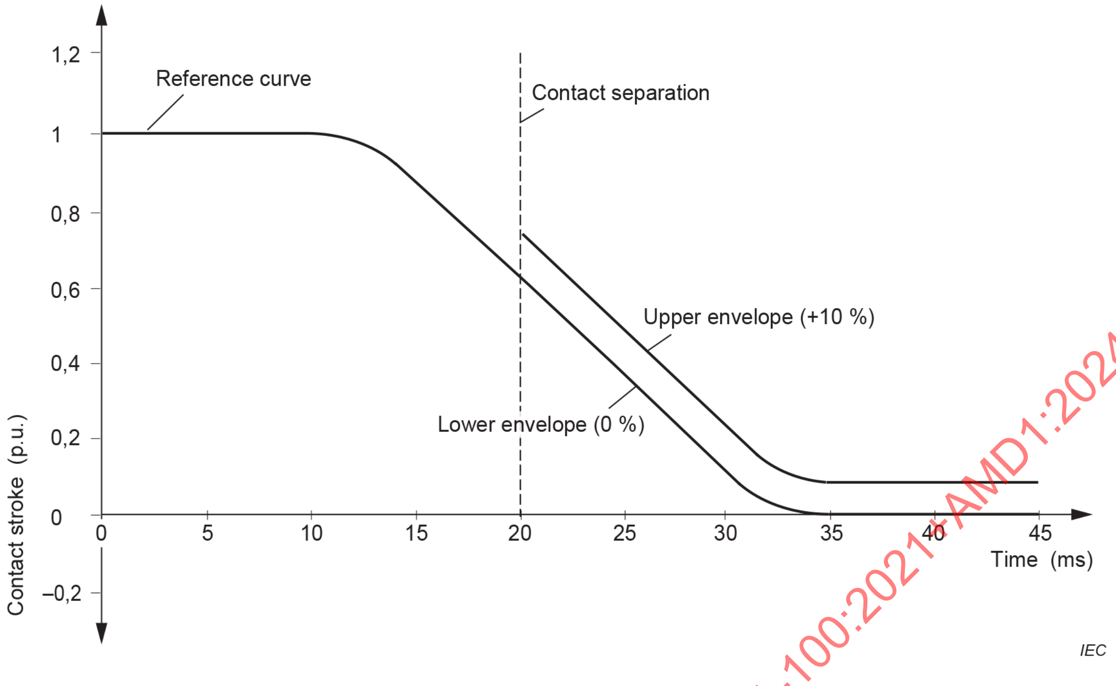



**Figure 16 – Reference mechanical characteristics of Figure 14 with the envelope fully displaced upward from the reference curve (+10 %, –0 %)**

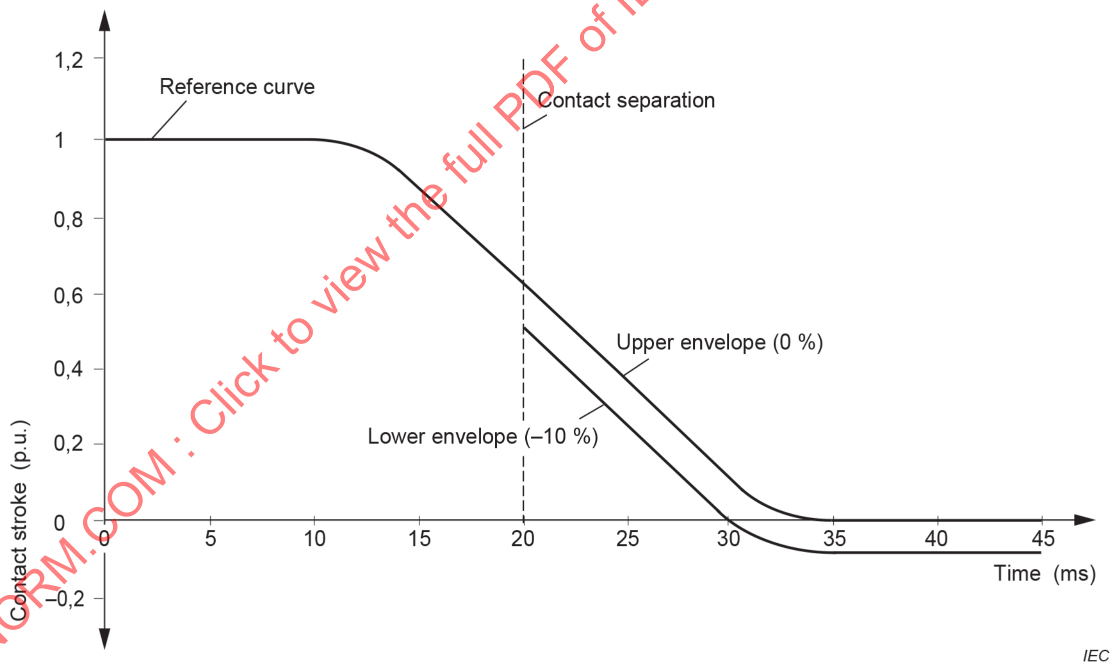



**Figure 17 – Reference mechanical characteristics of Figure 14 with the envelope fully displaced downward from the reference curve (+0 %, –10 %)**

Special attention should be paid to the emission of arc products. If it is considered that such emission would, for example, be likely to impair the insulation distance to adjacent poles, then this shall be checked, using earthed metallic screens (see 7.102.8).

When testing a circuit-breaker for 50 Hz and 60 Hz, verification tests shall only be performed at 50 Hz or 60 Hz, provided the following two conditions are met:

– the arcing time for breaking shall be the longest expected arcing time in the last-pole-to-clear at 50 Hz;
– during the making operation with asymmetrical current the rated short-circuit making current for 60 Hz shall be achieved.

**7.102.4.2 Unit testing**

**7.102.4.2.1 General**

Certain circuit-breakers are constructed by assembling identical making and breaking units in series, the voltage distribution between the making and breaking units of each pole often being improved by the use of parallel impedances.

This type of design enables the making and breaking performance of a circuit-breaker to be tested by carrying out tests on one or more making and breaking units.

The requirements of 7.101.1.1, 7.102.3 and 7.102.4.1 also apply for unit testing. Since therefore at least a complete pole assembly shall be made available for the verification tests on one or more making and breaking units, the test results relate only to this specific pole design.

**7.102.4.2.2 Configuration and requirements**

The following situations can be distinguished:

a) The circuit-breaker pole consists of making and breaking units (or assemblies of making and breaking units) which are separately operated and which have no mutual connections for the arc extinguishing medium.

   In this case unit testing is acceptable. However, the mutual influence through the electrodynamic forces of the current on the making and breaking units and the arc in the making and breaking units should be taken into account (see Figure 18). This can be done by substitution of the second making and breaking unit by a conductor with equivalent shape.

b) The circuit-breaker pole consists of making and breaking units (or assemblies of making and breaking units) which are separately operated but which have a mutual connection for the arc extinguishing medium.

   In this case, unit testing is only acceptable if the making and breaking units not under test arc during the test (for example used as auxiliary circuit-breaker in synthetic tests).

c) The circuit-breaker pole consists of making and breaking units (or assemblies of making and breaking units) which are not separately operated.

   In this case, unit testing is only acceptable if the mechanical characteristics for the unit test and for the full-pole test are the same. The procedure as given in 7.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly. Moreover, the influence of electrodynamic forces (see also item a) above) shall be covered.

   However, if the making and breaking units not under test arc during the test (for example, used as auxiliary circuit-breaker in synthetic tests), the requirements related to the mechanical characteristics are considered to be covered. In this case, the requirement for circuit-breakers, which have mutual connections for the extinguishing medium between making and breaking units (see also item b) above) is covered at the same time.

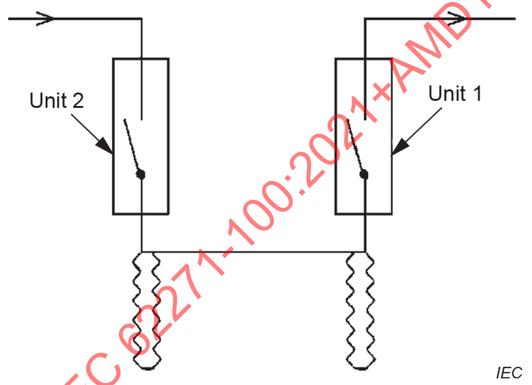
d) For test currents equal to or less than 60 % of the rated short-circuit current, unit test is permissible if the arc extinguishing medium volume of the single making and breaking unit under test is proportional to the applicable part of one assembly of making and breaking units having the same arc extinguishing medium.

The mechanical characteristics under no-load conditions for unit test and for full-pole testing shall be the same. The procedure for comparison of mechanical characteristics given in 7.102.4.1 for single-pole testing of a three-pole circuit-breaker shall be applied accordingly. The mutual influence through the electrodynamic forces of the current and the arc in the making and breaking units is considered to be negligible for test currents equal or less than 60 % of the rated short-circuit current.

When carrying out unit tests it is essential that the making and breaking units are identical and that the static voltage distribution for the type of test (for example terminal faults, short-line fault, out-of-phase, etc.) is known.

For unit testing of metal-enclosed circuit-breakers, see Annex H.

Pole of a circuit-breaker with two separate making and breaking units in series




Equivalent testing set-up for unit testing; the second making and breaking unit is substituted by a conductor of equivalent shape

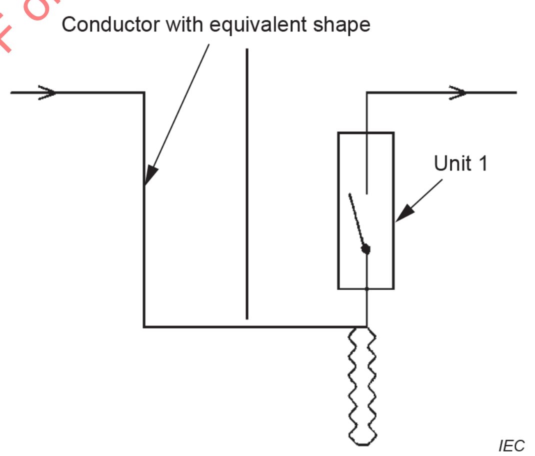



**Figure 18 – Equivalent testing set-up for unit testing of circuit-breakers with more than one separate making and breaking units**

#### 7.102.4.2.3 Identical nature of the making and breaking units

The making and breaking units of the circuit-breaker shall be identical in their shape, in their dimensions and in their operating conditions; only the devices for controlling the voltage distribution among making and breaking units can be different. In particular, the following conditions shall be fulfilled.

a) *Operation of contacts*

The operation of contacts shall be in accordance with 6.101. Rated operating pressures and voltages shall be used.

b) *Supply of the arc-extinguishing medium*

For a circuit-breaker using a supply of arc-extinguishing medium from a source external to the making and breaking units, the supply to each making and breaking unit shall, for all practical purposes, be independent of the supply to the other making and breaking units, and the arrangement of the supply pipes shall be such as to ensure that all making and breaking units are fed essentially together and in an identical manner.

#### 7.102.4.2.4 Voltage distribution

The test voltage is determined by analysing the voltage distribution between the making and breaking units of the pole.

The voltage distribution between making and breaking units of a pole, as affected by the influence of earth, shall be determined for the relevant test conditions laid down for tests on one pole:

– for terminal fault conditions see items c) and d) of 7.103.2.2 and Figure 19a, Figure 19b, Figure 20a and Figure 20b;

NOTE 1 The test circuits shown in Figure 19b and Figure 20b are not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex H and in IEC 62271-101.

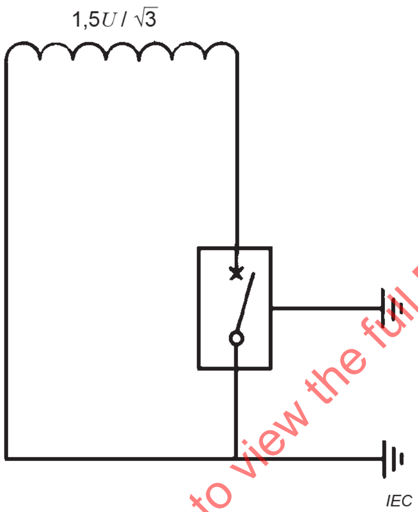



**Figure 19a – Preferred circuit**

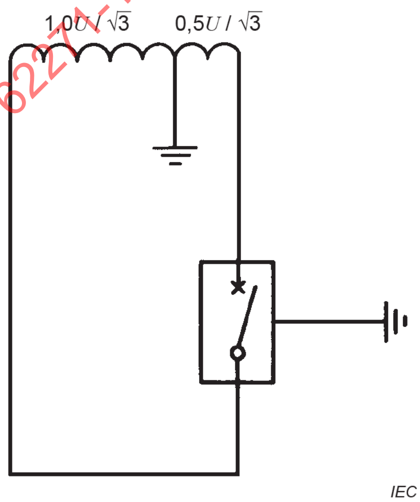



**Figure 19b – Alternative circuit**

**Figure 19 – Earthing of test circuits for single-phase short-circuit tests, $k_{pp}$ = 1,5**

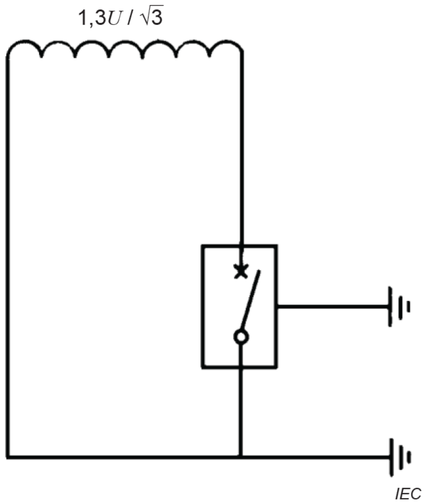



Figure 20a – Preferred circuit

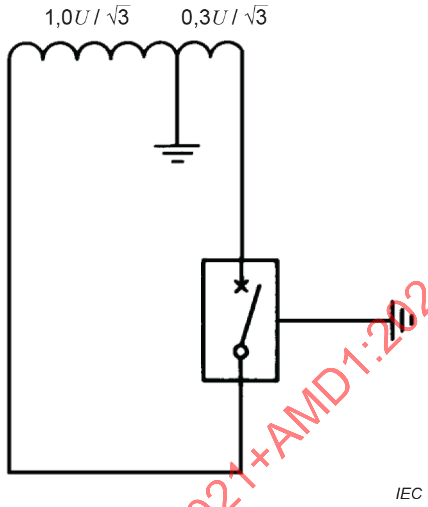


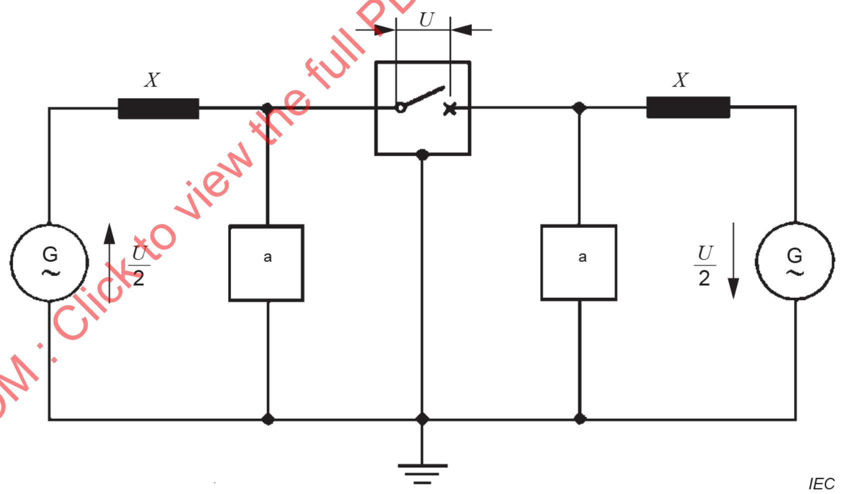

Figure 20b – Alternative circuit

**Figure 20 – Earthing of test circuits for single-phase short-circuit tests, $k_{pp}$ = 1,3**

– for short-line fault conditions see 7.109.3;

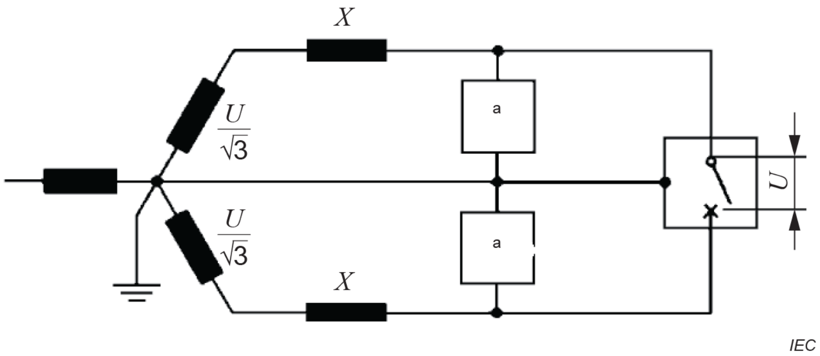
– for out-of-phase conditions see 7.110.1 and Figure 21, Figure 22 and Figure 23;

– for capacitive making and breaking conditions see 7.111.3, 7.111.4 and 7.111.5.



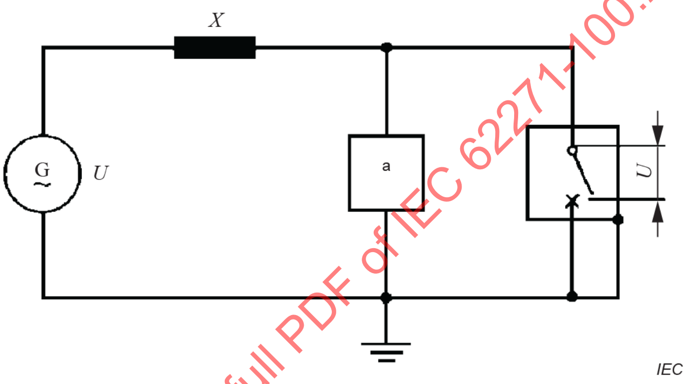

[a] The squares represent TRV control elements.

**Figure 21 – Test circuit for single-phase out-of-phase tests**




[a] The squares represent TRV control elements.

**Figure 22 – Test circuit for out-of-phase tests using two voltages separated by 120 electrical degrees**




[a] The square represents TRV control elements.

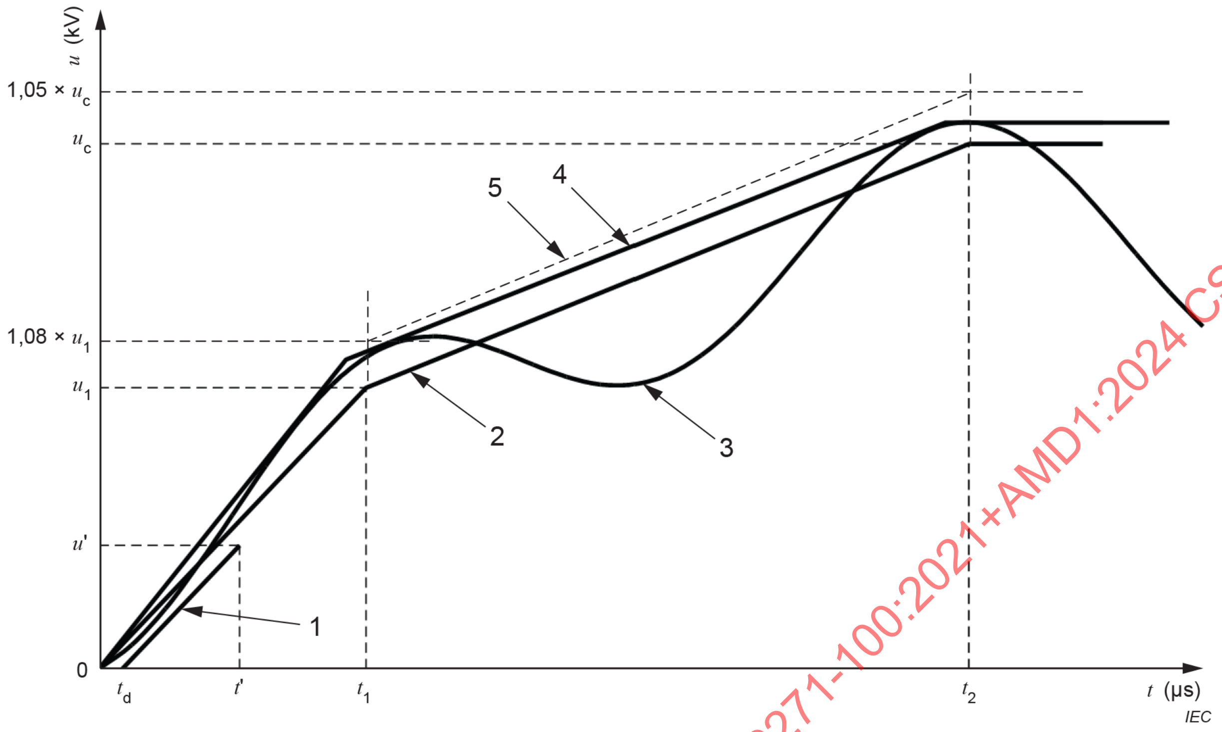
**Figure 23 – Test circuit for out-of-phase tests with one terminal of the circuit-breaker earthed (subject to agreement of the manufacturer)**

Where the making and breaking units are not symmetrically arranged, the voltage distribution shall be determined also with reverse connections.

The voltage distribution is determined either by measurement or by calculation. Values used in the calculations shall be supported by measurements of the stray capacitances of the circuit-breaker. Such calculations and supporting measurements verifying the assumptions used in the calculations are the responsibility of the manufacturer.

If the circuit-breaker is fitted with parallel resistors, the voltage distribution shall be calculated or measured statically at the equivalent frequency involved in the TRV.

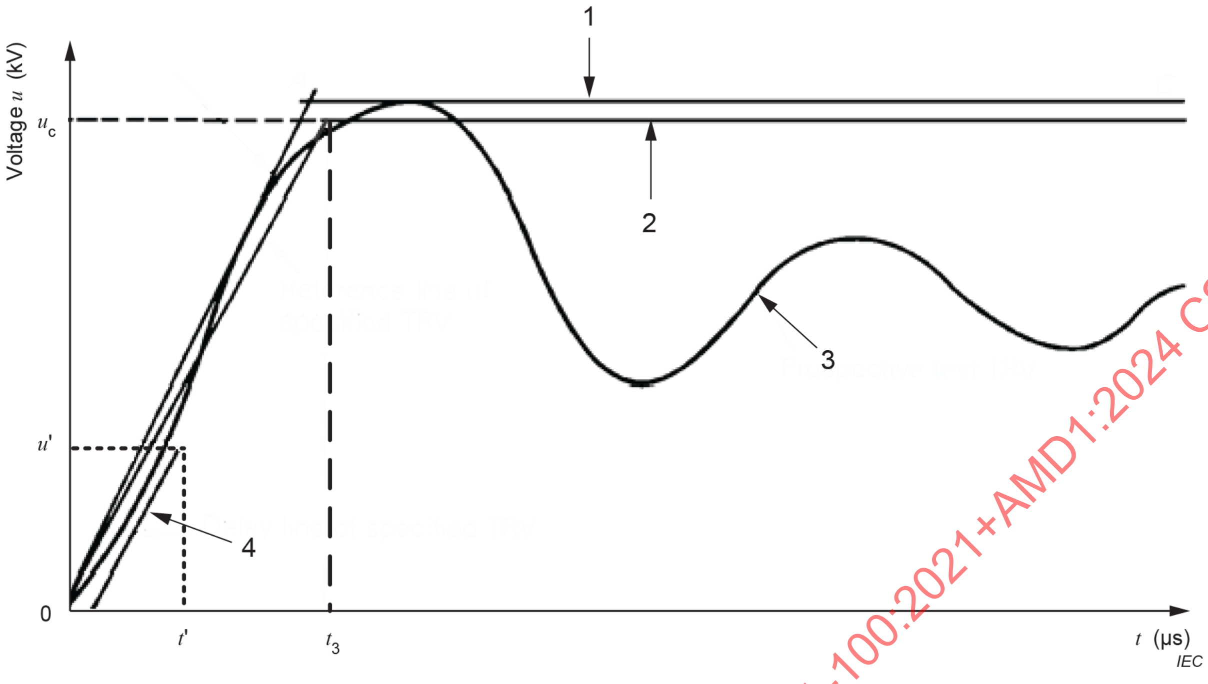
NOTE 2 The equivalent frequency is considered to be $1/(2t_1)$ in the case of four parameters or $1/(2t_3)$ in the case of two parameters (see Figure 24 and Figure 25).




**Key**

| | |
|---|---|
| 1 | Delay line of the specified TRV |
| 2 | Reference line of the specified TRV |
| 3 | Prospective test TRV |
| 4 | Envelope of the prospective test TRV |
| 5 | Upper limit of the envelope of the prospective test TRV |

**Figure 24 – Example of prospective test TRV with four-parameter envelope which satisfies the conditions to be met during type test – Case of specified TRV with four-parameter reference line**




**Key**

1 Envelope of the prospective test TRV

2 Reference line of the specified TRV

3 Prospective test TRV

4 Delay line of the specified TRV

**Figure 25 – Example of prospective test TRV with two-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with two-parameter reference line**

Where short-line fault tests are performed with unit test method, both source and line side TRV shall be determined with the single voltage distribution factor, corresponding to the voltage distribution of the line side TRV.

If only capacitors are used, the voltage distribution can be calculated or measured at power frequency.

The manufacturing tolerances for resistors and capacitors shall be taken into account. The manufacturer shall state the value of these tolerances.

NOTE 3 It can be taken into account that the voltage distribution is more favourable during the out-of-phase and capacitive current breaking tests than during the terminal fault or short-line fault tests. This also applies when, in exceptional cases, tests are performed under the conditions of unearthed faults in effectively earthed neutral systems.

NOTE 4 The influence of pollution is not considered in determining voltage distribution. In some cases, pollution can affect this voltage distribution.

#### 7.102.4.2.5 Additional requirements for unit testing

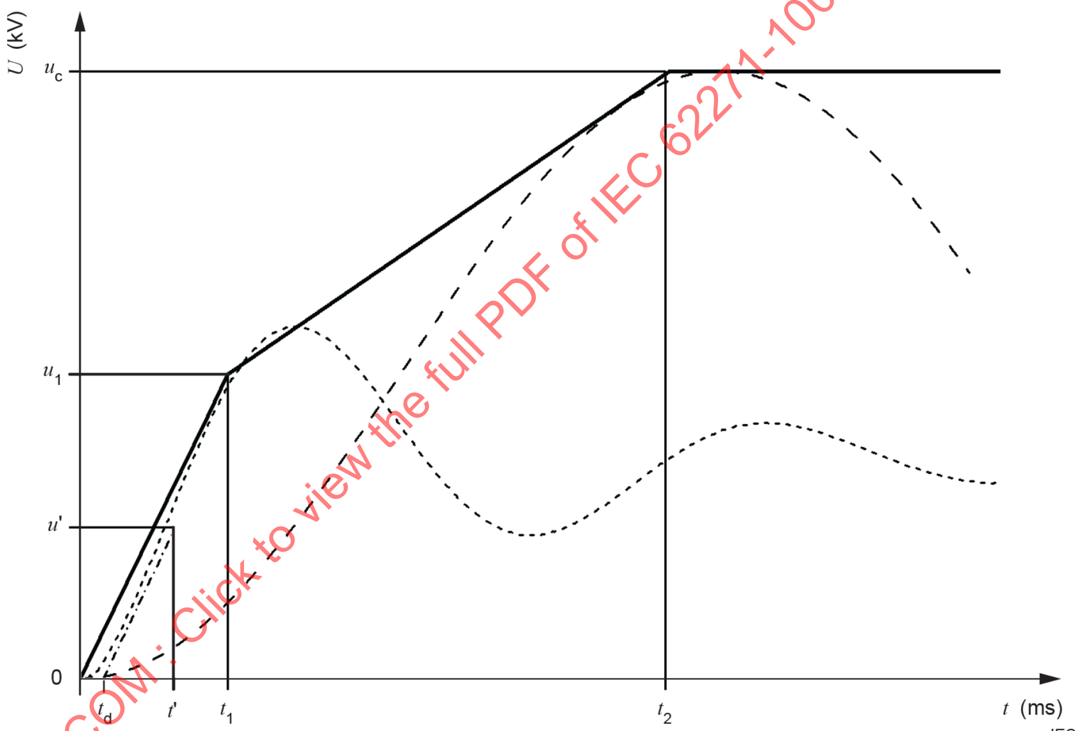
When testing a single making and breaking unit, the test voltage shall be the voltage of the most highly stressed making and breaking unit of the complete pole of the circuit-breaker, determined in accordance with 7.102.4.2.4. For short-line fault conditions, the making and breaking unit referred to is that most highly stressed at the specified time of the first peak of the line side transient voltage.

When testing a group of making and breaking units, the voltage appearing at the terminals of the most highly stressed making and breaking unit of the group shall be equal to the voltage of the most highly stressed making and breaking unit of the pole, both determined in accordance with 7.102.4.2.4.

Additional guidance is given in Annex H.

#### 7.102.4.3 Multi-part testing

If all recovery voltage requirements for the given test-duty cannot be met simultaneously, the test can be carried out in two successive parts, for example as illustrated in Figure 26.




**Key**

| | |
|---|---|
| ———— (solid line) | Required 4-parameter envelope |
| - - - - - - (dotted) | Test TRV part 1 |
| — — — — (dashed) | Test TRV part 2 |
| -·-·-·-·- | Delay line |

**Figure 26 – Example of prospective test TRV-waves and their combined envelope in two-part test**

In the test circuit used for the first part, the initial portion of the TRV shall not cross the straight line defining the delay time and shall meet the specified reference line up to the voltage $u_1$ and the time $t_1$.

In the test circuit used for the second part, the voltage $u_c$ and the time $t_2$ shall be attained.

Multi-part testing can also be carried out in order to obtain the power frequency recovery voltage of $U_r/\sqrt{3}$ for terminal fault after one half-cycle of rated frequency during single-phase tests in substitution for three-phase tests as specified in 7.103.4.

The number of tests for each part shall be the same as the number required for the test-duty, and the arcing times for each part shall meet the requirements of 7.104. The arcing times in separate tests forming part of one multi-part test shall be the same with a tolerance of ±1 ms. Moreover, if the minimum arcing time in one part differs from that established in the other part by more than 1 ms then the maximum arcing time associated with the longer of the two minimum arcing times shall be used for both parts.

When multi-part testing is used to separately meet the requirements for TRV and for the power frequency recovery voltage, during tests with power frequency recovery voltage it is not necessary to search for the minimum arcing time. Arcing times shall be based on the minimum arcing time obtained during tests with TRV.

The circuit-breaker can be re-conditioned between the parts of the multi-part testing procedure in accordance with 7.102.9.6.

In rare cases, it may be necessary to perform the test in more than two parts. In such cases, the principles stated above shall be applied.

#### 7.102.5 Synthetic tests

Synthetic testing methods can be applied for making and breaking tests as required in 7.107 to 7.111. Synthetic testing techniques and methods are described in IEC 62271-101.

#### 7.102.6 No-load operations before tests

Before commencing making, breaking tests, C and O operations shall be made and the mechanical characteristics recorded. Details such as closing time and opening time shall be recorded. For these no-load operations, conditions stated in 7.101.1.1 apply. Additional no-load operations can be necessary (see also 7.102.3.1).

In addition, it shall be demonstrated that the mechanical behaviour of the circuit-breaker under test conforms to that of the reference mechanical travel characteristics required in 7.101.1.1. After a change of contacts or any kind of maintenance, these mechanical travel characteristics shall be reconfirmed by repeating these no-load tests.

For a circuit-breaker fitted with a making current release, it shall be shown that this does not operate on no-load.

The pressure of the compressed gas for making and breaking shall be set at the value corresponding to that required for the test-duty to be performed.

For electrically or spring-operated circuit-breakers, operations shall be made with the closing solenoid or shunt-closing releases energised at 100 % and 85 % of the rated supply voltage of the closing device and with the shunt-opening release energised at 100 % and 85 % in the case of AC, and 100 % and 70 % in the case of DC of the rated supply voltage.

### 7.102.7 Alternative operating mechanisms

In this subclause, it is considered that one version of a circuit-breaker with its operating mechanism is completely type-tested in accordance with this document; this version is referred to as the completely tested circuit-breaker. The other versions, differing in the operating mechanisms (see definition in 3.5.130), are referred to as circuit-breakers with alternative operating mechanisms.

For a circuit-breaker equipped with alternative operating mechanisms, repetition of T100s and T100a (if required in c) below) only is required for the demonstration of the making and breaking capabilities.

Therefore, the tests to be performed on the circuit-breaker equipped with the alternative operating mechanism are as follows:

a) the mechanical characteristics shall be recorded in accordance with 7.101.1.1 and the results of a comparison with the characteristics of the completely tested circuit-breaker shall comply with the requirements given in Annex G;
b) test-duty T100s shall be performed. In addition, the mechanical characteristics during the breaking operations with the longest arcing time shall be compared with the completely tested circuit-breaker according to the method required in 7.101.1.1 and comply with the requirements given in Annex G;
c) in the particular case where the minimum clearing time (see 3.7.151) is falling in a shorter category, test-duty T100a shall be performed.

If requirements a), b) and c) are met, the reference mechanical characteristics of the completely tested circuit-breaker shall apply also for the circuit-breakers equipped with alternative operating mechanisms.

### 7.102.8 Behaviour of circuit-breaker during tests

During making and breaking tests, the circuit-breaker shall not

– show signs of distress;
– show harmful interaction between poles and to earth;
– show harmful interaction with adjacent laboratory equipment;
– exhibit behaviour which could endanger an operator.

If faults occur which are neither persistent nor due to defect in design, but rather are due to errors in assembly or maintenance, the faults can be rectified and the circuit-breaker subjected to the repeated test-duty concerned. In those cases, the test report shall include reference to the invalid tests.

Resumption of power-frequency current in any pole before one cycle after breaking shall be cleared by the circuit-breaker. A resumption of power frequency current later than one cycle after the first breaking of the short-circuit in all poles is a failure.

NSDDs can occur during the recovery voltage period following a breaking operation. However, their occurrence is not a sign of distress of the switching device under test. Therefore, their number is of no significance to interpreting the performance of the device under test. They shall be reported in the test report in order to differentiate them from restrikes.

It is not the intent to require the installation of special measuring circuits to detect NSDDs. They should only be reported when seen on an oscillogram.

### 7.102.9 Condition of the circuit-breaker after making and breaking tests

#### 7.102.9.1 General

After each short-circuit test-duty, the circuit-breaker shall be capable of making and breaking its rated continuous current at the rated voltage, although its short-circuit making and breaking performance can be impaired. The circuit-breaker shall be inspected after any test-duty or a number of test-duties. Its mechanical parts and insulators shall be in essentially the same condition as before the tests. Visual inspection is usually sufficient for verification of the insulating properties. In some cases as specified in 7.102.9.2, the condition checking test according to 7.2.12 is required to prove the insulation properties.



#### 7.102.9.2 Insulation properties

For sealed-for-life circuit-breakers the voltage test as condition check according to 7.2.12 is mandatory after the tests according to 7.107 through 7.112 and shall be performed as follows:

– in case of a single-phase test, the condition check test shall only be carried out on the pole tested;
– in case of three-phase tests the condition check test shall be carried out on all three poles.

Terminals to which no test voltage is applied shall be earthed during the condition check test.

For other than sealed-for-life circuit-breakers the condition check test shall be performed after test-duty $L_{90}$. If test-duty $L_{90}$ is not required, the condition check shall be carried out after test-duty T100s.

After all other test-duties a visual inspection is sufficient for verification of the insulating properties. There shall be no evidence of puncture, flashover or tracking of the internal parts that contribute to the insulation, except that moderate wear of the parts of arc control devices exposed to the arc is permissible.

If, during the capacitive current tests, one or more restrikes occurred, a dielectric condition checking test according to 7.2.12 shall be performed before visual inspection, provided that the tested peak recovery voltage during the capacitive current tests is lower than the peak voltage of the specified dielectric condition checking test. The subsequent visual inspection shall demonstrate that the restrike occurred between the arcing contacts only. There shall be no evidence of puncture, flashover or permanent tracking of internal parts that contribute to the insulation. Wear of the parts of arc control devices exposed to the arc is permissible as long as it does not impair the breaking capability. Moreover, the inspection of the insulating gap between the main contacts, if they are different from the arcing contacts, shall not show any trace of a restrike.

If no restrike occurred during the capacitive current tests visual inspection is sufficient.

#### 7.102.9.3 Integrity of making and breaking units placed in an insulating fluid

If making and breaking units are placed in an insulating fluid with different characteristics and other than air at atmospheric pressure, that also might withstand the test voltages when replacing the original arc extinguishing medium (for example a vacuum interrupter in an enclosure filled with $SF_6$) the integrity check as requested in 7.2.12.102 shall be performed after the short-circuit making and breaking tests. This is not required after a capacitive current test.

#### 7.102.9.4 Continuous current carrying capability

The main contacts shall be in such a condition, in particular with regard to wear, contact area, pressure and freedom of movement, that they are capable of carrying the rated continuous current of the circuit-breaker without their temperature rise exceeding by more than 10 K the values specified for them in Table 14 of IEC 62271-1:2017 with the exception that after capacitive current tests for class C1 the maximum temperature rise does not exceed the values specified in Table 14 of IEC 62271-1:2017.

Contacts shall be considered as "silver-faced" only if there is still a layer of silver at the contact points after any of the short-circuit test-duties; otherwise, they shall be treated as "not silver-faced" (see 7.5.6.2, point 6 of IEC 62271-1:2017).

For other than sealed-for-life ciruit-breakers, visual inspection is usually sufficient for verification of the capability of the circuit-breaker to carry the continuous current and to make and break its rated continuous current at the rated voltage.

For circuit-breakers with sealed-for-life circuit-breakers the following applies:

– a measurement of the resistance as condition check according to 7.4.4 is mandatory for verification of the capability of the circuit-breaker to carry and to make and break the rated continuous current at the rated voltage;
– by-products resulting from arcing can generate a non-conductive layer on contact surfaces, showing high resistance if measured with limited current source. Such value might not be representative of real current carrying capability as this layer might disappear at contact spots under rated continuous current flow;
– if the resistance increase exceeds 100 % it is allowed to repeat the resistance measurement after a maximum of 10 no-load CO operating cycles;
– if the resistance increase still exceeds 100 %, it is allowed to repeat the measurement after applying a current not exceeding the rated continuous current for a maximum duration of 15 min. A cooling time of maximum 30 min is also allowed prior to this resistance measurement;
– if the resistance increase still exceeds 100 % then a continuous current test according to 7.5 is applicable to determine if the test object can carry its rated continuous current;
– the circuit-breaker passed the tests if the maximum temperature rise recorded at the terminals of any making and breaking unit does not exceed by more than 10 K the values specified in Table 14 of IEC 62271-1:2017.

#### 7.102.9.5 No-load tests after a test-duty

No load operations after an individual test-duty are only necessary if change of the contacts or other kinds of maintenance is intended to be performed after the test-duty. The no-load operations shall be compared with the corresponding operations made in accordance with 7.102.6 and shall remain within the tolerances given by the manufacturer.

In order to check the operation of the circuit-breaker after the completion of an entire test series of making and breaking tests, the no-load operating sequence according to 7.102.6 shall be repeated. These no-load tests shall be compared with the corresponding operations made in accordance with 7.102.6. The requirements of 7.101.1.1 and of Annex G shall be fulfilled. The circuit-breaker shall close and latch satisfactorily.

#### 7.102.9.6 Reconditioning during making and breaking tests

For some-circuit breakers it may be necessary to carry out maintenance work after performing a test-duty. After the maintenance work the circuit-breaker shall be in a practically new condition. It is also allowed to exchange the complete circuit-breaker or a big part of the circuit-breaker. Before continuation of the tests on the maintained, reconditioned or new circuit-breaker it shall be demonstrated that the mechanical behaviour of the circuit-breaker under test conforms to that of the reference mechanical travel characteristics required in 7.101.1.1.

It is the responsibility of the manufacturer to specify when the circuit-breaker needs to be maintained, reconditioned or replaced as long as the following requirements are fulfilled:

a) It is not allowed to maintain, recondition or replace the circuit breaker during the specified operating sequence of a terminal fault test-duty, a short-line fault test-duty or an out-of-phase making and breaking test-duty;
b) It is not allowed to maintain, recondition or replace the circuit-breaker during test-duty 1 and test-duty 2 for class C1 and during pre-condition test, test-duty 1 and test-duty 2 for class C2 circuit-breakers. This is also not allowed when combinations of capacitive test-duties for line, cable or capacitor bank charging current tests are made or when reclassification tests are made in accordance with 7.111.11.4;
c) A class E2 circuit-breaker, intended to use without auto-reclosing, shall not be maintained, reconditioned or replaced during the terminal fault test-duties, given in 7.107;
d) A class E2 circuit-breaker, intended to use with auto-reclosing, shall not be maintained, reconditioned or replaced during the test series described in 7.112.2.

## 7.103 General considerations for making and breaking tests

### 7.103.1 General

This subclause describes some general considerations for making and breaking tests. The manufacturer shall specify the values required.

### 7.103.2 Test circuits for short-circuit making and breaking tests

#### 7.103.2.1 Frequency

Circuit-breakers shall be tested at rated frequency with a tolerance of ±8 %.

However, for convenience of testing, some deviations from the above tolerance are allowable; for example, when circuit-breakers rated at 50 Hz are tested at 60 Hz and vice versa, care should be exercised in the interpretation of the results, taking into account all significant facts such as the type of the circuit-breaker and the type of test performed.

#### 7.103.2.2 Earthing of test circuit

The connections to earth of the test circuit for short-circuit making and breaking tests shall be in accordance with the following requirements and shall be indicated in the diagram of the test circuit included in the test report (see item f) of C.2.4).

a) Three-phase tests of a three-pole circuit-breaker, $k_{pp}$ = 1,5:

   The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply isolated and the short-circuit point earthed as shown in Figure 27a, or vice versa as shown in Figure 27b, if the test can only be made in the latter way.

   In accordance with Figure 27a, the neutral of the supply source can be earthed through a resistor, the resistance of which is as high as possible and, expressed in ohms, in no case less than $U$/10, where $U$ is the numerical value in volts of the voltage between lines of the test circuit.

   When a test circuit according to Figure 27b is used, it is recognised that in case of an earth fault at one terminal of the test circuit-breaker, the resulting earth current could be dangerous. It is consequently permitted to connect the supply neutral to earth through an appropriate impedance.

b) Three-phase tests of a three-pole circuit-breaker, $k_{pp}$ = 1,3:

   The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply connected to earth by an appropriate impedance and the short-circuit point earthed as shown in Figure 28a, or vice versa as shown in Figure 28b, if the test can only be made in the latter way.

The impedance in the neutral connection shall be selected appropriate to a $k_{pp}$ of 1,3. Assuming $Z_0$ = 3,25 × $Z_1$ the appropriate value of the impedance in the neutral connection is 0,75 times the phase impedance.

NOTE 1 The test circuit shown in Figure 28b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex H and in IEC 62271-101.

c) Single-phase tests of a single pole of a three-pole circuit-breaker with $k_{pp}$ = 1,5:

The test circuit and the circuit-breaker structure shall be connected as in Figure 19a, so that the voltage conditions between live parts and the structure after arc extinction are the same as those which would exist in the first-pole-to-clear of a three-pole circuit-breaker if tested in the test circuit shown in Figure 27a.

The preferred test circuit is shown in Figure 19a. Where there are limitations on test station equipment, then the circuit shown in Figure 19b can be used.

NOTE 2 The test circuit shown in Figure 19b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex H and in IEC 62271-101.

d) Single-phase tests of a single pole of a three-pole circuit-breaker with $k_{pp}$ = 1,3:

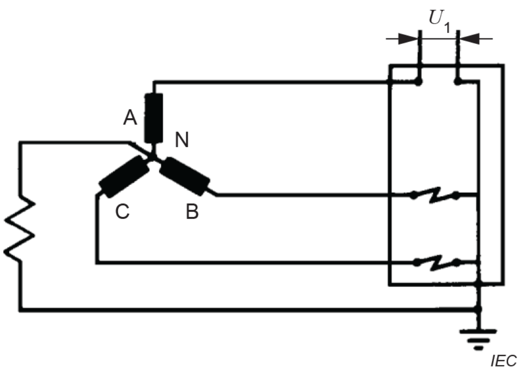
The test circuit and the circuit-breaker structure shall be connected as in Figure 20a, so that the voltage conditions between live parts and the structure after arc extinction are approximately the same as those that would exist in the first-pole-to-clear of a three-pole circuit-breaker if tested in the test circuit shown in Figure 28a.

The preferred test circuit is shown in Figure 20a. Where there are limitations on test station equipment, then the circuit shown in Figure 20b can be used.

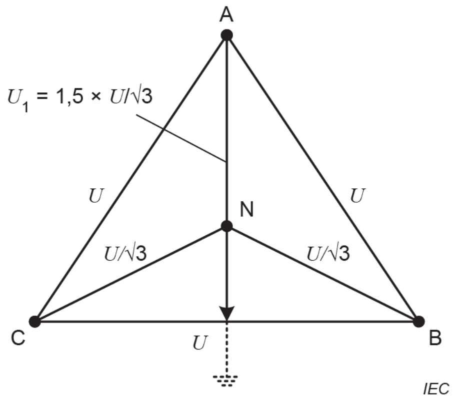
NOTE 3 The test circuit shown in Figure 20b is not applicable for circuit-breakers where the insulation between phases and/or to earth is critical (for example GIS or dead tank circuit-breakers). Appropriate testing methods for those circuit-breakers are presented in Annex H and in IEC 62271-101.

e) Single-phase tests of a single-pole circuit-breaker:

The test circuit and the circuit-breaker structure shall be connected so that the voltage conditions between live parts and earth within the circuit-breaker after arc extinction reproduce the service voltage conditions. The connections used shall be indicated in the test report.

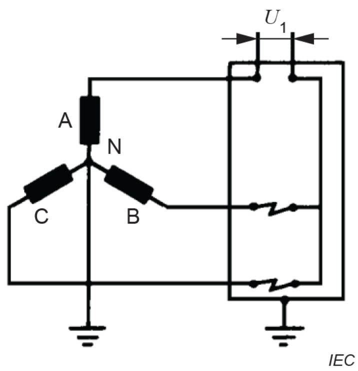



**Circuit**

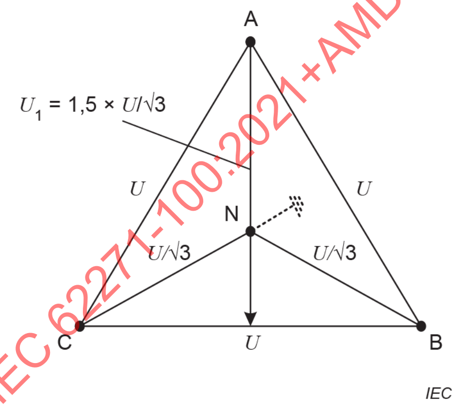



**Vector diagram**

**Figure 27a – Preferred circuit with vector diagram**




**Circuit**




**Vector diagram**

**Figure 27b – Alternative circuit with vector diagram**

**Figure 27 – Earthing of test circuits for three-phase short-circuit tests, $k_{pp}$ = 1,5**

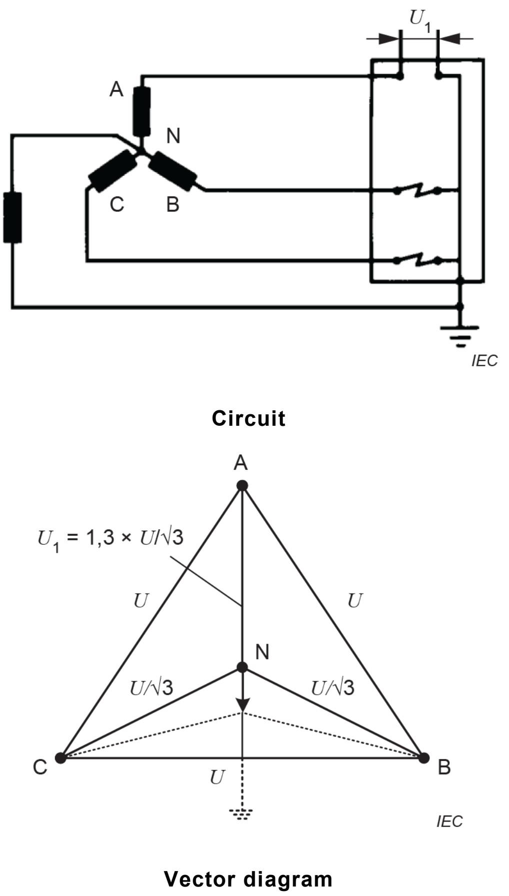



**Figure 28a – Preferred circuit**

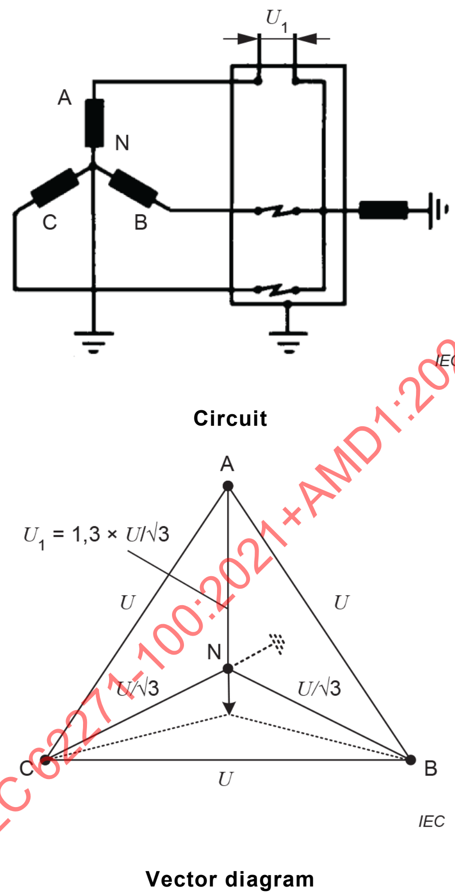



**Figure 28b – Alternative circuit**

**Figure 28 – Earthing of test circuits for three-phase short-circuit tests, $k_{pp}$ = 1,3**

### 7.103.2.3 Connection of test circuit to circuit-breaker

Where the physical arrangement of one side of the circuit-breaker differs from that of the other side, the live side of the test circuit shall be connected for testing to that side of the circuit-breaker which gives the more severe conditions, unless the circuit-breaker is especially designed for feeding from one side only.

Where it cannot be demonstrated satisfactorily which connection gives the more severe conditions, test-duties T10 and T30 shall be made with opposite connections, and likewise for test-duties T100s and T100a. If test-duty T100a is omitted, test-duty T100s shall be made with each of the two connections.

### 7.103.3 Measurement of the TRV during test

During a short-circuit test, the circuit-breaker characteristics such as arc voltage, post-arc conductivity and presence of switching resistors (if any) will affect the TRV. Thus, the test TRV will differ from the prospective TRV-wave of the test circuit upon which the performance requirements are based to a degree depending upon the characteristics of the circuit-breaker.

Methods for the assessment of the TRV characteristics are given in Annex D.

The TRV during the test shall be recorded.

**7.103.4 Power frequency recovery voltage**

The power frequency recovery voltage of the test circuit can be stated as a percentage of the power frequency recovery voltage specified below. It shall not be less than 95 % of the specified value and shall be maintained for at least 0,3 s.

For synthetic test circuits, details and tolerances are given in IEC 62271-101.

For the terminal fault test-duties of 7.107, the power frequency recovery voltage shall be as follows, subject to the 95 % minimum stated above:

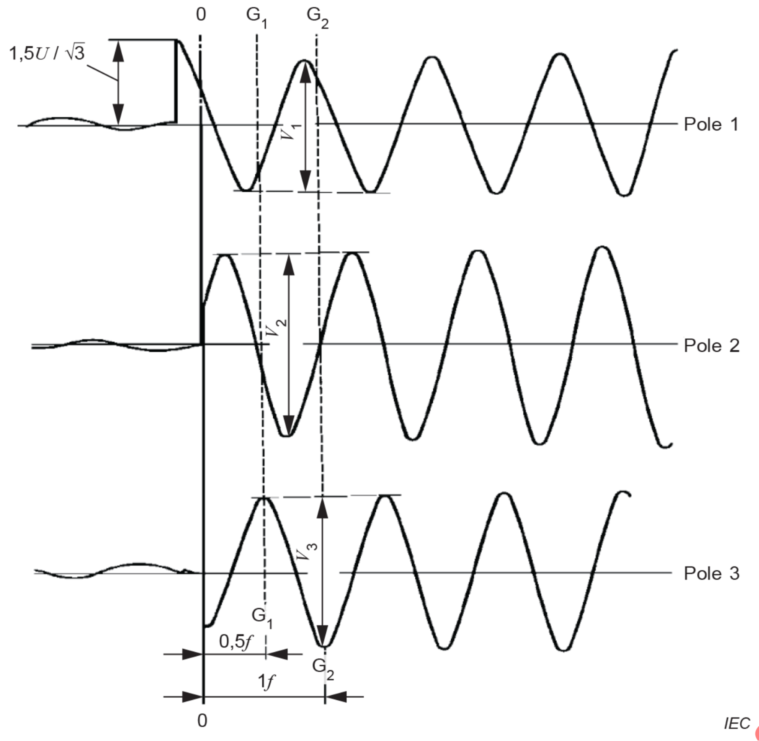
a) For three-phase tests on a three-pole circuit-breaker, the average value of the power frequency recovery voltage shall be equal to the rated voltage $U_r$ of the circuit-breaker divided by √3.

   The power frequency recovery voltage of any pole should not deviate by more than 20 % from the average value at the end of the time for which it is maintained.

   For an effectively earthed neutral system, it shall be proved that the insufficient build-up of dielectric strength in one pole will not lead to prolonged arcing and possible failure. The single-phase test (7.108.2) shall be applied as a demonstration.

b) For single-phase tests on a three-pole circuit-breaker, the power frequency recovery voltage shall be equal to the product of the phase-to-earth value $U_r/\sqrt{3}$ and the first-pole-to-clear factor (1,2, 1,3 or 1,5); the power frequency recovery voltage can be reduced to $U_r/\sqrt{3}$ after an interval of half a cycle of the rated frequency.

The power frequency recovery voltage shall be measured between terminals of a pole in each phase of the test circuit. Its RMS value shall be determined on the oscillogram within the time interval of one half-cycle and one cycle of test frequency after final arc extinction, as indicated in Figure 29. The vertical distance ($V_1$, $V_2$ and $V_3$ respectively) between the peak of the second half-wave and the straight line drawn between the respective peaks of the preceding and succeeding half-waves shall be measured, and this, when divided by 2√2 and multiplied by the appropriate calibration factor, gives the RMS value of the power frequency recovery voltage recorded.




Pole 1 = first-pole-to clear

00 = instant of final arc-extinction on all phases

$G_1G_1$ = instant $\frac{1}{2f}$ from 00

$G_2G_2$ = instant $\frac{1}{f}$ from 00

$f$ = test frequency

$\frac{V_1}{2\sqrt{2}}$ = value of power frequency recovery voltage of Pole 1

$\frac{V_2}{2\sqrt{2}}$ = value of power frequency recovery voltage of Pole 2

$\frac{V_3}{2\sqrt{2}}$ = value of power frequency recovery voltage of Pole 3

In Pole 3 a voltage peak occurs exactly at instant $G_1G_1$. In such event measurement is made at later instant $G_1G_1$

Average value of the power frequency recovery voltages of poles 1, 2 and 3

$$= \frac{\frac{V_1}{2\sqrt{2}} + \frac{V_2}{2\sqrt{2}} + \frac{V_3}{2\sqrt{2}}}{3}$$

The example illustrates three voltages obtained during a test of a three-pole circuit-breaker in a three-phase test circuit having one of its neutral points insulated, see Figure 27a or Figure 27b, thus producing momentarily in the first pole-to-clear a 50 % increase in the recovery voltage, as shown in pole 1.

**Figure 29 – Determination of power frequency recovery voltage**

### 7.103.5 Initial transient recovery voltage (ITRV)

Every part of the TRV wave can influence the making and breaking capability of a circuit-breaker. The very beginning of the TRV can be of importance for some types of circuit-breakers. This part of the TRV, called initial TRV (ITRV), is caused by the initial oscillation of small amplitude due to reflections from the first major discontinuity along the busbar. Standard values are given in Table 9. The explanation of the ITRV parameters is given in 7.105.5.1.

**Table 9 – Standard values of ITRV – Rated voltages 100 kV and above**

| Rated voltage | Multiplying factor to determine $u_i$ as function of the RMS value of the short-circuit breaking current $I_{sc}$ [a] | | Time |
|---|---|---|---|
| $U_r$ | $f_i$ | | $t_i$ |
| kV | kV/kA | | µs |
| | 50 Hz | 60 Hz | |
| 100 | 0,046 | 0,055 | 0,4 |
| 123 | 0,046 | 0,055 | 0,4 |
| 145 | 0,046 | 0,055 | 0,4 |
| 170 | 0,058 | 0,069 | 0,5 |
| 245 | 0,069 | 0,083 | 0,6 |
| 300 | 0,081 | 0,097 | 0,7 |
| 362 | 0,092 | 0,111 | 0,8 |
| 420 | 0,092 | 0,111 | 0,8 |
| 550 | 0,116 | 0,139 | 1,0 |
| 800 | 0,159 | 0,191 | 1,1 |
| 1 100 | 0,173 | 0,208 | 1,5 |
| 1 200 | 0,173 | 0,208 | 1,5 |

[a] The actual initial peak voltages are obtained by multiplying the values in these columns by the RMS value of the short-circuit current.

NOTE These values cover both three-phase and single-phase faults and are based on the assumption that the busbar, including the elements connected to it (supports, current and voltage transformers, disconnectors, etc.), can be roughly represented by a resulting surge impedance $Z_i$ of about 260 Ω with the exception of a rated voltage 800 kV for which the resulting surge impedance $Z_i$ is about 325 Ω. The relation between $f_i$ and $t_i$ is then:

$$f_i = t_i \times Z_i \times \omega \times \sqrt{2}$$

where

$\omega = 2\pi f_r$ is the angular frequency corresponding to the rated frequency $f_r$ of the circuit-breaker.

If a circuit-breaker for use in systems with a rated voltage equal to or less than 800 kV has a short-line fault rating, the ITRV requirements are covered if the short-line fault test-duty $L_{90}$ is carried out using a line with a time delay less than 100 ns (see 7.105.5.2 and 7.109.3) unless both terminals are not identical from an electrical point of view (for instance when an additional capacitance is used as mentioned in 7.109.3). When terminals are not identical from an electrical point of view, test circuits which produce an equivalent TRV stress across the circuit-breaker can be used.

For circuit-breakers for use in systems with a rated voltage higher than 800 kV, the ITRV requirements are considered to be covered if the short-line fault test-duty $L_{90}$ is carried out using a line with a time delay less than 100 ns and a surge impedance of 450 Ω unless both terminals are not identical from an electrical point of view (for instance when an additional capacitance is used as mentioned in 7.109.3). When terminals are not identical from an electrical point of view, test circuits which produce an equivalent TRV stress across the circuit-breaker can be used.

Since the ITRV is proportional to the busbar surge impedance and to the current, the ITRV requirements can be neglected for all circuit-breakers with a rated short-circuit breaking current of less than 25 kA and for circuit-breakers with a rated voltage below 100 kV. In addition the ITRV requirements can be neglected for GIS circuit-breakers because of the low surge impedance. ITRV requirements can also be neglected for circuit-breakers directly connected to a busbar with a total source side capacitance of more than 800 pF.

### 7.104 Demonstration of arcing times

#### 7.104.1 General

The requirements described in this subclause are relevant for the adjustment of prospective arcing times. The actual arcing times can vary from the prospective ones. Tests are valid as long as the actual arcing times are within the tolerances given in Annex B.

The terminal fault tests T100a in 7.104.2.2 and 7.104.3.3 consist of three valid breaking operations independent of the rated operating sequence.

NOTE The arcing times required in this subclause are adequate to cover the effect of the unintentional non-simultaneity of the circuit-breaker poles.

Throughout this subclause the following symbols are used:

$T$ is the duration of one cycle of rated frequency;

$t_{a100s}$ in case of a three-phase test $t_{a100s}$ is the minimum of the arcing times of any first-pole-to-clear during the breaking operations of test-duty T100s;

in case of a single-phase test $t_{a100s}$ is the minimum arcing time of terminal fault test-duty T100s;

$d\alpha$ = 18°;

$\tau$ is the DC time constant of the rated short-circuit breaking current;

$\hat{I}$ the p.u. value of peak of the short-circuit current during the last major or major extended loop prior to breaking;

$\Delta t_1$ is the duration of the last major loop of the first-pole-to-clear;

$\Delta t_2$ is the duration of the major extended loop of the last-pole-to-clear for $k_{pp}$ = 1,5;

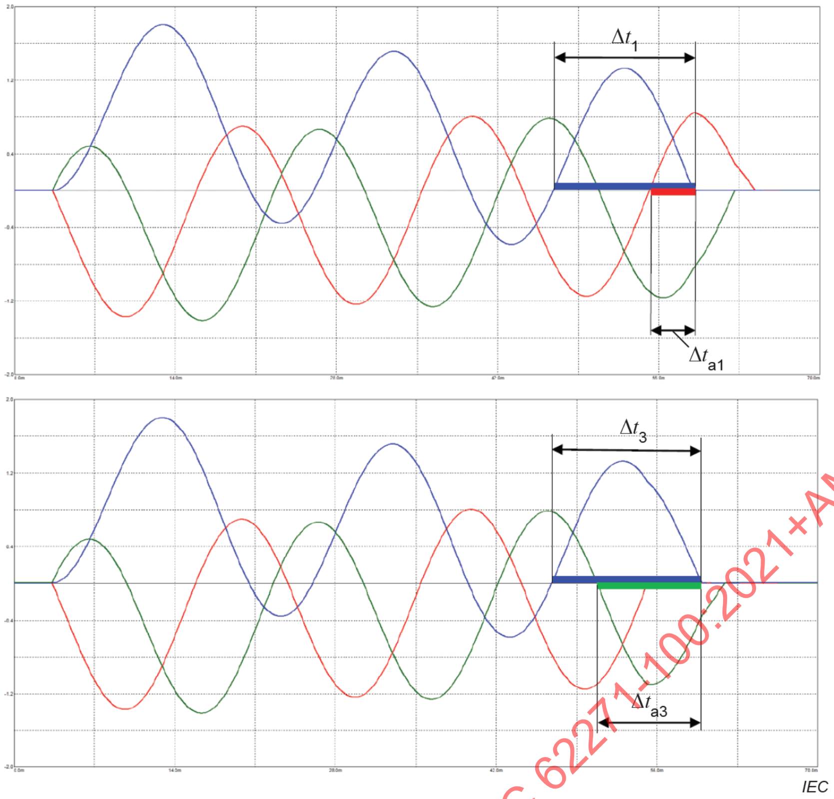
$\Delta t_3$ is the duration of the major extended loop of the second-pole-to-clear for $k_{pp}$ = 1,3 or 1,2;

$\Delta t_{a1}$ is the time interval between the moment of current breaking in the first-pole-to-clear after a major loop with the required asymmetry and the moment of the first preceding current zero;

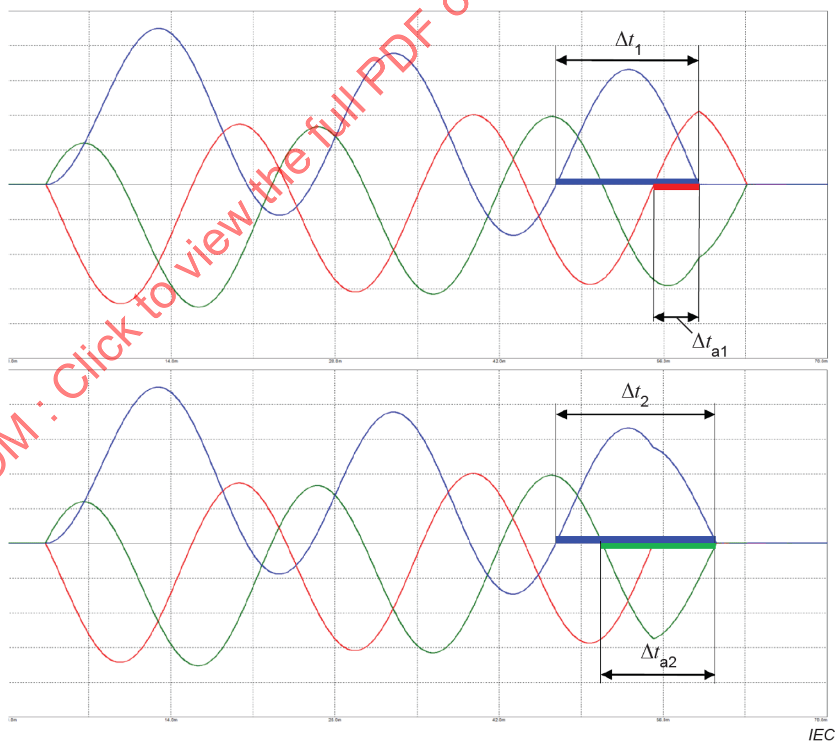
$\Delta t_{a2}$ is the time interval between the moment of current breaking in the last-pole-to-clear after an major extended loop with the required asymmetry for $k_{pp}$ = 1,5 and the moment of the second preceding current zero;

$\Delta t_{a3}$ is the time interval between the moment of current breaking in the second-pole-to-clear after an major extended loop with the required asymmetry for $k_{pp}$ = 1,3 or 1,2 and the moment of the second preceding current zero.

For explanation of $\Delta t_1$, $\Delta t_2$, $\Delta t_3$, $\Delta t_{a1}$, $\Delta t_{a2}$ and $\Delta t_{a3}$ see Figure 30.




a) Time parameters for $k_{pp}$ = 1,2 or 1,3




b) Time parameters for $k_{pp}$ = 1,5

**Figure 30 – Graphical representation of the time parameters for the demonstration of arcing times in three-phase tests of test-duty T100a**

### 7.104.2 Three-phase tests

#### 7.104.2.1 Test-duty T10, T30, T60, T100s, T100s(b)

For these tests, the tripping command shall be advanced by 40 electrical degrees (40°) between each opening operation. For T100s(b), see 7.107.1.

A graphical representation of an example of the three valid breaking operations for $k_{pp}$ = 1,5 is given in Figure 31 and for $k_{pp}$ = 1,3 or 1,2 in Figure 32.

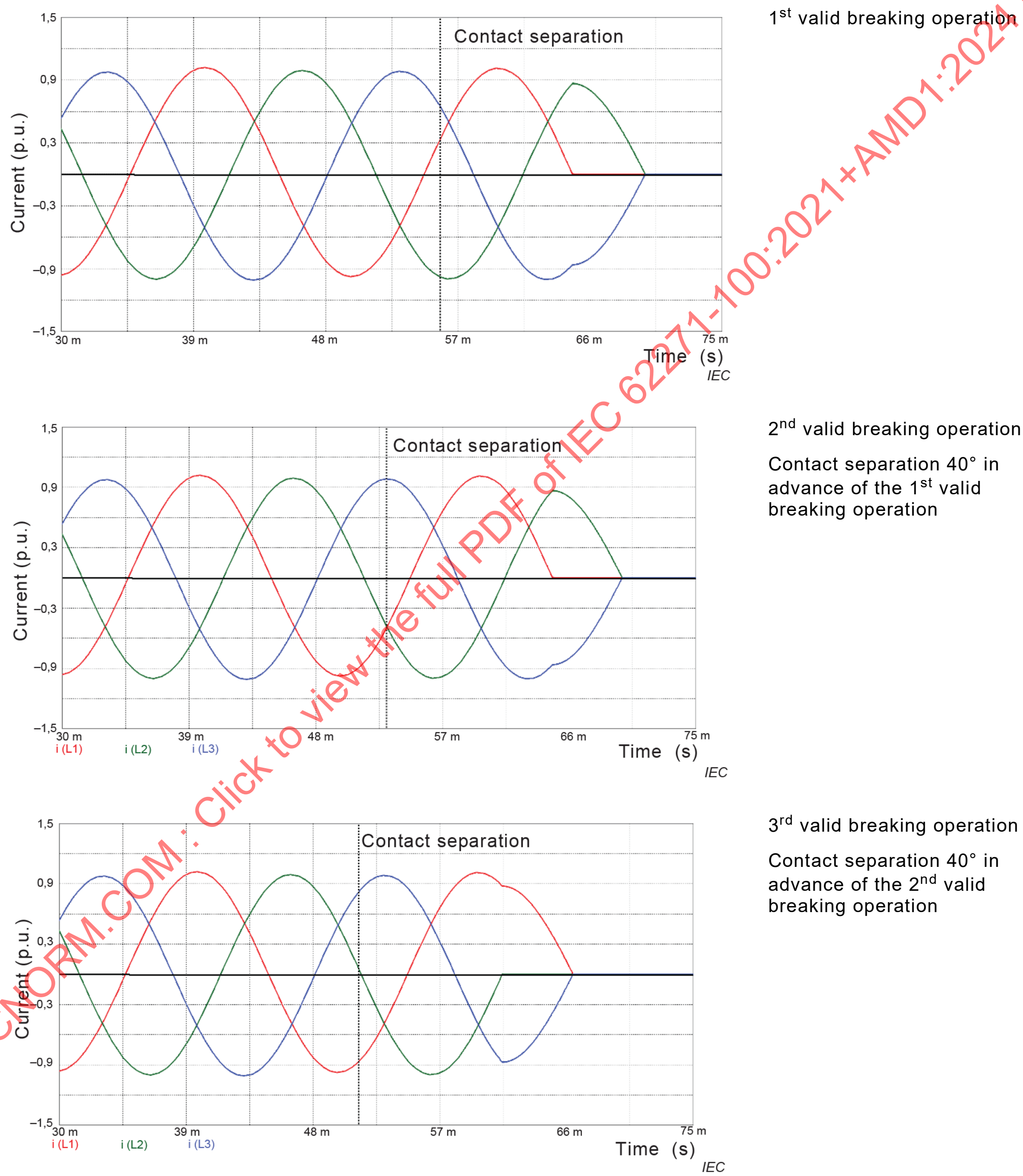
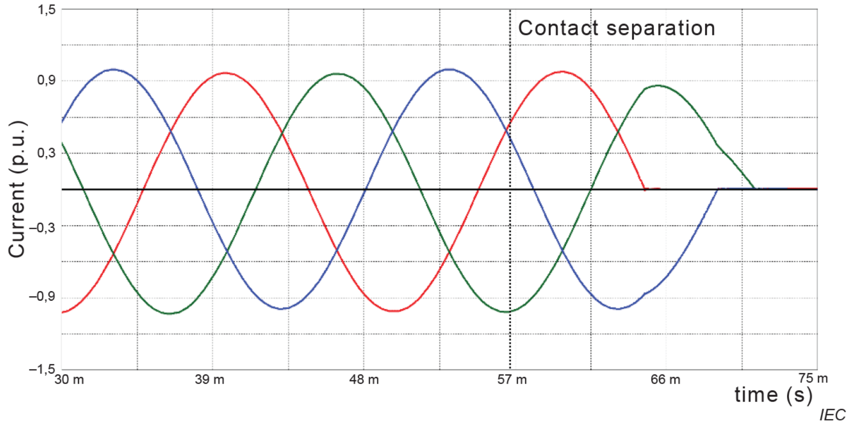
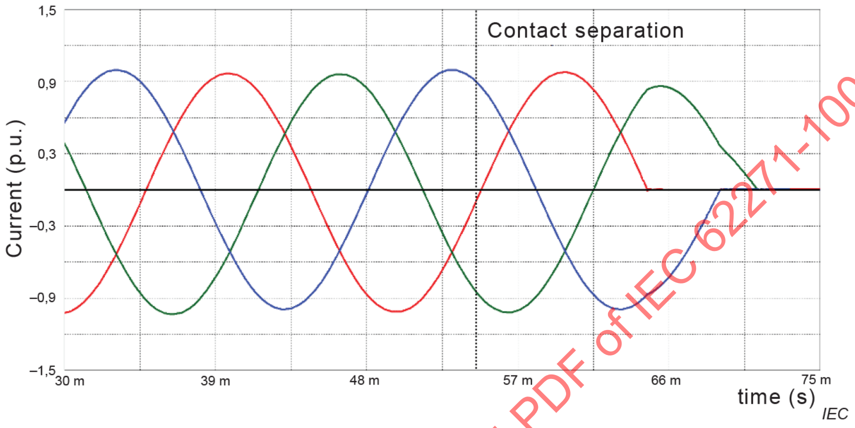



**Figure 31 – Graphical representation of an example of the three valid symmetrical breaking operations for $k_{pp}$ = 1,5**

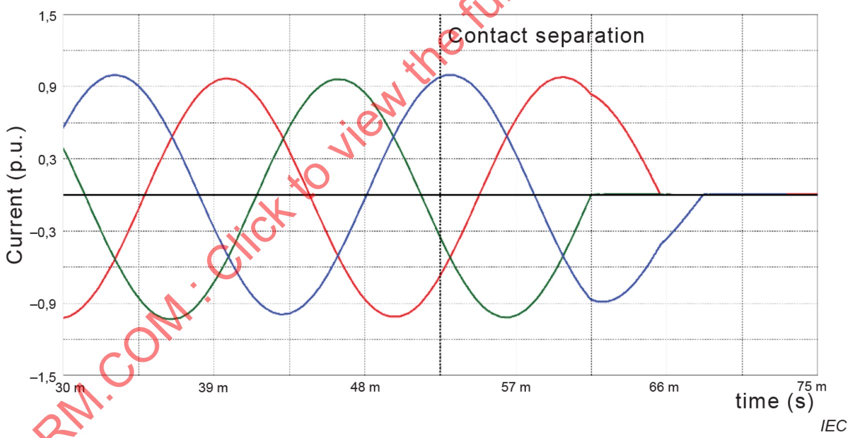



1st valid breaking operation




2nd valid breaking operation

Contact separation 40° in advance of the 1st valid breaking operation




3rd valid breaking operation

Contact separation 40° in advance of the 2nd valid breaking operation



**Figure 32 – Graphical representation of the three valid symmetrical breaking operations for $k_{pp}$ = 1,2 or 1,3**

### 7.104.2.2 Test-duty T100a

The initiation of the short-circuit shall be changed between tests in order to transfer the required asymmetry criteria from phase to phase.

The breaking operations are valid if the prospective current meets the following asymmetry criteria:

– the peak short-circuit current $\hat{I}$ during the last loop prior to breaking is between 90 % and 110 % of the required value; and

– the duration of the short-circuit current loop $\Delta t$ prior to breaking is between 90 % and 110 % of the required value;

– the product "$\hat{I} \times \Delta t$" prior to breaking is between 90 % and 110 % of the required value.

Table 10 and Table 11 give the required prospective values of the peak short-circuit current and loop duration that shall be attained by the last major loop prior to the breaking. In these tables the $k_{pp}$ factors of 1,3 and 1,2 are combined because of very small differences in arcing time requirements.

**Table 10 – Last current loop parameters in three-phase tests and in single-phase tests in substitution for three-phase conditions in relation with short-circuit test-duty T100a – Tests for 50 Hz operation**

| $\tau$ | Minimum clearing time | $\hat{I}$ | $k_{pp}$ = 1,5 , 1,3 or 1,2 | | $k_{pp}$ = 1,5 | | $k_{pp}$ = 1,3 or 1,2 | |
|---|---|---|---|---|---|---|---|---|
| | | | $\Delta t_1$ | $\Delta t_{a1}$ | $\Delta t_2$ | $\Delta t_{a2}$ | $\Delta t_3$ | $\Delta t_{a3}$ |
| ms | ms | p.u. | ms | ms | ms | ms | ms | ms |
| 45 | 10,0 < $t$ ≤ 27,0 | 1,52 | 13,6 | 4,1 | 15,0 | 10,6 | 14,4 | 10,0 |
| | 27,0 < $t$ ≤ 47,5 | 1,33 | 12,2 | 3,8 | 13,7 | 9,8 | 13,1 | 9,1 |
| | 47,5 < $t$ ≤ 68,0 | 1,21 | 11,4 | 3,7 | 12,9 | 9,2 | 12,3 | 8,6 |
| 60 | 10,0 < $t$ ≤ 27,0 | 1,61 | 14,2 | 4,3 | 15,6 | 11,1 | 15,1 | 10,5 |
| | 27,0 < $t$ ≤ 47,5 | 1,44 | 12,9 | 4,0 | 14,3 | 10,2 | 13,8 | 9,6 |
| | 47,5 < $t$ ≤ 67,5 | 1,31 | 12,1 | 3,8 | 13,6 | 9,7 | 12,9 | 9,1 |
| | 67,5 < $t$ ≤ 88,0 | 1,22 | 11,4 | 3,7 | 13,0 | 9,3 | 12,3 | 8,6 |
| 75 | 10,0 < $t$ ≤ 27,0 | 1,67 | 14,8 | 4,4 | 16,1 | 11,3 | 15,6 | 10,8 |
| | 27,0 < $t$ ≤ 47,5 | 1,51 | 13,4 | 4,2 | 14,9 | 10,6 | 14,3 | 10,0 |
| | 47,5 < $t$ ≤ 67,5 | 1,39 | 12,6 | 3,9 | 14,1 | 10,1 | 13,4 | 9,4 |
| | 67,5 < $t$ ≤ 87,5 | 1,30 | 12,0 | 3,8 | 13,5 | 9,7 | 12,8 | 9,0 |
| | 87,5 < $t$ ≤ 108,0 | 1,23 | 11,5 | 3,7 | 13,1 | 9,3 | 12,4 | 8,7 |
| 120 | 10,0 < $t$ ≤ 27,0 | 1,78 | 15,7 | 4,8 | 17,0 | 11,9 | 16,6 | 11,4 |
| | 27,0 < $t$ ≤ 47,0 | 1,66 | 14,6 | 4,4 | 15,9 | 11,3 | 15,3 | 10,8 |
| | 47,0 < $t$ ≤ 67,5 | 1,56 | 13,8 | 4,3 | 15,2 | 10,8 | 14,6 | 10,3 |
| | 67,5 < $t$ ≤ 87,5 | 1,47 | 13,2 | 4,1 | 14,6 | 10,4 | 14,0 | 9,8 |
| | 87,5 < $t$ ≤ 108,0 | 1,40 | 12,6 | 4,0 | 14,1 | 10,1 | 13,5 | 9,5 |

**Table 11 – Last current loop parameters in three-phase tests and in single-phase tests in substitution for three-phase conditions in relation with short-circuit test-duty T100a – Tests for 60 Hz operation**

| $\tau$ | Minimum clearing time | $\hat{I}$ | $k_{pp}$ = 1,5 , 1,3 or 1,2 | | $k_{pp}$ = 1,5 | | $k_{pp}$ = 1,3 or 1,2 | |
|---|---|---|---|---|---|---|---|---|
| | | | $\Delta t_1$ | $\Delta t_{a1}$ | $\Delta t_2$ | $\Delta t_{a2}$ | $\Delta t_3$ | $\Delta t_{a3}$ |
| ms | ms | p.u. | ms | ms | ms | ms | ms | ms |
| 45 | 8,5 < $t$ ≤ 22,5 | 1,58 | 11,6 | 3,5 | 12,8 | 9,1 | 12,4 | 8,6 |
| | 22,5 < $t$ ≤ 39,5 | 1,40 | 10,5 | 3,3 | 11,8 | 8,4 | 11,2 | 7,9 |
| | 39,5 < $t$ ≤ 56,5 | 1,27 | 9,8 | 3,1 | 11,1 | 7,9 | 10,6 | 7,4 |
| | 56,5 < $t$ ≤ 73,0 | 1,19 | 9,3 | 3,0 | 10,7 | 7,6 | 10,1 | 7,1 |
| 60 | 8,5 < $t$ ≤ 22,5 | 1,66 | 12,2 | 3,7 | 13,3 | 9,4 | 12,9 | 9,0 |
| | 22,5 < $t$ ≤ 39,5 | 1,50 | 11,1 | 3,4 | 12,4 | 8,8 | 11,8 | 8,3 |
| | 39,5 < $t$ ≤ 56,5 | 1,38 | 10,4 | 3,3 | 11,7 | 8,3 | 11,2 | 7,8 |
| | 56,5 < $t$ ≤ 73,0 | 1,29 | 9,9 | 3,1 | 11,2 | 8,0 | 10,6 | 7,5 |
| | 73,0 < $t$ ≤ 90,0 | 1,22 | 9,5 | 3,1 | 10,8 | 7,7 | 10,2 | 7,2 |
| 75 | 8,5 < $t$ ≤ 22,5 | 1,72 | 12,6 | 3,8 | 13,7 | 9,6 | 13,3 | 9,2 |
| | 22,5 < $t$ ≤ 39,5 | 1,57 | 11,6 | 3,6 | 12,8 | 9,1 | 12,3 | 8,6 |
| | 39,5 < $t$ ≤ 56,0 | 1,46 | 10,9 | 3,4 | 12,1 | 8,6 | 11,6 | 8,1 |
| | 56,0 < $t$ ≤ 73,0 | 1,37 | 10,3 | 3,2 | 11,6 | 8,3 | 11,1 | 7,8 |
| | 73,0 < $t$ ≤ 90,0 | 1,30 | 9,9 | 3,1 | 11,2 | 8,0 | 10,7 | 7,5 |
| | 90,0 < $t$ ≤ 106,5 | 1,24 | 9,6 | 3,1 | 10,9 | 7,8 | 10,4 | 7,3 |
| 120 | 8,5 < $t$ ≤ 22,5 | 1,81 | 13,4 | 4,1 | 14,4 | 10,1 | 14,1 | 9,7 |
| | 22,5 < $t$ ≤ 39,0 | 1,71 | 12,5 | 3,8 | 13,6 | 9,6 | 13,2 | 9,2 |
| | 39,0 < $t$ ≤ 56,0 | 1,62 | 11,8 | 3,7 | 13,0 | 9,3 | 12,5 | 8,8 |
| | 56,0 < $t$ ≤ 73,0 | 1,54 | 11,3 | 3,5 | 12,5 | 8,9 | 12,0 | 8,5 |
| | 73,0 < $t$ ≤ 89,5 | 1,47 | 10,9 | 3,4 | 12,1 | 8,7 | 11,6 | 8,1 |
| | 89,5 < $t$ ≤ 106,5 | 1,41 | 10,6 | 3,3 | 11,8 | 8,4 | 11,3 | 7,9 |

When the last current loop parameters are within the required tolerances, the resulting deviations on the DC component at current zero, the associated d$i$/d$t$ and the following TRV peak value are within acceptable limits compared to those calculated with rated values.

The intention is to achieve three valid tests and the duty is satisfactory if following conditions are met. There is no preferred order to demonstrate the three valid tests.

a) One operation where arc extinction occurs in the first-pole-to-clear at the end of a major current loop in the phase with the required asymmetry criteria and with the longest possible arcing time.

   The longest possible arcing time $t_{arc1}$ for the first-pole-to-clear is achieved, when following condition is met:

$$t_{arc1} = (t_{a100s} - T \times \frac{d\alpha}{360°}) + \Delta t_{a1}$$

b) One operation where arc extinction occurs at the end of an major extended loop in the last-pole-to-clear or in the second-pole-to-clear with the required asymmetry criteria and with the longest possible arcing time.

– The longest possible arcing time $t_{arc2}$ for the last-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,5 is achieved, when following condition is met:

$$t_{arc2} = (t_{a100s} - T \times \frac{d\alpha}{360°}) + \Delta t_{a2}$$

– The longest possible arcing time $t_{arc3}$ for the second-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2 is achieved, when following condition is met:

$$t_{arc3} = (t_{a100s} - T \times \frac{d\alpha}{360°}) + \Delta t_{a3}$$

c) If the required conditions of a) and b) are fulfilled, arc extinction for the third operation can occur at the end

– of a major current loop for first-pole-to-clear conditions, or

– of a major extended loop for last-pole-to-clear conditions for circuit-breakers rated for $k_{pp}$ = 1,5, or

– of a major extended loop for second-pole-to-clear conditions for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2.

There are no further requirements regarding arcing times.

$\Delta t_{a1}$, $\Delta t_{a2}$ and $\Delta t_{a3}$ are the relevant time parameters to be selected from Table 10 and Table 11.

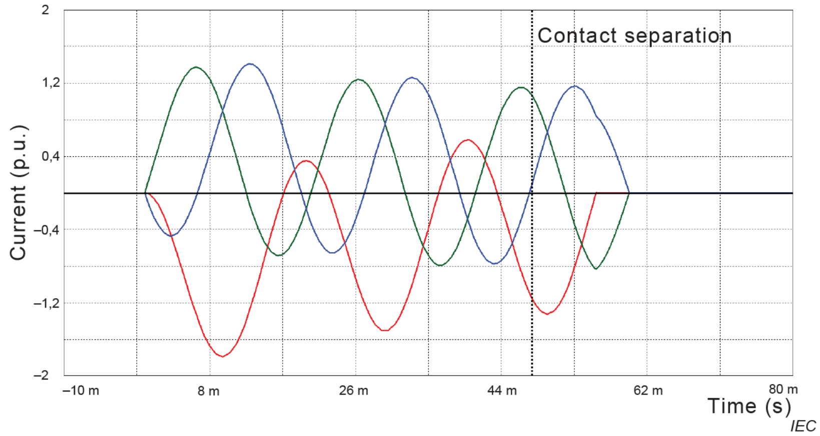
The conditions for current breaking in test-duty T100a for the last-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2 are covered by the tests in test-duty T100s.

Some circuit-breakers will not clear at the end of a major loop or a major extended loop after the required arcing time. However, this test is valid if the circuit-breaker cleared the subsequent minor current loop and it is proven that the longest possible arc-duration was achieved.

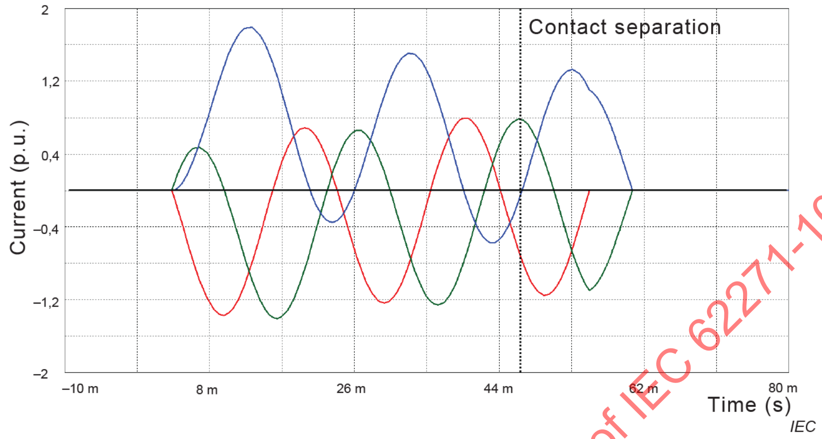
If the behaviour of the circuit-breaker is such that the required conditions of a) and b) are not fulfilled, the test-duty shall be continued by changing the tripping command of the circuit-breaker in steps of 18°. If during tests the required arcing times are not achieved because of minimum arcing times differing from $t_{a100s}$ the maximum achievable arcing times shall be demonstrated. The total number of tests is limited to 6, when attempting to meet the requirements. After these six tests, the test-duty is valid no matter which arcing times have been obtained.

The circuit-breaker can be reconditioned with renewable parts or replaced by a second one before the extended operations (see 7.102.9.6).

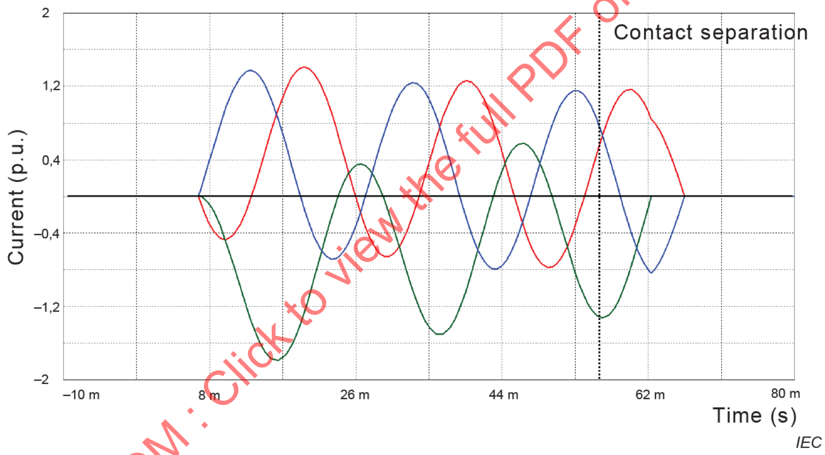
A graphical representation of an example of the three valid breaking operations for $k_{pp}$ = 1,5 is given in Figure 33 and for $k_{pp}$ = 1,3 or 1,2 in Figure 34.



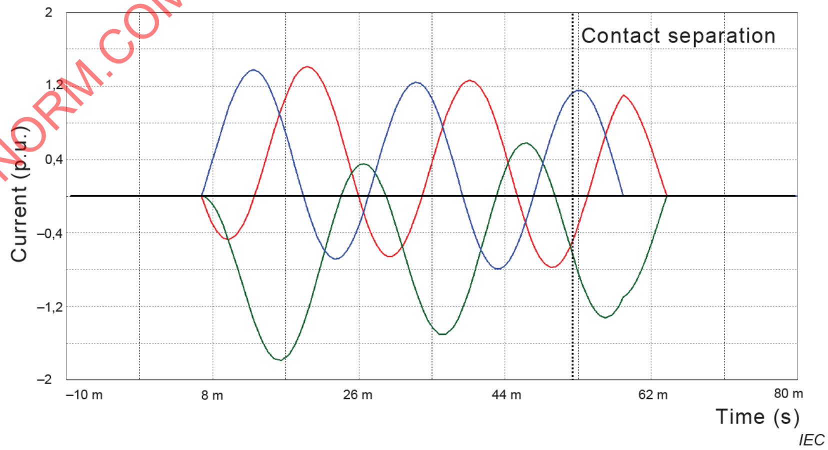

1st valid breaking operation
First-pole-to-clear on a major loop with the required maximum arcing time
(assumption $t_{a100s}$ = 5 ms)




2nd valid breaking operation
Current initiation delayed 60° from that of the first breaking operation
Last-pole-to-clear on an major extended loop with the required maximum arcing time

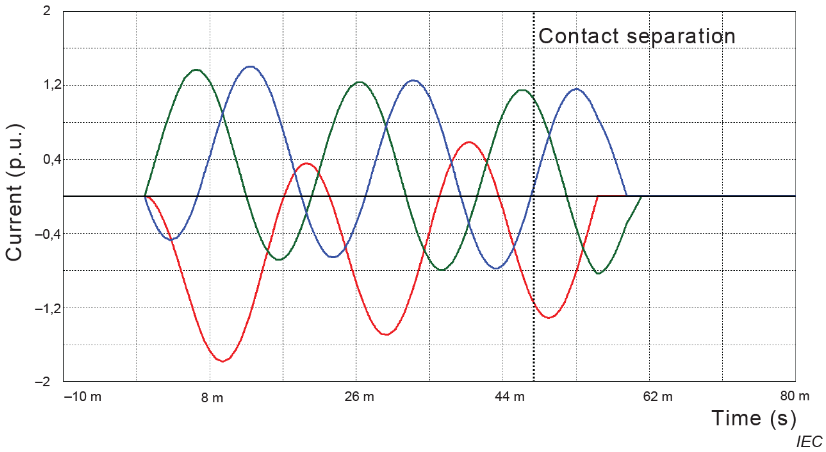



3rd valid breaking operation, option 1
Current initiation delayed 60° from that of the second breaking operation
First-pole-to-clear on a major loop, no requirement regarding arcing time

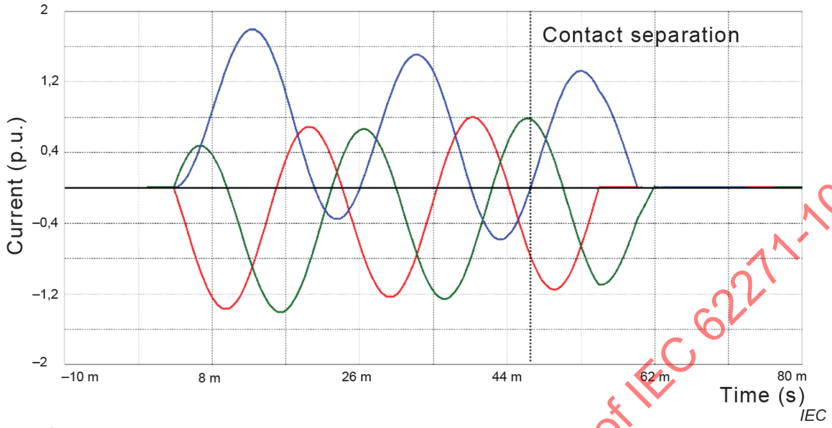



3rd valid breaking operation, option 2
Current initiation delayed 60° from that of the second breaking operation
Last-pole-to-clear on a major extended loop, no requirement regarding arcing time

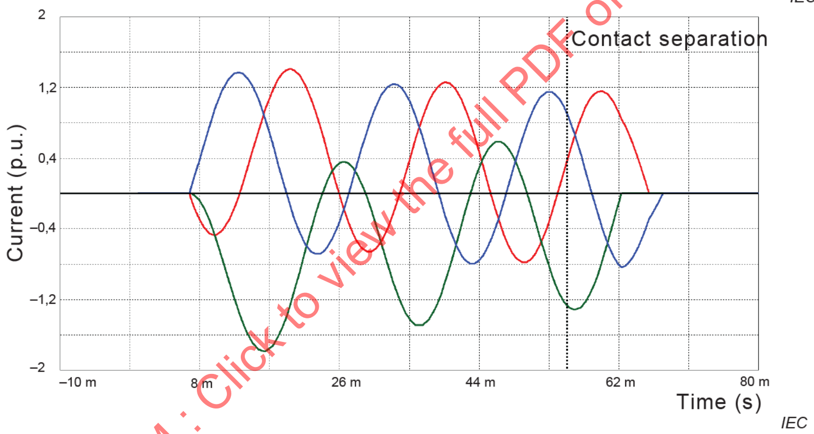
**Figure 33 – Graphical representation of an example of the three valid asymmetrical breaking operations for $k_{pp}$ = 1,5**



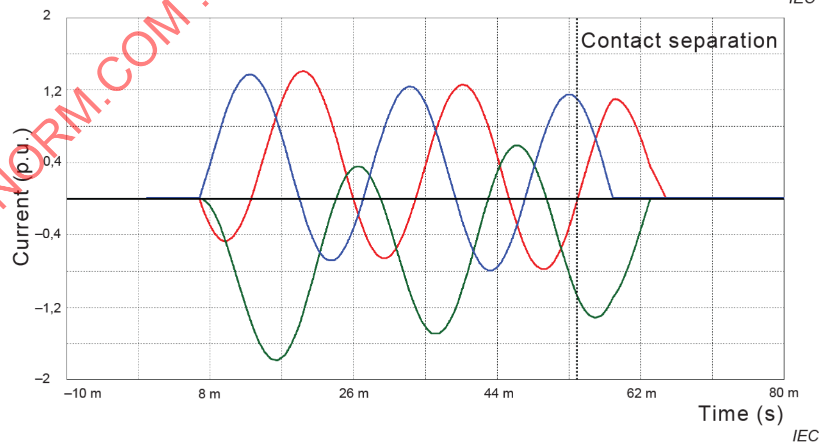

1st valid breaking operation
First-pole-to-clear on a major loop with the required maximum arcing time
(assumption $t_{a100s}$ = 5 ms)




2nd valid breaking operation
Current initiation delayed 60° from that of the first breaking operation
Second-pole-to-clear on an major extended loop with the required maximum arcing time




3rd valid breaking operation, option 1
Current initiation delayed 60° from that of the second breaking operation
First-pole-to-clear on a major loop, no requirement regarding arcing time




3rd valid breaking operation, option 2
Current initiation delayed 60° from that of the second breaking operation
Second-pole-to-clear on an major extended loop, no requirement regarding arcing time

**Figure 34 – Graphical representation of an example of the three valid asymmetrical breaking operations for $k_{pp}$ = 1,2 or 1,3**

### 7.104.2.3 Tests covering the conditions for $k_{pp}$ = 1,3 and $k_{pp}$ = 1,5

In order to cover the performance for $k_{pp}$ = 1,3 and $k_{pp}$ = 1,5, two separate series of duties with their specific earthing of test circuits as described in 7.103.2.2 should be performed.

If a complete series of test-duties demonstrating the circuit-breaker performance for $k_{pp}$ = 1,5 is already performed, it is not necessary to repeat all terminal fault test-duties required by this document for demonstrating the performance of the circuit-breaker for $k_{pp}$ = 1,3. In that case, test-duties T100s and T100a shall be repeated with a test-circuit simulating $k_{pp}$ = 1,3, see 7.103.2.2.

The repetition of test-duties T100s and T100a with a three-phase circuit for $k_{pp}$ = 1,3 can, as an alternative, be replaced by additional single-phase tests specified below. In this case the three-phase verification test according to 7.102.4.1 is not required. Single-phase tests are allowed for all types of circuit-breakers except for metal-enclosed circuit-breakers with three phases in one enclosure where direct gas dynamic interaction between phases is involved, as per 7.102.3.2 and H.4.1.

The tests shall be carried out with the following parameters:

– a first test shall demonstrate the performance of the second-pole-to-clear under symmetrical fault conditions in an effectively earthed neutral system. The arcing time shall be set to:

$$t_{arc} = t_{a100s} + T \times \frac{119°}{360°}$$

The TRV parameters shall be adjusted in accordance with Table 12.

The test voltage is 1,26 × $U_r/\sqrt{3}$ and can be reduced to $U_r/\sqrt{3}$ after one half cycle of rated frequency after current breaking.

**Table 12 – Prospective TRV parameters for single-phase tests in substitution for three-phase tests to demonstrate the breaking of the second-pole-to-clear for $k_{pp}$ = 1,3**

| $K_{pp}$ | Rated voltage | | | | | |
|---|---|---|---|---|---|---|
| | $U_r$ < 100 kV<br>2-parameter-TRV | | $U_r$ ≥ 100 kV<br>4-parameter-TRV | | | |
| | $u_{c,sp}$ | $t_{3,sp}$ | $u_{1,sp}$ | $t_{1,sp}$ | $u_{c,sp}$ | $t_{2,sp}$ |
| 1,3 | $1{,}26 \times k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $\frac{u_{c,sp}}{\frac{u_c}{t_3} \times 0{,}95}$ | $0{,}95 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $\frac{u_{1,sp}}{\frac{u_1}{t_1} \times 0{,}95}$ | $1{,}26 \times k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | a |

[a] 4 × $t_{1,sp}$ for rated voltages from 100 kV up to and including 800 kV.

– a second test shall demonstrate the performance of the third-pole-to-clear under symmetrical fault conditions in an effectively earthed neutral system. The arcing time shall be set to:

$$t_{arc} = t_{a100s} + T \times \frac{162°}{360°}$$

The TRV-parameters shall be adjusted according to Table 13:

**Table 13 – Prospective TRV parameters for single-phase tests in substitution for three-phase tests to demonstrate the breaking of the third-pole-to-clear for $k_{pp}$ = 1,3**

| $k_{pp}$ | Rated voltage | | | | | |
|---|---|---|---|---|---|---|
| | $U_r$ < 100 kV<br>2-parameter-TRV | | $U_r$ ≥ 100 kV<br>4-parameter-TRV | | | |
| | $u_{C,sp}$ | $t_{3,sp}$ | $u_{1,sp}$ | $t_{1,sp}$ | $u_{C,sp}$ | $t_{2,sp}$ |
| 1,3 | $k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $\frac{u_{c,sp}}{\frac{u_c}{t_3} \times 0{,}7}$ | $0{,}75 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $\frac{u_{1,sp}}{\frac{u_1}{t_1} \times 0{,}7}$ | $k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | a |

[a] 4 × $t_{1,sp}$ for rated voltages from 100 kV up to and including 800 kV, 3 × $t_{1,sp}$ for rated voltages above 800 kV.

The single-phase tests with symmetrical currents can be combined using the prospective TRV peak value required for the second-pole-to-clear with the arcing time required for the third-pole-to-clear.

– an additional single-phase fault test with an asymmetrical current that fulfils the asymmetry criteria as defined in 7.104.2.2 shall be performed. This additional test demonstrates the performance of the second and third-pole-to-clear under asymmetrical fault current on the major extended loop.

The test voltage to be applied is 1,26 × $U_r/\sqrt{3}$ for the verification of $k_{pp}$ = 1,3;

and can be reduced to $U_r/\sqrt{3}$ after one quarter of a cycle of rated frequency after current breaking.

When the last current loop parameters are within the required tolerances, the resulting deviations on the DC component at current zero, the associated d$i$/d$t$ and the following TRV peak value are within acceptable limits compared to those calculated with rated values.

The arcing time shall be the maximum arcing time calculated for a three-phase condition considering the minimum arcing time value found during test-duty T100s performed for $k_{pp}$ = 1,5.

$$t_{arc} = (t_{a100s} - T \times \frac{d\alpha}{360°}) + \Delta t_{a3}$$

where

$\Delta t_{a3}$ is the relevant time parameter to be selected from Table 10 and Table 11.

### 7.104.3 Single-phase tests in substitution for three-phase conditions, out-of-phase and short-line fault tests

#### 7.104.3.1 General

The procedure for establishing a minimum arcing time might result in a test with maximum arcing time or with an arcing time in excess of the maximum arcing time. The aim of the following single-phase tests is to satisfy the conditions of the first-pole-to-clear, the second-pole-to-clear and the last pole-to-clear for each test-duty in one test circuit.

The following procedures are applicable if all operations of the rated operating sequence fulfil the requirements of 6.101.

#### 7.104.3.2 Test-duties T10, T30, T60, T100s and T100s(b), OP1 and OP2, $L_{90}$, $L_{75}$ and $L_{60}$

Each test-duty shall consist of three valid breaking operations. The order of the breaking operations of each test-duty is not specified.

A valid breaking operation shall demonstrate breaking with an arcing time as small as possible. The resultant arcing time is known as the minimum arcing time ($t_{arc\ min}$). This is established when any extra delay in the contact separation with respect to the current waveform results in breaking at the next current zero. This minimum arcing time is found by changing the setting of the tripping command by steps of 18°.

Another valid breaking operation shall demonstrate breaking with the maximum arcing time. The required maximum arcing time is known as $t_{arc\ max}$ and is determined as follows:

– for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2 and short-line fault tests, by

$$t_{arc\ max} = t_{arc\ min} + T \times \frac{162°}{360°};$$

– for circuit-breakers rated for $k_{pp}$ = 1,5, by

$$t_{arc\ max} = t_{arc\ min} + T \times \frac{132°}{360°};$$

where

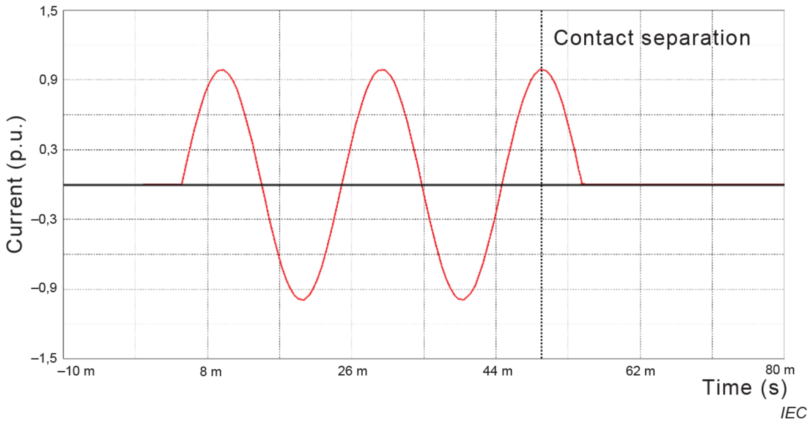
$t_{arc\ min}$ is the minimum arcing time obtained from the first valid operation.

Another valid breaking operation shall demonstrate breaking with an arcing time which is approximately equal to the average value of the minimum arcing time and the required maximum arcing time. This arcing time is known as the medium arcing time ($t_{arc\ med}$) and is determined by

$$t_{arc\ med} = (t_{arc\ max} + t_{arc\ min})/2$$

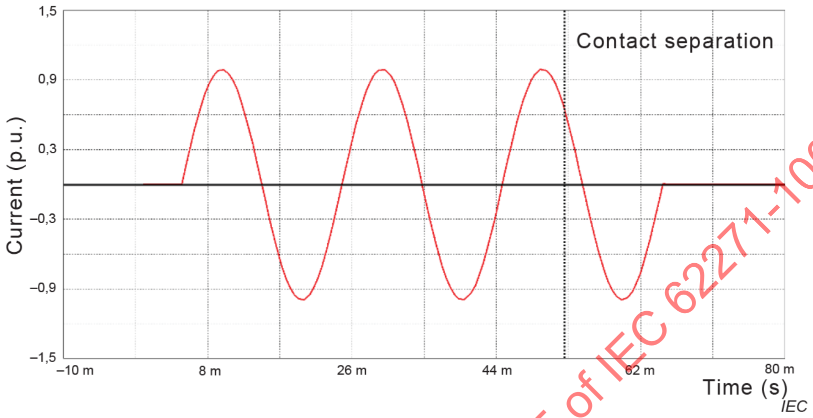
If the circuit-breaker does not interrupt at the expected current zero with medium and/or maximum arcing time but at a subsequent current zero no additional testing is required.

A graphical representation of an example of the three valid breaking operations for $k_{pp}$ = 1,5 is given in Figure 35 and for $k_{pp}$ = 1,3 or 1,2 in Figure 36.



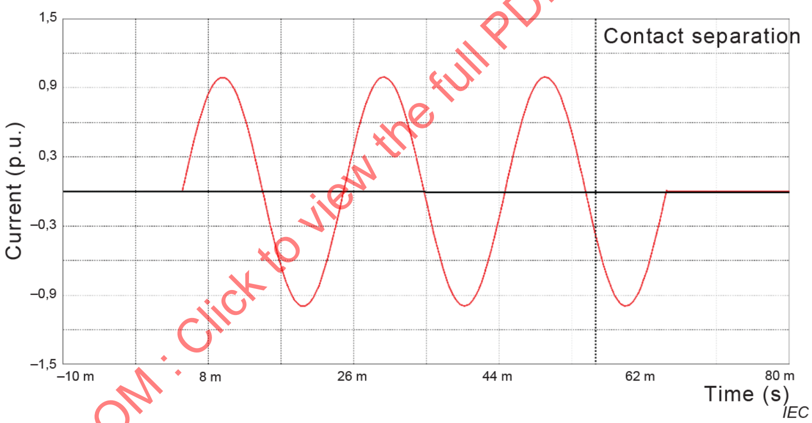

1st valid breaking operation

Minimum arcing time




2nd valid breaking operation

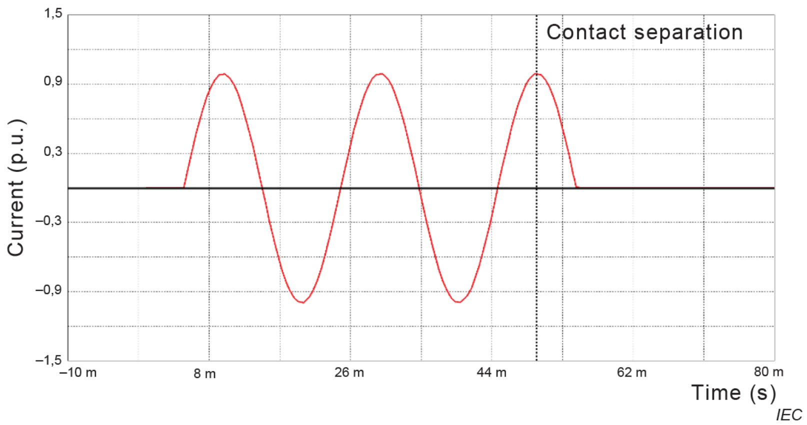
Maximum arcing time




3rd valid breaking operation

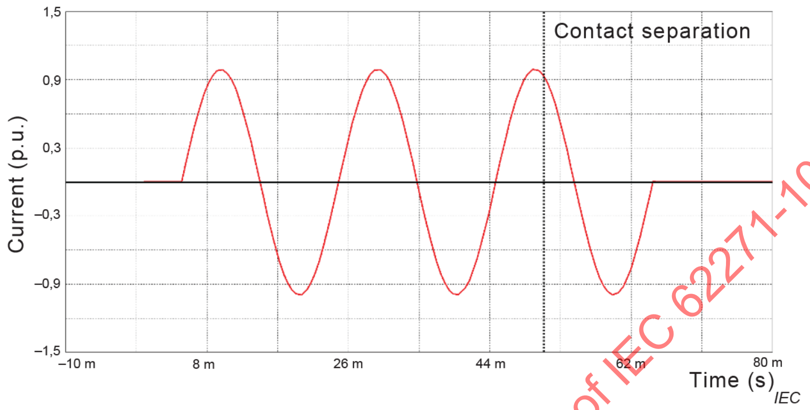
Medium arcing time

**Figure 35 – Example of a graphical representation of the three valid symmetrical breaking operations for single-phase tests in substitution of three-phase conditions for $k_{pp}$ = 1,5**



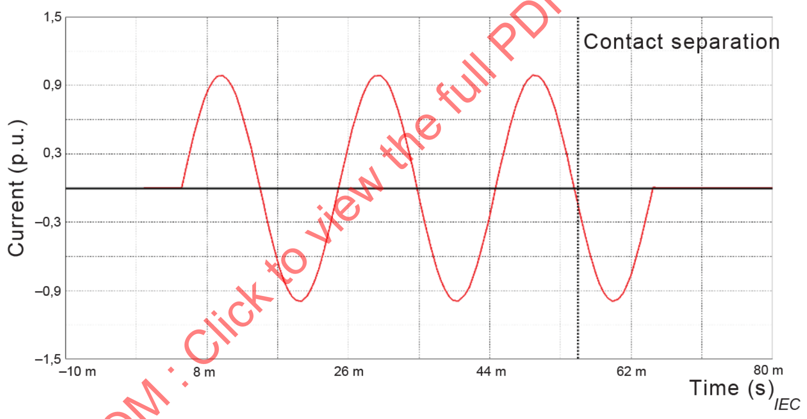

1st valid breaking operation

Minimum arcing time




2nd valid breaking operation

Maximum arcing time




3rd valid breaking operation

Medium arcing time

**Figure 36 – Example of a graphical representation of an example of the three valid symmetrical breaking operations for single-phase tests in substitution of three-phase conditions for $k_{pp}$ = 1,2 or 1,3**

### 7.104.3.3 Test-duty T100a

The breaking operations are valid if the prospective current meets the following asymmetry criteria as given in 7.104.2.2.

Table 10 and Table 11 give the required values of the peak short-circuit current and loop duration that shall be attained by the last loop prior to the intended breaking. All tests shall be performed with the current parameters of the first-pole-to-clear.

A breaking operation shall demonstrate breaking at the end of the major loop with an arcing time equivalent to the maximum arcing time under three-phase conditions $t_{arc1}$ of the first-pole-to-clear.

This is achieved, when following condition is met:

$$t_{arc1} = t_{a100s} + \Delta t_{a1} - T \times \frac{d\alpha}{360°}$$

Another breaking operation shall demonstrate breaking at the end of the major loop with an arcing time equivalent to the maximum arcing time of the major extended loop under three-phase conditions

– $t_{arc2}$ for the last-pole-to clear of circuit-breakers rated for $k_{pp}$ = 1,5

  This is achieved, when following condition is met:

$$t_{arc2} = t_{a100s} + \Delta t_{a2} - T \times \frac{d\alpha}{360°}$$

– $t_{arc3}$ for the second-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,3 or 1,2.

  This is achieved, when following condition is met:

$$t_{arc3} = t_{a100s} + \Delta t_{a3} - T \times \frac{d\alpha}{360°}$$

$\Delta t_{a1}$, $\Delta t_{a2}$ and $\Delta t_{a3}$ are the relevant time parameters to be selected from Table 10 and Table 11.

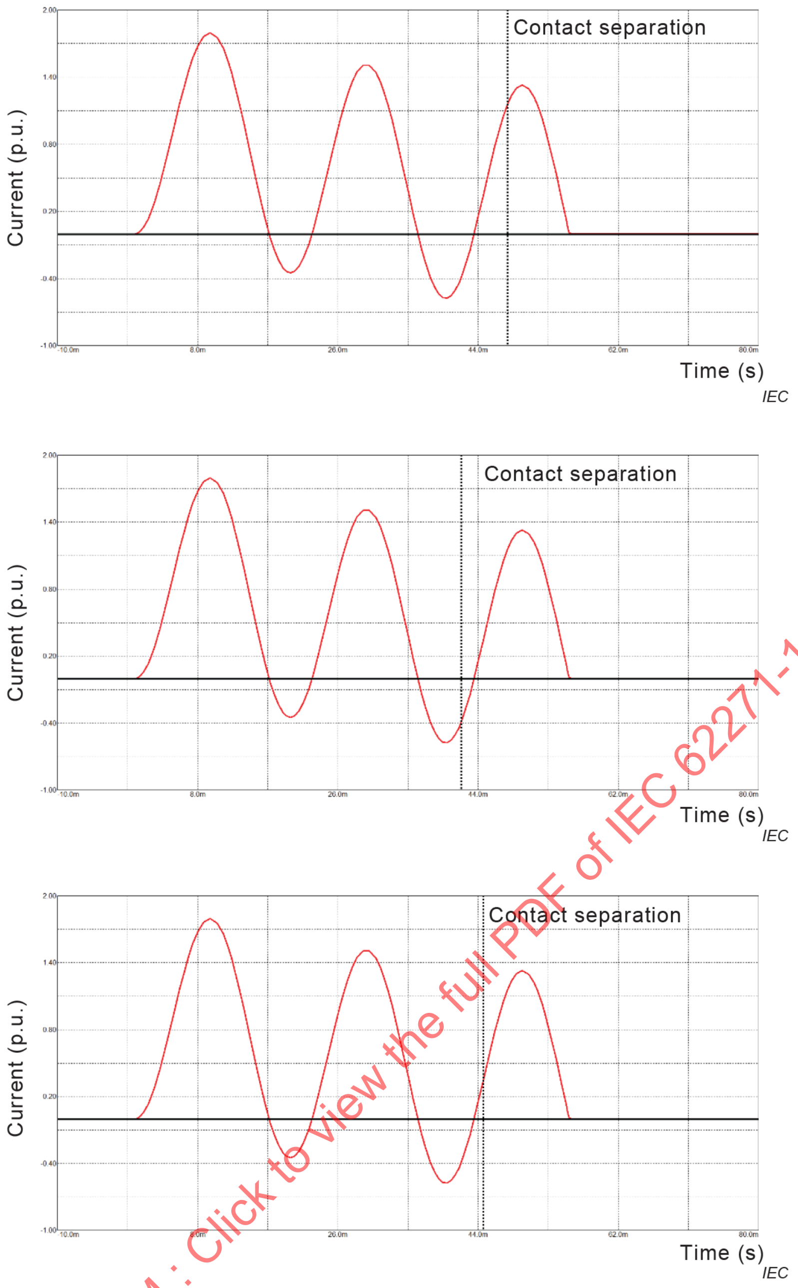
Another breaking operation shall demonstrate the conditions of breaking after a major loop as first-pole-to-clear or after a major extended loop as last-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,5 or after a major extended loop as second-pole-to-clear for circuit-breakers rated for $k_{pp}$ = 1,2 or 1,3. There are no further requirements regarding arcing times.

If the circuit-breaker fails to interrupt after the required major loop and interrupts after the subsequent minor loop, the required maximum arcing time is extended by the duration of this minor loop.

If the behaviour of the circuit-breaker is such that the required arcing times are not achieved, the test-duty shall be continued by changing the tripping command of the circuit-breaker in steps of 18°. If during tests the required arcing times are not achieved because of minimum arcing times differing from T100s, the maximum achievable arcing times shall be demonstrated. The total number of tests is limited to 6, when attempting to meet the requirements. After 6 tests the test-duty is valid regardless of the arcing times that have been obtained.

The circuit-breaker can be reconditioned with renewable parts before the extended operations (see 7.102.9.6). Another test sample can also be used for the extended operations.

A graphical representation of an example of the three valid breaking operations for $k_{pp}$ = 1,5 is given in Figure 37 and for $k_{pp}$ = 1,3 and 1,2 in Figure 38.




1st valid breaking operation

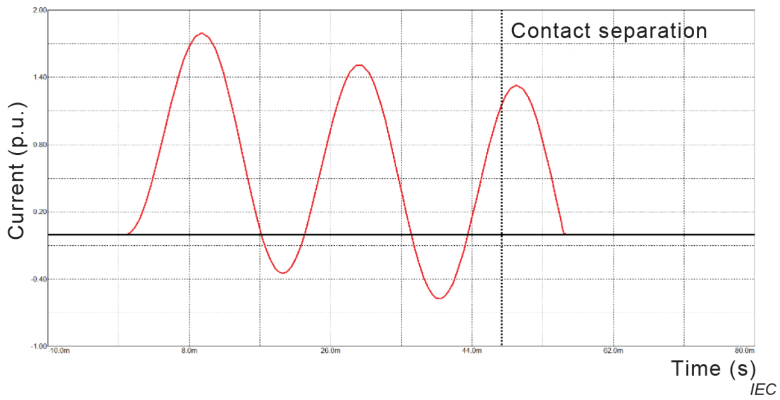
Demonstration of maximum arcing time for first-pole-to-clear conditions

2nd valid breaking operation

Demonstration of maximum arcing time for last-pole-to-clear conditions

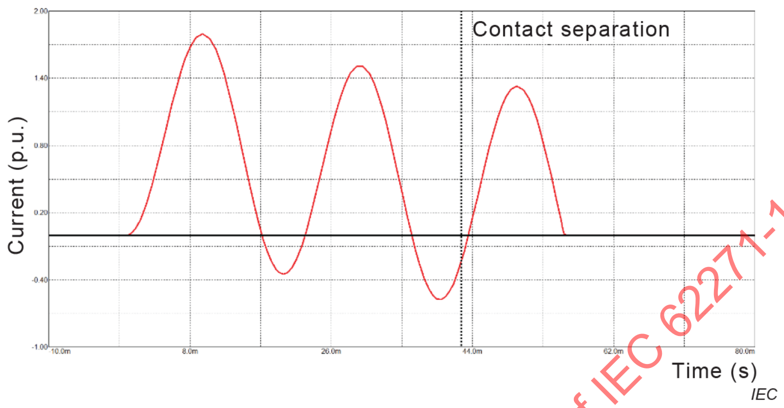
3rd valid breaking operation

**Figure 37 – Example of a graphical representation of an example of the three valid asymmetrical breaking operations for single-phase tests in substitution of three-phase conditions for $k_{pp}$ = 1,5**



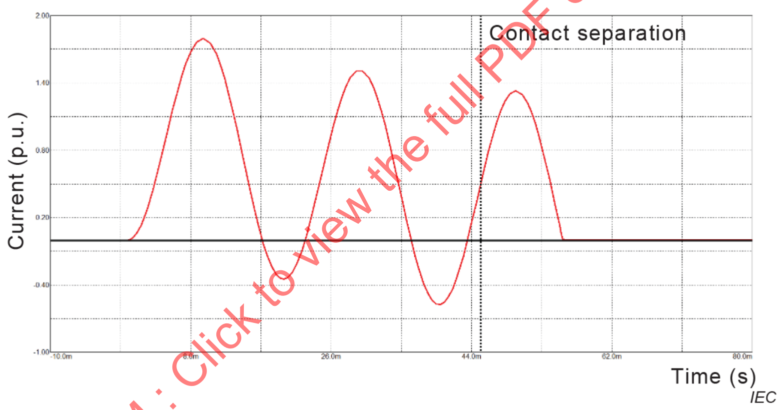

1st valid breaking operation

Demonstration of maximum arcing time for first-pole-to-clear conditions




2nd valid breaking operation

Demonstration of maximum arcing time for second-pole-to-clear conditions




3rd valid breaking operation

**Figure 38 – Example of a graphical representation of an example of the three valid asymmetrical breaking operations for single-phase tests in substitution of three-phase for $k_{pp}$ = 1,2 and 1,3**

### 7.104.3.4 Tests covering the conditions for $k_{pp}$ = 1,5 and $k_{pp}$ = 1,3

Both conditions, $k_{pp}$ = 1,5 and $k_{pp}$ = 1,3 can be combined in one test series. The transient and power frequency voltages to be used shall be those applicable to a non-effectively earthed neutral system and the arcing times shall be those applicable to an effectively earthed neutral system.

For test-duty T100a the arcing times shall be those applicable to a non-effectively earthed neutral system.

#### 7.104.3.5 Splitting of test-duties in test series taking into account the associated TRV for each pole-to-clear

It is recognised that single-phase tests in substitution of three-phase conditions are more severe than three-phase tests because the arcing time of the last-pole-to-clear is used together with the prospective TRV of the first-pole-to-clear. As an alternative, the manufacturer can choose to split each test-duty into two or three separate test series, each test series demonstrating a successful breaking with the minimum and maximum arcing times for each pole-to-clear with its associated prospective TRV. The standard multipliers for the prospective TRV values for the second and third clearing poles are given in Table 14. They are applicable for test-duties T10, T30, T60, T100s, OP1 and OP2.

**Table 14 – Standard multipliers for TRV values for second and third clearing poles**

| First-pole-to-clear factor $k_{pp}$ | Multipliers | | | |
|---|---|---|---|---|
| | 2nd clearing pole | | 3rd clearing pole | |
| | RRRV | $u_c$ | RRRV | $u_c$ |
| 1,2 (terminal fault)<br>2,0 (out-of-phase) | 0,95 | 0,95 | 0,83 | 0,83 |
| 1,3 (terminal fault)<br>2,0 (out-of-phase) | 0,95 | 0,97 | 0,70 | 0,77 |
| 1,5 (terminal fault)<br>2,5 (out-of-phase) | 0,70 | 0,58 | 0,70 | 0,58 |

Reconditioning of the circuit-breaker is permitted after a minimum of three breakings and shall comply with the requirements of 7.102.9.6.

Assuming that the simultaneity of poles during all operations of the rated operating sequence is within the tolerances of 6.101, for tests with symmetrical current the arcing window for each phase is within the band stated in Table 15, if the instant of breaking for the first clearing pole with the minimum arcing time is taken as reference. A graphical representation of the arcing window and the pole factor $k_p$, determining the TRV of the individual pole, is given for terminal fault in Figure 39 and Figure 40 for systems with a $k_{pp}$ of 1,2 and 1,3 and in Figure 41 for systems with a $k_{pp}$ of 1,5.

**Table 15 – Arcing window for tests with symmetrical current**

| First-pole-to-clear factor | First clearing pole<br>° | Second clearing pole<br>° | Third clearing pole<br>° |
|---|---|---|---|
| 1,5 (Terminal fault)<br>2,5 (Out-of-phase) | 0 to 42 | 90 to 132 | 90 to 132 |
| 1,3 (Terminal fault)<br>2,0 (Out-of-phase) | 0 to 42 | 77 to 119 | 120 to 162 |
| 1,2 (Terminal fault)<br>2,0 (Out-of-phase) | 0 to 42 | 71 to 113 | 120 to 162 |

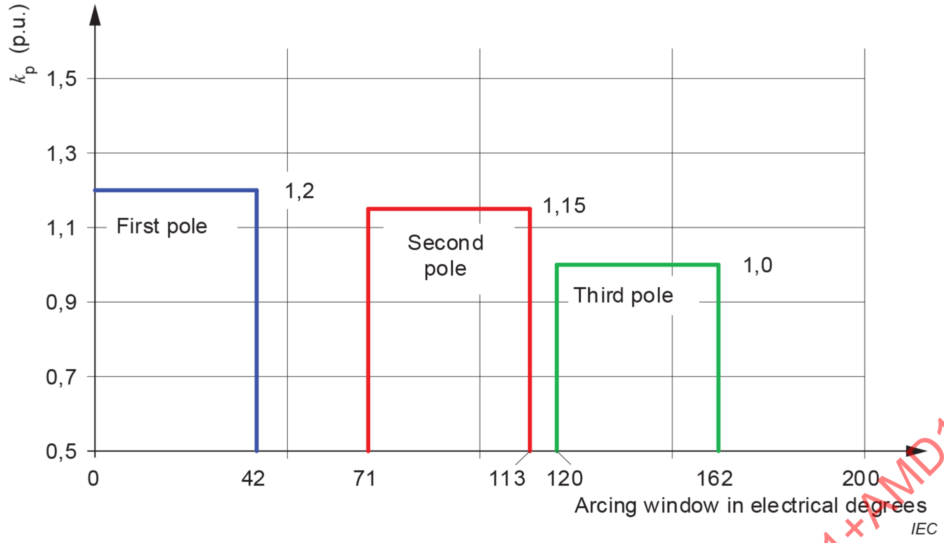



**Figure 39 – Graphical representation of the arcing window and the pole factor $k_p$, determining the TRV of the individual pole, for systems with a $k_{pp}$ of 1,2**

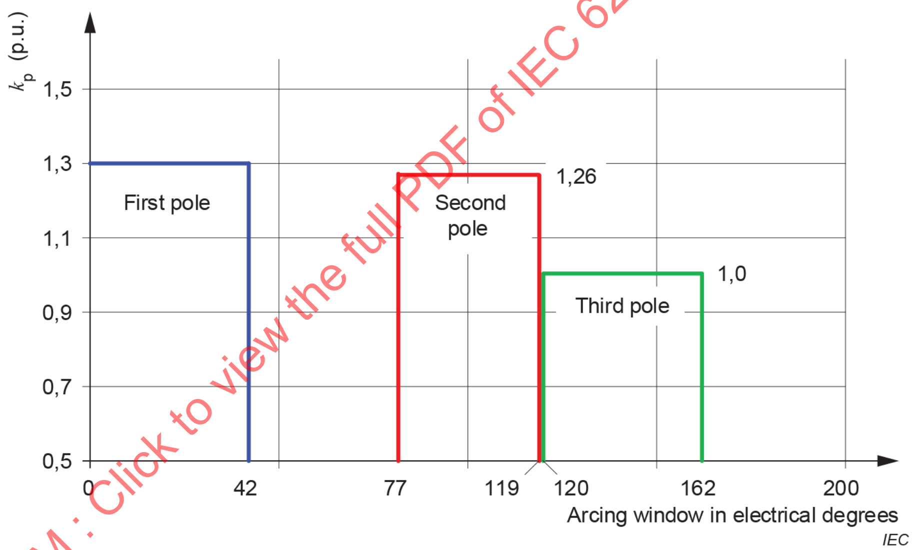



**Figure 40 – Graphical representation of the arcing window and the pole factor $k_p$, determining the TRV of the individual pole, for systems with a $k_{pp}$ of 1,3**

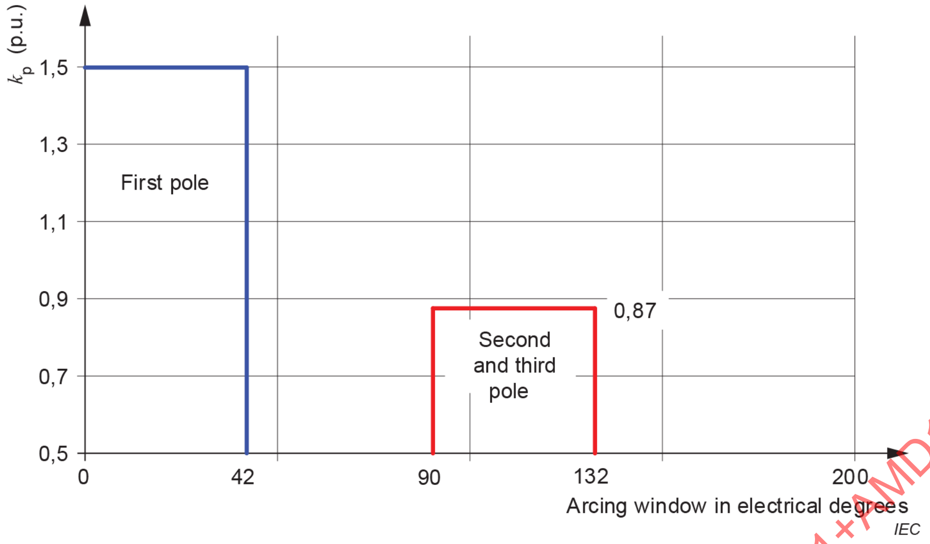



**Figure 41 – Graphical representation of the arcing window and the pole factor $k_p$, determining the TRV of the individual pole, for systems with a $k_{pp}$ of 1,5**



### 7.105 Short-circuit test quantities

#### 7.105.1 Applied voltage before short-circuit making tests

For the short-circuit making tests of 7.107, the applied voltage shall be as follows.

a) For three-phase tests on a three-pole circuit-breaker, the average value of the applied voltages phase-to-phase shall not be less than the rated voltage $U_r$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

   The differences between the average value and the applied voltages of each pole shall not exceed 5 %.

b) For single-phase tests on a three-pole circuit-breaker, the applied voltage shall not be less than the phase-to-earth value $U_r/\sqrt{3}$ and shall not exceed this value by more than 10 % without the consent of the manufacturer.

   With the manufacturer's consent it is permissible, for convenience of testing, to apply a voltage equal to the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,3 or 1,5) of the circuit-breaker.

   Where the circuit-breaker can be arranged for a single-pole reclosing cycle and the maximum time difference between the contacts touching in a subsequent three-pole closing operation exceeds one-quarter of a cycle of rated frequency (see note of 6.101), the applied voltage shall be the product of the phase-to-earth voltage and the first-pole-to-clear factor (1,3 or 1,5) of the circuit-breaker.

#### 7.105.2 Short-circuit making current

##### 7.105.2.1 General

The ability of the circuit-breaker to make the rated short-circuit making current is proven in test-duty T100s (see 7.107.5).

The circuit-breaker shall be able to make the current with pre-strike of the arc occurring at any point on the voltage wave. Two extreme cases are specified as follows (see Figure 1):

– making at the peak of the voltage wave (within the range between –15 ° and +15 °), leading to a symmetrical short-circuit current and the longest pre-striking arc;
– making at the zero of the voltage wave, without pre-striking, leading to a fully asymmetrical short-circuit current.

The test procedure as outlined below aims to demonstrate the ability of the circuit-breaker to fulfil the following two requirements:

a) the circuit-breaker can close against a symmetrical current as a result of the pre-arcing commencing at a peak of the applied voltage. This current shall be the symmetrical component of the rated short-circuit breaking current (see 5.101);
b) the circuit-breaker can close against a fully asymmetrical short-circuit current. This current shall be the rated short-circuit making current (see 5.103).

   A circuit-breaker shall be able to operate at voltages below its rated voltage at which it actually makes with a fully asymmetrical current. The lower limit of voltage, if any, shall be stated by the manufacturer.

Due to unintentional non-simultaneity of poles, the instants of contact touching during making can differ such as to provoke an even higher peak making current in one pole (see also 6.101). This is particularly the case if, in one pole, the current begins to flow about one-quarter of a cycle later than in the other two poles, provided that there is no pre-arcing. Failure of the circuit-breaker during such an event is considered a failure of a circuit-breaker to satisfy the test-duty as long as the prospective making current is within the tolerances given in Table B.1.

#### 7.105.2.2 Test procedure

##### 7.105.2.2.1 Three-phase tests

For three-phase tests on a three-pole circuit-breaker it is assumed that the requirements outlined in a) and b) above are adequately demonstrated during the test-duty T100s.

The control of the timing shall be such that at least in one of the two close-open (CO) cycles of test-duty T100s the rated short-circuit making current is obtained.

Where a circuit-breaker exhibits pre-arcing to such an extent that the rated short-circuit making current is not attained during the first CO operating cycle of test-duty T100s and, even after adjustment of the timing, the rated short-circuit making current is not achieved during the second CO operating cycle, further CO operating cycles can be carried out at reduced voltage until the making current is met. Before this operating cycle, the circuit-breaker can be reconditioned.

##### 7.105.2.2.2 Single-phase tests

For single-phase tests, test-duty T100s or T100s(a) shall be carried out in such a way that the requirement outlined in a) of 7.105.2.1 is met in one and that of b) of 7.105.2.1 in the other making operation. The sequence of these operations is not specified. If during test-duty T100s or T100s(a) (see 7.107.1) one of the requirements outlined in a) and b) has not been adequately demonstrated, an additional CO operating cycle is necessary. Before this operating cycle the circuit-breaker can be reconditioned.

The additional CO operating cycle shall, depending on the results obtained during the normal test-duty T100s or T100s(a), demonstrate either

– requirements in a) or b) of 7.105.2.1, or

– evidence that the short-circuit making currents attained are representative of the conditions to be met in service due to the pre-arcing characteristics of the circuit-breaker.

If, during the test-duty T100s or T100s(a), the rated short-circuit making current has not been attained due to the characteristics of the circuit-breaker, further CO operating cycles shall be carried out at reduced voltage until the making current is met.

If during the test-duty T100s or T100s(a) no symmetrical current has been obtained, as required in a) above, the additional CO test can be made at an applied voltage within the tolerances stated in 7.105.1.

#### 7.105.3 Short-circuit breaking current

The short-circuit current to be interrupted by a circuit-breaker shall be determined in accordance with Figure 8 at the instant of contact separation of the last pole to open and shall be stated in terms of the following two values:

– the average of the RMS values of the AC components in all phases;
– the last loop duration and amplitude for test-duty T100a.

The RMS value of the AC component in any phase shall not vary from the average by more than 10 %.

Although the short-circuit breaking current is measured at the instant corresponding to contact separation, the breaking performance of the circuit-breaker is determined, among other factors, by the current which is finally interrupted in the last loop of arcing. The decrement of the AC component of the short-circuit current is therefore very important, particularly when testing those circuit-breakers which arc for several loops of current. To obviate an easement of duty, the decrement of the AC component of the short-circuit current shall be such that at a time corresponding to the final extinction of the current in the last-pole-to-clear, the AC component of the prospective current is not less than 90 % of the appropriate value for the test-duty. This shall be proven by a record of the prospective current before commencing the tests.

If the characteristics of the circuit-breaker are such that it reduces the short-circuit current value below the prospective breaking current, or if the oscillogram is such that the current wave envelope cannot be drawn successfully, the average prospective short-circuit breaking current in all phases shall be used as the short-circuit breaking current and shall be measured from the oscillogram of prospective current at a time corresponding to the instant of contact separation.

The instant of contact separation can be determined according to the experience of the testing station and the type of apparatus under test by various methods, for instance, by recording the contact travel during the test, by recording the arc voltage or by a test on the circuit-breaker at no-load.

#### 7.105.4 DC component of the short-circuit breaking current

For circuit-breakers that prevent the control of the DC component, for example self-tripping circuit-breakers when in a condition for test as set out in 7.102.3, this DC component can be greater than that specified for test-duties T10, T30, T60 and T100s of 7.107.

#### 7.105.5 TRV for short-circuit breaking tests

##### 7.105.5.1 General

The prospective TRV of the test circuits shall be determined by such a method as will produce and measure the TRV wave without significantly influencing it. It shall be measured at the terminals to which the circuit-breaker will be connected with all necessary test-measuring devices, such as voltage dividers, etc. Suitable methods are described in Annex E (see also

7.103.3). In such cases where a measurement is not possible, a calculation of the prospective TRV is allowed. Guidance is given in Annex E.

For three-phase circuits, the prospective TRV refers to the first-pole-to-clear, i.e. the voltage across one open pole with the other two poles closed, with the appropriate test circuit arranged as specified in 7.103.3.

The TRV specified for the test is represented by a reference line, a delay line and ITRV envelope in the same manner as the TRV related to the rated short-circuit breaking current in accordance with 7.103.5 and Figure 42, Figure 43, Figure 44 and Figure 45.

The prospective TRV for the test is represented by its envelope, drawn as shown in Annex D, and by its initial portion.

The special case of circuit-breakers with a connection of low capacitance to a transformer is covered in Annex F.

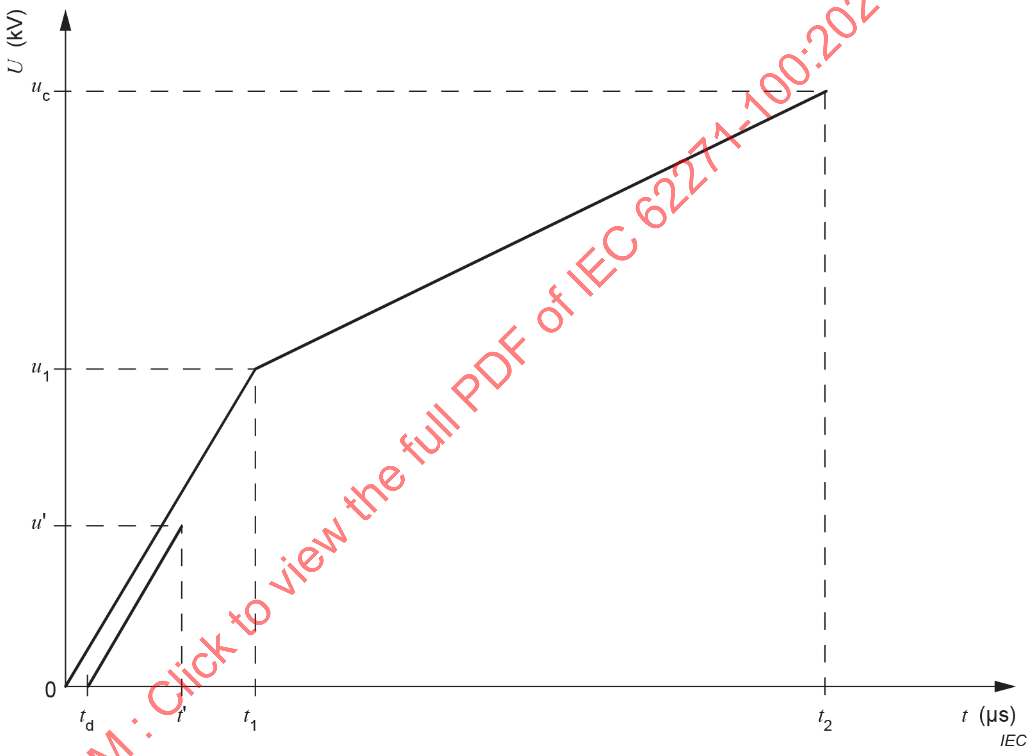



**Figure 42 – Representation of a specified TRV by a 4-parameter reference line and a delay line**

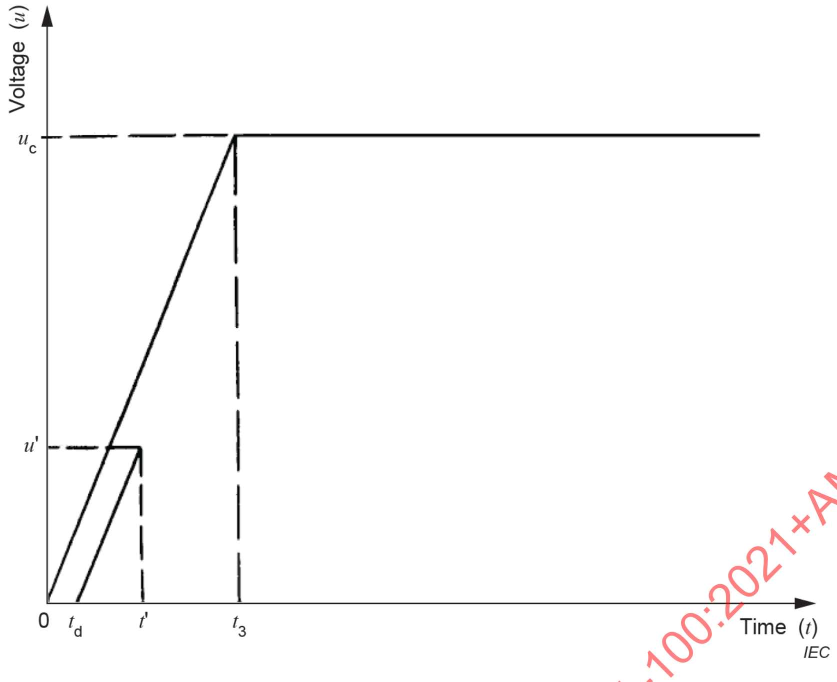
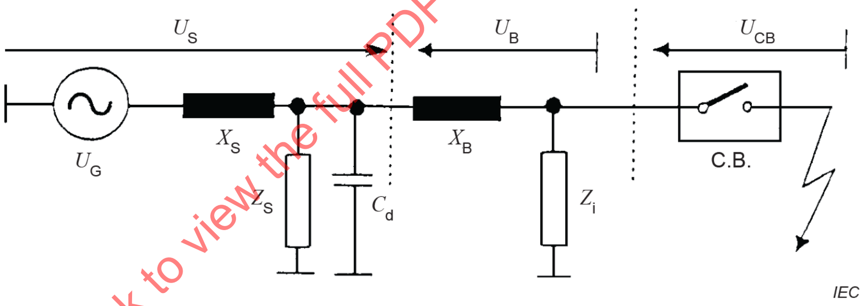


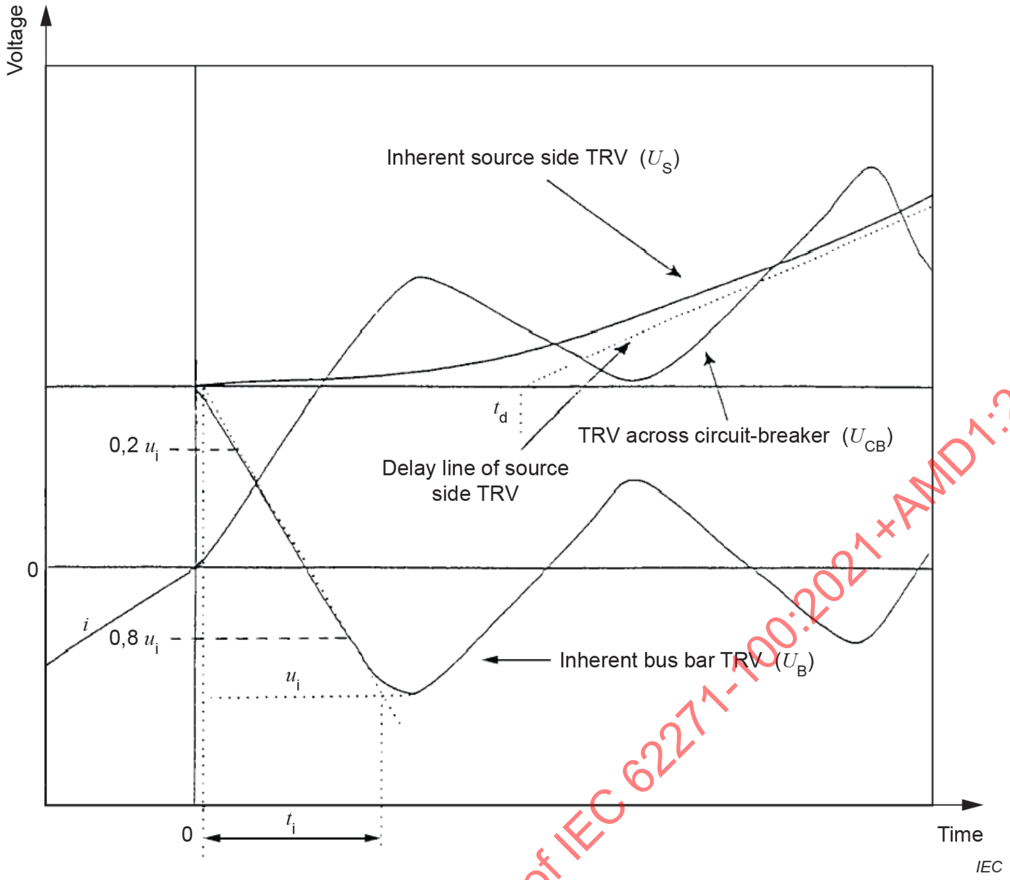

**Figure 43 – Representation of a specified TRV by a two-parameter reference line and a delay line**




| | | | |
|---|---|---|---|
| C.B. | circuit-breaker | $C_d$ | time delaying source side capacitance |
| $U_G$ | supply side voltage | $Z_s$ | source side TRV control components |
| $U_B$ | bus voltage | $Z_i$ | ITRV controlling components |
| $U_{CB}$ | voltage across circuit-breaker | $X_S$ | power frequency source side reactance |
| $U_S$ | source side voltage | $X_B$ | power frequency busbar reactance |

NOTE If a lumped inductance is used as $X_S$, the ITRV controlling components can be connected in parallel to this inductance.

**Figure 44 – Basic circuit for terminal fault with ITRV**




$u_i$ peak voltage of ITRV

$t_i$ time co-ordinate of ITRV

**Figure 45 – Representation of ITRV in relationship to TRV**

TRV parameters are a function of the rated voltage ($U_r$), the rated first-pole-to-clear factor ($k_{pp}$) and the amplitude factor ($k_{af}$). The values of $k_{pp}$ and $k_{af}$ are stated in Table 16 through Table 27. $k_{pp}$ is given in 5.102.

a) *For rated voltages less than 100 kV*

A representation by two parameters of the prospective TRV is used for all test-duties.

– In Table 16 and Table 17, for class S1 circuit-breakers.

TRV peak value $u_c = k_{pp} \times k_{af}\sqrt{(2/3)} \times U_r$ where $k_{af}$ is equal to 1,4 for test-duty T100, 1,5 for test-duty T60, 1,6 for test-duty T30 and 1,7 for test-duty T10, 1,25 for out-of-phase breaking.

Time $t_3$ for test-duty T100 is taken from Table 16 and Table 17. Time $t_3$ for test-duties T60, T30 and T10 is obtained by multiplying the time $t_3$ for test-duty T100 by 0,44 for T60, 0,22 for T30, 0,22 for T10 in Table 16 and 0,25 for T10 in Table 17.

– In Table 18 and Table 19, for class S2 circuit-breakers.

TRV peak value $u_c = k_{pp} \times k_{af}\sqrt{(2/3)} \times U_r$ where $k_{af}$ is equal to 1,54 for test-duty T100 and the supply side circuit for short-line fault, 1,65 for test-duty T60, 1,74 for test-duty T30 and 1,8 for test-duty T10, 1,25 for out-of-phase breaking.

Time $t_3$ for test-duty T100 is taken from Table 18 and Table 19. Time $t_3$ for test-duties T60, T30 and T10 is obtained by multiplying the time $t_3$ for test-duty T100 by 0,67 for T60, 0,40 for T30, 0,40 for T10 in Table 18 and 0,46 for T10 in Table 19.

Time $t_3$ for the supply side circuit of short-line fault is obtained by dividing $t_3$ for test-duty T100 by $k_{pp}$. The ratios $u_c$ / $t_3$ for the supply circuit of SLF is the same as for T100s.

– Time delay $t_d$ for test-duty T100 is 0,15$t_3$ for class S1 circuit-breakers, 0,05$t_3$ for class S2 circuit-breakers, 0,05$t_3$ for the supply side circuit for short-line fault.

– Time delay $t_d$ is 0,15$t_3$ for test-duties T60, T30 and T10 and for out-of-phase breaking.

– Voltage $u'$=$u_c$/3.

– Time $t'$ is derived from $u'$, $t_3$ and $t_d$ according to Figure 43, $t'$ = $t_d$ + $t_3$/3.

**Table 16 – Values of prospective TRV for class S1 circuit-breakers rated for $k_{pp}$ = 1,5**

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 3,6 | T100 | 1,5 | 1,4 | 6,17 | 40,7 | 6,10 | 2,06 | 19,7 | 0,152 |
| | T60 | 1,5 | 1,5 | 6,61 | 17,9 | 2,68 | 2,20 | 8,65 | 0,370 |
| | T30 | 1,5 | 1,6 | 7,05 | 8,95 | 1,34 | 2,35 | 4,32 | 0,788 |
| | T10 | 1,5 | 1,7 | 7,50 | 8,95 | 1,34 | 2,50 | 4,32 | 0,838 |
| 4,76 | T100 | 1,5 | 1,4 | 8,16 | 44,8 | 6,73 | 2,72 | 21,7 | 0,182 |
| | T60 | 1,5 | 1,5 | 8,74 | 19,7 | 2,96 | 2,91 | 9,54 | 0,443 |
| | T30 | 1,5 | 1,6 | 9,33 | 9,87 | 1,48 | 3,11 | 4,77 | 0,945 |
| | T10 | 1,5 | 1,7 | 9,91 | 9,87 | 1,48 | 3,30 | 4,77 | 1,00 |
| 7,2 | T100 | 1,5 | 1,4 | 12,3 | 51,5 | 7,73 | 4,12 | 24,9 | 0,240 |
| | T60 | 1,5 | 1,5 | 13,2 | 22,7 | 3,40 | 4,41 | 11,0 | 0,584 |
| | T30 | 1,5 | 1,6 | 14,1 | 11,3 | 1,70 | 4,70 | 5,48 | 1,24 |
| | T10 | 1,5 | 1,7 | 15,0 | 11,3 | 1,70 | 5,00 | 5,48 | 1,32 |
| 8,25 | T100 | 1,5 | 1,4 | 14,1 | 54,0 | 8,09 | 4,72 | 26,1 | 0,262 |
| | T60 | 1,5 | 1,5 | 15,2 | 23,7 | 3,56 | 5,05 | 11,5 | 0,638 |
| | T30 | 1,5 | 1,6 | 16,2 | 11,9 | 1,78 | 5,39 | 5,74 | 1,36 |
| | T10 | 1,5 | 1,7 | 17,2 | 11,9 | 1,78 | 5,73 | 5,74 | 1,45 |
| 12 | T100 | 1,5 | 1,4 | 20,6 | 61,8 | 9,27 | 6,86 | 29,9 | 0,333 |
| | T60 | 1,5 | 1,5 | 22,0 | 27,2 | 4,08 | 7,35 | 13,1 | 0,811 |
| | T30 | 1,5 | 1,6 | 23,5 | 13,6 | 2,04 | 7,84 | 6,57 | 1,73 |
| | T10 | 1,5 | 1,7 | 25,0 | 13,6 | 2,04 | 8,33 | 6,57 | 1,84 |
| 15 | T100 | 1,5 | 1,4 | 25,7 | 67,7 | 10,2 | 8,57 | 32,7 | 0,380 |
| | T60 | 1,5 | 1,5 | 27,6 | 29,8 | 4,47 | 9,19 | 14,4 | 0,925 |
| | T30 | 1,5 | 1,6 | 29,4 | 14,9 | 2,23 | 9,80 | 7,20 | 1,97 |
| | T10 | 1,5 | 1,7 | 31,2 | 14,9 | 2,23 | 10,4 | 7,20 | 2,10 |
| 15,5 | T100 | 1,5 | 1,4 | 26,6 | 68,7 | 10,3 | 8,86 | 33,2 | 0,387 |
| | T60 | 1,5 | 1,5 | 28,5 | 30,2 | 4,53 | 9,49 | 14,6 | 0,943 |
| | T30 | 1,5 | 1,6 | 30,4 | 15,1 | 2,27 | 10,1 | 7,30 | 2,01 |
| | T10 | 1,5 | 1,7 | 32,3 | 15,1 | 2,27 | 10,8 | 7,30 | 2,14 |
| 17,5 | T100 | 1,5 | 1,4 | 30,0 | 72,5 | 10,9 | 10,0 | 35,0 | 0,414 |
| | T60 | 1,5 | 1,5 | 32,1 | 31,9 | 4,79 | 10,7 | 15,4 | 1,00 |
| | T30 | 1,5 | 1,6 | 34,3 | 16,0 | 2,39 | 11,4 | 7,71 | 2,15 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ μs | $t_d$ μs | $u'$ kV | $t'$ μs | $u_c/t_3$ kV/μs |
|---|---|---|---|---|---|---|---|---|---|
| | T10 | 1,5 | 1,7 | 36,4 | 16,0 | 2,39 | 12,1 | 7,71 | 2,28 |
| 24 | T100 | 1,5 | 1,4 | 41,2 | 85,0 | 12,7 | 13,7 | 41,1 | 0,484 |
| | T60 | 1,5 | 1,5 | 44,1 | 37,4 | 5,61 | 14,7 | 18,1 | 1,18 |
| | T30 | 1,5 | 1,6 | 47,0 | 18,7 | 2,80 | 15,7 | 9,04 | 2,52 |
| | T10 | 1,5 | 1,7 | 50,0 | 18,7 | 2,80 | 16,7 | 9,04 | 2,67 |
| 25,8 | T100 | 1,5 | 1,4 | 44,2 | 88,4 | 13,3 | 14,7 | 42,7 | 0,500 |
| | T60 | 1,5 | 1,5 | 47,4 | 38,9 | 5,84 | 15,8 | 18,8 | 1,22 |
| | T30 | 1,5 | 1,6 | 50,6 | 19,5 | 2,92 | 16,9 | 9,40 | 2,60 |
| | T10 | 1,5 | 1,7 | 53,7 | 19,5 | 2,92 | 17,9 | 9,40 | 2,76 |
| 27 | T100 | 1,5 | 1,4 | 46,3 | 90,7 | 13,6 | 15,4 | 43,8 | 0,511 |
| | T60 | 1,5 | 1,5 | 49,6 | 39,9 | 5,99 | 16,5 | 19,3 | 1,24 |
| | T30 | 1,5 | 1,6 | 52,9 | 20,0 | 2,99 | 17,6 | 9,64 | 2,65 |
| | T10 | 1,5 | 1,7 | 56,2 | 20,0 | 2,99 | 18,7 | 9,64 | 2,82 |
| 36 | T100 | 1,5 | 1,4 | 61,7 | 107 | 16,1 | 20,6 | 51,8 | 0,576 |
| | T60 | 1,5 | 1,5 | 66,1 | 47,2 | 7,07 | 22,0 | 22,8 | 1,40 |
| | T30 | 1,5 | 1,6 | 70,5 | 23,6 | 3,54 | 23,5 | 11,4 | 2,99 |
| | T10 | 1,5 | 1,7 | 75,0 | 23,6 | 3,54 | 25,0 | 11,4 | 3,18 |
| 38 | T100 | 1,5 | 1,4 | 65,2 | 111 | 16,6 | 21,7 | 53,5 | 0,589 |
| | T60 | 1,5 | 1,5 | 69,8 | 48,7 | 7,30 | 23,3 | 23,5 | 1,43 |
| | T30 | 1,5 | 1,6 | 74,5 | 24,3 | 3,65 | 24,8 | 11,8 | 3,06 |
| | T10 | 1,5 | 1,7 | 79,1 | 24,3 | 3,65 | 26,4 | 11,8 | 3,25 |
| 40,5 | T100 | 1,5 | 1,4 | 69,4 | 115 | 17,2 | 23,1 | 55,5 | 0,605 |
| | T60 | 1,5 | 1,5 | 74,4 | 50,5 | 7,58 | 24,8 | 24,4 | 1,47 |
| | T30 | 1,5 | 1,6 | 79,4 | 25,3 | 3,79 | 26,5 | 12,2 | 3,14 |
| | T10 | 1,5 | 1,7 | 84,3 | 25,3 | 3,79 | 28,1 | 12,2 | 3,34 |
| 48,3 | T100 | 1,5 | 1,4 | 82,8 | 127 | 19,0 | 27,6 | 61,4 | 0,652 |
| | T60 | 1,5 | 1,5 | 88,7 | 55,9 | 8,38 | 29,6 | 27,0 | 1,59 |
| | T30 | 1,5 | 1,6 | 94,6 | 27,9 | 4,19 | 31,5 | 13,5 | 3,39 |
| | T10 | 1,5 | 1,7 | 101 | 27,9 | 4,19 | 33,5 | 13,5 | 3,60 |
| 52 | T100 | 1,5 | 1,4 | 89,2 | 132 | 19,8 | 29,7 | 63,9 | 0,674 |
| | T60 | 1,5 | 1,5 | 95,5 | 58,2 | 8,73 | 31,8 | 28,1 | 1,64 |
| | T30 | 1,5 | 1,6 | 102 | 29,1 | 4,37 | 34,0 | 14,1 | 3,50 |
| | T10 | 1,5 | 1,7 | 108 | 29,1 | 4,37 | 36,1 | 14,1 | 3,72 |
| 72,5 | T100 | 1,5 | 1,4 | 124 | 166 | 24,9 | 41,4 | 80,1 | 0,750 |
| | T60 | 1,5 | 1,5 | 133 | 72,9 | 10,9 | 44,4 | 35,2 | 1,83 |
| | T30 | 1,5 | 1,6 | 142 | 36,5 | 5,47 | 47,4 | 17,6 | 3,90 |
| | T10 | 1,5 | 1,7 | 151 | 36,5 | 5,47 | 50,3 | 17,6 | 4,14 |

NOTE $k_{pp}$ = 1,5 is specified to cover transformer-limited fault conditions with $X_0/X_1$ higher than 3,0 (for example non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems).

**Table 17 – Values of prospective TRV for class S1 circuit-breakers rated for $k_{pp}$ = 1,3**

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 3,6 | T100 | 1,3 | 1,4 | 5,35 | 35,2 | 5,29 | 1,78 | 17,0 | 0,152 |
| | T60 | 1,3 | 1,5 | 5,73 | 15,5 | 2,33 | 1,91 | 7,50 | 0,370 |
| | T30 | 1,3 | 1,6 | 6,11 | 7,75 | 1,16 | 2,04 | 3,75 | 0,788 |
| | T10 | 1,5 | 1,7 | 7,50 | 8,95 | 1,34 | 2,50 | 4,32 | 0,838 |
| 4,76 | T100 | 1,3 | 1,4 | 7,07 | 38,9 | 5,83 | 2,36 | 18,8 | 0,182 |
| | T60 | 1,3 | 1,5 | 7,58 | 17,1 | 2,57 | 2,53 | 8,27 | 0,443 |
| | T30 | 1,3 | 1,6 | 8,08 | 8,55 | 1,28 | 2,69 | 4,13 | 0,945 |
| | T10 | 1,5 | 1,7 | 9,91 | 9,87 | 1,48 | 3,30 | 4,77 | 1,00 |
| 7,2 | T100 | 1,3 | 1,4 | 10,7 | 44,6 | 6,70 | 3,57 | 21,6 | 0,240 |
| | T60 | 1,3 | 1,5 | 11,5 | 19,6 | 2,95 | 3,82 | 9,49 | 0,584 |
| | T30 | 1,3 | 1,6 | 12,2 | 9,82 | 1,47 | 4,08 | 4,75 | 1,24 |
| | T10 | 1,5 | 1,7 | 15,0 | 11,3 | 1,70 | 5,00 | 5,48 | 1,32 |
| 8,25 | T100 | 1,3 | 1,4 | 12,3 | 46.8 | 7.01 | 4,09 | 22,6 | 0,262 |
| | T60 | 1,3 | 1,5 | 13,1 | 20,6 | 3,09 | 4,38 | 9,94 | 0,638 |
| | T30 | 1,3 | 1,6 | 14,0 | 10,3 | 1,54 | 4,67 | 4,97 | 1,36 |
| | T10 | 1,5 | 1,7 | 17,2 | 11,9 | 1,78 | 5,73 | 5,74 | 1,45 |
| 12 | T100 | 1,3 | 1,4 | 17,8 | 53,6 | 8,03 | 5,94 | 25,9 | 0,333 |
| | T60 | 1,3 | 1,5 | 19,1 | 23,6 | 3,54 | 6,37 | 11,4 | 0,811 |
| | T30 | 1,3 | 1,6 | 20,4 | 11,8 | 1,77 | 6,79 | 5,70 | 1,73 |
| | T10 | 1,5 | 1,7 | 25,0 | 13,6 | 2,04 | 8,33 | 6,57 | 1,84 |
| 15 | T100 | 1,3 | 1,4 | 22,3 | 58,7 | 8,80 | 7,43 | 28,4 | 0,380 |
| | T60 | 1,3 | 1,5 | 23,9 | 25,8 | 3,87 | 7,96 | 12,5 | 0,925 |
| | T30 | 1,3 | 1,6 | 25,5 | 12,9 | 1,94 | 8,49 | 6,24 | 1,97 |
| | T10 | 1,5 | 1,7 | 31,2 | 14,9 | 2,23 | 10,4 | 7,20 | 2,10 |
| 15,5 | T100 | 1,3 | 1,4 | 23,0 | 59,5 | 8,93 | 7,68 | 28,8 | 0,387 |
| | T60 | 1,3 | 1,5 | 24,7 | 26,2 | 3,93 | 8,23 | 12,7 | 0,943 |
| | T30 | 1,3 | 1,6 | 26,3 | 13,1 | 1,96 | 8,77 | 6,33 | 2,01 |
| | T10 | 1,5 | 1,7 | 32,3 | 15,1 | 2,27 | 10,8 | 7,30 | 2,14 |
| 17,5 | T100 | 1,3 | 1,4 | 26,0 | 62.8 | 9,43 | 8,67 | 30,4 | 0,414 |
| | T60 | 1,3 | 1,5 | 27,9 | 27,7 | 4,15 | 9,29 | 13,4 | 1,01 |
| | T30 | 1,3 | 1,6 | 29,7 | 13,8 | 2,07 | 9,91 | 6,68 | 2,15 |
| | T10 | 1,5 | 1,7 | 36,4 | 16,0 | 2,39 | 12,1 | 7,71 | 2,28 |
| 24 | T100 | 1,3 | 1,4 | 35,7 | 73,6 | 11,0 | 11,9 | 35,6 | 0,484 |
| | T60 | 1,3 | 1,5 | 38,2 | 32,4 | 4,86 | 12,7 | 15,7 | 1,18 |
| | T30 | 1,3 | 1,6 | 40,8 | 16,2 | 2,43 | 13,6 | 7,83 | 2,52 |
| | T10 | 1,5 | 1,7 | 50,0 | 18,7 | 2,80 | 16,7 | 9,04 | 2,67 |
| 25,8 | T100 | 1,3 | 1,4 | 38,3 | 76,6 | 11,5 | 12,8 | 37,0 | 0,500 |
| | T60 | 1,3 | 1,5 | 41,1 | 33,7 | 5,06 | 13,7 | 16,3 | 1,22 |
| | T30 | 1,3 | 1,6 | 43,8 | 16,9 | 2,53 | 14,6 | 8,15 | 2,60 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| | T10 | 1,5 | 1,7 | 53,7 | 19,5 | 2,92 | 17,9 | 9,4 | 2,76 |
| 27 | T100 | 1,3 | 1,4 | 40,1 | 78,6 | 11,8 | 13,4 | 38,0 | 0,511 |
| | T60 | 1,3 | 1,5 | 43,0 | 34,6 | 5,19 | 14,3 | 16,7 | 1,24 |
| | T30 | 1,3 | 1,6 | 45,9 | 17,3 | 2,59 | 15,3 | 8,36 | 2,65 |
| | T10 | 1,5 | 1,7 | 56,2 | 20,0 | 2,99 | 18,7 | 9,64 | 2,82 |
| 36 | T100 | 1,3 | 1,4 | 53,5 | 92,9 | 13,9 | 17,8 | 44,9 | 0,576 |
| | T60 | 1,3 | 1,5 | 57,3 | 40,9 | 6,13 | 19,1 | 19,8 | 1,40 |
| | T30 | 1,3 | 1,6 | 61,1 | 20,4 | 3,07 | 20,4 | 9,88 | 2,99 |
| | T10 | 1,5 | 1,7 | 75,0 | 23,6 | 3,54 | 25,0 | 11,4 | 3,18 |
| 38 | T100 | 1,3 | 1,4 | 56,5 | 95,9 | 14,4 | 18,8 | 46,4 | 0,589 |
| | T60 | 1,3 | 1,5 | 60,5 | 42,2 | 6,33 | 20,2 | 20,4 | 1,43 |
| | T30 | 1,3 | 1,6 | 64,5 | 21,1 | 3,16 | 21,5 | 10,2 | 3,06 |
| | T10 | 1,5 | 1,7 | 79,1 | 24,3 | 3,65 | 26,4 | 11,8 | 3,25 |
| 40,5 | T100 | 1,3 | 1,4 | 60,2 | 99,5 | 14,9 | 20,1 | 48,1 | 0,605 |
| | T60 | 1,3 | 1,5 | 64,5 | 43,8 | 6,57 | 21,5 | 21,2 | 1,47 |
| | T30 | 1,3 | 1,6 | 68,8 | 21,9 | 3,28 | 22,9 | 10,6 | 3,14 |
| | T10 | 1,5 | 1,7 | 84,3 | 25,3 | 3,79 | 28,1 | 12,2 | 3,34 |
| 48,3 | T100 | 1,3 | 1,4 | 71,8 | 110 | 16,5 | 23,9 | 53,2 | 0,652 |
| | T60 | 1,3 | 1,5 | 76,9 | 48,4 | 7,26 | 25,6 | 23,4 | 1,59 |
| | T30 | 1,3 | 1,6 | 82,0 | 24,2 | 3,63 | 27,3 | 11,7 | 3,39 |
| | T10 | 1,5 | 1,7 | 101 | 27,9 | 4,19 | 33,5 | 13,5 | 3,60 |
| 52 | T100 | 1,3 | 1,4 | 77,3 | 115 | 17,2 | 25,8 | 55,4 | 0,674 |
| | T60 | 1,3 | 1,5 | 82,8 | 50,4 | 7,57 | 27,6 | 24,4 | 1,64 |
| | T30 | 1,3 | 1,6 | 88,3 | 25,2 | 3,78 | 29,4 | 12,2 | 3,50 |
| | T10 | 1,5 | 1,7 | 108 | 29,1 | 4,37 | 36,1 | 14,1 | 3,72 |
| 72,5 | T100 | 1,3 | 1,4 | 108 | 144 | 21,6 | 35,9 | 69,4 | 0,750 |
| | T60 | 1,3 | 1,5 | 115 | 62,2 | 9,48 | 38,5 | 30,5 | 1,83 |
| | T30 | 1,3 | 1,6 | 123 | 31,6 | 4,74 | 41,0 | 15,3 | 3,90 |
| | T10 | 1,5 | 1,7 | 151 | 36,5 | 5,47 | 50,3 | 17,6 | 4,14 |

NOTE $k_{pp}$ = 1,5 is specified to cover transformer-limited fault conditions with $X_0/X_1$ higher than 3,0 (for example non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems).

**Table 18 – Values of prospective TRV for class S2 circuit-breakers rated for $k_{pp}$ = 1,5**

| $U_r$ kV | Test-duty | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 3,6 | T100 | 1,5 | 1,54 | 6,79 | 11,5 | 0,57 | 2,26 | 4,40 | 0,591 |
| | T60 | 1,5 | 1,65 | 7,27 | 7,70 | 1,15 | 2,42 | 3,72 | 0,945 |
| | T30 | 1,5 | 1,74 | 7,67 | 4,59 | 0,689 | 2,56 | 2,22 | 1,67 |
| | T10 | 1,5 | 1,80 | 7,94 | 4,59 | 0,689 | 2,65 | 2,22 | 1,73 |
| 4,76 | T100 | 1,5 | 1,54 | 8,98 | 13,9 | 0,697 | 2,99 | 5,35 | 0,644 |
| | T60 | 1,5 | 1,65 | 9,62 | 9,34 | 1,40 | 3,21 | 4,52 | 1,03 |
| | T30 | 1,5 | 1,74 | 10,1 | 5,58 | 0,837 | 3,38 | 2,70 | 1,82 |
| | T10 | 1,5 | 1,80 | 10,5 | 5,58 | 0,837 | 3,50 | 2,70 | 1,88 |
| 7,2 | T100 | 1,5 | 1,54 | 13,6 | 18,6 | 0,930 | 4,53 | 7,13 | 0,730 |
| | T60 | 1,5 | 1,65 | 14,6 | 12,5 | 1,87 | 4,85 | 6,02 | 1,17 |
| | T30 | 1,5 | 1,74 | 15,3 | 7,44 | 1,12 | 5,11 | 3,59 | 2,06 |
| | T10 | 1,5 | 1,80 | 15,9 | 7,44 | 1,12 | 5,29 | 3,59 | 2,13 |
| 8,25 | T100 | 1,5 | 1,54 | 15,6 | 20,4 | 1,02 | 5,19 | 7,83 | 0,761 |
| | T60 | 1,5 | 1,65 | 16,7 | 13,7 | 2,05 | 5,56 | 6,62 | 1,22 |
| | T30 | 1,5 | 1,74 | 17,6 | 8,18 | 1,23 | 5,86 | 3,95 | 2,15 |
| | T10 | 1,5 | 1,80 | 18,2 | 8,18 | 1,23 | 6,06 | 3,95 | 2,22 |
| 12 | T100 | 1,5 | 1,54 | 22,6 | 26,5 | 1,33 | 7,54 | 10,2 | 0,854 |
| | T60 | 1,5 | 1,65 | 24,3 | 17,8 | 2,67 | 8,08 | 8,59 | 1,36 |
| | T30 | 1,5 | 1,74 | 25,6 | 10,6 | 1,59 | 8.52 | 5,13 | 2,41 |
| | T10 | 1,5 | 1,80 | 26,5 | 10,6 | 1,59 | 8,82 | 5,13 | 2,49 |
| 15 | T100 | 1,5 | 1,54 | 28,3 | 31,0 | 1,55 (4,64) | 9,43 | 11,9 (15,0) | 0,914 |
| | T60 | 1,5 | 1,65 | 30,3 | 20,7 | 3,11 | 10,1 | 10,0 | 1,46 |
| | T30 | 1,5 | 1,74 | 32,0 | 12,4 | 1,86 | 10,7 | 5,99 | 2,58 |
| | T10 | 1,5 | 1,80 | 33,1 | 12,4 | 1,86 | 11,0 | 5,99 | 2,67 |
| 15,5 | T100 | 1,5 | 1,54 | 29,2 | 31,7 | 1,58 (4,75) | 9,74 | 12,1 (15,3) | 0,923 |
| | T60 | 1,5 | 1,65 | 31,3 | 21,2 | 3,18 | 10,4 | 10,3 | 1,48 |
| | T30 | 1,5 | 1,74 | 33,0 | 12,7 | 1,90 | 11,0 | 6,12 | 2,61 |
| | T10 | 1,5 | 1,80 | 34,2 | 12,7 | 1,90 | 11,4 | 6,12 | 2,70 |
| 17,5 | T100 | 1,5 | 1,54 | 33,0 | 34,5 | 1,72 (5,17) | 11,0 | 13,2 (16,7) | 0,958 |
| | T60 | 1,5 | 1,65 | 35,4 | 23,1 | 3,46 | 11,8 | 11,2 | 1,53 |
| | T30 | 1,5 | 1,74 | 37,3 | 13,8 | 2,07 | 12,4 | 6,66 | 2,70 |
| | T10 | 1,5 | 1,80 | 38,6 | 13,8 | 2,07 | 12,9 | 6,66 | 2,80 |
| 24 | T100 | 1,5 | 1,54 | 45,3 | 42,9 | 2,15 (6,44) | 15,1 | 16,5 (20,7) | 1,05 |
| | T60 | 1,5 | 1,65 | 48,5 | 28,8 | 4,31 | 16,2 | 13,9 | 1,69 |
| | T30 | 1,5 | 1,74 | 51,1 | 17,2 | 2,58 | 17,0 | 8,32 | 2,98 |
| | T10 | 1,5 | 1,8 | 52,9 | 17,2 | 2,58 | 17,6 | 8,32 | 3,08 |
| 25,8 | T100 | 1,5 | 1,54 | 48,7 | 45,1 | 2,26 (6,77) | 16,2 | 17,3 (21,8) | 1,08 |
| | T60 | 1,5 | 1,65 | 52,1 | 30,2 | 4,54 | 17,4 | 14,6 | 1,72 |
| | T30 | 1,5 | 1,74 | 55,0 | 18,1 | 2,71 | 18,3 | 8,73 | 3,04 |
| | T10 | 1,5 | 1,80 | 56,9 | 18,1 | 2,71 | 19,0 | 8,73 | 3,15 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 27 | T100 | 1,5 | 1,54 | 50,9 | 46,6 | 2,33 (6,99) | 17,0 | 17,9 (22,5) | 1,09 |
| | T60 | 1,5 | 1,65 | 54,6 | 31,2 | 4,68 | 18,2 | 15,1 | 1,75 |
| | T30 | 1,5 | 1,74 | 57,5 | 18,6 | 2,80 | 19,2 | 9,01 | 3,09 |
| | T10 | 1,5 | 1,80 | 59,5 | 18,6 | 2,80 | 19,8 | 9,01 | 3,19 |
| 36 | T100 | 1,5 | 1,54 | 67,9 | 56,9 | 2,85 (8,54) | 22,6 | 21,8 (27,5) | 1,19 |
| | T60 | 1,5 | 1,65 | 72,8 | 38,1 | 5,72 | 24,3 | 18,4 | 1,91 |
| | T30 | 1,5 | 1,74 | 76,7 | 22,8 | 3,41 | 25,6 | 11,0 | 3,37 |
| | T10 | 1,5 | 1,80 | 79,4 | 22,8 | 3,41 | 26,5 | 11,0 | 3,49 |
| 38 | T100 | 1,5 | 1,54 | 71,7 | 59,1 | 2,95 (8,90) | 23,9 | 22,6 (28,7) | 1,21 |
| | T60 | 1,5 | 1,65 | 76,8 | 39,6 | 5,94 | 25,6 | 19,1 | 1,94 |
| | T30 | 1,5 | 1,74 | 81,0 | 23,6 | 3,54 | 27,0 | 11,4 | 3,43 |
| | T10 | 1,5 | 1,80 | 83,8 | 23,6 | 3,54 | 27,9 | 11,4 | 3,54 |
| 40,5 | T100 | 1,5 | 1,54 | 76,4 | 61,8 | 3,09 (9,26) | 25,5 | 23,7 (29,8) | 1,24 |
| | T60 | 1,5 | 1,65 | 81,8 | 41,4 | 6,21 | 27,3 | 20,0 | 1,98 |
| | T30 | 1,5 | 1,74 | 86,3 | 24,7 | 3,71 | 28,8 | 11,9 | 3,49 |
| | T10 | 1,5 | 1,80 | 89,3 | 24,7 | 3,71 | 29,8 | 11,9 | 3,61 |
| 48,3 | T100 | 1,5 | 1,54 | 91,1 | 69,8 | 3,49 (10,5) | 30,4 | 26,8 (33,7) | 1,31 |
| | T60 | 1,5 | 1,65 | 97,6 | 46,8 | 7,01 | 32,5 | 22,6 | 2,09 |
| | T30 | 1,5 | 1,74 | 103 | 27,9 | 4,19 | 34,3 | 13,5 | 3,69 |
| | T10 | 1,5 | 1,80 | 106 | 27,9 | 4,19 | 35,5 | 13,5 | 3,81 |
| 52 | T100 | 1,5 | 1,54 | 98,1 | 73,5 | 3,67 (11,0) | 32,7 | 28,2 (35,5) | 1,33 |
| | T60 | 1,5 | 1,65 | 105 | 49,2 | 7,38 | 35,0 | 23,8 | 2,13 |
| | T30 | 1,5 | 1,74 | 111 | 29,4 | 4,41 | 36,9 | 14,2 | 3,77 |
| | T10 | 1,5 | 1,80 | 115 | 29,4 | 4,41 | 38,2 | 14,2 | 3,90 |
| 72,5 | T100 | 1,5 | 1,54 | 137 | 92,6 | 4,63 (13,9) | 45,6 | 35,5 (44,7) | 1,48 |
| | T60 | 1,5 | 1,65 | 147 | 62,0 | 9,30 | 48,8 | 30,0 | 2,36 |
| | T30 | 1,5 | 1,74 | 155 | 37,0 | 5,55 | 51,5 | 17,9 | 4,17 |
| | T10 | 1,5 | 1,80 | 160 | 37,0 | 5,55 | 53,3 | 17,9 | 4,32 |

NOTE Where two values of times $t_d$ and $t'$ are given for test-duty T100 separated by brackets, the time $t_d$ in brackets is the upper limit of the time delay $t_d$ that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at $t'$ given in brackets. If this is not the case, the lower values of $t_d$ and $t'$ apply.

**Table 19 – Values of prospective TRV for class S2 circuit-breakers rated for $k_{pp}$ = 1,3**

| $U_r$<br>kV | Test-duty | $k_{pp}$<br>p.u | $k_{af}$<br>p.u | $u_c$<br>kV | $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 3,6 | T100 | 1,3 | 1,54 | 5,88 | 9,95 | 0,498 | 1,96 | 3,82 | 0,591 |
| | T60 | 1,3 | 1,65 | 6,30 | 6,67 | 1,00 | 2,10 | 3,22 | 0,945 |
| | T30 | 1,3 | 1,74 | 6,65 | 3,98 | 0,597 | 2,22 | 1,92 | 1,67 |
| | T10 | 1,5 | 1,80 | 7,94 | 4,59 | 0,689 | 2,65 | 2,22 | 1,73 |
| 4,76 | T100 | 1,3 | 1,54 | 7,78 | 12,1 | 0,604 | 2,59 | 4,63 | 0,644 |
| | T60 | 1,3 | 1,65 | 8,34 | 8,10 | 1,21 | 2,78 | 3,91 | 1,03 |
| | T30 | 1,3 | 1,74 | 8,79 | 4,83 | 0,725 | 2,93 | 2,34 | 1,82 |
| | T10 | 1,5 | 1,80 | 10,5 | 5,58 | 0,837 | 3,50 | 2,70 | 1,88 |
| 7,2 | T100 | 1,3 | 1,54 | 11,8 | 16,1 | 0,806 | 3,92 | 6,18 | 0,730 |
| | T60 | 1,3 | 1,65 | 12,6 | 10,8 | 1,62 | 4,20 | 5,22 | 1,17 |
| | T30 | 1,3 | 1,74 | 13,3 | 6,45 | 0,967 | 4,43 | 3,12 | 2,06 |
| | T10 | 1,5 | 1,80 | 15,9 | 7,44 | 1,12 | 5,29 | 3,59 | 2,13 |
| 8,25 | T100 | 1,3 | 1,54 | 13,5 | 17,7 | 0,886 | 4,50 | 6,79 | 0,761 |
| | T60 | 1,3 | 1,65 | 14,5 | 11,9 | 1,78 | 4,82 | 5,74 | 1,22 |
| | T30 | 1,3 | 1,74 | 15,2 | 7,09 | 1,06 | 5,08 | 3,42 | 2,15 |
| | T10 | 1,5 | 1,80 | 18,2 | 8,18 | 1,23 | 6,06 | 3,95 | 2,22 |
| 12 | T100 | 1,3 | 1,54 | 19,6 | 23,0 | 1,15 | 6,54 | 8,81 | 0,854 |
| | T60 | 1,3 | 1,65 | 21,0 | 15,4 | 2,31 | 7,01 | 7,44 | 1,36 |
| | T30 | 1,3 | 1,74 | 22,2 | 9,19 | 1,38 | 7.39 | 4,44 | 2,41 |
| | T10 | 1,5 | 1,80 | 26,5 | 10,6 | 1,59 | 8,82 | 5,13 | 2,49 |
| 15 | T100 | 1,3 | 1,54 | 24,5 | 26,8 | 1,34 (4,03) | 8,17 | 10,3 (13,0) | 0,914 |
| | T60 | 1,3 | 1,65 | 26,3 | 18,0 | 2,70 | 8,76 | 8,69 | 1,46 |
| | T30 | 1,3 | 1,74 | 27,7 | 10,7 | 1,61 | 9,23 | 5,19 | 2,58 |
| | T10 | 1,5 | 1,80 | 33,1 | 12,4 | 1,86 | 11,0 | 5,99 | 2,67 |
| 15,5 | T100 | 1,3 | 1,54 | 25,3 | 27,5 | 1,37 (4,12) | 8,45 | 10,5 (13,3) | 0,923 |
| | T60 | 1,3 | 1,65 | 27,2 | 18,4 | 2,76 | 9,05 | 8,89 | 1,48 |
| | T30 | 1,3 | 1,74 | 28,6 | 11,0 | 1,65 | 9,54 | 5,31 | 2,61 |
| | T10 | 1,5 | 1,80 | 34,2 | 12,7 | 1,90 | 11,4 | 6,12 | 2,70 |
| 17,5 | T100 | 1,3 | 1,54 | 28,6 | 29,9 | 1,49 (4,48) | 9,54 | 11,5 (14,4) | 0,958 |
| | T60 | 1,3 | 1,65 | 30,6 | 20,0 | 3,00 | 10,2 | 9,67 | 1,53 |
| | T30 | 1,3 | 1,74 | 32,3 | 11,9 | 1,79 | 10,8 | 5,78 | 2,70 |
| | T10 | 1,5 | 1,80 | 38,6 | 13,8 | 2,07 | 12,9 | 6,66 | 2,80 |
| 24 | T100 | 1,3 | 1,54 | 39,2 | 37,2 | 1,86 (5,58) | 13,1 | 14,3 (18,0) | 1,05 |
| | T60 | 1,3 | 1,65 | 42,0 | 24,9 | 3,74 | 14,0 | 12,0 | 1,69 |
| | T30 | 1,3 | 1,74 | 44,3 | 14,9 | 2,23 | 14,8 | 7,19 | 2,98 |
| | T10 | 1,5 | 1,80 | 52,9 | 17,2 | 2,58 | 17,6 | 8,32 | 3,08 |
| 25,8 | T100 | 1,3 | 1,54 | 42,2 | 39,1 | 1,96 (5,87) | 14,1 | 15,0 (18,9) | 1,08 |
| | T60 | 1,3 | 1,65 | 45,2 | 26,2 | 3,93 | 15,1 | 12,7 | 1,72 |
| | T30 | 1,3 | 1,74 | 47,7 | 15,6 | 2,35 | 15,9 | 7,56 | 3,04 |
| | T10 | 1,5 | 1,80 | 56,9 | 18,1 | 2,71 | 19,0 | 8,73 | 3,15 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u | $k_{af}$ p.u | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|
| 27 | T100 | 1,3 | 1,54 | 44,1 | 40,4 | 2,02 (6,06) | 14,7 | 15,5 (19,5) | 1,09 |
| | T60 | 1,3 | 1,65 | 47,3 | 27,1 | 4,06 | 15,8 | 13,1 | 1,75 |
| | T30 | 1,3 | 1,74 | 49,9 | 16,2 | 2,42 | 16,6 | 7,83 | 3,09 |
| | T10 | 1,5 | 1,80 | 59,5 | 18,6 | 2,80 | 19,8 | 9,01 | 3,19 |
| 36 | T100 | 1,3 | 1,54 | 58,8 | 49,3 | 2,47 (7,40) | 19,6 | 18,9 (23,8) | 1,19 |
| | T60 | 1,3 | 1,65 | 63,1 | 33,0 | 4,96 | 21,0 | 16,0 | 1,91 |
| | T30 | 1,3 | 1,74 | 66,5 | 19,7 | 2,96 | 22,2 | 9,53 | 3,37 |
| | T10 | 1,5 | 1,80 | 79,4 | 22,8 | 3,41 | 26,4 | 11,0 | 3,49 |
| 38 | T100 | 1,3 | 1,54 | 62,1 | 51,2 | 2,56 (7,68) | 20,7 | 19,6 (24,8) | 1,21 |
| | T60 | 1,3 | 1,65 | 66,6 | 34,3 | 5,15 | 22,2 | 16,6 | 1,94 |
| | T30 | 1,3 | 1,74 | 70,2 | 20,5 | 3,07 | 23,4 | 9,90 | 3,43 |
| | T10 | 1,5 | 1,80 | 83,8 | 23,6 | 3,54 | 27,9 | 11,4 | 3,54 |
| 40,5 | T100 | 1,3 | 1,54 | 66,2 | 53,5 | 2,68 (8,03) | 22,1 | 20,5 (25,9) | 1,24 |
| | T60 | 1,3 | 1,65 | 70,9 | 35,9 | 5,38 | 23,6 | 17,3 | 1,98 |
| | T30 | 1,3 | 1,74 | 74,8 | 21,4 | 3,21 | 24,9 | 10,3 | 3,49 |
| | T10 | 1,5 | 1,80 | 89,3 | 24,7 | 3,71 | 29,8 | 11,9 | 3,61 |
| 48,3 | T100 | 1,3 | 1,54 | 79,0 | 60,5 | 3,02 (9,07) | 26,3 | 23,2 (29,2) | 1,31 |
| | T60 | 1,3 | 1,65 | 84,6 | 40,5 | 6,08 | 28,2 | 19,6 | 2,09 |
| | T30 | 1,3 | 1,74 | 89,2 | 24,2 | 3,63 | 29,7 | 11,7 | 3,69 |
| | T10 | 1,5 | 1,80 | 106 | 27,9 | 4,19 | 35,5 | 13,5 | 3,81 |
| 52 | T100 | 1,3 | 1,54 | 85,0 | 63,7 | 3,18 (9,55) | 28,3 | 24,4 (30,8) | 1,33 |
| | T60 | 1,3 | 1,65 | 91,1 | 42,7 | 6,40 | 30,4 | 20,6 | 2,13 |
| | T30 | 1,3 | 1,74 | 96,0 | 25,5 | 3,82 | 32,0 | 12,3 | 3,77 |
| | T10 | 1,5 | 1,80 | 115 | 29,4 | 4,41 | 38,2 | 14,2 | 3,90 |
| 72,5 | T100 | 1,3 | 1,54 | 119 | 80,2 | 4,01 (12,0) | 39,5 | 30,8 (38,8) | 1,48 |
| | T60 | 1,3 | 1,65 | 127 | 53,7 | 8,06 | 42,3 | 26,0 | 2,36 |
| | T30 | 1,3 | 1,74 | 134 | 32,1 | 4,81 | 44,6 | 15,5 | 4,17 |
| | T10 | 1,5 | 1,80 | 160 | 37,0 | 5,55 | 53,3 | 17,9 | 4,32 |

NOTE Where two values of times $t_d$ and $t'$ are given for test-duty T100 separated by brackets, the time $t_d$ in brackets is the upper limit of the time delay $t_d$ that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at $t'$ given in brackets. If this is not the case, the lower values of $t_d$ and $t'$ apply.

b) *For rated voltages from 100 kV to 800 kV*

A representation by four parameters of the prospective TRV is used for test-duties T100 and T60, and the supply circuit of SLF for test-duties $L_{90}$ and $L_{75}$ and for out-of-phase test-duties OP1 and OP2 and by two parameters for test-duties T30 and T10.

– First reference voltage $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$

– Time $t_1$ for terminal fault test-duties is derived from $u_1$ and the specified value of the rate of rise $u_1/t_1$. For test-duties OP1 and OP2, $t_1$ is two times $t_1$ for test-duty T100 and the rate of rise is derived from $u_1$ and $t_1$. For the supply side circuit of short-line fault, time

$t_1$ is derived from $u_1$ and the specified value of the rate of rise $u_1/t_1$ which is the same as for test-duty T100.

– TRV peak value $u_c = k_{pp} \times k_{af} \times U_r \times \sqrt{\frac{2}{3}}$

where $k_{af}$ is equal to 1,4 for test-duty T100 and for the supply side circuit for SLF, 1,5 for test-duty T60, 1,54 for test-duty T30, 1,765 for test-duty T10 in case of $k_{pp}$ is 1,3, 1,53 (0,9 × 1,7) for test-duty T10 in the case of $k_{pp}$ is 1,5, and 1,25 for out-of-phase breaking.

– Time $t_2$ is equal to $4t_1$ for test-duty T100 and for the supply side circuit for short-line fault and between $t_2$ (for T100) and $2t_2$ (for T100) for out-of-phase breaking. Time $t_2$ is equal to $6t_1$ for T60.

– For test-duties T30 and T10, time $t_3$ is derived from $u_c$ and the specified value of the rate of rise $u_c/t_3$.

– Time delay $t_d$ is 2 µs for test-duty T100, between 2 µs and $0{,}3t_1$ for test-duty T60, between 2 µs and $0{,}1t_1$ for test-duties OP1 and OP2. Time delay is 0,15 $t_3$ for test-duties T30 and T10. For the supply side circuit for short-line fault the time delay is equal to 2 µs. When short-line fault tests are performed, the time delay $t_d$ for test-duty T100 can be extended up to 0,28 $t_1$. The relevant value of $t_d$ to be used for testing is given in 7.105.5.2 to 7.105.5.5.

– Voltage $u'$ = $u_1/2$ for test-duties T100 and T60 and the supply side for SLF and out-of-phase breaking, and $u_c/3$ for test-duties T30 and T10.

– Time $t'$ is derived from $u'$, $u_1/t_1$ and $t_d$ for test-duties T100, T60 and the supply circuit for SLF and out-of-phase breaking, and according to Figure 42; and from $u'$, $u_c/t_3$ and $t_d$ for test-duties T30 and T10 according to Figure 43.

c) *For rated voltages higher than 800 kV*

A representation by four parameters of the prospective TRV is used for test-duties T100 and T60, and the supply circuit of SLF for test-duties $L_{90}$ and $L_{75}$ and by two parameters for test-duties T30, T10 and for out-of-phase test-duties OP1 and OP2.

– First reference voltage $u_1 = 0{,}75 \times k_{pp} \times U_r \sqrt{\frac{2}{3}}$

– Time $t_1$ for terminal fault test-duties is derived from $u_1$ and the specified value of the rate of rise $u_1/t_1$. For the supply side circuit of short-line fault, time $t_1$ is derived from $u_1$ and the specified value of the rate of rise $u_1/t_1$ which is the same as for test-duty T100.

– Time $t_3$ for out-of-phase test-duties OP1 and OP2 is derived from $u_c$ and the specified value of the rate of rise.

– TRV peak value $u_c = k_{pp} \times k_{af} \times U_r \times \sqrt{\frac{2}{3}}$

where $k_{af}$ is equal to 1,5 for test-duty T100 and for the supply side circuit for SLF, 1,5 for test-duty T60, 1,54 for test-duty T30, 1,765 for test-duty T10, and 1,25 for out-of-phase breaking.

– Time $t_2$ is equal to 3 $t_1$ for test-duty T100 and for the supply side circuit for short-line fault. Time $t_2$ is equal to 4,5 $t_1$ for T60.

– For test-duties T30 and T10, time $t_3$ is derived from $u_c$ and the specified value of the rate of rise $u_c/t_3$.

– Time delay $t_d$ is 2 μs for test-duty T100, between 2 μs and 0,3 $t_1$ for test-duty T60. Time delay is 0,15 $t_3$ for test-duties T30 and T10, 0,05 $t_3$ for test-duties OP1 and OP2. For the supply side circuit for short-line fault the time delay is equal to 2 μs. When short-line fault tests are performed, the time delay $t_d$ for test-duty T100 can be extended up to 0,28 $t_1$. The relevant value of $t_d$ to be used for testing is given in 7.105.5.2 to 7.105.5.5.

– Voltage $u'$ = $u_1$/2 for test-duties T100 and T60 and the supply side for SLF, and $u_c$/3 for test-duties T30, T10 and out-of-phase test-duties.

– Time $t'$ is derived from $u'$, $u_1/t_1$ and $t_d$ for test-duties T100, T60 and the supply circuit for SLF, and according to Figure 42; and from $u'$, $u_c/t_3$ and $t_d$ for test-duties T30, T10 and out-of-phase test-duties according to Figure 43.

For rated voltages of 100 kV and above, the specified values are given in Table 20 and Table 21.

**Table 20 – Values of prospective TRV for circuit-breakers rated for $k_{pp}$ = 1,2 or 1,3 – Rated voltages of 100 kV and above**

| $U_r$<br>kV | Test-duty | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_1$<br>kV | $t_1$<br>μs | $u_c$<br>kV | $t_2$ or $t_3$<br>μs | $t_d$ [a]<br>μs | $u'$<br>kV | $t'$ [a]<br>μs | $u_1/t_1$<br>$u_c/t_3$<br>kV/μs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | T100 | 1,3 | 1,40 | 80 | 40 | 149 | 160 | 2 (11) | 40 | 22 (31) | 2 |
| | T60 | 1,3 | 1,50 | 80 | 27 | 159 | 160 | 2-8 | 40 | 15-21 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 163 | 33 | 5 | 54 | 16 | 5 |
| | T10 | 1,3 | 1,765 | - | - | 187 | 27 | 4 | 62 | 13 | 7 |
| 123 | T100 | 1,3 | 1,40 | 98 | 49 | 183 | 196 | 2 (14) | 49 | 26 (38) | 2 |
| | T60 | 1,3 | 1,50 | 98 | 33 | 196 | 196 | 2-10 | 49 | 18-26 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 201 | 40 | 6 | 67 | 19 | 5 |
| | T10 | 1,3 | 1,765 | - | - | 230 | 33 | 5 | 77 | 16 | 7 |
| 145 | T100 | 1,3 | 1,40 | 115 | 58 | 215 | 232 | 2 (16) | 58 | 31 (45) | 2 |
| | T60 | 1,3 | 1,50 | 115 | 38 | 231 | 232 | 2-12 | 58 | 21-31 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 237 | 47 | 7 | 79 | 23 | 5 |
| | T10 | 1,3 | 1,765 | - | - | 272 | 39 | 6 | 91 | 19 | 7 |
| 170 | T100 | 1,3 | 1,40 | 135 | 68 | 253 | 272 | 2 (19) | 68 | 36 (53) | 2 |
| | T60 | 1,3 | 1,50 | 135 | 45 | 271 | 272 | 2-14 | 68 | 25-36 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 278 | 56 | 8 | 93 | 27 | 5 |
| | T10 | 1,3 | 1,765 | - | - | 319 | 46 | 7 | 106 | 22 | 7 |
| 245 | T100 | 1,3 | 1,40 | 195 | 98 | 364 | 392 | 2 (27) | 98 | 51 (76) | 2 |
| | T60 | 1,3 | 1,50 | 195 | 65 | 390 | 392 | 2-20 | 98 | 35-52 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 400 | 80 | 12 | 133 | 39 | 5 |
| | T10 | 1,3 | 1,765 | - | - | 459 | 66 | 10 | 153 | 32 | 7 |
| 300 | T100 | 1,3 | 1,40 | 239 | 119 | 446 | 476 | 2 (33) | 119 | 62 (93) | 2 |
| | T60 | 1,3 | 1,50 | 239 | 80 | 478 | 476 | 2-24 | 119 | 42-64 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 490 | 98 | 15 | 163 | 47 | 5 |
| | T10 | 1,3 | 1,765 | - | - | 562 | 80 | 12 | 187 | 39 | 7 |
| 362 | T100 | 1,3 | 1,40 | 288 | 144 | 538 | 576 | 2 (40) | 144 | 74 (112) | 2 |
| | T60 | 1,3 | 1,50 | 288 | 96 | 576 | 576 | 2-29 | 144 | 50-77 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 592 | 118 | 18 | 197 | 57 | 5 |

| $U_r$ kV | Test-duty | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_1$ kV | $t_1$ µs | $u_c$ kV | $t_2$ or $t_3$ µs | $t_d$ [a] µs | $u'$ kV | $t'$ [a] µs | $u_1/t_1$ $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | T10 | 1,3 | 1,765 | - | - | 678 | 97 | 15 | 226 | 47 | 7 |
| 420 | T100 | 1,3 | 1,40 | 334 | 167 | 624 | 668 | 2 (47) | 167 | 86 (130) | 2 |
| | T60 | 1,3 | 1,50 | 334 | 111 | 669 | 668 | 2-33 | 167 | 58-89 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 687 | 137 | 21 | 229 | 66 | 5 |
| | T10 | 1,3 | 1,765 | - | - | 787 | 112 | 17 | 262 | 54 | 7 |
| 550 | T100 | 1,3 | 1,40 | 438 | 219 | 817 | 876 | 2 (61) | 219 | 111 (171) | 2 |
| | T60 | 1,3 | 1,50 | 438 | 146 | 876 | 876 | 2-44 | 219 | 75-117 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 899 | 180 | 27 | 300 | 87 | 5 |
| | T10 | 1,3 | 1,765 | - | - | 1 031 | 147 | 22 | 344 | 71 | 7 |
| 800 | T100 | 1,3 | 1,40 | 637 | 318 | 1 189 | 1 272 | 2 (89) | 318 | 161 (248) | 2 |
| | T60 | 1,3 | 1,50 | 637 | 212 | 1 274 | 1 272 | 2-64 | 318 | 108-170 | 3 |
| | T30 | 1,3 | 1,54 | - | - | 1 308 | 262 | 39 | 436 | 126 | 5 |
| | T10 | 1,3 | 1,765 | - | - | 1 499 | 214 | 32 | 500 | 103 | 7 |
| 1 100 | T100 | 1,2 | 1,50 | 808 | 404 | 1 617 | 1 212 | 2 (113) | 404 | 204 (315) | 2 |
| | T60 | 1,2 | 1,50 | 808 | 269 | 1 617 | 1 212 | 2-81 | 404 | 137-216 | 3 |
| | T30 | 1,2 | 1,54 | - | - | 1 660 | 332 | 50 | 553 | 161 | 5 |
| | T10 | 1,2 | 1,765 | - | - | 1 902 | 271 | 41 | 634 | 131 | 7 |
| 1 200 | T100 | 1,2 | 1,50 | 882 | 441 | 1 764 | 1 323 | 2 (123) | 441 | 222 (343) | 2 |
| | T60 | 1,2 | 1,50 | 882 | 294 | 1 764 | 1 323 | 2-88 | 441 | 149-235 | 3 |
| | T30 | 1,2 | 1,54 | - | - | 1 811 | 362 | 54 | 604 | 175 | 5 |
| | T10 | 1,2 | 1,765 | - | - | 2 075 | 296 | 44 | 692 | 143 | 7 |

NOTE Test-duty T10 covers transformer-limited fault conditions with $X_0/X_1$ higher than 3,0 (for example non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems). For rated voltages higher than 170 kV the TRV specified covers also cases of three-phase line faults with effectively earthed neutral systems where coupling between phases can lead to an amplitude factor of 1,765.

[a] Where two values of times $t_d$ and $t'$ are given for terminal fault test-duty T60, those indicate the lower and upper limits which should be used for testing. The time delay $t_d$ and the time $t'$ during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.

[b] Where two values of times $t_d$ and $t'$ are given for test-duty T100 separated by brackets, the time $t_d$ in brackets is the upper limit of the time delay $t_d$ that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at $t'$ given in brackets. If this is not the case, the lower values of $t_d$ and $t'$ apply.

**Table 21 – Values of prospective TRV for circuit-breakers rated for $k_{pp}$ = 1,5 – Rated voltages of 100 kV to 170 kV**

| $U_r$<br>kV | Test-duty | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_1$<br>kV | $t_1$<br>µs | $u_c$<br>kV | $t_2$ or $t_3$<br>µs | $t_d$ [a]<br>µs | $u'$<br>kV | $t'$ [a]<br>µs | $u_1/t_1$<br>$u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | T100 | 1,5 | 1,40 | 92 | 46 | 171 | 184 | 2 (13) | 46 | 25 (36) | 2 |
| | T60 | 1,5 | 1,50 | 92 | 31 | 184 | 186 | 2-8 | 46 | 15-21 | 3 |
| | T30 | 1,5 | 1,54 | - | - | 189 | 38 | 5 | 63 | 16 | 5 |
| | T10 | 1,5 | 1,53 | - | - | 187 | 27 | 4 | 62 | 13 | 7 |
| 123 | T100 | 1,5 | 1,40 | 113 | 56 | 211 | 224 | 2 (16) | 56 | 30 (44) | 2 |
| | T60 | 1,5 | 1,50 | 113 | 38 | 226 | 228 | 2-10 | 56 | 18-26 | 3 |
| | T30 | 1,5 | 1,54 | - | - | 232 | 46 | 6 | 77 | 19 | 5 |
| | T10 | 1,5 | 1,53 | - | - | 230 | 33 | 5 | 77 | 16 | 7 |
| 145 | T100 | 1,5 | 1,40 | 133 | 67 | 249 | 268 | 2 (19) | 67 | 35 (52) | 2 |
| | T60 | 1,5 | 1,50 | 133 | 44 | 266 | 264 | 2-12 | 67 | 21-31 | 3 |
| | T30 | 1,5 | 1,54 | - | - | 273 | 55 | 7 | 91 | 23 | 5 |
| | T10 | 1,5 | 1,53 | - | - | 272 | 39 | 6 | 91 | 19 | 7 |
| 170 | T100 | 1,5 | 1,40 | 156 | 78 | 291 | 312 | 2 (22) | 78 | 41 (61) | 2 |
| | T60 | 1,5 | 1,50 | 156 | 52 | 312 | 312 | 2-14 | 78 | 25-36 | 3 |
| | T30 | 1,5 | 1,54 | - | - | 321 | 64 | 8 | 107 | 27 | 5 |
| | T10 | 1,5 | 1,53 | - | - | 319 | 46 | 7 | 106 | 22 | 7 |

[a] Where two values of times $t_d$ and $t'$ are given for terminal fault test-duty T60, those indicate the lower and upper limits which should be used for testing. The time delay $t_d$ and the time $t'$ during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.

Where two values of times $t_d$ and $t'$ are given for test-duty T100, separated by brackets, the time $t_d$ in brackets is the upper limit of the time delay $t_d$ that can be used for test-duty T100 if short-line fault tests are also made. For such cases, the delay line terminates at $t'$ given in brackets. If this is not the case, the lower values of $t_d$ and $t'$ apply.

NOTE Test-duty T10 covers transformer-limited fault conditions with $X_0/X_1$ higher than 3,0 (for example non-effectively earthed transformers in effectively earthed neutral systems, or cases of transformers having one side effectively earthed and the other connected to non-effectively earthed neutral systems).



The prospective TRV wave of the test circuit shall comply with the following two requirements:

– Requirement a)

Its envelope shall at no time be below the specified reference line.

It is stressed that the extent by which the envelope can exceed the specified reference line requires the consent of the manufacturer (see 7.105); this is of particular importance in the case of two-parameter envelopes when four-parameter reference lines are specified, and in the case of four-parameter envelopes when two-parameter reference lines are specified.

For convenience of testing it is allowed to carry out test-duties for which a four parameter TRV is specified with a two parameter TRV, provided that the rate-of-rise of recovery voltage corresponds to the standard value $u_1/t_1$ and the peak value to the standard value $u_c$. This procedure requires the consent of the manufacturer.

– Requirement b)

Its initial portion shall fulfil the specified ITRV requirements. The ITRV shall be handled like a short-line fault. Consequently, it is necessary to measure the ITRV circuit independently of the source side in an inherent way. The ITRV is defined by the peak value $u_i$ and the time coordinate $t_i$ (Figure 45). The inherent waveshape shall mostly follow a straight line reference line drawn from the beginning of the ITRV to the point defined by $u_i$ and $t_i$. The inherent ITRV waveshape shall follow this reference line from 20 % to 80 % of the required ITRV peak value. Deviations from the reference line are permitted for the ITRV amplitude below 20 % and above 80 % of the specified ITRV peak value. It shall not be significantly higher than the above-mentioned reference line. If the 80 % value cannot be reached without significant increase of the rate of rise of the ITRV, it is preferred to raise the peak value $u_i$ above the specified value in order to reach the 80 % point. The rate of rise of the ITRV shall not be increased, because this would be connected to a change of the impedance and thus to an essential change of the severity of the test.

Testing under ITRV conditions is necessary for T100a, T100s and $L_{90}$. However, if a circuit-breaker with rated voltage equal or less than 800 kV has a short-line fault rating, the ITRV requirements are considered to be covered if $L_{90}$ is carried out using a line with a time delay less than 100 ns (see also 7.105.5.2).

If a circuit-breaker with rated voltage higher than 800 kV has a short-line fault rating, the ITRV requirements are covered if $L_{90}$ is carried out using a line with a time delay less than 100 ns and a surge impedance of 450 Ω (see also 7.105.5.2 and 7.109.3).

#### 7.105.5.2 Test-duties T100s and T100a

For rated voltages less than 100 kV, the specified values are given in

– Table 16 and Table 17 for class S1 circuit-breakers,
– Table 18 and Table 19 for class S2 circuit-breakers.

The specific reference lines, delay lines and ITRV are given by the values in Table 9, Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21.

With reference to ITRV, if a test is made with a TRV following the straight reference line specified in requirement a) and b) of 7.105.5.1 and shown in Figure 45, it is assumed that the effect on the circuit-breaker is similar to that of any ITRV defined in requirement b) of 7.105.5.1 and Figure 45.

Owing to limitations of the testing station, it may not be feasible to comply with the requirement of item b) of 7.105.5.1 with respect to the time delay $t_d$ as specified in Table 16 through Table 21.

Where short-line fault duties are also to be performed, any such deficiency of the TRV of the supply circuit shall be compensated by an increase of the voltage excursion to the first peak of the line-side voltage (see 7.109.3). The time delay of the supply circuit shall be as small as possible, but shall in any case not exceed the values given in brackets in Table 18, Table 19, Table 20 or Table 21.

Where short-line fault duties are also to be performed, it may be convenient to combine the ITRV and $L_{90}$ requirements in the line-side circuit. When the ITRV is combined with the transient voltage of a short line having a time delay $t_{dL}$ as specified in 7.109.3 the total stress is, for practical considerations, equal or covered by the stress of a short line with a time delay less than 100 ns and a surge impedance of 450 Ω. Therefore the ITRV requirements for test-duties T100s and T100a are considered to be covered when $L_{90}$ is performed using a line with a time delay less than 100 ns and a surge impedance of 450 Ω.

Where short-line fault test-duty $L_{90}$ with a time delay less than 100 ns is used to cover ITRV requirements, the initial part of the line side transient voltage up to 0,2 $u_L$* shall not cross the 20 % to 80 % $L_{90}$ reference except if the time delay as defined in Figure 46 is less than 100 ns.

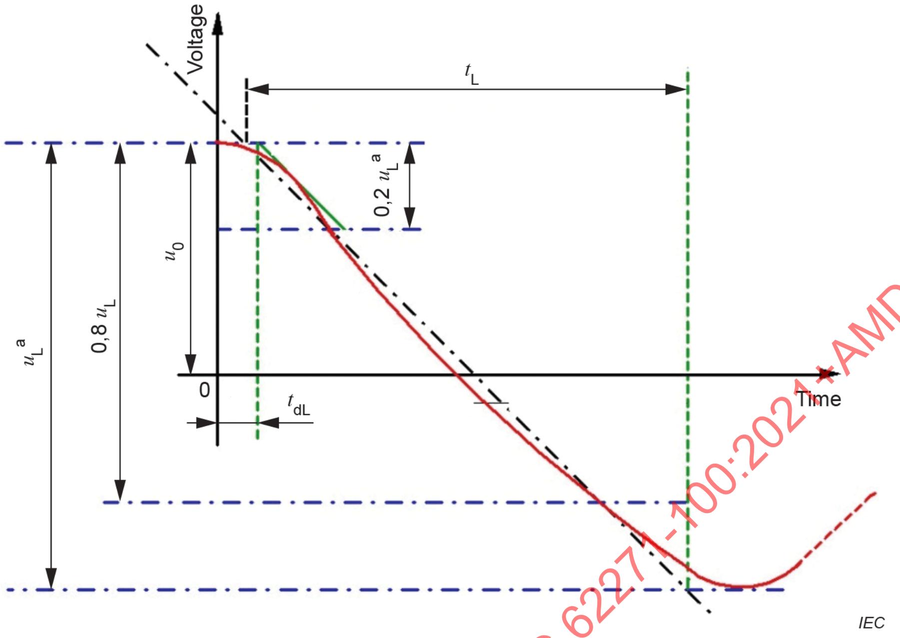



**Figure 46 – Example of line transient voltage with time delay with non-linear rate of rise**

### 7.105.5.3 Test-duty T60

For rated voltages less than 100 kV, the specified values are given in

– Table 16 and Table 17 for class S1 circuit-breakers,

– Table 18 and Table 19 for class S2 circuit-breakers.

For rated voltages of 100 kV and above, the specified standard values are given in Table 20 and Table 21.

### 7.105.5.4 Test-duty T30

a) For rated voltages less than 100 kV, the specified values are given in
   – Table 16 and Table 17 for class S1 circuit-breakers,
   – Table 18 and Table 19 for class S2 circuit-breakers.

b) For rated voltages of 100 kV and above, the specified standard values are given in Table 20 and Table 21.

In case that small values of time $t_3$ cannot be met, the shortest time that can be met shall be used. The values used shall be stated in the test report.

NOTE The contribution of transformers to the short-circuit current is relatively larger at smaller values of short-circuit current as in T30 and T10 conditions. However, most systems have effectively earthed neutrals at ratings of 100 kV up to 800 kV. With the system and transformer neutrals effectively earthed, a $k_{pp}$ of 1,3 is applicable for all test-duties except for T10, where in general a $k_{pp}$ of 1,5 is used in order to take also transformer fed faults into account. For rated voltages higher than 800 kV, a $k_{pp}$ of 1,2 is applicable for all test-duties.

In some systems for rated voltages of 100 kV up to and including 170 kV, transformers with non-effectively earthed neutrals are in service, even though the rest of the system can have effectively earthed neutrals. Such systems are considered special cases and are covered in Table 21 where the TRVs specified for all test-duties are based on a $k_{pp}$ of 1,5. For rated voltages above 170 kV, all systems and their transformers are considered to have effectively earthed neutrals.

### 7.105.5.5 Test-duty T10

a) For rated voltages less than 100 kV, the specified values are given in
   - Table 16 and Table 17 for class S1 circuit-breakers,
   - Table 18 and Table 19 for class S2 circuit-breakers.

b) For rated voltages of 100 kV and above, the specified standard values are given in Table 20 and Table 21. The time $t_3$ is a function of the natural frequency of transformers.

In case that small values of time $t_3$ cannot be met, the shortest time that can be met shall be used. The values used shall be stated in the test report.

### 7.105.5.6 Test-duties OP1 and OP2

For rated voltages up to and including 72,5 kV, the specified values are given in the following Tables.

- Table 22 for class S1 circuit-breakers for use in non-effectively earthed neutral systems;
- Table 23 for class S1 circuit-breakers for use in effectively earthed neutral systems;
- Table 24 for class S2 circuit-breakers for use in non-effectively earthed neutral systems;
- Table 25 for class S2 circuit-breakers for use in effectively earthed neutral systems.

For rated voltages of 100 kV and above, the specified values are given in Table 26 and Table 27.

**Table 22 – Values of prospective TRV for out-of-phase tests on class S1 circuit-breakers for $k_{pp}$ = 2,5**

| $U_r$<br>kV | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_c$<br>kV | $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|
| 3,6 | 2,5 | 1,25 | 9,19 | 81,3 | 12,2 | 3,06 | 39,3 | 0,113 |
| 4,76 | 2,5 | 1,25 | 12,1 | 89,7 | 13,5 | 4,05 | 43,4 | 0,135 |
| 7,2 | 2,5 | 1,25 | 18,4 | 103 | 15,5 | 6,12 | 49,8 | 0,178 |
| 8,25 | 2,5 | 1,25 | 21,1 | 108 | 16,2 | 7,02 | 52,3 | 0,195 |
| 12 | 2,5 | 1,25 | 30,6 | 124 | 18,5 | 10,2 | 59,7 | 0,248 |
| 15 | 2,5 | 1,25 | 38,3 | 135 | 20,3 | 12,8 | 65,4 | 0,283 |
| 15,5 | 2,5 | 1,25 | 39,5 | 137 | 20,6 | 13,2 | 66,4 | 0,288 |
| 17,5 | 2,5 | 1,25 | 44,7 | 145 | 21,8 | 14,9 | 70,1 | 0,308 |
| 24 | 2,5 | 1,25 | 61,2 | 170 | 25,5 | 20,4 | 82,1 | 0,360 |
| 25,8 | 2,5 | 1,25 | 65,8 | 177 | 26,5 | 21,9 | 85,5 | 0,372 |
| 27 | 2,5 | 1,25 | 68,9 | 181 | 27,2 | 23,0 | 87,7 | 0,380 |
| 36 | 2,5 | 1,25 | 91,9 | 214 | 32,2 | 30,6 | 104 | 0,428 |
| 38 | 2,5 | 1,25 | 97,0 | 221 | 33,2 | 32,3 | 107 | 0,438 |
| 40,5 | 2,5 | 1,25 | 103 | 229 | 34,5 | 34,4 | 111 | 0,450 |
| 48,3 | 2,5 | 1,25 | 123 | 254 | 38,1 | 41,1 | 123 | 0,485 |
| 52 | 2,5 | 1,25 | 133 | 265 | 39,7 | 44,2 | 128 | 0,502 |
| 72,5 | 2,5 | 1,25 | 185 | 332 | 49,7 | 61,7 | 160 | 0,558 |

**Table 23 – Values of prospective TRV for out-of-phase tests on class S1 circuit-breakers for $k_{pp}$ = 2,0**

| $U_r$ kV | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|
| 3,6 | 2,0 | 1,25 | 7,35 | 65,1 | 9,76 | 2,45 | 31,5 | 0,113 |
| 4,76 | 2,0 | 1,25 | 9,72 | 71,8 | 10,8 | 3,24 | 34,7 | 0,135 |
| 7,2 | 2,0 | 1,25 | 14,7 | 82,4 | 12,4 | 4,90 | 39,8 | 0,178 |
| 8,25 | 2,0 | 1,25 | 16,8 | 86,3 | 12,9 | 5,61 | 41,7 | 0,195 |
| 12 | 2,0 | 1,25 | 24,5 | 98,9 | 14,8 | 8,16 | 47,8 | 0,250 |
| 15 | 2,0 | 1,25 | 30,6 | 108 | 16,2 | 10,2 | 52,3 | 0,283 |
| 15,5 | 2,0 | 1,25 | 31,6 | 110 | 16,5 | 10,6 | 53,1 | 0,288 |
| 17,5 | 2,0 | 1,25 | 35,7 | 116 | 17,4 | 11,9 | 56,1 | 0,308 |
| 24 | 2,0 | 1,25 | 49,0 | 136 | 20,4 | 16,3 | 65,7 | 0,360 |
| 25,8 | 2,0 | 1,25 | 52,7 | 141 | 21,2 | 17,6 | 68,4 | 0,372 |
| 27 | 2,0 | 1,25 | 55,1 | 145 | 21,8 | 18,4 | 70,1 | 0,380 |
| 36 | 2,0 | 1,25 | 73,5 | 172 | 25,7 | 24,5 | 82,9 | 0,428 |
| 38 | 2,0 | 1,25 | 77,6 | 177 | 26,6 | 25,9 | 85,6 | 0,438 |
| 40,5 | 2,0 | 1,25 | 82,7 | 184 | 27,6 | 27,6 | 88,8 | 0,450 |
| 48,3 | 2,0 | 1,25 | 98,6 | 203 | 30,5 | 32,9 | 98,2 | 0,485 |
| 52 | 2,0 | 1,25 | 106 | 212 | 31,8 | 35,4 | 102 | 0,502 |
| 72,5 | 2,0 | 1,25 | 148 | 265 | 39,8 | 49,3 | 128 | 0,558 |

**Table 24 – Values of prospective TRV for out-of-phase tests on class S2 circuit-breakers for $k_{pp}$ = 2,5**

| $U_r$ kV | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_c$ kV | $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|
| 3,6 | 2,5 | 1,25 | 9,19 | 23,0 | 3,45 | 3,06 | 11,1 | 0,400 |
| 4,76 | 2,5 | 1,25 | 12,1 | 27,9 | 4,18 | 4,05 | 13,5 | 0,435 |
| 7,2 | 2,5 | 1,25 | 18,4 | 37,2 | 5,58 | 6,12 | 18,0 | 0,494 |
| 8,25 | 2,5 | 1,25 | 21,1 | 40,9 | 6,13 | 7,02 | 19,8 | 0,515 |
| 12 | 2,5 | 1,25 | 30,6 | 53,0 | 7,96 | 10,2 | 25,6 | 0,577 |
| 15 | 2,5 | 1,25 | 38,3 | 61,9 | 9,29 | 12,8 | 29,9 | 0,618 |
| 15,5 | 2,5 | 1,25 | 39,5 | 63,4 | 9,50 | 13,2 | 30,6 | 0,624 |
| 17,5 | 2,5 | 1,25 | 44,7 | 68,9 | 10,3 | 14,9 | 33,3 | 0,648 |
| 24 | 2,5 | 1,25 | 61,2 | 85,9 | 12,9 | 20,4 | 41,5 | 0,713 |
| 25,8 | 2,5 | 1,25 | 65,8 | 90,3 | 13,5 | 21,9 | 43,6 | 0,729 |
| 27 | 2,5 | 1,25 | 68,9 | 93,2 | 14,0 | 23,0 | 45,0 | 0,739 |
| 36 | 2,5 | 1,25 | 91,9 | 114 | 17,1 | 30,6 | 55,0 | 0,807 |
| 38 | 2,5 | 1,25 | 97,0 | 118 | 17,7 | 32,3 | 57,1 | 0,821 |
| 40,5 | 2,5 | 1,25 | 103 | 124 | 18,5 | 34,5 | 59,7 | 0,837 |
| 48,3 | 2,5 | 1,25 | 123 | 140 | 21,0 | 41,1 | 67,5 | 0,883 |
| 52 | 2,5 | 1,25 | 133 | 147 | 22,0 | 44,2 | 71,0 | 0,903 |
| 72,5 | 2,5 | 1,25 | 185 | 185 | 27,8 | 61,7 | 89,5 | 0,999 |

**Table 25 – Values of prospective TRV for out-of-phase tests on class S2 circuit-breakers for $k_{pp}$ = 2,0**

| $U_r$<br>kV | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_c$<br>kV | $t_3$<br>µs | $t_d$<br>µs | $u'$<br>kV | $t'$<br>µs | $u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|
| 3,6 | 2,0 | 1,25 | 7,35 | 18,4 | 2,76 | 2,45 | 8,88 | 0,400 |
| 4,76 | 2,0 | 1,25 | 9,72 | 22,3 | 3,35 | 3,24 | 10,8 | 0,435 |
| 7,2 | 2,0 | 1,25 | 14,7 | 29,7 | 4,46 | 4,90 | 14,4 | 0,494 |
| 8,25 | 2,0 | 1,25 | 16,8 | 32,7 | 4,91 | 5,61 | 15,8 | 0,515 |
| 12 | 2,0 | 1,25 | 24,5 | 42,4 | 6,36 | 8,16 | 20,5 | 0,577 |
| 15 | 2,0 | 1,25 | 30,6 | 49,5 | 7,43 | 10,2 | 23,9 | 0,618 |
| 15,5 | 2,0 | 1,25 | 31,6 | 50,7 | 7,60 | 10,6 | 24,5 | 0,624 |
| 17,5 | 2,0 | 1,25 | 35,7 | 55,1 | 8,27 | 11,9 | 26,7 | 0,648 |
| 24 | 2,0 | 1,25 | 49,0 | 68,7 | 10,3 | 16,3 | 33,2 | 0,713 |
| 25,8 | 2,0 | 1,25 | 52,7 | 72,2 | 10,8 | 17,6 | 34,9 | 0,729 |
| 27 | 2,0 | 1,25 | 55,1 | 74,5 | 11,2 | 18,4 | 36,0 | 0,739 |
| 36 | 2,0 | 1,25 | 73,5 | 91,0 | 13,7 | 24,5 | 44,0 | 0,807 |
| 38 | 2,0 | 1,25 | 77,6 | 94,5 | 14,2 | 25,9 | 45,7 | 0,821 |
| 40,5 | 2,0 | 1,25 | 82,7 | 98,8 | 14,8 | 27,6 | 47,8 | 0,834 |
| 48,3 | 2,0 | 1,25 | 98,6 | 112 | 16,8 | 32,9 | 54,0 | 0,883 |
| 52 | 2,0 | 1,25 | 106 | 118 | 17,6 | 35,4 | 56,8 | 0,903 |
| 72,5 | 2,0 | 1,25 | 148 | 148 | 22,2 | 49,3 | 71,6 | 0,999 |

**Table 26 – Values of prospective TRV for out-of-phase tests on circuit-breakers rated for $k_{pp}$ = 2,5 – Rated voltages of 100 kV to 170 kV**

| $U_r$<br>kV | $k_{pp}$<br>p.u. | $k_{af}$<br>p.u. | $u_1$<br>kV | $t_1$<br>µs | $u_c$<br>kV | $t_2$ or $t_3$ [a]<br>µs | $t_d$ [a]<br>µs | $u'$<br>kV | $t'$ [a]<br>µs | $u_1/t_1$<br>$u_c/t_3$<br>kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 2,5 | 1,25 | 153 | 92 | 255 | 184-368 | 2-8 | 77 | 42-48 | 1,67 |
| 123 | 2,5 | 1,25 | 188 | 112 | 314 | 224-448 | 2-10 | 94 | 51-59 | 1,67 |
| 145 | 2,5 | 1,25 | 222 | 134 | 370 | 268-536 | 2-12 | 111 | 60-70 | 1,67 |
| 170 | 2,5 | 1,25 | 260 | 156 | 434 | 312-624 | 2-14 | 130 | 70-82 | 1,67 |

[a] The values of times $t_2$, $t_d$ and $t'$ indicate the lower and upper limits which should be used for testing. The time delay $t_d$ and the time $t'$ during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.

**Table 27 – Values of prospective TRV for out-of-phase tests on circuit-breakers rated for $k_{pp}$ = 2,0 – Rated voltages of 100 kV and above**

| $U_r$ kV | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_1$ kV | $t_1$ µs | $u_c$ kV | $t_2$ or $t_3$ [a] µs | $t_d$ [a] µs | $u'$ kV | $t'$ [a] µs | $u_1/t_1$ $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 2 | 1,25 | 122 | 80 | 204 | 160-320 | 2-8 | 61 | 42-48 | 1,54 |
| 123 | 2 | 1,25 | 151 | 98 | 251 | 196-392 | 2-10 | 75 | 51-59 | 1,54 |
| 145 | 2 | 1,25 | 178 | 116 | 296 | 232-464 | 2-12 | 89 | 60-70 | 1,54 |
| 170 | 2 | 1,25 | 208 | 136 | 347 | 272-544 | 2-14 | 104 | 70-82 | 1,54 |
| 245 | 2 | 1,25 | 300 | 196 | 500 | 392-784 | 2-20 | 150 | 99-117 | 1,54 |
| 300 | 2 | 1,25 | 367 | 238 | 612 | 476-952 | 2-24 | 184 | 121-143 | 1,54 |
| 362 | 2 | 1,25 | 443 | 288 | 739 | 576-1 152 | 2-29 | 222 | 146-173 | 1,54 |
| 420 | 2 | 1,25 | 514 | 334 | 857 | 668-1 336 | 2-33 | 257 | 169-200 | 1,54 |
| 550 | 2 | 1,25 | 674 | 438 | 1 123 | 876-1 752 | 2-44 | 337 | 221-263 | 1,54 |
| 800 | 2 | 1,25 | 980 | 636 | 1 633 | 1 272- 2 544 | 2-64 | 490 | 320-382 | 1,54 |
| 1 100 | 2 | 1,25 | - | - | 2 245 | 1 458 | 2-73 | 748 | 488-559 | 1,54 |
| 1 200 | 2 | 1,25 | - | - | 2 449 | 1 590 | 2-80 | 816 | 532-610 | 1,54 |

[a] The values of times $t_2$, $t_d$ and $t'$ indicate the lower and upper limits which should be used for testing. The time delay $t_d$ and the time $t'$ during testing should not be shorter than their respective lower limits and should not be longer than their respective upper limits.



### 7.105.6 Multipliers for TRV for second and third clearing poles

The TRV is defined for the first-pole-to-clear. In order to obtain the values of RRRV and $u_c$ for the second and third clearing poles, a multiplier shall be applied to the values of RRRV and $u_c$ of the first clearing pole at the relevant first-pole-to-clear factor. The values of these multipliers are given in Table 14.

The multipliers of Table 14 have been calculated with the assumptions given in IEC TR 62271-306 [4].

For three-phase testing the test circuit shall be designed to achieve the prospective $u_c$ values for the second and third clearing poles. It is not necessary to meet the prospective RRRV values for the second and third clearing poles. The actual values shall be stated in the test report.

## 7.106 Short-circuit test procedure

### 7.106.1 Time interval between tests

The time intervals between individual operations of a test sequence shall be the time intervals of the rated operating sequence of the circuit-breaker, given in 5.104. For the make-break tests 7.106.3 applies. If, due to test plant limitations, the rated operating sequence cannot be achieved, the following applies:

a) The test shall be performed with the shortest achievable time interval $t'$. The time interval achieved shall be stated in the report. For time intervals longer than 10 min the reason for the delay shall be stated in the report;

b) For different time intervals $t$ the following applies:

1) $t$ = 0,3 s: the time interval is mandatory;

2) $t \geq 15$ s, procedure a) applies.

Prolonged time intervals shall not be due to faulty operation of the circuit-breaker.

#### 7.106.2 Application of auxiliary power to the opening release – Breaking tests

Auxiliary power shall be applied to the opening release after the initiation of the short-circuit, but when due to test plant limitations this is impracticable the power can be applied before the initiation of the short-circuit (with the limitation that contacts shall not start to move before the initiation of the short-circuit).

#### 7.106.3 Application of auxiliary power to the opening release – Make-break tests

In make-break tests the auxiliary power shall not be applied to the opening release before the circuit-breaker has reached the closed position. In the close-open operations of the short-circuit test-duties the power shall not be applied until at least one half-cycle has elapsed from the instant of contact touch. The close-open time shall remain as close as possible to the minimum close-open time declared by the manufacturer, but it is permissible to delay the circuit-breaker opening such that the level of asymmetry is within the permissible limit.

#### 7.106.4 Latching on short-circuit

A circuit-breaker is latched when the main current-carrying contacts have achieved a stationary, fully engaged position at closing and this position is maintained until intentionally released, either mechanically or electrically. Unless the circuit-breaker is fitted with a making current release, or equivalent device, it shall be verified that it latches satisfactorily without undue hesitation when there is negligible decrement of the AC component of the current during the closing period.

The ability of the circuit-breaker to latch on short-circuit making current can be verified in test-duty T100s (see 7.107.5) or in the verification test for making (see 7.102.4.1). During this test the following applies:

- for three-phase tests on a three-pole circuit-breaker, the closing angle should be chosen in order to stress the pole most remote from the drive with the peak making current;
- if a single-phase test is carried out, care should be taken to stress the pole most remote from the mechanism in the same way as during a three-phase test in respect to applied voltage across the pole and current through the pole.

If the characteristics of the test plant are such that it is impossible to carry out test-duty T100s within the specified limits of the applied voltage stated in 7.105.1, the test shall be repeated at reduced voltage using a test circuit which gives the rated short-circuit making current, with negligible decrement of the AC component.

Several methods can be used to establish whether a circuit-breaker has closed and latched, for example:

- by recording of the auxiliary contacts or the contact travel;
- by visually checking the latching position after the performance of the making test;
- by recording the action of the device in order to detect latching (for example a micro-switch suitably fitted to the mechanism).

The method employed to prove satisfactory latching shall be recorded in the test report.

### 7.107 Terminal fault tests

#### 7.107.1 General

The terminal fault tests shall consist of test-duties T10, T30, T60, T100s and T100a, as specified below. Tests carried out with rapid auto-reclosing sequence cover testing without rapid auto-reclosing.

In the cases explained in 7.106.4, it can be necessary to separate the making and breaking tests of test-duty T100s. In this case, the part consisting of the making operations is designated T100s(a) and the part consisting of the breaking operations is designated T100s(b).

The peak short-circuit current during the breaking-current tests of test-duties T100s, T100s(b) and T100a shall not exceed 110 % of the rated short-circuit making current of the circuit-breaker.

For convenience of testing the making operations of test-duties T10, T30 and T60 can be performed as no-load operations. The time intervals between the individual breaking operations, shall be the time intervals of the rated operating sequence of the circuit-breaker (see 7.106.1).

#### 7.107.2 Test-duty T10

Test-duty T10 consists of the rated operating sequence at 10 % of the rated short-circuit breaking current with a DC component at contact separation not exceeding 20 % and a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.5 (see also Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21).

#### 7.107.3 Test-duty T30

Test-duty T30 consists of the rated operating sequence at 30 % of the rated short-circuit breaking current with a DC component at contact separation not exceeding 20 % and a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.4 (see also Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21).

#### 7.107.4 Test-duty T60

Test-duty T60 consists of the rated operating sequence at 60 % of the rated short-circuit breaking current with a DC component at contact separation not exceeding 20 % and a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.3 (see also Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21).

#### 7.107.5 Test-duty T100s

##### 7.107.5.1 General

Test-duty T100s consists of the rated operating sequence at 100 % of the rated short-circuit breaking current taking account of 7.105.3, and with a transient and power frequency recovery voltage as specified in 7.103.4, 7.105.1 and 7.105.2 (see also Table 16, Table 17, Table 18, Table 19, Table 20 and Table 21) and 100 % of the rated short-circuit making current taking account of 7.105.2 and an applied voltage as specified in 7.105.1.

For this test-duty, the percentage of the DC component at contact separation shall not exceed 20 % of the AC component.

When making single-phase tests on one pole of a three-pole circuit-breaker, or when the characteristics of the test plant are such that it is impossible to carry out test-duty T100s within the specified limits of applied voltage in 7.105.1, making current in 7.105.2, breaking current in 7.105.3 and transient and power frequency recovery voltages in 7.103.4 and 7.105.5.2 taking account also of 7.106.3 and 7.106.4 the making and breaking tests in test-duty T100s can be made separately. The short-circuit current in the separate making operations shall be maintained for an interval of at least 100 ms.

#### 7.107.5.2 Time constant of the DC component of the test circuit equal to the specified value

Where the time constant of the DC component of the test circuit is equal to the specified value as defined by 5.101.3, the alternative for performing test-duty T100s described above is as follows:

a) making tests, test-duty T100s(a)

The sequence C – *t'* – C shall be carried with one making operation against a symmetrical current equal to the rated short-circuit breaking current and the other making operation against the rated short-circuit making current according to 7.105.2. The making operation against symmetrical current shall be carried out at the applied voltage specified in 7.105.1;

b) breaking tests, test-duty T100s(b)

These making operations detailed in a) shall be followed by O – *t* – CO – *t'* – CO at 100 % of the rated short-circuit breaking current and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2.

During this test sequence, the following applies:

– no maintenance is allowed between a) and b);
– the second making operation of a) can be omitted, provided that during b) one of the making operations is such that the rated short-circuit making current is achieved;

#### 7.107.5.3 Time constant of the DC component of the test circuit less than the specified value

Where the time constant of the DC component of the test circuit is less than the specified value as defined by 5.101.3, the alternative for performing test-duty T100s described above is as follows:

a) making tests, test-duty T100s(a)

A single closing operation against the rated short-circuit making current according to 7.105.2 shall be performed. This making operation can be performed at reduced voltage with the limitations stated in 7.105.2;

b) breaking tests, test-duty T100s(b)

This making operation shall be followed by O – *t* – CO – *t'* – CO at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 7.105.1 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. In this second part, one of the making operations shall be such that it closes against a symmetrical current equal to the rated short-circuit breaking current.

NOTE Due to the smaller time constant of the DC component of the test circuit with respect to the specified value used for the rated short-circuit breaking current, the symmetrical value of the current during a) will need to be greater than the rated value. During b), for the same reason, the current peak, already demonstrated during a), will be smaller than the rated short-circuit making current.

During this test sequence the following applies:

– no maintenance is allowed between a) and b);
– for synthetic testing IEC 62271-101 applies.

**7.107.5.4 Time constant of the DC component of the test circuit greater than the specified value**

Where the time constant of the DC component of the test circuit is greater than the specified value as defined by 5.101.3, the alternative for performing test-duty T100s described above is as follows:

a) Making tests, test-duty T100s(a)

A single making operation against the rated short-circuit making current according to 7.105.2 shall be performed. This making operation can be performed at reduced voltage with the limitations stated in 7.105.2;

b) The sequence O – $t$ – CO – $t'$ – CO shall be carried out at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 7.105.1 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. During this sequence, one of the making operations shall be such that the circuit-breaker closes against a symmetrical current equal to the rated short-circuit breaking current, and the other against a full asymmetrical current. Due to the larger time constant of the DC component of the test circuit with respect to the specified value as per 5.101.3, the current peak during the asymmetrical making will be larger than the rated short-circuit making current. Therefore, the making operation can be controlled by use of point-on-wave control to obtain the required rated short-circuit making current. The performance of the test procedure a) is, however, subject to the consent of the manufacturer;

NOTE 1 Because of the larger peak of the current during the asymmetrical making, a separate closing operation against the rated short-circuit making current according to 7.105.2 is not required.

c) Alternatively sequence b) can be performed with the first making operation against a symmetrical current equal to the rated short-circuit breaking current and the second making operation at no load, i.e. O – $t$ – CO – $t'$ – O at 100 % of the rated short-circuit breaking current, at the applied voltage specified in 7.105.1 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2.

In this case evidence of the ability of the circuit-breaker to perform the rated operating sequence will be demonstrated by repeating the test sequence b), with relevant requirements, and with a symmetrical current smaller than the rated short-circuit breaking current in such a manner that the rated short-circuit making current is obtained in one of the making operations. During this repeated duty, the making operations can be performed at reduced voltage with the limitations stated in 7.105.2.

NOTE 2 Since the ability of the circuit-breaker to close against the rated short-circuit making current is proven during the repeated duty, a separate making operation against the rated short-circuit making current according to 7.105.2 is not required.

During this test sequence the following applies:

– where sequence c) is adopted, maintenance before repetition of the rated operating sequence is permitted;

**7.107.5.5 Significant decay of the AC component of the test circuit**

Where the decay of the AC component of the test circuit is significant, it may be impossible to test the rated operating sequence without overstressing the circuit-breaker extensively. In such cases it is permitted to split the making and the breaking tests in test-duty T100s as follows, provided that the time constant of the AC component of the test circuit, corresponding to the decay of the AC component, is at least three times longer than the specified DC time constant of the system the circuit-breaker under test is intended to be used for:

a) Making tests, test-duty T100s(a)

C – $t'$ – C

with the making current as specified in 7.105.2 and the applied voltage as specified in 7.105.1. For the time interval between the individual tests 7.106.1 applies.

b) Breaking tests, test-duty T100s(b)

- The making operations of test-duty T100s(a) shall be followed by the testing sequence O – $t$ – CO – $t'$ – CO at 100 % of the rated short-circuit breaking current as specified in 7.105.3 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. For the time interval between the individual tests 7.106.1 applies.

  The operating sequence O – $t$ – CO can be demonstrated by two tests. In this case the following applies:

  In the first test the first breaking operation shall be tested at 100 % of the rated short-circuit breaking current as specified in 7.105.3 and with a transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. The subsequent making and breaking operations shall be tested with making current and applied voltage or breaking current and transient and power frequency recovery voltage respectively as close as possible to the values specified for test-duty T100s.

  In the second test an additional CO operating cycle shall be performed with the breaking operation at 100 % of the rated short-circuit current as specified in 7.105.3 and with the transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. This CO operating cycle shall be preceded by a no-load opening operation to complete the operating sequence O – $t$ – CO. For the C operation the provisions of 7.105.1 and 7.105.2 may be omitted, however, the making current and the applied voltage shall meet the specified values as close as possible.

  The operating cycle CO is demonstrated by another CO operating cycle where the breaking operation shall be performed at 100 % of the rated short-circuit current as specified in 7.105.3 and with the transient and power frequency recovery voltage as specified in 7.103.4 and 7.105.5.2. For the making operation the provisions of 7.105.1 and 7.105.2 may be omitted, however, the making current and the applied voltage shall meet the specified values as close as possible.

- Where a making operation in test-duty T100s(b) fulfils the requirements given in a) above, the respective making operation in test-duty T100s(a) may be omitted. In order to not overstress the circuit-breaker controlled closing can be necessary in test-duty T100s(b). Where needed an auxiliary circuit-breaker can be used. If due to inconsistency of the opening or the closing time the specified test values cannot be met, it is allowed to supply the releases at their maximum operating voltage; in this case the provisions of 7.102.3.1 as to the supply voltage of closing and opening devices are omitted.

No maintenance is allowed between the test-duties T100s(a) and T100s(b). When this testing procedure results in actual stresses exceeding the limits specified in Table B.1 the consent of the manufacturer is necessary.

### 7.107.6 Test-duty T100a

Test-duty T100a is only applicable when the minimum opening time $T_{op}$ of the circuit-breaker, as stated by the manufacturer, plus the relay time is such that the DC component at the instant of contact separation is higher than 20 %. The DC component at contact separation is determined by the following equation:

$$\%\ \mathrm{DC} = 100 \times \mathrm{e}^{\frac{-(T_{op}+T_r)}{\tau}}$$

where

% DC  percentage of DC component at contact separation;

$T_{op}$  minimum opening time declared by the manufacturer;

$T_r$  relay time (0,5 cycle; 10 ms for 50 Hz and 8,3 ms for 60 Hz);

$\tau$  DC time constant of the rated short-circuit current (45 ms, 60 ms, 75 ms or 120 ms, see 5.101.3).

Test-duty T100a consists of three valid breaking operations at 100 % of the rated short-circuit breaking current with the required asymmetry criteria regarding the peak and duration of the last major loop and the related arcing time conditions given in 7.104 and a transient and prospective power frequency recovery voltage under symmetrical conditions as specified in 7.103.4 and 7.105.5.2.

The change of an opening or a closing release does not constitute an alternative operating mechanism. If the opening time of the circuit-breaker is reduced, due exclusively to the use of a faster acting release, it should be checked whether the range of the minimum clearing time, as stated in Table 10 and Table 11 for this release, is still covered by tests performed with the initial release. If the circuit-breaker falls into a range with shorter minimum clearing times, it is sufficient to repeat test-duty T100a only for that range, the rest of the type tests remains valid, provided the release is tested to the relevant subclauses and standards.

### 7.108 Additional short-circuit tests

#### 7.108.1 Critical current tests

##### 7.108.1.1 Applicability

These tests are short-circuit tests additional to the terminal fault test-duties covered by 7.107 and are applicable only to circuit-breakers which have a critical current. It shall be assumed that this is the case if the minimum arcing times in any of the test-duties T10, T30 or T60 is one half-cycle or more longer than the minimum arcing times in the adjacent test-duties. For three-phase tests the arcing times of all three phases shall be taken into account.

##### 7.108.1.2 Test current

Where applicable, the behaviour of the circuit-breaker with respect to the critical current shall be tested in two test-duties.

The test currents for these two test-duties shall be equal to the average of the breaking current corresponding to the test-duty in which the prolonged arcing times occurred (see 7.108.1.1) and:

a) the breaking current corresponding to the next higher breaking current for one test-duty; and
b) the breaking current corresponding to the next lower breaking current for the other test-duty.

In the case of prolonged arcing times in test-duty T10, the critical current tests shall be performed at a current of 20 % of the rated short-circuit breaking current for one test-duty and at a current of 5 % of the rated short-circuit breaking current for the other one.

##### 7.108.1.3 Critical current test-duty

The critical current test-duty consists of the rated operating sequence at the current according to 7.108.1.2 with a DC component at contact separation not exceeding 20 %. The transient and power frequency recovery voltage shall be that associated with the terminal fault test-duty having the breaking current the next higher to the critical current.

The critical current test-duty can be performed on a reconditioned circuit-breaker.

### 7.108.2 Single-phase and double-earth fault tests

#### 7.108.2.1 Applicability

Circuit-breakers shall be capable of clearing single-phase short-circuit currents which can occur in two different cases:

– in effectively earthed neutral systems in case of single-phase faults or,

– in non-effectively earthed neutral systems in case of double-earth faults, i.e. earth faults on two different phases, one of which occurs on one side of the circuit-breaker and the other one on the other side.

Depending on the neutral earthing condition of the system in which the circuit-breaker is intended to be used, on the circuit-breaker operating mechanism design (single-pole or three-pole operated) and on whether the circuit-breaker was tested single-phase or three-phase in test-duty T100s, additional single-phase breaking tests may be necessary (see Figure 47).

These tests are intended to demonstrate

– that the circuit-breaker is able to clear a single-phase fault current at relevant parameters;

– for circuit-breakers having a common operating mechanism for all three poles and being fitted with a common opening release, that the operation of the circuit-breaker is not adversely affected by unbalanced forces produced in the case of a single-phase fault current.

The test for single-phase fault shall be performed on an outer pole resulting in the maximum stress on the interpole coupling mechanism, while the test for double-earth fault can be performed on any pole.

NOTE If two single-phase tests are carried out on a circuit-breaker with a three-pole common operating mechanism, the test can be carried out on two different poles to prevent overstressing of one pole.

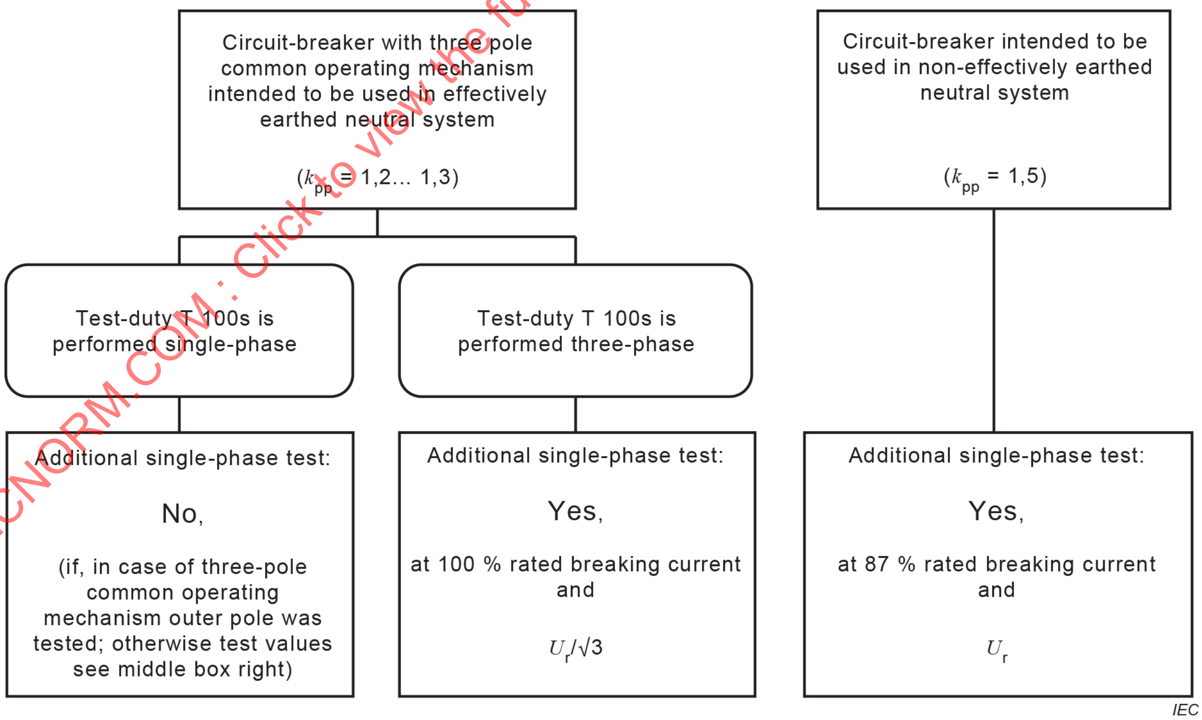



**Figure 47 – Necessity of additional single-phase tests and requirements for testing**

#### 7.108.2.2 Test current and recovery voltage

The breaking current and the recovery voltage for the additional single-phase breaking tests are as shown in Figure 47.

The DC component of the breaking current at contact separation shall not exceed 20 % of the AC component. The TRV shall meet the requirements of Items a), b) and c) of 7.105.5.1 with standard values derived from Table 16, Table 17, Table 18, Table 19, Table 20, and Table 21. The values to be used for single-phase and double-earth fault tests are given in Table 28 marked by the index (sp).

**Table 28 – Prospective TRV parameters for single-phase and double-earth fault tests**

| System neutral | Rated voltage | | | | | |
|---|---|---|---|---|---|---|
| | $U_r$ < 100 kV<br>2-parameter-TRV | | $U_r$ ≥ 100 kV<br>4-parameter-TRV | | | |
| | $u_{c,sp}$ | $t_{3,sp}$ | $u_{1,sp}$ | $t_{1,sp}$ | $u_{c,sp}$ | $t_{2,sp}$ |
| Effectively earthed | $k_{af} \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $t_3 \times u_{c,sp} / u_c$ | $0{,}75 \times \frac{\sqrt{2}}{\sqrt{3}} \times U_r$ | $t_1 \times u_{1,sp} / u_1$ | $k_{af} \times u_{1,sp} / 0{,}75$ | [a] |
| Non-effectively earthed | $k_{af} \times \sqrt{2} \times U_r$ | | $0{,}75 \times \sqrt{2} \times U_r$ | | | |

[a] 4 × $t_{1,\,sp}$ for rated voltages from 100 kV up to and including 800 kV, 3 × $t_{1,\,sp}$ for rated voltages above 800 kV.

The other parameters are related to $u_{1,sp}$, $u_{c,sp}$, $t_{1,sp}$ and $t_{3,sp}$ as defined in 7.105.5.1 for test-duty T100. Where necessary, advantage can be taken of the provisions of 7.105.5.2 concerning test plant limitations.

#### 7.108.2.3 Test-duty

The test-duty for each of the two specified fault cases shall consist of one single breaking operation.

The arcing time during the breaking operation shall not be shorter than the following value $t_a$:

$$t_a \geq t_{a100s} + 0{,}7 \times T/2$$

where

$t_{a100s}$ – is the minimum of the arcing times of first-poles-to-clear during the three breaking operations of test-duty T100s, if terminal fault test-duty T100s is tested in three-phase;

– is the minimum arcing time of terminal fault test-duty T100s, if terminal fault test-duty T100s is tested in single-phase.

$T$ is the duration of one cycle of rated frequency.

If the minimum arcing time under the conditions of single-phase or double-earth fault tests is shorter than the minimum arcing time of terminal fault test-duty T100s by more than 0,1 × $T$, the test can be carried out at a shorter arcing time based on the following equation:

$$t_a \geq t_{a\ \text{min single-phase}} + 0{,}9 \times T/2$$

where

$t_{a\ min\ single\text{-}phase}$ is the minimum arcing time under the conditions of single-phase or double-earth fault tests.

NOTE It is not necessary to determine the minimum arcing time for single-phase or double-earth fault breaking tests. However, the manufacturer can show that under these conditions a shorter minimum arcing time than for T100s is achievable. Then testing can be done, as shown above, with this shorter minimum arcing time.

To reduce the amount of testing, it is allowed to replace the two applicable tests by one test, provided that both test conditions are met simultaneously. This allowance is permitted only with the consent of the manufacturer.

### 7.109 Short-line fault tests

#### 7.109.1 Applicability

A short-line fault breaking capability is required for circuit-breakers intended for direct connection to overhead lines, having a rated voltage equal to or higher than 15 kV and a rated short-circuit breaking current exceeding 12,5 kA.

Short-line fault tests are short-circuit tests additional to the terminal fault test-duties covered by 7.107. These tests shall be made to determine the ability of a circuit-breaker to break short-circuit currents under short-line fault conditions characterised by a TRV as a combination of the source and the line side components.

The short-line fault current is the maximum current that the circuit-breaker shall be capable of breaking under the conditions of use and behaviour required in this document in a circuit having a recovery voltage as specified in 7.109.

#### 7.109.2 Test current

The test current shall take into account the source and line side impedances. The source side impedance shall be that corresponding to approximately 100 % rated short-circuit breaking current $I_{sc}$ and the phase-to-earth value of the rated voltage $U_r$.

Standard values of the line side impedance are specified corresponding to a reduction of the AC component of the rated short-circuit breaking current to:

– 90 % ($L_{90}$) and 75 % ($L_{75}$) for circuit-breakers with a rated voltage higher than 52 kV;
– 75 % ($L_{75}$) for circuit-breakers with a rated voltage of 15 kV up to and including 52 kV.

In a test, the line length represented on the line side of a circuit-breaker can differ from the length of the line corresponding to currents equal to 90 % and 75 % of the rated short-circuit breaking current.

For rated voltages higher than 52 kV, tolerances on these standardised lengths are –20 % and 0 % for tests at 90 % of the rated short-circuit breaking current and ±20 % for tests at 75 % of the rated short-circuit breaking current.

For rated voltages higher than 12 kV and up to and including 52 kV, tolerances on these standardised lengths are 0 % and –20 % for tests at 75 % of the rated short-circuit breaking current.

These tolerances for the line lengths give the following deviations of the short-circuit currents:

- $L_{90}$ at 0 % deviation: $I_L$ = 90 % of $I_{sc}$;
- $L_{90}$ at –20 % deviation: $I_L$ = 92 % of $I_{sc}$;
- $L_{75}$ at +20 % deviation: $I_L$ = 71 % of $I_{sc}$;
- $L_{75}$ at 0 % deviation: $I_L$ = 75 % of $I_{sc}$;
- $L_{75}$ at –20 % deviation: $I_L$ = 79 % of $I_{sc}$.

For the case stated in 7.109.4, item c) another test ($L_{60}$) at 60 % of the rated short-circuit breaking current is required. The tolerance on the corresponding standardised line length is ±20 %. This results in the following deviations of the short-circuit current:

- $L_{60}$ at +20 % deviation: $I_L$ = 55 % of $I_{sc}$;
- $L_{60}$ at –20 % deviation: $I_L$ = 65 % of $I_{sc}$.

For further information see IEC TR 62271-306.

### 7.109.3 Test circuit

The test circuit shall be single-phase and consists of a supply circuit and a line circuit (see Figure 48, Figure 49 and Figure 50). The source side TRV shall be based on a $k_{pp}$ of 1,0. The values of line characteristics are given in Table 29. The basic requirements are:

- values of the RRRV factor, based on the line surge impedance $Z$, the peak factor $k$ and the line side time delay $t_{dL}$ are given in Table 29. For determination of the line side time delay and the rate-of-rise of the line side voltage, see Figure 46 and Figure 51;
- the method for calculation of TRVs from the characteristics is given in Annex A.

**Table 29 – Values of line characteristics for short-line faults**

| Rated voltage | Surge impedance | Peak factor | RRRV factor 50 Hz | RRRV factor 60 Hz | Time delay |
|---|---|---|---|---|---|
| $U_r$<br>kV | $Z$<br>Ω | $k$ | $s$ [b]<br>kV/μskA | | $t_{dL}$<br>μs |
| 15 ≤ $U_r$ ≤ 48,3 | 450 | 1,6 | 0,200 | 0,240 | 0,1 |
| 52 ≤ $U_r$ ≤ 170 | 450 | 1,6 | 0,200 | 0,240 | 0,2 |
| 245 ≤ $U_r$ ≤ 800 | 450 | 1,6 | 0,200 | 0,240 | 0,5 |
| $U_r$ > 800 | 330 [a] | 1,6 | 0,147 | 0,176 | 0,5 |

[a] A value of 450 Ω can be used during testing to cover ITRV requirements.

[b] For the RRRV factor $s$, see Annex A.

NOTE These values cover the short-line faults dealt with in this document. For very short lines ($t_L$ < $5t_{dL}$) not all requirements as given in the table can be met. The procedures for approaching very short lines are given in IEC TR 62271-306 [4].

Regarding the time delays on the source side and on the line side and the ITRV (see 7.105.5), two main requirements are specified and shall be distinguished:

a) source side: with time delay ($t_d$) and without ITRV;

line side: with time delay ($t_{dL}$);

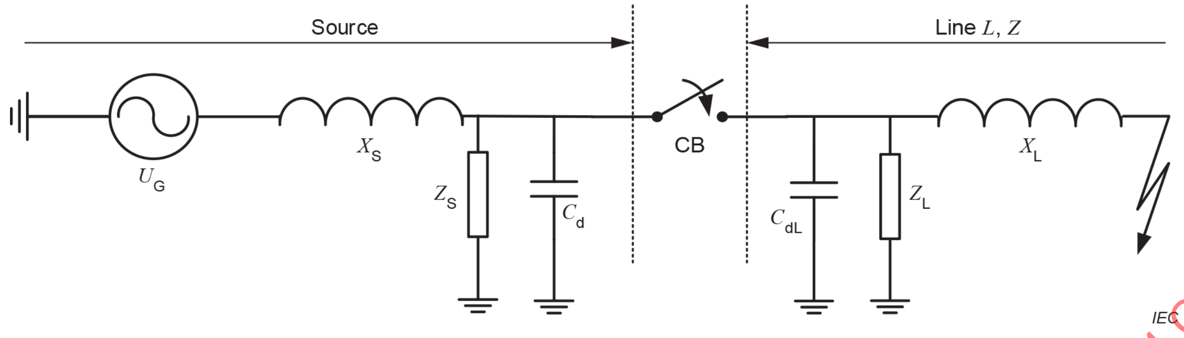
b1) source side: with ITRV;

line side: with time delay ($t_{dL}$);

b2) source side: with time delay ($t_d$);

line side: with a time delay less than 100 ns ($t_{dL}$).

The representation of the ITRV on the source side can be neglected if a line side oscillation with a time delay less than 100 ns is used.




| | | | |
|---|---|---|---|
| $U_G$ | Supply voltage, phase to earth value | $X_L$ | Power frequency line side reactance |
| $X_S$ | Power frequency source side reactance | $Z_L$ | Line side TRV controlling components |
| $Z_S$ | Source side TRV controlling components | $C_{dL}$ | Time delaying line side capacitance |
| $C_d$ | Time delaying source side capacitance | $Z$ | Surge impedance of line |
| CB | Circuit-breaker | $L$ | Length of line to fault |

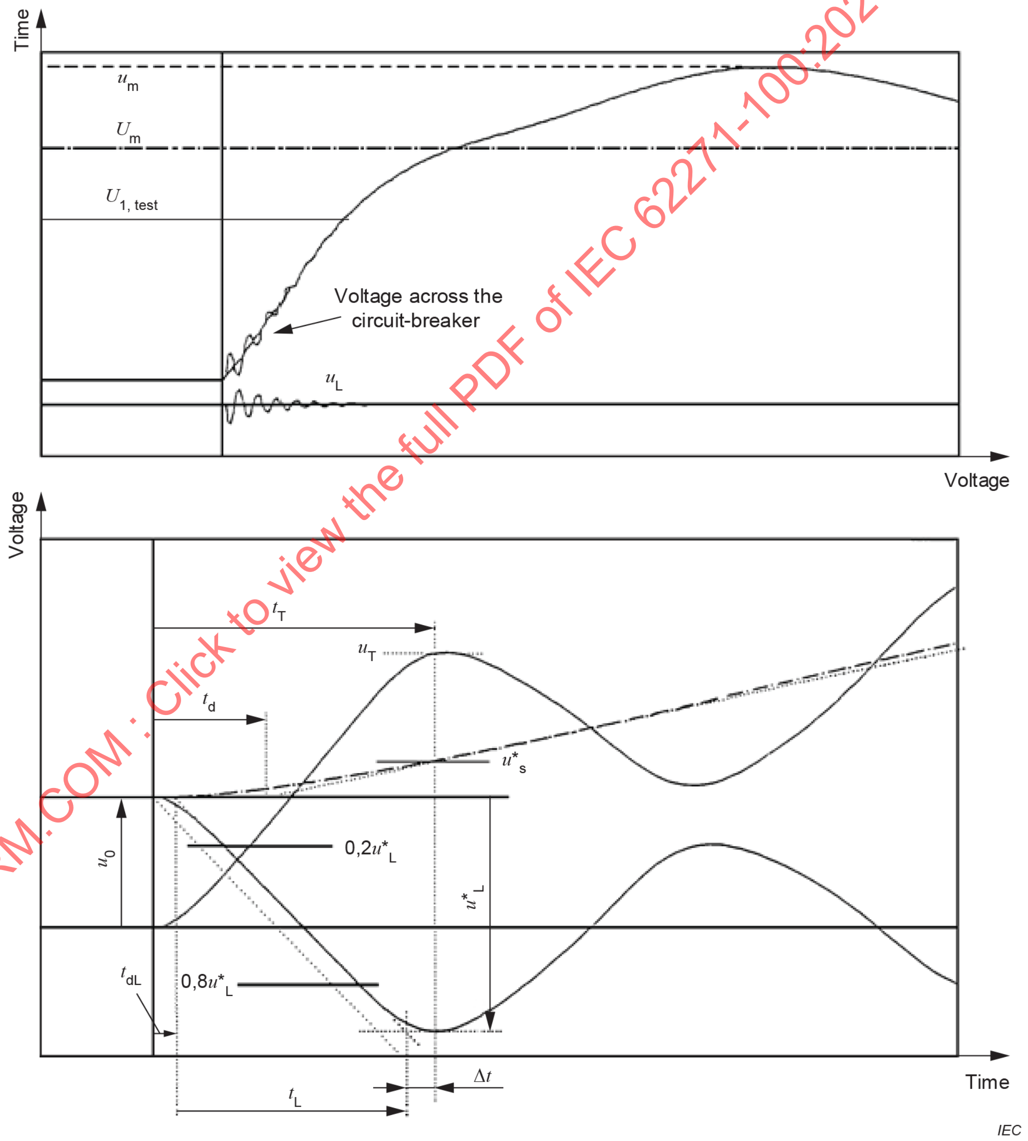
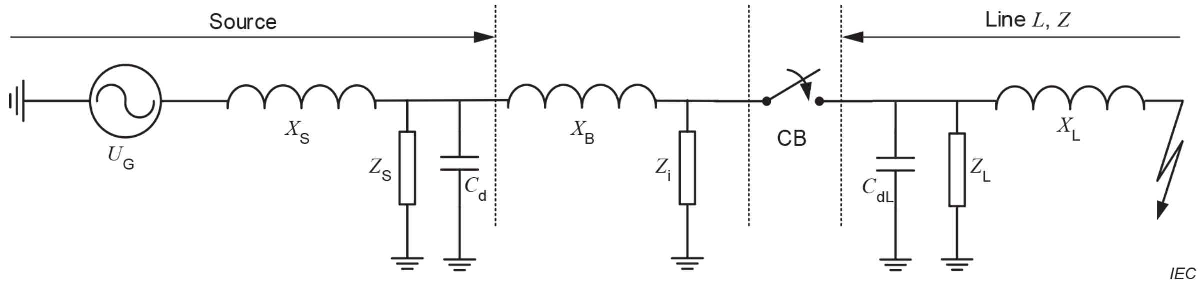



**Figure 48 – Basic circuit arrangement for short-line fault testing and prospective TRV-circuit-type a) according to 7.109.3: Source side and line side with time delay**




$U_G$ Supply voltage, phase to earth value

$X_S$ Power frequency source side reactance

$Z_S$ Source side TRV controlling components

$C_d$ Time delaying source side capacitance

CB Circuit-breaker

$X_B$ Power frequency busbar reactance

$Z_i$ ITRV controlling components

$X_L$ Power frequency line side reactance

$Z_L$ Line side TRV controlling components

$C_{dL}$ Time delaying line side capacitance

$Z$ Surge impedance of line

$L$ Length of line to fault

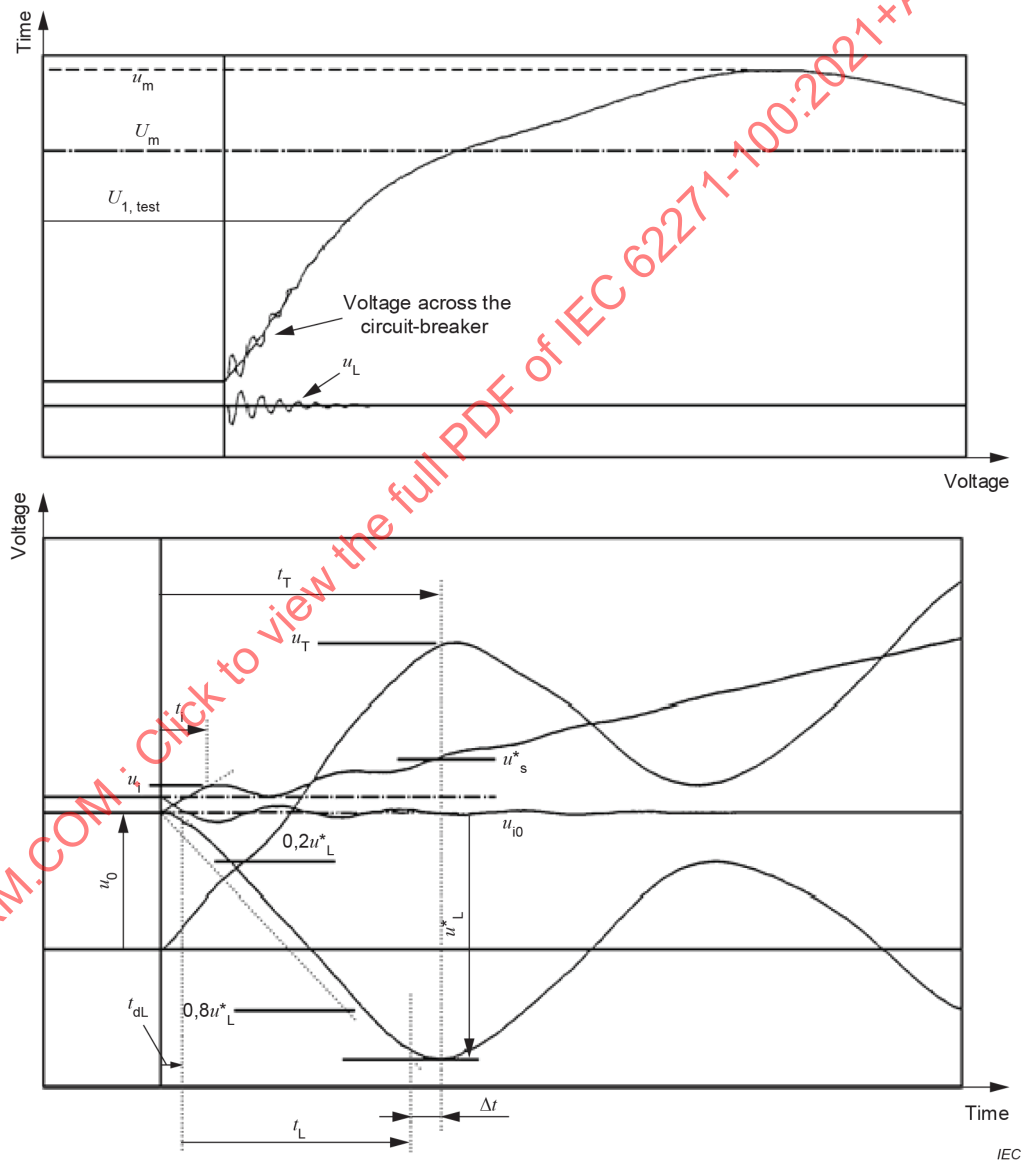
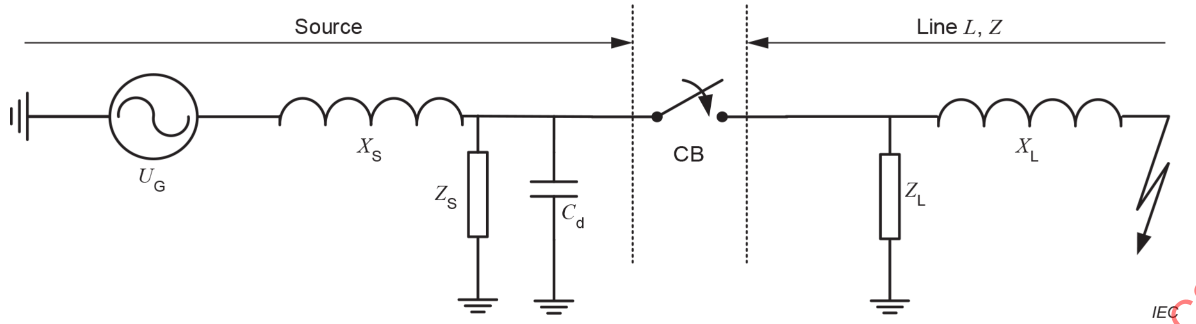



**Figure 49 – Basic circuit arrangement for short-line fault testing – circuit type b1) according to 7.109.3: Source side with ITRV and line side with time delay**




$U_G$ Supply voltage, phase to earth value
$X_S$ Power frequency source side reactance
$Z_S$ Source side TRV controlling components
$C_d$ Time delaying source side capacitance
CB Circuit-breaker
$X_L$ Power frequency line side reactance
$Z_L$ Line side TRV controlling components
$Z$ Surge impedance of line
$L$ Length of line to fault

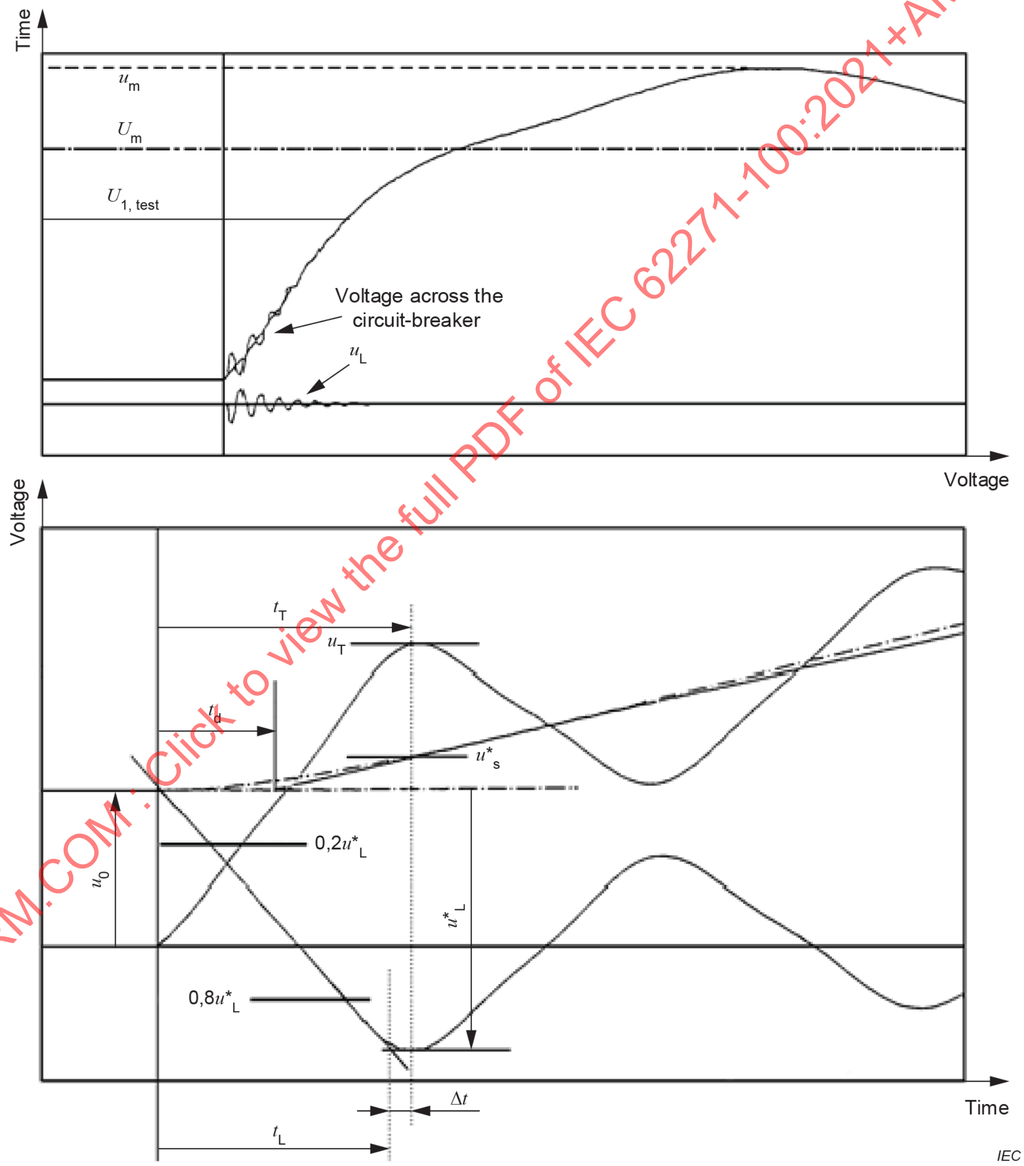



**Figure 50 – Basic circuit arrangement for short-line fault testing – circuit type b2) according to 7.109.3: Source side with time delay and line side without time delay**

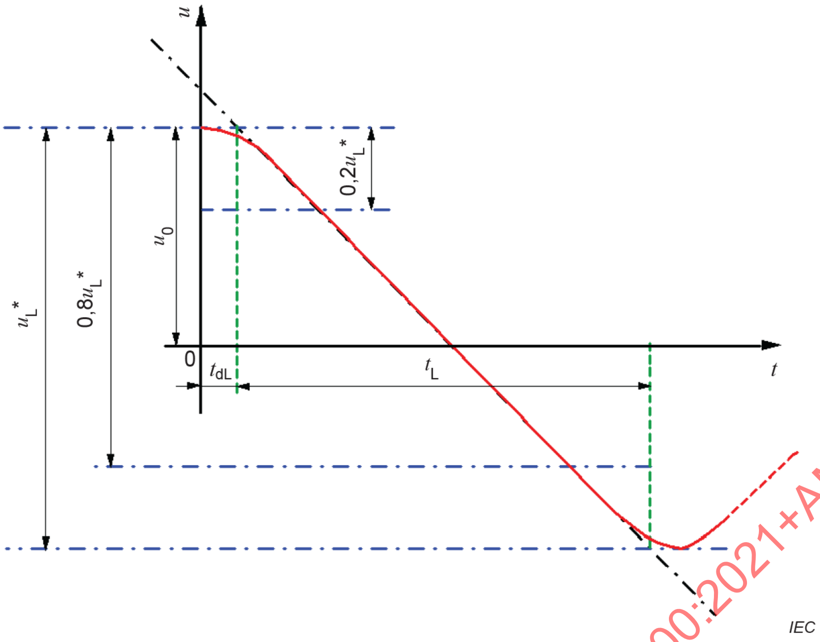



**Figure 51 – Example of a line side transient voltage with time delay**

Figure 46 shows the determination of the line side time delay in case of a non-linear rate of rise.

The line side time delay is defined as the time between the origin and the point where the tangent of the straight line drawn through $0{,}2u_L$ and $0{,}8u_L$ crosses the zero line (see Figure 51). See also 7.3.1.1 of IEC TR 62271-306:2012.

Taking this into account, three types of test circuits characterised by their time delays are applicable for testing:

- circuit SLF a): source side with time delay ($t_d$) and line side with time delay ($t_{dL}$) (see A.4.2); circuit shown in Figure 48;
- circuit SLF b1): source side with ITRV and line side with time delay ($t_{dL}$) (see A.4.3); circuit shown in Figure 49;
- circuit SLF b2): source side with time delay ($t_d$) and line side with a time delay less than 100 ns ($t_{dL}$); circuit shown in Figure 50.

Circuit a) shall only be used in the case where no ITRV requirements apply. Circuit b2) can be used as a substitute for the circuit b1) unless both terminals are not identical from an electrical point of view.

For the choice of test circuit, see flow chart diagram, Figure 52.

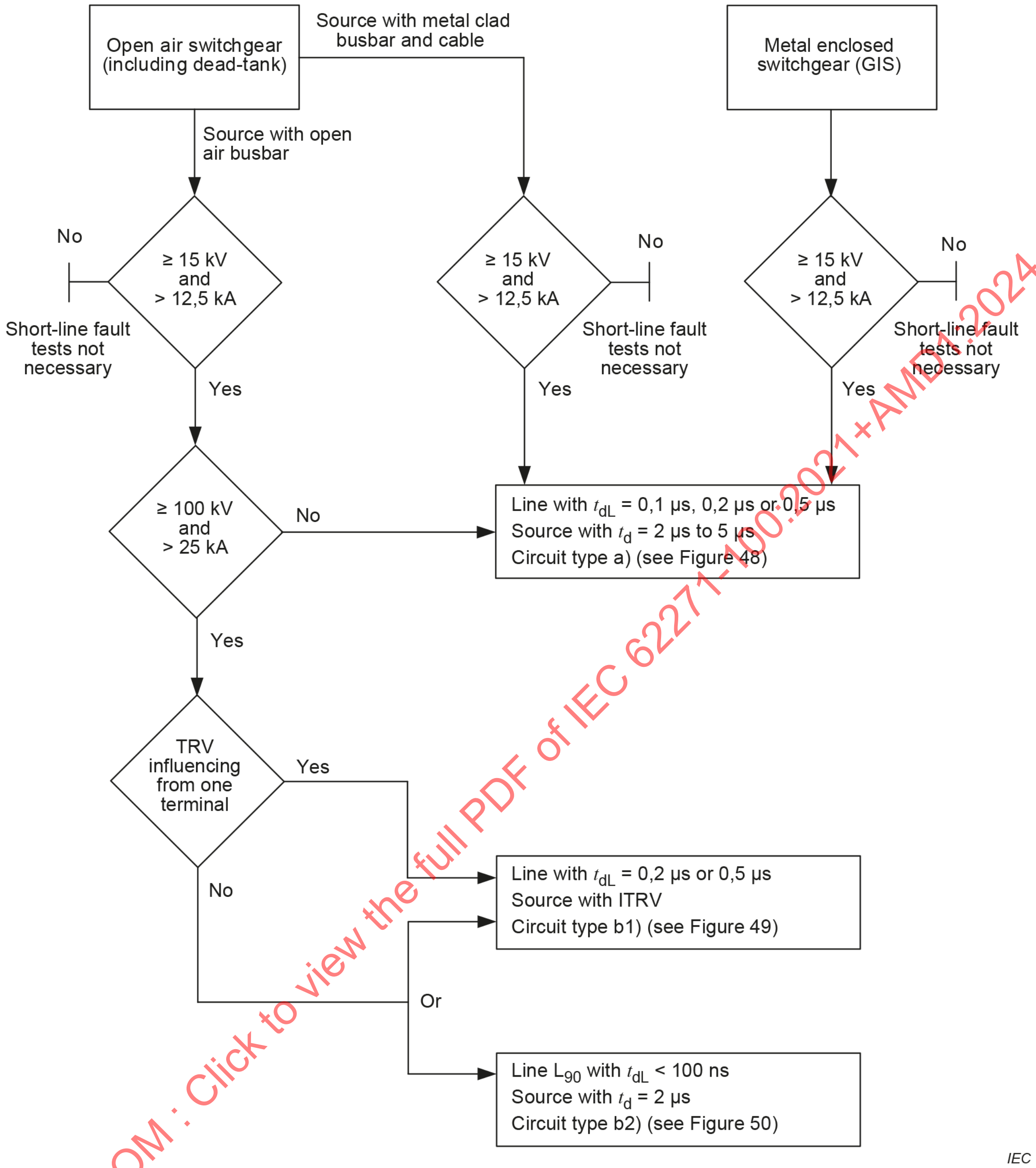



**Figure 52 – Flow chart for the choice of short-line fault test circuits**



Other characteristics of the source side and the line side of the test circuit shall be in line with the explanations and calculations given in Annex A.

Where applicable, a circuit-breaker with rated voltage higher than 800 kV can be tested with a line having a time delay less than 100 ns and a surge impedance of 450 Ω (see 7.105.5.1). If the circuit-breaker fails during this test procedure after a time corresponding to the first peak of ITRV, the test can be repeated with the required test circuit having the specified ITRV and a line having a surge impedance of 330 Ω and the specified time delay ($t_{dL}$). For both cases it is not required to perform T100s and T100a with circuits reproducing the rated ITRV.

If the TRV requirements of the source side cannot be met due to testing station limitations, a deficiency of the time delay of the source side TRV can be compensated by an increase of the excursion of the line side voltage. The increased value $u_{L,mod}^*$ is calculated as follows (see also Figure 46, Figure 51 and Figure 53):

$$t_d < t'_d \leq t_L \quad u_{L,mod}^* = u_L^* + L_f \times RRRV \times (t'_d - t_d)$$

$$t_d < t_L \leq t'_d \quad u_{L,mod}^* = u_L^* + L_f \times RRRV \times (t_L - t_d)$$

where

| | |
|---|---|
| $RRRV$ | is the required rate of rise of recovery voltage of the source side (kV/µs); |
| $L_f$ | is the SLF current factor $I_L/I_{sc}$ (0,9 or 0,75 or 0,6); |
| $t_d$ | is the required time delay of the source side (µs); |
| $t'_d$ | is the actual time delay of the source side (µs); |
| $t_L$ | is the time to the peak voltage $u_L^*$ of the line side transient voltage (µs); |
| $u_L^*$ | is the required peak voltage across the line (kV); |
| $u_{L,mod}^*$ | is the adjusted peak voltage across the line (kV). |

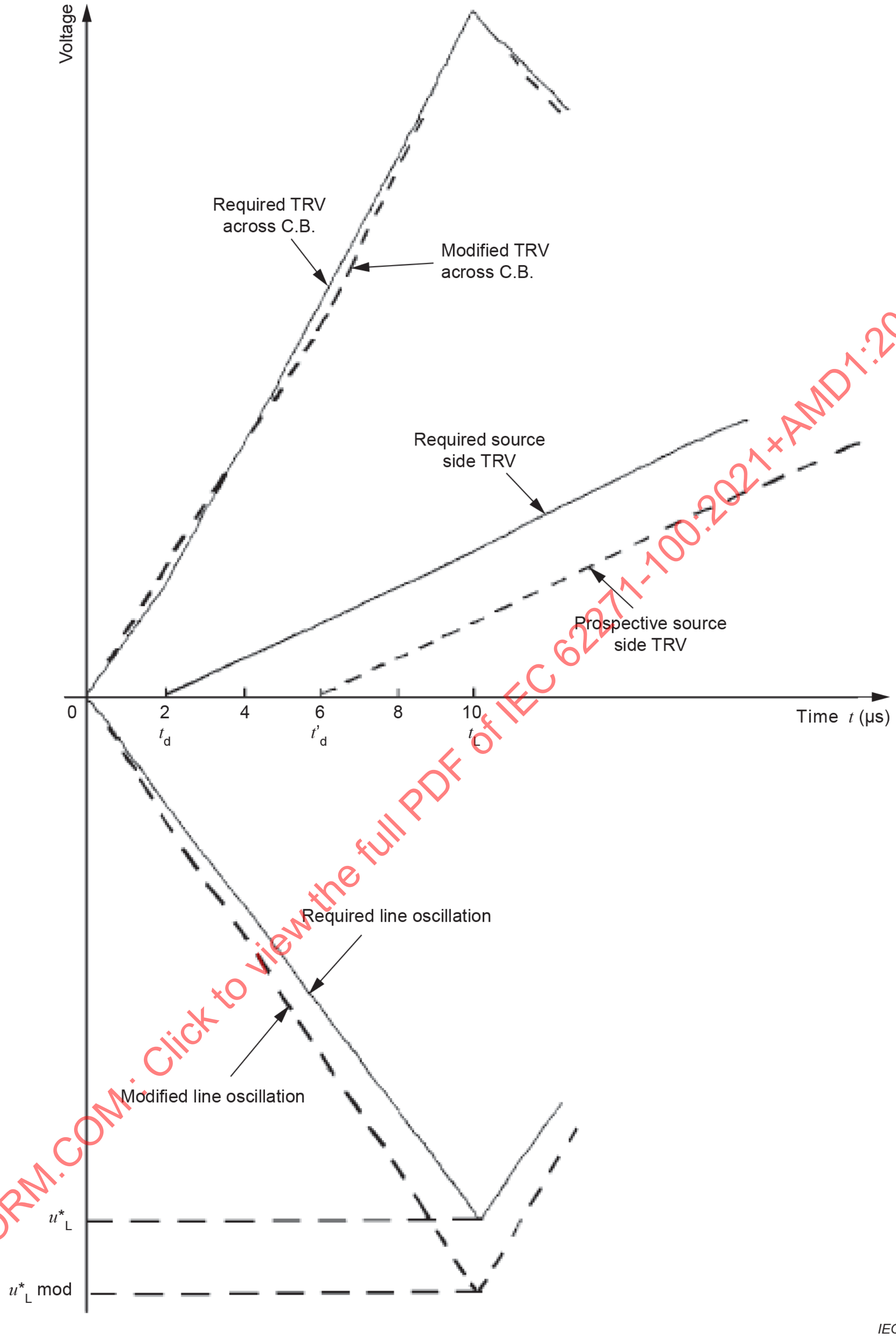



**Figure 53 – Compensation of deficiency of the source side time delay by an increase of the excursion of the line side voltage**

If the tests are carried out on a circuit-breaker with one terminal earthed, as may be the case during synthetic testing, measurements or calculations of voltage distribution factors of line and source side oscillations shall be carried out. The higher stressed making and breaking unit from the line side oscillation is the lower stressed making and breaking unit from the source side oscillation. It is recognised that the more significant stress is due to the line. The voltage distribution factors shall be as follows:

– unit tests: factors calculated or measured on the line side making and breaking unit;
– multi-unit tests: factors calculated or measured on the multi-making and breaking unit next to the line-side. Attention should be paid that the factors to be applied do not overstress the circuit-breaker because of the voltage distribution within the multi-making and breaking unit. A new measurement or calculation can be required for the portion to be tested.

The measurement of the prospective TRV shall be carried out with the line connected to the actual circuit in order to take into account all the effects due to voltage dividers, stray capacitances and inductances of the test circuit.

An extra capacitance can be applied at the line side or at the source side of the circuit-breaker or across the circuit-breaker in order to adjust the time delays of the individual sections of the test circuit.

NOTE 2 The term “actual” is used as distinct from the nominal value (90 %, 75 % or 60 %); the use of prospective short-circuit breaking current in accordance with 7.105.3 is not precluded.

NOTE 3 If an extra capacitance is applied in order to adjust the time delay of the line to the standard value given in Table 29 the rate of rise of the line side TRV will reach its standard value ($\mathrm{d}u_L/\mathrm{d}t = - s \times I_L$) after the decay of the delaying effect of this extra capacitance.

Where the breaking capability of the circuit-breaker is not sufficient to interrupt a short-line fault, an additional capacitance at the line side of the circuit-breaker or parallel to the making and breaking unit(s) can be used, both during the test and in service. In this way, the stress on the circuit-breaker is facilitated. The value and the location of this additional capacitance used during the tests shall be stated in the test report.

For a large additional capacitance, the surge impedance of the line and the line side time delay may seem to be reduced, caused by the effect of this additional capacitance. However, the correct value of the surge impedance of the line itself (in advance adjusted in accordance with the standard values given in Table 29) remains unchanged. Since the period of the decay of the delaying effect of the additional capacitance can be longer than the time to the first peak of the line side TRV, the lower rate of rise at the rising slope of the TRV may be misinterpreted as a decreased surge impedance of the line. Therefore, the values of the time delay and the surge impedance evaluated for the line in connection with the additional capacitance are not relevant to the test.

The test report should show the specified TRV appropriate to the rating of the circuit-breaker, and, for comparative purposes, the prospective TRV of the test circuit used.

### 7.109.4 Test-duties

The short-line fault tests shall be single-phase tests. The series of test-duties is specified below. Each test-duty consists of the rated operating sequence. For convenience of testing, the making operations can be performed as no-load operations.

The test circuit shall be in accordance with 7.109.3.

The prospective TRV of the supply circuit shall be in accordance with Table 30.

**Table 30 – Values of prospective TRV for the supply circuit of short-line fault tests**

| $U_r$ kV | $k_{pp}$ p.u. | $k_{af}$ p.u. | $u_1$ kV | $t_1$ µs | $u_c$ kV | $t_2$ or $t_3$ µs | $t_d$ µs | $u'$ kV | $t'$ µs | $u_1/t_1$ $u_c/t_3$ kV/µs |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 1 | 1,54 | - | - | 18,9 | 20,6 | 1,03 | 6,29 | 7,91 | 0,914 |
| 15,5 | 1 | 1,54 | - | - | 19,5 | 21,1 | 1,06 | 6,50 | 8,10 | 0,923 |
| 17,5 | 1 | 1,54 | - | - | 22,0 | 23,0 | 1,15 | 7,33 | 8,81 | 0,958 |
| 24 | 1 | 1,54 | - | - | 30,2 | 28,6 | 1,43 | 10,1 | 11,0 | 1,05 |
| 25,8 | 1 | 1,54 | - | - | 32,4 | 30,1 | 1,50 | 10,8 | 11,5 | 1,08 |
| 27 | 1 | 1,54 | - | - | 34,0 | 31,1 | 1,55 | 11,3 | 11,9 | 1,09 |
| 36 | 1 | 1,54 | - | - | 45,3 | 37,9 | 1,90 | 15,1 | 14,5 | 1,19 |
| 38 | 1 | 1,54 | - | - | 47,8 | 39,4 | 1,97 | 15,9 | 15,1 | 1,21 |
| 40,5 | 1 | 1,54 | - | - | 50,9 | 41,2 | 2,06 | 17,0 | 15,8 | 1,24 |
| 48,3 | 1 | 1,54 | - | - | 60,7 | 46,5 | 2,33 | 20,2 | 17,8 | 1,31 |
| 52 | 1 | 1,54 | - | - | 65,4 | 49,0 | 2,45 | 21,8 | 18,8 | 1,33 |
| 72,5 | 1 | 1,54 | - | - | 91,2 | 61,7 | 3,09 | 30,4 | 23,7 | 1,48 |
| 100 | 1 | 1,40 | 61 | 31 | 114 | 124 | 2 | 31 | 17 | 2 |
| 123 | 1 | 1,40 | 75 | 38 | 141 | 152 | 2 | 38 | 21 | 2 |
| 145 | 1 | 1,40 | 89 | 44 | 166 | 176 | 2 | 44 | 24 | 2 |
| 170 | 1 | 1,40 | 104 | 52 | 194 | 208 | 2 | 52 | 28 | 2 |
| 245 | 1 | 1,40 | 150 | 75 | 280 | 300 | 2 | 75 | 40 | 2 |
| 300 | 1 | 1,40 | 184 | 92 | 343 | 368 | 2 | 92 | 48 | 2 |
| 362 | 1 | 1,40 | 222 | 111 | 414 | 444 | 2 | 111 | 57 | 2 |
| 420 | 1 | 1,40 | 257 | 129 | 480 | 516 | 2 | 129 | 66 | 2 |
| 550 | 1 | 1,40 | 337 | 168 | 629 | 672 | 2 | 168 | 86 | 2 |
| 800 | 1 | 1,40 | 490 | 245 | 914 | 980 | 2 | 245 | 124 | 2 |
| 1 100 | 1 | 1,50 | 674 | 337 | 1 347 | 1 011 | 2 | 337 | 170 | 2 |
| 1 200 | 1 | 1,50 | 735 | 367 | 1 470 | 1 101 | 2 | 367 | 186 | 2 |

For these test-duties, the percentage DC component at the instant of contact separation shall not exceed 20 % of the AC component.

The test-duties related to test currents according to 7.109.2 are as follows:

Test-duty $L_{90}$

a) At the current for $L_{90}$ given in 7.109.2 and the appropriate prospective TRV.

This test-duty is only mandatory for circuit-breakers with a rated voltage higher than 52 kV.

b) Test-duty $L_{75}$

At the current for $L_{75}$ given in 7.109.2 and the appropriate prospective TRV.

c) Test-duty $L_{60}$

At the current for $L_{60}$ given in 7.109.2 and the appropriate prospective TRV.

This test-duty is mandatory only for circuit-breakers with a rated voltage higher than 52 kV and only if the minimum arcing time obtained during test-duty $L_{75}$ is a quarter of a cycle or more longer than the minimum arcing time determined during test-duty $L_{90}$.

#### 7.109.5 Short-line fault tests with a test supply of limited power

When the maximum short-circuit power available at a testing plant is not sufficient to make the short-line fault tests on a complete pole of a circuit-breaker, it is possible to make unit tests (see 7.102.4.2).

Short-line fault tests can also be made at reduced power frequency voltage, the provisions of 7.109.3 being relaxed. These provisions shall be met as well as possible and, for the TRV at least up to three times the specified time of the first line side peak. This method is used if the terminal fault tests in 7.107 have been satisfactory, it being assumed that the dielectric strength of the circuit-breaker near the peak value of TRV is independent of stresses applied immediately after current zero. The test method can also be used in combination with unit tests.

If short-line fault tests are performed at reduced power frequency voltage and in any one short-line fault test-duty the maximum arcing time according to 7.104.3.2 is more than 2 ms longer than the maximum arcing time achieved in test-duty T100s, a single opening operation with the maximum arcing time achieved in the short-line fault tests shall be performed, applying the test conditions of terminal fault T100s. The TRV parameters for this additional operation can be reduced to values corresponding to a $k_{pp}$ of 1,0, as usual for short-line fault testing. The circuit-breaker is considered to have passed the short-line fault test only, if the current is interrupted successfully in this additional opening operation.

### 7.110 Out-of-phase making and breaking tests

#### 7.110.1 Test circuit

Usually the tests are carried out in a single-phase test circuit. This subclause therefore concerns single-phase test procedures only.

Instead of single-phase tests, three-phase tests are permissible. Where three-phase tests are performed, the test procedure should be agreed upon between the manufacturer and user.

The test circuit should be so arranged that approximately one half of the applied voltage and of the recovery voltage is on each side of the circuit-breaker (see Figure 21).

If it is not practicable to use this circuit in the testing station, it is permissible, with the agreement of the manufacturer, to use two identical voltages separated in phase by 120° instead of 180°, provided that the total voltage across the circuit-breaker is as stated in 7.110.2 (see Figure 22).

Tests with one terminal of the circuit-breaker earthed are permissible, with the agreement of the manufacturer (see Figure 23).

#### 7.110.2 Test voltage

For the test voltages used during making and breaking operations the following applies:

a) for circuit-breakers intended to be used in effectively earthed neutral systems the applied voltage and the power frequency recovery voltage shall have a value of 2,0/√3 times the rated voltage;

b) for circuit-breakers intended to be used in non-effectively earthed neutral systems the applied voltage during the making operation shall have a value of 2,0/√3 times the rated voltage and the power frequency recovery voltage shall have a value of 2,5/√3 times the rated voltage.

The TRV shall be in accordance with 7.105.5.6.

### 7.110.3 Test-duties

The test-duties to be made are indicated in Table 31. For arcing times see 7.104.3.

**Table 31 – Test-duties to demonstrate the out-of-phase rating**

| Test-duty | Operating sequence | Breaking current in per cent of the rated out-of-phase breaking current |
|---|---|---|
| OP1 | O – O – O | 30 |
| OP2 | CO – O – O<br>or alternatively<br>C* – C**O – O – O<br><br>C* = C at full voltage<br>C** = C at no-load | 100 |

NOTE 1 For circuit-breakers fitted with closing resistors, the thermal capability of the closing resistors can be tested separately on agreement between manufacturer and user.

NOTE 2 Test-duty OP1 can be omitted for those circuit-breakers for which the T10 current is not a critical current as per 7.108.1.

For the breaking operation of each test-duty, the DC component of the breaking current at contact separation shall not exceed 20 % of the AC component.

For the making operation of the close-open cycle of test-duty OP2:

a) the applied voltage shall be $2U_r/\sqrt{3}$; for convenience of testing the applied voltage for circuit-breakers intended to be used in non-effectively earthed neutral systems can be increased with the agreement of the manufacturer to $2{,}5U_r/\sqrt{3}$.

   NOTE 1 A power frequency voltage of 2,0 p.u. is specified for making as it is the highest value the first-pole-to-close (which is stressed by the longest pre-arcing time) is normally exposed to.

   NOTE 2 Power frequency recovery voltages corresponding to out-of-phase voltage factors of 2,0 p.u. and 2,5 p.u. are specified for breaking, in effectively earthed neutral systems and non-effectively earthed neutral systems, respectively, as they cater to the great majority of applications of circuit-breakers intended for making and breaking during out-of-phase conditions (see 9.103.3). The out-of-phase angle corresponding to 2,0 p.u. in effectively earthed neutral systems is approximately 105° for rated voltages up to 800 kV and approximately 115° for rated voltages higher than 800 kV. The out-of-phase angle corresponding to 2,5 p.u. in non-effectively earthed neutral systems is approximately 115°. However higher values of angle are covered when considering other factors such as the non-simultaneity of voltage peaks, lower $k_{pp}$ (see IEC TR 62271-306 [4]).

b) the making shall occur within ± 15° of the peak of the applied voltage.

c) the making shall produce a symmetrical current with the longest pre-arcing time. The making current shall be equal to the rated out-of-phase making current.

   If the pre-arcing time when making at the peak of the applied voltage is shorter than or equal to half a cycle of the rated frequency, then the making current can be reduced to any smaller value, but not less than 1 kA;

   If the pre-arcing time when making at the peak of the applied voltage does not exceed ¼ cycle of power frequency with a tolerance of 20 %, due to possible limitations of the testing facilities it is allowed to replace the CO operating cycle of OP2 by the following sequence:

   – C at full voltage;

   – CO with C at no load.

### 7.111 Capacitive current tests

#### 7.111.1 General

This subclause describes capacitive current test procedures for the different ratings defined in 5.106 and their associated restrike class.

Ratings and class demonstrated for back-to-back capacitor bank are also valid for single capacitor bank application for the same earthing conditions.

Tests at 60 Hz cover tests for 50 Hz for same class of probability of restrike.

Tests at 50 Hz cover tests for 60 Hz, provided that the voltage across the circuit-breaker is not less during the first 8,3 ms than it would be during a test at 60 Hz. This test method requires the consent of the manufacturer.

#### 7.111.2 Applicability

Capacitive current tests are applicable to all circuit-breakers to which one or more of the following ratings have been assigned:

– rated line-charging breaking current;
– rated cable-charging breaking current;
– rated single-capacitor bank breaking current;
– rated back-to-back capacitor bank breaking and inrush making current.

Preferred values of rated capacitive currents are given in Table 1.

Tests specified for these ratings are individual type tests, each comprising a tests series with two test-duties.

NOTE 1 The determination of overvoltages when switching capacitive loads is not covered by this document.

NOTE 2 Explanatory notes on switching of capacitive loads are given in IEC TR 62271-306 [4].

When point-on-wave energising is used for back-to-back capacitor bank making, IEC TR 62271-302 [10] applies.

#### 7.111.3 Characteristics of supply circuits

In laboratory tests the lines and cables can be partly or fully replaced by artificial circuits with lumped elements of capacitors, reactors or resistors.

The test circuit shall fulfil the following requirements:

a) the characteristics of the test circuit should be such that the power frequency voltage variation, when breaking, should be less than 2 % for test-duty 1 (LC1, CC1 and BC1) and less than 5 % for test-duty 2 (LC2, CC2 and BC2). Where the voltage variation is higher than the values specified, it is alternatively permissible to perform tests with the specified recovery voltage (7.111.10) or synthetic tests;
b) the impedance of the supply circuit shall not be so low that its short-circuit current exceeds the rated short-circuit current of the circuit-breaker.

For line-charging, cable-charging and single capacitor bank current tests the prospective TRV of the supply circuit shall not be more severe than the TRV specified for test-duty T100s in 7.105.5.2.

For back-to-back capacitor bank making and breaking tests, the capacitance of the supply circuit and the impedance between the capacitors on the supply and load sides shall be such as to give the rated back-to-back capacitor bank inrush making current when testing with 100 % of the rated back-to-back capacitor bank breaking current.

For back-to-back capacitor bank making and breaking tests where separate making tests are performed, a lower capacitance of the supply circuit can be chosen for the breaking tests. The capacitance should, however, not be so low that the prospective TRV of the supply side exceeds that specified for short-circuit in 7.105.5.2.

The test circuit frequency shall be the rated frequency with a tolerance of ± 2 %.

#### 7.111.4 Earthing of the test circuit

##### 7.111.4.1 Supply circuit

For single-phase laboratory tests, either terminal of the single-phase supply circuit can be earthed. However, when it is necessary to ensure that the correct voltage distribution exists between the making and breaking units of the circuit-breaker, another point of the supply circuit can be connected to earth.

For three-phase tests, the earthing of the supply circuit shall be as follows:

a) for capacitor bank making and breaking tests, the neutral of the supply circuit shall be earthed. For capacitor banks with effectively earthed neutral, the zero-sequence impedance shall not be more than three times its positive sequence impedance. For capacitor banks with isolated neutral this ratio is not relevant. For the purpose of switching of capacitive loads the high impedance neutral system is considered to fall under effectively earthed neutral systems;

   NOTE The condition for high impedance neutral systems applies to the switching of capacitive loads only.

b) for line-charging and cable-charging current tests, the earthing of the supply circuit should correspond to the earthing conditions in circuits for which the circuit-breaker is to be used:
   – for three-phase tests of a circuit-breaker intended for use in effectively earthed neutral systems, the neutral point of the supply circuit shall be earthed and its zero-sequence impedance shall be no more than three times its positive sequence impedance;
   – for three-phase tests of a circuit-breaker intended for use in non-effectively earthed neutral systems, the neutral point of the supply side shall be isolated.

For convenience of testing, an alternative test circuit can be used as long as the equivalent values of the recovery voltage as given in Table H.1 and Table H.2 will be obtained.

Attention should be given to the influence of TRV control capacitors on the values of the recovery voltage especially for low capacitive currents. Table 32 gives values of the required recovery voltage.