UL 347A

STANDARD FOR SAFETY

Medium Voltage Power Conversion Equipment

UL Standard for Safety for Medium Voltage Power Conversion Equipment, UL 347A

Second Edition, Dated January 5, 2021

Summary of Topics

This revision of ANSI/UL 347A dated April 5, 2022 includes the following changes in requirements:

– Color Coding of Grounding and Bonding Conductors in UL 347A; 18.4, 18.5

– Revisions to Section 21.7 – Spacings for Printed Wiring Boards; 21.7.1 – 21.7.4

– Addition of New Section 21.8 – Alternate Approach for Spacings

– Revisions to Section 26 – Spacings within Gate Driver Circuit; 26.1, 26.2, 26.4 – 26.10, Table 26.2

– Revision to Breakdown of Components Requirements; 35.2.2, 35.2.14, 39.1.2, 39.1.3, 39.8.1, 41.7, 41.9, 41.10

Text that has been changed in any manner or impacted by UL's electronic publishing system is marked with a vertical line in the margin.

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated September 17, 2021, January 14, 2022 and March 4, 2022.

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UL 347A

Standard for Medium Voltage Power Conversion Equipment

First Edition – September, 2015

Second Edition

January 5, 2021

This ANSI/UL Standard for Safety consists of the Second Edition including revisions through April 5, 2022.

The most recent designation of ANSI/UL 347A as an American National Standard (ANSI) occurred on April 5, 2022. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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INTRODUCTION

1 Scope

1.1 These requirements cover enclosed medium voltage power conversion equipment, such as variable frequency controllers, that control and transfer power to motors. These requirements also cover power-supply modules, input/output modules, and electronic assemblies, for use in or with power conversion equipment.

1.2 These requirements cover equipment rated above 1500 volts to 38kV. The equipment may have input ratings greater than 1500 V, output ratings greater than 1500 V, or both.

1.3 These requirements do not cover equipment for use in hazardous locations as defined by the National Electrical Code, NFPA 70.

1.4 These requirements do not cover solid state reduced voltage motor controllers (soft starters). This type of equipment is covered by the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347.

1.5 These requirements do not cover low voltage power conversion equipment with both input and output voltage ratings of 1500 volts and below. This type of equipment is covered by the Standard for Adjustable Speed Electrical Power Drive Systems – Part 5-1: Safety Requirements – Electrical, Thermal and Energy, UL 61800-5-1.

2 Glossary

2.1 For the purpose of this document, the following definitions apply.

2.2 AMBIENT TEMPERATURE – The temperature of the air medium into which the heat of the equipment is dissipated. See 32.1.3.

2.3 BUS – A conductor, or group of conductors, that serve as a common connection for two or more circuits.

2.4 BUS, HORIZONTAL – A bus that extends through a vertical section, that is intended to connect to another vertical section, that may be provided in the future.

2.5 BUS, VERTICAL – A bus that connects one or more controllers in a vertical section together. Where the assembly also contains a horizontal bus, the vertical bus connects the controllers in a vertical section to the horizontal bus.

2.6 BYPASS CIRCUIT – A circuit, typically consisting of a switch or contactor, that when closed, creates an alternate path for current flow in parallel with the circuit being bypassed, allowing the original circuit to be turned off while maintaining current flow to the load.

2.7 CONTACTOR – A two-state (ON-OFF) device for repeatedly establishing and interrupting an electric power circuit.

2.8 CONTACTOR, AIR-GAP – A contactor that introduces a gap (in air) between contacts to interrupt a circuit.

2.9 CONTACTOR, SOLID-STATE – A contactor that introduces a high impedance to interrupt a circuit. Typical solid-state contactors use silicon controlled rectifiers (SCR) or insulated gate bipolar transistors (IGBT) as the switching device(s).

2.10 CONTACTOR, VACUUM – A contactor that introduces a gap between contacts (located in a vacuum) to interrupt a circuit.

2.11 CONTROL CIRCUIT – A circuit that carries the electric signals directing the performance of a controller, and that does not carry the main power circuit. A control circuit is generally limited to 15 amperes or less.

2.12 CONTROLLER – A device or group of devices that serves to govern, in some predetermined manner, the electric power delivered to the apparatus to which it is connected.

2.13 COVER – An unhinged portion of an enclosure that covers an opening.

2.14 DOOR – A hinged portion of an enclosure that covers an opening, that is intended to be opened during routine maintenance, operations and adjustments.

2.15 ENCLOSURE – A surrounding case designed to protect:

a) Personnel against injury due to accidental contact with electrical or moving mechanical parts of the enclosed device(s), and

b) Internal device(s) against specified external conditions.

2.16 FAULT CURRENT – A current that results from the loss of insulation between conductors or between a conductor and ground.

2.17 GALVANICALLY ISOLATED SECONDARY CIRCUIT – A circuit having no direct electrical connection to a medium voltage circuit, with isolation between the circuits obtained by the use of transformers or optical isolation.

2.18 INTERLOCK – A device that prevents operation of some other device with which it is directly associated under specific conditions. Interlocks may be electrical, mechanical, or a combination of both.

2.19 INTERLOCK, MECHANICAL – An interlock that performs its function solely by mechanical means.

2.20 ISOLATED SECONDARY CIRCUIT – A circuit derived from an isolating source (such as a transformer, optical isolator, voltage divider or electro-mechanical relay) and having no direct connection back to the primary circuit.

2.21 ISOLATING MEANS – A mechanical switching device that provides, in the open position, isolating distance in the main circuit, from the source of power.

2.22 LOW VOLTAGE – Voltage of 1500 V or less.

Note: The National Electrical Code, NFPA 70 defines low voltage to be voltages of 1000 V or less.

2.23 LOW VOLTAGE SECTION (of a voltage divider) – That portion of a voltage divider where a small fraction (no greater than 1500 V total) of the input voltage is present during normal operation.

2.24 MEDIUM VOLTAGE – Voltage greater than 1500 V, up to and including 38 kV.

Note: National Electrical Code, NFPA 70 defines any voltage above 1000 V as High Voltage.

2.25 OVERCURRENT – Overcurrent is a current in excess of the continuous rated current.

2.26 PANEL, HINGED – A portion of an enclosure that has hinges, but no hand-operable latching system, secured in the closed position by multiple bolts or other hardware requiring a tool other than a key to operate.

Note: Hinged panels are not intended to be opened during normal operation, routine adjustment or simple maintenance operations such as replacement of fuses.

2.27 PHASE LEAST LIKELY TO STRIKE GROUND – A phase that is referenced to ground or by virtue of its position, potential, or both, relative to other phases of the device is defined as less likely than any other phase to strike ground. In a three phase device, this phase is usually the center phase. It is possible for several phases to be equally likely to strike to ground.

2.28 POLLUTION DEGREE 1 – No pollution or only dry, nonconductive pollution occurs. The pollution has no influence.

2.29 POLLUTION DEGREE 2 – Normally, only nonconductive pollution occurs; however, temporary conductivity is expected when equipment is out of operation.

2.30 POLLUTION DEGREE 3 – Conductive pollution occurs, or dry, nonconductive pollution occurs that becomes conductive due to condensation that is expected.

2.31 PRIMARY CIRCUIT – A circuit in which the wiring and components are conductively connected to the branch circuit.

2.32 PRIMARY SECTION (of a voltage divider) – That portion of a voltage divider where a large fraction of the input voltage is present during normal operation.

2.33 PROTECTION, OVERLOAD – A protective device or circuit that detects excessive current, (not necessarily short-circuit current) and functions to cause interruption or limitation of the flow of current through the protected device or circuit.

2.34 PROTECTION, OVERVOLTAGE – A protective device or circuit that detects excessive voltage and functions to interrupt power or reduce voltage to the protected device or circuit.

2.35 RATING – A designated limit of operating characteristics based on definite conditions. Operating characteristics such as current, voltage, frequency, and other characteristics comprise the rating.

2.36 RELAY, OVERLOAD – A relay that functions at a predetermined value of overcurrent to provide a signal or to result in disconnection of the load from the power supply, or both. An overload relay is intended to protect the motor branch circuit conductors, the motor control apparatus, and the motor against overcurrent. It does not necessarily protect itself.

2.37 REVERSING – Reversing is a control function that provides for changing operation of the controlled motor from one direction to the other.

2.38 ROUTINE MAINTENANCE – Maintenance that involves simple tasks such as changing of filters, adjustment of controls, replacement of fuses, or resetting of protective functions or devices. Routine maintenance does not include repair or replacement of components other than fuses or filters.

2.39 SOLID STATE MOTOR OVERLOAD PROTECTION – Circuitry integral to the power conversion equipment that acts to protect a motor under overload conditions by reducing current flow to the motor output terminals. This protection is typically achieved through an algorithm based on the I^2t of the current to the motor. The protection circuitry is usually comprised of hardware, firmware and software components.

2.40 SOLID STATE SHORT CIRCUIT PROTECTION – Circuitry integral to power conversion equipment that acts to suspend current flow to the motor output terminals upon sensing a preset or predetermined condition such as a rapid rate of change in output current or bus voltage. The protection circuitry may be comprised of hardware, firmware and software components.

2.41 SWITCH, ISOLATING – A switching device intended for isolating an electric circuit from the source of power. It does not have an interrupting rating, and it is intended to be operated only after the circuit has been opened by some other means.

2.42 SWITCH, LOAD BREAK – A switch that has an interrupting rating equal to or greater than the circuit that it controls, and is intended for control of the particular load type to which it is connected.

2.43 TRIP CURRENT – Current above rated output motor current at which the motor overload protection circuitry will function. May be provided as a percent of motor current or as an actual stated current value. Typical values are 125 percent of full load motor current or less.

2.44 VOLTAGE DIVIDER – A combination of components intended to produce an output voltage that is a fraction of the voltage input to the combination.

3 Components

3.1 Other than where specifically referenced in this standard, or as indicated in 3.2, a component of a product covered by this standard shall comply with the requirements for that component.

3.2 A component need not comply with a specific requirement that:

a) Involves a feature or characteristic not needed in the application of the component in the product covered by this standard, or

b) Is superseded by a requirement in this standard.

3.3 An unevaluated component, such as a capacitor, resistor, or inductor, is not required to comply with a specific requirement when the system incorporating the component complies with the requirement.

3.4 A low voltage subassembly located in low voltage circuitry, that is both physically and electrically isolated by a transformer, electromechanical relay, or other isolation device, from medium voltage equipment shall be investigated in accordance with the Standard for Industrial Control Panels, UL 508A. Any protection circuitry shall be evaluated with the controller to the requirements of this standard.

3.5 Printed wiring boards shall be suitable for direct support of live parts in accordance with the Standard for Printed Wiring Boards, UL 796.

3.6 Metal oxide surge arrestors connected to the medium voltage line shall comply with IEEE C62.11 or IEC 60099-4 and shall have voltage ratings no less than the maximum voltage at which the arrestor is applied.

4 Referenced Publications

4.1 Any undated reference to a code or standard appearing in the requirements of this Standard shall be interpreted as referring to the latest edition of that code or standard.

4.2 The following publications are referenced in this Standard:

ANSI Z535 Series, *Safety Alerting Standards*

IEC 61800-5-1, *Adjustable Speed Electrical Power Drive Systems – Part 5-1: Safety Requirements – Electrical, Thermal and Energy*

IEEE 4, *Techniques for High Voltage Testing*

IEEE C37.09, *Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*

ISA MC96.1, *Temperature Measurement Thermocouples*

NFPA 70, *National Electrical Code*

UL 50, *Enclosures for Electrical Equipment, Non-Environmental Considerations*

UL 50E, *Enclosures for Electrical Equipment, Environmental Considerations*

UL 248 Series, Fuses

UL 347, *Medium Voltage AC Contactors, Controllers, and Control Centers*

UL 489, *Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures*

UL 508, *Industrial Control Equipment*

UL 508A, *Industrial Control Panels*

UL 746C, *Polymeric Materials – Use In Electrical Equipment Evaluations*

UL 796, *Printed Wiring Boards*

UL 810, *Capacitors*

UL 840, *Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment*

UL 969, *Marking and Labeling Systems*

UL 1077, *Supplementary Protectors for Use in Electrical Equipment*

UL 1562, *Transformers, Distribution, Dry-Type – Over 600 Volts*

UL 60950-1, *Information Technology Equipment – Safety – Part 1: General Requirements*

UL 61800-5-1, *Adjustable Speed Electrical Power Drive Systems – Part 5-1: Safety Requirements – Electrical, Thermal and Energy*

5 Units of Measurement

5.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

RATING

6 General

6.1 Power conversion equipment shall be rated according to:

a) Input.

1) Voltage.

2) Maximum current.

3) Number of phases.

4) Frequency.

b) Output.

1) Voltage.

2) Full load current or maximum horsepower.

3) Number of phases.

4) Base frequency and frequency range (applies only to alternating current outputs).

6.2 Power conversion equipment shall also be rated with the following:

a) Short circuit current rating.

b) Maximum voltage.

c) Control voltage.

d) Impulse test voltage (expressed in kilovolts).

e) Dielectric withstand voltage.

6.3 Ratings of equipment covered by this standard are based on normal service conditions as defined in Section 2.1 of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347. Section 2.2 of UL 347 provides additional guidance when equipment is used in special service conditions.

CONSTRUCTION

7 General

7.1 Equipment covered by these requirements shall be constructed as to provide for compliance with the rules for installation and use of such equipment as given in the National Electrical Code, NFPA 70.

8 Enclosure

8.1 General

8.1.1 In addition to the following, the enclosure construction requirements of UL 50 and UL 50E, apply. If there is a conflict between the requirements in this standard and UL 50 or UL 50E, the requirements in this standard apply.

8.1.2 Enclosures shall be metallic and built to the requirements of UL 50 and UL 50E. External parts of the equipment may be of insulating material, provided that medium-voltage parts are completely enclosed by grounded metallic partitions or grounded shutters. These metallic partitions or shutters shall meet the thickness requirements of UL 50 and UL 50E. Excepted are inspection windows complying with 8.3. The enclosure shall comply with the rod entry test of Section 44.

8.1.3 A nonmetallic plug or other closure assembled as part of the enclosure shall be considered acceptable if evaluated in accordance with UL 50 and UL 50E.

8.1.4 Enclosures shall be supplied with a bottom plate unless marked in accordance with 47.24.

8.1.5 Equipment shall be substantially complete when shipped by the manufacturer with necessary bus splices, instructions, and hardware for field connecting to provide a completed control center.

8.1.6 Single vertical sections and vertical sections shipped assembled together shall be designed with provisions for lifting, handling, storage, and installation.

8.2 Exterior doors, covers, and similar parts of enclosures

8.2.1 A part of the enclosure, such as a door or cover, shall be provided with means, such as latches, locks, interlocks, or screws, for firmly securing it in place.

8.2.2 If bare live parts are exposed by the opening of such doors or covers, means requiring the use of a tool to open them or provision for locking them shall be provided to secure them in the closed position. If parts operating above 600 V are exposed by the opening of covers or doors, a warning marking shall also be provided in accordance with 47.26.

8.2.3 Doors shall be provided with a latch or with a captive fastener. Such fasteners shall be located or used in multiples so as to hold the cover closed over its entire length. A door more than 1220 mm (4 ft) long on the hinged side shall have at least a two-point latch operated by a single knob or handle, or shall have two or more separate latches or captive fasteners.

8.2.4 Doors and hinged panels of compartments containing medium-voltage components that can be opened without the use of a tool other than a key shall be mechanically interlocked in accordance with Section 16.

8.2.5 Covers of compartments containing medium-voltage components shall be bolted closed.

8.2.6 Where a door must be opened for maintenance of equipment or removal of drawout elements, low-voltage energized uninsulated live parts mounted on the door shall be effectively guarded or enclosed, to provide protection against unintentional contact.

8.2.7 All doors and hinged panels shall be capable of being opened to a minimum of 90 degrees from the closed position.

8.2.8 Low-voltage compartments required to be opened during normal operation, thus exposing bare live parts, shall have:

a) Doors hinged such that the door will not come off inadvertently, and

b) Barriers installed to prevent inadvertent contact with bare live parts during normal operation.

NOTE: The replacement of fuses is not considered a normal operation with respect to controllers, but the resetting of overload devices, repeated adjustment of timers or switches, etc., are considered normal operations.

8.3 Inspection windows

8.3.1 A transparent material covering an observation opening and forming a part of the enclosure shall:

a) Be of clear safety-type glass or wire-reinforced glass or another clear material found suitable with respect to flammability and UV resistance in accordance with UL 746C, Standard for Polymeric Materials – Use in Electrical Equipment Evaluations;

b) Be secured in such a manner that it cannot be removed without tools; and

c) Meet the requirements of impact and pressure tests for viewing panes specified in Section 45.

8.4 Ventilation openings

8.4.1 When provided, ventilation openings shall comply with 8.4.2 – 8.4.10.

8.4.2 A ventilating opening shall not be employed in an enclosure unless the conditions of use necessitate such ventilation and the equipment complies with all the tests in this standard when the equipment under test includes the specified ventilation openings.

8.4.3 Any ventilation opening in the top of the enclosure shall be covered by a hood or protective shield spaced above the opening to prevent the entry of water or objects falling vertically downward, both with and without any cooling system or fans operating.

8.4.4 Ventilation openings, including perforations, louvers, and openings protected by means of wire screening, expanded metal, or a perforated cover, shall comply with the rod entry test specified in Clause 6.207 of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347.

8.4.5 Barriers shall be provided behind all ventilating openings into medium-voltage compartments. The barrier shall be effectively secured in place and shall be positioned such that a straight line (of zero diameter) may not be drawn from any point outside of the equipment, through the ventilation opening, to any insulated or uninsulated live part. Removable ventilation filters shall not be considered as barriers to meet this requirement.

8.4.6 The diameter of the wires of a screen shall not be less than 1.3 mm (0.050 in) if the screen openings are 320 mm^2 (0.497 in^2) or less in area, and shall be not less than 2.06 mm (0.081 in) thick for larger openings.

8.4.7 Perforated sheet steel and sheet steel employed for expanded metal mesh shall be not less than 1.07 mm (0.042 in) thick for mesh openings or perforations 320 mm^2 (0.497 in^2) or less in area, and shall be not less than 2.03 mm (0.080 in) thick for larger openings.

8.4.8 When ventilation is accomplished by one or more blowers within the enclosure that provide a positive intake and exhaust, the ventilation openings shall be located such that the exhaust air is not directed toward the area occupied by the equipment operator. The area occupied by the operator is defined to be an area 30 in (762 mm) wide, centered on any operator control, display, or disconnect handle, and extending from the bottom of the equipment to a height of 78 in (2 m).

8.4.9 When equipment incorporates a blower motor, it shall comply with 39.3.

8.4.10 When provided with filter(s) for ventilation openings, the construction shall comply with 39.4 and with (a) or (b) below:

a) The filter(s) shall be located such that it cannot be replaced without opening an interlock in accordance with Section 16, Interlocking, or

b) The filter(s) shall be located so that the filters may be replaced without operating an interlock. During any period of filter replacement, including with a filter access cover open and no filter installed, the construction shall comply with 8.4.2 through 8.4.7.

8.5 Environmental rating related enclosure requirements

8.5.1 The requirements of Section 5.102.210 of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347, apply to all enclosures intended for outdoor use. The Driven Rain Test of Section 6.203.1 of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347 is not required for type 4 and type 6 enclosures which meet the requirements of UL 50E, as the requirements are to obtain a watertight enclosure as verified by the Hosedown Test and the Submersion Test of UL 50E respectively. For all other enclosures, the driven rain test is required. When conducting the driven rain test on an enclosure with forced ventilation, the driven rain test shall be conducted with the ventilation system operating, and repeated with the ventilations system off. When an enclosure is marked with an enclosure type number, it shall comply with 8.5.2.

8.5.2 Other than as noted in 8.5.3, when marked with an enclosure type number, an enclosure shall comply with the requirements of the Standard for Electrical Equipment, Environmental Considerations, UL 50E, as they apply to the type number or numbers that are marked on the enclosure. When provided with forced ventilation, the environmental tests required for the type number(s) marked on the enclosure shall be conducted with the ventilation system operating, and repeated with the ventilation system off.

8.5.3 An enclosure complying with the Driven Rain Test of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347, is not required to comply with the Rain Test of the Standard for Electrical Equipment, Environmental Considerations, UL 50E, but shall comply with all other requirements for the enclosure type number that is marked on the enclosure.

8.6 Protection against corrosion

8.6.1 Enclosures shall be designed so that aluminum will not contact a concrete mounting pad when installed in accordance with the manufacturer's instructions.

8.6.2 Ferrous metals shall be suitably protected against corrosion as required by the Standard for Enclosures for Electrical Equipment, Non-Environmental Considerations, UL 50, and the Standard for Enclosures for Electrical Equipment, Environmental Considerations, UL 50E.

9 Arrangement of Components

9.1 Arrangement of devices in assemblies shall be such that individual components can perform their intended function without adversely affecting the operation of other components in the assembly.

9.2 Gas discharged during operation of interrupting devices shall be so directed as not to endanger personnel or impinge on other components of a controller.

9.3 External operating handles and control devices shall comply with 9.4 through 9.6.

9.4 Control, instrument, switch, and operator handles or external handles and pushbuttons shall be located in accordance with the following:

a) Pushbuttons, control switch handles, and transfer switch handles shall be located in a readily accessible location at an elevation above the mounting surface not in excess of 2 m (79 in).

b) Operating handles requiring more than 222 N (50 lbf) to operate shall not be higher than 1.7 m (66 in) in either the open or closed position.

c) Operating handles for infrequently operated devices, such as reset devices, drawout fuses, fused voltage transformer or CPT primary disconnects, and bus transfer switches, need not comply with (a) and (b) above.

9.5 In determining compliance with 9.3, measurements shall be made from the mounting surface to the center of the handle grip with the handle in its highest possible position. If the handle grip is not clearly defined, the center of the handle grip shall be considered to be at a point 76 mm (3 in) in from the end of the handle.

9.6 If the mechanism of a switching device is such that operation of a remote or automatic tripping device will permit sudden movement of an operating handle, the motion of the handle shall be restricted or the handle shall be guarded.

10 Guarding and Accessibility of Live Parts

10.1 When access is required to a compartment that contains energized medium-voltage parts, barriers shall be provided to:

a) Prevent unintentional contact with energized parts;

b) Prevent tools or other equipment from being dropped on energized parts; and

c) Protect against contact with live parts of adjacent functional units.

10.2 Any barrier intended to be removed during routine maintenance or servicing (such as barriers required to be removed for replacement of fuses or the examination of contacts) shall be marked in accordance with 47.25.

11 Grounding and Bonding

11.1 The requirements of Section 5.3 of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347, apply.

11.2 Within the low voltage compartment, a wire binding screw intended for the connection of a field-installed equipment grounding conductor shall have a green colored head that is hexagonal, slotted, or both.

11.3 Within the low voltage compartment, a pressure wire connector intended for connection of a field-installed equipment grounding conductor shall be plainly identified, such as being marked "G," "GR," "GRD," "Ground," "Grounding". The symbol ⏚ (IEC Publication 417, Symbol 5019) shall not be used alone unless the symbol is defined in the installation instructions provided with the equipment.

11.4 Insulated grounding and bonding conductors shall be identified by the color green with or without one or more yellow stripes. Insulated grounding and bonding conductors 6 AWG or larger may have black insulation, if the conductor is identified by green paint or tape applied at each end of the conductor. No other leads shall be so identified.

12 Protective Devices

12.1 Other than as noted in 12.5, equipment shall include coordinated protection that automatically interrupts overcurrents occurring in the driven motor, and in the motor-circuit conductors, both internal and external to the equipment itself. Protective devices shall open all ungrounded conductors of the protected circuit. When fuses provide this protection, there shall be a fuse in each ungrounded conductor of the circuit.

NOTE – In configurations involving cascaded power cells, the conductors between the internal transformer secondaries and the associated power cells are not considered motor-circuit conductors.

12.2 Motor overload protection shall be provided over the rated operating frequency range of the equipment by one of the following means:

a) Mechanical or electronic overload relay that complies with Section 13, Overload Relays; or

b) Solid state overload protection that complies with the Solid State Motor Overload Protection Test, 38.1 and is subjected to the requirements in Section 53, Burn-In and Diagnostic Tests.

12.3 Other than as noted in 12.5, in addition to the motor overload protection required by 12.2, branch circuit overcurrent protection shall be provided in the input circuit by one of the following:

a) A circuit breaker of suitable type and ratings. The circuit breaker may sense the fault current by means of integral or external sensing elements.

b) Fuses of suitable type and rating, placed in each ungrounded conductor.

12.4 The branch circuit overcurrent protection required by 12.3 shall not automatically reclose the circuit.

12.5 The branch circuit overcurrent protection required by 12.3 may be omitted when the equipment is marked, in accordance with 47.7, to indicate the specific overcurrent protection that shall be provided in the installation.

12.6 Polyphase controllers shall be provided with input phase loss protection. This protection shall prevent the controller from providing a single phase output to the motor terminals for more than 30 seconds. This protection shall comply with the single phase test requirements of 39.2.

12.7 Equipment shall comply with one of the following:

a) Be provided with motor load and speed sensitive overload protection with thermal memory retention, that complies with 38.2, 38.3, and 38.4,

b) Be provided with a means to accept and act upon a signal from a thermal sensor or switch imbedded in the motor or from an external protective relay, and be marked in accordance with 48.7, or

c) Have no provisions for motor overtemperature protection and be marked in accordance with 48.8.

12.8 When equipment is provided with current limiting protection that causes the output current to be limited to a specific current regardless of any increase in loading of the controlled motor, the protection shall comply with 39.5.

12.9 Equipment shall be provided with over speed protection. When a controller is provided with overspeed protection incorporating feedback, the protection shall operate to prevent over-speed upon loss of the feedback signal.

12.10 When equipment is provided with input phase reversal protection, the protection shall operate on the reversal of the phase rotation in a polyphase circuit to cause and maintain the interruption of power in all of the circuit until the phase reversal has been corrected and the protection has been manually reset. The protection shall comply with 39.7.

12.11 Equipment for controlling a synchronous AC motor shall not incorporate over current protection in a motor field supply circuit, unless such protection also operates to remove all power from the motor.

12.12 Equipment for controlling a DC motor shall not be provided with field supply circuit protection unless the equipment incorporates a detector that senses loss of field current or voltage and prevents over-speed upon field loss.

12.13 Opening of a single fuse in a three phase circuit shall not result in application of single phase conditions to the motor for more than 30 seconds. The equipment shall comply with 39.2.

12.14 Fuses may be used in parallel in medium voltage circuits when all of the following conditions are met:

a) The fuses in parallel have identical ratings;

b) The fuses are installed in a common mounting with electrical connections that divide the current equally; and

c) The equipment is marked in accordance with 47.31.

13 Overload Relays

13.1 Section 12 applies only when equipment is provided with a discrete overload relay.

13.2 The overload relay shall be of the ambient compensated type and shall comply with the requirements for overload relays as detailed in the Standard for Industrial Control Equipment, UL 508.

13.3 Equipment that incorporates an overload relay with removable overload relay current elements that is used with a current transformer shall be marked in accordance with 47.9, unless it is so interlocked that the motor cannot be energized with the overload relay current element either removed or open.

13.4 Equipment incorporating an overload relay with removable overload relay current elements shall be provided with instructions for selection of the proper element.

13.5 Equipment incorporating an adjustable overload relay shall be provided with instructions for such adjustment.

14 Isolating Means

14.1 Other than as noted in 14.12, a controller shall be provided with an externally-operable, gang-operated, power circuit isolating means with position indication that complies with 14.4 – 14.11.

14.2 For equipment with an input voltage rating exceeding 1000 V, the isolating means shall be one of the following:

a) Three-pole isolating switch;

b) Three-pole isolating switch in mechanical combination with medium-voltage motor circuit fuses;

c) Three-pole load break switch;

d) Draw out three-pole contactor (with or without fuse assembly); or

e) Draw out three pole circuit breaker.

14.3 For equipment with an input voltage rating of 1000 V or less, the isolating means shall be one of the following, with current, voltage, and short-circuit ratings no less than required by the application:

a) Three-pole fused switch;

b) Three-pole switch, in combination with separately mounted fuses; or

c) Three-pole circuit breaker, either fixed mounted or draw out type.

14.4 The isolating mechanism, indicated in 14.1, shall be arranged to be operated from a location where the operator is not exposed to energized parts and shall be arranged to open all ungrounded conductors of the circuit simultaneously with one operation. The disconnecting means shall not disconnect a permanently grounded conductor, unless the disconnecting means is so constructed that the pole in the grounded conductor cannot be opened without disconnecting all conductors of the circuit in the same operation.

14.5 For equipment having an input voltage rating above 1000 V, the isolating means shall provide visible evidence of an isolating gap in the circuit adequate for the operating voltage.

14.6 To comply with 14.5, the isolation gap or a mechanically operated indicator shall be visible through a viewing pane or by opening a door when the isolating gap is open. The mechanical operator shall be actuated by the movement of the actual isolating switch assembly, the shutter of a draw-out assembly, or the like. The action of the mechanical indicator shall not be dependent on the movement of the operating handle or mechanism alone.

14.7 For equipment with an input voltage rating of 1000 V or less, the isolating means shall be provided with position indication, but need not provide visible evidence of an isolation gap in the circuit.

14.8 The power-circuit isolating means shall be interlocked as indicated in Interlocking, Section 16.

14.9 The power-circuit isolating means shall have provision for being padlocked in the open position.

14.10 Other than as noted in 14.11, all switch blades shall be de-energized when the switch is in the open position.

14.11 Switches that are intended to be energized from both sides (for example, bus tie, loop sectionalizing) shall not have energized blades in the open position unless:

a) Barriers or enclosures are installed over the switches for protection against contact with the energized switch blades; and

b) The switch is marked in accordance with 47.9.

14.12 Equipment that is not provided with the isolating means noted in 14.1 shall comply with (a) – (d) below:

a) The equipment shall be marked in accordance with 47.8;

b) The equipment shall be provided with specific instructions indicating the specific external isolating means that shall be provided;

c) The equipment shall be provided with means for interlocking with the specified external isolating means. This requires a portion of the interlock system to be installed on the equipment, and the remaining portion (that will be installed on the external isolating means) to be provided in the form of a kit, that is shipped with the equipment. This kit shall include all the necessary parts of the interlock, all hardware required to install the interlock, and specific instructions detailing the installation of the interlock on the isolating means; and

d) When the interlock is properly installed on the external isolating means, the resulting assembly shall comply with all the requirements of 14.4 – 14.11 and the requirements of Interlocking, Section 16.

15 Service Equipment

15.1 An assembly intended for use as service equipment shall comply with the construction requirements of 5.204 of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347.

16 Interlocking

16.1 Interlocking shall be provided by a solely mechanical means and shall provide the following features:

a) Prevent opening or closing the isolating means if the controller is providing current to the load, unless the isolating means is a load break type switch or circuit breaker with appropriate ratings;

b) Prevent the opening of a door when the isolating means is closed, if the door provides access to a compartment containing medium-voltage energized parts or medium-voltage wiring;

c) Prevent closing the isolating means when any medium-voltage-compartment door of the controller is open; and

d) Prevent opening the isolating means while current is flowing in the secondary of a control transformer unless the isolating means has been made the subject of an investigation to determine its acceptability for this type of operation. See 34.4.

16.2 Equipment incorporating drawout devices with stored mechanical energy (such as contactors or circuit breakers) shall have mechanical interlocks so that there is no access to the drawout device unless the stored energy mechanism is in the discharged or blocked position.

16.3 When means for circumventing the interlock specified in 16.1(b) is provided for inspection or maintenance purposes, some degree of difficulty shall be required to bypass the interlock. The degree of difficulty shall involve a minimum of two separate and distinct operations. Turning a knob, moving a lever, removal of a single bolt, and the like, is not considered to provide the required degree of difficulty.

16.4 Electrical or electromechanical interlocks may be provided in addition to the mechanical interlocking required by 16.1, but may not be used as a substitute for the required interlocking, which must be solely mechanical.

16.5 Hinged panels over compartments containing medium voltage parts are not required to be interlocked under the following conditions:

a) The hinged panel is provided with the marking described in 47.27 on the exterior surface of the hinged panel;

b) The hinged panel has no hand or key operable hardware or latches, and is held closed by multiple bolts, screws, or other hardware that is not hand operable. Each edge of the cover, other than the hinged side, shall be secured by no less than 2 separate bolts, screws or other type of tool operated hardware. Lifting or positioning handle(s) may be provided, but shall not affect the securement of the cover to the enclosure;

c) The hinged panel is not required to be opened during normal operation, adjustment, fuse replacement, or other maintenance of the equipment, other than periodic inspection of wiring connections or maintenance of the equipment during scheduled equipment shutdown; and

d) Additional insulating barriers may be provided to prevent unintentional contact with medium voltage parts when the hinged panel is opened. These barriers shall be secured by multiple tool operated fasteners, and shall be marked in accordance with 47.28.

16.6 When circuitry is provided to energize the bus capacitors, and this circuit can be energized with the main isolating means in the open position, this circuit shall be provided with a separate isolating means. Interlocking of this charging circuit isolating means shall be provided by a solely mechanical means and shall provide the following features:

a) Prevent the opening of a door when the charging circuit isolating means is closed, if the door provides access to the bus capacitors or any compartment that contains medium-voltage energized parts or medium-voltage wiring; and

b) Prevent closing the charging circuit isolating means when any medium-voltage-compartment door of the controller is open.

17 Automatic Restarting

17.1 A fault interrupting device in the equipment shall not automatically reclose after a fault interrupting (short-circuit) operation.

17.2 Other than as noted in 17.3, an overload relay, undervoltage device, or any other protective or sensing device that is intended to interrupt the continuous operation of a motor shall not automatically reset after tripping.

17.3 An overload relay, undervoltage device, or other device may automatically reset after tripping when one or both of the following conditions are met:

a) A manual operation is required to close the motor circuit; or

b) The device is marked in accordance with 47.20.

17.4 If the wiring diagram of the equipment indicates that one side of the control circuit is, or may be grounded, the control circuit shall be so arranged that an unintentional ground in the remote control device circuit will not cause the motor to start.

18 Internal Wiring

18.1 Section 5.205 of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347 applies.

18.2 Internal wiring may be shielded or unshielded wire. Shielded wire shall have the shield bonded to the grounding system at one or both ends of the wire.

18.3 For equipment operating above 7200 V, instruments, meters, relays, secondary control devices, and their wiring shall be isolated by grounded metal barriers from the primary circuit elements, with the exception of short lengths of wire such as at instrument transformer terminals and secondary disconnecting devices. Type MC cable is considered to meet this requirement when the outer jacket of the type MC cable is properly bonded to the equipment frame or ground bus.

18.4 Insulated grounding and bonding conductors shall be identified by the color green with or without one or more yellow stripes throughout the entire product, or shall be identified at each termination point by a green or green/yellow marking, such as green tape wrapped around the conductor. No other leads shall be so identified. This requirement does not apply to a green or green/yellow insulated conductor provided in a wiring harness, ribbon cable, or similar prefabricated wiring assembly, which is not likely to be mistaken for a grounding conductor.

18.5 Insulated conductors that are connected to the grounded side of a transformer secondary (neutral conductors) may be identified by the color white or grey or by three continuous white stripes on other than green insulation. No other conductor shall be so identified other than as described below:

a) The insulation of type SIS wire used for control circuit wiring may be grey;

b) When color coding of phases in a multi-phase circuit is provided at the end(s) of phase conductors, using tape or similar methods, any color other than green may be used; and

c) Insulated conductors provided in a wiring harness, ribbon cable, or similar prefabricated wiring assembly, which are not likely to be mistaken for neutral conductors may have grey or white insulation.

19 Voltage Dividers

19.1 This section covers voltage dividers intended to be used in equipment rated over 1500 V to provide voltage measurement or signaling, such that there is no galvanic isolation between circuits operating above 1500 V and those operating at less than 1500 V.

19.2 Voltage dividers shall consist of a minimum of two sections, including one or more primary sections and one or more low voltage sections.

19.3 Each primary section of a voltage divider shall consist of no less than two components, connected in series.

19.4 Each low voltage section of a voltage divider shall consist of no less than two components, connected in parallel.

19.5 Accessibility of live parts of a voltage divider shall be judged based on the accessibility requirements elsewhere in this standard.

19.6 No portion(s) of any primary section of a voltage divider shall be located in a compartment considered to be a low voltage compartment.

19.7 Other than at the junction point between the primary and low voltage sections of a voltage divider, components and wiring of the low voltage section(s) of a voltage divider shall be separated from wiring and components operating above 1500 V. Through-air and over-surface spacings between the high and low voltage components and wiring shall comply with Section 21.

19.8 For voltage dividers operating above 7200 V, the low voltage section of the voltage divider shall be isolated by grounded metal barriers from primary wiring and components, with the following exceptions:

a) Wire not exceeding 12 inches in length, and rated for the maximum voltage rating in the compartment, that connects the high and low voltage sections of the voltage divider, and

b) The first 12 inches of wire connecting the low voltage terminal of the voltage divider to wiring and components located within the equipment low voltage compartment need not be isolated by grounded metal barriers. The length of the wire that is not isolated by grounded metal barriers shall be rated for the highest voltage in the compartment, or shall be spaced from all medium voltage parts by spacings in accordance with Section 21.

19.9 The voltage divider shall be constructed such that with the equipment operating at rated maximum voltage, under normal operation and under any single fault condition,

a) There shall be no voltage exceeding 1500 V on any portion of the low voltage section, when measured with respect to ground, to operator accessible metal parts, or to other low voltage circuits, and

b) The current available at any point of a low voltage section shall not exceed 5 mA, when a short of negligible impedance is placed between that point and ground.

The fault conditions to be considered include the opening and shorting of each component in the voltage divider circuit, one at a time.

19.10 Equipment incorporating a voltage divider shall comply with all performance requirements of this standard, including dielectric voltage-withstand and impulse tests, with the voltage divider installed as intended. When voltage dividers are connected between medium voltage circuits and ground, the ground connection for the voltage divider shall be disconnected from ground during the dielectric voltage-withstand and impulse tests.

20 Terminals and Connections

20.1 Sections 5.206 through 5.208 of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347 apply.

20.2 Where field connections are to be made to circuits rated over 1500 V, wire bending space shall be provided in accordance with Section 5.210 of the Standard for Medium Voltage AC Contactors, Controllers, and Control Centers, UL 347.

20.3 Where field connections are to be made to circuits rated 1500 V and below, wire bending space shall be provided in accordance with Section 7.14 of the Standard for Industrial Control Equipment, UL 508.

20.4 Terminals for field connections to circuits rated 1500 V and below, other than control circuits, shall be marked to indicate the tightening torque to be applied to the wire connector. These markings may be adjacent the wiring terminal, or marked on the wiring diagram.

20.5 With respect to the requirement in 20.4, a marking shall indicate the specific tightening torque in N-m (in-lb or ft-lb) for each wire connector in the equipment that is intended for field-wiring. If different connectors are used for different connections, the specific torques to be applied to each connector shall be clearly indicated. The torque marking may be provided in a written format or pictorially.

20.6 The tightening torque for a field-wiring terminal shall be as specified by the equipment manufacturer and shall be marked as required by 20.5. Other than as noted in 20.7, the specified tightening torque shall not be less than 90 percent of the value employed in the static heating test as specified in UL 486A-486B, Standard for Wire Connectors, for that wire size corresponding to the ampere rating of the equipment.

20.7 With respect to 20.6, the torque value may be less than 90 percent if the connector is investigated in accordance with the lesser assigned torque value in UL 486A-486B, Standard for Wire Connectors.

20.8 A field-wiring terminal intended only for the connection of a control circuit conductor is not required to be marked with a value of tightening torque when tested in accordance with the applicable requirements in UL 486A-486B or UL 486E, with tightening torque value of 7 lbf-in (0.8 N-m).

20.9 Terminals for field connections to circuits rated 1500 V and below, other than control circuits, shall be marked to indicate the temperature rating of the conductors to be connected to the terminals. Control terminals are not required to be marked to indicate the temperature rating.

20.10 Other than as noted in 20.11, the marking required by 20.9 shall indicate use of 60°C, 60/75°C, or 75°C wire only, based on the wire used during the temperature test, and the temperatures measured on the wiring terminals.

20.11 As an alternative to the marking in 20.10, the marking may state "Size wire based on ampacity for __°C wire" where the blank is filled by 60 or 75 as appropriate, to allow the use of higher temperature wire, as long as it is sized based on the lower temperature wire ampacity.

20.12 Field-wiring terminals for circuits rated above 1500 V need not be marked with conductor temperatures or with tightening torques.

21 Spacings

21.1 General

21.1.1 Spacings shall comply with the requirements in this section.

21.1.2 Spacings are not specified within a circuit supplied by a Class 2 power supply, but spacings shall be provided between the Class 2 circuit and all other circuits in accordance with the spacing requirements for the other circuit. All portions of the Class 2 circuit are considered to be uninsulated grounded parts for this purpose.

21.1.3 A ceramic, vitreous-enamel, or similar coating shall not be employed as insulation in place of spacings unless, upon investigation, the coating is found to be uniform, reliable, and otherwise acceptable for the purpose.

21.1.4 Enamel-insulated and similar film-insulated wire is considered to be the same as an uninsulated live part in determining compliance of a device with the spacing requirements in this document.

21.1.5 An insulated conductor shall be considered uninsulated, for the purpose of measuring spacings to uninsulated medium-voltage parts, unless the insulation is acceptable for the medium-voltage involved.

21.1.6 The spacings between live parts and metal parts that may be grounded, such as the heads of mounting screws that pass through an insulating panel, shall be judged as if they were grounded parts within an enclosure.

21.1.7 The spacing between uninsulated live parts and the surface on which the complete controller is mounted is to be judged as if the mounting surface were part of a metal enclosure.

21.1.8 The spacings at fuses and fuseholders are to be measured with the fuses having maximum standard dimensions in place. Where the fuseholder construction permits a fuse to be partially inserted and remain in that position, spacings shall be measured with the fuse in the partially inserted position as well as in the fully inserted position.

21.1.9 The spacing at a field-wiring terminal is to be measured with wire connected to the terminal as in service. The connected wire is to be the next larger size than is normally required for the equipment rating when the terminal accommodates it or when the equipment is not marked to restrict its use.

21.2 Circuits connected to the medium voltage line

21.2.1 Circuits that are not isolated from the medium voltage line, either galvanically or by a voltage divider complying with Section 19 are considered to be connected to the medium voltage line. Low voltage circuits on the load side of voltage dividers that comply with the requirements of Section 19 may be treated as isolated circuits.

21.2.2 The electrical through-air and over surface spacings for circuits connected to the line shall be not less than those indicated in Table 21.1.

Table 21.1
Minimum Clearance and Creepage Distances – Medium Voltage Circuits

Circuit type	Potential involved, volts (rms or direct-current)[a,b]	Minimum clearance and creepage distance							
		To other than enclosure walls[g]				To walls of metal enclosure[c,d]			
		Clearance through Air		Creepage along surface Air		Clearance through air		Creepage along surface	
		mm	inches	mm	inches	mm	inches	mm	inches
Line Voltage Circuits	2500 max[e]	25.4	1.0	50.8	2.0	50.8	2.0	76.2	3.0
	7200 max[e]	50.8	2.0	88.9	3.5	76.2	3.0	101.6	4.0
	15 kV max[e]	101.6	4.0	114.3	4.5	101.6	4.0	127.0	5.0
	38 kV max[e]	153	6.0	203	8.0	153	6.0	203	8.0
Series Connected Components[f]	51 – 150	3.2	0.125	6.4	0.25	12.7[h]	0.5[h]	12.7[h]	0.5[h]
	151 – 300	6.4	0.25	9.5	0.375	12.7[h]	0.5[h]	12.7[h]	0.5[h]
	301 – 600	9.5	0.375	12.7	0.5	12.7[h]	0.5[h]	12.7[h]	0.5[h]
	601 – 1000	14	0.55	21.6	0.85	20.3[h]	0.8[h]	25.4[h]	1.0[h]
	1000 – 1500	17.8	0.7	30.5	1.2	30.5[h]	1.2[h]	41.9[h]	1.65[h]

[a] Where the repetitive peak voltage on which the device used is more than 1.5 times the rms volts, the peak voltage shall be divided by √2 to obtain an equivalent rms rating in volts.

[b] For grounded power systems, such as 3-phase, 4-wire systems, the clearance and creepage distances to ground shall be governed by the voltage to ground.

[c] For the purpose of this requirement, a metal piece attached to the enclosure is considered to be a part of the enclosure if deformation of the enclosure is likely to reduce clearance and creepage distances between the metal piece and uninsulated live parts.

[d] For subassembly enclosures where clearance and creepage distances are rigidly maintained, and when mounted inside another enclosure, the distances for "to other than enclosure walls" may be used instead of "to walls of metal enclosure."

[e] Because of the effect of configuration, spacings in excess of those indicated may be required to meet the performance requirements of this document.

[f] In a series circuit such as a voltage divider or multi-tap transformer, the spacings between resistor terminals, transformer taps, and the like are to be based on the normal operating voltage existing between such parts.

Table 21.1 Continued on Next Page

Table 21.1 Continued

Circuit type	Potential involved, volts (rms or direct-current)[a,b]	Minimum clearance and creepage distance							
		To other than enclosure walls[g]				To walls of metal enclosure[c,d]			
		Clearance through Air		Creepage along surface Air		Clearance through air		Creepage along surface	
		mm	inches	mm	inches	mm	inches	mm	inches

[g] For locations other than field wiring terminals, linear interpolation based on the voltage involved is allowed for spacings between ungrounded parts of opposite polarity , when the potential involved is greater than 2500 V. Interpolation is not permissible for spacings from live parts to grounded parts.

[h] Where the voltage between the part and the enclosure wall does not exceed 1500 V during either normal or abnormal operating conditions (i.e. one output phase connected to ground in a cascaded power module configuration), creepage and clearance shall be selected from the appropriate row of this table for series connected components, based on the voltage involved between the part and the enclosure wall. For parts where the voltage between the part and the enclosure wall exceeds 1500 V, the creepage and clearance shall be selected from the row for line voltage circuits, based on the voltage involved.

21.2.3 See Section 26 for spacing considerations for gate drive circuits.

21.3 Circuits isolated from the medium voltage line

21.3.1 General

21.3.1.1 Isolated circuits operating at more than 1500 V shall comply with the spacings shown in Table 21.1. For the purpose of this requirement, in constructions that involve using multiple controller cells that are individually fed from isolated, low voltage windings of a transformer, with their output circuits connected in series to create higher output voltages, the spacings internal to each controller cell are to be investigated in accordance with 21.3.1.2 through 21.5. The output circuits are considered medium voltage circuits with respect to ground, and shall meet the spacings between live parts and grounded metal parts shown in Table 21.1. Spacings between live parts of opposite polarity within the output circuit are to be based on the potential involved across the spacing.

21.3.1.2 Spacings at field wiring terminals of isolated low voltage circuits, and between uninsulated live parts and conduit bushings, shall comply with Table 21.2.

Table 21.2
Minimum Acceptable Spacings:
Between Field Wiring Terminals of Opposite Polarity in Low Voltage Isolated Circuits, and Between Uninsulated Low Voltage Parts and Conduit Bushings

Potential involved, in volts	Between any uninsulated live part and an uninsulated live part of opposite polarity, an uninsulated grounded part other than the enclosure, or an exposed metal part				Between any uninsulated live part and the walls of a metal enclosure, including fittings for conduit or armored cable			
	Through air		Over surface		Through air		Over surface	
	mm	inch	mm	inch	mm	inch	mm	inch
0 – 50	3.2	0.125	3.2	0.125	12.7	0.50	12.7	0.50
51 – 150	3.2	0.125	6.4	0.25	12.7	0.50	12.7	0.50
151 – 300	6.4	0.25	9.5	0.375	12.7	0.50	12.7	0.50
301 – 600	9.5	0.375	12.7	0.5	12.7	0.50	12.7	0.50
601 – 1000	14.0	0.55	21.6	0.85	20.3	0.8	25.4	1.0
1001 – 1500	17.8	0.70	30.5	1.2	30.5	1.2	41.9	1.6

21.3.2 Spacings for low voltage isolated circuits – other than at field-wiring terminals

21.3.2.1 Spacings other than at field-wiring terminals, and other than between uninsulated live parts and conduit bushings shall comply with one of the following:

a) Spacings per Table 21.3;

b) Spacings for components used in pollution degree 1 or 2 micro environments (see 21.3.3, and Table 21.4); or

c) Spacings for assemblies used in accordance with the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, (see 21.7).

Table 21.3
Minimum Acceptable Spacings for Low Voltage Isolated Circuits Other Than at Field Wiring Terminals or Between Uninsulated Live Parts and Conduit Bushings

Potential involved in volts rms ac or dc		Minimum spacing, inch (mm)[b,c]		
		51 – 150	151 – 300	301 – 600
Between any uninsulated live part and an uninsulated live part of opposite polarity, uninsulated grounded part other than the enclosure, or exposed metal part	Through air or oil	0.125 (3.2)	0.25 (6.4)	0.375 (9.5)
	Over surface	0.25 (6.4)	0.375 (9.5)	0.5 (12.7)
Between any uninsulated live part and the walls of a metal enclosure including fittings for conduit or armored cable[a]	Shortest distance	0.5 (12.7)	0.5 (12.7)	0.5 (12.7)

[a] For the purpose of this requirement, a metal piece attached to the enclosure is considered to be a part of the enclosure if deformation of the enclosure is likely to reduce the spacings between the metal piece and uninsulated live parts.

[b] A slot, groove, or the like, 0.013 inch (0.33 mm) wide or less in the contour of insulating material is to be disregarded.

[c] An air space of 0.013 inch (0.33 mm) or less between a live part and an insulating surface is to be disregarded for the purpose of measuring over surface spacings.

Table 21.4
Spacings Other Than at Field-Wiring Terminals for Low Voltage Isolated Parts in Pollution Degree 2 Micro Environments

Potential involved in volts		Minimum spacings[a], inch (mm)			
rms	Peak	Over surface		Through air	
0 – 50	0 – 70.7	0.047	(1.2)	0.047	(1.2)
51 – 125	72.1 – 176.8	0.063	(1.6)	0.063	(1.6)
126 – 250	178.2 – 353.6	0.094	(2.4)	0.094	(2.4)
251 – 600	355.0 – 848.5	0.5	(12.7)[b]	0.375	(9.5)[b]

[a] On printed-wiring boards, their connectors, and board-mounted electrical components, wired on the load side of line filters of similar voltage peak reduction networks and components, a minimum spacing of 0.0230 inch (0.584 mm) plus 0.0002 inch (0.005 mm) per volt peak shall be maintained over surface and through air between uninsulated live parts and any other uninsulated live or dead conductive parts not of the same polarity.

[b] Film-coated wire is considered to be an uninsulated live part. However, a spacing of not less than 3/32 inch (2.4 mm) over surface and through air is acceptable between a dead metal part and film-coated wire that is rigidly supported and held in place on a coil.

21.3.3 Spacings for low voltage components located in pollution degree 1 or 2 micro-environments

21.3.3.1 This section does not apply to medium voltage components or to low voltage components that are not isolated, either galvanically or by a voltage divider that complies with Section 19, from medium voltage circuits.

21.3.3.2 For the purposes of this document, a pollution degree 1 microenvironment can be achieved by the following constructions:

a) The use of conformal coating on printed wiring board foil traces that complies with the requirements for Conformal Coatings in the Standard for Polymeric Materials – Use In Electrical Equipment Evaluations, UL 746C;

b) The use of any potting material or encapsulation, such as epoxy;

c) The use of a case or enclosure that is hermetically sealed against the entrance of an external atmosphere by means of fusion – such as from soldering, brazing, welding, or the fusion of glass to metal.

21.3.3.3 For the purposes of this document, a pollution degree 2 microenvironment can be achieved by reducing both the possibilities of conductive pollution and the possibilities of condensation or high humidity at the creepage distances.

a) Constructions that reduce the possibility of conductive pollution are:

1) The use of an unventilated enclosure;

2) The use of a filtered ventilated enclosure when all openings are provided with filters.

b) Constructions that reduce the effects of condensation or high humidity are:

1) The use of a ventilated enclosure;

2) The continuous application of heat through the use of heaters;

3) The use of conformal coatings, on printed wiring board foil traces.

21.3.3.4 At other than field wiring terminals, the spacings for low voltage components intended for use in a pollution degree 1 or 2 microenvironment shall be at least those specified in Table 21.4.

21.3.3.5 At field wiring terminals of low voltage components intended for use in a pollution degree 1 or 2 microenvironment shall be at least those specified in Table 21.3.

21.4 Insulating material used as a barrier in lieu of spacings

21.4.1 When an insulation material is used as a barrier in lieu of spacings within a low voltage circuit that is isolated from medium voltage circuits, either galvanically or by a voltage divider complying with Section 19, it shall comply with the requirements in 4.15DV.1.7 in the Standard for Adjustable Speed Electrical Power Drive Systems – Part 5-1: Safety Requirements – Electrical, Thermal and Energy, UL 61800-5-1.

21.4.2 Insulation materials used as barriers in lieu of spacings in medium voltage circuits or in low voltage circuits that are not galvanically isolated from medium voltage circuits shall not be in contact with live medium voltage parts, and shall comply with the impulse and dielectric voltage withstand requirements of this document.

21.5 Clamped insulating joints in lieu of spacings

21.5.1 With respect to spacings within isolated low voltage circuits, the requirements of 4.3.6.4DV.1.1.5 in the Standard for Adjustable Speed Electrical Power Drive Systems – Part 5-1: Safety Requirements – Electrical, Thermal and Energy, UL 61800-5-1 are applicable.

21.6 Voltage dividers and other circuits provided with solid insulation

21.6.1 Clearance and creepage distances between circuits within circuit assemblies provided with solid insulation may be less than those required in Table 21.1 when all of the following conditions are met:

a) The circuit is provided with solid insulation such as encapsulation, that completely fills the area between the circuit components, and is applied in a manner (such as assembly in a sub-atmospheric pressure environment) that reduces the likelihood of voids or gas bubbles within the encapsulant,

b) The solid insulation material is determined to be resistant to aging with consideration given to temperature of parts covered by the material,

c) Clearance and creepage distances between circuits that are not covered by the solid insulation are no less than those required in Table 21.1,

d) Clearance distances between the circuit prior to being covered by the solid insulation shall be no less than those required for Pollution Degree 1 in Table 10 of the Standard for Adjustable Speed Electrical Power Drive Systems, UL 61800-5-1, and

e) The component or circuit assembly complies with the Impulse Test, Section 36, using the impulse voltage as shown in Table 26.1.

21.7 Spacings for printed wiring boards used in accordance with the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840

21.7.1 This section applies only to circuits on printed wiring boards with connection to grounded parts, and does not apply to spacings at field wiring terminals.

21.7.2 Other than as noted in 21.7.3, clearances and creepage distances in circuits of printed wiring boards may be evaluated in accordance with the requirements in the Standard for Insulation Coordination Including Clearance and Creepage Distances for Electrical Equipment, UL 840, as modified by 21.7.4 and 21.7.5. For circuits with working voltages above 1000 V, Table 8.1 and 9.2 of UL 840 are to be replaced by Table 21.5 and Table 21.6. In circuits having serial connected components, the clearances and creepage distances are based on the potential involved across the individual component.

Table 21.5
Minimum Acceptable Clearance Distances for Circuits on Printed Wiring Boards, mm

Column 1	Column 2	Column 3
Working voltage across clearance, V (recurring peak)	Rated Impulse Voltage of equipment, kV	Minimum Clearance, mm
1000	2.5	1.5
1600	4.0	3.0
3000	8.0	8.0
4600	12	14

Table 21.5 Continued on Next Page

Table 21.5 Continued

Column 1	Column 2	Column 3
Working voltage across clearance, V (recurring peak)	Rated Impulse Voltage of equipment, kV	Minimum Clearance, mm
7200	19	24
15000	38	56
23000	60	90
Interpolation is permitted. Clearance is to be determined based on the working voltage and also determined based on the rated impulse voltage of the equipment. The required minimum clearance shall be the larger of the two.		

Table 21.6
Minimum Acceptable Creepage Distances on Printed Wiring Boards, mm

Column 1	Column 2	Column 3			Column 4		
Working voltage (rms)	Pollution Degree 1	Pollution Degree 2			Pollution Degree 3		
	Insulating material group I, II, or III	Insulating Material Group			Insulating Material Group		
		I	II	III	I	II	III
1000	3.2	5	7.1	10	12.5	14	16
2000	7.5	10	14	20	25	28	32
2500	10	12.5	18	25	32	36	40
5000	20	25	36	50	64	72	80
7200	29	36	51	72	90	101	115
10000	40	50	72	100	128	140	160
15000	60	75	108	150	192	210	240
Interpolation is permitted.							

21.7.3 Clearances between an uninsulated live part and the walls of a metal enclosure, including fittings for conduit or armored cable, shall be in accordance with Table 21.3. For potentials above 600V, Table 21.1 shall be used. The clearances shall be determined by physical measurement.

21.7.4 In conducting evaluations in accordance with the requirements in the Standard for Insulation Coordination Including Clearance and Creepage Distances for Electrical Equipment, UL 840, the following guidelines shall be used:

a) The macro-environment in which a controller is installed is considered pollution degree 3;

b) While the macro-environment in which a controller is installed is considered pollution degree 3, a pollution degree 1 or 2 micro-environment can be created within the controller by incorporating one of the constructions defined in 21.3.3.2 or 21.3.3.3;

c) Overvoltage Category IV shall apply to equipment permanently connected at the origin of an installation that is upstream of the main distribution board, or to equipment installed at the service entrance. Overvoltage Category III shall apply to equipment permanently connected in fixed installations that are downstream of, and including, the main distribution board.

d) Any printed wiring board that complies with the requirements in the Standard for Printed Wiring Boards, UL 796, shall be considered to provide a minimum Comparative Tracking Index (CTI) of 100;

e) Evaluation of clearances, only, to determine equivalence with current through air spacings requirements may be conducted in accordance with Clearance A (Equivalency) of UL 840. An impulse test potential having a value as determined in UL 840 is to be applied across the same points of the device as required for the Dielectric Voltage-Withstand Test, Section 33;

f) Evaluation of clearances and creepage distances shall be conducted in accordance with the requirements for Clearance B (Controlled Overvoltage), and for Creepage Distances of UL 840;

g) Determination of the dimensions of clearance and creepage distances shall be conducted in accordance with the requirements for Measurement of Clearance and Creepage Distances of UL 840;

h) On printed wiring boards, the use of a solder resist coating is considered to create a pollution degree 2 environment between any printed wiring board traces that are completely covered by the solder resist coating, and any trace or solder pad, that is not covered by the coating. Solder resist coatings do not provide any reduction in pollution degree when considering spacings between solder pads or between solder pads and traces that are not covered by the coating.

21.7.5 Spacings between any medium voltage circuit and all low voltage circuits that are accessible outside the enclosure and may be contacted by the operator (such as circuits associated with devices described in Section 28) shall be 1.6 times the spacings required by 21.7.2 for the medium voltage circuit.

21.8 Alternate approach for spacings

21.8.1 Other than at field-wiring terminals, the electrical spacings within power conversion equipment rated up to 35kV shall meet the requirements for insulation specified in IEC 61800-5-1.

21.8.2 Compliance requires that the power conversion equipment be investigated in accordance with all portions that are part of IEC 61800-5-1, regarding the insulation coordination.

22 Means for Switching

22.1 When a circuit breaker or switch is mounted such that movement of the operating handle, either vertically or rotationally, between the on and off positions results in one position being above the other position, the upper position shall be the on position. The requirement does not apply to a circuit breaker or switch that is operated horizontally or that is operated rotationally and the on and off positions are at the same level, nor to a switching device having two on positions, such as a transfer switch or a double throw switch.

23 Capacitors

23.1 Other than as noted in 23.2, a means shall be provided to discharge each bus capacitor to a voltage level below 50 V dc within 1 minute. See Section 42 for the capacitor discharge test.

23.2 Equipment is not required to comply with the discharge requirement of 23.1 if the equipment complies with (a) and (b) below:

a) The equipment is provided with a marking in accordance with 47.29; and

b) The equipment is provided with a mechanical or electro-mechanical interlock to prevent access to all circuits connected to the capacitor until the voltage has discharged to a level below 50 V, or the equipment is provided with an indicator that is visible prior to accessing the circuit(s) that indicates the presence of more than 50 V on the circuit.

23.3 A motor starting capacitor employing a liquid dielectric medium more combustible than askarel shall comply with the protected oil filled capacitor requirements, contained in the Standard for Capacitors, UL 810, including faulted overcurrent conditions based on the circuit in which it is used (see the Short Circuit

Interruption Test, Section 35). A motor starting capacitor and any associated solid state component shall be evaluated in accordance with the Breakdown of Components Test, Section 41.

23.4 A non-motor starting capacitor employing a liquid dielectric medium more combustible than askarel, and any associated solid-state component, need only be evaluated in accordance with the Breakdown of Components Test, Section 41.

24 Control Circuits

24.1 Control circuit conductors shall be no smaller than 22 AWG (0.32 mm^2). This requirement does not apply to conductors such as ribbon cables used to connect adjacent printed wiring board assemblies, where the conductors make no more than casual contact with insulated or uninsulated parts of opposite polarity or with grounded parts, and the conductors are no longer than 305 mm (12 inches) long.

24.2 Other than as noted in 24.3, 24.4 and 24.5, control circuit wiring sized from 22 – 12 AWG (0.32 – 3.3 mm^2) shall be provided with protection that complies with 24.6.

24.3 Wiring located within a Class 2 circuit need not be provided with additional protection.

24.4 Protection is not required on any wiring measuring a maximum of 305 mm (12 inches) long.

24.5 Any low voltage wiring connected to a printed wiring board having no connections external to the controller and having no more than casual contact with insulated or uninsulated parts of opposite polarity or with grounded parts need not be additionally protected.

24.6 The wiring protection required by 24.2 shall:

a) Be located within the equipment;

b) Be rated in accordance with Table 24.1;

c) Be provided in each ungrounded conductor;

d) Be located no more than 305 mm (12 inches) from the point where the wiring is connected to its source of power;

e) Either be a supplementary or a branch circuit type fuse or circuit breaker in accordance with the Standard for Supplementary Protectors for Use in Electrical Equipment, UL 1077, the UL 248 series for fuses, or the Standard for Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures, UL 489 respectively; and

f) Be provided with a marking in accordance with 48.3.

Table 24.1
Overcurrent Protection

Control-circuit wire size, AWG (mm^2)	Maximum protective device rating, amperes
22 (0.32)	3
20 (0.52)	5
16 (0.82)	7
16 (1.3)	10
14 (2.1)	20
12 (3.3)	25

25 Bypass Circuits

25.1 Bypass contactors rated 15 kV and less

25.1.1 Other than as noted in 25.1.2, contactors used to bypass the converter and inverter portions of the controller (connecting the input directly to the output) shall comply with the requirements of the Standard for Medium-Voltage AC Contactors, Controllers, and Control Centers, UL 347.

25.1.2 If the bypass contactor is interlocked and sequenced with the output section of the controller, such that the bypass contactor never makes or breaks motor current, the contactor need not comply with the overload test or the make and break capability test in the Standard for Medium-Voltage AC Contactors, Controllers, and Control Centers, UL 347.

25.1.3 Unless previously investigated and rated for the short circuit withstand current rating of the equipment, bypass contactors shall be subjected to the short circuit test detailed in Section 35, Short Circuit Interruption Test. Testing with reduced available short circuit currents as described in 35.2.18 shall not be allowed when testing the bypass contactor(s).

25.1.4 Other than as noted in 25.1.5, when provision is made for a bypass circuit with open transfer, the bypass device shall be electrically interlocked and sequenced with the output section of the controller so that the bypass and the output section cannot be in the closed or load position simultaneously.

25.1.5 If the equipment control prevents operation of the bypass circuit unless the voltage, frequency and phasing of the output match the voltage and phase of the power source (within 5 percent), the bypass device is not required to be provided with interlocking.

25.1.6 The interlocking and sequencing circuitry required in 25.1.2, 25.1.4, and 25.1.5 shall comply with the requirements of Section 53, Burn-In and Diagnostic Tests. Any single component failure shall not render this circuitry inoperable.

25.2 Bypass Circuits Rated Over 15 kV

25.2.1 Bypass circuits rated over 15 kV shall not be provided, unless the bypass device consists of a circuit breaker or switch, mounted in Metal-Clad or Metal-Enclosed Switchgear, that has been previously investigated.

26 Gate Drive Circuits

26.1 Gate drive circuits, which may consist of multiple sub-circuits at medium voltage potential including the connection to the switching devices, shall provide isolation between the gates of medium voltage solid state switching devices and low voltage control circuits. This isolation shall comply with the Dielectric Voltage Withstand Test, Section 33, and the Impulse Withstand Test, Section 36 with the potentials applied between the gate drive circuits and the low voltage control circuit. This insulation may be provided by a dedicated gate drive circuit power supply.

26.2 Other than as noted in 26.3 – 26.10, clearance and creepage distances between the gate of the switching device and the low voltage control circuit shall comply with Table 21.1.

26.3 Clearance and creepage distances between the gate of the switching device and the control circuit may be less than those required in Table 21.1 when all of the following conditions are met:

a) The circuit is provided with solid insulation such as encapsulation, that completely fills the area between the gate and control circuits,

b) The solid insulation material is determined to be resistant to aging with consideration given to temperature of parts covered by the material,

c) Clearance and creepage distances between the gate and control circuits that are not covered by the solid insulation are no less than those required in Table 21.1,

d) Clearance distances between the gate and control circuits prior to being covered by the solid insulation shall be no less than those required for Pollution Degree 1 in Table 9.1 of the Standard for Insulation Coordination Including Clearance and Creepage Distances for Electrical Equipment, UL 840.

e) The assembly complies with the Impulse Test, Section 36, with the impulse voltage as shown in Table 26.1 applied between the gate and control circuit, and

f) If the voltage stress on the insulation is greater than 1 kV/mm (25.4 kV/in), the assembly shall comply with the partial discharge test described in 5.2.3.3 of IEC 61800-5-1. For purpose of this requirement, the voltages stress is the recurring peak voltage divided by the distance between two parts of different potential.

Table 26.1
Impulse voltage

System voltage[a]	Impulse test voltage[b]
> 1.5 kV	12.8 kV
3.6 kV	32 kV
7.2 kV	64 kV
12 kV	96 kV
17.5 kV	120 kV
24 kV	152 kV
38 kV	208 kV

[a] For intermediate voltages, Interpolation is permitted.

[b] The impulse test voltage shall not be less than the rated impulse voltage of the equipment.

26.4 Spacings within the gate drive circuits, including the connection to the solid state switching devices at medium voltage potential, shall be evaluated to the requirements in 26.5 – 26.10.

26.5 A circuit analysis described in IEC 61800-5-1 clause 4.2 shall show that a failure of the insulation does not result in a hazard.

26.6 For circuits having a serial connected component the clearances and creepage distances are based on the potential involved across the individual component.

26.7 Minimum clearances shall comply with columns 1 and 2 of Table 26.2.

Table 26.2
Minimum clearance – within gate drive circuit

1	2	3	4	5	6
Working voltage		Impulse	Minimum clearance		
			Pollution Degree		
			1	2	3
Volts (rms or direct current)	Volts (recurring peak)	Volts	mm	mm	mm
50	340	330	0.01	0.2	0.8
100	530	500	0.01	0.2	0.8
150	700	800	0.1	0.5	0.8
300	960	1500	0.5	0.5	0.8
600	1600	2500	1.5		
1000	2600	4000	3		
2040	3700	6000	5.5		
3080	4800	8000	8		
4870	7400	12000	14		
8240	12000	20000	25		
17500	26000	40000	60		
Interpolation is permitted.					

26.8 Clearances above an altitude of 2000 m must be multiplied by the factor provided in Table D.1. of IEC 61800-5-1.

26.9 Creepage distances may be evaluated in accordance with the requirements in Section 9 of UL 840. When the creepage distance determined is less than the clearance required, then it shall be increased to that clearance.

26.10 The spacings between the gate drive circuits and the low voltage control circuit shall comply with Table 21.1.

27 Transformers, Reactors, and Voltage Sensing Devices

27.1 A transformer employed in power conversion equipment shall comply with the appropriate standard for the transformer.

27.2 Transformers and other voltage sensing devices that are connected between medium voltage and low voltage circuits shall provide isolation between the circuits that complies with the Dielectric Voltage Withstand Test, Section 33 and the Impulse Withstand Test, Section 36.

27.3 Insulation systems of transformers or reactors operating at medium voltage shall comply with the requirement for insulation systems of medium voltage transformers in the Standard for Transformers, Distribution, Dry-Type – Over 600 Volts, UL 1562.

28 Cord-Connected Programming and Diagnostic Units

28.1 This section applies only to devices intended to be connected only to low voltage circuits that are isolated from medium voltage circuits.

28.2 Auxiliary units such as portable programmers intended to be used only on a temporary basis, to diagnose or program industrial controls shall comply with the requirements in the Standard for Information Technology Equipment Safety – Part 1: General Requirements, UL 60950-1. These units are a subsystem of the complete equipment.

29 Accessories

29.1 An accessory intended to be attached in the field shall comply with Section 5.211 of the Standard for Medium-Voltage AC Contactors, Controllers, and Control Centers, UL 347. See Instructions and Markings Pertaining to Accessories, Section 52.

29.2 The installation shall be capable of being accomplished using tools that are readily available unless a special tool is provided with the accessory, as verified by the Field Accessory Installation Test, Section 46.

29.3 The complete assembly, with accessories installed, shall comply with all the construction and performance requirements of this standard.

30 Cooling Systems

30.1 Power conversion equipment containing cooling systems other than convection or forced air, shall comply with 30.2 through 30.8.

30.2 The cooling medium used in a cooling system shall be water, glycol, a mixture of water and glycol, oil, or other refrigerants investigated for the purpose. The temperature of the cooling medium shall not exceed 70°C under normal operating conditions.

30.3 All tubing, tanks, and other cooling system components integral to or included with the controller shall be constructed of corrosion resistant material and shall be suitable for use with the cooling medium.

30.4 Copper or steel tubing used to connect refrigerant-containing components shall comply with the minimum wall thickness requirements of Table 30.1. Tubing made of metals other than copper or steel shall meet the minimum thickness shown for copper. Thickness of non-metallic tubing is not specified, but the tubing shall be protected as defined in footnote b of Table 30.1.

Table 30.1
Tubing Wall Thickness

Outside diameter		Minimum wall thickness,[a] mm (inch)					
		Copper				Steel	
		Protected[b]		Unprotected[b]			
mm	(inch)						
6.35	(1/4)	0.62	(0.0245)	0.67	(0.0265)	0.64	(0.025)
7.94	(5/16)	0.62	(0.0245)	0.72	(0.0285)	0.64	(0.025)
9.53	(3/8)	0.62	(0.0245)	0.72	(0.0285)	0.64	(0.025)
12.70	(1/2)	0.62	(0.0245)	0.72	(0.0285)	0.64	(0.025)
15.88	(5/8)	0.80	(0.0315)	0.80	(0.0315)	0.81	(0.025)
19.05	(3/4)	0.80	(0.0315)	0.98	(0.0385)	0.81	(0.032)
22.23	(7/8)	1.04	(0.0410)	1.04	(0.0410)	1.17	(0.032)

Table 30.1 Continued on Next Page

Table 30.1 Continued

Outside diameter		Minimum wall thickness,[a] mm (inch)					
		Copper					
mm	(inch)	Protected[b]		Unprotected[b]		Steel	
25.40	(1)	1.17	(0.0460)	1.17	(0.0460)	1.17	(0.046)
28.58	(1-1/8)	1.17	(0.0460)	1.17	(0.0460)	1.17	(0.046)
31.75	(1-1/4)	1.28	(0.0505)	1.28	(0.0505)	1.17	(0.046)
34.93	(1-3/8)	1.28	(0.0505)	1.28	(0.0505)	1.58	(0.046)
38.10	(1-1/2)	1.41	(0.0555)	1.41	(0.0555)	1.58	(0.062)
41.3	(1-5/8)	1.410	(0.0555)	1.410	(0.0555)	–	(0.062)
54.0	(2-1/8)	1.626	(0.0640)	1.626	(0.0640)	–	–
66.7	(2-5/8)	1.880	(0.0740)	1.880	(0.0740)	–	–

[a] Nominal wall thickness of tubing will have to be greater than the thickness indicated to maintain the minimum wall thickness.

[b] Protected means that the tubing is shielded by the cabinet or assembly, to the extent that unintended damage caused by objects such as tools falling on or otherwise striking the tubing during handling and after installation of the unit, is prevented. This protection may be provided in the form of baffles, channels, flanges, perforated metal, or equivalent means. If a cabinet is employed for the intended installation of a unit, the tubing is considered shielded. Tubing not so shielded is considered to be unprotected.

30.5 If a means for relieving pressure from the cooling system is provided as part of the power conversion equipment, it shall be investigated for the purpose in accordance with the Hydrostatic Pressure Test requirements of Section 40.

30.6 When normal operation of the cooling system results in expected condensation inside the power conversion equipment, the spacings of the equipment shall be evaluated for a Pollution Degree 3 environment (see 2.30). The possibility of accumulation of water due to condensation and a means for its exit from the enclosure shall be determined.

30.7 There shall be no leakage of the cooling medium onto live parts as a result of:

a) Normal operation, including expected condensation;

b) Servicing of the equipment; or

c) Loosening or detachment of hoses or other cooling system parts over time.

30.8 The equipment cooling system, including all tubing, shall comply with the Loss of Cooling Medium Circulation Test, 39.6, and the Hydrostatic Pressure Test requirements of Section 40.

PERFORMANCE

31 General

31.1 The performance of medium voltage power conversion equipment shall be investigated by subjecting a representative sample or samples in commercial form to the tests described in Sections 32 – 43. Other than as indicated in Table 31.1, the sequence in which these tests are conducted is not specified. Unless otherwise indicated, these tests shall be conducted at each rated supply frequency. Representative samples are to be determined based on optional features, and the effects of such features on the performance during specific tests.

Table 31.1
Sequence of Tests

Section	Test	Sequence[a,b,c,d]			
		1	2	3	4
32	Temperature Test	1			
33	Dielectric Voltage-Withstand Test		2[f]	2	X
34	Switching Capability Test – Isolating Means				X
35	Short Circuit Interruption Test				X
36	Impulse Withstand Test				X
37	Calibration Tests – Overload				X
38	Solid State Motor Overload Protection Test				X
39	Operation Tests		1		
40	Hydrostatic Pressure Test			1[e]	
41	Breakdown of Components Test				X
42	Capacitor Discharge Test				X
43	Mechanical Operation and Interlock Integrity Test				X
46	Accessory Installation Test				X

[a] All or any combination of sequences may be conducted on a single sample if agreeable to those concerned. In the event that a single sample is used for more than one sequence, the sample may be repaired and parts replaced upon the completion of a specific sequence.

[b] For test sequences 1, 2, and 3, the tests shall be conducted in the order indicated. The tests identified in sequence 4 may be conducted in any order, and each test in sequence 4 may be conducted on a separate sample.

[c] One sequence need not be started as a prerequisite to the starting of another.

[d] A dielectric voltage-withstand test may be conducted prior to the start of any sequence.

[e] Test is required only for equipment having cooling systems other than convection or forced air.

[f] The dielectric withstand test is only required if the operation test sequence includes the loss of cooling medium test.

32 Temperature Test

32.1 General

32.1.1 When tested under the conditions in 32.2.1 – 32.2.18, the equipment shall not attain a temperature at any point high enough to constitute a risk of fire or to damage any materials employed in the equipment, nor show temperature rises at specific points greater than those indicated in Table 32.1, nor exceed the temperature limits for exterior surfaces as defined in 32.2.19.

32.1.2 Equipment intended to be used in an enclosure shall be tested in a representative enclosure.

32.1.3 The temperature test may be made at any ambient temperature, within the range of 10 – 40°C. It shall be assumed that the temperature rise is the same for all ambient temperatures between the limits of 10 and 40°C. The ambient temperature shall be measured by means of several thermometers or thermocouples placed at different points around the apparatus at a distance of 3 to 6 feet (1 to 2 m) and protected from drafts and abnormal heat radiation. Thermometers or thermocouples shall be located in the path of the cooling medium. The value to be adopted for the ambient temperature during a test is the mean of the readings of the thermometers or thermocouples taken at equal intervals of time during the last quarter of the duration of the test. When the ambient temperature is subject to variations that result in errors in taking the temperature rise, the thermometers (for determining the ambient temperatures) are to be immersed in a liquid such as oil in a heavy metal cup. Thermocouples used to measure ambient temperatures shall be attached to metal plates, or submerged in liquid as described for thermometers.

32.1.4 A convenient form for such an oil cup consists of a metal cylinder with a hole drilled partly through it. This hole is filled with oil and the thermometer is placed therein with its bulb well immersed. The response of the thermometer to various rates of temperature change depend largely upon the size, kind of material, and mass of the containing cup and is to be further regulated by adjusting the amount of oil in the cup. The larger the apparatus under test, the larger the metal cylinder employed as an oil cup in the determination of the cooling air temperature is to be. The smallest size of oil cup employed in any case shall consist of a metal cylinder 25 mm (1 inch) in diameter and 50 mm (2 inch) high. A convenient form for a metal plate used for a thermocouple measuring ambient temperature is a solid copper bus, measuring 25.4 mm (1 inch) by 25.4 mm (1 inch) by 3 mm (0.12 inch) thick.

Table 32.1
Maximum Acceptable Temperature Rises

Part, material, or place of temperature measurements[h]	Maximum rise, K
1. Rubber- or thermoplastic-insulated conductors[a,b]	35
2. Field-wiring terminals for medium voltage conductors[c]	50
3. Field-wiring terminals for low voltage conductors	
Equipment marked for use with 60°C or 60/75°C wire	50
Equipment marked for use with 75°C wire	65
4. Buses and connecting straps[d]	65
5. Class 105 insulation systems	
Thermocouple method	65
Resistance method	85
6. Class 130 insulation systems	
Thermocouple method	85
Resistance method	105
7. Class 155 insulation systems	
Thermocouple method	95
Resistance method	115
8. Class 180 insulation systems	
Thermocouple method	115
Resistance method	140
9. Class 200 insulation systems	
Thermocouple method	135
Resistance method	160
10. Class 220 insulation systems	
Thermocouple method	150
Resistance method	180
11. Class 240 insulation systems	
Thermocouple method	165
Resistance method	200
12. Class 105 insulation system on single-layer series coil with exposed surfaces either uninsulated or enameled, thermocouple method	90

Table 32.1 Continued on Next Page

Table 32.1 Continued

Part, material, or place of temperature measurements[h]		Maximum rise, K
13.	Phenolic composition[a]	125
14.	On bare resistor material	
	Thermocouple method	375
15.	Capacitor	e
16.	Power switching semiconductor	f
17.	Printed wiring board	g

[a] The limitation on phenolic and on rubber and thermoplastic insulation does not apply to compounds that have been investigated and found to have special heat-resistant properties.

[b] For standard insulated conductors other than those mentioned in item 1, and the maximum allowable temperature rise is not to exceed the rated maximum operating temperature of the wire in question minus an assumed ambient (room) temperature 40°C.

[c] The temperature on a wiring terminal or lug is measured at the point most likely to be contacted by the insulation of a conductor installed as in actual service.

[d] The limit does not apply to connections to a source of heat, such as resistors, current elements of overload relays, and contacts.

[e] For a capacitor, the maximum acceptable temperature rise is the marked temperature limit of the capacitor minus an assumed ambient temperature of 40°C.

[f] The maximum acceptable temperature rise on the case is the maximum junction temperature for the applied power dissipation recommended by the semiconductor manufacturer minus an assumed ambient of 40°C for an enclosed device and 50°C for an open device.

[g] The maximum acceptable temperature rise of the printed-wiring board is the maximum rated temperature of the printed wiring board minus an assumed ambient of 40°C.

[h] Alternatives to the thermocouple method may be used in accordance with 32.2.25.

32.2 Test conditions

32.2.1 The temperature test shall be conducted using the maximum continuous current intended for the device.

32.2.2 To determine whether the equipment complies with the temperature test requirements, the device is to be operated under intended operating conditions and is to carry its rated current continuously at the rated test potential. The frequency of the supply voltage shall be equal to the rated supply frequency. For devices rated both 50 and 60 Hz and containing no iron-core components (such as reactors or transformers), testing at 60 Hz may be considered representative of testing at 50 Hz, but not vice versa.

Exception: Circuits that do not have a continuous current rating (such as circuits that only carry current for charging bus capacitors prior to normal operation of the equipment), shall be operated under the duty cycle for these circuits as defined by the manufacturer until temperatures are stabilized. In this case, thermal equilibrium is to be considered to exist when three successive readings of the maximum temperature in each cycle indicate no change in temperature greater than 1°C, and do not indicate an upward trend.

32.2.3 The test shall be continued until maximum temperatures are attained. Thermal equilibrium is to be considered to exist when three successive readings indicate no change in temperature greater than 1°C, and do not indicate an upward trend. Readings shall be taken at the end of consecutive equal periods, the duration of each interval being the longer of the following:

a) 15 minutes; or

b) 10 percent of the previously elapsed duration of the test.

32.2.4 The recorded temperature shall be the highest of the three readings.

32.2.5 The equipment is to be tested with not less than 4 feet (1.2 m) of copper wire attached to each field-wiring terminal. The wire is to be of the smallest size having an ampacity of at least 125 percent of the test current for motor loads and at least 100 percent for other loads. Conductor ampacities shall be determined in accordance with Table 32.2. When the terminal is not capable of receiving the size of wire required for testing in accordance with 32.2.1, or when the device is marked to limit the size of wire, the maximum allowable wire size is to be used. Smaller conductor sizes may be used at the manufacturer's option.

Table 32.2
Insulated Copper Conductor Ampacities – Temperature Test

Conductor size		2001 – 5000 V conductors	5001 – 150,000 V conductors
AWG – kcmil	(mm^2)		
8	(8.4)	64	–
6	(13.3)	85	90
4	(21.1)	110	115
2	(33.6)	145	155
1	(42.4)	170	175
1/0	(53.5)	195	200
2/0	(67.4)	220	230
3/0	(85.0)	250	260
4/0	(107)	290	295
250	(127)	320	325
350	(177)	385	390
500	(253)	470	465
750	(372)	585	565
1000	(497)	670	640

32.2.6 When testing an assembly containing two or more motor controllers, the incoming conductors shall have an ampacity equal to the sum of the full load current rating of all the motor controllers plus 25 percent of the highest rated motor controller in the group.

32.2.7 A single or three phase source of supply of any convenient voltage may be used for temperature tests on parts other than coils, heaters, or the like. The test on all parts shall be made simultaneously.

32.2.8 Anti-condensation heaters, representative of the maximum wattage rating to be provided shall be installed and energized at their rated voltage during the temperature test, unless the anti-condensation heaters are automatically de-energized when the equipment is energized.

32.2.9 Any control transformers are required to be energized unless the transformer heat loss is simulated by an equivalent heat source representing the largest transformer available.

32.2.10 When equipment is intended for use with a horizontal bus, the temperature test shall be conducted using a representative length of horizontal bus, consisting of a length long enough to pass through one vertical section that includes one or more bus connecting joints.

32.2.11 For the temperature test, the equipment shall be loaded as follows:

a) A current equal to the horizontal bus rating shall be passed through the incoming section of bus;

b) Each controller in a vertical section shall be loaded to the maximum rated current; and

c) The remainder of the current shall be passed through the outgoing section of the horizontal bus. When agreeable to those concerned, the horizontal and vertical bus structures is to be energized from separate sources.

32.2.12 When a range of horizontal busses are available or in the case of a tapered bus, the bus bar or section of tapered bus having the maximum current density is representative of the range of horizontal busses or other sections of the tapered bus.

32.2.13 In a device employing motor circuit fuses, live fuses shall be used during the temperature test. When a range of fuse ratings is applicable, the fuse rating having the highest power loss shall be used. These fuses shall not open during the temperature test.

32.2.14 An overload relay shall not trip during the temperature test.

32.2.15 The temperature rise of buses and connecting straps shall be determined. The limits specified do not apply to connections to a source of heat (for example, resistors, thermal heaters, fuses, and other components).

32.2.16 The temperature rise of field wiring terminals shall be determined.

32.2.17 Insulating materials, other than those listed in Table 32.1, are to be evaluated with respect to properties, such as flammability, arc-resistance, and other properties based on an operating temperature equal to the measured temperature rise plus 40°C.

32.2.18 Insulated cables passing through compartments having elevated ambients or through metal walls or partitions having magnetic properties are to be evaluated to determine that insulating materials are not adversely affected. See Section 18, Internal Wiring.

32.2.19 Parts handled by the operator in the normal course of his duties shall have no higher total temperature than 60°C. External surfaces accessible to an operator in the normal course of his duties shall have no higher total temperature on these surfaces than 70°C. External surfaces not accessible to an operator in the normal course of his duties shall have no higher total temperature on these surfaces than 110°C. The temperatures stated are based on a 40°C ambient. Surfaces more than 90 inches (229 cm) above the level of the floor or working platform are considered to be inaccessible to an operator in the normal course of his duties.

32.2.20 The temperature of all stationary parts shall be measured during the progress of the test. Temperatures of movable parts shall be taken during the test if practicable and, in any case, as soon after the completion of the test run as possible. When the temperature of a part is measured during the test, the temperature shall also be measured after the completion of the test run, and the highest figure obtained shall be used.

32.2.21 The temperature shall be determined in accordance with one of the methods in 32.2.22 – 32.2.25.

32.2.22 Thermometer Method – The temperature shall be determined by mercury or alcohol thermometers or by resistance thermometers. Thermometers shall not be used for the measurement of temperatures other than ambient.

32.2.23 Resistance Method – The temperature shall be determined by comparing the resistance of the winding after the temperature test with the resistance of the winding at a known temperature prior to the temperature test.

32.2.24 Thermocouple Method – The temperature shall be determined by thermocouples secured to the part being measured. When using the thermocouple method for measuring the temperature of any part, the following guide should be observed.

a) The junction of the thermocouple should be in contact with the point on the part of which the temperature is to be measured. Care should be used to keep the bare thermocouple wire from being twisted together ahead of the point of contact with the part, as this results in the effective junction being some distance from the part and results in errors.

b) Temperatures are to be measured using a temperature indicating instrument and thermocouples consisting of wires not larger than 24 AWG (0.21 mm^2) and not smaller than 30 AWG (0.05 mm^2). Whenever referee temperature measurements by thermocouples are required, thermocouples consisting of 30 AWG iron and constantan wire and a potentiometer-type instrument are to be used.

c) When the part whose temperature is to be measured is a spring-loaded part, such as a movable contact, the thermocouple wire shall be small enough and arranged in such a manner that it does not materially affect the contact force.

d) The thermocouple junction should be firmly clamped, cemented, soldered, or peened to the part under test so that the part and the junction are at the same temperature.

e) When solder or cement is used to secure the thermocouple to the part under test, a minimum amount of this material is to be used so that it does not increase the thermal capacity or radiating ability of the part and thus affect its temperature.

f) Care should be taken to support the thermocouple firmly and to mount the point of contact to the part so that no cement or other material gets between the part being measured and the thermocouple.

g) When one or more thermocouples are connected directly to electrically energized parts, care shall be taken for safety and to prevent damage due to potential differences and grounds.

32.2.25 Other measurement methods – Other methods, such as temperature indicating labels, may be used when agreeable to all concerned, and when it can be demonstrated that these methods have accuracy comparable to that of the thermocouple method. This may require a reduction the maximum allowable measured temperatures to adjust for anticipated measurement inaccuracies when using temperature indicating labels.

32.2.26 Infrared thermal analysis may be used to determine maximum temperature locations for placement of thermocouples for the temperature test. Infrared thermal analysis shall not be used to determine acceptability of test results.

32.2.27 Thermocouples and related instruments are to be accurate and calibrated in accordance with good laboratory practice. The thermocouple wire is to conform with the requirements for special thermocouples as specified in the Initial Calibration for Thermocouples table in the Standard for Temperature Measurement Thermocouples, ANSI/ISA MC96.1-1982.

32.2.28 The resistance method consists of the determination of the temperature of a copper or aluminum winding by comparing the resistance of the winding at the temperature to be determined with the resistance at a known temperature, according to the formula:

$$\Delta t = \frac{R}{r}(k + t_1) - (k + t_2)$$

in which

Δt is the temperature rise,

R is the resistance of the coil at the end of the test,

r is the resistance of the coil at the beginning of the test,

t_1 is the ambient temperature in °C at the beginning of the test

t_2 is the ambient temperature in °C at the end of the test, and

k is 234.5 for copper, 225.0 for electrical conductor grade (EC) aluminum. Values of the constant for other grades shall be determined.

32.2.29 When it is required to de-energize the winding before measuring *R*, the value of *R* at shutdown is to be determined by taking several resistance measurements at short intervals beginning as quickly as possible after the instant of shutdown. A curve of the resistance values and the time is then to be plotted and extrapolated to give the value of *R* at shutdown.

33 Dielectric Voltage-Withstand Test

33.1 General

33.1.1 Equipment shall withstand for 1 minute without breakdown the application of a potential:

a) Between any uninsulated live parts and the walls of a metal enclosure including fittings for conduit or armored cable;

b) Between isolated secondary circuit uninsulated live parts, involving potential in excess of 30 V ac or 42.4 V peak, and any uninsulated live parts and the walls of a metal enclosure including fittings for conduit or armored cable; and

c) Between primary circuit uninsulated live parts and isolated secondary circuit uninsulated live parts.

33.1.2 When the test position is obtained by means of a removable element, the test is to be conducted between the live parts of the isolating means and all parts of the removable element.

33.1.3 The applied potential shall be an essentially sinusoidal, 48 – 62 Hz voltage. The value of the test voltage shall be no less than the rated dielectric voltage withstand rating of the equipment, and shall be no less than the values shown in Table 33.1. When the ac potential is not able to be applied due to leakage current conditions, a dc potential of 1.414 times the required AC dielectric voltage is to be applied.

Table 33.1
Test Voltages for Dielectric Voltage-Withstand Test

Voltage rating	Test voltage
0 V – 50 V	500 V
Over 50 V – 600 V	1000 V plus (2 times nominal voltage rating)
Over 600 V to 15 kV	2000 V plus (2-1/4 times nominal voltage rating) or dielectric voltage rating of the equipment, whichever is higher
Over 15 kV to 27 kV	60 kV
Over 27 kV to 38 kV	80 kV

33.1.4 For definition of the applied wave shape, see Standard Techniques for High Voltage Testing, ANSI/IEEE 4-1978.

33.1.5 A device operating at under 30 V to ground that is galvanically isolated from all medium voltage circuits is not required to be tested in accordance with this section.

33.1.6 The isolating distance of the equipment shall be tested. The test potential shall be 110% of the voltage required in Table 33.1, and shall be applied:

a) Across the open contacts of the isolating distance; and

b) If the equipment has a test position obtained by means of a drawout element, across the open contacts of the isolating distance, with the drawout element in the test position, with the contacts of the drawout element open and closed.

33.2 Meters

33.2.1 When equipment includes a low voltage meter or meters, such instruments shall be disconnected from the circuit and the complete device subjected to a dielectric voltage-withstand test as indicated in 33.1.1. The meter or meters shall be tested separately for dielectric voltage-withstand, with an applied potential of 1000 V in the case of an ammeter, and 1000 V plus twice rated voltage in the case of any other instrument having a potential circuit. The test potential shall be applied between live parts and the mounting panel, including the meter face, zero adjuster, and so forth.

33.3 Test procedure

33.3.1 Other than as noted in 33.3.2, to determine whether equipment complies with the requirements in 33.1 and 33.2, the equipment is to be tested, by means of a 500 VA or larger capacity transformer, whose output is essentially sinusoidal and can be varied. The applied potential is to be increased from zero until the required test voltage is reached and held at that level for 1 minute. The increase in the applied potential is to be at a uniform rate and as rapidly as is consistent with its value being correctly indicated by a voltmeter.

33.3.2 A test transformer of less than 500 VA capacity may be used if the applied potential is measured at the output of the test transformer, either directly or through a potential transformer.

33.3.3 Care is to be taken not to apply a test voltage across the open contact of a vacuum interrupter that exceeds the manufacturer's recommendation to reduce the possibility of generating harmful x-radiation.

34 Switching Capability Test – Isolating Means

34.1 A controller employing a disconnect switch or mechanism, used to interrupt the magnetizing current of the control transformer, shall be subjected to 25 close-open operations of the disconnect device with the transformer connected in the intended manner. The voltage for this test shall be 110 percent of the maximum rated voltage of the controller. The control transformer mentioned above shall be the transformer having the largest magnetizing current intended to be used in the motor controller.

34.2 The controller structure and enclosure shall be connected to ground through a 3-A fuse with a voltage rating no less than the voltage rating of the equipment under test.

34.3 The fuse described in 34.2 shall not open and the device shall be capable of continuing the test program without servicing or replacement of parts.

34.4 When a disconnect switch is not interlocked to prevent opening when the control power transformer is providing secondary current, such a switch shall be the subject of an appropriate investigation. The investigation shall evaluate the ability of the disconnect switch to make and break the transformer primary current under the most adverse conditions.

34.5 This test is to be conducted at each rated input frequency.

35 Short Circuit Interruption Test

35.1 General requirements

35.1.1 A minimum of one sample of the representative model from each controller series is to be tested. Controller models are to be considered for testing and each representative model selected shall be subjected to only one short circuit test.

35.1.2 When a series of equipment uses solid state short circuit protection circuitry for compliance with this test, one model from the series may be considered representative of the entire series, based on the following:

a) The same solid state protection circuitry is used throughout the series;

b) Any revisions to the protection circuitry will require re-evaluation;

c) The protection circuitry will turn off the output devices (Insulated Gate Bi-polar Transistor (IGBT), bi-polar, and other output devices) prior to the time when the devices are damaged by any increase in current;

d) Any increase in current experienced by the output devices is the result of the DC bus capacitor bank discharging;

e) The output devices are turned off by the protection circuitry prior to any significant increase in the input current;

f) When relying on current sensing (as opposed to output device collector voltage sensing) to actuate the protection circuitry, either the DC bus or all main motor output lines shall be monitored; and

g) The basic construction of the various models is similar.

35.2 Interruption ratings

35.2.1 Tests shall be made to substantiate the short circuit rating of the equipment over the range of rated voltages, in accordance with 35.2.3 – 35.2.15. During the test the equipment shall meet the performance requirements of 35.2.2.

35.2.2 When tested in accordance with 35.2.3 – 35.2.15, a controller shall comply with the following:

a) The equipment shall successfully open the circuit. This may be by operation of a solid state short circuit protection circuitry that is subjected to the requirements in 53.1, or by an overcurrent protective device such as a motor circuit fuse or the like;

b) The controller shall be in substantially the same mechanical condition as at the beginning of the test, other than the opening of medium-voltage motor circuit fuses;

c) The cotton indicator described in 35.2.16 shall not ignite;

d) The ground conductor as described in 39.1.2 shall not have opened;

e) *Deleted*

f) Components containing oil shall not rupture so as to permit loss of oil;

g) The door or cover shall not be blown open during the test, and it shall be possible to open the door or cover in the intended manner at the conclusion of the test;

h) The isolating means of a controller shall be capable of being opened in its intended manner at the conclusion of the test;

i) There shall be no breakage of insulating bases to the extent that the integrity of the mounting of live parts is impaired;

j) Neither end of a motor circuit fuse shall be completely ejected from the mounting means, and no line end of a motor circuit fuse shall bridge from its mounting means to dead metal; and

k) If after a visual examination, there is any doubt as to the ability of the controller to carry rated current continuously, the controller shall comply with the requirements of the Temperature Test, Section 32, except that the total allowable temperature rise may be increased 10°C. For the purposes of this test, thermocouple need only be placed on current carrying parts in the vicinity of the contact structure.

35.2.3 For the short circuit interruption test the sample controller shall be mounted in a test enclosure that is representative of the size and construction of the smallest enclosure with which the controller is intended to be used. The line terminals shall be connected by bus bars or cables to the test circuit described in 35.2.8.

35.2.4 The load terminals of the controller under test shall be short-circuited by means of an appropriately rated switching device using bus bars or cables having a cross-section approximately equivalent to that of the load terminals and a length as short as practical.

35.2.5 All doors on the test enclosure shall be closed and secured by their latching or fastening means. No external padlocks or the like shall be used. The control circuit power may be derived from a separate supply source or from a transformer connected to the line side of the controller.

35.2.6 Other than as noted in 35.2.18, the test circuit shall have an available symmetrical short-circuit current at least equal to the interrupting rating of the equipment and shall comply with 35.2.7 through 35.2.12.

35.2.7 The test circuit, with the controller short-circuited at its line terminals shall be capable of producing a 3-phase short-circuit current based on the average of the current in the three phases – provided that the circuit components are such that the three currents are essentially equal – whose rms symmetrical value (that is, omitting any direct-current components) is at least equal to the interrupting rating of the controller. The test circuit shall be capable of producing this short circuit from the instant of initiation of the short-circuit to the instant of interruption. The test circuit may include current limiting reactors, resistors, and transformers in addition to the generating system. In setting up the test circuit, the leads between the reactors and the controllers shall be made as short as practicable so as to keep the capacitance to ground at the controller terminals small. No capacitance shall be added in the circuit. The normal-frequency recovery voltage, measured after interruption of the device under test, shall be not less than the rated voltage of the controller when measured in accordance with the Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, ANSI/IEEE C37.09.

35.2.8 Reactive components of the impedance in the line may be paralleled if of the air core type but no reactance shall be connected in parallel with resistance. Shunt resistance shall not be added to this circuit.

35.2.9 The power factor of the test circuit shall not exceed 0.05 lagging. The power factor shall be determined from the design constants of the generator and the measured alternating-current resistance and reactance of the remainder of the circuit, from oscillographic records, or by any other appropriate method.

35.2.10 The test shall be conducted with an input test frequency of 50 or 60 Hz. For controllers with rated input frequencies other than 50 or 60 Hz, the test shall be conducted at each rated frequency.

35.2.11 The circuit shall be tested and oscillograms shall be taken to record the three line currents and the three line-to-line voltages to assure compliance with 35.2.7 and 35.2.9.

35.2.12 Measurements of the currents shall be made on the calibration oscillograms. The available symmetrical short-circuit test current in each phase shall be the alternating current component as determined by drawing the envelope of the current wave measuring the peak-to-peak values at the appropriate instant and dividing them by 2.828 as illustrated in the Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, ANSI/IEEE C37.09. The total rms current at the times specified shall be determined in accordance with ANSI/IEEE C37.09.

35.2.13 The equipment test circuit shall be identical to the calibration test circuit, except that the short circuit shall be removed from the line terminals of the device. The short circuit for the test shall be initiated in accordance with 35.2.4, and the current shall be maintained until the circuit is interrupted by the controller.

35.2.14 The equipment structure shall be grounded in accordance with 39.1.2.

35.2.15 If the controller is intended to be used with more than one type or make of medium-voltage fuse, the test shall be conducted using the fuse having the highest let-through characteristics. The characteristics referred to are peak let-through current (I_p) and ampere-squared-seconds (I^2t).

35.2.16 A cotton pad shall completely cover any opening in a controller during the short-circuit interruption test. Close fitting seams and flanged joints are not to be considered openings. The cotton pad shall be secured to the outside of the enclosure so as not to be dislodged during the test. At the option of the manufacturer, the cotton may be omitted from the test if all the following conditions are met:

a) Ventilation openings in the enclosure are located 12 or more inches from any components within the controller that may be affected by the test;

b) There is no visible flame, smoke, or arc emitted from the controller during the test; and

c) At the conclusion of the test, the controller is fully functional and visual examination of the controller reveals no evidence of any arcing byproducts within the controller.

In the event that there is any doubt of compliance with (b) or (c), the test may be considered inconclusive, and the test repeated with the cotton in place to determine compliance.

35.2.17 During the test oscillograms shall be taken to indicate the following information:

a) Line-to-line voltages of all three phases before, during and immediately following the short-circuit.

b) Currents through controller during test.

35.2.18 The test may be conducted using a test circuit that provides an available short circuit current less than the rated short circuit current of the controller, but not less than 5 kA, when all of the following conditions are met:

a) The controller uses solid state protection circuitry that turns off the output devices and similar devices prior to the time in which the devices are damaged by an increase in current as calculated from manufacturer's ratings of the output devices, and as demonstrated by this test;

b) Any increase in output current is the result of discharging of the DC bus capacitors;

c) The output devices are turned off by the protection circuitry prior to any collapse of the input voltage;

d) Other than allowed under (e), branch circuit devices in the input circuit do not trip or open;

e) At the option of the manufacturer, the test may be conducted with a device in addition to the required branch circuit protection on the line side of the equipment under test. This device may be responsive to a trip signal provided by fault detection circuitry within the equipment under test. Under this condition, the branch circuit devices shall not trip or open during the test, but the additional device may open or trip to terminate the test when signaled by the fault detection circuitry;

f) When the internal protection circuitry relies on current sensing (as opposed to output device collector voltage sensing) to activate the protection circuitry, either the DC bus voltage or all output motor lines are monitored;

g) It can be demonstrated, either by testing at higher levels of current or by engineering analysis, that in response to higher levels of current, the protection circuitry will respond in an equal or faster time than at lower levels of current; and

h) If solid state protective circuitry within the controller causes the termination of the test, this circuitry is subjected to the burn-in and diagnostic test requirements of Section 53.

35.3 Branch circuit short circuit protection requirements

35.3.1 Other than as noted in 35.3.5 and 35.3.6, equipment shall always be tested with branch circuit protection provided in accordance with the following:

a) If the branch circuit short circuit protection is intended to be provided by fuses only, the short circuit tests are to be conducted using fuses only. The equipment shall be marked in accordance with 49.1.

b) If the branch circuit short circuit protection is intended to be provided by a medium voltage circuit breaker only, the short circuit tests are to be conducted using a specific circuit breaker and protective relay combination. This specific combination of circuit breaker and protective relay shall be included in the instructions for the equipment. The equipment shall be marked in accordance with 49.2.

c) If the branch circuit short circuit protection is intended to be provided by fuses or by a medium voltage circuit breaker, the short circuit tests are to be conducted first with fuses, and also with a specific circuit breaker and protective relay combination. The equipment shall be marked in accordance with 49.3.

d) When the equipment is provided with solid state short circuit protection circuity that operates to terminate the short circuit test, no branch circuit short circuit protection is required during the test. In this case, the solid state short circuit protection circuity shall be subjected to the requirements of 53.1. The equipment shall be marked in accordance with 49.4.

e) At the manufacturer's option, the equipment may be provided with an auxiliary input device in series with the required branch circuit protection. This auxiliary input device may be used to terminate a test when signaled to open by fault protection circuitry that is an integral part of the drive under test. If this auxiliary input device is provided with internal overcurrent protection, the overcurrent protection shall be disabled during the test, or shall be rated to trip at higher current levels and longer time intervals than the required branch circuit protection.

35.3.2 Testing with fuses cannot be used to waive testing with circuit breakers or vice versa.

35.3.3 Fuses used in this test shall have a voltage rating at least equal to the input voltage rating of the controller and may have any current rating greater than that of the equipment.

35.3.4 Circuit breakers used in this test shall have a voltage rating at least equal to the input voltage rating of the controller, and any current rating greater than that of the equipment.

35.3.5 Equipment provided with internally mounted semiconductor type fuses need not be tested with branch circuit protection on the line side of the equipment when all of the following conditions are met:

a) The semiconductor fuses are internally mounted on the line side of the equipment, with no components other than conductors between the line terminals and the fuses;

b) The short circuit testing is conducted using a circuit capable of delivering no less than the rated short circuit current of the controller; and

c) The cotton indicators, as described in 35.2.16, are not omitted during the testing.

35.3.6 If the branch circuit short circuit protection is intended to be provided by an external circuit breaker only, the equipment may be tested without branch-circuit protection on the line side of the equipment when all of the following conditions are met:

a) Protection circuitry within the equipment detects the short-circuit condition and provides a signal to trip the external circuit breaker on the line side of the equipment;

b) The protection circuitry identified in (a) is subjected to the requirements of Section 53;

c) The equipment is marked in accordance with 49.6 and provided with instructions in accordance with 49.7;

d) The test voltage is maintained after the short-circuit is initiated and the trip signal is received, for no less than the time specified in the markings of 49.6, plus the 110% of the latency time of the protection circuit and signaling;

e) The short circuit testing is conducted using a circuit capable of delivering no less than the rated short circuit current of the controller; and

f) The cotton indicators, as described in 35.2.16, are not omitted during the testing.

36 Impulse Withstand Test

36.1 General

36.1.1 The medium voltage circuits of previously untested equipment shall be capable of withstanding voltage impulses as specified in 36.1 – 36.3, using a full-wave 1.2 × 50 microsecond impulse in accordance with the Standard Techniques for High-Voltage Testing, ANSI/IEEE 4-1978, and having a crest value equal to or greater than the rated impulse voltage of the equipment. The preferred rated impulse voltages are shown in Table 36.1. These values are preferred, and are not mandatory. Equipment may have impulse voltage ratings higher or lower than shown in Table 36.1. Lower rated impulse voltages may be applicable when appropriate surge suppression is provided in the equipment installation.

Table 36.1
Preferred Impulse Voltage Ratings

Rated voltage (v_u) of equipment, kV	Preferred Rated Impulse Voltage kV[a]
$1.5 < v_u \le 3.6$	30 or 45
$3.6 < v_u \le 7.2$	45 or 60
$7.2 \le v_u \le 15$	60 or 95
$15 \le v_u \le 27$	95 or 125
$27 \le v_u \le 38$	125 or 150

[a] The higher impulse voltage rating in each row correlates with the preferred impulse voltage rating for switchgear in the specific voltage range. Use of the lower impulse voltage rating may require application of transient reduction methods between the switchgear and the power conversion equipment in the final installation.

36.1.2 The test sample shall be subjected to a sequence of tests in accordance with 36.1.3 or 36.1.4 using one of the test methods described in 36.2.

36.1.3 For equipment provided with an isolating means, the sequence of tests shall be as follows:

a) For Test 1, the isolating means is to be closed, the medium-voltage motor circuit fuses and control circuit fuses are to be in place, and the test voltage is to be applied between the medium voltage input terminals and ground. For this test, all the input terminals are to be connected together, and all low voltage circuits are to be connected to ground during the test.

b) For Test 2, the isolating means is to be open and an impulse voltage of 110 percent of the rated impulse withstand voltage is to be applied in each phase individually between the contacts of the isolating means across the isolating gap. If the isolation means has provision for automatically grounding its load side when in the fully opened position, the test voltage is to be value specified under Test 1.

36.1.4 For equipment that is not provided with an isolating means, only one test is required. In this case, the medium-voltage motor circuit fuses and control circuit fuses are to be in place, and the test voltage is to be applied between the medium voltage input terminals and ground. For this test, all the input terminals are to be connected together, and all low voltage circuits are to be connected to ground during the test.

36.2 Impulse voltage withstand test methods

36.2.1 Method 1 (3×3 test procedure): This is the historic test method, and is included for reference purposes. It should not be used for impulse tests conducted after adoption of this standard. In each of these tests, three positive and three negative impulses shall be applied to each phase individually without causing a disruptive discharge, except as noted in 36.3.

36.2.2 Method 2 (3×9 test procedure): This method is preferred for new tests. In each of these tests, three positive and three negative impulses shall be applied to each phase individually without causing a disruptive discharge, except as noted in 36.3.

36.2.3 Method 3 (2/15 test procedure): This method is an alternate preferred test method for new tests. In each of these tests, fifteen positive and fifteen negative impulses shall be applied to each phase individually without causing a disruptive discharge, except as noted in 36.3.

36.2.4 Some insulating materials retain a charge after an impulse test, and for these cases care should be taken when reversing the polarity. To allow the discharge of insulating materials, the use of appropriate methods, such as the application of 3 impulses at about 80% of the test voltage in the reverse polarity before the test, is recommended.

36.3 Evaluation

36.3.1 The controller shall be considered to have passed the test if no disruptive discharge on non-self-restoring insulation occurs. A discharge that occurs through an integrally connected surge arrester is acceptable (see 36.3.5).

36.3.2 Test method 1, 3×3 test procedure: If a disruptive discharge occurs on only one test during any group of three consecutive tests, three more tests shall be made. If the equipment successfully withstands all three of the second group of tests, the flashover in the first group shall be considered a random flashover, and the controller shall be considered as having successfully completed the test.

36.3.3 Test method 2, 3×9 test procedure: If a disruptive discharge occurs on only one test during any group of three consecutive tests, nine more tests shall be made. If the equipment successfully withstands all nine of the second group of tests, the flashover in the first group shall be considered a random flashover, and the controller shall be considered as having successfully completed the test.

36.3.4 Test method 3, 2/15 test procedure: The controller shall be considered as having successfully completed the test if the following conditions are fulfilled:

a) Each group has at least 15 tests.

b) The number of disruptive discharges does not exceed two for each complete group.

c) No disruptive discharges on non-self-restoring insulation occur. This is confirmed by 5 consecutive impulse withstands following the last disruptive discharge.

This procedure leads to a maximum possible number of 25 impulses per group.

36.3.5 When flashover occurs at an integrally mounted surge arrester, the surge arrester shall be disconnected from the equipment, and additional Impulse Withstand Tests shall be conducted on the equipment. The crest value of the additional tests shall be equal to or greater than the crest value at which the surge arrester begins to conduct. The entire test sequence shall be conducted at this lower crest value in accordance with 36.1 – 36.3.

37 Calibration Tests – Overload

37.1 Solid state overload protection shall comply with the Solid State Motor Overload Protection Test, Section 38.

37.2 When provided with a discrete overload relay, if the overload relay is not of the ambient compensated type, it shall be subjected to the Calibration Tests specified in the Standard for Industrial Control Equipment, UL 508, with the overload relay installed in the equipment during the tests.

38 Solid State Motor Protection Tests

38.1 Solid state motor overload protection test

38.1.1 Equipment that incorporates solid state motor overload protection circuitry shall have one sample of the series selected for testing. The selected test sample shall be mounted, connected, and operated as described in the Temperature Test, Section 32, and then subjected to the overload condition. The test shall be conducted with the equipment operating at an output frequency equal to the rated supply frequency, and also with the output frequency equal to the minimum rated operating frequency. Each test shall be conducted at the lowest and highest rated input frequencies of the controller, except a controller with an input frequency rating of both 50 and 60 Hz may be tested at either 50 or 60 Hz.

38.1.2 The solid state overload protection circuitry in the representative model shall operate as described in (a), (b), and (c). Operation of overload protection prior to reaching the 200 or 600 percent overload condition in tests (b) and (c) respectively is considered to comply with the requirements in (b) and (c) respectively.

a) The protection circuitry shall ultimately operate, when subjected to 100 percent of the maximum rated tripping current appropriate for the horsepower rating under test;

b) The protection circuity shall operate within 8 minutes when subjected to 200 percent of the maximum rated tripping current appropriate for the horsepower rating under test; and

c) The protection circuitry shall operate within 20 seconds when subjected to 600 percent of the maximum rated tripping current appropriate for the horsepower rating under test.

38.1.3 The overloading of each controller shall be accomplished by one of the following methods:

a) The connection of an actual motor to the motor output terminals that can provide the necessary overload condition; or

b) The connection of a resistive or resistive-inductive load to the motor output terminals that can provide the necessary overload condition.

38.1.4 After the protection circuitry has operated under the overload conditions noted in 38.1.2, the controller shall still be electrically and mechanically operational.

38.1.5 Marking or instructions in accordance with 48.1 are required to indicate the overload ratings.

38.2 Thermal memory retention test (shutdown)

38.2.1 Equipment incorporating thermal memory retention shall have one sample of the series selected for this test. The equipment shall be connected to a supply of rated voltage and frequency. Equipment rated both 50 and 60 Hz may be tested at either frequency.

38.2.2 Starting from a state where the thermal memory is reset, the controller shall be operated as in 38.1.2(b) and the elapsed time between the start of the overload condition and the operation of the overload protection shall be recorded.

38.2.3 After the overload protection circuit operates to cause output current to cease, without removing power from the input to the controller, the controller shall be restarted and the same overload condition shall be applied. The time until operation of the overload protection shall be recorded. The elapsed time between the start of the overload condition and the operation of the overload protection shall be less than the value previously recorded in 38.2.2.

38.3 Thermal memory retention test (loss of power)

38.3.1 Equipment incorporating thermal memory retention shall have one sample of the series selected for this test. The equipment shall be connected to a supply of rated voltage and frequency. Equipment rated both 50 and 60 Hz may be tested at either frequency.

38.3.2 Starting from a state where the thermal memory is reset, the controller shall be operated as in 38.1.2(b) and the elapsed time between the start of the overload condition and the operation of the overload protection shall be recorded.

38.3.3 After the overload protection circuit operates to cause output current to cease, power shall be removed from the controller until all control logic functions cease to operate. This does not apply to circuits