UL 1741

STANDARD FOR SAFETY

Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

UL Standard for Safety for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741

Third Edition, Dated September 28, 2021

Summary of Topics:

This revision of UL 1741 dated May 19, 2023 includes the addition of requirements Arc-Fault Circuit Protection: Section 34A, 93.18, 94.1 and Appendix A.

Text that has been changed in any manner or impacted by ULSE'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 October 19, 2022 and April 12, 2023.

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UL 1741

Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

Before November 7, 2005, the title for UL 1741 was Standard for Inverters, Converters, and Controllers for Use in Independent Power Systems.

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Third Edition

September 28, 2021

This UL Standard for Safety consists of the Third edition including revisions through May 19, 2023.

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

NOTE – The user's attention is called to the possibility that compliance with this standard may require use of an invention covered by patent rights.

By publication of this standard, no position is taken with respect to the validity of this claim or of any such claim(s) or of patent rights in connection therewith. If a patent holder has filed a statement of willingness to grant a license under these rights on reasonable and nondiscriminatory terms and conditions to applicants desiring to obtain such a license, then details may be obtained from ULSE.

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INTRODUCTION

1 Scope

1.1 These requirements cover inverters, converters, charge controllers, and interconnection system equipment (ISE) intended for use in stand-alone (not grid-connected) or interactive (grid-connected) power systems. Interactive inverters, converters, and ISE are intended to be operated in parallel with an electric power system (EPS) to supply power to common loads.

1.2 For interactive equipment, these requirements are intended to supplement and be used in conjunction with the Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE 1547, and the Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547.1.

1.3 These requirements cover AC modules that combine flat-plate photovoltaic modules and inverters to provide AC output power for stand-alone use or interaction with the electric power system (EPS), commonly the electric utility grid, and power systems that combine other alternative energy sources with inverters, converters, charge controllers, and interconnection system equipment (ISE), in system specific combinations.

1.4 These requirements also cover power systems that combine independent power sources with inverters, converters, charge controllers, and interconnection system equipment (ISE) in system specific combinations.

1.5 The products covered by these requirements are intended to be installed in accordance with the National Electrical Code, NFPA 70.

1.6 These requirements also cover rapid shutdown equipment and systems.

2 Glossary

2.1 General

2.1.1 In the text of this standard, the term "unit" refers to any product covered by this Standard. For the purpose of this Standard, the definitions in 2.1.2 – 2.1.54 apply.

2.1.2 AC MODULE – The smallest complete unit that includes solar cells, optics, inverters, and other components, excluding tracking devices, intended to generate ac power from sunlight.

2.1.3 BARRIER – A part inside an enclosure that reduces access to a part that involves a risk of fire, electric shock, injury to persons, or electrical energy-high current levels.

2.1.4 BRANCH CIRCUIT – The portion of the building wiring system beyond the final overcurrent protective device in the power-distribution panel that protects the ac output of the field-wiring terminals in a permanently connected unit.

2.1.5 BYPASS SOURCE – A branch circuit or generator to which the load is connected when the power conversion portion of the inverter is not supplying power to the load.

2.1.6 CHARGE CONTROLLER – A device intended to control the charging process of storage batteries used in photovoltaic power systems.

2.1.7 CLASS 2 TRANSFORMER – A step-down transformer complying with the applicable requirements in the Standard for Low Voltage Transformers – Part 1: General Requirements, UL 5085-1, and the Standard for Low Voltage Transformers – Part 3: Class 2 and Class 3 Transformers, UL 5085-3.

2.1.8 CONTROL CIRCUIT – A circuit that carries low-voltage, limited-energy (LVLE) electric signals and not main power, voltage or current.

2.1.9 CONVERTER – A device that accepts ac or dc power input and converts it to another form of ac or dc power. For the purposes of this standard and unless otherwise specified, ac output converters intended to directly supply power to loads are to be subjected to all of the requirements for inverters.

2.1.10 DC GROUND FAULT DETECTOR/INTERRUPTER – A device that provides protection for photovoltaic arrays by detecting a ground fault and interrupting the fault path in the dc circuit.

2.1.11 DEGREE OF PROTECTION – The extent of protection provided by an enclosure against access to parts which involve a risk of injury to persons, ingress of foreign solid objects, and/or ingress of water as verified by standardized test methods.

2.1.12 DISCONNECT DEVICE – A device that disconnects the conductors of a circuit from a supply, source, utility, or load.

2.1.12A DOOR – A cover provided with a hinge and a hand-operable latch.

2.1.13 ELECTRIC POWER SYSTEM (EPS) – Equipment or facilities that deliver electric power to a load. The most common example of an EPS is an electric utility.

2.1.14 ENCLOSURE – A surrounding case constructed to provide a degree of protection against:

a) The accessibility of a part that potentially involves a risk of fire, electric shock or injury to persons, or

b) The risk of propagation of flame, sparks, and molten metal initiated by an electrical disturbance occurring within.

2.1.15 FIELD-WIRING LEAD – A lead to which a supply, load, or other wire is intended to be connected by an installer.

2.1.16 FIELD-WIRING TERMINAL – A terminal to which a supply, load, or other wire is intended to be connected by an installer.

2.1.17 FIXED UNIT – A unit that is intended to be permanently connected mechanically and electrically and only able to be detached by the use of a tool.

2.1.18 GRID SUPPORT UTILITY-INTERACTIVE INVERTER / GRID SUPPORT UTILITY-INTERACTIVE ISE – An inverter or ISE intended for use in parallel with an electric utility that complies with the advanced interconnection requirements in Supplement SA for Grid Support Utility-Interactive Equipment, and/or Supplement SB for Grid Support Utility-Interactive Inverters and Converters Based upon IEEE 1547-2018 and IEEE 1547.1-2020.

2.1.19 GROUNDED CONDUCTOR – A system or circuit conductor that is intentionally grounded.

2.1.20 GUARD – A part outside of the enclosure that reduces access to a component involving a risk of injury to persons. See Enclosures and Guards, Section 38.

2.1.21 INTERACTIVE EQUIPMENT – Generic reference for equipment that operates in parallel with an EPS. Some examples are; utility interactive, grid support utility-interactive or special purpose utility-interactive equipment including generation sources such as inverters, converters, or rotating generators. Another example is ISE that performs interconnection monitoring, protection and control that may be used in conjunction with DERs to address the requirements for interactive equipment.

2.1.22 INTERCONNECTION SYSTEM EQUIPMENT (ISE) – A component or system of components that performs protective and control functions used to interconnect a distributed resource to an EPS. ISE may be a control subassembly(s) of an inverter or non-inverter distributed energy resource (DER).

2.1.23 INVERTER – An electronic device that changes dc power to ac power.

2.1.24 ISLANDING PROTECTION – Protection against the continuous operation of the inverter and part of the utility load while isolated from the remainder of the electric utility system.

2.1.25 ISOLATED CIRCUIT – A circuit having an isolation transformer or isolating components such as optically or magnetically coupled devices.

2.1.26 ISOLATION TRANSFORMER – A transformer having its primary winding electrically isolated from its secondary winding and constructed so that there is no electrical connection – under normal and overload conditions – between the primary and secondary windings, between the primary winding and the core, or between separate adjacent secondary windings, where such connection results in a risk of fire or electric shock.

2.1.27 KNOCKOUT – A portion of the wall of an enclosure so fashioned that it is capable of being readily removed by a hammer, screwdriver, and pliers at the time of installation in order to provide an opening or hole for the attachment of an auxiliary device, raceway, cable, or fitting.

2.1.28 LIMITED-ENERGY (LE) CIRCUIT – An ac or dc circuit having a voltage not exceeding 1000 volts and the energy limited to 100 volt-amperes by:

a) The secondary winding of a transformer,

b) One or more resistors complying with 31.10, or

c) A regulating network complying with 31.11.

2.1.29 LIVE PART – An electrically conductive part within a unit that during intended use has a potential difference with respect to earth ground.

2.1.29A LOW-VOLTAGE COMPARTMENT – A portion of an enclosure that does not contain wiring or components operating above 1000 Vac or above 1500 Vdc and that is completely separated from any medium-voltage compartment by grounded metal barriers.

Note: It is acknowledged that other standards and codes may have different definitions and voltage limits for medium voltage.

2.1.30 LOW-VOLTAGE, LIMITED-ENERGY (LVLE) CIRCUIT – A circuit involving an ac voltage of not more than 30 volts rms (42.4 volts peak) or a dc voltage of not more than 60 volts and supplied by:

a) An inherently limited Class 2 transformer or a not inherently limited Class 2 transformer and an overcurrent protective device that is:

1) Not of the automatic reclosing type,

2) Trip-free from the reclosing mechanism, and

3) Not readily interchangeable with a device of a different rating or the device is marked in accordance with 67.7.

b) A combination of an isolated transformer secondary winding and one or more resistors or a regulating network complying with 31.11 that complies with all the performance requirements for an inherently limited Class 2 transformer or power source; or

c) A battery that is isolated from the primary circuit or a combination of a battery, including the battery charging circuit of a unit that is isolated from the primary circuit, and one or more resistors or a regulating network complying with 31.11.

2.1.31 MANUFACTURER-SPECIFIED EXTERNAL ISOLATION TRANSFORMER – A manufacturer-specified isolation transformer that is external to the product, but which is always required for proper operation of the product. For example, when an isolation transformer is required to prevent circulating ground current in installations that have a grounded conductor in the ac or dc input power circuit.

2.1.32 MAXIMUM INPUT SHORT-CIRCUIT CURRENT (I_{sc} MAX) – Absolute maximum prospective short circuit current that a DC port of the DUT is rated to have connected to it.

Note: This could be the short circuit from a PV array, battery or, energy storage device. For a PV source it would account for worst-case conditions of ambient temperature, irradiance, etc. For NEC compliant installation, this Maximum Input Short Circuit Current rating equates to 1.25 × I_{sc} of the PV array.

2.1.33 MAXIMUM SYSTEM VOLTAGE – The open-circuit voltage (Voc) of the photovoltaic module or panel multiplied by the temperature correction factor specified in Article 690.7 of the National Electrical Code, ANSI/NFPA 70, for crystalline and multi-crystalline silicon photovoltaic modules and panels. The maximum system voltage is equal to the Voc for amorphous silicate and thin film photovoltaic modules and panels.

2.1.33A MEDIUM VOLTAGE – Voltage above 1000 Vac or above 1500Vdc.

Note: It is acknowledged that other standards and codes may have different definitions and voltage limits for medium voltage.

2.1.33B MEDIUM VOLTAGE COMPARTMENT – A portion of an enclosure that contains any wiring or component operating at medium voltage.

2.1.33C MEDIUM VOLTAGE DOOR – A door that provides access to insulated or uninsulated medium voltage components, equipment or wiring, other than those in individual grounded metal enclosures.

2.1.34 OPEN-CIRCUIT VOLTAGE (Voc) – The maximum no load output voltage of a photovoltaic module or panel at standard test conditions (STC). See 2.1.49.

2.1.35 PERMANENTLY CONNECTED UNIT – A unit connected to the electrical supply by means other than a supply cord and an attachment plug.

2.1.36 POWER CONNECTOR – A single conductor or multiple conductor, cable mounted or chassis (bulkhead) mounted connector that carries the main input or output power of the device under test. Connectors used for control, communication or data signals or cables carrying limited power for these devices are not considered power connectors.

2.1.37 PRESSURE TERMINAL CONNECTOR – A terminal that accomplishes the connection of one or more conductors by means of pressure without the use of solder. Examples of pressure terminal connectors are:

a) Barrel and setscrew type,

b) Crimp-type barrel, or

c) Clamping plate and screw type.

2.1.38 PRIMARY CIRCUIT – Wiring and components that are conductively connected to a branch circuit.

2.1.39 PULSE-WIDTH MODULATED (PWM) CHARGING – A charge control method that enables the photovoltaic current to bring the battery voltage to constant voltage type regulation using pulse width modulated control by setting the voltage regulation reconnect (V_{rr}) setpoint photovoltaic array closer to the disconnect (V_r) using pulse-width-modulated control circuitry. Based on the rate of switching, the overall current is able to taper similar to the constant voltage type regulation.

2.1.40 PV MODULES WITH INTEGRATED ELECTRONICS (PVIE) – A PV module with electronics physically connected.

2.1.41 RISK OF ELECTRICAL ENERGY- HIGH CURRENT LEVEL – The capability for damage to property or injury to persons, other than by electric shock, from available electrical energy existing between a live part and an adjacent dead metal part or between live parts of different polarity, where there is a potential of 2 volts or more and:

a) An available continuous power level of 240 volt-amperes or more, or

b) A reactive energy level of 20 joules or more.

For example, a tool, or other metal, short-circuiting a component that is able to result in a burn or a fire when enough energy is available at the component to vaporize, melt, or more than warm the metal.

2.1.42 SAFETY CIRCUIT – Any primary or secondary circuit that is used to reduce the risk of fire, electric shock, injury to persons, or electrical energy – high current levels. A safety interlock circuit, for example, is a safety circuit.

2.1.43 SAFETY INTERLOCK – A means relied upon to reduce the accessibility to an area that involves a risk of electric shock, electrical energy – high current levels, or injury to persons until the risk has been removed, or to automatically remove the risk when access is gained.

2.1.44 SECONDARY CIRCUIT – A circuit supplied from a secondary winding of an isolation transformer.

2.1.45 SERIES CHARGE CONTROLLER – A control element for battery charging that is in series with a photovoltaic array and a battery. The control element usually operates in an on/off mode, a pulse-width modulated (PWM) mode, or a linear control mode. The control element is usually a solid state switching device or a mechanical relay.

2.1.46 SERVICE PERSONNEL – Trained persons having familiarity with the construction and operation of the equipment and the risks involved.

2.1.47 SPECIAL PURPOSE INTERACTIVE INVERTER / CONVERTER / PRODUCT – An interactive inverter / converter / product evaluated for specific applications different from those where utility-interactive and grid support inverters are generally used. These units may have specific utility interconnection protection settings that allow them to provide specific interactive functions for a special application. These products may rely upon internal or external utility interconnection protection functions or devices, as identified for the particular product. External utility interconnection protection may be provided by means of utility protection relays as required by the local electric utility. IEEE 1547-2018 refers to this type of product as a Partially Compliant Product.

Note: Special purpose interactive products are intended for use in specific power production applications that export power to the electric utility. These units are often installed in power farm applications. These units may be evaluated for compliance to a subset of the published grid interconnection requirements and they may also include additional special purpose interactive features addressed through other documents, standards, and other functions that may be enabled in accordance with local utility interconnection protection requirements.

2.1.48 STAND-ALONE INVERTER – An inverter intended to supply a load and does not provide power back to the electric utility.

2.1.49 STANDARD TEST CONDITIONS (STC) – Test conditions consisting of:

a) 100 mW/cm^2 irradiance,

b) AM 1.5 spectrum, and

c) 25 °C (77 °F) cell temperature.

2.1.50 TOOL – A screwdriver, coin, key, or any other object that is usable to operate a screw, latch, or similar fastening means.

2.1.51 TOTAL HARMONIC DISTORTION (THD) – The ratio of the root-mean-square (rms) of the harmonic content to the root-mean-square value of the fundamental quantity, expressed as a percentage.

$$THD = [(\text{sum of squares of amplitudes of all harmonics})/(\text{square of amplitude of fundamental})]^{1/2} \times 100$$

2.1.52 UTILITY-INTERACTIVE INVERTER – An inverter intended for use in parallel with an electric utility to supply common loads and sometimes deliver power to the utility.

Note: This term is traditionally associated with products compliant with IEEE 1547-2003 and IEEE1547.1-2005.

2.1.53 VOLTAGE REGULATION (V_r) SETPOINT – The maximum battery voltage that a charge controller enables the battery to reach under charging conditioners. At this voltage the charge controller discontinues charging or begins to minimize the charging current to the battery.

2.1.54 VOLTAGE REGULATION RECONNECT (V_{rr}) SETPOINT – The battery voltage at which the charge controller reconnects the array to the battery when it has been disconnected at the V_r setpoint.

2.2 PV rapid shutdown equipment and systems

2.2.1 ATTENUATE OR ATTENUATED – To reduce either the voltage or current, or both, in controlled conductors resulting in a reduction of the respective magnitudes and a reduction in available energy to levels as specified in sections of this standard where the function is required. The attenuation or attenuation equipment as specified in this standard may use active electronic circuits or dissipative methods that are switched or permanently connected.

2.2.2 CONTROLLED CONDUCTOR(S) – PV system conductors that are subject to the Rapid Shutdown System requirements in Section 690.12 of the NEC (NFPA 70). Controlled conductors may include PV source and PV output conductors, PV input conductors to an inverter, ac output conductors of an inverter, input and output conductors of a charge controller (CC) and conductors connected to an energy storage system that is directly connected to a PV dc source.

2.2.3 CONTROLLED STATE – A condition related to Controlled Conductors under which the voltage, volt-amperes, and currents on the conductors adhere to the rapid shutdown safety specifications of this standard when the rapid shutdown is activated.

2.2.4 INITIATION DEVICE(S) or INITIATOR(S) – One or more manual or automatic switching device(s), input port(s) or signal(s) that will result in the activation of the rapid shutdown system function(s).

2.2.5 NOMINAL OPERATING CELL TEMPERATURE (NOCT) – The equilibrium cell junction temperature corresponding to nominal module service operating conditions in a reference environment of 80 mW/cm^2 irradiance, 20 °C (68 °F) ambient air temperature, 1 m/s wind across the module from side to side, an electrically open circuit, and a mounting method in accordance with the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703.

2.2.6 PV RAPID SHUTDOWN EQUIPMENT (PVRSE) – Equipment intended to be used in a PVRSS to initiate, disconnect, isolate or attenuate the controlled conductors of a PV system.

2.2.7 PV RAPID SHUTDOWN SYSTEM (PVRSS) – System consisting of PVRSE intended to initiate, in addition to disconnect, isolate or attenuate the controlled conductors of a PV system.

2.2.8 RAPID SHUTDOWN TIME LIMIT – The rated time limit that a PVRSE or PVRSS takes to achieve the required level in Section 98.1. The rated time limit of a PVRSS shall not exceed the limit defined in Section 690.12 of the NEC (NFPA 70).

Note: NEC 690.12 specifies the response time as no greater than 30 seconds in the 2017 NEC and 2014 NEC as amended by TIA 14-10 log number 1223 dated August 13, 2016.

2.2.9 RESET DEVICE – A device used to return the PVRSS to its normal state.

2.2.10 SIMULTANEOUSLY – For the purpose of testing within this standard, the term simultaneously indicates that multiple switching events will all occur with no intentional delay. Test circuits shall be designed to minimize temporal switching event differences.

2.2.11 STATUS INDICATOR – Visual indicator located at an initiation device or other location showing a visual confirmation to the operator that the rapid shutdown command has been effectively implemented.

3 Components

3.1 Except as indicated in 3.2, a component of a product covered by this standard shall comply with the requirements for that component. See Annex A for a list of standards covering components commonly used in the products covered by this Standard.

3.2 A component is not required to comply with a specific requirement that:

a) Involves a feature or characteristic not required 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 A component shall be used in accordance with its rating established for the intended conditions of use.

3.4 Specific components are incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions.

4 Units of measurement

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

5 References

5.1 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.

CONSTRUCTION

6 General

6.1 A unit intended to operate at rated voltages of 50 volts or less shall operate as intended in both grounded and ungrounded circuits.

6.2 Converters shall be subjected to all of the requirements for inverters.

7 Frame and Enclosure

7.1 General

7.1.1 A unit shall be provided with an enclosure that houses all current-carrying parts. The enclosure shall protect the various parts of the unit against mechanical damage from forces external to the unit. The parts of the enclosure that are required to be in place to comply with the requirements to reduce the risk of fire, electric shock, injury to persons shall comply with the applicable enclosure requirements specified in this Standard.

7.1.2 The frame or chassis of a unit shall not be relied upon to carry current during normal operation.

Exception: As provided in the Exception to 22.12.

7.1.3 A part, such as a dial or nameplate that is a part of the enclosure shall comply with the enclosure requirements.

7.1.4 An enclosure other than a Type 1 (indoor use only) shall comply with Environmental Rated Enclosures, Section 7.9, or the requirements for the respective Type in the Standard for Enclosures for Electrical Equipment, UL 50.

7.1.5 Sheet-metal screws threading directly into metal shall not be used to attach a cover, door, or other part that is to be removed to install field wiring or for operation of the equipment. Machine screws, self-tapping machine screws, and thread forming screws are able to thread directly into sheet-metal when they allow for at least two full threads of screw engagement.

7.1.6 Sheet-metal screws mounting internal components that are not removed for installation or operation are able to thread directly into metal.

7.1.7 All medium voltage wiring and components shall be completely enclosed by grounded metal enclosures or metallic raceway, with the exception of viewing panes and ventilation openings. Polymeric enclosures shall not be used for enclosing medium voltage wiring or components.

Exception: Shielded medium voltage wiring may be exposed in units rated only for installation in restricted areas which are not in general access areas.

7.2 Access covers

7.2.1 For a unit used as a load center, a cover that gives access to a fuse or other overload-protective device, the functioning of which requires renewal shall be hinged. A hinged cover is also required for a unit when it is required to open the cover in connection with normal operation of the unit. The cover shall not depend solely upon screws or other similar means requiring the use of a tool to hold it closed; however, it shall be provided with a spring latch or catch, or a hand operable captive fastener. Live parts shall not be accessible when the cover is open.

Exception No. 1: A cover is not required to be provided with a hinge when the only overload-protective devices enclosed are:

a) Supplementary types in control circuits and the protective device and the circuit loads are within the same enclosure,

b) Supplementary types rated 2 amperes or less for loads not exceeding 100 volt-amperes,

c) Extractor fuses having an integral enclosure, or

d) Protective devices connected in a low-voltage, limited-energy (LVLE) circuit.

Exception No. 2: A cover is not required to be provided with a hinge for an enclosure that contains no user-serviceable or -operable parts and which is provided with a marking in accordance with 67.6.

7.2.2 With reference to 7.2.1, a door or cover giving access to a fuse shall comply with the requirements for doors and covers, in the Standard for Industrial Control Equipment, UL 508.

7.2A Doors for medium voltage equipment

7.2A.1 Doors providing access to live medium voltage components, equipment or wiring shall be interlocked to prevent opening the door when medium voltage parts are energized. This interlocking shall comply with Interlocking of Medium Voltage Equipment, Section 15A.

7.3 Cast metal enclosures

7.3.1 The thickness of cast metal for an enclosure shall not be less than indicated in Table 7.1.

Exception: Cast metal of lesser thickness is usable where the enclosure complies with Compression Test, Section 63.

Table 7.1
Thickness of Cast-Metal Enclosures

Use, or dimension of area involved	Minimum thickness, mm (inch)			
	Die-cast metal		Cast metal other than die-cast type	
Area of 154.8 cm^2 (24 in^2) or less and having no dimension greater than 152 mm (6 inches)	1.6[a]	(1/16)	3.2	(1/8)
Area greater than 154.8 cm^2 (24 in^2) or having any dimension greater than 152 mm (6 inches)	2.4	(3/32)	3.2	(1/8)
At a threaded conduit hole	6.4	(1/4)	6.4	(1/4)
At an unthreaded conduit hole	3.2	(1/8)	3.2	(1/8)

[a] The area limitations for metal 1.6 mm (1/16 inch) thick are attainable by the provision of reinforcing ribs subdividing a larger area.

7.4 Sheet metal enclosures

7.4.1 The thickness of a sheet-metal enclosure shall not be less than that specified in Table 7.2 and Table 7.3; however, uncoated steel shall not be less than 0.81 mm (0.032 inch) thick, zinc-coated steel shall not be less than 0.86 mm (0.034 inch) thick, and nonferrous metal shall not be less than 1.14 mm (0.045 inch) thick at points at which a wiring system is to be connected.

Exception: Sheet metal of lesser thickness is usable where the enclosure complies with Compression Test, Section 63.

7.4.2 With reference to Table 7.2 and Table 7.3, a supporting frame is a structure consisting of angles, channels, or folded rigid sections of sheet metal that is rigidly attached to and has similar outside dimensions as the enclosure surface and that has the torsional rigidity to resist the bending moments that result when the enclosure surface is deflected. A construction that has equivalent reinforcing is one that is as rigid as one built with a frame of angles or channels.

Table 7.2
Thickness of Sheet Metal for Enclosures, Carbon Steel or Stainless Steel

Without supporting frame[a]				With supporting frame or equivalent reinforcing[a]				Minimum thickness, mm (inch)			
Maximum width,[b]		Maximum length,[c]		Maximum width,[b]		Maximum length,[c]					
cm	(inch)	cm	(inch)	cm	(inch)	cm	(inch)	Uncoated		Coated	
10.2	(4.0)	Not limited		15.9	(6.25)	Not limited		0.51[d]	(0.020)	0.58[d]	(0.023)
12.1	(4.75)	14.6	(5.75)	17.1	(6.75)	21.0	(8.25)				
15.2	(6.0)	Not limited		24.1	(9.5)	Not limited		0.66[d]	(0.026)	0.74[d]	(0.029)
17.8	(7.0)	22.2	(8.75)	25.4	(10.0)	31.8	(12.5				
20.3	(8.0)	Not limited		30.5	(12.0)	Not limited		0.81	(0.032)	0.86	(0.034)
22.9	(9.0)	29.2	(11.5)	33.0	(13.0)	40.6	(16.0)				
31.8	(12.5	Not limited		49.5	(19.5)	Not limited		1.07	(0.042)	1.14	(0.045)
35.6	(14.0	45.7	(18.0)	53.3	(21.0)	63.5	(25.0)				
45.7	(18.0)	Not limited		68.6	(27.0)	Not limited		1.35	(0.053)	1.42	(0.056)
50.8	(20.0)	63.5	(25.0)	73.7	(29.0)	91.4	(36.0)				
55.9	(22.0)	Not limited		83.8	(33.0)	Not limited		1.52	(0.060)	1.60	(0.063)

Table 7.2 Continued on Next Page

Table 7.2 Continued

Without supporting frame[a]				With supporting frame or equivalent reinforcing[a]				Minimum thickness, mm (inch)			
Maximum width,[b]		Maximum length,[c]		Maximum width,[b]		Maximum length,[c]		Uncoated		Coated	
cm	(inch)	cm	(inch)	cm	(inch)	cm	(inch)				
63.5	(25.0)	78.7	(31.0)	88.9	(35.0)	109.2	(43.0)				
63.5	(25.0)	Not limited		99.1	(39.0)	Not limited		1.70	(0.067)	1.78	(0.070)
73.7	(29.0)	91.4	(36.0)	104.1	(41.0)	129.5	(51.0)				
83.8	(33.0)	Not limited		129.5	(51.0)	Not limited		2.03	(0.080)	2.13	(0.084)
103.4	(38.00	119.4	(47.0)	137.2	(54.0)	167.6	(66.0)				
106.7	(42.0)	Not limited		162.6	(64.0)	Not limited		2.36	(0.093)	2.46	(0.097)
119.4	(47.0)	149.9	(59.0)	172.7	(68.0)	213.4	(84.0)				
132.1	(52.0)	Not limited		203.2	(80.0)	Not limited		2.74	(0.108)	2.82	(0.111)
152.4	(60.0)	188.0	(74.0)	213.4	(84.0)	261.6	(103.0)				
160.0	(63.0)	Not limited		246.4	(97.0)	Not limited		3.12	(0.123)	3.20	(0.126)
185.4	(73.0)	228.6	(90.0)	261.6	(103.0)	322.6	(127.0)				

[a] See 7.4.2 and 7.4.3.

[b] The width is the smaller dimension of a rectangular sheet metal piece that is part of an enclosure. In some cases, adjacent surfaces of an enclosure have supports in common and are made of a single sheet.

[c] "Not limited" applies only where the edge of the surface is flanged at least 12.7 mm (1/2 inch) or fastened to adjacent surfaces not normally removed in use.

[d] Sheet steel for an enclosure intended for outdoor use shall not be less than 0.86 mm (0.034 inch) thick for coated metal and not less than 0.81 mm (0.032 inch) thick for uncoated metal.

Table 7.3
Thickness of Sheet Metal for Enclosures, Aluminum, Copper, or Brass

Without supporting frame[a]				With supporting frame or equivalent reinforcing[a]				Minimum thickness,	
Maximum width[b],		Maximum length[c],		Maximum width[b],		Maximum length[c],			
cm	(inch)	cm	(inch)	cm	(inch)	cm	(inch)	mm	(inch)
7.6	(3.0)	Not limited		17.8	(7.0)	Not limited		0.58[d]	(0.023)
8.9	(3.5)	10.2	(4.0)	21.6	(8.5)	24.1	(9.5)		
10.2	(4.0)	Not limited		25.4	(10.0)	Not limited		0.74	(0.029)
12.7	(5.0)	15.2	(6.0)	26.7	(10.5)	34.3	(13.5)		
15.2	(6.0)	Not limited		35.6	(14.0)	Not limited		0.91	(0.036)
16.5	(6.5)	20.3	(8.0)	38.1	(15.0)	45.7	(18.0)		
20.3	(8.0)	Not limited		48.3	(19.0)	Not limited		1.14	(0.045)
24.1	(9.5)	29.2	(11.5)	53.3	(21.0)	63.5	(25.0)		
30.5	(12.0)	Not limited		71.1	(28.0)	Not limited		1.47	(0.058)
35.6	(14.0)	40.6	(16.0)	76.2	(30.0)	94.0	(37.0)		
45.7	(18.0)	Not limited		106.7	(42.0)	Not limited		1.91	(0.075)
50.8	(20.0)	63.5	(25.0)	114.3	(45.0)	139.7	(55.0)		
63.5	(25.0)	Not limited		152.4	(60.0)	Not limited		2.41	(0.095)
73.7	(29.0)	91.4	(36.0)	162.6	(64.0)	198.1	(78.0)		

Table 7.3 Continued on Next Page

Table 7.3 Continued

Without supporting frame[a]				With supporting frame or equivalent reinforcing[a]					
Maximum width[b],		Maximum length[c],		Maximum width[b],		Maximum length[c],		Minimum thickness,	
cm	(inch)	cm	(inch)	cm	(inch)	cm	(inch)	mm	(inch)
94.0	(37.0)	Not limited		221.0	(87.0)	Not limited		3.10	(0.122)
106.7	(42.0)	134.6	(53.0)	236.2	(93.0)	289.6	(114.0)		
132.1	(52.0)	Not limited		312.4	(123.0)	Not limited		3.89	(0.152)
152.4	(60.0)	188.0	(74.0)	330.2	(130.0)	406.4	(160.0)		

[a] See 7.4.2 and 7.4.3.

[b] The width is the smaller dimension of a rectangular sheet metal piece that is part of an enclosure. In some cases, adjacent surfaces of an enclosure have supports in common and are made of a single sheet.

[c] "Not limited" applies only where the edge of the surface is flanged at least 12.7 mm (1/2 inch) or fastened to adjacent surfaces not normally removed in use.

[d] Sheet copper, brass, or aluminum for an enclosure intended for outdoor use shall not be less than 0.74 mm (0.029 inch) thick.

7.4.3 With reference to 7.4.2 and Table 7.2 and Table 7.3, a construction does not have a supporting frame when it is:

a) An enclosure formed or fabricated from sheet metal,

b) A single sheet with single formed flanges or formed edges,

c) A single sheet that is corrugated or ribbed, or

d) An enclosure surface loosely attached to a frame, for example, by spring clips.

7.5 Nonmetallic enclosures

7.5.1 A polymeric enclosure or polymeric part of an enclosure shall comply with the requirements in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C. See 7.5.3.

Exception: A polymeric enclosure which complies with the Standard for Enclosures for Electrical Equipment, UL 50, is not required to be investigated for compliance with UL 746C.

7.5.2 Where an electrical instrument, such as a meter, forms part of the enclosure, the face or the back of the instrument housing, or both together, shall comply with the requirements for an enclosure.

Exception: A meter complying with the Standard for Electrical Analog Instruments – Panelboard Type, UL 1437, complies with this requirement.

7.5.3 The requirement in 7.5.1 does not apply to a nonmetallic part that forms part of the enclosure under any one of the following conditions:

a) The part covers an opening that has no dimension greater than 25.4 mm (1 inch) and the part is made of a material Classed as V-0, V-1, V-2, or HB, in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94,

b) The part is made of a material Classed V-0, V-1, V-2, or HB and covers an opening which does not give access to the user, when the part is removed, to live parts involving a risk of fire, electric shock, or electric energy-high current levels or moving parts.

c) The part covers an opening that has no dimension greater than 101.6 mm (4 inches) and the part is made of a material Classed as V-0, V-1, V-2, or HB, and there is no source of a risk of fire closer than 4 inches from the surface of the enclosure, or

d) The part is made of a material Classed V-0, V-1, V-2, or HB and there is a barrier or a device that forms a barrier made of a material Classed V-0 between the part and a source of a risk of fire.

Exception: A part of a component is not required to be Classed V-0, V-1, V-2, or HB when it complies with the flammability requirements applicable to the component. See Components, Section 3.

7.5.4 A nonmetallic enclosure intended for connection to a rigid conduit system shall comply with the Polymeric Enclosure Rigid Metallic Conduit Connection Tests in the Standard for Enclosures for Electrical Equipment, UL 50.

7.6 Openings covered by glass

7.6.1 Glass covering an opening shall comply with 7.6.2, shall be secured in place so that it is not readily displaced in service, and shall provide mechanical protection for the enclosed parts.

7.6.2 Glass for an opening:

a) Not more than 102 mm (4 inches) in any dimension shall not be less than 1.6 mm (1/16 inch) thick,

b) Glass for an opening other than described in (a) and not more than 929 cm^2 (144 square inches) in area and having no dimension greater than 305 mm (12 inches), shall not be less than 3.2 mm (1/8 inch) thick, and

c) Glass used to cover an area greater than described in (b) shall not be less than 3.2 mm thick and:

1) Shall be of a nonshattering or tempered type that, when broken, complies with the Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings, ANSI Z97.1-1984 (R1994), or

2) Shall withstand a 3.38 joules (2-1/2 ft-lbf) impact from a 50.8-mm (2-inch) diameter, 535 gram (1.18 pound) steel sphere without cracking or breaking to the extent that a piece is dislodged from its normal position.

7.6.3 Infrared viewports shall comply with the Outline of Investigation for Infrared Viewports, UL 50V.

7.7 Openings for wiring system connections

7.7.1 Where threads for the connection of conduit are tapped all the way through a hole in an enclosure wall, or where an equivalent construction is employed, there shall not be less than three, or more than five threads in the metal; and the construction of the enclosure shall be such that a conduit bushing is attachable as intended. Where threads for the connection of conduit are not tapped all the way through a hole in an enclosure wall, conduit hub, or a similar component; there shall not be less than 3-1/2 threads in the metal, and there shall be a smooth, rounded inlet hole for the conductors equivalent to that provided by a standard conduit bushing and the hole shall have an internal diameter that corresponds with the applicable trade size of rigid conduit.

7.7.2 Clamps and fasteners for the attachment of conduit, electrical metallic tubing, armored cable, nonmetallic flexible tubing, nonmetallic-sheathed cable, service cable, or equivalent, that are supplied as a part of an enclosure shall comply with the Standard for Conduit, Tubing, and Cable Fittings, UL 514B.

7.7.3 A knockout in a sheet-metal enclosure shall be secured and shall be removable without undue deformation of the enclosure.

7.7.4 A knockout shall be provided with a flat surrounding surface so a conduit bushing of the corresponding size seats as intended. A knockout intended to be used for installation purposes, shall be located so that installation of a bushing does not result in spacings between uninsulated live parts and the bushing of less than required in Spacings, Section 26.

7.7.5 In measuring a spacing between an uninsulated live part and a bushing installed in a knockout as specified in 7.7.4, it is to be assumed that a bushing having the dimensions specified in Table 5.4 is in place, in conjunction with a single locknut installed on the outside of the enclosure.

Table 5.4
Knockout or Hole Sizes and Dimensions of Bushings

Trade size of conduit,	Knockout or hole diameter		Bushing dimensions			
			Overall diameter		Height	
Inch	mm	(inch)	mm	(inch)	mm	(inch)
1/2	22.2	(7/8)	25.4	(1)	9.5	(3/8)
3/4	27.8	(1-3/32)	31.4	(1-15/64)	10.7	(27/64)
1	34.5	(1-23/64)	40.5	(1-19/32)	13.1	(33/64)
1-1/4	43.7	(1-23/32)	49.2	(1-15/16)	14.3	(9/16)
1-1/2	50.0	(1-31/32)	56.0	(2-13/64)	15.1	(19/32)
2	62.7	(2-15/32)	68.7	(2-45/64)	15.9	(5/8)
2-1/2	76.2	(3)	81.8	(3-7/32)	19.1	(3/4)
3	92.1	(3-5/8)	98.4	(3-7/8)	20.6	(13/16)
3-1/2	104.8	(4-1/8)	112.7	(4-7/16)	23.8	(15/16)
4	117.5	(4-5/8)	126.2	(4-31/32)	25.4	(1)
4-1/2	130.2	(5-1/8)	140.9	(5-35/64)	27.0	(1-1/16)
5	142.9	(5-5/8)	158.0	(6-7/32)	30.2	(1-3/16)
6	171.5	(6-3/4)	183.4	(7-7/32)	31.8	(1-1/4)

7.7.6 For an enclosure not provided from the factory with conduit openings or knockouts, spacings not less than the minimum required in this Standard shall be provided between uninsulated live parts and a conduit bushing installed at any location on the enclosure. Permanent marking on the enclosure, a template, or a full-scale drawing furnished with the unit is usable to limit such a location.

7.7.7 A plate or plug for an unused conduit opening or other hole in the enclosure shall have a thickness not less than:

a) 0.36 mm (0.014 inch) for steel or 0.48 mm (0.019 inch) for nonferrous metal for a hole having a 6.4-mm (1/4-inch) maximum dimension, and

b) 0.69-mm (0.027-inch) steel or 0.81-mm (0.032-inch) nonferrous metal for a hole having a 34.9-mm (1-3/8-inch) maximum dimension.

A closure for a larger hole shall have a thickness equal to that required for the enclosure of the unit or a standard knockout seal shall be used. Such plates or plugs shall be securely mounted.

7.7.8 An opening in an environmental rated enclosure shall be closed with components having the applicable environmental ratings as specified in Table 5.5.

Table 5.5
Openings in Environmental Rated Enclosures

Enclosure type	Openings shall be closed by components rated for enclosure types
2	2, 3, 3R, 3S, 4, 4X, 6, 6P, 12, 12K, 13
3	3S, 4, 4X, 6, 6P
3R	3, 3S, 4, 4X, 6, 6P
3S	3, 4, 4X, 6, 6P
4	4, 4X, 6, 6P
4X	4X
6	6, 6P
6P	6P
12, 12K	12, 12K, 13
13	13

7.8 Openings for ventilation

7.8.1 General

7.8.1.1 The enclosure of a unit shall be constructed to protect the unit against the emission of flame, molten metal, flaming or glowing particles, or flaming drops from the enclosure.

7.8.1.2 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.

7.8.2 Ventilation openings in enclosure bottoms

7.8.2.1 The requirement in 7.8.1.1 necessitates a complete noncombustible bottom or a construction employing individual noncombustible barriers as specified in Figure 5.1, under components, groups of components, or assemblies.

Exception No. 1: Ventilation openings provided in the bottom of an enclosure meet the intent of the requirement where noncombustible baffle plates are provided to obstruct or deflect materials from falling directly from the interior of the unit onto the supporting surface or other locations under the unit. An example of a baffle that meets the intent of this requirement is illustrated in Figure 5.2.

Exception No. 2: Ventilation openings provided in the bottom of an enclosure meet the intent of the requirement where the openings are covered by a perforated metal plate as described in Table 5.6, or where a galvanized or stainless steel screen having a 14- by 14-mesh per 25.4 mm (1 inch) constructed of wire with a diameter of 0.5 mm (0.018 inch) minimum is used.

Exception No. 3: The bottom of the enclosure under areas containing only materials Classed V-1 or better in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94, are able to have openings no larger than 6.4 mm (1/4 inch) square. Openings that are not square shall not have an area greater than 40 mm^2 (1/16 square inch).

Exception No. 4: Ventilation openings without limitation on their size and number that comply with 11.7 meet the intent of the requirement where the openings are only in the bottom panel in areas:

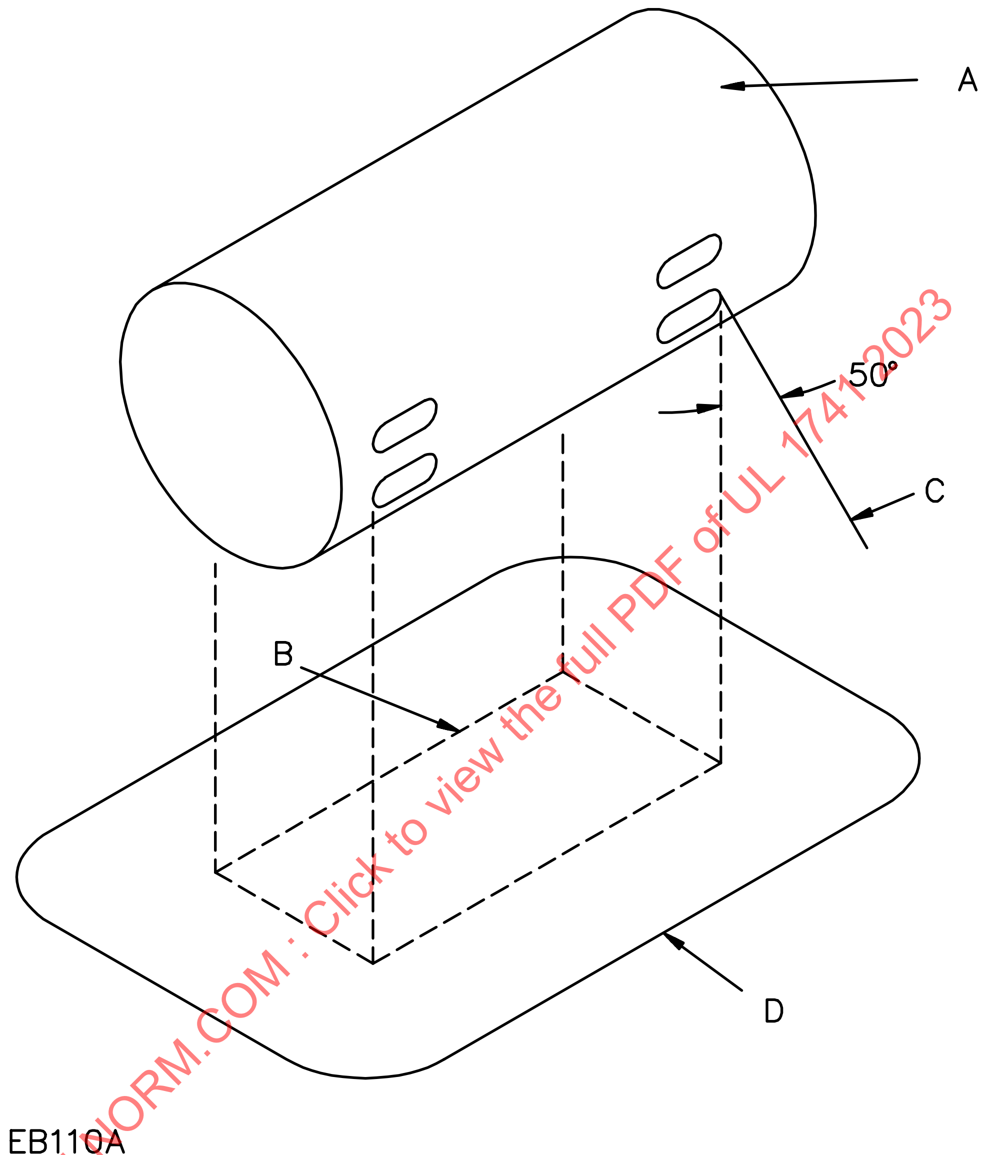
a) That contain only wires, cables, plugs, receptacles, and transformers, and

b) In areas that contain low-voltage, limited-energy (LVLE) circuits.

Exception No. 5: Ventilation openings are provided in the bottom of an enclosure meet the intent of the requirement where the openings incorporate an expanded metal mesh as described in 7.8.5.

Figure 5.1

Baffle Plates



NOTES –

A. The entire component under which a barrier (flat or dished with or without a lip or other raised edge) of noncombustible material is to be provided. The sketch (Figure 5.1) is of an enclosed component with ventilation openings showing that the protective barrier is required only for those openings through which flaming parts are able to be emitted. When the component or assembly does not have its own noncombustible enclosure, the area to be protected is the entire area occupied by the component or assembly.

B. Projection of the outline of the area of A that requires a bottom barrier vertically downward onto the horizontal plane of the lowest point on the outer edge D of the barrier.

C. Inclined line that traces out an area D on the horizontal plane of the barrier. Moving around the perimeter of the area B that requires a bottom barrier, this line projects at a 50-degree angle from the line extending vertically at every point around the perimeter of A and is oriented to trace out the largest area; however, an angle less than 50 degrees complies where the barrier or portion of the bottom cover contacts a vertical barrier or side panel of noncombustible material, or where the horizontal extension of the barrier B to D exceeds 152 mm (6 inches).

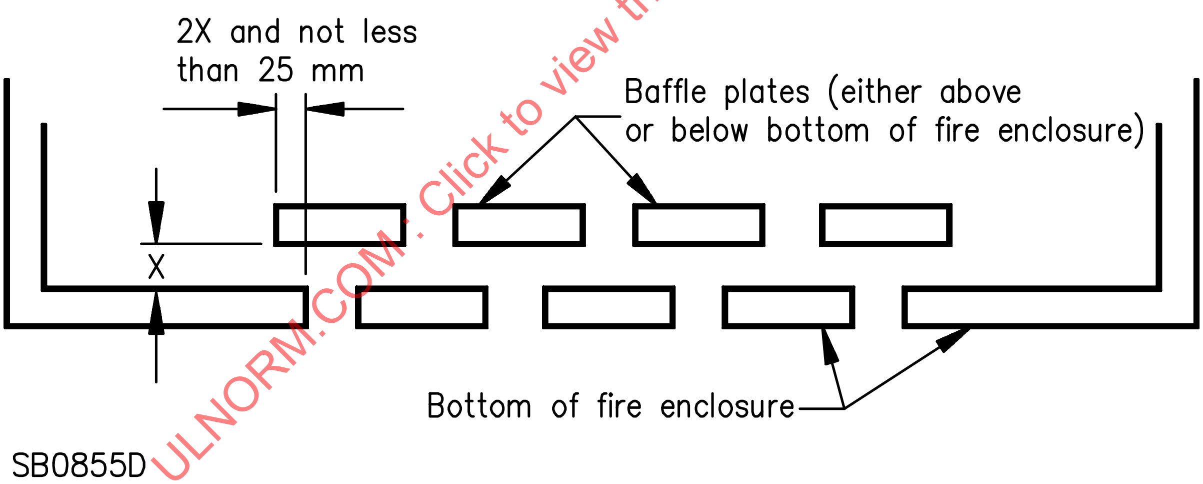
D. Minimum outline of the barrier; however, the extension B to D is not required to exceed 152 mm (6 inches) (flat or dished with or without a lip or other raised edge). The bottom of the barrier is able to be flat or formed in any manner where every point of area D is at or below the lowest point on the outer edge of the barrier.

Table 5.6
Perforated Metal Plates for Enclosure Bottom

Minimum thickness,		Maximum diameter of holes,		Minimum spacings of holes center to center,	
mm	(inch)	mm	(inch)	mm	(inch)
0.66	(0.026)	1.14	(0.045)	1.70	(0.067), or
				233 holes per 645 mm^2 (1 $inch^2$)	
0.66	(0.026)	1.19	(0.047)	2.36	(0.093)
0.76	(0.030)	1.14	(0.045)	1.70	(0.067)
0.76	(0.030)	1.19	(0.047)	2.36	(0.093)
0.81	(0.032)	1.91	(0.075)	3.18	(0.125), or
				72 holes per 645 mm^2 (1 $inch^2$)	
0.89	(0.035)	1.90	(0.075)	3.18	(0.125)
0.91	(0.036)	1.60	(0.063)	2.77	(0.109)
0.91	(0.036)	1.98	(0.078)	3.18	(0.125)
0.99	(0.039)	1.60	(0.063)	2.77	(0.109)
0.99	(0.039)	2.00	(0.079)	3.00	(0.118)

Figure 5.2

Example of Baffle Overlap



7.8.3 Openings in enclosure tops

7.8.3.1 Openings in the top of an enclosure shall be located and sized to protect against the entry of foreign objects. Openings directly over uninsulated live parts:

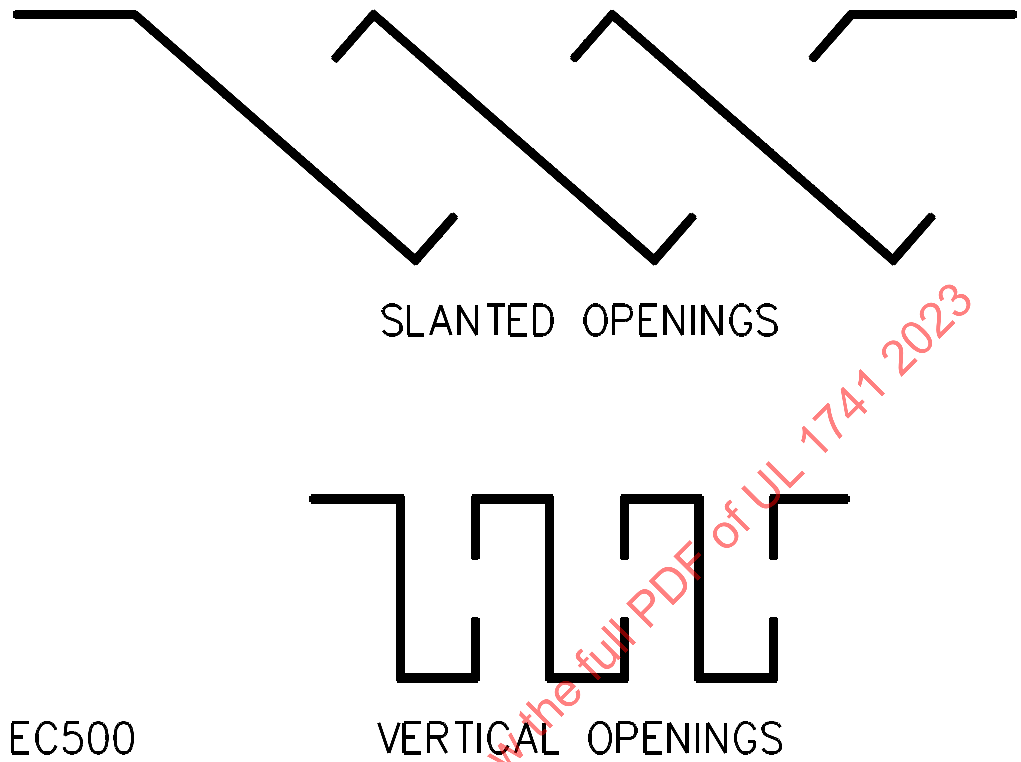
a) Shall not exceed 4.7 mm (0.187 inch) in any dimension,

b) Be configured as illustrated in Figure 5.3, or

c) Be constructed to provide equivalent protection against the entry of foreign objects.

Figure 5.3

Cross Sections of Top-Cover Design



7.8.4 Openings in enclosure sides

7.8.4.1 A louver shall not be more than 305 mm (12 inches) long.

7.8.4.2 The area of an opening covered by louvers, perforated sheet steel, or by expanded-metal mesh that is thinner than the enclosure shall not exceed 0.129 m^2 (200 square inches).

7.8.5 Expanded metal mesh and screens

7.8.5.1 The thickness of perforated sheet steel and sheet steel employed for expanded-metal mesh used to cover an opening in the enclosure shall comply with of Table 5.7.

Exception: Thicknesses less than specified in Table 5.7, and not less than specified in Table 5.8 meet the intent of the requirement where:

a) The indentation of the material does not adversely affect performance or reduce spacings to live parts below the minimum values specified in Spacings, Section 26, or Alternate Spacings-Clearances and Creepage Distances, Section 27, and

b) The opening has an area of not more than 464.5 cm^2 (72 in^2) and no dimension greater than 304.8 mm (12 inches), or

c) The width of the opening is not greater than 88.9 mm (3-1/2 inches).

Table 5.7
Minimum Thickness of Expanded Metal Mesh

Opening area	Uncoated,		Zinc coated, mm (inch)	
	mm	(inch)	mm	(inch)
Maximum 323 mm^2 (0.5 in^2) or less	1.07	(0.042)	1.14	(0.045)
More than 323 mm^2 (0.5 in^2)	2.03	(0.080)	2.13	(0.084)

Table 5.8
Minimum Thickness of Expanded Metal Mesh

Uncoated,		Zinc coated,	
mm	(inch)	mm	(inch)
0.51	(0.020)	0.61	(0.024)

7.8.5.2 The diameter of the wires of a screen shall not be less than 1.30 mm (0.051 inch) where the screen openings are 323 mm^2 (0.5 in^2) or less in area, and not less than 2.06 mm (0.081 inch) for larger screen openings.

7.8.6 Barriers used with ventilation openings in low voltage compartments

7.8.6.1 Unless a ventilation opening is located at least 305 mm (12 inches) from an arcing part, such as a switch, fuse, circuit breaker or a similar source, a barrier shall be placed between the ventilation opening and the source of arcing.

7.8.6.2 The barrier shall be of such dimensions and so located that any straight line drawn from an arcing part past the edge of the barrier intersects a point in the ventilation opening plane that is at least 6.4 mm (0.25 inch) outside of the edge of the ventilation opening.

7.8.6.3 A sheet-metal barrier shall not be less than 1.35 mm (0.053 inch) thick when uncoated steel, 1.42 mm (0.056 inch) thick when zinc-coated, or 1.19 mm (0.075 inch) thick when aluminum.

Exception: A metal barrier of thinner material meets the intent of the requirement when its strength and rigidity are not less than that of flat sheet steel having the same dimensions of the barrier and having the specified thickness.

7.9 Environmental rated enclosures

7.9.1 An enclosure shall comply with the construction requirements applicable to an enclosure of the Type number or numbers with which it is marked.

7.9.2 An environmental type connection, such as a watertight connection at a conduit entrance, shall be a conduit hub or the equivalent, such as a knockout or fitting, located so that when conduit is connected and the enclosure is mounted in the intended manner, the enclosure complies with the tests specified in the Enclosure Types Table, in the Standard for Enclosures for Electrical Equipment, UL 50.

7.9.3 Type 3, 3R, and 3S enclosures shall comply with the Rain and Sprinkler Tests, Section 64.

7.9.4 A Type 2 enclosure shall have provision for drainage of water and shall have a threaded conduit hub or the equivalent for the connection of conduit in the top or sidewalls.

Exception No. 1: A threaded conduit hub or the equivalent is not required where the conduit connection opening is wholly below the lowest terminal lug or other live part within the enclosure. See 66.33.

Exception No. 2: A conduit hub or fitting is not required when information is provided in accordance with 66.31.

7.9.5 A Type 3 enclosure shall have:

a) A threaded conduit hub or the equivalent for a watertight connection at conduit entrances – see 7.9.2,

b) A mounting means external to the equipment cavity, and

c) Provision for locking a door, when a door is provided.

Exception: A conduit hub or fitting is not required when information is provided in accordance with 66.31.

7.9.6 A Type 3R enclosure shall have:

a) A threaded conduit hub or the equivalent for a watertight connection at conduit entrances – see 7.9.2,

b) Provision for drainage of water, and

c) Provision for locking a door, when a door is provided.

Exception No. 1: A threaded conduit hub or the equivalent is not required where the conduit connection opening is wholly below the lowest terminal lug or other live part intended for use within the enclosure. See 66.33.

Exception No. 2: A conduit hub or fitting is not required when information is provided in accordance with 66.31.

7.9.7 A Type 3S enclosure shall have:

a) A threaded conduit hub or the equivalent for a watertight connection at conduit entrances – see 7.9.2,

b) A mounting means external to the equipment cavity,

c) Provision for locking a door, when a door is provided, and

d) Operating mechanisms that support the additional weight of ice and that withstand the removal of ice by means of a hand tool used to gain access to the interior of the enclosure when ice is present. Auxiliary means are able to be provided to break the ice and to enable operation of external mechanisms.

Exception: A conduit hub or fitting is not required when information is provided in accordance with 66.31.

7.9.8 A Type 4, 4X, 6, 6P, or 11 enclosure shall have a conduit hub or the equivalent mounted in place to provide a watertight connection at conduit entrances and shall have mounting means external to the equipment cavity – see 7.9.2.

Exception No. 1: The watertight conduit connection is not required to be mounted in place when information is provided in accordance with 68.2.4.

Exception No. 2: A hub or a fitting is not required to be provided or installed on a Type 4 or 4X enclosure when instructions are provided as specified in 68.2.6.

7.9.9 A Type 12 enclosure shall have no conduit knockout or conduit opening and no hole through the enclosure other than a hole for a Type 12 mechanism, or the equivalent. A gasket, when provided, shall be oil resistant.

Exception: A Type 12 enclosure is able to employ a conduit opening when the enclosure is marked in accordance with 66.35.

7.9.10 A Type 12K enclosure is to be as specified in 7.9.9, unless it has knockouts located in the top or bottom walls, or both.

7.9.11 A Type 13 enclosure shall have oil-resistant gaskets and, when intended for wall or machine mounting, shall have a mounting means external to the equipment cavity. There shall be no conduit knockout or unsealed opening providing access to the equipment cavity. All conduit openings shall have provisions for oiltight connections.

7.9.12 A gasket of an elastomeric or thermoplastic material or a composition gasket utilizing an elastomeric material employed to comply with the requirements for a Type 2, 3, 3R, 3S, 4, 4X, 6, 6P, 11, 12, 12K, or 13 enclosure shall comply with the Gasket Tests, Section 43, in the Standard for Enclosures for Electrical Equipment, UL 50.

7.9.13 When a component, such as a pilot light, a disconnect, a pushbutton, or similar component, intended for use with a Type designated environmental enclosure is used with a specific Type enclosure, it shall meet the following:

a) The component has been evaluated for its intended use installed on a representative enclosure.

b) All hardware, gaskets, or other parts required to complete the installation are provided with the component.

Exception: Hardware, gaskets, or other parts are not required to be provided with the component when they are available from the component manufacturer in the form of a kit and are marked or rated for the application.

c) Installation instructions including such information as mounting hole location, opening configuration, and similar information, are provided on the component, in the component package, or on a stuffer sheet.

d) The component, its carton, or accompanying instruction sheet shall be marked or rated for use on a flat surface of the specific type enclosure in the construction.

7.9.14 A drain hole shall be provided on all units to prevent the accumulation of water above a level that results in the wetting of an electrical part or opening for the connection of conduit or for an auxiliary part under all mounting orientations specified by the installation instructions. The hole shall be as specified in Table 5.9.

Exception: A unit that has been subjected to the Rain and Sprinkler Tests, Section 64, is not required to be provided with a drain hole where no water enters the fixture.

Table 5.9
Size of Drain Holes

Opening shape	Minimum dimension		Minimum area		Maximum dimension		Maximum area	
	mm	(inch)	mm^2	$(inch^2)$	mm	(inch)	cm^2	$(inches^2)$
Slot	3.2	(1/8)	7.74	(0.012)	9.6	(3/8)	9.68	(1-1/2)
	(width)				(width)			
Square	3.2	(1/8)	–		12.7	(1/2)	–	
	(side)				(side)			
Round	3.2	(1/8)	–		12.7	(1/2)	–	
	(diameter)				(diameter)			
Irregular	–		7.74	(0.012)	–		9.68	(1-1/2)

8 Protection Against Corrosion

8.1 Iron and steel parts shall be protected against corrosion by enameling, galvanizing, plating, or other equivalent means. This applies to all springs and other parts which are relied upon for the intended mechanical operation.

Exception No. 1: Parts such as bearings and thermal elements for which such protection is impracticable.

Exception No. 2: Small minor parts of iron or steel such as washers, screws, or bolts that are not current-carrying and are not in the equipment grounding conductor path, when corrosion of such unprotected parts does not result in a risk of fire, electric shock, or injury to persons.

Exception No. 3: Parts made of stainless steel.

9 Mechanical Assembly

9.1 A unit shall be assembled so that it is not adversely affected by the vibration of normal operation.

9.2 A switch, a fuseholder, or a lampholder shall be securely mounted and shall be prevented from turning or shifting in its mounting panel.

Exception: The requirement that a switch be prevented from turning or shifting does not apply where:

a) The switch is a plunger, slide, or other type that does not rotate when operated. A toggle switch is subjected to forces that tend to turn the switch during normal operation of the switch,

b) Means for mounting the switch prevents the switch from loosening during operation,

c) Spacings are not reduced below the minimum specified in Spacings, Section 26, or Alternate Spacings-Clearances and Creepage Distances, Section 27, when the switch rotates, and

d) Normal operation of the switch is by mechanical means rather than by direct contact by persons.

9.3 With reference to 9.2, friction between surfaces shall not be the sole means to prevent shifting or turning of live parts for a device having a single-hole mounting means. An additional means such as a lock washer applied as intended shall be used.

10 Mounting

10.1 Provision shall be made for securely mounting a unit in position. Bolts, screws, or other parts used for mounting a unit shall be independent of those used for securing components to the frame, base, or panel.

Exception: A provision for mounting is not required for a floor supported or freestanding unit. See Stability, Section 61.

10.2 A keyhole slot for a mounting screw shall be provided with at least one round hole for accommodation of a permanent mounting screw. A keyhole slot shall be arranged so that a wall-mounting screw does not project into a compartment containing electrical parts and reduce spacings to less than those specified in Spacings, Section 26, or Alternate Spacings – Clearances and Creepage Distances, Section 27.

10.3 A unit shall not be provided with casters unless the casters are used solely for transporting the unit and the unit is provided with four leveling feet that are intended to be lowered after the unit is installed or the unit is provided with an equivalent means for securing the unit in position.

11 Protection of Users – Accessibility of Uninsulated Live Parts

11.1 The requirements in this Section apply to a part that is accessible to the user. For protection of service personnel, see Protection of Service Personnel, Section 12.

11.2 To reduce the potential for unintentional contact that involves a risk of electric shock from an uninsulated live part or film-coated wire; electrical energy – high current levels; or injury to persons from a moving part; an opening in an enclosure shall comply with (a) or (b):

a) For an opening that has a minor dimension (see 11.5) less than 25.4 mm (1 inch), the part or wire shall not be contacted by the probe illustrated in Figure 11.1.

b) For an opening that has a minor dimension of 25.4 mm (1 inch) or more, the part or wire shall be spaced from the opening as specified in Table 11.1.

Figure 11.1

Accessibility Probe

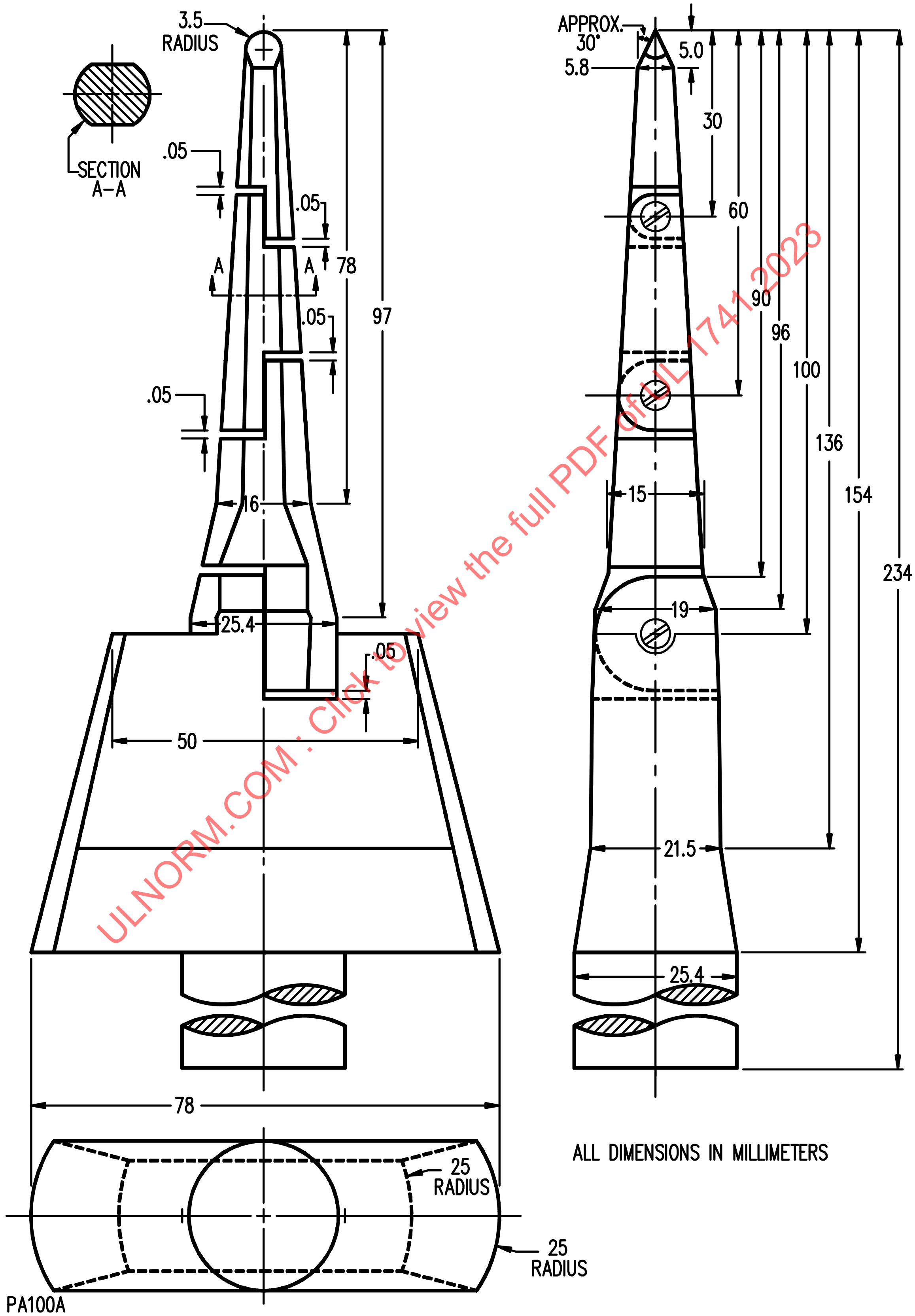


Table 11.1
Minimum Distance from an Opening to a Part That Involves a Risk of Electric Shock, Electrical Energy-High Current Levels, or Injury to Persons

Minor dimension of opening[a,b]		Minimum Distance from opening to part[b]	
mm	(inch)	mm	(inch)
25.4	(1)	165.0	(6-1/2)
31.8	(1-1/4)	190.0	(7-1/2)
38.1	(1-1/2)	318.0	(12-1/2)
47.6	(1-7/8)	394.0	(15-1/2)
54.0	(2-1/2)	444.0	(17-1/2)
(c)		762.0	(30)

[a] See 11.5.

[b] Between 25.4 and 54.0 mm, interpolation is to be used to determine a value between values specified in the table.

[c] More than 54.0 mm, and not more than 152.0 mm (5.98 in).

11.3 The probe illustrated in Figure 11.1 shall be applied to any depth that the opening accommodates; and shall be rotated or angled before, during, and after insertion through the opening to any position that is required to examine the enclosure. The probe shall be applied in any possible configuration; and, when required, the configuration shall be changed after insertion through the opening.

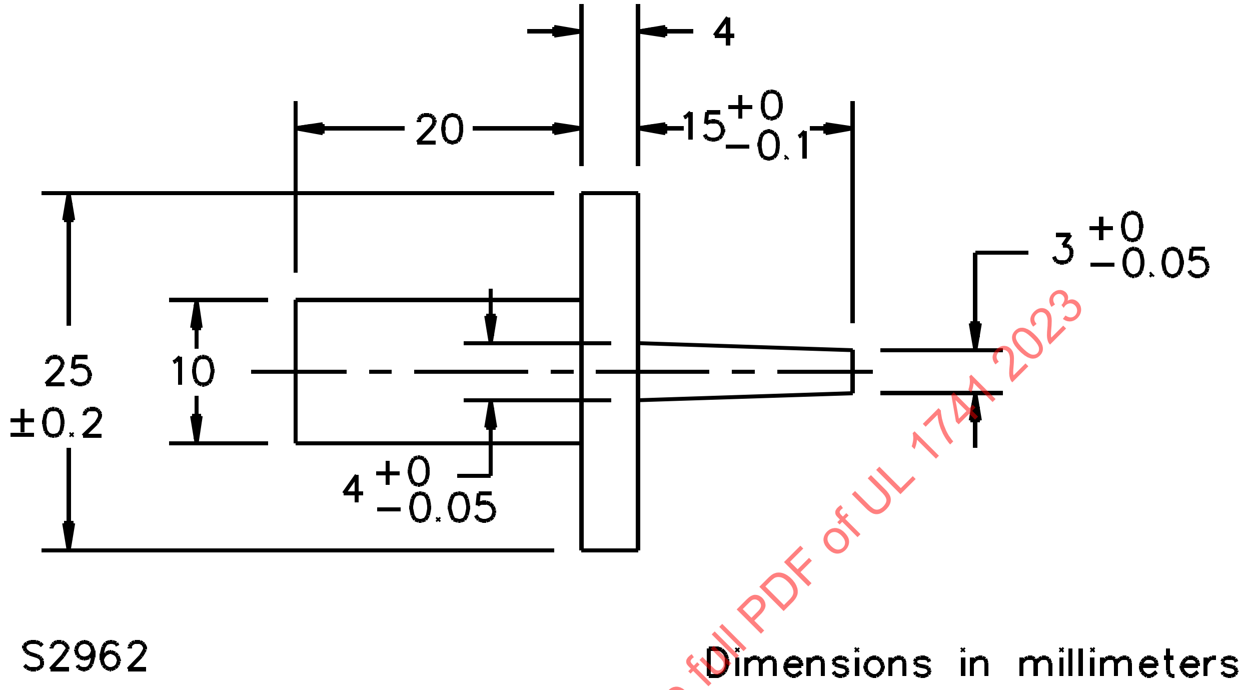
11.4 The probe specified in 11.3 shall be used as a measuring instrument to investigate the accessibility provided by an opening, and not as an instrument to investigate the strength of a material; it shall be applied with a maximum force of 4.4 N (1 pound).

11.5 With reference to 11.2, the minor dimension of an opening is equal to the diameter of the largest cylindrical probe that is able to be inserted through the opening.

11.6 The test pin illustrated in Figure 11.2, when inserted as specified in 11.3 through an opening in an enclosure, shall not touch any uninsulated live part that involves a risk of electric shock.

Figure 11.2

Test Pin



11.7 The probe shown in Figure 11.1 and the test pin shown in Figure 11.2 are to be inserted as specified in 11.3 into all openings, including those in the bottom of the unit. The unit is to be positioned so that the entire bottom is accessible for insertion of the probe.

Exception: For openings in the bottom of a floor-standing unit, the probe and test pin are only to be inserted into openings that are accessible without tipping, turning over, or otherwise moving the unit from its intended installed position.

11.8 During the examination of a unit to determine compliance with 11.2 through 11.7, a part of the enclosure that is able to be opened or removed by the user without using a tool (to attach an accessory, to make an operating adjustment, to give access to a fuse or other overload protective device as described in 7.2.1, or for other reasons) is to be opened or removed. A fastener, such as a slotted-head thumb screw, that is able to be turned by hand, does not require the use of a tool.

11.9 For medium voltage applications, interlocking is required by Interlocking of Medium Voltage Equipment, Section 15A, and barriers are required in accordance with 7.8.1.2 to be placed behind ventilation openings to prevent user access to medium voltage components, equipment and circuits.

12 Protection of Service Personnel

12.1 The requirements in this Section apply to the protection of service personnel who reach over, under, across, or around uninsulated electrical parts or moving parts to make adjustments or measurements while the unit is energized. For requirements covering protection of users, see Protection of Users – Accessibility of Uninsulated Live Parts, Section 11.

Exception: Performing service in medium voltage compartments when the equipment is energized is not possible based on the interlocking requirements of Interlocking of Medium Voltage Equipment, Section 15A.

12.2 Live parts shall be arranged and covers located to reduce the risk of electric shock or electrical energy-high current levels while covers are being removed and replaced.

12.3 An uninsulated live part involving a risk of electric shock or electrical energy-high current levels and a moving part that involves a risk of injury to persons shall be located, guarded, or enclosed to protect against unintentional contact by service personnel adjusting or resetting controls, or similar actions, or performing mechanical service functions that are performed with the equipment energized, such as lubricating a motor, adjusting the setting of a control with or without marked dial settings, resetting a trip mechanism, or operating a manual switch.

12.4 Live parts involving a risk of electric shock or electrical energy-high current levels and located on the back side of a door shall be guarded or insulated to protect against unintentional contact with live parts by service personnel.

12.5 A component that requires examination, resetting, adjustment, servicing, or maintenance while energized shall be located and mounted with respect to other components and with respect to grounded metal parts so that it is accessible for electrical service functions without subjecting service personnel to a risk of electric shock, electrical energy-high current levels, or injury to persons by adjacent moving parts. Access to a component shall not be impeded by other components or by wiring.

12.6 For an adjustment that is to be made with a screwdriver or similar tool when the unit is energized, protection shall be provided against inadvertent contact with adjacent uninsulated live parts involving a risk of electric shock. Misalignment of the tool with the adjustment means when an adjustment is attempted is to be taken into account. This protection is able to be provided by:

a) Location of the adjustment means away from uninsulated live parts involving a risk of electric shock, or

b) A guard to reduce the potential for the tool contacting uninsulated live parts.

12.7 A live heat sink for a solid-state component, a live relay frame, and similar components, involving a risk of electrical shock or electrical energy-high current levels, which is mistakable for dead metal, shall be guarded to protect against unintentional contact by service personnel or shall be marked in accordance with 67.4.

Exception: This requirement does not apply to a heat sink mounted on a printed wiring board.

12.8 A moving part that involves a risk of injury to persons and that must be in motion during service operations not involving the moving part shall be located or protected against unintentional contact with the moving parts.

12.9 Reduction of the risk of electric shock and injury to persons is able to be accomplished by mounting control components so that unimpeded access to each component is provided by an access cover or panel in the outer cabinet.

13 Electric Shock

13.1 Voltage

13.1.1 The requirements described in 13.1.2 – 13.2.2 are to be used to determine whether or not the voltage of an accessible live part involves a risk of electric shock.

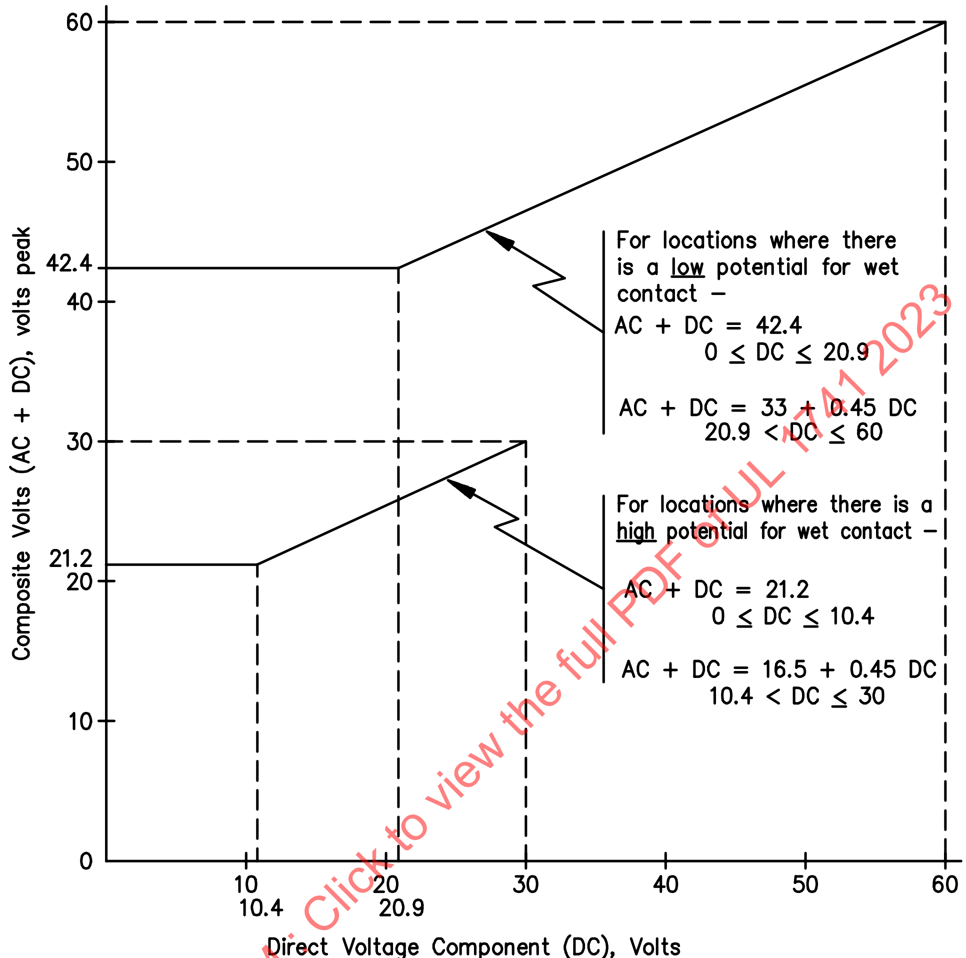
13.1.2 A live part does not involve a risk of electric shock where the voltage of the part does not exceed the values specified in Table 13.1.

Table 13.1
Risk of Electric Shock – Maximum Voltage

	Voltage type	Indoor-use units (low potential for wet contact)	Outdoor-use units (high potential for wet contact – immersion not included)
1.	Sinusoidal ac	30 V rms	15 V rms
2.	Nonsinusoidal ac	42.4 V peak	21.2 V peak
3.	Pure dc	60 V	30 V
4.	DC interrupted at a rate of 10 to 200 Hz	24.8 V peak	12.4 V peak
5.	Combinations of dc and sinusoidal ac at frequencies not greater than 100 Hz	See Figure 13.1	See Figure 13.1

Figure 13.1

Maximum Voltage



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13.2 Stored energy

13.2.1 The capacitance between capacitor terminals that are accessible as determined in accordance with Protection of Users – Accessibility of Uninsulated Live Parts, Section 11, and Protection of Service Personnel, Section 12, shall satisfy the following expressions:

$V < 40,000$	where $C < 0.00328$
$V < 729\ C^{-0.7}$	where $0.00328 \le C < 2.67$
$V < 367$	where $2.67 \le C < 13.9$
$V < 2314\ C^{-0.7}$	where $13.9 \le C < 184.5$ in a DRY environment
$V < 60$	where $C \ge 184.5$ in a DRY environment
$V < 2314\ C^{-0.7}$	where $13.9 \le C < 497$ in a WET environment
$V < 30$	where $C \ge 497$ in a WET environment

in which:

C is the capacitance of the capacitor in microfarads, and

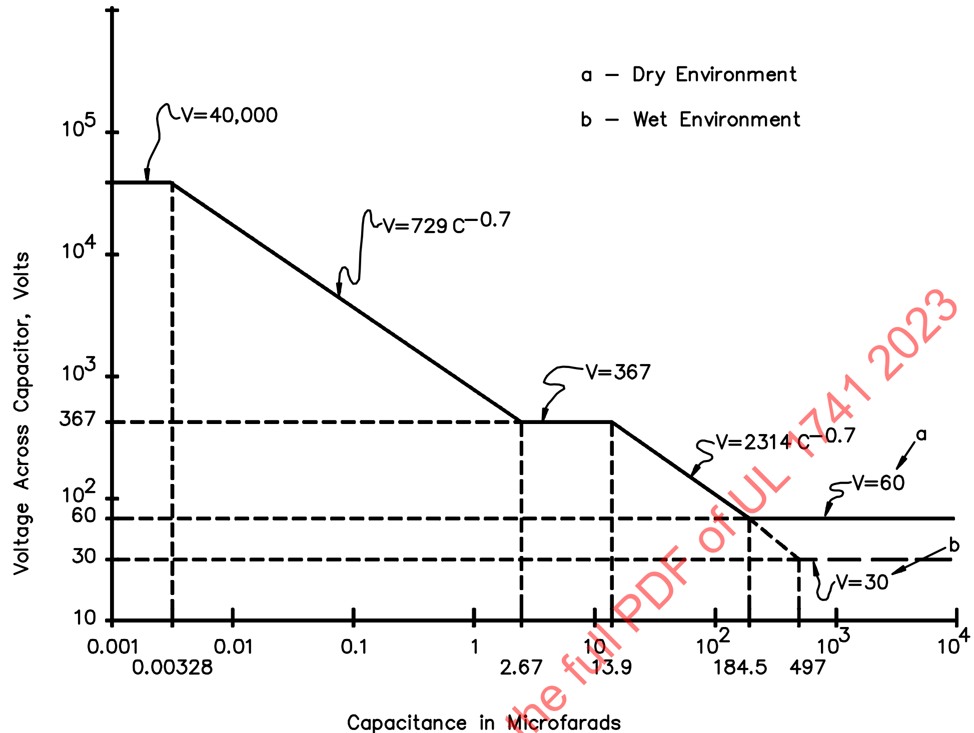
V is the voltage across the capacitor. The voltage is to be measured in accordance with 60.1. Typical calculated values are specified in Table 13.2, and the equation is shown graphically in Figure 13.2.

Table 13.2
Risk of Electric Shock – Stored Energy Current

Environment	Capacitance in microfarads	Maximum voltage across the capacitor, in volts peak
Wet or Dry	0.00328 or less	40,000
	0.005	29,749
	0.01	18,313
	0.02	11,273
	0.05	5,936
	0.1	3,654
	0.2	2,249
	0.5	1,184
	1.0	729
	2.0	449
	2.0	449
	2.67 to 13.9	367
	20.0	284
	50.0	150
	100.0	92.1
	184.5	60.0
Dry only	184.5 or more	60.0
Wet	200	56.7
	497 or more	30.0

Figure 13.2

Voltage Limits Across Capacitors



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13.2.2 With reference to 13.2.1, a part involving a potential of more than 40 kilovolts peak shall be investigated to determine whether or not it involves a risk of electric shock.

13.2.3 A means such as a bleeder resistor shall be provided to drain the charge stored in a capacitor so that it does not provide a risk of electric shock or a risk of electrical energy-high current level. A risk of electric shock exists when the voltage across the capacitor, determined in accordance with Capacitor Voltage Determination Test, Section 60, exceeds the limits specified in 13.1.2. A risk of electrical energy-high current level exists when the stored energy exceeds 20 joules as determined by the following equation:

$$J = 5 \times 10^{-7} \ CV^2$$

in which:

J is the stored energy in Joules,

C is the capacitance in microfarads, and

V is the voltage determined in accordance with Capacitor Voltage Determination Test, Section 60.

Exception No. 1: The requirement does not apply where:

a) A tool is required to remove a panel to reach the capacitor or accessible uninsulated portions of the associated circuit, *b) The time required to discharge the capacitor is within the limitations specified in 13.2.1 and is less than 5 minutes, and*

c) The unit is marked as specified in 67.11.

Exception No. 2: The requirement does not apply where:

a) The unit is marked in accordance with 67.12, and

b) The unit is provided with a built-in, insulated circuit that discharges the capacitor or capacitor bank by the actuation of a switch or by plugging in a connector. When a connector or a non-momentary type switch is used, the circuit assembly shall be constructed and evaluated for continuous operation. When a momentary type switch is used, the capacitor or capacitor bank shall be discharged to levels in accordance with Table 13.2 within 1 minute.

Exception No. 3: The requirement does not apply where:

a) The capacitor terminals and all parts connected to these terminals are insulated to protect against contact with these terminals and parts by the serviceman, and

b) A cautionary marking in accordance with 67.13 is provided.

13.2.4 Any equipment connecting to a controlled conductor of PV source or output circuits and has devices that may store energy (e.g. batteries, capacitors, etc.) shall comply with 97.1.10 and provide the markings and instructions in accordance with 101.3 and 102.4.

14 Switches and Controls

14.1 An ac or dc switch or similar control device shall have current and voltage ratings not less than those of the circuit that it controls when the unit is operated in its intended manner.

14.2 A primary-circuit switch that controls an inductive load having a power factor less than 75 percent, and that does not have an inductive rating, shall:

a) Be rated not less than twice the maximum load current under normal operating conditions, or

b) Be investigated for the application.

14.3 A switch used to connect a load to various sources or potentials shall be rated for such use. This includes a switch used for switching a voltmeter, frequency meter, or power factor meter between various phases.

14.4 A switch or other device controlling a relay coil, solenoid coil, or similar coil load shall have a pilot-duty rating.

Exception: A device as described in 14.5 is not required to have a pilot duty-rating.

14.5 A device that is rated for across-the-line motor starting of an alternating current motor is usable for alternating current pilot-duty without further tests when the power factor is 0.5 or less and the overload current is at least 150 percent of the pilot-duty inrush current at the same voltage. Switching devices rated in accordance with Table 14.1 are in compliance with this requirement.

Table 14.1
Horsepower Rating Versus Pilot Duty Rating

Horsepower rating 1-phase (120 – 600 volts)	AC pilot-duty rating
1/10	125 VA (light duty)
1/2	360 VA (standard duty)
1	720 VA (heavy duty)

14.6 Each pole of a snap switch rated as a 2-circuit, 3-circuit, or multi-circuit switch is not prohibited from controlling a separate load at the full voltage rating of the switch. Each pole of a snap switch rated as a 240-volt, 2-pole switch is not prohibited from controlling a separate 120-volt load, and both poles are not prohibited from controlling both legs of a single 240-volt load. Each pole of a snap switch rated as a 240-volt, 3-pole switch is not prohibited from controlling a separate load not exceeding 139 volts and the three poles are not prohibited from controlling the three legs of a 3-phase, 240-volt load.

14.7 A 240-volt or 250-volt snap switch used in a circuit involving more than 120 volts to ground shall be rated for such use.

14.8 A switch shall not disconnect the grounded conductor of a circuit.

Exception No. 1: The grounded conductor is able to be disconnected by a switch that simultaneously disconnects all conductors of the circuit.

Exception No. 2: The grounded conductor is able to be disconnected by a switch that is so arranged that the grounded conductor is not disconnected until the ungrounded conductors of the circuit have been disconnected.

14.9 A bypass switch or maintenance bypass used to connect the load directly to the bypass source shall comply with the Standard for Transfer Switch Equipment, UL 1008.

Exception: A bypass switch or maintenance bypass complying with Load Transfer Test, Section 50.7, is not required to comply with UL 1008. See 14.10.

14.10 With reference to the Exception to 14.9, a solid-state switch shall comply with the requirements in this Standard. A mechanical or electromechanical switch shall comply with the applicable requirements for switches in the Standard for General-Use Snap Switches, UL 20, and the Standard for Industrial Control Equipment, UL 508.

14.11 Where a unit switch or circuit breaker is mounted such that movement of the operating handle between the on position and off position results in one position being above the other position, the upper position shall be the on position.

Exception: This requirement does not apply to:

a) A switching device having more than one on position (such as a bypass switch),

b) A double throw switch,

c) A rotationally-operated switch, or

d) A rocker switch.

15 Disconnect Devices

15.1 General

15.1.1 A disconnect device serving as an isolating device, equipment disconnect or system disconnect means required by the NEC shall be evaluated to the requirements in this section.

15.1.2 A disconnect device shall open all conductors of the circuit to which it is connected that are not solidly grounded.

Note: "Grounded" PV systems with overcurrent devices, resistors, etc. in the connection between the PV system and ground are "functional grounded" systems, and the "functional grounded" conductors are not solidly grounded.

15.1.3 System Disconnecting Means: A device serving the function of the NEC-required system disconnecting means shall:

a) Consist of a manually operated switch or a circuit breaker,

b) Employ an actuating mechanism that is accessible from outside of the enclosure or located behind a hinged cover not requiring a tool (other than a key) for opening, and

c) Be marked in accordance with 66.21 and 66.27.

Disconnect actuating mechanisms shall clearly indicate the operational status of the disconnect with the following text “ON (CLOSED)” and “OFF (OPEN)” or symbols in accordance with 66.21.

15.1.4 Equipment Disconnecting Means: A device serving the function of the NEC-required equipment disconnecting means shall:

a) Consist of a manually operated switch or a circuit breaker,

b) Employ an actuating mechanism that is capable of being operated without exposing the operator to inadvertent contact with live parts, and

c) Be marked in accordance with 66.21 and 66.27 to indicate its function.

Disconnect actuating mechanisms shall clearly indicate the operational status of the disconnect with the following text “ON (CLOSED)” and “OFF (OPEN)” or symbols in accordance with 66.21.

15.2 Provision for locking

15.2.1 Isolating and disconnecting devices serving as the means of de-energization of external sources of supply to the equipment, to facilitate safe servicing, shall have provision for being locked in the "off" (open or de-energized) position.

15.3 Medium voltage disconnect devices (isolating means)

15.3.1 Medium voltage isolating means may be any one of the following:

a) A three-pole switch complying with IEEE C37.20.4;

b) A three-pole switch complying with IEEE C37.20.4; in mechanical combination with medium-voltage fuses;

c) Metal-enclosed switchgear complying with IEEE C37.20.2, IEEE C37.20.3, or IEEE C37.20.9; or

c) A drawout assembly, complying with UL 347 or NEMA C37.54.

15.3.2 The medium voltage isolating means shall be:

a) Arranged to be operated from a location where the operator is not exposed to energized parts;

b) Arranged to open all ungrounded conductors of the main circuit simultaneously with one operation (gang operated); and

c) Interlocked with the medium voltage door in accordance with Interlocking of Medium Voltage Equipment, Section 15A.

15.3.3 Where an enclosed isolating switch is located inside another outer enclosure, and no medium voltage components or wiring are accessible when accessing the isolating switch, the door for the outer enclosure is not considered a medium voltage door.

15.3.4 Any doors of the inner enclosure that give access to medium voltage components or wiring shall be interlocked with the switch in accordance with Section 15A.

15.3.5 All switch blades shall be de-energized when the switch is in the open position, unless a switch is required to be energized from both sides (e.g., bus-tie and loop-sectionalizing), in which case:

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

b) The switch is marked in accordance with 67.8.

15.3.6 Medium voltage isolating means shall:

a) Be gang-operated so all poles are operated in a single operation;

b) Provide the isolating distance of the controller complying with the requirements of the impulse and power frequency dielectric test requirements of this standard;

c) Include position indication in accordance with 15.3.7 that verifies that the isolating distance has been established;

d) Be capable of interrupting the no-load current of all transformers connected to the load side of the disconnecting means;

e) Be capable of interrupting the full-load current of any transformers connected to the load side of the disconnecting means, unless interlocking with the secondary load circuits is provided to prevent opening the switch with a transformer delivering second current;

f) Have provision for being padlocked in the open position;

g) Be interlocked in accordance with Section 15A; and

h) Be arranged so that gravity will not cause movement towards the closed position.

15.3.7 Medium voltage isolating means shall provide visible evidence of an isolating distance in the circuit adequate for the rated voltage complying with all of the following:

a) Isolating and load-break switches or drawout assemblies shall be provided with position indicators indicating the fully closed and fully open positions.

b) For drawout type isolating means, the isolation gap or a mechanically operated indicator shall be visible through a viewing pane. The mechanical operator shall be actuated by the movement of the actual isolating switch assembly, the shutter of a drawout assembly, or the like. The action of the mechanical indicator shall not be dependent on the movement of the operating handle or mechanism alone.

c) Non-drawout type isolating and load-break switches shall have an observation window (or windows) through which the isolating distance is visible. Alternatively, a camera system may be provided that complies with the requirements for Alternate Viewing Systems in IEEE C37.20.9.

d) The isolating means operating system shall provide indication of “Open” and “Closed” position via one or more of the following means; color coding (red – closed, black or green – open), words (“OPEN,” ”ON,” “CLOSED,” “OFF”) or symbols in accordance with 66.21.

15A Interlocking of Medium Voltage Equipment

15A.1 If an isolating means is not rated for making and breaking the required current, the isolating means shall be mechanically interlocked with a device capable of interrupting the current to prevent opening or closing the isolating means unless the load interrupting device is in the open position. The interlocking shall also prevent energizing the isolating means unless it is in the closed position or the drawout isolating means is separated by the isolating distance.

15A.2 When the sum of the full load ratings of any connected transformers exceeds the interrupting capacity of the isolating means, electrical interlocks shall be provided to disconnect secondary loads of transformers before the isolating means can be opened.

15A.3 In addition to the requirements of 15A.1 and 15A.2, equipment using a drawout element shall be provided with mechanical interlocks that will:

a) Positively lock the drawout element in the housing when the primary disconnecting devices are in their fully closed or fully connected position;

b) Discharge or block stored-energy devices prior to complete removal of the drawout element; and

c) Prevent contact with medium-voltage live parts as determined by the rod entry test in Section 64A with the drawout element in the test position and with the drawout element removed from the cubicle, when the medium voltage compartment door is open.

Note: Means to padlock a shutter assembly in a closed position may be used to meet this requirement when the drawout element is removed from the cubicle.

15A.4 In addition to the requirements of 15A.3, equipment using a drawout element that is used as the isolating means shall be provided with an automatic shutter assembly or the equivalent that:

a) Is maintained in the closed position in a manner that prevents inadvertent opening. Opening of the shutter shall require a degree of difficulty involving a minimum of two separate and distinct operations. Turning a knob, or moving a lever, or removing a single bolt, or the like, shall not be considered to provide the required degree of difficulty; and

b) Complies with the shutter integrity test described in Section 64B.

15A.5 Mechanical door interlocks shall be provided to meet these requirements:

a) Interlocks shall prevent the opening of a door to a medium-voltage compartment when the isolating means is closed.

b) Interlocks shall prevent the isolating means from being closed when the door of any medium-voltage compartment of the equipment is open.

c) Where equipment is being back fed by other medium voltage power source(s), low voltage stand-alone or multiple mode inverters, interlocks shall be provided to prevent opening of a door to a medium-voltage compartment when the isolating means of the back-fed power source is closed, and to prevent closing of the isolating means of the back-fed power source when a door to a medium-voltage compartment is open.

Note: Key interlocking schemes are considered to meet this requirement.

15A.6 Where a means for circumventing the door interlock described in 15A.5 or 15A.7 is provided for inspection or maintenance purposes, the method to bypass the interlock shall involve a minimum of two separate and distinct operations. Turning a knob, moving a lever, or removing a single bolt, or the like, shall not be considered sufficient for this purpose. This method shall not be indicated on the product, but may be indicated in the instruction manual.

15A.7 If provision is made for a test position, the isolating means shall be interlocked to ensure that the isolating distance is established when the drawout (withdrawable) element is in the test position. The control circuit shall be arranged so that it must be disconnected from the normal control power before it can be connected to a separate source of control power. Should it be necessary to defeat a mechanical interlock in order to close the drawout contactor on test power, the isolating means shall be prevented from being closed until the interlock mechanism has been restored to normal.

15A.8 Doors giving access to medium-voltage compartments shall be provided with one of the following interlock systems:

a) An interlock that is solely mechanical, that meets the requirements of 15A.5.

b) An electromechanical interlock system that combines electrical and mechanical interlock protection that:

1) Meets the requirements of 15A.5 (other than the requirement to be solely mechanical);

2) Has at least two different protection means:

i) With different actuation methodologies; and

ii) Requiring use of a tool to disable the protection.

3) Complies with the functional safety requirements in Table 15A.1.

Table 15A.1
Functional Safety Standards

Interlocks using electronic devices	Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991. Critical components evaluated using the Computational Investigation method shall have predicted failure rates equivalent or better than IEC 61508 SIL 2 or ISO 13849-1 PL d.
Interlocks using firmware/software	Standard for Software in Programmable Components and or Equipment, UL 1998. UL 1998 shall be used in conjunction with Functional Safety standards, such as UL 991, to also evaluate discrete component hardware and non-programmable IC's.
Alternate standards may be used in place of UL 1998 and UL 991 for evaluating the unit's functional safety. If other standards are used, the environmental stress testing as described in UL 991 shall be applied in addition to the requirements of the other	

Table 15A.1 Continued on Next Page

Table 15A.1 Continued

standards. If tests in the other standards are similar to those prescribed in UL 991, the more severe criteria of both standards shall be applied. • Automatic Electrical Controls – Part 1: General requirements, UL 60730-1. A unit shall comply with Control Class B as a minimum. • Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems, IEC 61508. A unit shall comply with a minimum of SIL 2. • Safety of Machinery – Functional Safety of Safety-Related Electrical, Electronic and Programmable Electronic Control Systems, IEC 62061. A unit evaluated to this standard shall comply with a minimum of SIL CL 2. • Safety of Machinery – Safety-Related Parts of Control Systems – Part 1: General Principles for Design, ISO 13849-1. A unit shall comply with a minimum of PL d.

15A.9 Covers giving access to medium-voltage compartments shall comply with all the following conditions:

a) The cover shall be bolted on all sides with a minimum of two bolts per side;

b) No bolts are operable by hand, without the use of a tool;

c) All bolts are captive fasteners;

d) The cover does not provide access to fuses; and

e) The cover is marked “DANGER: High Voltage Risk of Electric Shock – Do not open cover while energized”.

16 AC Output Connections

16.1 Stand-alone inverters

16.1.1 The ac output of a stand-alone inverter shall be provided with (a) or (b), or both:

a) Receptacles which comply with 16.1.2.

b) Provision for connection of a fixed wiring system in accordance with Supply Connections, Section 18.

Exception: Medium voltage standalone inverters shall comply with Supply Connections, Section 18.

16.1.2 An inverter provided with an ac output receptacle shall comply with the following:

a) The receptacle shall be of the grounding type,

b) The ac output conductor that is connected to the white or silver terminal of the receptacle shall be bonded to ground in accordance with 21.1, 21.3, and 21.5,

c) An equipment-grounding connection as described in Equipment Grounding, Section 20, shall be provided. Grounding of the receptacle shall not rely on mounting means only. The ground terminal provided as part of the receptacle shall be employed, and

d) Receptacles installed in raised covers shall not be secured solely by a single screw.

16.1.3 A ground-fault circuit-interrupter shall comply with the Standard for Ground-Fault Circuit-Interrupters, UL 943.

16.2 Utility-interactive inverters

16.2.1 A utility-interactive inverter shall have provision for connection of a wiring system complying with Supply Connections, Section 18.

16.2.2 A general-use ac output receptacle shall not be provided on a utility-interactive inverter unless it is internal to the unit and accessible for service personnel use only.

16.2.3 An inverter with an ac output shall comply with the following:

a) The installation instructions shall comply with 68.2, and

b) The output circuit shall not be bonded to the enclosure. See also 21.2.

17 Receptacles for Low Voltage Output Circuits

17.1 A general-use receptacle in an inverter shall be of the grounding type.

17.2 A receptacle supplied from the output ac circuit of an inverter shall comply with the following:

a) The white or silver terminal of the receptacle shall be grounded, see AC Output Circuit Grounded Conductor, Section 21,

b) The equipment-grounding terminal of the receptacle shall be conductively connected to the equipment-grounding means in accordance with Internal Bonding for Grounding, Section 22, and

c) A receptacle installed in a raised cover shall be in accordance with Section 410.56(i) of the National Electrical Code, ANSI/NFPA 70.

18 Supply Connections

18.1 General

18.1.1 A unit shall have provision for connection of a wiring system consisting of:

a) Wiring terminals as specified in 18.1.3 – 18.2.10 or wiring leads as specified in 18.1.3 and 18.3.1 – 18.3.6, and

b) A means for connection of cable or conduit as specified in 18.5.1.

Exception No. 1: The requirements described in 18.1.3 – 18.4.3 do not apply to the means for connection to isolated accessible signal circuits complying with the requirements specified in Isolated Accessible Signal Circuits, Section 30.

Exception No. 2: This requirement does not apply to ac output power circuit of an inverter consisting of receptacles complying with the requirements specified in Receptacles, Section 17.

18.1.2 The requirement in 18.1.1 applies to the wiring connection means for ac and dc input and output power circuits of a unit intended to be made in the field when the unit is installed.

18.1.3 A wiring terminal or lead shall be rated and sized for connection to a field wiring conductor having an ampacity based on Table 310.15(B)(16) of the National Electrical Code, ANSI/NFPA 70, of no less than 125 percent of the RMS or dc current that the circuit carries during rated conditions. For determining the appropriate column in Table 310.15(B)(16), see 69.4 (L) and (M).

18.1.4 A wiring terminal for a circuit above 2000 V ac or dc shall be sized for connection to a field wiring conductor having an ampacity of no less than 100 percent of the current that the circuit carries during rated conditions, based on Tables 310.60(C)(77) and (78) of the National Electrical Code, ANSI/NFPA 70.

18.2 Wiring terminals

18.2.1 A wiring terminal shall comply with the requirement in 18.1.3 for a wire of each metal for which it is marked. See 66.12.

18.2.2 A wiring terminal shall be provided with a factory-installed pressure terminal connector that is securely fastened in place – for example, firmly bolted or held by a screw.

Exception No. 1: A field-installed pressure terminal connector in accordance with 18.2.4 meets the intent of this requirement.

Exception No. 2: A wire-binding screw employed at a wiring terminal intended for connection of a 10 AWG (5.3 mm^2) or smaller conductor and having upturned lugs, a cupped washer, or the equivalent to hold the wire in position meets the intent of this requirement.

Exception No. 3: Wiring terminals for medium voltage circuits shall comply with 18.2.11.

18.2.3 A wiring terminal shall be secured in position, by a means other than friction between surfaces, so that it does not turn or shift. This is able to be accomplished by two screws or rivets; by square shoulders or mortises; by a dowel pin, lug, or offset; by a connecting strap or clip fitted into an adjacent part; or by an equivalent method.

Exception: A pressure terminal connector used in accordance with 18.2.4 is able to turn when the spacing complies with Spacings, Section 26, when the connector is oriented in the position resulting in the least spacing between adjacent terminals and also between terminals and dead metal parts.

18.2.4 With reference to Exception No. 1 to 18.2.2, a pressure terminal connector is not required to be factory installed when the conditions in (a) – (e) are met:

a) One or more component terminal assemblies shall be available from the unit manufacturer or others and specified in the instruction manual. See 69.4 (B) and (C).

b) The fastening hardware such as a stud, nut, bolt, spring, or flat washer, and similar hardware, as required for an effective installation, shall be:

1) Provided as part of the terminal assembly,

2) Mounted on or separately packaged with the unit, or

3) Specified in the instruction manual.

c) The installation of the terminal assembly shall not involve the loosening or disassembly of parts other than a cover or other part giving access to the terminal location. The means for securing the terminal connector shall be readily accessible for tightening before and after installation of conductors.

d) When the pressure terminal connector provided in a terminal assembly requires the use of other than a common tool for securing the conductor, identification of the tool and any additional instructions shall be included in the assembly package or with the unit. See 69.4(D).

e) Installation of the pressure terminal connector in the intended manner shall result in a unit complying with the requirements of this Standard.

18.2.5 A terminal block or insulating base for support of a pressure terminal connector shall comply with the Standard for Terminal Blocks, UL 1059.

18.2.6 A wire-binding screw at a field-wiring terminal shall not be smaller than No. 10 (4.8 mm diameter).

Exception No. 1: A No. 8 (4.2 mm diameter) screw is usable at a terminal intended only for the connection of:

a) 14 AWG (2.1 mm^2) conductor, or

b) 16 or 18 AWG (1.3 or 0.82 mm^2) control-circuit conductor.

Exception No. 2: A No. 6 (3.5 mm diameter) screw is usable for the connection of a 16 or 18 AWG (1.3 or 0.82 mm^2) control-circuit conductor.

18.2.7 A wire-binding screw shall thread into metal.

18.2.8 A terminal plate tapped for a wire-binding screw shall be of metal not less than 1.27 mm (0.050 inch) thick.

Exception: A terminal plate of metal less than 1.27 mm (0.050 inch) thick complies where used in a low-voltage, limited-energy (LVLE) circuit or limited energy (LE) circuit (see 2.1.28 and 2.1.30) and the tapped threads are capable of withstanding the tightening torque specified in Table 18.1 without stripping.

Table 18.1
Tightening Torque for Wire-Binding Screws

Size of terminal screw, No.	(diameter, mm)	Wire sizes to be tested, AWG (mm^2)	Tightening torque Newton meters	(Pound-inch)
6	(3.5)	Stranded 16 – 18 (1.3 – 0.82)	1.4	(12)
8	(4.2)	Solid 14 (2.1) and Stranded 16 – 18	1.8	(16)
10	(4.8)	Solid 10 – 14 (4.8 – 2.1) and Stranded 16 – 18	2.3	(20)

18.2.9 There shall be two or more full threads in the metal of a terminal plate. The metal is to be extruded at the tapped hole to provide at least two full threads.

Exception: Two full threads are not required for a terminal in a low-voltage, limited-energy (LVLE) circuit or limited-energy (LE) circuit, see 2.1.28 and 2.1.30, when a lesser number of threads results in a secure connection in which the threads do not strip when subjected to the tightening torque specified in Table 18.1.

18.2.10 A terminal for connection of a grounded conductor of an ac circuit shall be identified as described in 66.16.

18.2.11 Terminals for field connection of medium voltage conductors shall conform to any one of the following:

a) Bus bars provided with hole patterns meeting the requirements of ANSI/NEMA CC 1-2018;

b) Connectors complying with IEEE 386.

18.3 Wiring leads for low voltage field conductors

18.3.1 A field-wiring lead shall not be more than two wire sizes smaller than the copper conductor to which it is to be connected, and shall not be smaller than 18 AWG (0.82 mm^2). For example, a 10 AWG (5.3 mm^2) or larger field-wiring lead is required for connection to a 6 AWG (13.3 mm^2) field-provided conductor. A field-wiring lead shall not be less than 152.4 mm (6 inches) long.

Exception: A lead is able to be more than two wire sizes smaller than the field-provided copper conductor to which it is to be connected, and be not smaller than 18 AWG (0.82 mm^2), when more than one factory-provided copper lead is intended for connection to the same field-provided lead, and the construction complies with the following:

a) A wire connector for connection of the field-provided wire is factory-installed as part of the unit or remote-control assembly, and the wire connector is rated for the combination of wires that are to be spliced,

b) The factory-provided leads are bunched or otherwise arranged so that stress does not result on an individual lead, and

c) Instructions are provided in accordance with 69.4(E).

18.3.2 A field-wiring lead shall consist of general building wire, or of other wiring having an insulation of:

a) At least 0.8-mm (1/32-inch) thick thermoplastic material,

b) At least 0.4-mm (1/64-inch) thick rubber plus a braid cover for applications of 300 volts or less, or

c) At least 0.8-mm thick rubber plus a braid cover for applications between 301 and 600 volts.

18.3.3 A field-wiring lead shall comply with Strain Relief Test, Section 53.

18.3.4 A field-wiring lead provided for connection to an external line-voltage circuit shall not be connected to a wire-binding screw or pressure terminal connector located in the same compartment as the free end of the wiring lead unless the screw or connector is rendered unusable for field-wiring connection or:

a) The lead is insulated at the unconnected end, and

b) A marking is provided on the unit in accordance with 66.24.

18.3.5 The free end of a field-wiring lead that is not used in every installation, such as a lead for a tap of a multivoltage transformer, shall be insulated. For an equipment-grounding lead, see 20.1.7.

18.3.6 A field-wiring lead for connection of a grounded conductor of an ac circuit shall be identified as described in 66.16.

18.4 Wiring compartments for low voltage field conductors

18.4.1 A wiring compartment for a unit shall be located so that wire connections therein are accessible for inspection, without disturbing factory or field connected wiring, after the unit is installed in the intended manner.

18.4.2 A wiring compartment, raceway, or similar device, for routing and stowage of conductors connected in the field shall not contain rough, sharp, or moving parts that are capable of damaging conductor insulation.

18.4.3 A wiring compartment shall not have a volume less than specified in Table 18.2. The volume is to be determined in accordance with the Standard for Metallic Outlet Boxes, UL 514A, or the Standard for Nonmetallic Outlet Boxes, Flush-Device Boxes and Covers, UL 514C, as applicable. No compartment enclosure dimension shall be less than 19.1 mm (3/4 inch).

Table 18.2
Wiring Compartment Volume

Size of conductor,		Free space for each conductor	
AWG	(mm^2)	Cubic centimeter	(Cubic inches)
18	(0.82)	24.60	(1.50)
16	(1.3)	28.70	(1.75)
14	(2.1)	32.80	(2.00)
12	(3.3)	36.90	(2.25)
10	(5.3)	40.00	(2.50)
8	(8.4)	49.20	(3.00)
6	(13.3)	82.00	(5.00)

18.5 Openings for conduit or cable connection

18.5.1 For a fixed unit, an opening or knockout complying with the requirements specified in 7.7.1 – 7.7.7 shall be provided for connection of conduit or a cable wiring system.

Exception: A unit complying with 7.7.6 is not required to be provided with an opening or a knockout.

18.6 Openings for class 2 circuit conductors

18.6.1 An opening for the entry of a conductor or conductors of a Class 2 circuit, such as a control or sensor circuit, shall be supplied with an insulating bushing. The bushing shall be factory-installed in the opening or shall be supplied within the enclosure so that it is available for installation when the unit is installed.

Exception: A bushing is not required where:

a) The opening is sized and intended for armored cable or conduit, and

b) The installation instructions indicate that Class 1 wiring methods are to be used as indicated in 69.4(N).

18.6.2 For Type 1 enclosures only, a bushing of rubber or rubber type material provided in accordance with 18.6.1 shall not be less than 3.2 mm (1/8 inch) thick; however, it shall not be less than 1.2 mm (3/64 inch) thick when the metal around the hole is eyeletted or similarly treated to provide smooth edges. A bushing shall be located so that it is not exposed to oil, grease, oily vapors, or other substances having a deleterious effect on the material of the bushing. A hole in which such a hinge is mounted shall be free from sharp edges, burrs, or projections capable of damaging the bushing.

19 Wire-Bending Space for Low Voltage Field Conductors

19.1 A permanently connected unit employing pressure terminal connectors for field connection of circuits described in 18.1.2 shall be provided with wire-bending space within the enclosure for the installation of conductors (including grounding conductors) that are to be employed in the installation as specified in 18.1.2 – 18.2.4.

19.2 The conductor size used to determine compliance with 19.1 is to be based on the use of a conductor sized in accordance with 18.1.3.

Exception No. 1: Where a unit is marked with a maximum wire size for a field-installed conductor in accordance with 66.28, the marked maximum size is to be used.

Exception No. 2: The requirements in 18.4.3 are to be used to investigate the wire-bending space in a wiring compartment.

19.3 Wire-bending space for field installed conductors shall be provided opposite any:

a) Pressure wire connector as specified in 19.4 or 19.5, and

b) Opening or knockout for a conduit or wireway in a gutter as specified in 19.9.

19.4 Where a conductor is able to be installed such that it enters or leaves the enclosure surface opposite its wire-terminal, the wire-bending space shall be as specified in Table 19.1. A wire is able to enter or leave a top, back, bottom, or side surface when there is an opening or knockout for a wireway or conduit.

Table 19.1
Minimum Wire-Bending Space for Conductors Through a Wall Opposite Terminals in mm (inch)

Wire size, AWG or		Wires per terminal (pole)[a]											
		1			2			3			4 or More		
kcmil	(mm^2)	mm		(inch)	mm		(inch)	mm		(inch)	mm		(inch)
14 – 10	(2.1 – 5.3)	Not specified				–			–			–	
8	(8.4)	38.1		(1-1/2)		–			–			–	
6	(13.3)	50.8		(2)		–			–			–	
4	(21.1)	76.2		(3)		–			–			–	
3	(26.7)	76.2		(3)		–			–			–	
2	(33.6)	88.9		(3-1/2)		–			–			–	
1	(42.4)	114		(4-1/2)		–			–			–	
0	(53.5)	140		(5-1/2)	140		(5-1/2)	179		(7)		–	
2/0	(67.4)	152		(6)	152		(6)	191		(7-1/2)		–	
3/0	(85.0)	165	[12.7]	(6-1/2)	165	[12.7]	(6-1/2)	203		(8)		–	
4/0	(107)	179	[25.4]	(7)	191	[38.1]	(7-1/2)	216	[12.7]	(8-1/2)		–	
250	(127)	216	[50.8]	(8-1/2)	216	[50.8]	(8-1/2)	229	[25.4]	(9)	254		(10)
300	(152)	254	[76.2]	(10)	254	[50.8]	(10)	279	[25.4]	(11)	305		(12)
350	(177)	305	[76.2]	(12)	305	[76.2]	(12)	330	[76.2]	(13)	355	[50.8]	(14)
400	(203)	330	[76.2]	(13)	330	[76.2]	(13)	355	[76.2]	(14)	381	[76.2]	(15)
500	(253)	355	[76.2]	(14)	355	[76.2]	(14)	381	[76.2]	(15)	406	[76.2]	(16)
600	(304)	381	[76.2]	(15)	406	[76.2]	(16)	457	[76.2]	(18)	483	[76.2]	(19)
700	(355)	40	[76.2]	(16)	457	[76.2]	(18)	508	[76.2]	(20)	559	[76.2]	(22)

Table 19.1 Continued on Next Page

Table 19.1 Continued

Wire size, AWG or kcmil	(mm²)	1 mm		(inch)	2 mm		(inch)	3 mm		(inch)	4 or More mm		(inch)
750	(380)	432	[76.2]	(17)	483	[76.2]	(19)	559	[76.2]	(22)	610	[76.2]	(24)
800	(405)	457		(18)	508		(20)	559		(22)	610		(24)
900	(456)	483		(19)	559		(22)	610		(24)	610		(24)
1000	(507)	508		(20)		–			–			–	
1250	(633)	559		(22)		–			–			–	
1500	(760)	610		(24)		–			–			–	
1750	(886)	610		(24)		–			–			–	
2000	1013	610		(24)		–			–			–	

Note – This table includes only those multiple-conductor combinations that are commonly used. Combinations not specified shall be further investigated.

[a] Compliance with the following conditions reduces the wire-bending space by the number of mm's shown in brackets:

1) Only removable or lay-in wire connectors receiving one wire each are used (sometimes there is more than one removable wire connector per terminal) and

2) A removable wire connector is able to be removed from its intended location and reinstalled with the conuductor in place without disturbing structural or electrical parts other than a cover.

19.5 Where a conductor is intended to enter or leave the enclosure surface adjacent (not opposite) to its wire terminal, the wire-bending space shall be as specified in Table 19.2 where:

a) A barrier is provided between the connector and the opening, or

b) Drawings are provided specifying that the conductor is not to enter or leave the enclosure directly opposite the wire connector. See Illustrations A, B, and C of Figure 19.1.

Table 19.2
Minimum Wire-Bending Space and Width of Gutter for Conductors Through a Wall Not Opposite Terminals in mm (inches)

Size of wire, AWG or kcmil	(mm²)	1 mm	1 (inch)	2 mm	2 (inch)	3 mm	3 (inch)	4 mm	4 (inch)	5 mm	5 (inch)
14 – 10	(2.1 – 5.3)	Not specified	–	–		–		–		–	
8 – 6	(8.4 – 13.3)	38.1	(1-1/2)	–		–		–		–	
4 – 3	(21.1 – 26.7)	50.8	(2)	–		–		–		–	
2	(33.6)	63.5	(2-1/2)	–		–		–		–	
1	(42.4)	76.2	(3)	–		–		–		–	
1/0 – 2/0	(53.5 – 7.4)	88.9	(3-1/2)	127	(5)	178	(7)	–		–	
3/0 – 4/0	(85.0 – 107)	102	(4)	152	(6)	203	(8)	–		–	
250	(127)	114	(4-1/2)	152	(6)	203	(8)	254	(10)	–	
300 – 350	(152 – 177)	127	(5)	203	(8)	254	(10)	305	(12)	–	
400 – 500	(203 – 253)	152	(6)	203	(8)	254	(10)	305	(12)	356	(14)

Table 19.2 Continued on Next Page

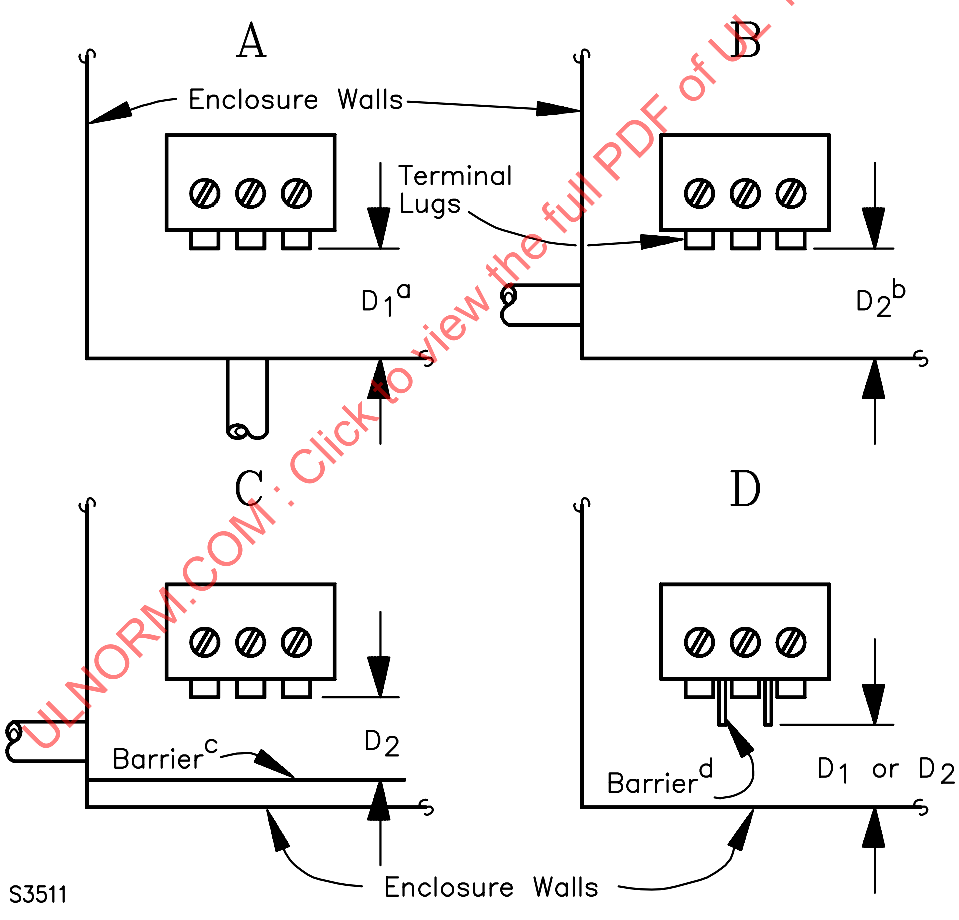
Table 19.2 Continued

Size of wire, AWG or kcmil	(mm²)	Wires per terminal (pole)									
		1		2		3		4		5	
		mm	(inch)	mm	(inch)	mm	(inch)	mm	(inch)	mm	(inch)
600 – 700	(304 – 355)	203	(8)	254	(10)	305	(12)	356	(14)	406	(16)
750 – 900	(380 – 456)	8	(203)	305	(12)	356	(14)	406	(14)	457	(18)
1000 – 1250	(507 – 633)	254	(10)	–		–		–		–	
1500 – 2000	(760 – 1010)	305	(12)	–		–		–		–	

Note – This table includes only those multiple-conductor combinations that are commonly used. Combinations not specified shall be further investigated.

Figure 19.1

Wire-Bending Space

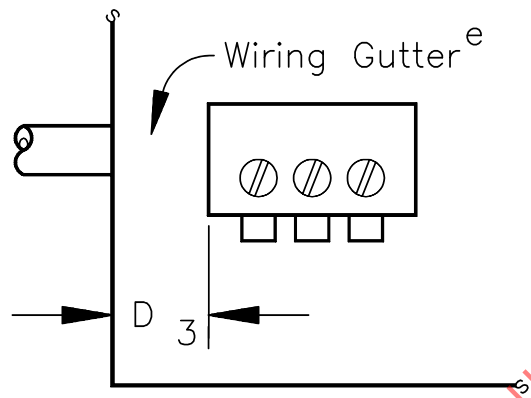


(Continued)

Figure 19.1 (cont'd)

Wire-Bending Space

E



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NOTES –

D_1 is the distance between a wire connector or an adjacent barrier and the opposite wall that conductors pass through.

D_2 is the distance between a wire connector or an adjacent barrier and the opposite wall or barrier that conductors do not pass through.

D_3 is the width of a wiring gutter having a side through which conductors pass through.

[a] A conduit opening or knockout is provided in the wall opposite the terminal lugs. D_1 shall not be less than the minimum wire-bending space specified in Table 19.1.

[b] A conduit opening or knockout is provided in the wall at a right angle to the wall opposite the terminal lugs. The wall opposite the terminal lugs:

1) Is not provided with a knockout or conduit opening, or

2) A marking is provided indicating that the conduit opening or knockout is not to be used. D_2 shall not be less than the minimum wire-bending space specified in Table 19.2.

[c] A conduit opening or knockout is provided in the wall at a right angle to the wall opposite the terminal lugs. In addition, a conduit opening or knockout is provided in the wall opposite the terminal lugs; however, a barrier preventing the use of the opening is provided. D_2 shall not be less than the minimum wire-bending space specified in Table 19.2.

[d] Where a barrier or other means restricts bending of the conductor, the distance D_1 or D_2, as appropriate – see notes D_1 – D_3 – is to be measured from the end of the barrier.

[e] A conduit opening or knockout is provided in a wiring gutter. The width of the gutter, D_3, shall not be less than the minimum wire-bending space specified in Table 19.2.

19.6 Where a conductor is restricted by a barrier or other means from being bent where it leaves the connector, the distance is to be measured from the end of the barrier. See illustration D of Figure 19.1.

19.7 For a unit not provided from the factory with a conduit opening or knockout, see 7.7.6, the minimum wiring-bending space specified in 19.4 – 19.6 shall be based on:

a) Any enclosure wall used for installation of the conduit, or

b) Only specific walls that are to be used as specified by a marking, drawing, or template furnished with the unit.

19.8 The distance specified in 19.3 – 19.5 is to be measured in a straight line from the edge of the wire terminal closest to the wall in a direction perpendicular to the box wall or barrier. See illustrations A – C of Figure 19.1. The wire terminal is to be turned so that the axis of the wire opening in the connector is as close to perpendicular to the wall of the enclosure as possible without defeating any means provided to prevent turning, such as a boss, shoulder, walls of a recess, multiple bolts securing the connector, or a similar means. A barrier, shoulder, or similar component is to be disregarded when the measurement is being made where it does not reduce the radius to which the wire must be bent. Where a terminal is provided with one or more connectors for the connection of conductors in multiple, the distance is to be measured from the wire opening closest to the wall of the enclosure.

Exception: See 19.6.

19.9 The width of a wiring gutter in which one or more knockouts are provided shall be large enough to accommodate (with respect to wire-bending space) conductors of the maximum size usable at that knockout. The width of a wiring gutter is given in Table 19.2. See illustration E of Figure 19.1.

Exception: The wiring space is able to be narrower when:

a) Knockouts are provided elsewhere that are in compliance with these requirements,

b) The wire-bending space at such other point or points is of a width that accommodates the conductors in question, and

c) The knockout or knockouts at such other points are able to be conveniently used in the intended wiring of the unit.

19A Wire-bending Space for Medium Voltage Field Conductors

19A.1 Wire bending space shall be such that, during installation, field-installed conductors need not be bent to a radius less than:

a) 8 times the overall diameter for non-shielded conductors; or

b) 12 times the overall diameter for shielded or lead-covered conductors.

19A.2 Wire bending space shall take into account the type and maximum size of wire, optional use of stress cones for field terminations, and other instructions provided by the manufacturer.

19A.3 For the purposes of determining the required bending space, the conductor size shall be determined using the worst case for type MV-90 cables from Tables 311.60(C)(73) through 311.60(C)(80), unless the equipment is provided with instructions limiting the type of cables (copper or aluminum only, single conductor, triplexed, or three conductor cable) and raceway location (in earth or air).

20 Equipment Grounding

20.1 General

20.1.1 There shall be means for grounding all dead metal parts of a unit.

20.1.2 The means for equipment grounding specified in 20.1.1 shall be provided for each wiring system to be connected to the unit for the following circuits:

a) Each dc input circuit,

b) Each ac input circuit,

c) Each ac output circuit, and

d) Each battery circuit.

Exception: An isolated accessible signal circuit complying with Isolated Accessible Signal Circuits, Section 30, is not required to have means for equipment grounding.

20.1.3 The equipment-grounding means for a fixed unit shall consist of an equipment-grounding terminal or lead.

20.1.4 An equipment-grounding terminal or lead shall be connected to the frame or enclosure by a positive means, such as by a bolted or screwed connection. The head of a screw or bolt, other than a double-nut secured bolt or screw, used to secure a terminal or lead, shall not be accessible from outside of the enclosure.

20.1.5 An equipment-grounding connection shall penetrate a nonconductive coating, such as paint or vitreous enamel.

20.1.6 An equipment-grounding means shall be located so that the means is not subject to inadvertent removal during servicing.

20.1.7 A free end of an equipment-grounding lead shall be insulated (for example, the end is to be folded back and taped to the lead) unless the lead is located so that the lead is not capable of contacting live parts in the event that the lead is not used in the field.

20.1.8 Equipment grounding leads or equipment grounding terminals shall be provided for each input and each output circuit. Any supplied lead shall have a free length of not less than 152 mm (6 inches) and the surface of the insulation shall be green with or without one or more yellow stripes. Where equipment ground leads are used, no other lead in a field-wiring compartment or that is visible to the installer shall be so identified. Equipment-grounding terminals shall be marked as described in 66.13. An equipment-grounding lead or equipment-grounding terminal shall have a minimum size or be rated to carry the required current in accordance with the following:

a) For a dc input from a photovoltaic source or output circuit, 1.25 times the rated short-circuit input current for that input, see Table 65.1.

b) For any ac input or output circuit or dc (non-PV) input or output circuit, Column 2 of Table 20.1 based on the size of the overcurrent device protecting that circuit.

Exception: The color coding requirement does not apply to Class 2 circuits where the leads are:

a) Located remote from the line-voltage connections and the segregation complies with the requirements in Separation of Circuits, Section 25, or

b) Marked in accordance with 66.25.

Table 20.1
Size of Equipment-Grounding and Grounding Electrode Conductors

Column 1	Column 2 Minimum size of equipment-grounding or bonding conductor AWG or kcmil (mm^2)				Column 3 Minimum size of grounding electrode conductor, AWG or kcmil (mm^2)			
Maximum current rating,[a] amperes	Copper		Aluminum or copper-clad aluminum		Copper		Aluminum or copper-clad aluminum	
15	14	(2.1)	12	(3.3)	8	(8.4)	6	(13.3)
20	12	(3.3)	10	(5.3)	8	(8.4)	6	(13.3)
30	10	(5.3)	8	(8.4)	8	(8.4)	6	(13.3)
40	10	(5.3)	8	(8.4)	8	(8.4)	6	(13.3)
60	10	(5.3)	8	(8.4)	8	(8.4)	6	(13.3)
90	8	(8.4)	6	(13.3)	8	(8.4)	6	(13.3)
100	8	(8.4)	6	(13.3)	6	(13.3)	6	(13.3)
150	6	(13.3)	4	(21.2)	6	(13.3)	4	(21.2)
200	6	(13.3)	4	(21.2)	4	(21.2)	2	(33.6)
300	4	(21.2)	2	(33.6)	2	(33.6)	1/0	(53.5)
400	3	(26.7)	1	(42.4)	1/0	(53.5)	3/0	(85.0)
500	2	(33.6)	1/0	(53.5)	2/0	(67.4)	4/0	(107.2)
600	1	(42.4)	2/0	(67.4)	2/0	(67.4)	4/0	(107.2)
800	1/0	(53.5)	3/0	(85.0)	3/0	(85.0)	250	(127)
1000	2/0	(67.4)	4/0	(107.2)	3/0	(85.0)	250	(127)
1200	3/0	(85.0)	250	(127)	3/0	(85.0)	250	(127)
1600	4/0	(107.2)	350	(127)	3/0	(85.0)	250	(127)
2000	250	(127)	400	(203)	3/0	(85.0)	250	(127)
2500	350	(177)	600	(304)	3/0	(85.0)	250	(127)
3000	400	(203)	600	(304)	3/0	(85.0)	250	(127)
4000	500	(253)	800	(405)	3/0	(85.0)	250	(127)
5000	700	(355)	1200	(608)	3/0	(85.0)	250	(127)
6000	800	(405)	1200	(608)	3/0	(85.0)	250	(127)

Note – See Table 21.2 for equivalent area of bus.

[a] Maximum ampere rating of the input circuit dc overcurrent protective device described in 50.1.5 or the ac output circuit overcurrent protective device described in 32.3.1 – 32.4.3, whichever is larger.

20.1.9 An equipment-grounding conductor shall not be spliced internal to the equipment.

20.1.10 An equipment-grounding connection, equipment-grounding conductor, enclosure, frame, component mounting panel, or other part connected to earth ground shall not carry current unless an electrical malfunction occurs. See 22.12.

Exception: This requirement does not apply to a line bypass capacitive impedance circuit for a radio frequency signal circuit or a transient voltage surge suppressor.

20.1.11 A soldering lug, a connection means that depends on solder, a screwless (push-in) connector, a quick-connect connector, or other friction-fit connector shall not be used as an equipment-grounding means.

20.1.12 An equipment-grounding terminal shall be rated for securing a conductor of a size based on the size of the overcurrent protection device to be employed in accordance with Columns 1 and 2 of Table 20.1 and shall be constructed in accordance with 18.2.1 – 18.2.9.

20.1.13 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. A pressure wire connector or a stud-and-nut type terminal intended for connection of such a conductor shall be marked as described in 66.13.

20.2 Grounding electrode terminal

20.2.1 Equipment intended to be installed as service entrance equipment or equipment containing the main dc or ac bonding connection shall be provided with a grounding electrode terminal. The terminal shall:

a) Be capable of securing a conductor size based on the maximum current rating of the highest current circuit connected to the unit, as specified in Column 3 of Table 20.1,

b) Comply with 18.2.1 – 18.2.10 for construction, and

c) Be marked as described in 66.17.

20.2.2 A grounding-electrode terminal shall be connected to the main bonding point (ac or dc) in the equipment by a positive means, such as by a bolted or screwed connection. For grounding electrode connections that are internal to a product, the head of a screw or bolt, other than a double-nut secured bolt or screw, used to secure a terminal shall not be accessible from outside of the enclosure.

21 AC Output Circuit Grounded Conductor

21.1 The requirements for circuit grounding specified in 21.3 – 21.5 apply to the ac output circuit of a stand-alone inverter.

21.2 An inverter intended to be utility-interactive shall not have a direct/solid electrical connection between any output ac conductor and the enclosure.

21.3 Other than as specified in 21.2, each ac output circuit shall have a grounded conductor. The ac output circuit conductor to be grounded shall be as follows:

a) Single-phase, 2-wire – one conductor.

b) Single-phase, 3-wire – the neutral conductor.

c) Multiphase system having one wire common to all phases – the common conductor.

d) Multiphase system in which one phase is used as in (b) – the neutral conductor.

21.4 The conductor specified in 21.3 is to be connected by a bonding jumper connected between the grounded conductor and:

a) The enclosure of a metal-enclosed unit, or

b) For a nonmetallic enclosed unit, the metal chassis that is bonded to the equipment-grounding conductor or terminal. See 20.2.1.

21.5 The size of the bonding jumper specified in 21.4 shall not be less than specified in Table 21.1.

Table 21.1
Minimum Size of Bonding Jumper

Maximum circuit current rating, amperes	Copper, AWG or kcmil (mm^2)		Aluminum or copper-clad aluminum, AWG or kcmil (mm^2)	
15	8	(8.4)	6	(13.3)
20	8	(8.4)	6	(13.6)
30	8	(8.4)	6	(13.3)
40	8	(8.4)	6	(13.3)
60	8	(8.4)	6	(13.3)
90	8	(8.4)	6	(13.3)
100	6	(13.3)	4	(21.2)
150	6	(13.3)	4	(21.2)
200	4	(21.2)	2	(33.6)
300	2	(33.6)	1/0	(53.5)
400	1/0	(53.5)	3/0	(85.0)
500	1/0	(53.5)	3/0	(85.0)
600	2/0	(67.4)	4/0	(107.2)
800	2/0	(67.4)	4/0	(107.2)
1000	3/0	(85.0)	250	(127)
1200	250	(127)	250	(127)
1600	300	(152)	400	(203)
2000	400	(203)	500	(253)
2500	500	(253)	700	(355)
3000	600	(304)	750	(380)
4000	700	(380)	1000	(508)
500	900	(456)	1250	(635)
6000	1200	(608)	1500	(759)
Note – See Table 21.2 for equivalent area of bus.				

Table 21.2
Equivalent Cross-Sectional Areas of Wires and Buses

Wire size, AWG or kcmil (mm^2)		Minimum cross section of bus	
		mm^2	($inch^2$)
8	(8.4)	8.39	(0.013)
6	(13.3)	13.55	(0.021)

Table 21.2 Continued on Next Page

Table 21.2 Continued

Wire size, AWG or kcmil (mm²)		Minimum cross section of bus	
		mm²	(inch²)
4	(21.1)	21.29	(0.033)
3	(26.7)	26.45	(0.041)
2	(33.6)	33.55	(0.052)
1	(42.4)	42.58	(0.066)
0	(53.5)	53.55	(0.083)
2/0	(7.4)	67.74	(0.105)
3/0	(85.0)	85.16	(0.132)
4/0	(107)	107.10	(0.166)
250	(127)	236.45	(0.196)
300	(152)	152.26	(0.236)
350	(177)	177.42	(0.275)
400	(203)	202.58	(0.314)
500	(253)	253.55	(0.393)
600	(304)	303.87	(0.471)
700	(355)	364.84	(0.550)
750	(380)	380.00	(0.589)
800	(405)	405.16	(0.628)
1000	(507)	506.45	(0.785)
1200	(608)	607.73	(0.942)
1250	(633)	632.90	(0.981)
1500	(760)	760.00	(1.178)

22 Internal Bonding for Grounding

22.1 All exposed dead metal parts, which in the event of an electrical malfunction, involve a risk of electric shock or electrical energy-high current levels, shall be conductively connected to the equipment-grounding means specified in Equipment Grounding, Section 20.

22.2 In a unit having means for grounding, all uninsulated metal parts of the enclosure, motor frames and mounting brackets, component mounting brackets, capacitors, and other electrical components that involve a risk of electric shock or electrical energy-high current levels shall be bonded for grounding where they are accessible for contact by the user or inadvertent contact by a serviceman.

Exception: A metal part as described in (a) – (g) is not required to be bonded for grounding:

a) An adhesive-attached metal foil marking, a screw, a handle, or similar metal part, that is located on the outside of an enclosure or cabinet and isolated from electrical components or wiring by grounded metal parts so that they do not become energized.

b) An isolated metal part, such as a magnet frame and an armature, a small assembly screw, or similar part, that is positively separated from wiring and uninsulated live parts.

c) A panel or cover that does not enclose uninsulated live parts; and wiring is positively separated from the panel or cover so that it is unable to become energized.

d) A panel or cover that is secured in place and that is insulated from electrical components and wiring by an insulating barrier of vulcanized fiber, varnished cloth, phenolic composition, or similar material not less than 0.8 mm (1/32 inch) thick.

e) An isolated metal part that is mounted on a printed wiring board – such as transformer and choke cores and heat sinks.

f) An isolated metal part that is marked in accordance with 67.12.

g) A capacitor sleeved with insulating tubing complying with 26.2.2.

22.3 A metal-to-metal piano-type hinge is usable as a means for bonding a door for grounding.

22.4 Where the continuity of the grounding system relies on the dimensional integrity of a nonmetallic material, the material shall be in accordance with the requirements for creep in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A. See also 22.9.

22.5 A conductor or strap used for bonding shall be of copper, a copper alloy, or an equivalent material. A conductor or strap:

a) Shall be protected from mechanical damage or be located within the outer enclosure or frame,

b) Shall not be secured by a removable fastener used for any purpose other than bonding for grounding, unless there is a low risk of the bonding conductor being omitted after removal and replacement of the fastener, and

c) Shall not be spliced.

22.6 A connection in the bonding path shall be by a positive means, such as by a clamp, a rivet, a bolted or screwed connection, or by welding, soldering, or brazing with materials having a softening or melting point greater than 455 °C (850 °F). The bonding connection shall penetrate nonconductive coatings, such as paint or vitreous enamel. Ferrous metal parts in the grounding path shall be protected against corrosion by painting, galvanizing, plating, or equivalent means. Bonding around a resilient mount shall not depend on the clamping action of rubber or similar material.

22.7 A bolted or screwed connection that incorporates a star washer under the screwhead shall penetrate nonconductive coatings and shall comply with Grounding Impedance Test, Section 51.

22.8 Where the bonding connection depends on screw threads in metal, two or more screws or two full threads of a single screw engaging two full threads in the metal shall be used.

22.9 A connection that depends on the clamping action exerted by rubber or similar material shall comply with Bonding Conductor Test, Section 55, when installed as intended. The material shall be rated for the condition of use, such as oil, grease, moisture, and thermal degradation that potentially occur in service. Before testing, the clamping device is to be disassembled as it is for maintenance purposes and then reassembled.

22.10 A bonding conductor or strap:

a) Shall not be smaller than the size specified in Column 2 of Table 20.1, see 22.11,

b) Shall not be smaller than the conductor supplying the component, or

c) Shall comply with Grounding Impedance Test, Section 51.

Exception: A smaller conductor or strap is usable when it complies with Bonding Conductor Test, Section 55.

22.11 With reference to Column 2 of Table 20.1, where more than one size branch-circuit overcurrent device is involved, the size of the bonding conductor or strap is to be based on the rating of the overcurrent device intended to provide ground-fault protection for the component bonded by the conductor.

22.12 The bonding connection, the enclosure, the frame, or a component mounting panel shall not carry current other than current resulting from an electrical malfunction.

Exception: An enclosure, frame, chassis, or panel, having bolted joints, is not restricted from carrying the current of a low-voltage, limited-energy (LVLE) circuit. Current shall not normally be carried through the field-equipment grounding means, the metallic raceway or other inverter grounding means, or the earth ground.

22A Connection of Medium Voltage Conductor Shields

22A.1 There shall be provision for bonding the conductor shields of each medium voltage field installed conductor to the ground bus. These provisions shall be located:

a) Such that the shield bonding conductor need not exceed 1.5 m (4.92 ft), and

b) In the same compartment as the wiring terminal for the associated shielded conductors.

22B Grounding of Medium Voltage Drawout Elements

22B.1 The metal frame of all drawout elements shall be grounded in the test and connected positions and in all locations between these positions.

22B.2 When in the test position, all dead metal parts that are likely to be touched by persons and are likely to become energized shall be grounded. A dead metal part shall be considered likely to become energized if the part contains or encloses live parts above the limits defined in Table 13.1 considering the unit rated installation location being wet or dry.

22C Ground Bus for Medium Voltage Equipment

22C.1 A ground bus shall be provided for all medium voltage equipment, and shall extend into each medium voltage compartment The ground bus shall be of equivalent cross-sectional area to the conductors shown in column 2 of Table 20.1. Splice bars shall be provided for field splicing sections as needed.

23 Internal Wiring

23.1 General

23.1.1 The internal wiring of a unit shall consist of general-use building wire or appliance wiring material rated for the temperature, voltage, and conditions of service to which the wiring is subjected. The insulation of low voltage appliance wiring material shall comply with Table 23.1.

Exception: Appliance wiring material having an insulation thickness other than specified in Table 23.1 complies when the insulation ratings are equivalent to that specified with respect to temperature, voltage, and conditions of service.

Table 23.1
Appliance-Wiring Material

Type of insulation	Thickness of insulation, mm (inch)[a]	
	600-volt applications	300-volt applications
Thermoplastic	0.8 (1/32)	0.8 (1/32)[b,c]
Rubber	0.8 (1/32) plus an impregnated braid cover	0.4 (1/64) plus impregnated braid cover
		0.8 (1/32) without a braid cover
Neoprene	0.2 (3/64)	0.4 (1/64) plus an impregnated braid cover
		0.8 (1/32) without a braid cover
Silicone rubber	0.8 (1/32) plus an impregnated braid cover	0.4 (1/64) plus an impregnated braid cover
	0.8 (1/32) without a braid cover[d]	0.8 (1/32) without a braid cover[d]
Cross-linked synthetic polymer	0.4 (1/64)	0.4 (1/64)

[a] The minimum thickness is 0.71 mm (0.028 inch) for 0.8 mm-thick insulation; the minimum thickness is 0.33 mm (0.013 inch) for 0.4 mm-thick insulation

[b] Shall not be less than 0.33 mm (0.013 inch) for short, moving pigtails or coil leads in a small device, where such leads make no more than casual contact with parts of opposite polarity or ungrounded parts.

[c] Shall not be less than 0.18 mm (0.007 inch) where routed away from live parts of opposite polarity and protected from mechanical damage during installation of field wiring and while the equipment is in operation.

[d] Applies only when routed away from live parts of opposite polarity and protected from mechanical damage during installation of field wiring and while the equipment is in operation.

23.1.2 Insulating tubing or sleeving shall not be used as insulation other than for a short length of insulated conductor, for example, a short coil lead, or similar component. Where so used:

a) The tubing or sleeving shall not be subjected to compression, repeated flexure, or sharp bends,

b) The conductor covered with the tubing or sleeving shall be well rounded and free from sharp edges,

c) A shrinkable tubing shall be used in accordance with the tubing manufacturer's instructions, and

d) The tubing or sleeving shall not be subjected to a temperature or voltage higher than that for which the tubing or sleeving is rated.

23.1.3 Where wiring extends to a hinged door or other part that is subject to movement in use, stranded conductors shall be employed, and the arrangement shall preclude twisting or stressing of conductors as a result of the movement. The wiring shall be routed or protected against damage to the insulation. The conductors shall be secured so that stress is not transmitted to terminals or splices.

23.2 Protection of wiring

23.2.1 Internal wiring shall not be accessible from outside the enclosure in accordance with 11.1.

23.2.2 Wires within an enclosure, compartment, raceway, or similar housing, shall be located or protected against contact with any sharp edge, burr, fin, moving part, or similar part, that is able to damage the conductor insulation.

23.2.3 Mounting screws and nuts shall be constructed or located so that sharp edges do not damage wiring. A screw shall have a flat or blunt end. The end of the screw shall not have burrs, fins, or sharp edges that are able to abrade wire insulation, and the end shall not project more than 4.8 mm (3/16 inch) into a wireway.

23.2.4 A hole through which insulated wires pass in a sheet metal wall internal to the overall enclosure of a unit shall be provided with smooth, rounded surfaces upon which the wires bear, to protect against abrasion of the insulation.

23.3 Electrical connections

23.3.1 A splice or connection shall be mechanically secure and shall make reliable electrical contact.

23.3.2 A soldered connection shall be made mechanically secure before being soldered.

Exception: A connection is not required to be mechanically secured before soldering when:

a) A soldering or brazing material having a softening or melting point greater than 454 °C (849 °F) is used,

b) A hand-soldered lead is passed through a hole in a printed wiring board and bent 90 degrees to the board to make contact with the conductor before soldering,

c) Soldering on a printed wiring board is done by a machine process in which the soldering time and solder temperature are automatically controlled – bending over of leads is not required, or

d) The lead wire is strapped in place, or the equivalent, adjacent to the soldered connection to hold the lead end in place.

23.3.3 A stranded internal wiring connection shall be such that it reduces the potential for loose strands of wire contacting dead metal parts or other live parts not always of the same potential. This is able to be accomplished by the use of a pressure terminal connector, a soldering lug, a crimped eyelet, soldering of all strands together, or an equivalent means.

23.3.4 An open-end spade lug secured by a screw or nut shall be secured by additional means, such as upturned ends on the lug, or bosses or shoulders on the terminal, to hold the lug in place in the event the screw or nut loosens.

23.3.5 A nominal 0.110-, 0.125-, 0.187-, 0.205-, or 0.250-inch wide quick-connect terminal shall comply with the Standard for Electrical Quick-Connect Terminals, UL 310. Other sizes of quick-connect terminals shall be investigated with respect to crimp pull-out, engagement-disengagement forces of the connector and tab, and temperature rises in accordance with UL 310.

23.3.6 Aluminum conductors, insulated or uninsulated, used as internal wiring, such as for interconnection between current-carrying parts or in a component winding, shall be terminated at each end by a terminal that is rated for the combination of metals involved at the connection points. A wire-binding screw or a pressure wire connector used as a terminating device shall be rated for use with aluminum under the conditions involved – for example, temperature, heat cycling, vibration, and other similar conditions.

23.3.7 A splice shall be provided with insulation equivalent to that of the wires involved unless permanent spacings are maintained between the splice and other metal parts.

a) Splicing devices such as pressure wire connectors insulated for the voltage and temperature to which they are subjected are in compliance with this requirement.

b) Insulating tubing or sleeving used to cover a splice shall comply with 23.1.2.

c) Two layers of thermoplastic tape, or two layers of friction tape, or one layer of friction tape and one layer of rubber tape, are able to be used on a splice when the voltage involved is less than 250 volts. The use of thermoplastic tape wrapped over a sharp edge is not in compliance with the requirement.

23.3.8 Open-end spade lugs and quick-connect terminals shall not be used for medium voltage circuits.

24 Live Parts

24.1 A current-carrying part shall be of silver, copper, copper alloy, aluminum, or the equivalent.

24.2 Uninsulated live parts and components that have uninsulated live parts shall be secured so they do not turn or shift in position where such displacement results in a reduction of spacings below the minimum values specified in Spacings, Section 26, or Alternate Spacings – Clearances and Creepage Distances, Section 27.

25 Separation of Circuits

25.1 Factory wiring

25.1.1 Insulated conductors of different circuits – see 25.1.2 – within a unit, including wires in a terminal box or compartment, shall be separated by barriers or segregated and shall also be so separated or segregated from uninsulated live parts connected to different circuits.

Exception: For insulated conductors of different circuits, where each conductor is provided with insulation rated for the highest of the circuit voltages, no barriers or segregation are required.

25.1.2 For the purpose of determining compliance with 25.1.1, different circuits include:

a) Circuits connected to the primary and secondary windings of an isolation transformer,

b) Circuits connected to different isolated secondary windings of a multi-secondary transformer,

c) Circuits connected to secondary windings of different transformers,

d) Input and output circuits of an optical isolator,

e) Isolated circuits, and

f) AC power and dc power circuits.

Exception: Power circuits that are derived from the taps of an autotransformer or similar component – that does not provide isolation – are not different circuits.

25.1.3 Segregation of insulated conductors shall be by means of clamping, routing, or an equivalent means that maintains permanent separation from insulated and uninsulated live parts and from conductors of a different circuit.

25.1.4 Medium voltage wiring and low voltage shall be reliably separated. They shall not be bundled together and shall not occupy the same raceway, wiring harness, or wire trough. Medium voltage wiring operating at above 7200 V shall be separated from low voltage components and wiring by grounded metal barriers, with the exception of short lengths of wire such as at instrument transformer terminals.

25.1.5 Medium voltage 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.

25.1.6 Circuits that are connected to medium voltage circuits or circuits that do not have the required isolation and the required spacing from adjacent medium voltage circuits shall be treated as medium voltage circuits and shall comply with the medium voltage spacings defined in Table 26.1 as well as the medium voltage tests in Section 47A for the highest voltage in either circuit.

25.2 Field wiring

25.2.1 A unit shall be constructed so that a field-installed conductor of a circuit is separated as specified in 25.2.2 or separated by barriers as specified in 25.3.1 and 25.3.2 from:

a) Factory-installed conductors connected to any other circuit, unless the conductors of both circuits are insulated for the maximum voltage of one of the circuits.

b) An uninsulated live part of another circuit or from an uninsulated live part where a short circuit between the conductors involves a risk of fire, electric shock, electrical energy-high current levels, or injury to persons.

c) Field-installed conductors connected to any other circuit unless:

1) Both circuits are Class 2 or Class 3 or both circuits are other than Class 2 or Class 3, and

2) Both circuits are insulated for the maximum voltage of one of the circuits.

Exception: A field-installed conductor is not required to be separated from a field wiring terminal of a different circuit where the field wiring is intended to be insulated for the maximum voltage of one of the circuits, and both circuits are Class 2 or Class 3 or both circuits are other than Class 2 or Class 3.

25.2.2 Separation of a field-installed conductor from another field-installed conductor and from an uninsulated live part connected to another circuit is able to be accomplished by locating an opening in the enclosure for the conductor opposite to the conductor terminal so that, when the installation is complete, the conductors and parts of different circuits are separated by a minimum of 6.4 mm (1/4 inch). In determining whether a unit having such openings complies with this requirement, it is to be wired as in service including 152.4 mm (6 inches) of slack in each conductor within the enclosure. No more than average care is to be exercised in routing the wiring and stowing the conductor slack into the wiring compartment.

25.2.3 With reference to 25.2.2, when the number of openings in the enclosure does not exceed the minimum required for the intended wiring of the unit, and where each opening is located opposite a set of terminals, it is to be assumed that a conductor entering an opening is to be connected to the terminal opposite that opening. When more than the minimum number of openings are provided, the possibility of a conductor entering an opening other than the one opposite the terminal to which it is intended to be connected and the potential for it to contact insulated conductors or uninsulated current-carrying parts connected to a different circuit is to be investigated.

25.2.4 With reference to 25.2.1 – 25.2.3, conductors of all medium voltage circuits must always be separated from conductors of all low voltage circuits, even if both are insulated for the highest voltage.

25.3 Separation barriers

25.3.1 A barrier used for separation between the wiring of different circuits shall be:

a) Grounded metal or 0.71 mm (0.028 inch) minimum thick insulating material, and

b) Supported so that it is unable to be readily deformed or displaced to defeat its purpose.

25.3.2 A barrier used for separation between field wiring of one circuit and field or factory wiring or uninsulated live parts of another circuit shall not be spaced more than 1.6 mm (1/16 inch) from the surface that serves to provide separated compartments.

25.3.3 With reference to 25.3.1(a), insulating material is not considered a suitable barrier between medium voltage circuits above 7200 V and all low voltage circuits. Circuits of 7200 V and greater shall be separated from low voltage circuits by a grounded metal barrier.

26 Spacings

26.1 General

26.1.1 The spacings in a unit shall not be less than specified in Table 26.1.

Exception No. 1: For low voltage circuits, where liners and barriers are employed, 26.2.1 shall be used to determine the spacings.

Exception No. 2: As an alternative to Table 26.1, the spacings in low voltage circuits are able to be investigated in accordance with Alternate Spacings – Clearances and Creepage Distances, Section 27.

Exception No. 3: The inherent spacings of a component shall comply with the spacing requirements for the component.

Exception No. 4: The spacings specified in Table 26.1 do not apply within a circuit that complies with Isolated Accessible Signal Circuits, Section 30, or Control Circuits, Section 31. The spacing between these circuits and other circuits shall comply with Table 26.1.

Exception No. 5: Spacings between adjacent foils on a printed wiring board involving low voltage circuits only, and having a conformal coating complying with the requirements in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluation, UL 746C, are not required to comply with Table 26.1.

Exception No. 6: On printed wiring boards involving low voltage circuits only, and having a flammability classification of V-0 and constructed from a base material having a minimum Comparative Tracking Index (CTI) rating of 175 volts, spacings (other than spacings to ground, between primary and secondary circuits, between the battery supply circuit and other circuits and at field wiring terminal) are not specified between traces of different potential connected in the same circuit where:

a) The spacing complies with Reduced Spacings on Printed Wiring Boards Tests, Section 54, or

b) An analysis of the circuit indicates that no more than 12.5 milliamperes of current is able to flow between short-circuited traces having reduced spacings.

Exception No. 7: For multilayer printed wiring boards involving low voltage circuits only, the minimum spacing between adjacent internal foils of opposite polarity and between an internal foil and a plated through-hole shall not be less than 0.8 mm (1/32 inch).

Exception No. 8: Spacing requirements do not apply between adjacent terminals of a power switching semiconductor device, including the connection points of the terminals of the device.

Exception 9: Where liners or barriers are employed for medium voltage circuits, Insulating Liners and Barriers for Medium Voltage Circuits, 26.3, shall be applied.

Table 26.1
Spacings

Potential involved, volts rms (peak)	Minimum spacings, mm (inch)					
	Between an uninsulated live part and an uninsulated live part of opposite polarity, uninsulated grounded part other than the enclosure, or exposed metal part[a]				Between an uninsulated live part and the walls of a metal enclosure including a fitting for conduit or armored cable[b]	
	Through air		Over surface		Shortest distance	
0 – 50 (0 – 70.7)	1,6[c,d]	(1/16)	1.6[c,d]	(1/16)	1.6[c]	(1/16)
Greater than 50 to 150 (70.7 to 212.1)	3.2[c,d]	(1/8)	6.4[d]	(1/4)	6.4	(1/4)
Greater than 150 to 300 (212.1 to 424.2)	6.4	(1/4)	9.5	(3/8)	12.7	(1/2)
Greater than 300 to 600 (424.2 to 848.4)	9.5	(3/8)	12.7	(1/2)	12.7	(1/2)
Greater than 600 to 1000 (848.4 to 1414)	14	(0.55)	21.6	(0.85)	25.4	(1.0)
Greater than 1000 to 1500 (1414 to 2121)	17.8	(0.7)	30.5	(1.2)	41.9	(1.65)
Greater than 1500 to 2500[e]	25.4	(1.0)	50.8	(2.0)	76.2	(3.0)
Greater than 2500 to 7200[e]	50.8	(2.0)	88.9	(3.5)	101.6	(4.0)
Greater than 7200 to 15 kV[e]	101.6	(4.0)	124.3	(4.5)	127.0	(5.0)
Greater than 15 kV to 38 kV[e]	153	(6.0)	203	(8.0)	203	(8.0)

[a] For printed wiring boards, see Exceptions Nos. 2 – 7 to 26.1.1.

[b] A metal piece attached to the enclosure shall be investigated as a part of the enclosure where deformation of the enclosure reduces spacings between the metal piece and uninsulated live parts.

[c] The spacing between field-wiring terminals of opposite polarity and the spacing between a field-wiring terminal and a grounded dead metal part shall not be less than 6.4 mm (1/4 inch).

[d] At closed-in points only, such as a screw and washer construction of a insulated stud mounted in metal, the spacing shall not be less than 1.2 mm (3/64 inch).

[e] Because of the effect of configuration, spacings in excess of those indicated values may be required to meet the Impulse Withstand Test and Power Frequency Withstand Voltage Test performance requirements of this standard.

26.1.2 Uninsulated live parts connected to different circuits shall be investigated as though they are parts of opposite polarity and on the basis of the highest voltage involved. See Maximum-Voltage Measurements, Section 45.

26.1.3 The spacing at a field wiring terminal is to be measured with wires representative of field wiring in place and connected to the terminals as in actual service.

26.1.4 In a multi-component unit, the spacings from one component to another, from any component to the enclosure, and to another uninsulated dead metal part (excluding the component mounting surface), are to be based on the maximum voltage rating of the complete unit and not on the individual component ratings. The inherent spacings of an individual component is to be investigated on the basis of the voltage used and controlled by the individual component. Spacings between metal oxide varistors, capacitors, and other components shall comply with Table 26.1.

Exception: Components that comply with the requirements in the Standard for Fixed Capacitors for Use in Electronic Equipment – Part 14: Sectional Specification: Fixed Capacitors for Electromagnetic Interference Suppression and Connection to the Supply Mains, UL 60384-14, are not required to comply with Table 26.1.

26.1.5 Spacings for a fuse and fuseholder are to be measured with a fuse in place that has the maximum standard dimension for the rating, and such spacings shall not to be less than those specified in Table 26.1.

26.1.6 Where an uninsulated live part is not rigidly secured in position by means other than friction between surfaces, or where a movable dead metal part is in proximity to an uninsulated live part, the construction shall be such that for any position resulting from turning or other movement of the parts in question, at least the minimum required spacings shall be maintained.

26.1.7 With reference to 26.1.6, a lock washer is one means of rigidly securing a part.

26.1.8 Spacings to film coated wire are to be investigated as though the wire is an uninsulated live part.

26.1.9 Spacings within the circuits described in (a), (b), or (c) that are not safety circuits shall be such that the circuit complies with Dielectric Voltage-Withstand, Section 47. Spacings between these circuits and the enclosure, grounded dead metal, and other circuits shall comply with the applicable spacing requirements of this Standard.

a) Secondary circuits supplied by a transformer winding rated less than 200 volt-amperes or at a potential of 100 volts or less,

b) Battery circuits at a potential of 100 volts or less, or

c) A circuit derived from a battery rated over 100 volts in which the voltage within the circuit is limited to 100 volts or less by a regulating network complying with the requirement in 31.11.

26.2 Insulating liners and barriers for low voltage circuits

26.2.1 With reference to Exception No. 1 to 26.1.1, an insulating liner or barrier of material such as vulcanized fiber is able to be used when it is:

a) Not the sole support for uninsulated live parts involving a risk of fire, electric shock, or electrical energy-high current levels,

b) Not less than 0.71 mm (0.028 inch) thick, and

c) Located so that it is not adversely affected by arcing.

Other insulating materials used as a barrier or as direct or indirect support of uninsulated live parts involving a risk of fire, electric shock, or electrical energy-high current levels shall comply with the requirements in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C.

Exception No. 1: Vulcanized fiber not less than 0.33 mm (0.013 inch) thick is usable when:

a) In conjunction with an air spacing of not less than 50 percent of the minimum through air spacing as specified in Table 26.1, and

b) Between a heat sink and a metal mounting surface, including the enclosure, of an isolated secondary circuit rated 50 volts rms or less.

Exception No. 2: Mica shall be not less than 0.165 mm (0.006 inch) thick when used as insulation between a heat sink and a live case of a semiconductor device.

26.2.2 Insulating tubing complying with the requirements in the Standard for Extruded Insulating Tubing, UL 224, is usable for insulating a conductor including a bus bar in lieu of the minimum specified spacings and insulating a capacitor case in lieu of bonding the case for grounding, when the following conditions are met:

a) The conductor is not subjected to compression, repeated flexing, or sharp bends,

b) The conductor or case covered with the tubing is well rounded and free from sharp edges,

c) The tubing is used in accordance with the manufacturer's instructions, and

d) The conductor or case is not subjected to a temperature or voltage higher than that for which the tubing is rated.

26.2.3 A wrap of thermoplastic tape, complying with the requirements in the Standard for Polyvinyl Chloride, Polyethylene, and Rubber Insulating Tape, UL 510, is usable when all of the following conditions are met:

a) The wrap is no less than 0.33 mm (0.013 inch) thick, is applied in two or more layers, and is used in conjunction with not less than one-half the required through-air spacing.

b) The wrap is not less than 0.72 mm (0.028 inch) thick where used in conjunction with less than one-half the required through-air spacing.

c) The temperature rating of the tape is not less than the maximum temperature observed during the temperature test.

d) The tape is not subject to compression.

e) The tape is not wrapped over a sharp edge.

26.3 Insulating liners and barriers for medium voltage circuits

26.3.1 Vulcanized fiber shall not be used as an insulating barrier for medium voltage circuits.

26.3.2 Materials used as barriers for medium voltage circuits that are not in contact with live parts shall have a minimum flammability rating of HB. Insulating tapes shall meet the flame test requirements of UL 510.

26.3.3 Rigid sheet, molded, or cast insulating materials in contact with medium voltage live parts shall have a minimum flammability rating of V-0.

26.3.4 Shrinkable type tubing and insulation applied to conductor by dipping, molding, fluidized bed coating, or similar processes that cause the insulation to adhere to the conductor shall meet the flammability requirements for Applied Insulation and the thermal cycling withstand tests in IEEE C37.20.2, the Standard for Metal-Clad Switchgear.

27 Alternate Spacings – Clearances and Creepage Distances for Low Voltage Circuits

27.1 Other than specified in 27.2 and 27.3, as an alternative approach to the spacing requirements specified in Spacings, Section 26, clearances and creepage distances are able to be investigated in accordance with the requirements in the Standard for Insulation Coordination Including Clearances and

Creepage Distances for Electrical Equipment, UL 840, as described in 27.4. See Maximum-Voltage Measurements, Section 45.

27.2 The clearances between an uninsulated live part and the walls of a metal enclosure, including fittings for conduit or armored cable, shall be as specified in Table 26.1. The clearances are to be determined by physical measurement.

27.3 The clearances and creepage distances at field wiring terminals shall comply with Spacings, Section 26.

27.4 In conducting investigations in accordance with the requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, the following shall be used:

a) Unless specified elsewhere in this Standard, the pollution degree 3 applies,

b) An inverter shall comply with the requirements for Overvoltage Category IV,

c) Pollution degree 2 applies on a printed wiring board between adjacent conductive material which is covered by any coating which provides an uninterrupted covering over at least one side and the complete distance up to the other side of conductive material,

d) All printed wiring boards shall be identified as having a minimum Comparative Tracking Index (CTI) of 100 without further investigation.

e) The use of a coating which complies with the requirements for conformal coatings in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C is in compliance with the requirements of UL 840 to achieve pollution degree 1,

f) Pollution degree 1 is achievable at a specific printed wiring board location by application of at least a 0.79 mm (1/32 inch) thick layer of silicone rubber or for a group of printed wiring boards through potting, without air bubbles, in epoxy or potting material,

g) The Phase-to-Ground Rated System Voltage used in the determination of Clearances shall be the equipment rated supply voltage rounded to the next higher value (in the table for determining clearances for equipment) for all points on the supply side of an isolating transformer or the entire product when no isolating transformer is provided. The System Voltage used in the evaluation of secondary circuitry is able to be interpolated across the table for the Rated Impulse Withstand Voltage Peak and Clearance, and

h) 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.

27.5 This section does not apply to medium voltage components, equipment and circuits.

28 Insulating Materials

28.1 General

28.1.1 A polymeric material on which uninsulated live parts is mounted shall be Classed V-0, V-1, or V-2 in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. The use of a material Classed V-2 requires the use of an enclosure without ventilation openings. Drain holes are not prohibited regardless of the material Class.

Exception: This requirement does not apply to a material supporting only live parts connected in low-voltage, limited-energy (LVLE) circuits where deterioration of the material does not involve a risk of fire or electric shock.

28.1.2 Vulcanized fiber shall not be used as the sole support of an uninsulated live part where shrinkage, current leakage, or warpage introduces a risk of fire or electric shock. Electrical grade vulcanized fiber is able to be used for an insulating bushing, a washer, a separator, or a barrier.

Exception: Vulcanized fiber shall not be used in contact with, or to support, medium voltage parts.

28.1.3 A polymeric material used to support an uninsulated live part or parts, shall comply with the requirements for mechanical strength and rigidity, resistance to heat, resistance to flame propagation, and dielectric strength in the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A; Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B; and the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C.

28.2 Barriers for low voltage circuits

28.2.1 An insulating barrier of vulcanized fiber, thermoplastic, or other material used in lieu of required spacings shall not be less than 0.71 mm (0.028 inch) thick and shall be so located or of such material that it is not adversely affected by arcing.

Exception: Vulcanized fiber not less than 0.33 mm (0.013 inch) thick is usable:

a) In conjunction with an air spacing of not less than 50 percent of the minimum through-air spacing as specified in Table 26.1, and

b) Between a heat sink and a metal mounting surface, including the enclosure, or an isolated secondary circuit rated 50 volts rms or less.

28.2.2 Insulation used in lieu of required spacings between a magnet-coil winding and other uninsulated live parts or grounded dead metal parts, shall comply with 28.2.1.

28.2.3 This section does not apply to medium voltage components, equipment and circuits.

29 Capacitors

29.1 A capacitor used for electromagnetic interference elimination or power-factor correction that is oil filled shall comply with the Standard for Capacitors, UL 810.

Exception: The container of the capacitor is able to be of thinner sheet metal or be of material other than metal, where the capacitor is mounted inside a unit having an enclosure that complies with the requirements in 7.1.1 – 7.5.1 without Exceptions.

29.2 A capacitor connected across an input/output ac circuit that is connected to a utility shall comply with the requirements for across-the-line capacitors in the Standard for Fixed Capacitors for Use in Electronic Equipment – Part 14: Sectional Specification: Fixed Capacitors for Electromagnetic Interference Suppression and Connection to the Supply Mains, UL 60384-14.

Exception: This does not apply to medium voltage components, equipment and circuits.

30 Isolated Accessible Signal Circuits

30.1 An isolated accessible signal circuit having means for external connections, such as a RS232 communication port and similar connections, shall comply with 30.2 and 30.3.

30.2 A signal circuit that extends outside of a unit shall be an isolated circuit and shall be isolated from internal circuits having a voltage involving a risk of electric shock, as determined in accordance with Electric Shock, Section 13, by one of the following:

a) An optical isolator, complying with the Standard for Optical Isolators, UL 1577, having an isolation voltage rating of not less than the test potential required in 47.1,

b) An isolation transformer complying with the Standard for Low Voltage Transformers – Part 1: General Requirements, UL 5085-1, and the Standard for Low Voltage Transformers – Part 3: Class 2 and Class 3 Transformers, UL 5085-3, or an isolation transformer as defined in 2.1.26 – autotransformers are excluded,

c) A capacitor complying with the Standard for Fixed Capacitors for Use in Electronic Equipment – Part 14: Sectional Specification: Fixed Capacitors for Electromagnetic Interference Suppression and Connection to the Supply Mains, UL 60384-14,

d) An electro-mechanical relay complying with the requirements in the Standard for Industrial Control Equipment, UL 508, or

e) A voltage regulating network where:

1) The voltage being isolated is not directly derived from the ac circuit, and

2) The network does not involve a risk of electric shock at the external connection as determined in accordance with Electric Shock, Section 13, or as indicated by a failure mode and effect analysis in accordance with the method described in the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991.

30.3 The maximum power voltage and current available from an isolated accessible signal circuit shall comply with 31.4 – 31.11.

30.4 The maximum power available from an isolated accessible signal circuit that employs an overcurrent protection device to limit the current as described in the Exception to 31.4 shall not exceed the values specified in Table 30.1.

Table 30.1
Maximum Power of Isolated Accessible Signal Circuits

Circuit voltage, volts rms	Maximum power, volt-amperes
15 or less	350
More than 15 and not greater than 60	250

30.5 Accessible signal circuits shall be galvanically isolated from medium voltage circuits by medium voltage transformers, optical fiber systems, or connected through a voltage divider complying with Section 36A. The signal circuit shall comply with the maximum voltage, current, and power levels described in 30.3 and 30.4.

31 Control Circuits

31.1 A control circuit that is a low-voltage, limited-energy (LVLE) circuit or a limited-energy (LE) circuit is able to be connected to a single-point reference ground.

31.2 Other than for safety circuits, as indicated in 31.3, a low-voltage, limited-energy (LVLE) circuit is not required to be investigated. Printed-wiring boards and insulated wire used in such circuits shall comply with 23.1.1 and 35.1.

31.3 A control circuit that is a safety circuit shall be investigated in accordance with the requirements for primary circuits.

31.4 A control circuit, including associated electronic components on printed wiring boards, that does not extend out of the unit is not required to be investigated where the maximum voltage and current are limited as specified in (a) and (b). Printed wiring boards and insulated wires used in such circuits shall comply with 23.1.1 and 35.1.

a) The voltage shall not exceed the limits specified in Table 13.1, and

b) The current shall not exceed:

1) Eight amperes for 0 – 42.4 volts peak ac, or 0 – 30 volts dc, or

2) Amperes equal to 150 divided by the maximum voltage for 30 – 60 volts dc. See 31.5.

Exception: The maximum current specified is able to be exceeded where the circuit includes an overcurrent protective device as described in 31.8 and 31.9.

31.5 With reference to 31.4(b), the maximum current is to be measured under any condition of loading including short circuit using a resistor that is to be continuously readjusted during the 1-minute period to maintain maximum load current; however, the value indicated in (b) is not to be exceeded.

31.6 With reference to 31.4(a), measurement is to be made with the unit connected to the voltage specified in 47.1 and with all loading circuits disconnected. When a tapped transformer winding is used to supply a full-wave rectifier, voltage measurement is to be made from either end of the winding to the tap.

31.7 When the control circuit specified in 31.4 is not limited as to available short-circuit current by the construction of a transformer, and the circuit includes one or more resistors, a fuse, a nonadjustable manual-reset protective device, or a regulating network – see 31.11 – the circuits in which the current is limited in accordance with 31.8, 31.9, or 31.10 are not required to be investigated.

31.8 A fuse or circuit-protective device used to limit the current in accordance with 31.7 shall be rated or set at not more than the values specified in Table 31.1.

Table 31.1
Rating for Secondary Fuse or Circuit Protector

Circuit voltage, V rms	Maximum overcurrent protection, amperes
20 or less	5
More than 20 and not greater than 60	100/V[a]

[a] V is the maximum output voltage, regardless of load, with the primary energized in accordance with 47.1.

31.9 A fuse or circuit-protective device connected to the primary of a transformer to limit the current in accordance with 31.7 shall be equivalent to that specified in 31.8 as determined by conducting the Overcurrent Protection Calibration Test, Section 52.

Exception: The Overcurrent Protection Calibration Test, Section 52, does not apply when the combination of a fuse or overcurrent protective device and a transformer complies with the Standard for Low Voltage Transformers – Part 1: General Requirements, UL 5085-1, and the Standard for Low Voltage Transformers – Part 3: Class 2 and Class 3 Transformers, UL 5085-3.

31.10 A regulating network or one or more resistors used to limit the current in accordance with 31.7 shall be such that the current under any condition of load, including short circuit, does not exceed the values indicated in 31.4(b).

31.11 Where a regulating network is used to limit the voltage or current in accordance with 31.4 – 31.10, and the performance is affected by malfunction (short circuit or open circuit) of any single component – excluding short-circuiting a resistor – the network:

a) Shall comply with the tests specified in 31.13, and

b) Critical components identified by the failure mode and effect analysis in accordance with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991, shall be derated in accordance with the Electronic Reliability Design Handbook, Military Handbook Number 338-1988.

31.12 In a circuit of the type described in 31.7, the secondary winding of the transformer, the fuse or circuit protective device, or the regulating network, and all wiring up to the point at which the current and voltage are limited shall be investigated in accordance with the applicable requirements in this Standard.

31.13 With reference to 31.11(a), the regulating network shall comply with the following tests in accordance with the method described in the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991. See 31.14.

a) Transient Overvoltage Test,

b) Ramp Voltage Test,

c) Electromagnetic Susceptibility Tests,

d) Electrostatic Discharge Test,

e) Thermal Cycling Test,

f) Humidity Test, and

g) Effects of Shipping and Storage Test.

31.14 The following test parameters are to be used in the investigation of a regulating network covered by 31.13.

a) Electrical supervision of critical components applies,

b) Audibility is usable as a trouble indicator for an electrical supervision circuit,

c) A field strength of 3 volts per meter is to be used for the Radiated EMI Test, and

d) Exposure Class H5 is to be used for the Humidity Test.

32 Low Voltage Overcurrent Protection

32.1 General

32.1.1 An overcurrent protective device, the intended functioning of which requires renewal, replacement, or resetting, shall be accessible:

a) From outside of the enclosure, or

b) Behind a hinged cover – see 7.2.1.

Exception No. 1: A protective device that is normally unknown to the user because of its location and omission of reference to the device in the operating instructions provided with the unit is not required to be accessible.

Exception No. 2: A control-circuit fuse does not require renewal as an intended function when the fuse and the load are contained within the same enclosure.

32.1.2 The screw shell of a plug-type fuseholder and the contacts, including associated live parts that are able to be contacted by the probe illustrated in Figure 11.1, of an extractor-type fuseholder shall be connected toward the load.

32.1.3 The type of fuseholder described in 32.1.2 shall not be used in circuits where boths ends of the fuse are live, such as between an inverter and the utility or between a charge controller and a battery.

32.1.4 A fuse and a fuseholder shall have voltage and current ratings not less than the circuit in which they are connected. A plug fuse shall not be used in a circuit exceeding 125 volts or in a 125/250 volts, 3-wire, circuit.

32.1.5 A fuseholder shall be of the cartridge, plug, or extractor type.

Exception: A fuse intended to be replaced only by service personnel – see Protection of Service Personnel, Section 12 – that is bolted in place meets the intent of this requirement.

32.1.6 A plug-type fuseholder shall be of the Type S construction.

32.1.7 An appliance protector used in the output circuit of an inverter in lieu of a branch-circuit rated fuse or circuit breaker shall have a short-circuit interrupting rating not less than the maximum fault current available from the inverter and shall comply with the requirements in the Standard for Supplementary Protectors for Use in Electrical Equipment, UL 1077.

32.1.8 A circuit breaker in the input or output circuit shall open all ungrounded conductors of the circuit. A multipole circuit breaker shall be a common trip type.

Exception: Single-pole circuit breakers with handle ties, the combination of which complies with the applicable requirements in the Standard for Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures, UL 489, are usable as the protection for each ungrounded conductor supplying line-to-line connected loads of equipment rated for connection to one of the following circuits of a grounded system, where no conductor involves a potential to ground in excess of 150 volts (see 67.9):

a) In a single-phase circuit,

b) In a 3-wire dc circuit, or

c) In a circuit that is connected to a 4-wire, 3-phase; or 5-wire, 2-phase, system with a grounded neutral.

32.1.9 A unit shall be marked in accordance with 67.6 when it is provided with overcurrent protection consisting of an interchangeable fuse and when the fuse is:

a) Accessible to the user, or

b) Used to comply with the requirements in this Standard.

32.1.10 An overcurrent protective device shall not be connected in the grounded (neutral, in an ac circuit) side of the supply circuit unless the protective device simultaneously disconnects the grounded and ungrounded conductors of the supply circuit.

32.1.11 Temperature or current-sensitive devices such as temperature limiting thermostats, thermal cutoffs, appliance protectors, fuses, circuit breakers, or similar devices that are relied upon to comply with the Abnormal Tests, Section 50, shall comply with the requirements applicable to the particular component. See Components, 3.

32.1.12 Overcurrent protection employing solid-state component circuitry used for protection of control circuits in accordance with 32.2.1 – 32.2.5 shall comply with the calibration and interrupt requirements in the Standard for Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures, UL 489. The interrupt test is to be based on the maximum rated short circuit current available from the inverter.

Exception: These requirements do not apply to overcurrent protection whose performance is not affected by malfunction of any single component that is short-circuited or open-circuited.

32.1.13 Units having overcurrent protective devices connected directly to input or output terminals or having overcurrent device terminals serving as inputs or outputs shall have labels or markings near those input or output terminals showing conductor temperature limitations for field installed conductors in accordance with Section 110.14 of the National Electrical Code, ANSI/NFPA 70.

32.2 Low voltage Control circuit overcurrent protection

32.2.1 A control circuit that extends from the unit to a remote control panel, status panel, or a similar component shall be protected in accordance with 32.2.2 – 32.3.2.

Exception: An external control circuit derived from a Class 2 transformer is not required to be provided with overcurrent protection.

32.2.2 The overcurrent protective device specified in 32.2.1 shall be a circuit breaker or fuse that is:

a) Rated for branch-circuit overcurrent protection, or

b) In compliance with 32.1.6.

When the protective device is a fuse, the unit shall be marked in accordance with 67.6.

32.2.3 A Class 1 power-limited circuit, in accordance with the National Electrical Code, ANSI/NFPA 70, used to supply an external control circuit shall be supplied from a source having a rated output of no more than 30 volts and 1000 volt-amperes. When the source is other than a transformer, the circuit shall be protected by an overcurrent protection device rated no more than 167 percent of the volt-ampere rating divided by the rated voltage. The overcurrent device shall not be interchangeable with overcurrent devices of higher ratings.

32.2.4 An external control circuit derived from the secondary of a transformer other than that described in 32.2.3 and the Exception to 32.2.1 shall be provided with overcurrent protection in accordance with 32.2.5. For a transformer not having a rating, the rated primary or secondary current specified in 32.2.5 is to consist of the maximum current during normal operation of the unit.

32.2.5 A transformer used to supply a control circuit shall be provided with overcurrent protection in the primary circuit rated as indicated in Table 32.1.

Exception No. 1: Where the rated primary current of the transformer is 9 amperes or more and 125 percent of this current does not correspond to a Standard rating of fuse or circuit breaker, the next higher Standard rating of protective device shall be used. Standard ratings of protective devices are specified in Section 240.6 of the National Electrical Code, ANSI/NFPA 70.

Exception No. 2: Where the rated secondary current of the transformer is less than 9 amperes, the overcurrent protection in the secondary circuit is able to be rated or set at no more than 167 percent of the rated secondary current.

Exception No. 3: Where a control circuit is derived from the secondary of a transformer that is provided with primary circuit overcurrent protection rated at no more than 250 percent of the rated primary current of the transformer, additional overcurrent protection is not required in the primary circuit where the secondary circuit is protected at no more than 125 percent of the rated secondary current of the transformer.

Table 32.1
Primary Overcurrent Protection for Control Circuit Transformers

Rated primary current, amperes	Maximum rating of overcurrent device, percent of transformer primary current rating
Less than 2	300
2 or more and less than 9	167
9 or more	125

32.3 Low voltage output ac power circuit overcurrent protection

32.3.1 An ac output power circuit shall be provided with overcurrent protection for all ungrounded conductors as described in 32.3.2 and 32.3.3. The voltage rating of the overcurrent protection shall not be less than the rating of the circuit with which it is used. The voltage rating for a 3-phase circuit shall be based on the phase-to-phase voltage. The overcurrent protection device shall be a circuit breaker or a fuse rated for use as branch circuit protection.

Exception: Overcurrent protection is not required to be provided with a unit having provision for permanent wiring connection of the output circuit and the instruction manual indicates that the overcurrent protection is to be provided by others. See 69.4(Q).

32.3.2 For a unit having provision for permanent wiring connection of the ac output power circuit, the rating of the overcurrent protection shall not exceed the ampacity of the conductors intended to be connected to the unit as determined in accordance with 18.1.3.

32.3.3 Where a unit includes one or more attachment-plug receptacles for connections to the ac output circuit, overcurrent protection shall be provided for each receptacle. A single overcurrent protection device, whose rating does not exceed the ampere rating of any receptacle connected to it, is usable when all receptacles are connected in parallel.

Exception: Two or more 15 ampere rated receptacles in a unit with 12 AWG (3.3 mm^2) minimum internal wiring are able to be protected by a 20 ampere overcurrent protection device.

32.3.4 Where the unit uses a trunk cable or other output cable to connect multiple units in parallel without an overcurrent device for the output of each unit, the requirements of 32.3.1 and 32.3.2 shall be met for the individual unit and the combined output of all units connected in parallel. The instruction manual shall include the requirements found in 69.4(U).

32.4 Battery circuits

32.4.1 A unit intended for connection to a battery circuit shall have a maximum input short-circuit current rating as required in Table 65.1 and shall be provided with overcurrent protection complying with the requirements described in 32.4.2 – 32.4.4.

Exception: Overcurrent protection is not required to be provided when the instruction manual contains the statement indicated in 69.4(Q).

32.4.2 The overcurrent protective device shall be dc rated and shall be for branch-circuit protection in accordance with the National Electrical Code, NFPA 70.

32.4.3 The protective device shall be located adjacent to the battery connecting means ahead of any component which is able to malfunction under short-circuit conditions such as capacitors, solid-state devices, or similar components.

32.4.4 The rating of the overcurrent protective device shall be based on the ampacity of the conductors intended to be connected between the unit and battery as determined from the requirement described in 18.1.3 under inverter mode operating conditions.

32A Medium Voltage Overcurrent Protection

32A.1 General

32A.1.1 Overcurrent protection in a three phase circuit shall protect all ungrounded conductors. Circuit breakers shall open all phases of the protected circuit. When fuses are used, there shall be a fuse in each ungrounded phase of the circuit.

32A.1.2 Medium voltage fuses shall be located such that they can be accessed for replacement only after the entire circuit is de-energized.

32A.1.3 Medium voltage fuses shall provide both short circuit and overload protection for the protected circuit and conductors, unless they are properly coordinated with overload protection within the equipment, for example, by using medium voltage motor-circuit fuses in combination with a contactor and overload relay.

Note: UL 347 provides details regarding coordination of motor-circuit fuses and overload elements, including the requirements for testing coordination at the take-over current.

32A.2 Medium voltage switch gear control circuit overcurrent protection

32A.2.1 Voltage and current transformers used to monitor medium voltage switchgear circuits shall be used to reduce the voltage of control circuits to 254 Vac or less. The voltage of DC control circuits shall not exceed 280 Vdc.

32A.2.2 The primary circuits of all voltage transformers shall be protected by current limiting fuses. Secondary circuits shall be protected by fuses or branch circuit type circuit breakers, with the exception of circuits supplying voltage regulators or protective relays that are essential to proper operation of the equipment. The secondary circuits of current transformers shall not be provided with overcurrent protection.

32A.3 Medium voltage output ac power circuit overcurrent protection

32A.3.1 Medium voltage output circuits shall be provided with overcurrent protection, rated or set for the output current rating of the unit.

32A.3.2 The overcurrent protection required by 32A.3.1 may be provided by medium voltage fuses or by a medium voltage circuit breaker in combination with appropriate current transformers and protective relay(s).

33 Panelboard Features

33.1 This section covers panelboard features and functions, such as common busses, multiple panel mounted automatic overcurrent devices that are accessible and intended for the control and protection of power and load electrical circuits.

33.2 Panelboards that are complete in construction and are separate from the equipment covered by this standard, such as an accessory, shall comply with the Standard for Panelboards, UL 67, and also shall be marked and include instructions in accordance with 68.2.

33.3 Panelboard components shall comply with the applicable construction, performance, marking, and rating requirements of the Standard for Panelboards, UL 67, when they are:

a) Not complete in construction,

b) Internal to the equipment covered by this standard, and

c) Accessible from outside the enclosure of the end product.

34 DC Ground Fault Detector/Interrupter

34.1 Inverters or charge controllers with direct photovoltaic inputs from a grounded photovoltaic array or arrays shall be provided with a ground-fault detector/interrupter (GFDI). The GFDI shall be capable of detecting a ground fault, providing an indication of the fault, interrupting the flow of fault current, and either isolating the faulted array section or disabling the inverter to cease the export of power. The GFDI shall comply with 34.2 – 34.6 and Sections 56 – 59.

Exception No. 1: AC modules are not required to be provided with a GFDI.

Exception No. 2: Inverters or charge controllers without GFDI devices may be used when the unit includes markings in accordance with 69.4(S).

34.2 The ground-fault detector/interrupter (GFDI) shall sense a ground fault, interrupt the ground-fault current path and provide an indication of the fault when the ground-fault currents exceed the limits shown in Table 34.1.

Table 34.1
Maximum Allowable Ground Current Detection Settings

Device dc rating (kW)	Maximum ground-fault current detecting setting (Amperes)
0 – 25	1
25 – 50	2
50 – 100	3
100 – 250	4
> 250	5

34.3 A ground fault detector/interrupter that has tripped in accordance with 34.2 shall not be capable of automatic reclosure.

34.4 When a ground fault detector/interrupter trips as a result of utility loss of power in accordance with Interactive Equipment, Section 43, it shall be capable of automatic reclosure when power is restored.

34.5 When the ground fault detector/interrupter incorporates solid-state components, the ground fault detector/interrupter circuit shall be analyzed to determine the effect of malfunction of any component excluding the short circuiting of a resistor. Critical components identified by the failure mode and effect analysis in accordance with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991, shall be derated in accordance with the Electronic Reliability Design Handbook, Military Hand Book Number 338-1988.

34.6 When the analysis specified in 34.5 indicates that the malfunction of one or more components renders the ground fault detector/interrupter inoperative, the components shall comply with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991. See 34.7 and 34.8.

34.7 With reference to 34.6, the components are to be subjected to the following test in accordance with the methods described in the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991:

a) Transient Overvoltage Test,

b) Ramp Voltage Test,

c) Electromagnetic Susceptibility Tests,

d) Electrostatic Discharge Test,

e) Thermally Cycling Tests,

f) Humidity Test, and

g) Effects of Shipping and Storage Test.

34.8 For the tests specified in 34.7:

a) Electrical supervision of critical components applies,

b) Audibility is usable as a trouble indicator for an electrical supervision circuit,

c) A field strength of 3 volts per meter is to be used for the Radiated EMI Test, and

d) Exposure class H5 is to be used for the Humidity Test.

34.9 An integral ground-fault detector/interrupter (GFDI) or a separate device shall not be linked to any main photovoltaic disconnect (internal or external to the unit) and operation of the main photovoltaic disconnect shall not affect the normal grounding of the system.

34.10 An integral ground-fault detector/interrupter (GFDI) or a photovoltaic inverter intended for operation with a separate GFDI shall be marked in accordance with 67.15.

34A PV DC Arc-Fault Protection

34A.1 Equipment that includes PV DC arc-fault protection functionality shall comply with the applicable portions of the Standard for Photovoltaic (PV) DC Arc-Fault Circuit Protection, UL 1699B. PVRSS, PVRSE, PVIE and other electronics that are connected within PV array strings, shall be present in a normal operating condition during evaluation according to applicable UL 1699B requirements and tests including, but not limited to, those defined for PV AFCI for use with PV DC to DC converters.

34A.2 Equipment and systems such as, but not limited to, PVRSE, PVRSS, and PVIE that have components such as, but not limited to, power supplies and capacitors integrated or connected to PV system dc circuits, which are required to have PV DC arc-fault protection shall be evaluated and shall not interfere with the PV DC arc-fault protection functionality. Interference includes filtering, masking, and attenuation of arc signals.

Note: Switching noise and input filter capacitance from such equipment and systems integrated or connected to PV system dc circuits can interfere with the PV DC arc-fault protection functionality. Electromagnetic compatibility testing is outside the scope of this standard. However, manufacturers should ensure that such equipment and systems will not interfere with the PV DC arc-fault protection functionality. Both of the following should be considered:

a) Evaluate the conducted emissions from such equipment and systems back to PV system dc circuits using the test procedures in CISPR 11:2015 for dc ports from 9kHz to 150kHz. Since CISPR 11 does not have limits for this frequency range, evaluate the PV system dc circuits with and without such equipment and systems to determine noise their contribution. This noise contribution, especially broadband noise and switching noise, should not interfere with the PV DC arc-fault protection functionality. The test procedures and noise levels are part of a proposal, which is still being worked on and will be proposed in the future.

b) Evaluate the suitability of the input impedance of such equipment and systems using the applicable sections of the Standard for Photovoltaic (PV) DC Arc-Fault Circuit Protection, UL 1699B, to verify that the input filter design does not interfere with the PV DC arc-fault protection functionality.

35 Printed-Wiring Boards

35.1 A printed-wiring board in a unit shall comply with the Standard for Printed-Wiring Boards, UL 796. For a unit with miscellaneous or ventilation openings in the enclosure, the board shall be classed V-0 or V-1 in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. The use of a material Classed V-2 requires the use of an enclosure without openings. Drain holes are not prohibited regardless of the material Class.

Exception: This requirement does not apply to a printed wiring board connected only in low-voltage, limited-energy (LVLE) circuits and where deterioration or breakage of the bond between a conductor and the base material does not result in a risk of fire or electric shock.

36 External Transformers

36.1 A manufacturer-specified external isolation transformer, see 2.1.31, shall comply with the Standard for Dry-Type General Purpose and Power Transformers, UL 1561, or the Standard for Transformers, Distribution, Dry-Type – Over 600 Volts, UL 1562, whichever applies.

36.2 A product that measures the utility voltage and frequency through a manufacturer-specified external isolation transformer that is also used to export power to the EPS shall be provided with that manufacturer-specified external isolation transformer.

36.3 A product, not covered by 36.2, that uses a manufacturer-specified external isolation transformer shall be provided with instructions in accordance with 68.2.8.

36A Voltage Dividers

36A.1 This section covers voltage dividers intended to be used in equipment rated over 1500 V to provide voltage measurement or signaling. While these voltage dividers do not provide galvanic isolation, compliance with this section provides protection for accessible signal circuits as required by 30.5.

36A.2 Voltage dividers shall consist of a minimum of two sections, including one or more primary sections and one or more low voltage sections.

36A.3 Each primary section of a voltage divider shall consist of no less than two components, connected in series.

36A.4 Each low voltage section of a voltage divider shall consist of no less than two components, connected in parallel.

36A.5 Accessibility of live parts of a voltage divider shall be judged based on the accessibility requirements elsewhere in this standard.

36A.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.

36A.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 26.

36A.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 304.8 mm (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 304.8 mm (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 26.

36A.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.

36A.10 The fault conditions to be considered in 36A.9 are to include the opening and shorting of each component in the voltage divider circuit, one at a time.

36A.11 Equipment incorporating a voltage divider shall comply with all performance requirements of this standard, including power frequency withstand and impulse tests, with the voltage divider installed as intended.

36A.12 Voltage dividers that are supplied as part of switchgear complying with IEEE C37.20.9 are not required to be evaluated in accordance with 36A.1 – 36A.11.

PROTECTION AGAINST RISKS OF INJURY TO PERSONS

37 General

37.1 When operation, maintenance, or foreseeable misuse of a unit involves a risk of injury to persons, protection shall be provided to reduce the risk.

37.2 Among the factors to be regarded in judging exposed moving parts are:

a) Degree of exposure required to perform its intended function,

b) Sharpness of the moving part,

c) Potential for unintentional contact,

d) Speed of the moving part, and

e) Potential for a part of the body to be endangered or for clothing to be entangled by the moving part.

These factors are to be regarded with respect to both intended operation of the unit and foreseeable misuse.

37.3 Whether a guard, a release, an interlock, or similar device is required and whether such a device functions as intended shall be determined from a study of the complete unit, its operating characteristics, and the potential for a risk of injury to persons. The investigation is to include evaluation of the results of a breakdown or malfunction of any one component; however, not more than one component is to be investigated at a time, unless one event contributes to another. When the study shows that malfunction of a component is able to result in a risk of injury to persons, that component is to be investigated for reliability.

38 Enclosures and Guards

38.1 A part capable of resulting in a risk of injury to persons shall be enclosed.

38.2 An opening in a guard or enclosure around a moving part that is able to involve a risk of injury to persons shall have a minor dimension less than 25.4 mm (1 inch), and shall not accommodate the probe illustrated in Figure 11.1 to contact the part when the probe is inserted through the opening to its maximum depth in a straight or articulated position.

38.3 An enclosure, an opening, a frame, a guard, a knob, a handle, or similar component, shall not be sharp enough to constitute a risk of injury to persons in normal maintenance or use.

38.4 A guard or portion of an enclosure acting as a guard for a part that involves a risk of injury to persons shall be:

a) Mounted to the assembly so that the part is unable to be operated with the guard or portion of the enclosure removed,

b) Secured to the assembly using fasteners requiring a tool for removal, or

c) Provided with an interlock to reduce the risk of contacting the part.

39 Moving Parts

39.1 A rotating member, such as a fan blade, breakage of which results in a risk of injury to persons, shall be enclosed or guarded to reduce the risk of injury to persons.

39.2 A rotating or moving part that involves a risk of injury to persons when it becomes disengaged shall be provided with a positive means to retain it in place under conditions of use.

40 Switches and Controls

40.1 When unintentional operation of a switch involves a risk of injury to persons, the actuator of the switch shall be located or guarded so that such operation is unforeseeable.

40.2 When required in accordance with 40.1, the actuator of a switch shall be guarded by recessing ribs, barriers, or similar component.

41 Mounting

41.1 When mounting instructions furnished with a unit specify mounting hardware that is not readily available commercially, the manufacturer shall provide the hardware with the unit.

OUTPUT POWER CHARACTERISTICS AND INTERACTIVE COMPATIBILITY

42 General

42.1 A stand-alone inverter shall comply with 48.2.1 and with the harmonic voltage distortion requirements in 48.4.1.

42.2 A utility-interactive inverter shall comply with the applicable tests in Interactive Equipment, Section 43.

43 Interactive Equipment

43.1 A utility-interactive inverter or interconnection system equipment (ISE) shall comply with the Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE 1547-2003 or more recent amendments and versions, and the Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547.1-2005 or more recent amendments and versions, excluding the requirements for Interconnection Installation Evaluation, Commissioning Tests, and Periodic Interconnection Tests.

Note 1: NFPA 70 (NEC) article 705 for Interconnected Electric Power Sources uses the term Interactive Equipment, which is a generic term that covers utility interactive, grid support utility-interactive or special purpose utility interactive.

Note 2: Different local utility interconnection rules require multiple dated revisions of the IEEE 1547 and IEEE 1547.1 standards. Products may be evaluated to and rated for compliance with individual or multiple specific grid interconnection standards, some of which include specific SRDs.

43.2 Interactive equipment and interconnection system equipment (ISE) shall be provided with adjustable functions, parameters, limits and response times as defined by product ratings, including referenced interconnection requirements.

43.3 For interactive inverter or interconnection system equipment (ISE) with adjustable parameters, the controls (locally or accessible through communication) shall only be accessible to authorized personnel.

43.4 For units with adjustable parameters, the installation manual shall describe the adjustment ranges in addition to the default factory settings, see 68.2.1(g).

43.5 Units with adjustable parameters shall be provided with a means to indicate the programmed parameters. A display or interface for a companion tool (such as a smartphone, notebook, tablet, or any other accessory that can be used with the system) for the display of the programmed parameters complies with this requirement.

Exception: ISE with provisions for signal injection testing of trip limits, trip times and reconnect time delay complies with this requirement.

43.6 Each combination of microprocessor model, manufacturer and firmware/software version used in the production of an interactive inverter or interconnection system equipment (ISE) shall be evaluated in accordance with 43.1.

Exception: For units with firmware/software that is in compliance with the Standard for Software in Programmable Components, UL 1998, or Automatic Electrical Controls – Part 1: General Requirements, UL 60730-1, and any applicable Part 2 standard from the UL 60730 series subsequent firmware/software revisions may be entitled to a limited revaluation in accordance with 43.1 as determined by the subsequent UL 1998 or applicable UL 60730 standard evaluation of the revised firmware or software. The scope of the 43.1 re-evaluation shall be defined by the potential impact of the firmware or software revisions.

43.7 Interconnection systems equipment (ISE), end product DER's, and components that are subject to end product standards other than UL 1741 may be evaluated and tested for compliance in accordance to the end product standards with the addition of the various grid interconnection requirements in this standard, and as defined by referenced standards (such as IEEE 1547 and IEEE 1547.1), that are not covered by the end product standards.

Note: Multiple other standards such as the Standard for Stationary Engine Generator Assemblies, UL 2200, reference UL 1741 for evaluation of interactive compliance.

43.8 Medium voltage switchgear provided to interface with a utility shall comply with IEEE C37.20.2, IEEE C37.20.3, or IEEE C37.20.9 as appropriate. Such switchgear shall be provided with an isolation means to disconnect the equipment from the utility and interlocking to prevent access to the parts of the switchgear operating above 1000 V if the switchgear is not isolated from the utility. Consideration shall be given to providing a means to isolate the switchgear from the inverter output to allow for servicing the switchgear without being exposed to hazardous voltages.

PERFORMANCE

44 General

44.1 Inverters and converters shall be subjected to the tests described in Sections 46 – 60.

44.2 Unless otherwise specified, the unit is to be energized from a supply that simulates the current-voltage characteristics and time response of the input source. Where the results of a test could be affected by the voltage versus current characteristics and short circuit current capability of the supply, the source is to be adjusted to the maximum rated input voltage of the DUT. The current capability of the test source, measured at the DUT terminals, shall be equal to or greater than the rated maximum input short-circuit current of the DUT. The output of a utility-interactive inverter or converter is to be connected to a supply voltage as specified in 44.3 and Table 44.1.

Table 44.1
Output Voltages for Tests

Rated ac output voltage	AC test voltage
110 – 120	120
121 – 219	Rated voltage
220 – 240	240
241 – 253	Rated voltage
254 – 277	277
278 – 439	Rated voltage
440 – 480	480
481 – 525	Rated voltage
550 – 600	600

44.3 When a simulated utility source is required for a test, the impedance of the simulated utility source for a utility-interactive inverter shall be less than 5 percent of the inverter output impedance where the inverter output impedance is equal to the inverter rated output voltage divided by the inverter rated output current.

44.4 When a simulated utility source is required for a test, the actual utility is able to be used for the simulated utility.

44.5 Input and output overcurrent protection is to be installed in accordance with the manufacturer's instructions.

44.6 The equipment under test provided with, or intended for use with, specific defined input sources that cannot provide the input power range described in the test shall be tested within the limitations of the specified or supplied input source. Under these circumstances, the test may be performed with the actual utility source or a simulated source. Test results shall only be applicable to the combination of the equipment under test and the specified source, and this limitation is to be noted.

45 Maximum-Voltage Measurements

45.1 The maximum voltage determined in accordance with 45.2 and 45.3 is to be used as a basis for the:

a) Calculation of the dielectric voltage-withstand test potentials specified in 47.1, and

b) Determination of the minimum spacings specified in Spacings, Section 26, or Alternate Spacings – Clearances and Creepage Distances, Section 27.

45.2 A connector or comparable part that is expected to be disconnected during intended operation is to be both connected and disconnected during the test to obtain maximum voltage.

45.3 When a complex voltage is present, the peak value of the voltage is to be measured and this value is to be used for calculation of the dielectric voltage-withstand potential and determination of the minimum spacings. For a sinusoidal or a direct current voltage, the rms or average values respectively is to be measured.

46 Temperature

46.1 A unit shall not attain a temperature at any point so as to result in a risk of fire, to damage any material used, to result in the operation of a protective device, or to exceed the maximum temperatures specified in 46.2 and Table 46.1 and Table 46.2:

a) When the unit is delivering maximum rated output power in an ambient temperature as specified in 46.3, and

b) For a unit marked for operation at a higher ambient at reduced output power, the test is to also be performed at the specified higher ambient and the associated reduced output power.

Table 46.1
Maximum Temperature

Materials and components	Degrees °C	°F
1. Capacitors:		
a. Electrolytic types	65[b]	149[b]
b. Other than electrolytic	90[b]	194[b]
2. Field wiring terminals	75[c]	167[c]
3. Vulcanized fiber employed as electric insulation	90	194
4. Relays, solenoids, and similar components		
a. Class 105 (Class A) coil insulation systems:		
Thermocouple method	90[a]	194[a]
Resistance method	110	230
b. Class 130 (Class B) coil insulation systems:		
Thermocouple method	110[a]	230[a]
Resistance method	120	248
5. Transformer insulation systems:		
a. Class 105 (Class A):		
Thermocouple method	90[a]	194[a]
Resistance method	95	203
b. Class 130 (Class B):		
Thermocouple method	110[a]	230[a]
Resistance method	120	248
c. Class 155 (Class F):		

Table 46.1 Continued on Next Page

Table 46.1 Continued

Materials and components	Degrees °C	Degrees °F
Thermocouple method	135[a]	275[a]
Resistance method	140	284
d. Class 180 (Class H):		
Thermocouple method	150[a]	302[a]
Resistance method	160	320
e. Class 200 (Class N):		
Thermocouple method	165[a]	329[a]
Resistance method	175	347
f. Class 220 (Class R):		
Thermocouple method	180[a]	356[a]
Resistance method	190	374
6. Phenolic composition employed as electrical insulation or as a part the deterioration of which results in a risk of fire or electric shock	150[d]	302[d]
7. Wood and other combustible material	90	194
8. Rubber- or thermoplastic-insulated wire and cord	60[d,e]	140[d,e]
9. Other types of insulated wire	f	f
10. A surface upon which a stationary unit is mounted and surfaces that are adjacent to the unit when so mounted	90	194
11. Any point on or within a terminal box or wiring compartment of a fixed unit which field-installed conductors are able to contact	60[c]	140[c]
12. Thermoplastic sealing compound	g	g
13. Selenium rectifier	75[h,d]	167[h,d]
14. Power semiconductor	i	i
15. Printed-wiring board	j	j

[a] At a point on the surface of a coil where the temperature is affected by an external source of heat, the temperature measured by a thermocouple is able to be 5 °C (9 °F) higher than that specified when the temperature of the coil as measured by the resistance method is not more than that specified.

[b] A capacitor that operates at a temperature of more than 65 °C (149 °F) for electrolytic or more than 90 °C (194 °F) for other types that are rated for a higher temperature shall not exceed its marked temperature limit.

[c] The temperature observed on the terminals and at points within a terminal box or wiring component of a unit is able to exceed the values specified and shall not attain a temperature higher than the temperature marking required 66.12 and 69.4 (L) and (M).

[d] The temperature limitation on phenolic composition and on rubber and thermoplastic insulation do not apply to a compound that has heat-resistant properties in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

[e] For a short length of rubber- or thermoplastic-insulated cord inside the unit, a temperature greater than 60 ° C (140 °F) where each individual conductor has supplementary insulation rated for the measured temperature and has dielectric properties in accordance with the Standard for Polymeric Materials – Short Term Property Evaluations, UL 746A, and the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

[f] Other than specified in (e), the maximum temperature shall not to exceed the temperature rating of the wire.

[g] The sealing compound temperature limit is 15 °C (27 °F) less than the softening point of the compound as determined in accordance with the test method for Vicat Softening Temperature of Plastics, ASTM D1525-91.

[h] A maximum temperature of 85 °C (185 °F) applies where the stack assembly is insulated with phenolic composition or other insulating material rated for a temperature of 150 °C (302 °F) or more.

[i] For a power-switching semiconductor and similar devices, the maximum temperature limit on the case shall not exceed the maximum case temperature specified by the semiconductor manufacturer.

[j] For a printed-wiring board, the maximum temperature shall not exceed the temperature rating of the board.

46.2 The temperature of a surface that is subject to contact shall not be more than specified in Table 46.2.

Exception: The temperature maximums specified for casual contact in Table 46.2 do not apply when:

a) The unit is a fixed unit that is typically not subject to contact by persons;

b) The unit is marked as required by 67.8; and

c) The unit is provided with instructions as specified in 69.4(H).

Table 46.2
Maximum Surface Temperatures

Location	Composition of surface[a]			
	Metal		Nonmetallic	
Handles or knobs that are grasped for lifting, carrying, or holding	50 °C	(122 °F)	60 °C	(140 °F)
Handles or knobs that are contacted that do not involve lifting, carrying, or holding; and other surfaces subject to contact and user maintenance	60 °C	(140 °F)	85 °C	(185 °F)
Surfaces subject to casual contact[b]	70 °C	(158 °F)	95 °C	(203 °F)

[a] A handle, knob, or similar component made of a material other than metal that is plated or clad with metal having a thickness of 0.127 mm (0.005 inch) or less is to be judged as a nonmetallic part.

[b] See Exception to 46.2.

46.3 The temperature maximums in Table 46.1 and Table 46.2 are based on an ambient temperature of 25 °C (77 °F). Tests are to be performed in the ambient temperature specified in Table 46.3 and corrected in accordance with Table 46.3.

Table 46.3
Temperature Measurement Correction

Ambient temperature rating of unit	Test ambient temperature	Correction of observed temperature
1. 25 °C (77 °F)	Range of 10 – 40 °C (50 – 104 °F)	a
2. Range of 25 – 40 °C (77 – 104 °F)	Range of 20 – 40 °C (68 – 104 °F)	b
3. Above 40 °C (104 °F)	Rated ambient [c]	d

[a] The measured temperature is to be corrected by addition [when the test ambient temperature is lower than 25 °C (77 °F)] or by subtraction [when the test ambient is higher than 25 °C (77 °F)] of the difference between 25 °C (77 °F) and the test ambient temperature.

[b] The measured temperature is to be corrected by addition (when the test ambient temperature is lower than the rated ambient temperature) or by subtraction (when the test ambient temperature is higher than the rated ambient temperature) of the difference between the rated ambient temperature and the test ambient temperature.

[c] Tolerances are:

Minus – not less than 5 °C (9 °F) below rated ambient.

Plus – not specified.

[d] When the test ambient temperature equals rated ambient, no correction is to be made, and the measured temperature shall not exceed the maximum temperature limit specified in Table 46.1. When the test ambient temperature is other than rated ambient, correction is to be made as described in b.

46.4 Temperatures used to determine compliance are to be stable. A temperature is stable when three successive readings taken at intervals of 10 percent of the previously elapsed duration of the test, and not less than 15 minutes apart, indicate no further increase in temperature.

46.5 During the temperature test, the unit is to be connected as specified in 44.2 and mounted as in normal service to provide for normal convection cooling.

46.6 A unit intended for mounting or support in more than one position or in a confined location is to be tested in a manner representing the most severe conditions. An adjacent mounting or supporting surface shall consist of 25.4-mm (1-inch) thick soft-pine boards.

46.7 Thermocouples are to consist of wires not larger than 24 AWG and not smaller than 30 AWG. When thermocouples are used in determining temperatures, it is common practice to employ thermocouples consisting of 30 AWG iron and constantan wire and a potentiometer type instrument. Such equipment is to be used whenever referee temperature measurements by thermocouples are required. The thermocouples and related instruments are to be accurate and calibrated in accordance with laboratory practice. The thermocouple wire is to conform with the requirements specified in the Tolerances on Initial Values of EMF versus Temperature tables in the Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples, ANSI/ASTM E230/E230M.

46.8 A thermocouple junction is to be held securely in intimate thermal contact with the surface of the material being tested. Thermocouples are to be secured to surfaces by welding, brazing, soldering, fuller's earth and sodium silicate (waterglass), adhesive rated for the surface and temperatures involved, or an equivalent method. Tape is not to be used as a means of securing the thermocouple junction. The thermocouple lead is to be secured so that strain on the lead does not affect the adhered thermocouple junction. Tape is usable as a means of strain relief for the thermocouple junction.

46.9 Coil and winding temperatures are to be measured by thermocouples located on exposed surfaces.

Exception: The change-of-resistance method is to be used for a coil that is inaccessible for attachment of thermocouples, such as a coil:

a) Immersed in sealing compound,

b) Wrapped with thermal insulation, or

c) Wrapped with more than two layers of material, such as cotton, paper, or rayon, more than 0.8 mm (1/32 inch) thick.

46.10 The temperature of a winding by the change-of-resistance method is to be determined using the following formula:

$$T = \frac{R}{r}(k + t) - k$$

in which:

T is the temperature of the winding in degrees C;

R is the resistance of the winding at the end of the test in ohms;

r is the resistance of the winding at the beginning of the test in ohms;

t is the ambient temperature in degrees C at the beginning of the test; and *k* is 234.5 for copper, 225.0 for electrical conductor grade (EC) aluminum. Values of the constant for other conductor materials are to be determined.

46.11 Localized component heating is able to occur in products that reduce their output power with an increase in temperature. For example, heat generating components, such as Transformers, Inductors, Capacitors, Semiconductors and other similar components, which quickly increase in temperature, independent of the temperature sensing device, are able to attain thermal peaks prior to the first or subsequent power reductions. This is more prevalent in a lower ambient. In such instances, the measured peak temperature results is to be taken as the component operating temperature and shall comply with 46.1, or the results shall be investigated to the requirements for Temperature Excursions Beyond the Maximum Use Temperature in the Standard for Polymeric Material – Electrical Equipment Evaluations, UL 746C.

46.12 Measuring the temperatures of components or conductors operating at medium voltage using thermocouples is inherently dangerous. 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.

47 Dielectric Voltage-Withstand Test on Low Voltage Circuits

47.1 Immediately following the temperature test or with the unit at normal operating temperature, a unit shall withstand for 1 minute without breakdown the application of an ac rms test potential of:

a) One thousand volts plus twice the maximum voltage (see 45.1) between:

1) the input circuit and dead metal parts,

2) the output circuit and dead metal parts, and

3) the input and output circuits.

Exception: A test between input and output circuits is not required for an inverter not provided with a transformer or capacitor network isolating the input from the output circuit.

b) Five hundred volts between a secondary circuit operating at 50 volts or less and dead metal parts; 1000 volts plus twice the maximum secondary circuit voltage between a secondary circuit operating at more than 50 volts and dead metal parts.

c) One thousand volts plus twice the voltage between the terminals of a capacitor used across the ac or dc power circuit for electromagnetic interference elimination or power factor correction; and between the terminals of a capacitor connected between an ac or dc power circuit and the enclosure.

Exception: This test potential does not apply to capacitors that comply with either the Standard for Capacitors, UL 810, the Standard for Fixed Capacitors for Use in Electronic Equipment – Part 14: Sectional Specification: Fixed Capacitors for Electromagnetic Interference Suppression and Connection to the Supply Mains, UL 60384-14, or the Standard for Electromagnetic Interference Filters, UL 1283.

Exception: As an alternative to the ac rms test potential specified, use of a dc test potential of 1.414 times the ac rms value is not prohibited.

47.2 To determine whether a unit complies with the requirements in 47.1, the unit is to be tested using a 500 volt-ampere or larger capacity transformer, the output voltage of which is variable. The applied potential is to be increased from zero until the required test level is reached, and is to be held at that level for 1 minute. The increase in applied potential is to be at a substantially uniform rate as rapid as is consistent with correct indication of its value by a voltmeter.

Exception: When a voltmeter is connected across the output circuit to directly indicate the test potential, the transformer is not required to be rated 500 or more volt-amperes.

47.3 A low-voltage control circuit or a sensor circuit is not required to be connected during the test. Any circuit which is connected from input to output circuit shall remain connected during the test and provide proper isolation in accordance with 2.1.25.

47A Power Frequency Withstand Test on Medium Voltage Circuits

47A.1 Equipment having medium voltage circuits shall withstand for 1 minute without breakdown the application of an ac rms test potential equal to the dielectric voltage withstand rating of the equipment in accordance with Table 47A.1, between

a) All medium voltage circuits and ground, and

b) All medium voltage circuits and low voltage circuits.

47A.2 Medium voltage isolation means shall withstand for 1 minute without breakdown the application of an ac rms test potential equal to 110 % of the dielectric voltage withstand rating of the equipment between the line side terminals and load side terminals of the isolating means, with the isolating means in the open position.

Exception: This test is not required for an isolation means that has been previously subjected to this test as part of the evaluation of the medium voltage switchgear in which the isolating means is located.

Table 47A.1
Rated Insulation Levels

Rated Maximum Voltage (kV rms)	Insulation Levels	
	Power Frequency Withstand Voltage (kV rms)	Impulse Withstand (BIL) (kV peak)
4.76	19	60
8.25	36	95
15.0	36	95
27.0	60	125
38.0	80	150

48 Output Power Characteristics

48.1 General

48.1.1 When a utility-interactive inverter or AC module is required to be connected to a simulated utility source by Sections 48.2 – 48.4, the simulated utility source shall be in accordance with 44.3.

48.2 Output ratings

48.2.1 For a stand-alone inverter or converter, the output voltage shall be within ±10 percent of its rated output voltage range when it is connected to its rated input supply and loaded over its full range of rated output current. The output frequency shall be within ±1 Hz of rated output frequency.

48.2.2 A utility-interactive inverter or converter shall be capable of operating at rated output current ±10 percent when loaded and connected to the rated input and to a simulated utility source. The input source shall be capable of delivering twice the unit's rated input current rating of the inverter.

48.2.3 When connected to a simulated utility source, an AC module shall be within ±10 percent of its rated output power and current when run with a dc input voltage and current set at the photovoltaic module maximum power point, rated voltage (V_R), and current (I_R).

48.2.4 For units marked with lower output ratings at higher ambient temperatures, the ratings shall be verified in accordance with 48.2.1 – 48.2.2 at the higher ambient.

48.3 Input range

48.3.1 A utility-interactive inverter or converter shall operate as intended when the input is varied within the unit's marked input range. During the test, the utility-interactive inverter or converter is to be loaded to its rated load with the minimum and maximum input voltage supplied to the unit. The load for a stand-alone inverter or converter is to include both resistance and inductance with a power factor of 0.5.

Exception: This test does not apply to an AC module inverter that is provided integral to a photovoltaic panel.

48.4 Harmonic distortion

48.4.1 For a stand-alone inverter, the total rms of the harmonic voltages, excluding the fundamental delivered, shall not exceed 30 percent of the fundamental rms output voltage rating. The rms voltage in any single harmonic shall not exceed 15 percent of the nominal fundamental rms output voltage rating. The measurements are to be made with the inverter delivering 100 percent of its rating to a resistive load.

Exception: A unit having total rms harmonic voltages exceeding 30 percent of the fundamental rms output voltage rating meets the intent of the requirement when the inverter is marked in accordance with 66.29.

49 Utility Compatibility

49.1 Utility-interactive inverter and ISE shall comply with the Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE 1547-2003, and the Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547.1-2005, excluding the requirements for Interconnection Installation Evaluation, Commissioning Tests, and Periodic Interconnection Tests.

49.2 Grid support interactive inverters and ISE shall comply with:

a) Supplement SA for Grid Support Utility-Interactive Equipment, and/or

b) Supplement SB for Grid Support Utility-Interactive Inverters and Converters Based upon IEEE 1547-2018 and IEEE 1547.1-2020.

49.3 Special purpose interactive inverters and ISE shall comply with the corresponding requirements for the manufacturer’s product ratings and stated compliance with specific interconnection requirement(s).

50 Abnormal Tests

50.1 General

50.1.1 A unit shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons – see 50.1.3 – when subjected to the tests specified in 50.1.2 – 50.7.3. Separate units are usable for these tests.

50.1.2 Following each test, the unit shall comply with Dielectric Voltage-Withstand Test, Section 47. The potential is to be applied across the points indicated in Table 50.1. For medium voltage circuits, the voltage is to be applied between medium voltage and low voltage circuits, and between medium voltage circuits and ground.

Exception No. 1: More than one abnormal test is able to be conducted on a unit, and the dielectric voltage-withstand test is able to be conducted after completion of all abnormal tests.

Exception No. 2: This test is not required following the DC Input Miswiring Test, 50.4.

Table 50.1
Dielectric Voltage-Withstand Test Following Abnormal Tests

Test No.	Circuit parts
1	ac power circuits to dc power circuits
2	ac and dc power circuits to accessible dead metal parts
3[a]	primary to secondary winding of isolating transformer
[a] Perform only after Short-Circuit Test, Section 50.3.	

50.1.3 A risk of fire, electric shock, or injury to persons exists when there is:

a) Emission of flame, molten metal, glowing or flaming particles through any openings (pre-existing or created as a result of the test) in the product,

b) Charring, glowing, or flaming of the supporting surface, tissue paper, or cheesecloth,

c) Ignition of the enclosure,

d) Creation of any openings in the enclosure that results in accessibility of live parts, as determined in accordance with Accessibility of Uninsulated Live Parts, Section 11, or

e) Opening of the 3-ampere fuse connected to ground. See 50.1.6.

50.1.4 During these tests, the unit is to be placed on a softwood surface covered with white tissue paper. A single layer of cheesecloth is to be draped loosely over the entire enclosure. The cheesecloth is to be untreated cotton cloth running 28 – 30 m^2/kg (14 – 15 yards per pound), and having, for any square inch, a count of 32 threads in one direction and 28 in the other direction.

Exception No. 1: A unit not having bottom openings is not required to be placed on a softwood surface covered with tissue paper.

Exception No. 2: When it is inappropriate to drape the entire unit, cheesecloth is able to be placed only over all ventilation openings.

50.1.5 The input and output ports of the unit are to be connected as specified in 44.2 – 44.5 during these tests. Overcurrent protection for those ports shall be connected in accordance with the instructions provided with the unit and in accordance with the markings on the unit.

50.1.6 The enclosure of the unit is to be connected to ground through a 3-ampere fast acting fuse.

50.1.7 Each test is to be continued until ultimate results and there is no further change as a result of the test condition. When an automatically reset protector functions during a test, the test is to be continued for 7 hours. When a manual reset protector functions during a test, the test is to be continued until the protector is operated for 10 cycles using the minimum resetting time, and not at a faster rate than 10 cycles of operation per minute. The following defines the termination of the test:

a) Opening or shorting of one or more components such as capacitors, diodes, resistors, solid-state devices, printed wiring board traces, or similar components.

b) Opening of an internal fuse.

Exception No. 1: When the manually reset protector is a circuit breaker that complies with the Standard for Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures, UL 489, it is to be operated for 3 cycles using the minimum resetting time not exceeding 10 cycles of operation per minute.

Exception No. 2: A manual reset protector that becomes inoperative in the open condition is able to be operated fewer than 10 cycles, and not less than 3 cycles.

50.2 Output overload test

50.2.1 After thermal stabilization is reached during the conditions described in Temperature, Section 46, the following tests are to be performed:

a) A stand-alone inverter is to be subjected to the overload test described in 50.2.3, while delivering maximum rated output power to an adjustable resistive load connected to the output ac circuit, and

b) A utility-interactive inverter is to be subjected to the overload test described in 50.2.4.

As a result of the tests, a unit shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons, see 50.1.3.

50.2.2 Firmware or Software controlling the temperature limits of an inverter shall be disabled for the tests described in 50.2, or evaluated for reliability in accordance with the Standard for Software in Programmable Components, UL 1998.

50.2.3 For units that charge batteries, the dc output is to be connected to a simulated battery load in accordance with Sources and Loads, Section 75. The load is to be increased in increments of 10 percent of the maximum output rating of the unit and held for 1/2 hour at each increment until:

a) There is no further change as a result of the test condition, or

b) The unit shuts down.

Exception: Thermal stabilization is obtainable with a load adjusted to result in maximum obtainable output power without resulting in operation of overcurrent protective devices, followed by increased incremental loading as described in 50.2.3.

50.2.4 For a utility-interactive inverter, the input is to be connected to a source that delivers a minimum of twice the rated input current. The utility voltage is to be adjusted to provide for the maximum output current. The utility is not to be adjusted less than the utility trip voltage rating. The inverter is to remain in the loaded condition until it shuts down, reaches thermal stabilization, or has been operated for seven hours, whichever occurs first.

50.3 Short-circuit test

50.3.1 The dc battery circuit and the ac output circuit of a unit are to be shorted separately. The shorting is to be from line to neutral (when applicable) and from line to line.

50.3.2 When shorting the unit, the source (input or output/utility) is to be disconnected by a relay or similar device.

50.3.3 With reference to Table 65.1, item (m), the maximum inverter output fault current (peak and RMS) and short circuit current duration are to be measured immediately after the short is applied.

50.3.4 The short-circuit test is to be performed a total of four times so the short occurs in different portions of the line cycle.

50.3.5 For a unit with a 3-phase output, the test is to be performed with shorts applied from phase to phase and from phase to neutral or ground.

50.3.6 For a unit intended for use with external isolation transformers, the short is to be applied before and after the external transformer.

50.3.7 The location of the applied short in the test circuit shall not direct the output short-circuit test current through the 3-ampere ground fuse described in 50.1.6.

50.4 DC input miswiring test

50.4.1 The dc input of a unit is to be connected in accordance with Table 50.2. As a result of the tests, a unit shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons, see 50.1.3.

Table 50.2
DC Input Miswiring Test

Input terminal polarity	DC source polarity
Positive	Negative
Negative	Positive

50.5 Ventilation test

50.5.1 A unit having forced ventilation, using fan motors that have been investigated for the locked-rotor condition, is to be operated at full load with the power to the forced ventilation disconnected.

50.5.2 A unit having forced ventilation, using fan motors that have not been investigated for the locked-rotor condition or when the heating of the locked fan motor adds to the heating of the enclosure, is to be operated with the rotor of a fan motor locked. For a unit having more than one fan motor, the test is to be performed with the rotor of each fan motor locked, one at a time.

Exception: Simultaneously locking all fan motors in a unit having more than one fan motor is not prohibited.

50.5.3 A unit having filters, guards, or screens over input ventilation openings that are able to be clogged is to be operated with the openings blocked to represent clogging. The test is to be performed initially with the input ventilation openings blocked 50 percent and then repeated under a fully blocked condition. For a unit having multiple input ventilation openings, the test is to be performed with all of the input ventilation openings blocked 50 percent and then repeated with all of the input ventilation openings fully blocked.

50.6 Component short- and open-circuit

50.6.1 Components, such as capacitors, diodes, solid-state devices, and similar components, are to be short- or open-circuited, any two terminals, one pair at a time. Short circuiting a resistor is excluded.

Exception: This test is not required:

a) Where circuit analysis indicates that no other component or portion of the circuit is able to be overloaded.

b) For components in low-voltage, limited-energy (LVLE) circuits, or other circuits that are not required to be investigated in accordance with this Standard.

50.6.2 In addition to compliance with 50.1.3, during the test described in 50.6.1 for a utility-interactive inverter or converter, the maximum backfeed current that flows from the simulated utility source, see 44.3, into the input source as a result of a faulted component shall not exceed the marked maximum input source backfeed current. See Table 65.1, Item (e).

50.7 Load transfer test

50.7.1 With reference to the Exception to 14.9, a bypass switch shall continue to operate normally after completion of the test described in 50.7.2 and 50.7.3.

50.7.2 The bypass ac source is to be displaced 120 electrical degrees from the ac output of the inverter for a 3-phase supply or 180 electrical degrees for a single phase supply. The transfer switch is to be subjected to one operation of switching the load from the ac output of the inverter to a bypass ac source. The load is to be adjusted to draw maximum rated ac power.

50.7.3 For an inverter employing a bypass switch having a control preventing switching between two ac sources out of synchronization, the test specified in 50.7.2 is to be conducted under the condition of a component malfunction – see 50.6.1 – when such a condition results in an out-of-phase transfer between the two ac sources of supply.

50.8 Loss of control circuit

50.8.1 A utility-interactive inverter or interconnection system equipment (ISE) shall cease the export of power to the EPS upon the loss of control circuit power when tested in accordance with 50.8.2.

50.8.2 The inverter, converter, or interconnection system equipment (ISE) is to be connected to its rated input supply and simulated utility source. A single fault is to be placed such that it disables the power to the control circuit.

Exception No. 1: When the control circuit is unable to be disabled under any single fault condition, this test is not required to be performed.

Exception No. 2: The unit may continue to export power if it continues to meet 43.1 with the single fault specified in 50.8.2 in place.

51 Grounding Impedance Test

51.1 The impedance at 60 hertz between the point of connection of the equipment-grounding means and any other metal part that is required to be grounded (see 22.10) shall not be more than 0.1 ohm when measured in accordance with 51.2.

51.2 Compliance with 51.1 is determined by measuring the voltage when a current of 25 amperes derived from a 60-hertz source with a no-load voltage not exceeding 6 volts is passed between the grounding connection and the metal part in question.

52 Overcurrent Protection Calibration Test

52.1 With reference to 31.9, a fuse or circuit protective device connected to the primary of a transformer for protection of the secondary circuit shall operate to open the circuit in not more than the time indicated in Table 52.1 when the transformer is delivering the specified secondary current.

Table 52.1
Maximum Time To Open

Maximum transformer open circuit secondary voltage (V^{max}), volts	Secondary test current, amperes	Maximum time for overcurrent protective device to open, minutes
20 or less	10	2
20 or less	6.75	60
Over 20	$200/V_{max}$	2
Over 20	$135/V_{max}$	60

52.2 To determine whether a fuse or circuit protective device complies with the requirement in 52.1, the transformer is to deliver the test current to a resistance load with the primary connected to a circuit as described in 44.1. During the 2-minute test, the load is to be adjusted continuously to maintain the required test current. During the 60-minute test, the load is to be adjusted once after 15 minutes of operation and the test is to be continued without further adjustment.

52.3 Where the fuse or circuit protective device is used to protect more than one secondary winding or taps, each winding or partial winding is to be tested as indicated in 52.1 and 52.2 with the remaining windings delivering rated load.

53 Strain Relief Test

53.1 A wiring lead intended for field-wiring connection – see 18.3.1 and 18.3.3 – shall withstand without damage or displacement a direct pull of:

a) 89 N (20 lbf) for 1 minute applied to a lead extending from the enclosure (such as through a knockout), and

b) 44.5 N (10 lbf) for 1 minute applied to a lead within a wiring compartment.

53.2 An input or output cord shall withstand a 155.7 N (35 lbf) pull for one minute in the most severe direction without damage or displacement. All internal connections are to be severed during the test.

54 Reduced Spacings Tests for Low Voltage Printed Wiring Boards

54.1 General

54.1.1 With reference to Exception No. 6(a) to 26.1.1, printed wiring board traces of different potential having reduced spacings shall comply with:

a) Dielectric Voltage-Withstand Test, Section 54.2, or

b) Shorted Trace Test, Section 54.3.

54.2 Dielectric voltage-withstand test

54.2.1 A printed wiring board as specified in 54.1.1 shall withstand for 1 minute without breakdown the application of a potential between the traces having reduced spacings in accordance with 47.1, as appropriate.

54.2.2 Power-dissipating component parts, electronic devices, and capacitors connected between traces having reduced spacings are to be removed or disconnected so that the spacings and insulations, rather than these component parts, are subjected to the full test potential.

54.3 Shorted trace test

54.3.1 The printed wiring board traces described in 54.1.1 shall be short-circuited, one location at a time, and the test shall be performed as described in 50.1.1 – 50.1.7. As a result of the test:

a) The overcurrent protection associated with the branch circuit to the unit shall not open, and

b) A wire or a printed wiring board trace shall not open. When the circuit is interrupted by opening of a component, the test is to be repeated two additional times using new components, as required. Opening of an internal overcurrent protective device is a result that is in compliance with the requirement and the test is not required to be repeated.

55 Bonding Conductor Test

55.1 With reference to the Exception to 22.10, a bonding circuit, including the conductor, terminations and portions of the unit intended to be bonded, shall be subjected to the following tests using a separate bonding circuit for each test:

a) The conductor is to carry currents equal to 135 and 200 percent of the rating or setting of the intended branch-circuit overcurrent-protective device for the times specified in Table 55.1, and

b) Three specimens are to be subjected to a limited-short-circuit test using a test current as specified in Table 55.2 while connected in series with a nonrenewable fuse having a rating equal to the intended branch-circuit overcurrent-protective device.

Exception: When a fuse smaller than that indicated in (a) and (b) is employed in the unit for protection of the circuit to which the bonding conductor is connected, the magnitude of the test current and size of fuse used during the test is to be based on the rating of the smaller fuse.

Table 55.1
Duration of Overcurrent Test

Rating or setting of branch-circuit overcurrent protective device, amperes	Test time, minutes	
	135 percent of current	200 percent of current
0 – 30	60	2
31 – 60	60	4
61 – 100	120	6
101 – 200	120	8

Table 55.2
Circuit Capacity for Bonding Conductor Short-Circuit Test

Rating of unit, volt-ampere		Volts	Capacity of test circuit, amperes
Single phase	3-Phase		
0 – 1176	0 – 832	0 – 250	200
0 – 1176	0 – 832	251 – 600	1000
1177 – 1920	833 – 1496	0 – 600	1000
1921 – 4080	1497 – 3990	0 – 250	2000
4081 – 9600	3991 – 9145	0 – 250	3500
9601 or more	9146 or more	0 – 250	5000
1921 or more	1497 or more	251 – 600	5000

55.2 The test circuit described in 55.1(b) is to have a power factor of 0.9 – 1.0 and a closed-circuit test voltage as specified in Table 44.1. The open-circuit voltage is to be 100 – 105 percent of the closed-circuit voltage. The test is to be performed on each of the three specimens.

55.3 After the bonding circuits are subjected to the tests in 55.1, the circuits shall comply with Grounding Impedance Test, Section 51.

56 Voltage Surge Test

56.1 A unit provided with a ground fault detector/interrupter is to be preconditioned at a relative humidity of 93 ±2 percent at a temperature of 32.0 ±2.0 °C (89.6 ±3.6 °F). The inverter is to be exposed to ambient air at a temperature of at least 30 °C (89.6 °F) until thermal equilibrium is attained before being placed in the test chamber. An outdoor rated unit is to be kept in the chamber for 168 hours. Other units are to be kept in the chamber for 48 hours.

56.2 After conditioning the unit is to be subjected to the following surge voltage impulses in the order given:

a) Ten applications of a 6 kV surge impulse at 60 second intervals. Tripping of the interrupter is in compliance with the requirement when it does not result in a risk of fire or electric shock.

b) Ten applications of a 3 kV surge impulse at 60 second intervals. The ground-fault detector shall not trip.

A typical surge generator and dc control relay are shown in the Standard for Ground-Fault Circuit-Interrupters, UL 943.

56.3 The unit is to be connected to a supply of rated voltage. Utility-interactive inverters shall also be supplied from a simulated utility. The grounding lead or terminal of the unit is to be connected to the supply conductor serving as the neutral. The unit is to be in the "on" condition with no load connected. For each application, the voltage is to have the specified initial peak amplitude of 6 or 3 kV when applied to the supply to the unit under test. Each of the ten applications is to be random with respect to the phase of the 60 Hz supply voltage when applied on the ac circuits or at the peak voltage of the dc circuits. When three controlled applications are employed for the ac circuits, one application is to be at the zero crossing of the supply voltage wave, one at the positive peak, and one at the negative peak.

56.4 The surge generator is to have a surge impedance of 50 ohms. When there is no load on the generator, the waveform of the surge is to be as followed:

a) Initial rise time, 0.5 microseconds between 10 percent and 90 percent of peak amplitude,

b) The period of the following oscillatory wave, 10 microsecond, and

c) Each successive peak, 60 percent of the preceding peak.

56.5 After the voltage surge test is performed, the unit shall comply with the requirements of Calibration Test, Section 57, under the condition described in 57.1(a).

57 Calibration Test

57.1 The operating time of a ground fault detector/interrupter shall not exceed the time indicated in Table 57.1 when the ground fault current is as indicated in 57.2 – 57.8 under each of the specified conditions in the following sequence:

a) As received in a 25 ±3.0 °C (77.0 ±5.4 °F) ambient,

b) Immediately following conditioning 48 hours in 85 ±5 percent relative humidity at 32 ±2.0 °C (89.6 ±3.6 °F),

c) After 4 hours in 40 ±2.0 °C (104 ±3.6 °F) ambient,

d) After 5 cycles of thermal shock consisting of 4 hours at 40 ±2.0 °C (104 ±3.6 °F) followed by 4 hours at 0 ±2.0 °C (32 ±3.6 °F) for general use equipment or 4 hours at 66 ±2.0 °C (150.8 ±3.6 °F) followed by 4 hours at -35 ±2 °C (-31 ±3.6 °F) for outdoor use equipment, and

e) At 25 ±3.0 °C (77.0 ±5.4 °F).

Table 57.1
Operating Time

Ground-fault current, amperes	Time, seconds
115 percent of pickup	shall ultimately trip
150 percent of pickup	2.0
250 percent of pickup	1.0

57.2 A ground-fault detector/interrupter current relaying device with an indicated delay in operating time, whether fixed or adjustable, is, as part of the test sequence of 57.1 and in each of the conditions, to be evaluated for such delay.

57.3 With respect to 57.2, the delay is to be within the tolerance band specified by the manufacturer for the particular setting. When the tolerance band is temperature dependent, the particular band for the temperature involved in the test is to be used. When a range of delay is provided, the determination is to be made at the maximum, middle, and minimum settings of the delay adjustment. A delay expressed in terms of cycles is to be converted to time assuming a 60-Hz frequency.

57.4 In determining the operating time (including delay) under the environmental conditions of 57.1, the test is to be performed at the end of the specified exposure time while the device is still in the test environment.

57.5 To determine whether a ground fault detector/interrupter complies with the calibration test requirements, the interrupter is to be tested three times under each test condition. The test circuit is to be preset to deliver the required ground fault current. After the test current is applied to the interrupter sensor, the time required for the interrupter relaying device to operate is to be observed. When the interrupter is intended to be connected to a separate source of control power, the control voltage is to be adjusted to its rated value.

57.6 A field pick up current adjustment is to be set at its maximum value.

57.7 When power from a control power source is required to operate the device, the test described in 57.1 – 57.3 is to be repeated with the ground fault detector/interrupter connected to 55 percent of its rated voltage for ac control power and 80 percent of its rated voltage for dc control power.

57.8 The operation of a ground fault detector/interruupter shall not result in the tripping of the circuit interrupter on ground fault currents less than 85 percent of the pickup current trip limit of the ground fault sensing and realying device.

58 Overvoltage Test

58.1 A ground fault detector/interrupter intended to be continuously connected to a source of control voltage shall be capable of withstanding 110 percent of its rated control voltage continuously without damage.

58.2 Following the test in 58.1, the ground fault detector/interrupter shall comply with Dielectric Voltage-Withstand Test, Section 47.

59 Current Withstand Test

59.1 After a ground fault detector/interrupter is subjected to a high fault current condition in accordance with 59.2 and its withstand rating (current and time), it shall comply with the requirements of Calibration Test, Section 57, under the condition described in 57.1(a).

59.2 The high fault current condition referred to in 59.1 is to be created by any number of turns in the sensor "window" producing the required ampere turn value.

60 Capacitor Voltage Determination Test

60.1 In order to determine a capacitor's stored energy in accordance with 13.2.1 and 13.2.3, the unit is to be operated at a dc voltage equal to the peak value of the ac input sinewave for ac circuits, and at the maximum rated input for dc circuits, and then de-energized. Any access covers are to be quickly removed and immediately after removal, the residual voltage on any accessible capacitor is to be measured and the stored energy calculated in accordance with 13.2.3.

61 Stability

61.1 A unit positioned in the least stable normal operating position shall return to its normal at-rest position and not tip over when:

a) Canted through an angle of 10 degrees in the direction of least stability from an at-rest position on a horizontal surface,

b) Placed on a plane inclined at an angle of 10 degrees from the horizontal, or

c) Positioned in accordance with the manufacturer's instructions, and subjected to an externally-applied horizontal force of 20 percent of the weight of the unit or 22.7 kg (50 pounds), whichever is less. See 61.3.

Exception: A unit provided with instructions indicating that it is to be fastened to the supporting structure is not required to be tested for stability.

61.2 When a part or surface of the unit that is not normally in contact with the horizontal supporting surface touches the supporting surface before the unit has been tipped to an angle of 10 degrees, the tipping is to be continued until the surface or plane of the surface of the unit originally in contact with the horizontal supporting surface is at an angle of 10 degrees from the horizontal supporting surface.

61.3 The force specified in 61.1(c) is to be applied in a horizontal direction at that point on the unit that is expected to overturn the unit. The force is not to be applied more than 1.5 m (5 feet) above floor level. The legs or points of support are to be blocked to prevent the unit from sliding during the application of the force.

62 Static Load

62.1 When mounted as specified by the manufacturer, a unit intended to be fastened to a supporting structure shall be loaded as described in 62.2 with a force equal to three times the weight of the unit and not less than 89 N (20 lbf). As a result of the loading, there shall not be permanent deformation, breakage, dislocation, cracking, or other damage to the unit or its mounting hardware.

Exception: A unit intended for floor mounting or an AC module is not required to be subjected to this test.

62.2 The force is to be applied through the center of gravity of the unit, is to be increased gradually so as to reach the required value in 5 to 10 seconds, and is to be maintained at that value for 1 minute.

63 Compression Test

63.1 An enclosure that is thinner than that specified in Table 7.1, Table 7.2, or Table 7.3 shall be constructed so that during the test described in 63.2, the resulting deflection does not result in spacings less than specified in Spacings, Section 26, or Alternate Spacings – Clearances and Creepage Distances, Section 27.

63.2 A force of 445 N (100 pounds) is to be applied to the end, side, and walls of the enclosure. The enclosure is to rest on a smooth solid, horizontal surface. A vertical force is to be applied at any point through a rod having a 12.7 mm (1/2 inch) square flat steel face.

64 Rain and Sprinkler Tests

64.1 General

64.1.1 Before a rain or sprinkler test is performed, the unit is to be fitted with the intended supply connection means as described in the unit's installation instructions.

64.1.2 A unit intended for multiple mounting orientations shall be tested in all the intended orientations.

64.1.3 The rain and sprinkler tests are to be performed in the operating sequence specified in Table 64.1.

Table 64.1
Operating Sequence for Rain and Sprinkler Tests

Duration in hours	Unit	Water
1	On	Off
1/2	Off	On
1	On	On
1/2	Off	On

64.1.4 As a result of the rain and sprinkler tests, no water shall enter the unit.

Exception: When water enters ground-mounted or surface-mounted units and the water does not wet any wiring or other electrical parts that are not inherently waterproof, and when the unit is provided with drain holes in accordance with 7.9.14, the unit is in compliance with the rain and sprinkler tests.

64.2 Rain test

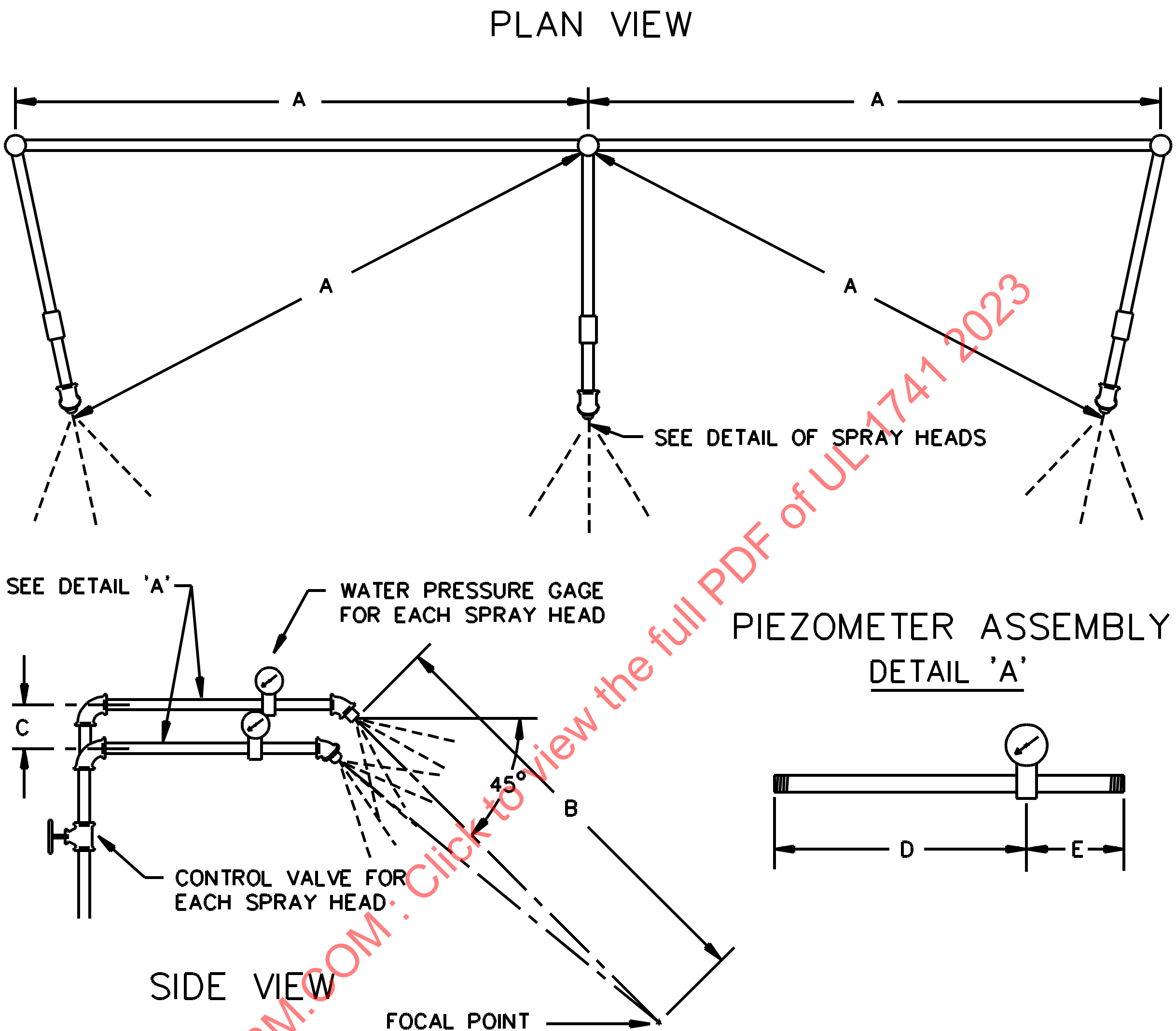
64.2.1 A unit required to be subjected to a rain test is to be tested as described in 64.2.2 and 64.2.3.

64.2.2 The water spray test apparatus is to consist of three spray heads mounted in a water supply pipe rack as shown in Figure 64.1. Spray heads are to be constructed in accordance with the details shown in Figure 64.2. The unit is to be set up as in a normal installation with conduit connections. The enclosure is to be positioned in the focal area of the spray heads so that the greatest possible quantity of water enters the enclosure. The water pressure is to be maintained at 34.5 kPa (5 psi) at each spray head.

64.2.3 A gasketed unit shall be tested after the temperature test or after operation for 1/2 hour, followed by removal and reinstallation of doors, access panels, frames, covers, or other removable parts serving to compress the gasket.

Figure 64.1

Spray Head Piping

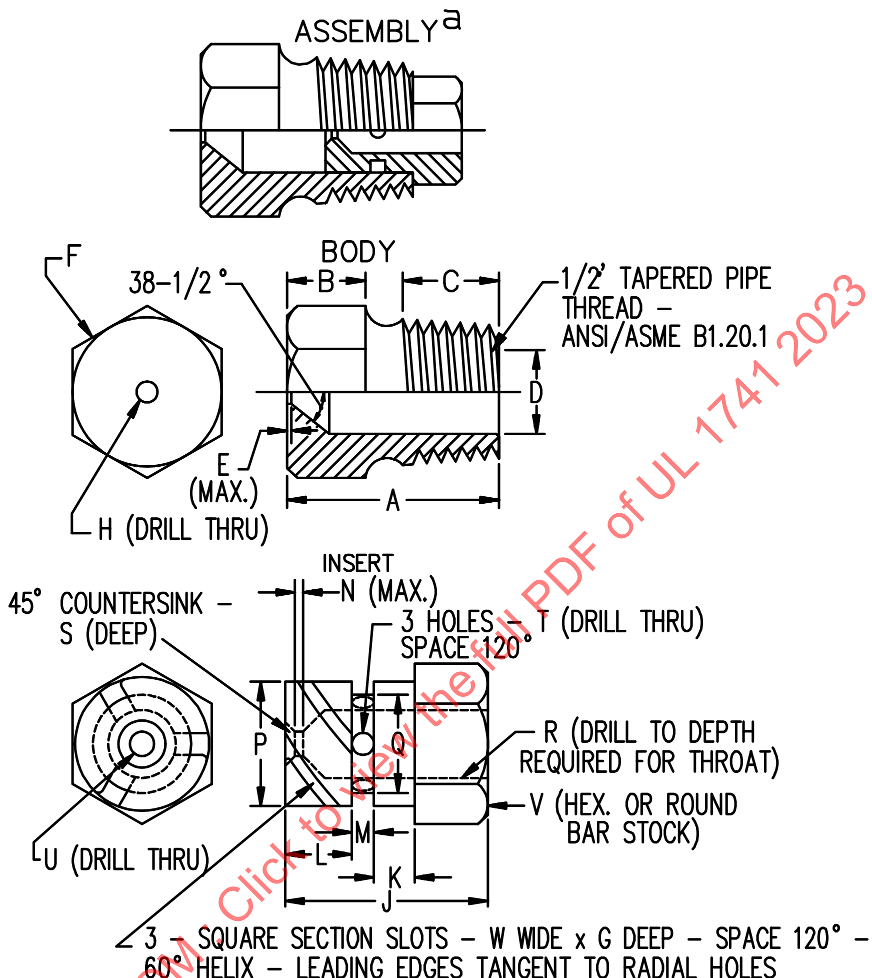


Item	inch	mm
A	28	710
B	55	1400
C	2-1/4	55
D	9	230
E	3	75

RT101E

Figure 64.2

Spray Head



Item	inch	mm	Item	inch	mm
A	1-7/32	31.0	N	1/32	0.80
B	7/16	11.0	P	.575	14.61
C	9/16	14.0		.576	14.63
D	.578	14.68	Q	.453	11.51
	.580	14.73		.454	11.53
E	1/64	0.40	R	1/4	6.35
F	c	c	S	1/32	0.80
G	.06	1.52	T	(No. 35)[b]	2.80
H	(No.9)[b]	5.0	U	(No. 40)[b]	2.50
J	23/32	18.3	V	5/8	16.0
K	5/32	3.97	W	0.06	1.52
L	1/4	6.35			
M	3/32	2.38			

[a] Nylon Rain–Test Spray Heads are available from Underwriters Laboratories

[b] ANSI B94.11M Drill Size

[c] Optional – To serve as a wrench grip.

RT100E

64.3 Sprinkler test

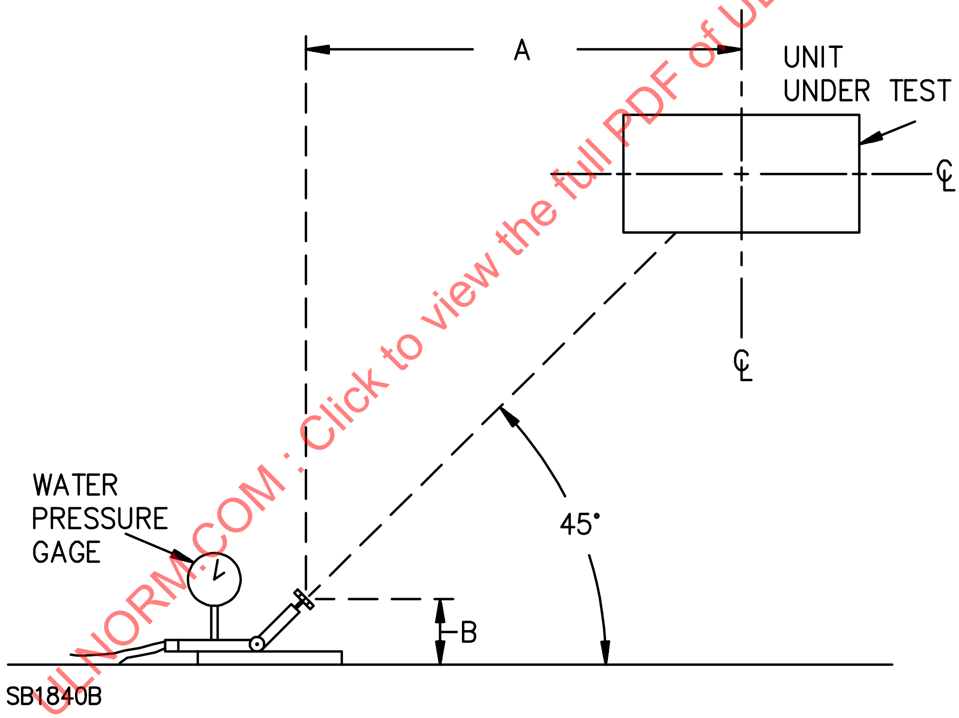
64.3.1 A unit required to be subjected to a sprinkler test is to be tested as described in 64.3.2 and 64.3.3.

64.3.2 An outdoor ground-mounted unit is to be turned about its vertical axis to each of four positions 90 degrees from each other, each for 30 minutes during the 2-hour portion of the test described in 64.1.3, with adjustable parts arranged for maximum vulnerability to the water spray. Wall-mounted units intended for mounting within 914 mm (3 feet) of the ground, are to be similarly tested in the most vulnerable normal mounting position.

64.3.3 The unit is to be positioned as shown in Figure 64.3 in front of a standard water spray head of the type shown in Figure 64.2, to which the water pressure is maintained at a gage pressure of 138 kPa (20 psi).

Figure 64.3

Representative Sprinkler Test Setup



NOTES –

The unit is to be mounted as intended with the dimensional center of the unit on a line projected from the centerline of the nozzle head.

A – 914.4 mm (36 inches)

B – 76.2 – 152.4 mm (3 – 6 inches)

64.4 Driven rain test

64.4.1 A unit with medium voltage ratings that is intended for outdoor use shall be subjected to the Driven Rain test as described in 64.4.2 – 64.4.9. This test is intended to simulate rain driven by a 29 m/s (65 mph) wind.

64.4.2 The equipment enclosure to be tested shall be fully equipped and complete with all appurtenances, such as roof bushings, conduits, busways, and the like, and it shall be mounted in the intended manner in the area to be supplied with artificial precipitation. For multiple-unit construction, a minimum of two units shall be used to test the joints and fittings between units, including a roof joint.

64.4.3 The tightening torque for rigid conduit threaded into the conduit openings in the enclosure shall be in accordance with Table 64.2.

Table 64.2
Tightening Torque

Torque		Conduit size	
N·m	(lb-ft)	Trade size	Metric designator
90	(67)	3/4 and smaller	21 and smaller
115	(83)	1, 1-1/4, and 1-1/2	27, 35, and 41
180	(135)	2 and larger	53 and larger

64.4.4 The artificial precipitation shall be supplied by a sufficient number of nozzles to produce a uniform spray over the entire surface or surfaces under test. The various vertical surfaces of an enclosure may be tested separately or collectively, provided that a uniform spray is simultaneously applied to both of the following:

a) The roof surfaces, from nozzles located at an appropriate height; and

b) The floor outside the enclosure for a distance of 1 m (3 ft) in front of the surface under test with the enclosure located at its normal height above the floor level.

64.4.5 The nozzles used for this test shall deliver a square-shaped spray pattern with uniform spray distribution and shall have a capacity of at least 450 ml/s (7.1 gal per min) at 41.4 N/cm^2 (60 psig) pressure, and a spray angle of approximately 75°. The centerline of the nozzles shall be inclined downward so that the top of the spray is horizontal as it is directed towards the vertical and roof surfaces being tested.

64.4.6 The pressure at the nozzles shall be a minimum of 41.4 N/cm^2 (60 psig) under flow conditions. This is approximately equivalent to rain driven by a 29 m/s (65 mi per h) wind. The quantity of water applied to each surface under test shall be at least 0.5 cm (0.2 in) per unit surface per minute, and each surface so tested shall receive this rate of artificial precipitation for a duration of 5 min. The spray nozzle shall not be more than 3 m (10 ft) from the nearest vertical surface under test.

64.4.7 If the unit has forced ventilation the test shall be performed with the ventilation functioning on or off whichever is the worst case. It the worst case is not clear, the test shall be performed with the forced ventilation operating and then performed again with the forced ventilation not operating.

64.4.8 At the conclusion of the spray application, the unit shall be considered to have met the requirements of this test if:

a) No water is visibly observable on primary or secondary insulation;

b) No water is visibly observable on any electrical components or mechanisms of the assembly; and

c) No significant accumulation of water is retained by the structure or other non-insulating parts (to minimize corrosion).

64.4.9 At the conclusion of the test, an enclosure marked "Raintight" shall be considered to have met the requirements of this test if there is no entrance of water.

64A Rod Entry Test

64A.1 This test is to be conducted to evaluate ventilation openings in medium voltage equipment.

64A.2 When medium voltage live parts are less than 102 mm (4 in) from an opening, this test shall be made by attempting to insert a rod having a diameter of 12.7 mm (0.5 in).

64A.3 When medium voltage live parts are 102 mm (4 in) or more from an opening, this test shall be made by attempting to insert a rod having a diameter of 19 mm (0.75 in).

64A.4 The equipment complies with these requirements if the rod cannot enter the opening.

64B Medium Voltage Shutter Integrity Test

64B.1 Any shutter assembly provided in accordance with 15A.4 shall withstand the application of a 90 N (20 lbf) force using a 12.7 mm (0.5 in) square metal bar at any point on the shutter.

64B.2 During and after the test, the shutter shall not be dislocated to the extent that permits entry of a rod having a diameter of 12.7 mm (0.5 in).

64C Impulse Withstand Tests

64C.1 General

64C.1.1 This Section shall be applied as referenced or required by other portions of this Standard. This test shall be performed for each EUT construction considering: distribution of charge, including location of any ground plane; changes in proximity of medium-voltage parts to grounded parts, other medium-voltage parts or low-voltage parts and shape of busbars and other medium-voltage parts.

Note: The results of this test are typically affected by the distribution of charge, location of any ground plane and shape of live parts. Sharp points such as corners and edges of busbars, bolts, screws, or other hardware commonly affect the results of this test.

64C.1.2 This test is required for the following situations:

a) End products that are comprised of assemblies of completely enclosed equipment that have not already been impulse tested individually according to their product standards,

b) Where MV or subassemblies are modified when assembled to complete the entire end product/system, and

c) Where the overall end product impulse rating is higher than the lowest impulse rating of the MV components in the end product.

64C.1.3 The Impulse Withstand Test is a design test intended to evaluate the rated insulation level (impulse voltage withstand, or basic insulation level [BIL]) rating of a given EUT field-wiring compartment assembly design. The medium-voltage circuits of a previously untested EUT field-wiring compartment assembly shall be capable of withstanding voltage impulses using a full-wave 1.2 × 50 microsecond impulse in accordance with IEEE 4 and having a crest value equal to or greater than the rated impulse voltage of the equipment in accordance with Table 47A.1.

64C.1.4 The test sample shall be subjected to a sequence of tests in accordance with 64C.1.5 using one of the following test methods:

a) Method 1 (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 64C.2.2.

b) Method 2 (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 64C.2.3.

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 percent of the test voltage in the reverse polarity before the test, is recommended.

64C.1.5 Two test sequences are required. Test 1 subjects the entire EUT to the rated impulse voltage with the isolating means closed. Test 2 verifies the isolating means provides adequate isolation when in the open position. The sequence of tests shall be as follows:

a) For Test 1, the isolating means is to be closed, all medium-voltage fuses and control circuit fuses are to be in place, and the test voltage is to be applied and shall be applied to each phase individually. If the phases are connected together through a transformer or rectifier, all the input terminals are to be connected together, all low voltage circuits are to be connected to ground, and the test voltage is to be applied between the medium voltage input terminals and ground.

b) For Test 2, the isolating means is to be open and an impulse voltage of 110 % 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.

64C.2 Evaluation

64C.2.1 The EUT 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.

64C.2.2 Test method 1, 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 EUT assembly shall be considered as having successfully completed the test.

64C.2.3 Test method 2, 2 × 15 test procedure: The EUT assembly 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; and

c) No disruptive discharges on non-self-restoring insulation occur. This is to be confirmed by 5 consecutive impulse withstands following the last disruptive discharge. This procedure leads to a maximum possible number of 25 impulses per group.

RATING

65 Details

65.1 A unit shall be rated as shown in Table 65.1.

Table 65.1
Unit Ratings

Rating type	Utility-interactive (UI)	Stand-alone (SA)	UI w/ CC[d]	SA w/ CC[d]	ISE	CC[d]	PVRSE-dc	PVRSE-ac	Product Marking
Max input voltage (dc)[a]	X[b]	X	X	X	X	X	X		
Range of input operating voltage (dc)	X[b]	X	X	X	X	X	X		X
Max input current (ac or dc)	X[b]	X	X	X		X	X	X	X
Max Input short circuit current	X	X	X	X	X	X	X		
Max backfeed current (see 50.6.2)	X		X						
Output power factor rating	X	X	X	X					X
Operating voltage range (ac)	X	X	X	X	X	X		X	
Operating frequency range or single freq	X	X	X	X		X		X	X
Nominal output voltage (ac)	X	X	X	X					X
Normal output frequency	X	X	X	X					X
Max cont. output current (ac)	X	X	X	X					X
Max cont. output power (ac)	X	X	X	X					X
Max output fault current and duration (ac)	X	X	X	X					
Max output overcurrent protection (amps) [c]	X	X	X	X		X		X	

Table 65.1 Continued on Next Page

Table 65.1 Continued

Rating type	Utility-interactive (UI)	Stand-alone (SA)	UI w/ CC[d]	SA w/ CC[d]	ISE	CC[d]	PVRSE-dc	PVRSE-ac	Product Marking
Nominal output voltage (dc)			X	X		X			X
Charging output voltage operating range (dc)			X	X		X			
UI trip limits and times	X				X				
Rapid shutdown time limit							X	X	
Sychronization in-rush current	X		X						
Trip limit and trip time accuracy	X		X		X				
Normal operation temperature range	X	X	X	X	X	X	X	X	
Output pwr temp derate/max pwr ambient [e]	X	X	X	X		X			
Control power source (ac/dc)							X	X	X
Control power or current range							X	X	X
Conductor AWG range	X	X	X	X	X	X	X	X	
Power Frequency Withstand (dielectric) rating[f]	X	X	X	X	X				
Basic Impulse Rating (BIL)[f]	X	X	X	X	X				

Notes:

AWG is American Wire Gauge

CC is charge controller

[a] The maximum input voltage determined in accordance with Section 690.7(a) of the National Electrical Code, NFPA 70, may be used for photovoltaic inverters and charge controllers.

[b] Not required for AC modules.

[c] Normally the branch-circuit overcurrent protection.

[d] Charging of batteries is able to originate from dc or ac sources. The rating types for either ac or dc are to be applied accordingly.

[e] Only for units that derate with output temperature.

[f] Required only for units with medium voltage ratings. This rating may appear on the medium voltage switchgear itself if the equipment nameplate references the switchgear nameplate.

MARKING

66 Details

66.1 Unless otherwise stated, all markings shall be permanent. The following types of markings or the equivalent meet this requirement:

a) Molded,

b) Die-stamped,

c) Paint-stenciled,

d) Stamped or etched metal that is permanently secured, or

e) Indelibly stamped on a pressure-sensitive label complying with the Standard for Marking and Labeling Systems, UL 969.

66.2 A unit shall be plainly and permanently marked on the exterior surface or behind an accessible cover with:

a) The manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product is able to be identified – hereinafter referred to as the manufacturer's name,

b) A distinctive catalog number or the equivalent,

c) The electrical ratings as specified in Table 65.1 for the specific type(s) of equipment, and

d) The date or other dating period of manufacture not exceeding any three consecutive months. The repetition time cycle of a date code shall not be less than 20 years.

The date code shall not require reference to the manufacturer's records to determine when the unit was manufactured.

Exception No. 1: The manufacturer's identification is able to be in a traceable code when the unit is identified by the brand or trademark of a private labeler.

Exception No. 2: The date of manufacture is able to be abbreviated in a nationally accepted conventional code, or in a code affirmed by the manufacturer.

66.3 When an inverter, converter, or interconnection system equipment (ISE) is intended for connection with an EPS and complies with Utility Compatibility, Section 49, it shall be marked "Utility-Interactive," "Interconnection System Equipment," or the equivalent.

66.4 When an inverter, converter, or interconnection system equipment (ISE) is intended for connection with an EPS, complies with Utility Compatibility, Section 49, and with IEEE 1547-2003, it shall be marked "Utility Interactive Inverter" or equivalent to indicate the specific document and version of the interconnect requirements to which it complies. Example "Compliant with IEEE 1547a-2014 (Amd. 1)" or equivalent. Inverters that comply with the requirements of UL 1741 Supplement SA, as well as the requirements for a utility interactive inverters shall be marked "Grid Support Interactive Inverter" or "Grid Support Utility Interactive Inverter". A reference to the specific standard(s) and version(s) complied with may optionally be added to the marking and shall be included in the installation instructions.

66.5 With reference to the Exception to 43.2, the inverter or interconnection system equipment (ISE) manual shall be marked with the following: "This unit or system is provided with fixed trip limits and shall not be aggregated above 30 kW on a single Point of Common Connection."

66.6 A unit or separate device provided with integral dc ground-fault detector/interrupter protection in accordance with DC Ground-Fault Detector/Interrupter, Section 34, shall be marked to indicate its presence. If the separate device is not self-contained and is intended for installation in another enclosure, the device shall be provided with a label for fixing to the outside of the enclosure to indicate its presence.

66.7 When a unit is produced or assembled at more than one factory, each unit shall have a distinctive marking – which is able to be in code – to identify the product of a particular factory.

66.8 The symbols described in (a) – (c) are usable for markings to comply with the requirement in Table 65.1:

a) A circuit intended to be connected to a dc circuit shall be identified by markings indicating that the circuit shall be dc. The symbol illustrated in Figure 66.1 meets the requirement for this marking. See 66.9.

b) A circuit intended to be connected to an ac circuit shall be identified by markings indicating that the circuit shall be ac. The markings shall include the supply-circuit frequency or supply-circuit frequency-range rating (cycles per second, cycles/second, hertz, c/s, cps, or Hz). The symbol illustrated in Figure 66.2 meets the requirement for this marking. See 66.9.

c) The number of phases shall be indicated when the unit is designed for use on a polyphase circuit. The symbol illustrated in Figure 66.3 is equivalent to the word "phase." See 66.9.

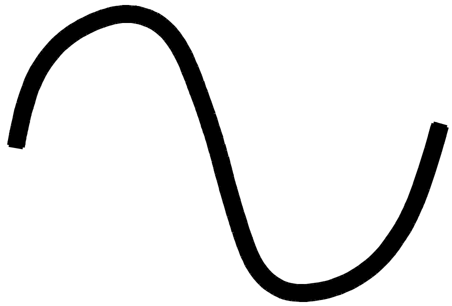
Figure 66.1

Direct Current Supply Symbol

IEC Publication 417, Symbol 5031

Figure 66.2

Alternating Current Supply Symbol

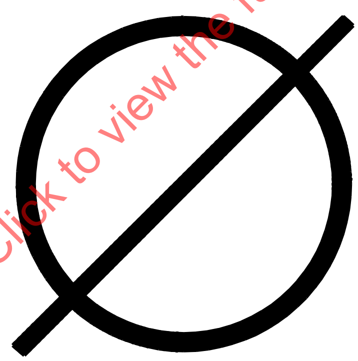


IEC5032

IEC Publication 417, Symbol 5032

Figure 66.3

Phase Symbol



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66.9 When a symbol referenced in 66.8 (a), (b), and (c) is used, the information described in 69.4(G) shall be provided as part of the Important Safety Instructions.

66.10 The operating positions of a handle, knob, or other means intended for manual operation by the user shall be marked.

66.11 Wiring terminals shall be marked to indicate the intended connections for the unit, or a wiring diagram coded to the terminal marking shall be securely attached to the unit.

Exception: The terminal markings are not required when the wire connections are evident.

66.12 Field-wiring terminals shall be marked in accordance with 69.4 (L) and (M), Table 69.3, and the following:

a) "Use Copper Conductors Only" when the terminal is rated only for connections to copper wire,

b) "Use Aluminum Conductors Only" or "Use Aluminum Or Copper-Clad Aluminum Conductors Only" when the terminal is rated only for connection to aluminum wire, or

c) "Use Copper Or Aluminum Conductors" or "Use Copper, Copper-Clad Aluminum, or Aluminum Conductors" when the terminal is rated for connection to copper or aluminum wire.

66.13 With reference to 20.1.13 a pressure wire connector or stud-and-nut type terminal intended for connection of an equipment-grounding conductor shall be identified by:

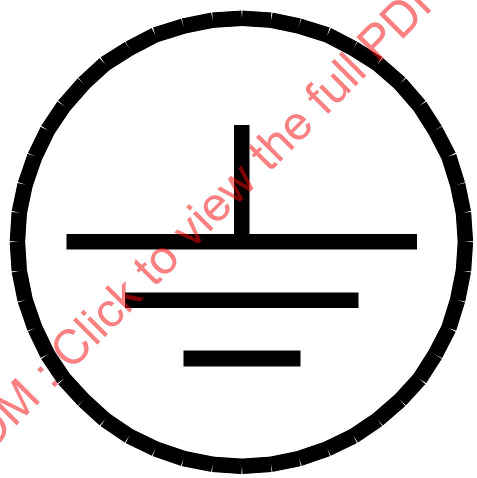
a) Being marked "G," "GR," "GND," "Ground," "Grounding," or equivalent,

b) A marking on a wiring diagram attached to the unit, or

c) The symbol illustrated in Figure 66.4 on or adjacent to the connector or on a wiring diagram provided on the unit. See 66.15.

Figure 66.4

Symbol for Equipment Grounding Conductor



66.14 In accordance with 46.3, a unit having an ambient temperature rating higher than 25 °C (77 °F) shall be marked to indicate the maximum ambient temperature rating. When tested in accordance with 46.1(c) and 48.2.4, this rating shall include the reduced output power rating.

66.15 With reference to 66.13(c), the following requirements apply when the symbol illustrated in Figure 66.4 is used:

a) The information described in 69.4(G) shall be provided in the Important Safety Instructions.

b) The symbol is usable for identifying only the field wiring equipment-grounding terminal. However, a symbol as shown in Figure 66.4 is usable with the circle omitted for identifying various points within the unit that are bonded to ground.

Exception: Where the symbol illustrated in Figure 66.4 is used with one of the alternate means of identification specified in 66.13 (a) and (b), the information is not required to be provided in the Important Safety Instructions.

66.16 A terminal for the connection of a grounded conductor shall be identified by means of a metallic plated coating substantially white in color, and shall be readily distinguishable from the other terminals; or identification of the terminal for the connection of the grounded conductor shall be clearly shown in some other manner, such as:

a) A marking on the unit,

b) An indication on a wiring diagram attached to the unit, or

c) Information provided in the instruction manual.

A field wiring lead intended to be grounded shall have a white or gray color and shall be readily distinguishable from other leads.

66.17 A terminal, as described in 20.2.1, intended for connection of the grounding electrode conductor shall be marked "Grounding Electrode Terminal."

66.18 A unit employing pressure terminal connectors for field wiring connections shall be provided with a marking making reference to the instruction manual for the tightening torque to be applied to the wiring terminals. See 69.4(F).

66.19 A unit intended to be used with a remote battery supply shall be plainly marked indicating the polarity of the connections between the battery supply and the unit with:

a) The words "positive" and "negative,"

b) The signs "+" for positive and "-" for negative, or

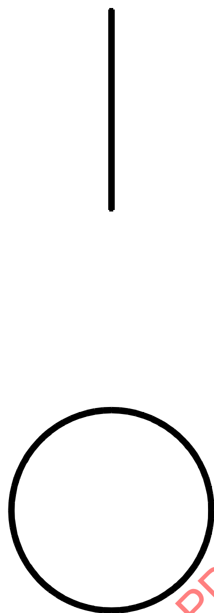
c) A pictorial representation illustrating the proper polarity, orientation, and similar properties of the battery connections, as applicable for the type of battery supply involved.

66.20 A multiple-voltage output unit for permanent connection to the branch circuit shall be marked to indicate the particular voltage for which it is set when shipped from the factory. The marking is able to be in the form of a paper tag or any other nonpermanent material.

66.21 Both the on and off positions of the disconnect control devices specified in Switches and Controls, Section 14, or in Disconnect Devices, Section 15, shall be identified. The symbols illustrated in Figure 66.5 are usable for this purpose. The identification shall not be by illumination only. See 66.22.

Figure 66.5

On and Off Symbols



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IEC Publication 417, Symbols 5007 and 5008

66.22 When the symbol illustrated in Figure 66.5 is used in accordance with 66.21, the information described in 69.2(G) shall be provided.

66.23 A clock, timing device, or alarm circuit– on or remote from a unit – that is not a low-voltage, limited-energy (LVLE) circuit and that remains energized during servicing functions shall be marked to indicate that the circuit remains energized while the unit is off.

66.24 With reference to 18.3.4(b), a unit containing a field-wiring lead that is intended to be connected to a wire binding screw located in the field-wiring compartment shall be marked with information clearly indicating the intended use of the lead.

66.25 With reference to the Exception to 20.1.8, low-voltage Class 2 field-wiring leads that are not color coded shall be identified. The identification shall not require the use of a separate wiring diagram to make proper connections.

66.26 A stand-alone unit having grounding type receptacles for the output ac current connections shall be marked: "One side of the output circuit is bonded to the inverter frame. Connect the grounding electrode terminal to a grounding electrode in accordance with the local codes."

66.27 With reference to 15.1(d), a marking shall be provided identifying the disconnect device, switch, or breaker for the output ac and dc power circuits.

66.28 With reference to the Exception to 19.2, a unit intended for use with a field installed conductor that is of a size smaller than maximum rated conductor size yet rated for use with the field connection pressure terminal shall be marked: "Use ____ maximum AWG wire only for field connector" or the equivalent.

66.29 In accordance with the Exception to 48.4.1, an inverter with a total harmonic distortion rms that exceeds 30 percent of the fundamental rms output voltage rating shall be marked to indicate the percentage that the total rms harmonic distortion exceeds the fundamental rms output voltage rating.

66.30 An enclosure other than Type 1 shall be permanently marked with the Type designation indicating the external conditions for which it is intended as specified in the Standard for Enclosures for Electrical Equipment, UL 50. An enclosure that complies with the requirements for more than one Type of enclosure is able to be marked with multiple designations. The marking shall be on the inside or outside surface and shall be visible after installation during inspection of the field wiring connections. In addition to the Type designation marking, the optional markings specified in Table 66.1 are able to be used.

Table 66.1
Optional Markings

Type of enclosure	Optional marking[a]
1	"indoor use only"
3, 3S, 4, 4X, 6, or 6P	"raintight"
3R	"rainproof"
4 or 4X	"watertight"
4X or 6P	"corrosion resistant"
2, 12, 12K, or 13	"drip tight"
3, 3S, 12, 12K, or 13	"dust tight"

[a] These markings are to be additional to the enclosure Type designation marking required in 66.30.

66.31 When conduit hubs are not provided for a Type 2, 3, 3R, or 3S enclosure, the enclosure, the instruction sheet provided with the enclosure, or the packaging carton shall be marked to indicate that raintight or wet location hubs that comply with the requirements in the Standard for Conduit, Tubing, and Cable Fittings, UL 514B, are to be used.

66.32 A separable conduit hub and a closure fitting shall be marked with the manufacturer's name or trademark and the catalog number or equivalent. Such a hub or fitting is able to be shipped separately, and any gasket, hardware, and instructions, required for installation shall be shipped with the fitting or packaged with the enclosure.

66.33 A Type 2 or 3R enclosure that has knockouts for conduit in the sides or back of the enclosure and in which the equipment to be installed is not known shall be marked to indicate the area in which live parts are to be installed. See Exception No. 1 to 7.9.4 and Exception No. 1 to 7.9.6.

66.34 A Type 4X enclosure intended for indoor use only shall be marked "4X Indoor Use Only" in letters not less than 4.0 mm (5/32 inch) high.

66.35 When required by the Exception to 7.9.9, a marking shall be provided to instruct the installer to fill the opening with a Type 12 conduit fitting.

67 Cautionary Markings

67.1 There shall be no substitute for the words "CAUTION," "WARNING," or "DANGER" in the text of a marking.

Exception: The words "WARNING" or "DANGER" are usable in lieu of the word "CAUTION."

67.2 A cautionary marking shall be prefixed by the word "CAUTION," "WARNING," or "DANGER" in letters not less than 3.2 mm (1/8 inch) high. The remaining letters shall not be less than 1.6 mm (1/16 inch) high.

67.3 A cautionary marking shall be:

a) Located on a part that is not removable without impairing the operation of the unit, and

b) Visible and legible to the operator during the normal operation of the unit.

Exception: Cautionary markings pertaining to internal parts that are applicable only to service personnel are to be located internally in an appropriate location with respect to the parts of concern.

67.4 A live heat sink or other part that:

a) Is mistakable for dead metal,

b) Involves a risk of electric shock in accordance with Electric Shock, Section 13, and

c) Is not guarded as specified in 12.7

shall be marked "CAUTION – Risk of Electric Shock – Plates (or other word describing the type of part) are live. Disconnect unit before servicing." The marking shall be located on or near the live part so as to make the risk known before the part is touched. A single marking for multiple parts is usable.

67.5 An inverter intended to be used with an isolation transformer that is not supplied with the inverter shall be marked "CAUTION – For Proper Circuit Isolation" and the following words or the equivalent "Connect a minimum ___ kVA rated isolating transformer between the output of the unit and the utility power line connections. The transformer is to be an isolation type having separate primary and secondary windings."

67.6 For compliance with Exception No. 2 to 7.2.1, a unit shall be marked with the word "CAUTION –" and the following or equivalent: "Risk of Electric Shock, Do Not Remove Cover. No User Serviceable Parts Inside. Refer Servicing To Qualified Service Personnel."

67.7 For each fuse that is used to comply with the requirements in this Standard, there shall be a legible and durable marking indicating the ampere, voltage and "ac" or "dc" rating of the fuse to be used for replacement. The marking shall be located so that it is obvious as to which fuse or fuseholder the marking applies. This marking is able to consist of a pictorial identifying the rating of one or more fuses. In addition, the following prominent marking shall be provided – a single marking is usable for a group of fuses: "WARNING – For Continued Protection Against Risk Of Fire, Replace Only With Same Type And Ratings Of Fuse."

Exception: The requirement does not apply to a fuse that is secured by solder.

67.8 An inverter shall be marked with the word "DANGER" and the following words "Risk Of Electric Shock –" and the following or the equivalent. The marking shall be located on the outside of the unit or shall be prominently visible with any cover or panel opened or removed:

a) “XX power sources are terminated inside this equipment. All circuits must be individually disconnected before servicing,” (XX shall be replaced by the number “two” or the number of sources if more than “two”), or "Both ac and dc voltage sources are terminated inside this equipment. All circuits must be individually disconnected before servicing," and

Exception: Equipment without a dc input source and having multiple ac sources shall be marked "CAUTION" and the following words "Risk Of Electric Shock – " and the following or the equivalent. “Multiple voltage sources are terminated inside this equipment. Each circuit must be individually disconnected before servicing”.

b) "When the photovoltaic array is exposed to light, it supplies a dc voltage to this equipment."

Exception: Equipment not rated for PV input sources need not be marked with (b).

67.9 A unit that exceeds the temperature limits specified in Table 46.2 – see the Exception to 46.2 – shall be legibly marked externally where readily visible after installation with the word "CAUTION" and the following or the equivalent: "Hot surfaces – To reduce the risk of burns – Do not touch."

67.10 A unit provided with single-pole circuit breakers in the input or output circuit in accordance with the Exception to 32.1.8 shall be marked internally with the word "CAUTION" and the following or the equivalent: "To reduce the risk of electric shock and fire – Do not connect to a circuit operating at more than 150 volts to ground."

67.11 A removable panel covering a capacitor in accordance with Exception No. 1 to 13.2.3 shall be marked "CAUTION – Risk of electric shock from energy stored in capacitor" and the following or equivalent wording: "Do not remove cover until ___ minutes after disconnecting all sources of supply." The time indicated in the marking is to be the time required to discharge the capacitor to within the limitations specified in 13.2.1, and shall be less than 5 minutes.

67.12 With reference to Exception No. 2 to 13.2.3, a unit shall be marked "CAUTION – Risk of electric shock and/or electric energy-high current levels" and the following or equivalent wording: "Disconnect and discharge (identify capacitor) before removing panel as follows." Appropriate instructions shall follow indicating how to discharge the capacitor. The procedure indicated shall be limited to functions such as operating a switch, unplugging a connector, or the equivalent. When the time to discharge the capacitor or capacitor bank is longer than 1 second, the unit shall be additionally marked to indicate the minimum discharge time with the following or the equivalent: "Do not remove cover until ___ minutes after connecting the discharge circuit." The time indicated in this marking shall not exceed 1 minute for momentary type switches and 5 minutes for other means that actuate the discharge circuit.

67.13 An ungrounded dead metal part specified in the Exception to 22.2(f), shall be marked with the word "CAUTION" and the following or the equivalent: "(Identify part or parts not earth grounded) (is) (are) not grounded – (it) (they) involve a risk of electric shock. Test before touching." The marking shall be provided on or adjacent to the ungrounded dead metal part and shall be visible so that each part or group of parts is positively identified.

67.14 With reference to Exception No. 3 to 13.2.3, a marking shall be provided indicating "CAUTION – Risk of electric shock or electrical energy-high current levels" and the following or the equivalent: "High-energy electric charge is stored in (identify capacitor) and associated circuitry. Test before touching." The marking shall be located internally adjacent to the capacitor.

67.15 With reference to 34.10, units with integral ground-fault detector/interrupter or separate devices having the same function shall be marked with the word "CAUTION" and the following or equivalent: "Risk of Electric Shock. Normally Grounded Conductors May Be Ungrounded and Energized When a Ground-Fault is Indicated." If the separate device is not self-contained and is intended for installation in another enclosure, the device shall be provided with a label for fixing to the outside of the enclosure to indicate the caution statement.

68 Equipment Information and Instructions

68.1 Separation of information

68.1.1 Operating and operator-servicing instructions shall be separated from servicing instructions.

68.1.2 Where servicing requires access to parts that involve a risk of electric shock, servicing instructions shall be preceded by a warning. The warning shall be worded as follows or the equivalent "Warning – These servicing instructions are for use by qualified personnel only. To reduce the risk of electric shock, do not perform any servicing other than that specified in the operating instructions unless you are qualified to do so." The letter height shall be in accordance with 67.2.

68.2 Operating and installation instructions

68.2.1 The operating and installation instructions shall:

a) Describe the equipment installation, including specifically:

1) Assembly, and mounting, where required,

2) Grounding means, and

3) Ventilation consideration;

b) Explain equipment markings, including specifically:

1) Symbols,

2) Controls, and

3) All applicable ratings in Table 65.1;

c) Identify and describe interconnections with:

1) The input source,

2) The utility, and

3) Auxiliary and accessory equipment;

d) Explain the operation of the equipment;

e) Indicate that the ac output (neutral) is (is not) bonded to ground;

f) In accordance with 16.2.3(a), an inverter provided with a fixed ac output shall inform the installer that the input and output circuits are isolated from the enclosure and that system grounding, when required by Sections 690.41, 690.42, and 690.43 of the National Electric Code, ANSI/NFPA 70, is the responsibility of the installer;

g) Field adjustable trip limits for voltage and frequency shall be described and include the adjustment range for voltage, frequency and trip time. The "as shipped" default settings shall be specified; and

h) Integral dc ground-fault detector/interrupter protection shall describe the proper method for connecting and grounding the photovoltaic system.

i) For any chassis mounted power socket or cable mounted power connector not manufactured to a NEMA standard, the following warning and information shall be provided:

1) The following statement: “Any power connector mated with a socket or connector attached to this product must be from the same manufacturer, the same series, and have a matching part number”, and

2) Inverters, microinverters, dc to dc converters and other equipment equipped with PV wiring connectors that comply with the Standard for Connectors for Use in Photovoltaic Systems, UL 6703, shall have the specific allowable mating connector manufacturer(s) and model number(s) listed, as well as contact information and/or website of the PV connector manufacturer. If a specific product is available with multiple PV wiring connectors from various manufacturers, then the following shall be included:

i) Means to identify each distinct PV connector manufacturer's product – such as a picture or illustration, unique physical features, markings, company logos, etc, and

ii) Allowable mating connector manufacturer and model number(s) listed for each distinct cable connector manufacturer's product(s), as well as contact information and/or website of the PV connector manufacturer.

j) For medium voltage equipment, instructions shall include information on any restrictions of wire type or raceway location that may be required to maintain proper wire bending space as noted in 19A.3.

68.2.2 The important safety instructions shall appear before the battery installation procedures and maintenance.

68.2.3 The installation instructions shall indicate that the wiring methods in accordance with the National Electrical Code, ANSI/NFPA 70 are to be used.

68.2.4 An enclosure marked Type 4, 4X, 6, or 6P shall be provided with instructions for installation of a watertight conduit connection when the connection is not mounted on the enclosure.

68.2.5 Installation instructions shall be provided with an enclosure intended for field assembly of the bonding means that identifies the parts for bonding and specifies the method of installation.

68.2.6 When a hub or fitting is not provided or installed on a Type 4 or 4X enclosure, instructions identifying the specific hub or fitting and installation instructions shall be provided with the enclosure.

68.2.7 A polymeric enclosure shall have instructions stating that the hub is to be connected to the conduit before the hub is connected to the enclosure when it:

a) Is intended for connection to a rigid conduit system,

b) Has not been subjected to the torque test described in Polymeric Enclosure Rigid Metallic Conduit Connection Tests in the Standard for Enclosures for Electrical Equipment, UL 50, and

c) Is not provided with a preassembled hub.

68.2.8 With reference to 36.3, a product, not covered by 36.2, that uses a manufacturer-specified external isolation transformer shall be provided with instructions that specify the manufacturer, model, electrical ratings, and environmental ratings for the external isolation transformer with which it is intended to be used.

69 Important Safety Instructions

69.1 The headings "IMPORTANT SAFETY INSTRUCTIONS" and "SAVE THESE INSTRUCTIONS" for the instruction manual, and the opening statements of the instructions in the important safety instructions shall be entirely in upper case letters not less than 4.8 mm (3/16 inch) high or emphasized to distinguish them from the rest of the text. Upper case letters in the instructions shall not be less than 2.0 mm (5/64 inch) high, and lower case letters shall not be less than 1.6 mm (1/16 inch) high.

69.2 There shall be no substitute for the words "CAUTION," "WARNING," or "DANGER" in the text of the instructions.

Exception: The words "WARNING" or "DANGER" are usable in lieu of the word "CAUTION."

69.3 The important safety instructions described in items A – U in 69.4, as appropriate, shall be provided with each unit. The information contained in items C – U is able to be marked on the unit or in the instruction manual.

69.4 The important safety instructions shall include instructions for the following items A – U. The statement "IMPORTANT SAFETY INSTRUCTIONS", and the statement "SAVE THESE INSTRUCTIONS" shall precede the list. The word "WARNING," "CAUTION," and "DANGER" shall be entirely in upper case letters.

IMPORTANT SAFETY INSTRUCTIONS

A. SAVE THESE INSTRUCTIONS – This manual contains important instructions for Models _________________ (blank space is to be filled in with appropriate model numbers) that shall be followed during installation and maintenance of the _________ (blank space is to indicate inverter or charge controller as appropriate).

Exception: When the instructions are exactly the same for all models, specific model numbers are not required.

B. In accordance with 18.2.4, when pressure terminal connectors or the fastening hardware are not provided on the unit as shipped, the instruction manual shall indicate which pressure terminal connector or component terminal assemblies are for use with the unit.

C. With reference to item B, the terminal assembly packages and the instruction manual shall include information identifying wire size and manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product is identifiable.

D. When a pressure terminal connector provided in the unit [or in a terminal assembly covered in 18.2.4(d)] for a field installed conductor requires the use of other than a common tool for securing the conductor, identification of the tool and any required instructions for using the tool shall be included in the instruction manual.

E. A unit provided with a wire connector for field installed wiring as covered in Exception No. 2 to 18.3.1 shall be provided with instructions specifying that the connector provided is to be used in making the field connection.

F. A unit employing pressure terminal connectors for field wiring connections shall be provided with instructions specifying a range of values or a nominal value of tightening torque to be applied to the clamping screws of the terminal connectors. The minimum specified tightening torque shall not be less than 90 percent of the value specified in Table 69.1 or Table 69.2 applicable to the wire size determined in accordance with 18.1.3.

Exception: A torque less than 90 percent is usable when the connector – using the lesser assigned torque value – complies with the Standard for Wire Connectors, UL 486A-486B, or the Standard for Equipment Wiring Terminals for Use with Aluminum and/or Copper Conductors, UL 486E.

G. When a symbol is used for compliance with marking requirements specified in 66.9, 66.14, or 66.22, the instruction manual shall identify the symbol.

H. The instruction manual for a unit that exceeds the temperature limits of Table 46.2 (see the Exception to 46.2) shall specify that the unit is to be installed so that it is not expected to be contacted by persons.

I. The instruction manual for a charge controller or an inverter intended to charge batteries shall indicate the nominal voltage rating of the battery supply and a generic description of the batteries, such as lead acid, nickel cadmium, and vented or sealed.

J. In accordance with 46.3, the instruction manual for an inverter having an ambient temperature rating higher than 25 °C (77 °F) shall indicate the maximum ambient temperature rating.

K. For a unit having a single equipment field-wiring terminal that is intended for connection of more than one conductor, the instruction manual shall include information identifying the number of conductors and range of conductor sizes.

L. For a unit provided with field-wiring terminals or leads, the instruction manual shall include the information indicated in Row 1, 2, 3, or 4 of Table 69.3 or with equivalent wording, when it is:

1) Intended for use on a supply circuit rated 110 amperes or less, or

2) Intended for field connection with 1 AWG (42.4 mm^2) or smaller conductors.

M. For a unit provided with field-wiring terminals or leads, the instruction manual shall include the information indicated in Row 3 or 4 of Table 69.3, or with equivalent wording, when it is:

1) Intended for use on a supply circuit rated more than 110 amperes, or

2) Intended for field connection with conductors larger than 1 AWG (42.4 mm^2).

N. When required by the Exception to 18.6.1, the instruction manual shall include a statement indicating that Class 1 wiring methods are to be used for field wiring connections to terminals of a Class 2 circuit.

O. In accordance with 50.1.7, when an abnormal test is terminated by operation of the intended branch-circuit overcurrent protective device, the instruction manual for a unit shall include the word "CAUTION" and the following or the equivalent: "To reduce the risk of fire, connect only to a circuit provided with _______ amperes maximum branch-circuit overcurrent protection in accordance with the National Electrical Code, ANSI/NFPA 70." The blank space is to be filled in with the ampere rating of branch-circuit overcurrent protection described in 50.1.7.

P. When required by the Exception to 32.3.1, the instruction manual shall include a statement indicating that overcurrent protection for the ac output circuit is to be provided by others.

Q. When required by the Exception to 32.4.1, the instruction manual shall include a statement indicating that overcurrent protection for the battery circuit is to be provided by others.

R. An inverter with 120 V output shall be provided with instructions that include the word "WARNING" and the following or the equivalent: "To reduce the risk of fire, do not connect to an ac load center (circuit breaker panel) having multiwire branch circuits connected."

S. When required by Exception No. 2 to 34.1, the manual shall include the word “WARNING” and the following or equivalent: “This unit is not provided with a GFDI device. This inverter or charge controller must be used with an external GFDI device as required by the Article 690 of the National Electrical Code for the installation location."

T. Any device, including a microinverter, PVIE, or string inverter provided with input or output leads or an ac output paralleling cable assembly or a trunk cable that has conductors with stranding finer than Class B or Class C (typically 19 strands for 14-2 AWG conductors), shall include the following statement, or equivalent, in the instruction manual: "The input or output leads or ac output paralleling cable assembly or trunk cable supplied with this device has fine stranded, flexible conductors and if unterminated or if any factory-installed connectors have been removed, shall only be terminated using connections that have been rated for use with such conductors."

U. Where the unit uses a trunk cable or other output cable to connect multiple units in parallel without an overcurrent protective device for the output of each unit, the instruction manual for each unit shall include the following statements:

a) Maximum number of units that can be connected in parallel without an overcurrent protective device for each unit.

b) The rating of the maximum overcurrent device protecting the combined output circuit of the maximum number of units after the outputs are connected in parallel.

c) The minimum ampacity of the conductors in the trunk cable or other cable connected to the output of each unit.

Table 69.1
Tightening Torque for Pressure Wire Connectors

Size of wire that is to be used for connection of the unit		Tightening torque, N·m (pound-inch)							
		Slotted head no. 10 and larger				Hexagonal head – external drive socket wrench			
		Slot width – 1.2 mm (0.047 inch) or less and slot length 6.4 mm (1/4 inch) or less		Slot width – over 1.2 mm (0.047 inch) or slot length-over 6.4 mm (1/4 inch)		Split-bolt connectors		Other connectors	
AWG/kcmil	(mm^2)								
18 – 10	(0.82 – 5.3)	2.3	(20)	4.0	(35)	9.0	(80)	8.5	(75)
8	(8.4)	2.8	(25)	4.5	(40)	9.0	(80)	8.5	(75)
6 – 4	(13.3 – 21.2)	4.0	(35)	5.1	(45)	18.6	(165)	12.4	(110)
3	(26.7)	4.0	(35)	5.6	(50)	31.1	(275)	16.9	(150)
2	(33.6)	4.5	(40)	5.6	(50)	31.1	(275)	16.9	(150)
1	(42.4)	–		5.6	(50)	31.1	(275)	16.9	(150)
1/0 – 2/0	(53.5 – 67.4)	–		5.6	(50)	43.5	(385)	20.3	(180)
3/0 – 4/0	(85.0 – 107.2)	–		5.6	(50)	56.5	(500)	28.2	(250)
250 – 350	(127 – 177)	–		5.6	(50)	73.4	(650)	36.7	(325)
400	(203)	–		5.6	(50)	93.2	(825)	36.7	(325)
500	(253)	–		5.6	(50)	93.2	(825)	42.4	(375)
600 – 750	(304 – 380)	–		5.6	(50)	113.0	(1000)	42.4	(375)
800 – 1000	(406 – 508)	–		5.6	(50)	124.3	(1100)	56.5	(500)
1250 – 2000	(635 – 1016)	–		–		124.3	(1100)	67.8	(600)

Table 69.2
Tightening Torque for Pressure Wire Connectors having Internal Drive, Socket-Head Screws

Socket size across flats, mm	(inch)	Tightening torque, N·m	(pound-inch)
3.2	(1/8)	5.1	(45)
4.0	(5/32)	11.4	(100)
4.8	(3/16)	13.8	(120)
5.6	(7/32)	17.0	(150)
6.4	(1/4)	22.6	(200)
7.9	(5/16)	31.1	(275)
9.5	(3/8)	42.4	(375)
12.7	(1/2)	56.5	(500)
14.3	(9/16)	67.8	(600)

Table 69.3
Termination Markings

Temperature rating of wire that is intended to be used for connection of the unit		Copper conductors only	Aluminum conductors or copper-clad conductors[a]
Row 1	60 or 75 °C	"Use either[b] AWG, 60 °C or[c] AWG, 75 °C copper wire"	"Use 60 °C wire, either[b] AWG copper or[b] AWG aluminum; or 75 °C wire, either No.[c] AWG aluminum.
Row 2	60 °C	"Use[b] AWG, 60 °C copper wire"	"Use 60 °C wire, either[b] AWG copper or[b] AWG aluminum"
Row 3	75 °C	"Use[c] AWG, 75 °C copper wire"	"Use 75 °C wire either[c] AWG copper or[c] AWG aluminum"
Row 4	90 °C	"Use[c] AWG, 90 °C copper wire"	"Use 90 °C wire, either[c] AWG copper or[c] AWG aluminum"

[a] Reference to copper wire is not to be included when wiring terminals are marked in accordance with 66.12(b).

[b] The wire size for 60 °C wire is not required to be included in the marking; however, when it is included, it shall be based on the ampacities given in Table 310.15(B)(16) of the National Electrical Code, ANSI/NFPA 70, for 60 °C wire and the derating factor described in 18.1.3.

[c] The conductor size shall not be smaller than the larger of the following:

a) The conductor size used for the temperature test; or

b) The 75 °C wire size based on the ampacities given in Table 310.15(B)(16) of the National Electrical Code, ANSI/NFPA 70, and the derating factor described in 18.1.3.

MANUFACTURING AND PRODUCTION TESTS

70 Dielectric Voltage-Withstand Test – Low Voltage Circuits

70.1 Each unit shall withstand without breakdown, as a routine production-line test, the application of a potential from Table 70.1 for AC rated circuits and from Table 70.2 for DC rated circuits:

a) From input and output wiring, including connected components, to accessible dead metal parts that are able to become energized, and

b) From input and output wiring to accessible low-voltage, limited-energy metal parts, including terminals.

70.2 Other than as noted in 70.3, the potential for the production-line test shall be in accordance with Condition A or Condition B of Table 70.1 or Table 70.2 at a frequency within the range of 40 – 70 Hertz.

Table 70.1
Production-Line Test Conditions AC Rated Circuits

Circuit rating, Vac	Condition A		Condition B		Condition C		Condition D	
	Potential, volts ac	Time, seconds	Potential, volts ac	Time, seconds	Potential, volts dc	Time, seconds	Potential, volts dc	Time, seconds
250 or less	1000	60	1200	1	1400	60	1700	1
More than 250	1000+2 V[a]	60	1200+ 2.4 V[a]	1	1400+ 2.8 V[a]	60	1700+3.4 V[a]	1

[a] Maximum marked voltage.

Note: The multipliers in the table are chosen with the following background:

2.4 – A 20 % adder on the multiplier 2 to account for reduced test time.

2.8 – A √2, truncated after the first decimal (=1.4) multiplier on "2" from condition A to account for the peak value of an AC rms voltage to calculate the DC test potential of AC circuits.

3.4 – A combination of the two above: 2*1.2*1.4, rounded to the next decimal.

Table 70.2
Production-Line Test Conditions for DC Rated Circuits

Circuit rating, Vdc	Condition A		Condition B		Condition C		Condition D	
	Potential, volts ac	Time, seconds	Potential, volts ac	Time, seconds	Potential, volts dc	Time, seconds	Potential, volts dc	Time, seconds
250 or less	1000	60	1200	1	1400	60	1700	1
More than 250	1000+1.4 V[a]	60	1200+ 1.7 V[a]	1	1400+ 2 V[a]	60	1700+2.4 V[a]	1

[a] Maximum marked voltage.

70.3 A unit employing circuitry that is able to be damaged by an ac potential is able to be tested using a dc potential in accordance with Condition C or Condition D of Table 70.1 or Table 70.2.

70.4 Testing of a unit in a heated or unheated condition meets the intent of the requirement for manufacturing and production tests.

70.5 The test is to be performed on a complete, fully assembled unit. It is not intended that the unit be unwired, modified, or disassembled for the test.

Exception No. 1: A part, such as a snap cover or a friction-fit knob, that interferes with the performance of the test is to be removed.

Exception No. 2: The test is able to be performed on a partial or modified unit as long as it has been evaluated to be representative of a complete unit.

Exception No. 3: The grounding connection of a grounded input terminal is able to be disconnected.

70.6 A unit employing a solid-state component that is not relied upon to reduce a risk of electric shock and that is susceptible to damage by the dielectric potential, is able to be tested before the component is electrically connected or after the component is electrically disconnected. The circuitry is able to be rearranged for the purpose of the test to minimize the potential of solid-state-component damage while retaining representative dielectric stress of the circuit.

70.7 The test equipment for supplying an ac potential is to include a transformer having a sinusoidal output. The test equipment is to include a means of indicating the test potential, an audible or visual indicator of breakdown, and a manually reset device to restore the equipment after breakdown or a feature to automatically reject a noncomplying unit.

70.8 Where the output rating of the test equipment transformer is less than 500 VA, the equipment is to include a voltmeter in the output circuit to directly indicate the test potential.

70.9 Where the output rating of the test equipment transformer is 500 VA or more, the test potential is to be indicated:

a) By a voltmeter in the primary circuit or in a tertiary-winding circuit,

b) By a selector switch marked to indicate the test potential, or

c) In the case of equipment having a single test-potential output, by a marking in a readily visible location to indicate the test potential. When marking is used without an indicating voltmeter, the equipment shall include a positive means, such as an indicator lamp, to indicate that the manually reset switch has been reset following a dielectric breakdown.

70.10 Test equipment, other than that described in 70.7 – 70.9, is usable when found to accomplish the intended factory control.

70.11 During the test, the unit switches are to be in the on position, both sides of the input and output circuits of the unit are to be connected together and to one terminal of the test equipment, and the second test-equipment terminal is to be connected to the accessible dead metal.

Exception: A switch is not required to be in the on position when the testing means applies full test potential from the input and output wiring to dead metal parts with the switch not in the on position.

70A Power Frequency Voltage Withstand Test – Medium Voltage Circuits

70A.1 Medium voltage circuits of units shall be subjected to the power frequency withstand test requirements of Section 47A.

Exception 1: This test is not required to be applied across the open gap of the isolating means.

Exception 2: This test of the MV circuits may be waived for MV circuits that are comprised of equipment and components that have already been subjected to similar routine MV production line testing on those components and equipment.

71 Production Tests for Interactive Equipment

71.1 Products rated for compliance with IEEE 1547-2003 and IEEE 1547.1-2005 shall comply with the applicable requirements in IEEE 1547.1-2005, Section 6, Production tests.

CHARGE CONTROLLERS

INTRODUCTION

72 General

72.1 These requirements cover permanently connected charge controllers that are intended to be installed in photovoltaic panels, photovoltaic power distribution equipment, and control panels or systems.

72.2 The requirements in Sections 72 – 83 supplement and, in some cases, amend the requirements in Sections 6 – 70.

CONSTRUCTION

73 General

73.1 One of the internal current-carrying conductors (normally the negative), connecting the charge controller's input to output, shall be identified as the grounded conductor where the controller is used in grounded circuits or systems. The grounded conductor shall not contain any components, such as relays, transistors or similar devices.

Exception: A shunt provided in the negative line is in compliance with the requirement.

73.2 When a shunt is provided in accordance with the Exception to 73.1, the point of connection to system ground shall be identified. The cross-sectional area of the shunt shall not be less than the minimum size conductor for the intended current and material type. See Table 21.2 for examples.

Exception: A smaller size shunt meets the intent of the requirement when:

a) The measured temperatures do not exceed the ratings of the support materials or surrounding components under normal operation, and

b) The shunt does not open as a result of the tests in Abnormal Tests, Section 50.

73.3 Controls for the adjustment of the state-of-charge of a battery shall be accessible for qualified service personnel only.

Exception: An on/off switch or disconnect device of a charge controller, power distribution panel, or inverter shall not be deemed a control for the state-of-charge of a battery.

73.4 When a charge controller employs temperature compensating monitoring, the monitoring means shall be remote from the charge controller, see 82.3 and 82.4.

Exception: The monitoring means is able to be internal to a unit when the unit is marked in accordance with 82.4 and, the unit is provided with instructions as described in 83.6.

73.5 The polymeric material in a charge controller that is intended to be installed internally to the wiring compartment of a photovoltaic module shall have a relative thermal index of 90 °C (194 °F) minimum.

PERFORMANCE

74 General

74.1 A charge controller shall be tested as described in 76.1 – 80.4.

74.2 A charge controller intended for use in a photovoltaic control panel is to be installed in the smallest specified size enclosure.

74.3 A charge controller intended for use in a photovoltaic module wiring compartment is to be installed in the smallest sized compartment in which the controller is able to be installed. Prior to testing, the charge controller is to be subjected to 20 cycles of the Temperature Cycle Test in accordance with the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703. When performing the tests, the charge controller, without an electrical enclosure, is to be in an ambient of 60 °C (140 °F) minimum or as rated by the manufacturer.

75 Sources and Loads

75.1 When performing tests on a charge controller using a simulated source for the PV input, the test source is to be adjusted to the maximum rated input voltage, and the current source shall be capable of delivering the DUT's rated maximum input short-circuit current measured at the DUT terminals.

75.2 For the charge controller output, a battery or a simulated battery load is able to be used. A simulated battery load is to consist of one of the loads defined in Table 75.1 and illustrated in Figure 75.1. The capacitance is to be in parallel with a load resistor and a power supply adjusted to simulate the battery voltage and adjusted to draw a specified operational battery charge current as required by the charge controller design. A series resistance shall be added to the capacitor bank in order to achieve a time constant of not less than 3ms for battery ports with an I_{sc} max rating of 10kA or less, or 8ms if the rating exceeds 10kA. The source shall be capable of delivering the DUT's rated maximum battery short-circuit current measured at the DUT terminals.

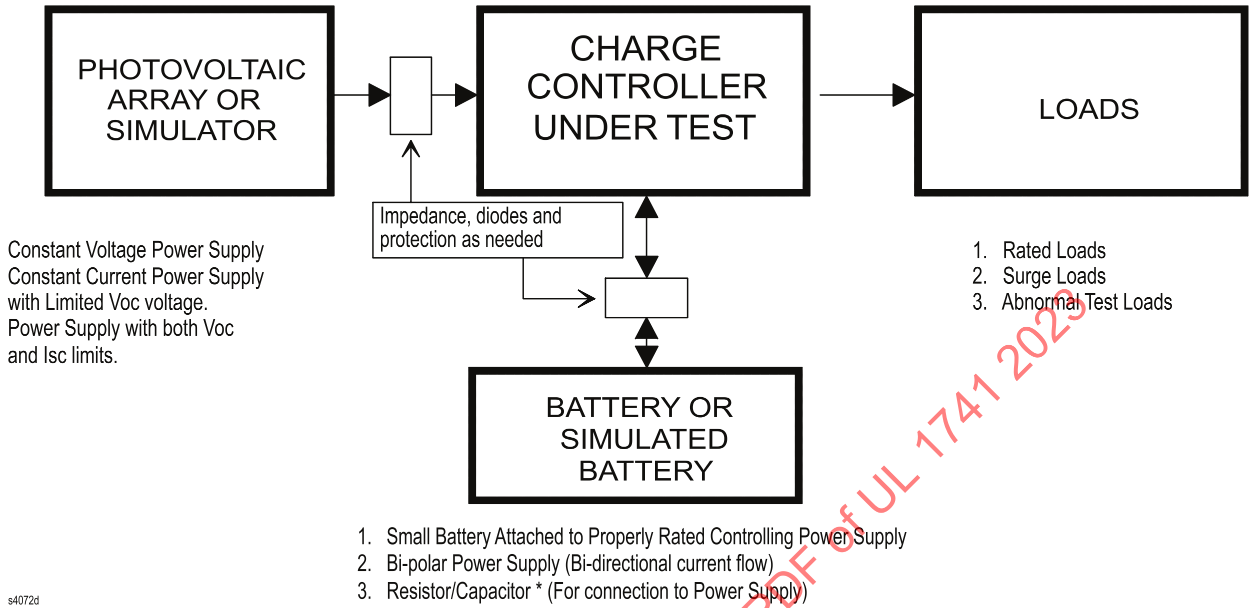
Note: These time constant specifications are aligned with the Standard for Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures, UL 489, for DC circuit breakers.

Table 75.1
Simulated Battery Loads

Battery current rating, amperes	Capacitance in microfarads
0 – 20	100,000
> 20 – 40	185,000
> 40	300,000

Figure 75.1

Charge Controller Test Configuration



* In accordance with 75.2.

76 Normal Operations

76.1 When tested as described in 76.3 – 76.5, a charge controller shall not exceed its rated input, output, or battery charge/discharge current by more than +10 percent.

76.2 When tested as described in 76.3 – 76.5, a charge controller shall not exceed its rated voltages. An on/off and constant voltage charge controller shall not have an output voltage at the battery terminals or at load terminals that exceeds its rated value by more than +10 percent after the first minute of operation.

76.3 The charge controller is to be connected to a photovoltaic array or simulated source adjusted as specified in Sources and Loads, Section 75. The battery interface terminals of the charge controller are to be open circuited. The output or load terminals of the charge controller are to be connected to a load. The load is to be adjusted to draw the maximum attainable output current from the charge controller and the voltage is to be measured at the load terminals and at the battery terminals. When the charge controller does not function with open-circuited battery terminals, the test method described in 76.5 is to be used.

76.4 Once operational, the load is then to be adjusted over a range of operation, excluding short-circuit, and the voltage is to be measured at the output (load) terminals and at the battery interface for each value of load.

76.5 For a charge controller that does not function with open-circuited battery terminals, the charge controller is to be connected to a photovoltaic source or simulated source capable of providing 125 percent of the rated current of the intended photovoltaic circuit. The output of the charge controller is to be connected to a load. The battery terminals are to be connected to a battery or battery simulator operating at the charge controller rated battery voltage. The load is to be adjusted to draw the maximum rated current of the charge controller. The test method specified in 76.4 is to be conducted while measuring output current.

77 Temperature

77.1 When tested as specified in Temperature, Section 46, the temperatures measured on polymeric materials in a charge controller intended to be installed in accordance with 73.5 shall not exceed the relative thermal index rating of the material determined in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

78 Temperature Compensation

78.1 While the temperature sensor input is in a short- or open-circuit condition, a charge controller provided with integral temperature compensation shall shut down or limit the output charge to the load when tested as specified in 78.2.

78.2 The charge controller is to be connected to its rated input supply and rated load. The temperature sensor input is to be open-circuited and then short-circuited, one at a time.

79 Connection Sequence

79.1 When tested as described in 79.2 – 79.4, the voltages and currents for a charge controller shall remain within their rated values.

79.2 A charge controller marked with a connection sequence is to be connected in the prescribed manner and then tested in accordance with Normal Operations, Section 76.

79.3 A charge controller not marked with a prescribed connection sequence is to be tested first, with the battery connected before the photovoltaic source, and then with the photovoltaic source connected and energized before the battery is connected. Output to the battery or load is to be measured in accordance with Normal Operations, Section 76.

79.4 For all charge controllers, the battery voltage is to be disconnected and reconnected during normal operation. The voltages and currents are to be measured at the photovoltaic input, load output, and battery terminals.

80 Abnormal Tests

80.1 General

80.1.1 When tested as described in 50.2 – 50.6 and 80.2 – 80.4, a charge controller shall comply with 50.1.1.

80.1.2 During any of the tests in 80.2 – 80.4, when shorting of the battery output terminals is required while under load, relaying shall be used to short the terminals of the unit under test while open-circuiting the battery.

80.2 Input and output faults

80.2.1 The photovoltaic array connections of a charge controller are to be connected to a dc simulator and the load (output) terminals are to be loaded to their rated load. While in a loaded state, the photovoltaic input to the charge controller is to be short-circuited.

80.2.2 The photovoltaic array connections of a charge controller are to be connected to a dc supply and the rated load (output). While in a loaded state, the output of the charge controller is to be short-circuited.

80.3 Charge controller miswiring

80.3.1 A charge controller is to be connected to its rated photovoltaic source or simulated photovoltaic source and battery as noted in Table 80.1. The connection order and polarity shall be as noted in the Table. When connecting the second supply source, battery or array, it is to be connected through a relaying device, such that the first source is already energized prior to the second source.

Exception: Those tests which limit the connection sequence do not apply to a charge controller which is marked in accordance with 81.1. For example, when a controller is marked in accordance with 81.1 indicating to connect array first, tests A, C, D, and E are not required to be performed.

Table 80.1
Connection Order and Polarity

Test condition	Supply to be connected first	Lead to be connected to positive terminal	Lead to be connected to negative terminal	Supply to be connected second[a] via relay	Lead to be connected to positive terminal	Lead to be connected to negative terminal
A	Battery	+	-	Array	+	-
B	Array	+	-	Battery	+	-
C	Battery	-	+	No connection		
D	Battery	-	+	Array	+	-
E	Battery	-	+	Array	-	+
F	Array	-	+	No connection		
G	Array	-	+	Battery	+	-
H	Array	–	+	Battery	–	+

[a] When connecting the second supply source, battery or array, it is to be connected through a relaying device, such that the first source is already energized prior to the second source.

80.3.2 When a simulated array source is used, a reverse-biased diode shall be placed across the supply to simulate the possible activation of an array bypass diode.

80.3.3 As a result of the test for charge controllers which have load control terminals, there shall not be reverse polarity voltage present on the terminals or current unless condition A of Table 80.1 occurs.

80.3.4 During the test, no additional external overcurrent protection is to be in the test circuit.

80.4 Low-voltage disconnect

80.4.1 When tested as described in 80.4.2, a charge controller shall operate in a stable, controlled manner over all ranges of charge and discharge of a battery load.

80.4.2 A charge controller with a low-voltage disconnect is to be connected to a source providing the charge controller's rated input, a battery or simulated battery load, and a rated load. The battery source is to be adjusted to 25 percent, 50 percent, 75 percent, and 100 percent of the rated battery voltage. The load is to be adjusted so that the charge controller cycles in accordance with the charge controller design from battery charge to battery discharge state. Adjustable charge set-points are to be set to their closest tolerance so that the charge controller cycles during the battery charge.

MARKING

81 Cautionary Markings

81.1 A charge controller which requires a specific connection method in accordance with 80.3.1 shall be marked "CAUTION: Risk of fire and shock, connect ________ terminals prior to the connection of __________ terminals" indicating the battery or array terminals as appropriate.

82 Details

82.1 A charge controller shall be marked in accordance with Details, Section 66, and Cautionary Markings, Section 67.

82.2 A charge controller intended to be installed in the wiring compartment of a photovoltaic module shall be marked to identify the manufacturer and model number of the photovoltaic module in which the controller is intended to be installed.

82.3 A charge controller with a temperature compensating set-point that is intended to be adjusted by service personnel shall be marked with set-point details.

82.4 A charge controller with an internal temperature compensating means shall be marked "CAUTION: Internal Temperature Compensation. RISK OF FIRE, USE WITHIN ____ m (ft) of BATTERIES" or "RISK OF FIRE, MOUNT IN CONTACT WITH BATTERIES."

82.5 A charge controller shall be marked with the minimum interrupting rating of the overcurrent protective device to be used for short-circuit protection. For example, "Minimum interrupting rating ______ A dc."

83 Important Safety Instructions

83.1 The installation instructions shall identify the conductor or the terminal described in 73.1 as the conductor or the terminal to be used as the grounded conductor in grounded circuits.

83.2 The installation instructions shall specify the type and chemical composition of the battery with which the charge controller is intended to be used [see 69.4(l)].

83.3 A charge controller intended for field installation shall be provided with a wiring diagram or installation instructions that specify the method of installation including the connection method and wire size range in accordance with Article 690 of the National Electrical Code, NFPA 70.

83.4 The installation instructions for a charge controller intended to be installed in the wiring compartment of a photovoltaic module shall specify the manufacturer and model of the photovoltaic module.

83.5 The installation instructions for a charge controller shall describe the maximum overcurrent protection to be provided in accordance with Article 690 of the National Electrical Code, NFPA 70.

83.6 The installation instructions for a charge controller with an internal temperature compensating means shall indicate where the controller is to be used with respect to the batteries (See 82.4) and the risks associated with the improper installation.

83.7 The installation instructions for a charge controller with service personnel adjustable temperature compensating set-points shall describe the battery chemistry and types for each set point. The instructions shall detail the risks associated with improper settings.

AC MODULES AND PV MODULES WITH INTEGRATED ELECTRONICS

INTRODUCTION

84 General

84.1 The requirements in Sections 85 – 91 supplement and, in some cases, amend the general requirements in Sections 6 – 71.

CONSTRUCTION

85 General

85.1 An AC module that is capable of utility interactive operation shall comply with the requirements for utility-interactive inverters in Sections 6 – 71.

85.2 The PV panel or module of an AC module or PVIE shall comply with the requirements in the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, or the Standard for Photovoltaic (PV) Module Safety Qualification – Part 1: Requirements For Construction, UL 61730-1 and the Standard for Photovoltaic (PV) Module Safety Qualification – Part 2: Requirements For Testing, UL 61730-2. Integrated electronics that provide a PV Module protective bypass diode functionality, shall comply with the construction requirements in 5.3.10 of UL 61730-1 as well as the referenced testing in UL 61730- The test shall provide power to the protection circuit as would be found in normal operation of the final assembly.

Note: UL 61730-1, Clause 5.3.10, requires that bypass diodes, and herein, integrated electronics exhibiting bypass diode protective functions, be rated to withstand the current and voltage for their intended use. Compliance is checked by bypass diode thermal test (MST 25), hot-spot endurance test (MST 22), bypass diode functionality test (MST 07) (following Sequences A-F sequential stress testing) and visual inspection (MST 01).

85.3 PV module junction boxes intended to be secured to the PV laminate shall comply with Standard for Photovoltaic Junction Boxes, UL 3730. Enclosures that are not a PV junction box shall be evaluated to the requirements in Sections 6 – 71.

85.4 All components across the dc input circuit of an AC module or module mounted electronics shall be rated for 125 percent of the PV module maximum open-circuit voltage or the voltage shall be derived from Sandia Report, SAND2004-3535 December 2004, under the conditions of -40 °C (-40 °F) ambient air temperature, 1000W/m^2 irradiance, AM1.5 Spectral content, and 1 m/s wind speed.

85.5 For amorphous silicate or thin film PV modules, the components across the dc input circuit shall be rated for the PV module open-circuit voltage regardless of the temperature.

85.6 An ac or dc disconnection means shall be rated for disconnection of the electrical load under normal and foreseeable abnormal conditions for the electronics. A disconnect in the PV circuit shall be rated for 125 percent of the PV module maximum open-circuit voltage or the voltage shall be derived from Sandia Report, SAND2004-3535 December 2004, under the conditions of -40 °C (-40 °F) ambient air temperature, 1000W/m^2 irradiance, AM1.5 Spectral content, and 1 m/s wind speed. PV connectors are typically not rated for disconnection under load at rated voltage, they may be evaluated for disconnect functionality at the reduced voltage of a single PV module.

85.7 Polymeric materials excluding materials serving as a PV module encapsulant shall have a relative thermal index in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B, not less than the temperature measured during the normal temperature test and not less than 90 °C (194 °F).

85.8 Connectors employed external to the module shall comply with the material and conditioning requirements in the Standard for Connectors for Use in Photovoltaic Systems, UL 6703, and connectors shall not be of a NEMA configuration used in other power systems. NEMA connectors configured specifically for use in PV or energy storage systems are permitted.

85.9 Wire harnesses shall comply with the Outline for Distributed Generation Wiring Harnesses, UL 9703.

85.10 Equipment grounding for a dc input circuit specified in 20.1.2 is not required for an AC module or PVIE.

85.11 Equipment bonding between the PV modules and electronics having accessible conductive surfaces shall comply with Section 88 and the Standard for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels, UL 2703, Section 18, Humidity Test. This testing may be combined with the performance testing described in Section 87 when required.

85.12 A gasket provided as part of the protective housing used on an enclosure shall comply with the requirements in the Standard for Photovoltaic Junction Boxes, UL 3730.

85.13 If a control circuit is relied on to maintain downstream voltage or current within specified limits, and those limits determine the output ratings of the converter, the control(s) shall comply with the applicable requirements in Sections 43 and 48, and with the Standard for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991, or with the Standard for Automatic Electrical Controls – Part 1: General Requirements, UL 60730-1. If software is involved in the control, it shall comply with the Standard for Software in Programmable Components, UL 1998, or with UL 60730-1.

85.14 PVIE and AC modules with input current rating, output current rating or electronics backfeed current rating greater than the PV module fuse rating shall be tested in accordance with the Standard for Photovoltaic (PV) Module Safety Qualification – Part 2: Requirements For Testing, UL 61730-2, Continuity Test for Equipotential Bonding (MST13) and Reverse Current Overload (MST 26) at the higher current.

85.15 An AC module that consists of a separate microinverter connected to a PV module with conductors and connectors may be repairable in the field if that repair has been determined to be possible by the original manufacturer or the manufacturer of a suitable retrofit kit. An AC module that can be repaired in the field by replacing the microinverter or the PV module shall comply with the following:

a) Any mechanical device, threaded or unthreaded, that is used to electrically bond the microinverter to the PV module shall comply with the grounding impedance test of Section 51 after having been removed and reinstalled five (5) times. Bonding shall comply with the requirements in 85.11.

b) Any disconnected and exposed (to the environment) connectors attached to the PV module or the trunk cable or other ac output connector shall comply with 85.8 and be provided with protection from the deteriorating effects of the environment, when not connected.

c) Any and all input and output connections shall be accessible in the field and be capable of being disconnected using the proper tool without opening the microinverter enclosure or the PV module junction box. Any connectors used or reused shall be mated to connectors from the same manufacturer and series number (mate-ability shall be maintained). The requirements of 85.8 shall be met.

d) The manufacturer of the AC module or the manufacturer of the retrofit kit shall identify a suitable replacement microinverter or PV module and provide appropriate replacement instructions if the original equipment microinverter or PV module is no longer available. The retrofit kit shall include detailed instruction and procedures to perform the retrofit installation, including a list identifying all critical components.

PERFORMANCE

86 General

86.1 Where electronics are mounted to the PV module with adhesive, the securement to the module shall be in accordance with PV Module Mounted Equipment Securement Test, Section 87.

86.2 The Temperature Test, Section 46, is to be conducted as defined in either 86.3 or 86.4 based on the manufacturer's specified environmental temperature rating. The environmental temperature rating used shall be marked on the product and included in the installation instructions.

86.3 The temperature test shall be performed in a controlled thermal chamber operating in a temperature range between 35 °C (95 °F) and the manufacturer's specified environmental ambient temperature rating of the AC module or PVIE + 5 °C (9 °F) with an irradiation of at least 1000w/m^2 from a class CCC (or better) continuous solar simulator in accordance with the Standard for Photovoltaic devices – Part 9: Solar simulator performance requirements, IEC 60904-9. The wind speed shall be 1 m/sec or less and the PV module shall be mounted according to the manufacturers installation instructions in the manner which will cause the highest heat build-up on the PVIE. The electronics are to be electrically loaded to maximum input and output current or other conditions that result in maximum heating of the assembly.

86.4 If a controlled thermal chamber with a solar simulator is not available for use, the following procedure may be used:

a) The baseline temperature profile of the module with the power converter or control device connected is to be determined using the UL 1703, Section 19, Temperature test at open circuit voltage or UL 61730-2, MST 21, maximum electrical load conditions. In addition to the thermocouple locations identified in Section 46, the following additional thermocouple locations shall be monitored:

1) The electronics' localized air ambient below the module, which is likely to be different than the ambient air temperature above the module.

2) The integrated electronics' surface in contact with or closest to the module, T_{close}.

3) The remaining integrated electronics' surfaces, T_a (average of remaining surfaces).

b) Using the data collected from (a), the module is to be operated in a controlled thermal chamber at T_a. The PV module is to be heated to T_{close} using either:

1) A power supply in the forward bias condition (+ to + and – to –) with current adjusted to reach the target T_{close} temperature, or

2) Via the application of an external heating source such as an electrically heated plate or pad applied adjacent to the electronics. The heating pad shall cover at least four times the area as the electronics enclosure and be centered over the installed electronics.

c) The module mounted electronics is to be energized to worst case operating conditions for the circuit design using an externally controlled power supply to cause the highest heating of the critical electronic circuit components. This is normally a maximum output current. Some electronic circuits may require two separate tests to attain the worst case normal conditions because as some circuits and components will be subjected to higher temperatures under a low voltage condition while other circuit components will be subjected to higher temperatures under a high voltage conditions.

86.5 For units that are not rated for installation in the test ambient, the temperature test data shall be corrected for the rated installation ambient rating of the unit in accordance with Table 46.3. The measured temperature is to be corrected by addition (when the test ambient temperature is lower than the rated ambient temperature) or by subtraction (when the test ambient temperature is higher than the rated ambient temperature) of the difference between the rated ambient temperature and the test ambient temperature.

86.6 Electronics for field installation on a module or mounting system with an enclosure rating shall be evaluated and found compliant with the requirements and testing for that enclosure rating.

87 PV Module Mounted Equipment Securement Test

87.1 Equipment secured to a PV module with adhesive shall comply with Sequence C in Figure 1 of the Standard for Photovoltaic (PV) Module Safety Qualification – Part 2: Requirements For Testing, UL 61730-2. During the MST 16 testing of Sequence C, the electronics may alternatively be tested with the Dielectric Voltage-Withstand Test, Section 47, in place of the Sequence C Insulation Test.

Exception No. 1: Connection means that do not include polymeric materials need not be subjected to the UV Test (MST 54) if in the intended installation configuration, the adhesive will not be exposed to sunlight.

Exception No. 2: The applied force shall be the greater of 156 N (35 lbf) or 4 times the weight of the complete module mounted electronics assembly.

87.2 In addition to the compliance criteria defined in the referenced tests for 87.1, the test shall not result in:

a) Exposure of live parts,

b) Separation of the enclosure from the substrate or superstrate, or

c) Fracturing of the enclosure, substrate, or superstrate.

88 Module to Electronics Bonding

88.1 Equipment bonding between the PV modules and electronics having accessible conductive surfaces shall comply with this Section.

88.2 Equipment bonding between the PV module equipment grounding conductor terminal or lead and the accessible conductive surfaces of AC modules and PVIE shall comply with the Section 13, Bonding Path Resistance Test of the Standard for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels, UL 2703, following preconditioning with the Section 18, Humidity Test.

Exception: The test sample from the testing in 87.1 may be used without the Section 18, Humidity Test preconditioning.

88.3 If multiple smaller diameter grounding conductors are used to provide the necessary cross-sectional area for an equipment ground or bond for circuits or equipment with higher fault currents, the combination of smaller conductors shall be evaluated and tested using one fewer than the minimum number required / rated by the manufacturer. Example – If a system is rated such that at least 5 microinverters on a string harness of microinverters is suitable to provide a grounding / bonding path for a mounting rack of PV modules the wire size and test current shall be based upon the use of 4 microinverters to account for one being removed from service.

RATING

89 General

89.1 AC module inverters and other module mounted electronics that are provided integral to the PV modules are not required to be provided with the dc input ratings specified in items (a) – (e) in Table 65.1.

89.2 A PV module with module mounted electronics that do not perform power conversion, voltage and/or current regulation shall provide the ratings required by the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, or the Standard for Photovoltaic (PV) Module Safety Qualification – Part 1: Requirements For Construction, UL 61730-1. The operating parameters which are controlled by the integrated device shall be clearly stated with supporting information. One example of such product is a PV module with rapid shutdown only functionality.

89.3 PVIE that have an ac output voltage that are not intended for direct connection to the EPS shall be provided with the applicable ratings and marking for an inverter as defined in Section 65.

MARKING

90 Details

90.1 AC modules and other module mounted electronics shall be marked with the maximum number of series and or parallel connected units to which it is intended to be connected.

90.2 AC modules and PVIE shall be marked with the ratings required in Section 89.

90.3 An AC module or other PVIE that require overcurrent protection in the final installation shall be marked with the maximum size overcurrent-protection to which it is to be connected.

90.4 PVIE that do not include GFDI protection, other than AC modules, shall be marked in accordance with 69.4(S).

90.5 Other markings as required by this standard shall be applied for the product and or function. See Sections 66 and 67 for additional information.

90.6 A PVIE shall be marked as follows:

a) AC module shall be marked with "AC module"

b) Other devices shall be marked "THIS PV MODULE CONTAINS INTEGRATED ELECTRONICS" and "REFER TO INSTALLATION INSTRUCTIONS" or the ISO 7000-1641 symbol.

90.7 An AC module, PVIE or other device provided with input or output cables or a trunk cable that has conductors with stranding finer than Class B or Class C (typically 19 strands for 14-2 AWG conductors) shall include the following statement, or equivalent, in the instruction manual: “The input, output or trunk cable supplied with this AC module, PVIE or other device has fine stranded, flexible conductors and if unterminated or if any factory-installed connectors have been removed, shall only be terminated using connections that have been rated for use with such conductors.”

90.8 An AC module not evaluated for field repair shall have the word “WARNING” and the following statement, or equivalent, marked on the microinverter and the PV module in a conspicuous location: “Risk of Electric Shock. This AC module has not been evaluated for field repair.”

91 Important Safety Instructions

91.1 The important safety instructions shall include a statement(s) indicating the applicable information in Sections 89 and 90.

91.2 An AC module that has been evaluated as suitable for field repair shall have the following information in the instruction manual.

a) Instructions for removing and replacing the microinverter or the PV module, as required, including opening the circuit breaker on the dedicated ac output circuit.

b) Instructions for protecting any disconnected and exposed (to the environment) dc and ac connectors.

c) Where an identical microinverter or PV module is not available, the manufacturer of the AC module, the manufacturer of the original microinverter or PV module, or the manufacturer of any retrofit kit, shall be queried as to a suitable replacement and for proper instructions for installing that replacement.

91.3 An AC module that has not been evaluated for field repair shall have the word "WARNING" and the following statement, or equivalent, in the instruction manual: "Risk of Electric Shock. This AC PV module has not been evaluated for field repair."

91.4 The important safety instructions shall include the instructions required by 69.4(U).

RAPID SHUTDOWN EQUIPMENT AND SYSTEMS

INTRODUCTION

92 General

92.1 The requirements in Sections 92 through 102 supplement and, in some cases, amend the general requirements in Sections 6 through 71.

92.2 The purpose of Sections 92 through 102 are to define requirements for PVRSE and PVRSS to reduce the level of electric shock and energy hazards for emergency responders working around PV arrays. These sections apply to the NEC 690.12 requirements addressing controlled conductors outside of the array. Products may perform rapid shutdown functions from within the array.

Note: NFPA 70, the National Electrical Code (NEC), Section 690.12, requires that all conductors leaving the PV array be controlled when a rapid shutdown initiation device is operated.

92.3 These requirements evaluate controlled conductors that may have a connection to ac circuits, such as inverter output circuits.

92.4 These controlled circuits are not required to be completely isolated as may be required for various electrical maintenance activities. The functional safety aspects of PVRSE and/or PVRSS are different from those for other electrical circuits.

92.5 The PVRSE and PVRSS shall comply with the functional safety points as follows:

a) Loss of control signal results in the PV system conductors being in a controlled state.

b) A complete loss of control power results in the PV system conductors being in a controlled state – multiple power sources may back up the primary power source, but when all power sources are removed, the PV system conductors shall revert to a controlled state.

c) PVRSS and PVRSE that relies on electronic control to initiate rapid shutdown shall be tested to the functional safety requirements of Section 97.

d) Attenuation devices shall be evaluated for the loss of continuity of any input or output connection (including the circuit being controlled).

92.6 For all components used as part of a PVRSS, the installation and configuration of this PVRSE identified as part of a PVRSS shall be consistent with and be capable of being integrated into a complete PVRSS.

CONSTRUCTION

93 Protection of Emergency Personnel

93.1 The requirements in this Section apply to PVRSE and PVRSS intended to reduce hazards from electric shock and energy hazards to emergency personnel or first responders, who may need to work in the vicinity of a PV system.

93.2 A PVRSS shall maintain controlled conductors at a limit of not more than 30 Vdc, 8A (for dc circuits) or 15 Vac, 8A (for ac circuits) within the time limit specified in the ratings. Both ac and dc circuits are required to not exceed 240 VA (volt-amperes) in the controlled state. PVRSE are evaluated to perform specific functions within PVRSS as defined by their specified functions and ratings.

Note: The 15 Vac (rms) voltage limit is in compliance with UL 1741 Limits for protection against electric shock in wet locations. The 240 VA limit is the UL 1741 defined threshold for reduced risk from electrical energy. The 240 VA limit applies to both ac and dc circuits.

93.3 An uninsulated live part involving a risk of electric shock or electrical energy at high current levels shall be located, guarded, or enclosed to protect against unintentional contact by personnel who may be called on to activate the initiating device while the equipment is energized.

93.4 A complete system that performs PVRSS functionality shall:

a) Include at least one initiator as defined in 2.2.4,

b) Be marked as described in 101.1, and

c) Include the information required in 102.1 in the installation instructions.

93.5 Components used in PVRSS and PVRSE shall comply with the applicable requirements for that component. If the component relies on electronic control, the component shall be tested to the applicable requirements for functional safety in Sections 97 and 99.

93.6 PVRSS and PVRSE with electronic controls shall comply with one of, or a combination of the functional safety based approaches described in Section 97 as necessary to evaluate the intended functionality of the PVRSS.

93.7 Mechanical and electro-mechanical PVRSE devices used to control ac or dc conductors in accordance with 93.2 shall comply with the requirements in 97.1.3, the environmental stress testing in Section 99, and shall be evaluated to the applicable requirements of at least one of the following standards based on the application and standard’s scope:

a) The Standard for Industrial Control Equipment, UL 508,

b) The Outline of Investigation for Manual Disconnect Switches Intended for Use in Photovoltaic Systems, UL 508I,

c) The Standard for Enclosed and Dead-Front Switches, UL 98,

d) The Outline of Investigation for Open-Type Switches, UL 98A,

e) The Outline of Investigation for Enclosed and Dead-Front Switches for Use in Photovoltaic Systems, UL 98B,

f) The Standard for Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures, UL 489,

g) The Standard for Circuit Breakers For Use in Communications Equipment, UL 489A, or

h) The Outline of Investigation for Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures For Use With Photovoltaic (PV) Systems, UL 489B.

PVRSE that are also intended to perform a system or equipment disconnect function shall comply with the applicable disconnect requirements in Section 15 and in the standards specified in this requirement, excluding UL 508.

93.8 A PVRSS that includes and relies upon multiple distributed switching devices or equipment that are intended to operate as a group to perform PVRSS function shall be evaluated considering the effect of individual equipment failures with respect to the overall system functionality and operation. The evaluation shall include, but not be limited to:

a) The possibility that failure of one component to operate may cause operational failures in other system equipment or components,

b) The worst case configuration (e.g. maximum number of switching elements allowed per power supply),

c) The effects of conducted or radiated EMI on electronic controls as part of a functional safety evaluation required by Section 97, and

d) Environmental effects on switch transition timing.

Note: An example of these devices would be contactors in multiple distributed dc combiner boxes.

93.9 Failures as noted in 93.8 shall be assessed during testing of systems, as to their impact upon the ability of the overall system to operate as intended. If a failure of a single piece of PVRSE with electronic controls results in failure of the remaining portions of the system to isolate or attenuate controlled conductors, or results in additional system equipment becoming disabled, the failure mode involved shall be evaluated using functional safety requirements as described in Section 97.

93.10 Functional self-test requirements:

a) A PVRSS shall be provided with a means or a method by which correct operation of the product is verified and it may be automatic through a manual initiator.

b) A PVRSS self-test function used to monitor and mitigate the failure of critical components shall be automatic and comply with 97.1.9.

93.11 PVRSE [inverter(s), converter(s) and other device(s)] that are rated to provide PVRSS functionality shall be evaluated to the applicable requirements in this standard and, if applicable, all individual PVRSE input and output circuits shall be evaluated to the applicable requirements in Section 98. PVRSE within a PVRSS with interaction between inputs and outputs of a single PVRSE shall be evaluated in all possible operating modes.

93.12 PVRSE rated as a component of a PVRSS or that provide a complete PVRSS function shall be marked according to Section 101 and instructions provided according to Section 102.

93.13 PVRSS that incorporate voltage sensitive devices that may change state with system voltage changes, such as, but not limited to, semiconductor switches and mechanical contactors, shall comply with Section 98, considering conditions in Section 97.2 and the functional safety evaluation in Section 99.

93.14 For PVRSS that incorporate multiple distributed switching devices intended to operate together in a series configurations, the individual switching devices shall be rated for interruption of the voltage and current for the PVRSS function they perform, (i.e. string current at the maximum system voltage).

Exception No. 1: Systems provided with a means (such as "soft start" or "soft stop" controls) to prevent individual series switching device operation (e.g. "hard" switching) outside of their electrical ratings may be used if the devices are maintained within their ratings during use.

Exception No. 2: Devices that are not rated for the maximum system voltage and current, and lack a reliable or adequate means to prevent asynchronous or "hard" switching shall comply with Section 98, considering conditions in Section 97.2 and the functional safety evaluation in Section 99.

The sum of the individual voltage ratings for the switches used in any system shall be equal to or greater than the rated maximum system voltage regardless of testing or other protective means provided.

93.15 PVRSE that is intended for mounting on PV modules shall comply with the requirements in Sections 85 – 91, which apply to the attachment and evaluation of inverters used on PV modules.

Exception: Devices that are not designed for connection to ac line circuits are not required to comply with requirements that are specific to that usage.

93.16 Upon loss of control power, a PVRSS shall either continue to operate normally with full functionality or it shall initiate a shutdown by placing the conductors in a controlled state complying with Section 98.1. A PVRSS that makes use of backup or stored power to operate shall initiate shutdown upon loss of the backup power supply.

93.17 A PVRSS that relies upon electronic functions, low voltage logic circuitry, or wireless communication for the initiation of PVRSS functions shall comply with the appropriate PVRSS Radiated EMI test as outlined in Section 99.

Exception: Individual equipment and or components that do not incorporate electronic functions, low voltage logic circuitry, or wireless communication are not required to comply with this test, except insofar as exposure to EMI may interfere with system operations via interconnections with other system equipment and components.

93.18 PVRSS, PVRSE or PVIE shall be evaluated to PV DC arc-fault protection functionality in accordance with Section 34A.

93.19 PVRSS that uses an attenuation device(s) to control conductors shall maintain compliance with 93.2 while applying conditions in 92.5 and Section 97. The installation instructions shall include the required location of attenuation device(s) in the circuit if this is not inherent to the design.

93.20 PVRSE and PVRSS shall be rated and evaluated for compliance in accordance with Table 93.1 based upon their intended application and installation location.

Table 93.1
PVRSS Rated Location Based Environmental Requirements

Rating	Environmental conditions per the manufacturer's specifications, subject to the following requirements				
	Outdoor	**Indoor, unconditioned**[c]	**Indoor, conditioned**	**Roof top (part of the PV module assembly or mounted less than 1/2 inch from the module substrate)**[e]	**Roof top**
Pollution degree[a]	Min. PD3	Min. PD3	Min. PD2	Min. PD3	Min. PD3
Wet location	Yes	No	No	Yes	Yes
Rated Ambient Temperature Range[b]	-40 °C to +50 °C or manufacturer specified	-40 °C to +50 °C or manufacturer specified	0 °C to +40 °C or manufacturer specified	-40 °C to +50 °C or manufacturer specified	-40 °C to +50 °C or manufacturer specified
Equipment test temperature range[f]	Same as Rated Ambient Temperature Range	Same as Rated Ambient Temperature Range	Same as Rated Ambient Temperature Range	Air: Larger of, -40 °C to +65 °C, or Rated Ambient.[d] On PV Substrate: Larger of, -40 °C to +85 °C or manufacturer specified using formula in note [d]	Same as Rated Ambient Temperature Range
Relative humidity range	4 % to 100 % (Condensing)	5 % to 95 % (Non (Non condensing)	5 % to 85 % (Non (Non condensing)	4 % to 100 % (Condensing)	4 % to 100 % (Condensing)
UV exposure	Required	Not Required	Not Required	Required	Required
Ingress protection	Min. Type 3R or IP34	Min. Type 1 or IP20	Min Type 1 or IP20	Min. Type 4X or IP65	Min. Type 3R or IP34.

[a] Describes the environment around the equipment with respect to moisture (such as rain or condensation) and contaminates. Equipment enclosure designs may allow for a reduction in pollution degree level applied to the internal circuit being evaluated. Pollution degree levels are defined in UL 840.

[b] Manufacturer's specified rated ambient range shall be clearly identified in the installation instructions with the intention that the AHJ will determine suitability. The temperature range for a geographic region shall be the Extreme Annual Mean Minimum Design Dry Bulb Temperature for the minimum design temperature and the 2 % high design temperature for the maximum design temperature. These values are found in the ASHRAE Handbook – Fundamentals, 2017 available online at https://www.ashrae.org/resources–publications/handbook/2017-ashrae-handbook-fundamentals.

[c] These spaces provide environmental protection and may not provide protection from cold ambient and may also result in an increased high ambient.

[d] Conditions stated are based on the PVRSE mounted behind the PV module and subjected to heat from the substrate and air temperature between the module and mounting surface. The specified air temperature assumes the module is mounted off the roof with no obstruction, which results in a 15 °C difference between the rated ambient air (per note b) and air behind the module. The module substrate temperature can be determined by the formula:

$$T_{cell} = T_{amb} + 1200/800 \cdot (NOCT - 20)$$

where T_{amb} is the rated ambient air temperature per note b.

Note: NOCT is determined at 800W/m^2 at an ambient temperature of 20 °C. The above adjusts this for more realistic worst-case irradiance to ensure maximum temperatures.

Air temperatures behind the module and substrate temperatures will be higher for other systems that are enclosed, built in or have other obstructions that restrict natural air movement under the array. Additional testing and evaluation of the design will be necessary to determine substrate and behind the module air temperatures for these systems.

Table 93.1 Continued on Next Page

Table 93.1 Continued

Rating	Environmental conditions per the manufacturer’s specifications, subject to the following requirements				
	Outdoor	Indoor, unconditioned[c]	Indoor, conditioned	Roof top (part of the PV module assembly or mounted less than 1/2 inch from the module substrate)[e]	Roof top

[e] The 1/2 inch distance, as measured from the module substrate to the closest point on the PVRSE housing exclusive of any mounting feet or standoff's, is solely used to determine the environmental requirements for PVRSE testing and does not address the requirements for the combination of PVRSS component/ equipment and PV module which may have separate requirements and conditions of use to address concerns including but not limited to electrical, mechanical and environmental impact on the PV module. For PVRSE mounted behind the PV module or array (> 1/2 inch), the ambient rating may need to be higher than the geographic location ratings.

[f] Unless otherwise specified, PVRSS/PVRSE test procedures in Section 98 shall be performed at the temperatures stated in this row. The functional safety evaluation in Section 97 shall consider effects of both cold and high temperatures. Tests specified in Section 99 shall be at room temperature unless specified otherwise.

94 Electrical Isolation Systems (EIS)

94.1 PVRSE that uses contactors or relays for isolation of controlled conductors shall contain electrical or electronic arc suppression devices on any contacts to minimize the radiated and conducted radio frequency (RF) signature of arcs created when those contacts switch and shall be evaluated to not interfere with the PV DC arc-fault protection functionality in accordance with Section 34A.

Exception: For those systems that combine PVRSS/PVRSE and PVIE functionality and PV DC arc-fault protection functionality in a single piece of equipment, the requirement to supply arc suppression devices shall be waived when the PVRSS/PVRSE function is tested with the PV DC arc-fault protection functionality enabled. The criteria shall be that the PV DC arc-fault protection functionality does not trip.

95 Initiators

95.1 An initiator for PVRSS functions shall be clearly identifiable for the function it performs.

a) The position of the initiators shall indicate the functional status of the controlled conductors, i.e. “ON” or OFF”. An “OFF” status indicates controlled conductors are in the controlled state, in accordance with 93.2.

b) The manually operable initiator shall require manual resetting, using a reset device or manipulation of the initiator.

c) An input designed to receive an external initiation signal from emergency devices, such as fire alarm systems, shall require manual resetting. An external initiation signal, that may initiate shutdown due to other non PVRSS conditions such as inverter shutdowns due to grid fault or loss shall be permitted to automatically reset.

d) Where the PVRSS is capable of accepting initiation inputs from multiple manual or external initiation devices (e.g. fire alarm), the initiation system shall have those devices or inputs connected in such a manner that activation of any one of the devices or inputs will result in initiating the PVRSS.

e) If a status indicator light is provided, it shall indicate not later than specified response time from the initiation of the rapid shutdown and only after the PVRSS function properly occurs.

96 PVRSS that Includes Disconnect Functionality

96.1 PVRSS that includes PVRSE that will also be evaluated as a system or equipment disconnect described in 93.7 shall comply with the additional following requirements:

a) The PVRSE shall have a means for remote control by an initiator and the switching device shall comply with requirements for an electrically tripped or power operable disconnect device from one of the standards listed in 93.7.

b) The manual switching device shall allow disconnection by either manual operation or by initiator.

c) The manual switching device shall not allow manual closure (connection) while the initiator is activated (conductors placed in the controlled state).

d) The manual switching device shall be able to determine the status of the initiator at all times. Failure mode analysis and functional safety evaluation shall result in the switching device being disconnected (conductors placed in the controlled state) due to loss of initiator status.

e) The combination PVRSE or PVRSS and the disconnect function shall comply with all applicable sections for PVRSE and PVRSS in this standard, including environmental stress testing applied to the mechanical devices.

97 PVRSS and PVRSE Functional Safety

97.1 General

97.1.1 PVRSS or PVRSE that use electronic controls, communication and/or firmware shall be subjected to a risk assessment for functional safety.

97.1.2 Standards listed in Table 97.1 shall be used along with the requirements in Section 99 to evaluate the PVRSE and if evaluating an entire PVRSS, each PVRSE of the PVRSS.

Table 97.1
Functional Safety Standards

PVRSE using electronic devices	Standard for Safety for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991. Critical components evaluated using the Computational Investigation method shall have predicted failure rates equivalent or better than IEC 61508 SIL 2 or ISO 13849-1 PL d.
PVRSE using firmware/software	Standard for Software in programmable components and or equipment, UL 1998. UL 1998 shall be used in conjunction with Functional Safety standards, such as UL 991, to also evaluate discrete component hardware and non-programmable IC's.
Alternate standards that may be used in place of UL 1998 and UL 991 for evaluating PVRSE risk and functional safety. The environmental stress testing in Section 99 is based on UL 991 with modifications made to the test procedure to represent both dc and ac equipment used in a PV RSS environment. If other standards are used, the environmental stress testing as described in Section 99 shall be applied in addition to the requirements of the other standards. If tests in the other standards are similar to those prescribed in Section 99, the more severe criteria of both standards shall be applied.	
	Automatic Electrical Controls – Part 1: General requirements, UL 60730-1. PVRSE shall comply with Control Class B as a minimum.
	• Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems, IEC 61508. PVRSE shall comply with a minimum of SIL 2.
	• Safety of Machinery – Functional Safety of Safety-Related Electrical, Electronic and Programmable Electronic Control Systems, IEC 62061. PVRSE evaluated to this standard shall comply with a minimum of SIL CL 2.
	• Safety of Machinery – Safety-Related Parts of Control Systems – Part 1: General Principles for Design, ISO 13849-1. PVRSE shall comply with a minimum of PL d.

97.1.3 All PVRSE, including mechanical devices, shall consider conditions noted in Section 97.2 and environmental stress testing in Section 99.

97.1.4 The rapid shutdown function of the PVRSS or PVRSE shall not be affected by the appropriate environmental stresses described in Table 99.1. Verification of function may be required during and/or after the applicable environmental stress tests.

97.1.5 An entire PVRSS can be evaluated as a combination. Each device within the PVRSS that uses electronic controls, communications and/or firmware to perform its rapid shutdown function shall be evaluated. The markings and instructions shall identify all the devices to be interconnected.

97.1.6 PVRSE may be evaluated individually when the interaction with other devices is considered in the evaluation and explained in the manufacturer's instructions.

97.1.7 Devices using electronic controls for the rapid shutdown function under evaluation shall have a failure mode and effect analysis (FMEA) performed as described in the standards listed in Table 97.1.

97.1.8 Devices that also use firmware/software for the PVRSS and PVRSE function shall include a risk assessment considering the interaction of the firmware and circuit as performed in UL 1998 or other standards listed in Table 97.1. The software/firmware version shall be controlled.

Exception: As defined by UL 1998, or other standards listed in Table 97.1, firmware or software independent from and segregated from the rapid shutdown functionality need not be evaluated.

97.1.9 Any single point component failure (short or open) that causes the device not to perform its intended function or does not cause the PVRSS to lock into the controlled conductor mode shall be identified as a critical component. Critical components shall be evaluated in accordance with UL 991 or the equivalent functional safety standard listed in Table 97.1. If the PVRSS has a self-test system to identify the failure of a critical component, then the operation of a self-test system shall be verified by testing with faults implemented to simulate failure of each of the system elements covered by the self-test system. Under each fault condition 10 test cycles of operation shall be conducted. The self-test system shall recognize the fault or failure and it shall initiate a shutdown as described in Section 98.1.

97.1.10 Inverters or other devices that have not been evaluated as part of a PVRSS and rely on a separate PVRSE for controlling conductors connected to input or output ports, do not require a functional safety evaluation if they are not performing PVRSS functions (such as but not limited to simple energy storage devices like capacitors, having no interactions in the PVRSS functions). Such devices shall be tested to verify that controlled input and output ports comply with 93.2 limits when the external source is removed as tested in Section 98.

Exception: Verification of dc levels is not required when the manufacturer's instructions state, in accordance with 102.6, that the inverter be placed in a location where the PV input conductors are not required to be controlled.

97.2 Conditions to be addressed for a PVRSS/PVRSE

97.2.1 A functional safety evaluation shall address the following:

a) Stated and intended functionality of the product.

1) Only PVRSS related functions and systems need to meet functional safety requirements as stated in this standard.

2) Auxiliary equipment and functions which may be provided with a PVRSS/PVRSE but which are unrelated to the PVRSS functions being provided, are only required to be evaluated for functional safety insofar as they interact or interfere with the PVRSS functions.

b) Effects of system or device failure, inaction, improper installation and component failures, such as:

1) Single point failure of components and equipment, including possible isolation/insulation failures. This may include effects such as, but is not limited to, arcing, which may take place between power and control circuits during switch operation.

2) Ground faults

3) Short and open circuits, including the loss of continuity of any input or output connection (including the circuit being controlled).

Note: Short circuits between conductors are unlikely for circuits run in raceways or with cables evaluated for crush resistance such as TC-ER, ICT-ER, DG cable, UF cable, NM cable or MC cable.

4) Incorrect installation wiring, including transposition of wires where possible, subject to constraints of wire lengths and connector types.

5) Loss of control signal or power

6) Improper sequencing and synchronization of controls that could result in inconsistent or unreliable operation of the switching, isolation, or attenuation components or equipment.

Note: Mechanical isolation devices will be tested to the standards listed in 93.7 considering short circuit current, overload rating and if used to interrupt load. The environmental testing in 93.13 and Section 98 are intended to evaluate the functionality of mechanical devices under extreme conditions that could adversely affect their ability to function. Additionally, the contacts are not considered to fail closed if also evaluated under abnormal temperature conditions, extremes of the rated operating temperature range, and the effect of abnormal temperature on the function of mechanical devices. Standards listed in 93.7 do not consider higher temperature conditions.

c) Humidity, water or dust exposure during normal operating conditions based on installation location and enclosure protection.

d) External environmental stresses listed in Table 99.1.

e) Electrical ratings, overvoltage, undervoltage, ride-through as described in Section 98.3, short circuit current, power quality as listed in Table 99.1.

f) The interconnection of multiple devices and how distance between devices or the number of devices impacts the result of environmental stresses listed in Table 99.1.

PERFORMANCE

98 General

98.1 Operational tests for PVRSS/PVRSE verification of levels – controlled conductors

98.1.1 The intent of this test is to validate PVRSS/PVRSE functionality and measure the available voltage, current, and power on controlled conductors at the rated rapid shutdown time limit following a shutdown or disconnection of a device intended for connection to a PV array with the equipment operating normally. This test shall be conducted on an unconditioned sample. If the PVRSS/PVRSE is specified for use with a particular conversion equipment or product family, the test shall be conducted with worst case representative equipment as specified by the manufacturer.

Note: Equipment connected to PV systems typically contain capacitors that can keep the circuit conductors energized even after de-energization of the equipment. Controlled conductors must therefore either be isolated from the equipment, or the capacitors in the equipment must be actively de-energized to comply with 98.1.2 (a) and (b).

98.1.2 After activation of a PVRSS, the following conditions shall apply:

a) The terminals shall not present voltage greater than 30 Vdc or 15 Vac (rms), measured between any two conductors and any conductor and ground, after the rated rapid shutdown time limit after the PVRSS/PVRSE is activated.

Exception: In PVRSS circuits where the voltage is measured at the output side of a device after humidity conditioning, a measurable voltage in excess of the requirement may be present due to leakage current across the isolating or attenuating device. Such devices may be considered to be in compliance with the stated voltage limit, if the output terminals of the isolation device can comply with the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, Section 21, Leakage Current test limits for "Accessible circuit parts" when measured across the terminals and from each terminal to ground. The test shall be conducted within 5 minutes after measuring the non-compliant voltage level. The limits in UL 1703, Section 21, shall apply to either ac RMS or dc leakage.

b) Not more than 240 VA continuous power, and no more than 8.0 A average current shall be available from the terminals being tested when connected to a load at the rated rapid shutdown time limit after the initiating event.

1) The load for verification of the 8 A limit shall be a resistor equal to (0.9*circuit voltage)/8 A) ±2 %.

2) The load for verification of the 240 VA limit shall be a resistor equal to (0.9*circuit voltage^2/240 VA) ±2 %.

c) The "circuit voltage" in the above equation shall be the open circuit voltage present in the circuit at the rated rapid shutdown time limit after the initiation of disconnection. The load shall be connected to the circuit at the rated rapid shutdown time limit (+1.0, -0.0 seconds) following initiation of disconnection. The circuit voltage shall be measured and recorded prior to and following the connection of the loads. The power measured following connection of the load shall be the average value measured for not less than one second and until no increase in current is observed. For the purpose of this test, the term continuous shall mean a power greater than 240 VA that persists for longer than 1.0 second.

98.2 Verification testing of PVRSS at rated extremes

98.2.1 The following verification tests shall be conducted. If the product provides multiple functions, then all functions shall be considered to create worst case conditions. The component, product or system shall be installed in accordance with its instructions using the rated wire/cable types, power sources and with all required equipment. It shall be operated and tested to confirm it provides the claimed isolation or attenuation function as defined in Section 98.1. Additionally, the component, product or system shall be evaluated for proper operation at its rated electrical extremes and temperature and humidity extremes as defined by the product ratings as specified in Table 93.1.

a) A device under test (DUT) powered by ac and Grid Support Compatible shall be tested using the range specified in Section 98.3.

b) A DUT powered by a dc input shall also be tested at the minimum and maximum operating voltage levels for the controlled circuits as per its ratings.

c) A DUT shall have each type of available control power removed individually and all types simultaneously, with a result that the DUT shall do one of the following:

1) Continue to operate normally with all critical functions available,

2) Initiate shutdown, placing Controlled Conductors in a controlled state complying with Section 98.1.

d) Units that use batteries as a control power source shall be tested using batteries of a type that can be used in the DUT. Alternatively they may be tested using equipment or batteries that simulate the necessary conditions.

Note: When selecting a battery source for testing, It shall be considered that similar rated batteries may have actual characteristics that are different from each other – such as 9V rated rechargeable batteries that can range from 7.2 – 8.4 – 9.6 V, when fully charged, depending on whether they are 6, 7, or 8 cell types.

For the overvoltage test, batteries shall be used that can exhibit the highest maximum voltage level that will be available from fully charged commercially available batteries of any type that can be used in the DUT.

For the undervoltage test, batteries shall be used that can be charged to a voltage of between 88 % and 92 % of the PVRSS mfr specified battery voltage. If the PVRSS specifies the use of multiple batteries (types, technology or voltage), the lowest operating voltage battery shall be used for this test. For batteries that are used to maintain critical functions during power loss, all other power sources that provide power in parallel with the battery shall be disconnected or disabled for the test.

Exception: For a DUT, which is provided with a low battery warning, the undervoltage test shall be conducted at the level that triggers the warning.

Steps shall be taken to prevent batteries from voltage recovery during the undervoltage test or discharge during the overvoltage test.

The product is to remain in the test condition until it shuts down successfully, reaches thermal stabilization, or has been operated for seven hours, whichever occurs first. As a result of the tests, a unit shall not emit flame or molten metal or become a risk of fire, electric shock, or injury to persons.

98.3 Power supply grid support ride through

98.3.1 PVRSS or PVRSE that receive operating power from the ac utility or units that have other power sources, are initiated by a loss of the ac utility and are controlling PV dc conductors that supply power to grid support utility interactive inverters shall be evaluated to this section. These PVRSE/PVRSS shall be identified as grid support compatible and marked in accordance with 101.4.

98.3.2 PVRSS or PVRSE described in 98.3.1 is tested to Sections SA9 and SA10 to determine that the device or system does not activate within the ride-through region. The ride through behavior noted in Sections SA9 and SA10 and SRD's for inverters are not applicable to PVRSS or PVRSE covered by this section. The only ride through behavior for this equipment is that it shall not initiate a rapid shutdown. Sections SA9.2 and SA10.5 is to be replaced with the test in 98.3.3 and it is not necessary for PVRSS or PVRSE to monitor magnitudes of the different regions or be tested for accuracy to IEEE 1547 unless this is a requirement of the equipment to perform its intended rapid shutdown function.

The SRD(s) or voltage and frequency ride through limits and times supported by PVRSS/PVRSE shall be included in the instructions.

Note: The PVRSS ride through functionality may be validated with a specific inverter during the grid support inverter testing in Sections SA9 and SA10.

98.3.3 PVRSS or PVRSE as described in 98.3.1 shall be capable of performing its intended function within each of the voltage and frequency regions in Sections SA9 and SA10.

98.3.4 The PVRSS shall be tested at the most severe rated ride through conditions based on the units PVRSS ratings. If the rated ride through time is less than the PVRSS rapid shutdown time limit, the test shall verify that the PVRSS activated due to the initiation. The PVRSS or PVRSE shall comply with 93.2.

98.4 Inverters rated as PVRSE

98.4.1 Utility-Interactive inverters may be rated as PVRSE on the ac output, the PV input or both. The DUT is to be connected to a PV input source (PV array or PV simulator) and an ac output source (utility or utility simulator). The ac source shall be at the nominal rated ac voltage ±2 % for the DUT and the PV input voltage shall be at the highest voltage in the peak power tracking range for the DUT. The DUT shall be exporting power.

a) To be rated on the ac output as PVRSE, the simulated utility ac source shall be disconnected. The output voltage on the DUT grid terminals shall meet the requirements established by 98.1.2(a) and be marked in accordance with 101.2.

b) To be rated on the PV input as PVRSE, the DUT shall comply with both of the following two tests and be marked in accordance with 101.2.

1) Both the ac output source and the PV input source shall also be disconnected simultaneously. The voltage on the PV input terminals of the DUT shall meet the requirements of 98.1.2(a).

2) The ac output source shall be disconnected and simultaneously the PV input source shall be increased to the rated maximum dc voltage of the DUT. After the input terminal voltage has reached the applied input source voltage within 5 %, the voltage of the dc source shall be disconnected. The voltage on the PV input terminals shall meet the requirements of 98.1.2(a) after the dc source voltage has been disconnected.

98.4.2 Stand-alone or Multimode inverters may be rated as PVRSE on one or more input/outputs.

a) The DUT will be connected to a dc input/output source (battery or battery simulator), an ac input/output source (utility or utility simulator) and an ac output load/source. If applicable, the ac source(s) shall be at the nominal rated ac voltage for the DUT ±2 %. The PV input voltage shall be at the highest voltage for the DUT. Each operating mode shall be tested and the DUT shall be exporting rated power in each mode.

Those modes shall correspond to the capabilities of the DUT and may include, PV input power flow to ac utility-interactive input/output, utility-interactive input/output power flow to the dc input/output, PV input power flow to the protected load input/output, protected load input/output power to the dc input/output, utility-interactive input/output power flow to the protected load input/output and protected load input/output power flow to the utility-interactive input/output.

To have a particular input/output set of terminals on a DUT rated as PVRSE, those terminals shall meet the requirements of 98.1.2(a) when all sources or loads are simultaneously disconnected from the DUT.

b) DUT complying with these tests for any set of terminals shall be marked according to 101.2 for those terminals.

98.5 Other equipment rated as PVRSE

98.5.1 Charge controllers, dc-to-dc converters, power supplies and other power processing equipment may be rated as PVRSE on the output, the input or both. The DUT is to be connected to an input source and an output source or load. The output source shall be at the nominal rated voltage for the DUT ±2 % and the input voltage shall be at the highest voltage in the peak power tracking range for the DUT ±2 %. The DUT shall be operating at maximum rated power ±5 %.

a) To be rated on the output as PVRSE, the output source or load shall be disconnected. The output voltage on the DUT terminals shall meet the requirements established by 98.1.2(a).

b) To be rated on the input as PVRSE, the DUT shall comply with both of the following two tests.

1) The output source or load is to be disconnected and simultaneously the input source shall also be disconnected. The voltage on the input terminals of the DUT shall meet the requirements of 98.1.2(a).

2) The output source is to be disconnected and simultaneously the input source shall increase to the rated maximum input voltage of the DUT +0/-2 %. After the input terminal voltage has stabilized at the maximum rated input source voltage +0/-2 % the input source shall be disconnected. The voltage on the input terminals shall meet the requirements of 98.1.2(a) after the source voltage has been disconnected.

c) Equipment complying with either or both tests shall be marked according to 101.2.

99 Functional Safety Evaluation and Environmental Stress Testing For PVRSS/PVRSE

99.1 A Rapid Shutdown System, a Rapid Shutdown System component, or an inverter or converter intended for use as a part of a PVRSS shall comply with the limits in 93.2 on its dc or ac input or output terminals upon the loss of control circuit power when tested in accordance with 99.2.

Exception: Utility-Interactive or grid support inverters evaluated to Section 50.8, Section 98.4 and IEEE 1547/IEEE 1547.1 comply with this requirement.

99.2 The DUT is to be connected to its rated input and output circuits, and its rated control circuit supply voltages if supplied separately. The circuit voltages shall be within ±2 % of rated. A single fault is to be placed in the control system such that it disables the power to the PVRSS control circuit.

Exception: When the control circuit is unable to be disabled under any single fault condition, this test is not required to be performed.

99.3 Additional fault testing shall be performed as identified in 97.1.7 through 97.1.9.

99.4 Equipment evaluated to this section shall have the appropriate environmental stress test applied as listed in Table 99.1 and the rapid shutdown function verified.

99.5 The method used to verify the correct function during a stress condition will depend on the PVRSS or PVRSE device being tested. It can include methods such as: verification of voltage levels, by communicating with the device or monitoring for a signal or change in state. For verification after the stress condition, the methods in Section 98 can be used.

99.6 Inverters performing a rapid shutdown function on the PV input conductors and/or ac output conductors by reacting to a loss of ac grid shall be evaluated to the appropriate environmental stress tests listed in Table 99.1. The alternate test methods listed in Table 99.1 for IEEE1547/IEEE1547.1 can be used in place of the Standard for Safety for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991, and combined with any utility-interactive or grid support function testing.

Table 99.1
Environmental Stress Testing (based on UL 991)

Stress test	UL 991 Section (IEEE1547 / IEEE1547.1 equivalent)	Example of devices this may apply to:	Condition to be met (see 99.7)
Overvoltage/Undervoltage	10 (4.2/5.2)	Devices that rely on a power source to perform the safety function, such as activating a mechanical device, communications or for powering the logic circuits.	(1) (7)
Power Supply Dips and Short Interruption	11 (4.2/5.2)	Devices that rely on a power source to perform the safety function, such as activating a mechanical device, communications or for powering the logic circuits.	(6) (7) (9)
Transient Overvoltage (Surge)	12 (4.1.8.2/5.5.2)	Test applied to power ports on all devices with electronic controls	(2) (7) (9)
Voltage Variation	13 (4.2/5.2)	Devices that rely on a power source to perform the safety function, such as activating a mechanical device, communications or for power the logic circuits.	(6) (7) (9)
Electrical fast Transient/burst	14.2 (4.1.8.2/5.5.2)	Test applied to communication and control ports on all devices with electronic controls	(3) (7) (9)
Signal Circuit fast transient	14.7 (4.1.8.2/5.5.2)	Electronic control devices with communication ports with external wiring not surrounded by a grounded conductive shield.	(3) (7) (9)
Radiated immunity (EMI)	14.8 (4.1.8.1/5.5.1)	All electronic control devices	(4a) (7) (8)
Digital equipment modulation	14.9 (4.1.8.1/5.5.1)	All electronic control devices	(5) (7) (8)
Keying interference	14.10 (4.1.8.1/5.5.1)	All electronic control devices	(4b) (7) (8)
ESD	15 to 15.4	Based on FMEA	(9)
Electric field	15.5	Based on FMEA	(9)
Magnetic field	15.6	Based on FMEA	(9)
Composite Operational and Thermal Cycling	16	All equipment using electronic control or mechanical devices	(10, Table 99.4)
Shipping and Storage	17 (None/5.1)	All electronic control devices	(1) (7) (9)
Thermal Cycling	See Table 99.4	All equipment using electronic control or mechanical devices.	(10)
Humidity	Table 99.5	All equipment using electronic control or mechanical devices.	(10)
Dust	20	Based on FMEA, installation location and enclosure protection rating	(9)
Vibration	21	Based on FMEA	(9)
Jarring	22	Based on FMEA	(9)
Note: Equivalent requirements from other standards listed in Table 97.1 can also be used.			

99.7 The following conditions are to be used with Table 99.1:

(1) Compliance with UL 991, Section 10, is covered testing performed in the following sections:

- Performance testing in Section 98.

- Power Supply Grid Support Ride Through testing in Section 98.3 if the device is identified for this application.

• Temperature and Humidity cycling as described in condition (10).

(2) ac powered controls shall be tested to UL 991 or IEEE 1547. Controls powered solely from a PV input shall be tested in accordance with Table 99.2 with the equipment connected to a dc source capable of supplying the maximum rated input voltage +0/-2 %. The device under test is allowed to be damaged if the PVRSS function locks into the controlled conductor mode. In this case, a failure mode analysis is performed and the equipment can be repaired or replaced to continue testing the remaining number of stated impulses in Table 99.2. If any of the remaining surge tests for that polarity cause the equipment to fail the same way, after two such failures, the testing for that polarity is complete.

(3) Test on Communications or control terminals if part of the PVRSS function.

(4a) Use a minimum field strength of 10V/m.

(4b) Use IEEE C37.90.2. This test is not required when the UL 1998 risk assessment does not identify electromagnetic interference as a potential cause for failure or misoperation.

(5) Inverters tested to IEEE C37.90.2 (as referenced from IEEE 1547 and IEEE 1547.1) shall additionally be subjected to and found compliant with the 10kHz Pulse or Square Wave Modulation Test in Section 14.9 of UL 991. This test is not required when the UL 1998 risk assessment does not identify electromagnetic interference as a potential cause for failure or misoperation.

(6) If the PVRSS function relies on power from a PV input for electronic controls or controlling mechanical devices, the dc source shall be varied from maximum rated +0/-2 % voltage to minimum rated voltage +2/-0 % for the “Voltage Dips” test of UL 991, Section 11, and the 40 % test of UL 991, Section 13.

(7) If the IEEE 1547 or equivalent grid support test method is used, the evaluation may need to include verifying PVRSS system operation to Section 98.1 on the ac circuit and other circuits in addition to IEEE 1547 criteria.

(8) Functional verification during stress. Reference 99.5.

(9) Functional verification after stress. Reference 99.5.

(10) The “Composite Operational and Thermal Cycling” and “Thermal Cycling and Humidity” tests shall comply with the requirements as stated in Table 99.4 and Table 99.5. A single sample shall be used for both tests. The sample is first tested to Table 99.4 and then to Table 99.5. The sample used shall complete the entire test sequence and is compliant if there are no mechanical or electrical hazards and it complies with the final functional verification. During functional checks, the switch transition timing shall be evaluated to address systems that rely upon multiple series switching devices to operate in unison or other systems that can be negatively impacted by increased or variable switch timing.

Table 99.2
PV Input Surge Requirements

Surge type	Surge/impulse voltage	Surge test resistance	Number of impulses per polarity	Surge polarity for each test point
100 kHz ring wave	Table 99.3	30 ohms	10	Negative
			10	Positive
Combination wave (1.2/50usec)	Table 99.3	12 ohms	10	Negative
			10	Positive
Equipment Test Points	Positive input to ground	Negative input to ground	Both to ground	Positive input to Negative input

Table 99.3
Surge Values

Maximum dc input rating of equipment	Test surge/impulse voltage
71 Vdc	500V
141 Vdc	800V
213 Vdc	1500V
424 Vdc	2500V
849 Vdc	4000V
1500 Vdc	6000V
Note: Interpolation is permitted.	

Table 99.4
Temperature Cycling

Test step	Test method	Exceptions to method/additional test information
Conditioning – 200 temperature cycles	UL 1703 Section 35 and Figure 35.1 (this figure also shown as Figure 99.1)	The sample used for this testing will have previously complied with the appropriate operational verification testing of Section 98. One sample of the PVRSE or PVRSS is required for the DUT. Note: It may be good practice to have a back-up DUT in case one is damaged in the post test or humidity-freeze testing. If the DUT is damaged or stops operating in a mode compliant with 93.2 rapid shutdown function and does not pose any other hazard, the sample does not fail the test. However, a new DUT must be verified to Section 98, repeat the 200 temperature conditioning cycles and repeat all remaining tests in order to complete the entire test sequence. The DUT is not powered during the 200 cycle conditioning test. However, if electrical continuity of safety critical circuits (such as grounding, bonding and rapid shutdown critical circuits) is also being evaluated, a separate power source can be used to monitor any interruption in continuity during the cycles. The temperature cycle profile of Figure 99.1 (which is from UL 1703 Figure 35.1) is used with the following clarification: a) The transition time shall not exceed 2 °C/minute. b) Each cycle shall have a dwell time no less than 0.5 hours and no more than 1.75 hours. Note: Dwell time will depend on the DUT construction attaining a temperature within 2 °C of the chamber temperature. See the dashed line on Figure 99.1 that illustrates how a module material temperature may track chamber temperature. Certain larger electronic components or large amounts of potting material may require more time to reach temperature.

Table 99.4 Continued on Next Page

Table 99.4 Continued

Test step	Test method	Exceptions to method/additional test information
		The cold and high dwell temperature is determined by the following DUT ratings: 1) DUT with a rated operating temperature of no more than 50 °C: Use the storage/transportation rated temperature range with the high temperature no less than 70 °C. Note: The cold storage temperature rating is rated as low or lower than the rated cold operating temperature. 2) DUT with a rated operating temperature over 50 °C: Use the greater of the storage/transportation temperature range, operating temperature range or UL 1703, Section 35, dwell temperatures.
Post conditioning checks		Perform a high temperature functional check: 1) Adjust the test chamber air temperature to the DUT maximum rated operating temperature. 2) Connect the DUT to all necessary power and control/communication ports as done for testing in Section 98. 3) Load all ports to full rating and activate any communication ports being evaluated as part of the PVRSE or PVRSS function. • Power ports will be set to either maximum voltage or nominal voltage (-/+2 %) • The rapid shutdown function is not initiated 4) Operate the DUT in this mode for a minimum of 24 hours at maximum rated operating temperature 5) After the 24 hour period – with the DUT in the chamber at maximum rated temperature, repeat the functional check of Section 98 five times at each rated voltage extreme. Refer to 99.5 for verifying the function. • For DUT with multiple power ports, the voltage varied for the test shall be the port that provides the logic/control power. • dc power ports shall use the minimum rated voltage -0/+2 % and maximum rated voltage +0/-2 %.

Table 99.4 Continued on Next Page

Table 99.4 Continued

Test step	Test method	Exceptions to method/additional test information
		• ac power ports shall use the most severe of the following conditions: 88 % (-0/+2 %) of nominal for the minimum and 110 % (-2/+0 %) of nominal for the maximum; or, the equipment minimum voltage rating (-0/+2 %) and maximum voltage rating (-2/+0 %) Perform visible inspections for items listed in UL 1703 Section 35.1(a) UL 1703 Section 35.1(b), (c), (d), (e) and (f) do not apply unless this temperature stress is being combined with another test program that requires this evaluation. If these evaluations are performed, the test connections and evaluation shall not jeopardize testing to this standard. Note: The use of additional samples should be considered if different test programs are combined to share chamber resources.

Figure 99.1

Temperature Cycle Conditioning Test

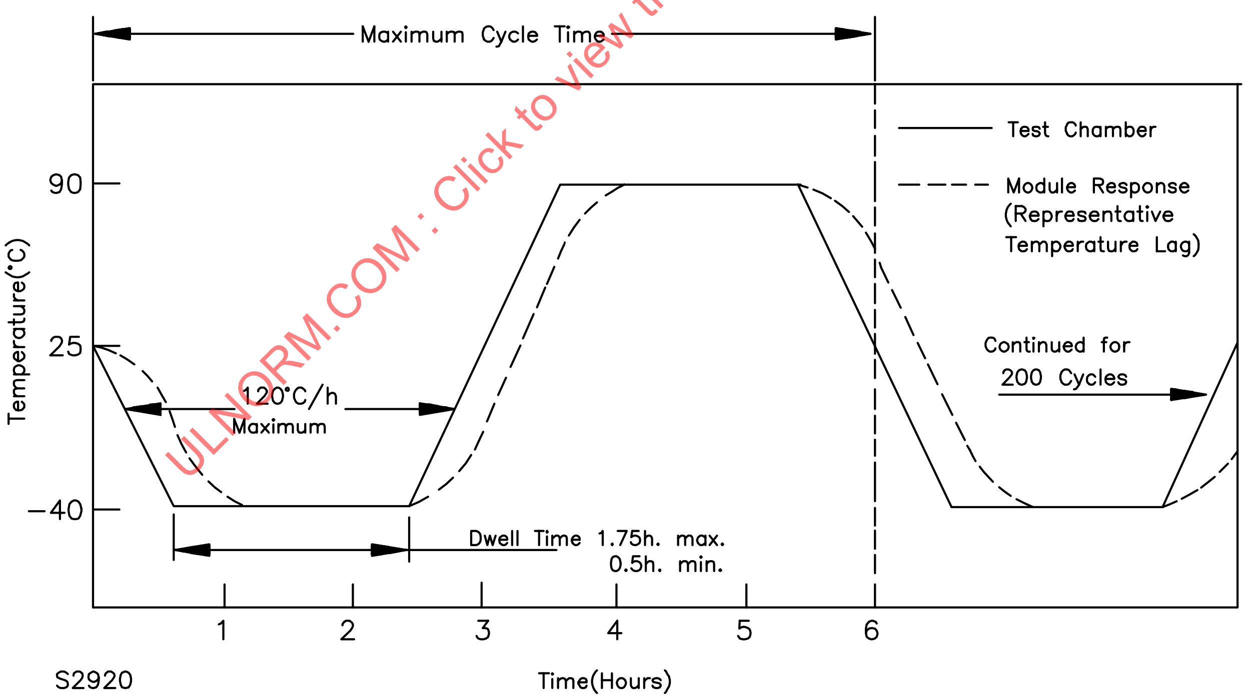


Table 99.5
Humidity-Freeze Cycling

Test step	Test method	Exceptions to method/additional test information
10 humidity-freeze cycles with functional checks	UL 1703, Section 36, modified	Refer to Figure 99.2 of this standard for the humidity-freeze cycling test profile and UL 1703, Section 36, for other details of the test set up. • At the end of the 10th cycle, the chamber shall be stabilized at 25 °C with humidity on until the DUT is removed for the post checks. • During the humidity-freeze cycling, the DUT is to be powered as shown in Figure 99.2 (a repeating sequence of: maxV, off, minV, off, minV, off, maxV, off). The result will be cycles 1, 3, 5, 7 and 9 having the same combination of Voltage and temperature/humidity (T/H-High and maxV; T-Low and minV) and cycles 2, 4, 6, 8 and 10 having the same combination (T/H-High and minV; T-Low and maxV). The temperature values for T/H-High and T-Low shall be based upon the PVRSE "Equipment test temperature range" as defined in Table 93.1. At the end of the 10th cycle (transition from freeze to 25 °C), the DUT will remain off until the post tests are performed. • dc power ports shall use the minimum rated voltage -0/+2 % and maximum rated voltage +0/-2 %. • ac power ports shall use the most severe of the following conditions: 88 to 90 % and 108 to 110 % or the minimum voltage rating -0/+2 % and maximum voltage rating -2/+0 % respectively. • For equipment with multiple power ports, the voltage varied for the test shall be the port that provides the logic/control power. Functional checks (FC) shall be done at the specified transition points, low temperature dwell and high temperature/humidity dwell times and corresponding voltage setting as shown in Figure 99.2. • FC1 – Transition from cycle 1 cold dwell to cycle 2. Turn on power at 25 °C and perform functional check while chamber temperature is in transition. The functional check shall be performed while the chamber temperature is between 25 °C and 40 °C. Voltage is at minV. • FC2 – Cycle 2 high temperature/humidity dwell (after at least 1 hour of dwell time). Voltage is at minV. • FC3 – Cycle 2 cold dwell (after at least 15 minutes of dwell time). Voltage is at maxV.

Table 99.5 Continued on Next Page

Table 99.5 Continued

Test step	Test method	Exceptions to method/additional test information
		• FC4 – Same as FC1, except at the transition from cycle 2 cold dwell to cycle 3 and the voltage is at maxV. • FC5 – Same as FC2 except at cycle 3 and the voltage is at maxV. • FC6 – Same as FC3 except at cycle 3 and the voltage is at minV. • Repeat the previous sequence for FC1 to FC6 starting at the transition from cycle 5 to cycle 6 (for the above sequence description, replace cycle 1 with cycle 5, cycle 2 with cycle 6 and cycle 3 with cycle 7). • The final functional checks are performed after the humidity-freeze cycles (refer to the post tests below).
Post humidity-freeze cycle checks	UL 1703, Section 36	Perform functional checks: At the end of the humidity-freeze cycles (end of the 10th cycle when the chamber reaches 25 °C), the equipment shall be removed after the chamber has stabilized at 25 ° C ±2 °C for 0.5 hours (±15 minutes) and functional tests below performed within 1 hour of removing the equipment from the chamber. The equipment shall be powered just long enough to perform the functional checks. 1) Connect the DUT to all necessary power and control/communication ports as done for testing in Section 98. 2) Load all ports to full rating and activate any communication ports being evaluated as part of the PVRSE or PVRSS function. • Power ports will be set to maximum voltage (+0/-2 %) 3) Initiate the rapid shutdown function and record results. • Refer to 99.5 for verifying the function. • Refer to the Exception to 98.1.2 for verification of voltage and leakage current on any part of the DUT that provides an isolated disconnection of the dc PV circuit (air-gap from a contactor, relay or similar device).

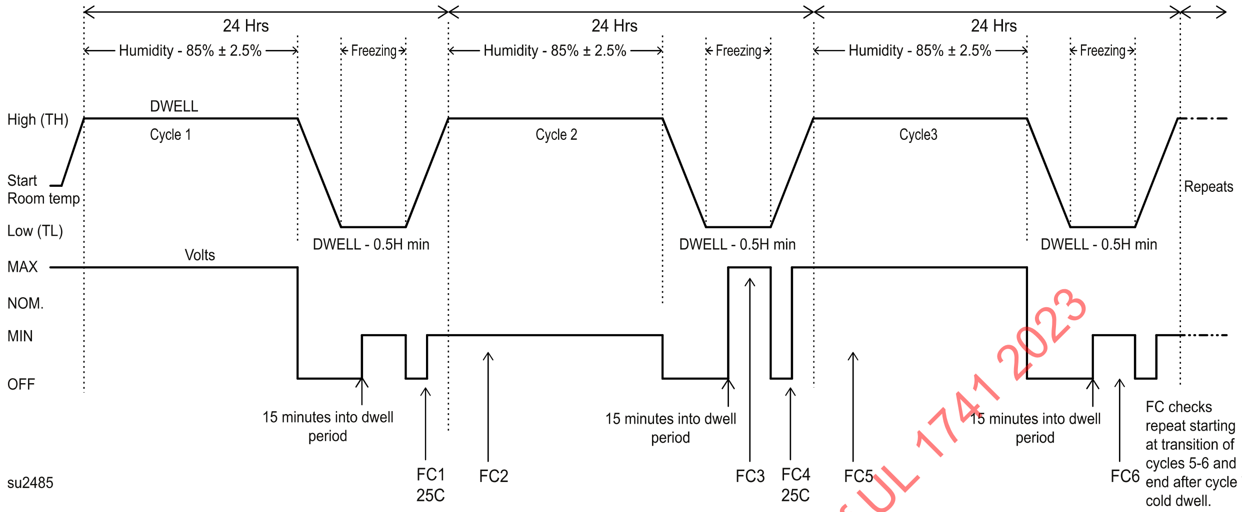
Table 99.5 Continued on Next Page

Table 99.5 Continued

Test step	Test method	Exceptions to method/additional test information
		4) Deactivate the rapid shutdown function and verify the DUT has returned to the state of operation before the rapid shutdown function was initiated. 5) Adjust power ports to the minimum rated voltage (-0/+2 %) and repeat steps 3 and 4. • For DUT with multiple power ports, the voltage varied for the test shall be the port that provides the logic/control power. 6) Turn off all power to the DUT. 7) DUT using electronic controls for the rapid shutdown function shall be set unpowered at room temperature for at least 3 hours, but no longer than 5 hours after the completion of the above functional check. Repeat steps 2 through 5. 8) Turn off all power to the DUT and perform the Dielectric Withstand test, Section 47. Perform visible inspections for items listed in UL 1703, Section 36.1(a). UL 1703, Section 36.1(b), (c), (d), (e) and (f) do not apply unless this temperature stress is being combined with another test program that requires this evaluation. If these evaluations are performed, the test connections and evaluation shall not jeopardize testing to this standard. Note: The use of additional samples should be considered if different test programs are combined to share chamber resources.

Figure 99.2

Humidity-Freeze Cycling Test



Humidity-Freeze profile is a general representation only. For full test details, including acceptable rate of change of temperature, refer to Section 36, of the Standard for Flat-Plate Photovoltaic Modules and Panels, UL 1703, and to Table 99.4 and Table 99.5 of this standard for modifications to the test procedure.

RATINGS

100 General

100.1 A PVRSS system or component, used solely for the purpose of rapid shutdown, shall be rated in accordance with Table 65.1.

Exception: Equipment that are not designed for connection to or control of a particular function or circuit are not required to be provided with ratings that reference that function or circuit.

MARKING

101 Details

101.1 Only a complete PVRSS may be marked "photovoltaic rapid shutdown system." Only PVRSE may be labeled "photovoltaic rapid shutdown system equipment." The term "PHOTOVOLTAIC" may be replaced with "PV."

101.2 Only PV systems equipment that has been found to comply with the relevant PVRSS and or PVRSE requirements to perform rapid shutdown functions may be marked with the following wording or equivalent:

> "All inputs and outputs of this product comply with photovoltaic rapid shutdown requirements for controlled conductors outside the array"
>
> Or

"Only the indicated terminals of this product comply with photovoltaic rapid shutdown requirements for controlled conductors outside the array"

101.3 Equipment described in 13.2.4 and 97.1.10 shall be marked on or near each port identified with the following markings: "PVRSS Controlled Conductor Connection Port – refer to instructions for conditions of use."

101.4 Only PVRSS and PVRSE complying with Section 98.3 may be marked as follows; "grid support interactive compatible."

101.5 Products evaluated as PVRSS or PVRSE shall include the relevant markings of Table 65.1 and Section 66, 101.1 – 101.4 in the installation instructions required in 102.14.

101.6 For products with power supply grid support ride through, documentation shall include the minimum ride through times for each region from the testing of Sections SA9 and SA10.

102 Installation Instructions

102.1 The installation instructions provided with the product shall include all the relevant items of 102.2 – 102.14 and shall be consistent with the evaluation performed on the product.

102.2 PVRSS and PVRSE shall comply with the relevant parts of Sections 68.2 and 69.

102.3 The installation instructions shall indicate whether the equipment qualifies as a PV Rapid Shutdown System (PVRSS) or as PV Rapid Shutdown Equipment (PVRSE).

102.4 Equipment described in 13.2.4 and 97.1.10 shall include instructions to ensure correct use of equipment with other connected devices, including:

a) The Port is not controlled, but has been evaluated for connection to controlled conductors,

b) Electrical characteristics of the port,

c) Characteristics (pertinent to the PVRSS system) of the conductors that can be connected to the port, and

d) Expected behavior of the electrical circuit during RVRSS initiation.

102.5 In relation to 68.2(d), the installation instructions shall describe the method(s) of initiating Rapid shutdown function and shall be marked in accordance with Section 690.56(C) of the NEC (NFPA 70).

102.6 The installation instructions shall instruct the installer to provide signage complying with Section 690.56(C) of the NEC (NFPA 70). The installation instructions shall state whether:

a) All conductors are controlled, or

b) Only conductors leaving the footprint of the array are controlled.

102.7 PVRSE shall have the following warning in the instruction manual:

WARNING – THIS PHOTOVOLTAIC RAPID SHUTDOWN EQUIPMENT (PVRSE) DOES NOT PERFORM ALL OF THE FUNCTIONS OF A COMPLETE PHOTOVOLTAIC RAPID SHUTDOWN SYSTEM (PVRSS). THIS PVRSE MUST BE INSTALLED WITH OTHER EQUIPMENT TO FORM A COMPLETE PVRSS THAT MEETS THE REQUIREMENTS OF NEC (NFPA 70) SECTION 690.12 FOR CONTROLLED CONDUCTORS OUTSIDE THE ARRAY. OTHER EQUIPMENT INSTALLED IN OR ON

THIS PV SYSTEM MAY ADVERSLY AFFECT THE OPERATION OF THE PVRSS. IT IS THE RESPONSIBILITY OF THE INSTALLER TO ENSURE THAT THE COMPLETED PV SYSTEM MEETS THE RAPID SHUT DOWN FUNCTIONAL REQUIREMENTS. THIS EQUIPMENT MUST BE INSTALLED ACCORDING TO THE MANUFACTURER'S INSTALLATION INSTRUCTIONS.

102.8 This equipment shall be installed and operated in an environment within the ratings and limitations of the equipment as published in these installation instructions.

102.9 All PVRSS and PVRSE shall be provided with installation instructions necessary for proper installation of the system including but not limited to details such as minimum control wire size, and maximum control wire length.

102.10 For PVRSE that will be mounted behind a PV module, no portion of the PVRSE enclosure will be less than 12.7 mm (1/2 in) from the module substrate, then the instructions for installing the PVRSE shall be specific enough to assure this distance is maintained. The instructions shall also inform the installer that the PV module instructions should be reviewed to determine if any restrictions for mounting devices under the module exist as part of the PV module listing.

102.11 The installation instructions shall provide system test or commissioning procedure(s) for validation of proper PVRSS operation, including compliance with the rated rapid shutdown time limit.

102.12 Installation instructions shall have revision control and revision level shall be marked on the document.

102.13 PVRSS and PVRSE that have complied with the requirements of Section 98.3 for grid support shall be provided with installation instructions that detail that the product is compatible with grid support functions and any limitations on the grid support functionality.

102.14 PVRSS will have the following warning in the instruction manual:

WARNING – THIS PHOTOVOLTAIC RAPID SHUTDOWN SYSTEM (PVRSS) INCORPORATES ONE OR MORE PIECES OF EQUIPMENT THAT EXERCISE THE RAPID SHUTDOWN CONTROL OF PV SYSTEM CONDUCTORS REQUIRED BY SECTION 690.12 OF THE NEC (NFPA 70). OTHER EQUIPMENT INSTALLED IN OR ON THIS PV SYSTEM MAY ADVERSELY AFFECT THE OPERATION OF THIS PVRSS. IT IS THE RESPONSIBILITY OF THE INSTALLER TO ENSURE THAT THE COMPLETED PV SYSTEM MEETS THE APPLICABLE RAPID SHUT DOWN FUNCTIONAL REQUIREMENTS. THIS EQUIPMENT MUST BE INSTALLED ACCORDING TO THE MANUFACTURER'S INSTALLATION INSTRUCTIONS.

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SUPPLEMENT SA – GRID SUPPORT UTILITY INTERACTIVE EQUIPMENT

PART 1 – GENERAL

SA1 Scope

SA1.1 These requirements cover grid support utility interactive inverters, converters and ISE. This Supplement to UL 1741 is intended to validate compliance with grid interactive functions which are not covered in IEEE 1547-2003. These grid support functions may include but are not limited to voltage and frequency ride through and active and reactive power control. These Grid Support Functions may impact an inverter's anti-Islanding functionality; therefore Anti-islanding testing will be conducted with these functions enabled as described in the applicable sections below.

SA1.2 As shown in Table SA1.1 the grid support utility-interactive requirements allow for the evaluation of products using either the UL 1741 SA tests or alternative testing methods using the requirements of IEEE 1547.1-2020 in accordance with IEEE 1547-2018 and IEEE 1547a-2020.

Note 1: It is anticipated that individual grid interconnection requirements will transition from requiring compliance with UL1741 SA to compliance with the new IEEE 1547.1-2020 in accordance with IEEE 1547-2018 and IEEE 1547a-2020. Allowance for grid support utility-interactive product compliance with either/both requirements will facilitate the transition which will be implemented differently and on different schedules for various jurisdictions.

Note 2: An optional path for evaluation of grid support interactive equipment is found in Supplement SB which references full compliance with IEEE 1547.1-2020 in accordance with IEEE 1547-2018 and IEEE 1547a-2020. Some jurisdictions require specific compliance with UL1741 Supplement SA in addition to specific SRD compliance, which is different from the requirements in Supplement SB that uses IEEE 1547-2018 as the functional SRD for testing in accordance to IEEE 1547.1-2020.

Table SA1.1
Grid Support Interactive Test Method Options

UL1741 SA test name	SA test section	Comparable IEEE 1547.1-2020 test section
Anti-Islanding Protection	SA8	5.10.2
Low and High Voltage Ride-Through	SA9	5.4.4, 5.4.7
Low and High Frequency Ride-Through	SA10	5.5.3, 5.5.4
Normal Ramp Rates	SA11.2	NA[a]
Soft-Start Ramp Rates	SA11.4	5.6
Specified Power Factor	SA12	5.14.3
Volt/Var Mode	SA13	5.14.4
Frequency-Watt	SA14	5.15.2
Volt-Watt	SA15	5.14.9
Disable Permit Service	SA17	5.6
Limit Active Power	SA18	5.13
For the purpose of Grid Support Interactive evaluations, this table provides options to use tests from either the UL 1741 SA or IEEE 1547.1 2020.		
[a] IEEE 1547-2018 and IEEE 1547.1-2020 do not have a requirement for, or test equivalent to, the UL 1741 SA Normal Ramp Rate which is presently a local requirement per California Rule 21 and/or Hawaii 14H which both require compliance with the Normal Ramp Rate test of SA11.2.		

SA1.3 The intention of this supplement is to define the evaluation criteria for utility interactive inverters with grid support functions that are rated and specified as “Grid Support Utility Interactive Inverters”. This new nomenclature is intended to differentiate these products from “utility interactive inverters.” The test requirements and protocols within this section are written to allow for the testing of multiple operational parameter sets of limits and times in an effort to accommodate the needs of different grid interconnection requirements. These functional requirements will be defined in a source requirements document (SRD). This Supplement is intended to validate compliance of a EUT with a stated SRD(s) across the range of EUT operation. Multiple SRDs may be encompassed by the range of operation and or addition of

functions. Where there are conflicting requirements between SRD(s), additional testing may be needed to evaluate the specific functional requirements of each SRD.

SA1.4 The requirements in this supplement are in addition to the other applicable requirements for utility interactive inverters and other applicable requirements within this standard.

SA1.5 Following the procedures described herein, manufacturers may rate their units to a variety of different regulatory requirements or have adjustable ranges of operation that will address the needs of a variety of different regulatory requirements.

SA1.6 The test procedures are not written with a specific regulatory regime in mind. These requirements and tests are intended to establish the template for the identified performance functions and allow for validation of conformance with specified performance parameters that can be used to demonstrate compliance with local requirements.

SA1.7 The manufacturer will utilize the ratings to state the settings for which the unit will be tested. Products shall be provided with ratings shown in SA16 including all of the defined parameters and settings in order to validate compliance.

SA1.8 This Supplement for Grid Support Utility Interactive Inverters was drafted using the "special purpose utility interactive inverter" CRD that allowed for manufacturer defined grid interconnection protection functions. While the Grid Support utility interactive inverters share some similar functionality with the previously defined special purpose utility interactive inverters that have potentially variable compliance requirements, the Grid Support Utility interactive inverters are required to and shall comply with the following defined requirements before they can be marked as a Grid Support Utility Interactive Inverters. Some of the requirements in this supplement are defined as optional, see Frequency-Watt (FW) – Optional, Section SA14, and Volt-Watt (VW) – Optional, Section SA15, and are not required to be included or complied with as part of the evaluation. Functions specified in this document as optional shall be evaluated if provided.

SA1.9 The tests in this supplement verify the performance of a single unit when connected to an area EPS. The single unit may include multiple pieces of equipment. Any additional equipment necessary for the proper functioning of the EUT shall be included in the test. Performance of systems of multiple units is beyond the scope of this document.

SA1.10 Within this supplement, the pass fail criteria is expressed mathematically or with defined limits and or time responses. Figures in this supplement are considered to be informative with exception of the test waveforms or if otherwise noted in the text.

SA2 Acronyms

AI	Anti-Islanding
ECP	Electrical Coupling Point
EPS	Electric Power System (electric utilities or their surrogates)
EUT	Equipment Under Test (this is also referred to as a "unit" elsewhere throughout the Standard and Supplement)
f	frequency
FPF	Fixed Power Factor
FW	Frequency Watt [also referred to as P(f)]
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IOU	Investor-Owned Utility
HV1	High-voltage range 1

HV2	High-voltage range 2
LV1	Low-voltage range 1
LV2	Low-voltage range 2
LV3	Low-voltage range 3
HF1	High-frequency range 1
HF2	High-frequency range 2
LF1	Low-frequency range 1
LF2	Low-frequency range 2
L/HFRT	Low/High Frequency Ride-through
L/HVRT	Low/High Voltage Ride-through
MSA	Manufacturer Stated Accuracy
NN	Near Nominal
PF	Displacement Power Factor
PFAP	Power Factor Mode with Active Power Priority
P(f)	Power as a function of frequency (also referred to as Frequency-Watt)
PUT	Parameter Under Test
Qf	Quality factor
Q(V)	Reactive Power as a Function of Voltage (Also known as VV, VV11 and VV12 and also referred to as Volt-VAr)
RLC	Resistance, Inductance, and Capacitance
RR	Ramp Rate
SPF	Specified Power Factor
SS	Soft-Start
SRD	Source Requirement Document
t	Time
VAr	Volt-Ampere Reactive
VW	Volt-Watt Active Power as a function of Voltage [also referred to as W(V)]

SA3 Definitions

SA3.1 Area Electric Power System(Area EPS) – An EPS that supplies local EPSs.

SA3.2 Cease to Energize – State or action in which the EUT ceases to export current to the area EPS in not more than the maximum specified time. Cease to energize does not imply galvanic separation (disconnection) of the EUT from the Area EPS.

Note: The intent is a target output current of zero, however it is recognized that even with the power electronics off or an output relay opened, passive components such as output filter capacitors will result in some current to or from the grid.

SA3.3 Continuous Operation – While the area EPS is within normal parameters the EUT shall operate normally and provide available active and/or reactive power to the area EPS.

SA3.4 Deadband – Signal domain interval or band where no action occurs.

SA3.5 Disable Permit Service – A function included in IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces, IEEE 1547-2018, which disables the EUT's permit service setting if not operating so that it will not start operation, or cause the EUT to cease to energize the area EPS and trip in no more than 2 seconds if the EUT is operating.

SA3.6 EUT Disconnect and Reconnect Command – Function 2 in California, Electric Rule 21, Generating Facility Interconnections, Phase 3 which enables the area EPS Operation to send a command to the EUT to disconnect from the Area EPS or prevent the EUT from energizing the area EPS. Analogous to Disable Permit Service in IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces, IEEE 1547-2018.

SA3.7 Limit Active Power – A function included in IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces, IEEE 1547-2018, which limits the EUT active power output to a percentage of the nameplate active power rating in no more than 30 s or in the minimum time for the primary energy source to reduce its output power, whichever is greater.

SA3.8 Limit Maximum Active Power Mode – Function 3 in California, Electric Rule 21, Generating Facility Interconnections, Phase 3 which establishes an upper limit on active power that a EUT or system of EUTs can produce or use.

SA3.9 Local Electric Power System (Local EPS) – An EPS contained entirely within a single premises or group of premises.

SA3.10 Mandatory Operation – A prescribed requirement for the EUT to provide current to the area EPS in response to an abnormal excursion of the area EPS, within the SRD defined range.

Note: EUT protective functions needed to prevent damage to the EUT shall be permitted to function during mandatory operation.

SA3.11 Manufacturer's Stated Accuracy – The tolerance or maximum error in measurement or performance metric as specified by the manufacturer of the EUT.

SA3.12 Momentary Cessation – State or action, in response to an abnormal excursion of the Area EPS, in which the EUT momentarily ceases to energize the Area EPS, and will restore output with no intentional delay after Area EPS parameters have returned to specified conditions as defined by the SRD.

SA3.13 Permissive Operation – In response to an abnormal excursion of the area EPS the EUT may continue to provide active and/or reactive current to the area EPS or may cease to energize.

SA3.14 Return to Service – The criteria required for and behavior of the EUT as it re-energizes the area EPS following an abnormal excursion resulting in a trip, cease to energize, or momentary cessation operation of the EUT.

SA3.15 Ride-Through – State or action in response to an abnormal excursion of the area EPS, in which the EUT does not trip in less than the minimum specified duration. While the EUT is in the ride-through state, the SRD may require particular action such as momentary cessation or mandatory operation.

SA3.16 Source Requirements Document (SRD) – A document that includes the required operational functions, operating parameters including limits and response times.

SA3.17 Specified Power Factor (SPF) – There are two modes for SPF; fixed power factor (FPF) and power factor mode with active power priority (PFAP).

Note: In general FPF mode should be used to ensure availability of reactive power at all DER output power levels. FPF is normally the preferred mode of operation. PFAP mode may be used in special cases and by mutual agreement between the system operator and the area EPS operator.

SA3.18 Tightest ride-through settings – Unit settings that minimize the range for the ride through time and voltage or frequency parameter regions. This setting needs to account for the manufacturer’s stated accuracy.

SA3.19 Trip – State or action in response to an abnormal excursion of the area EPS, in which the EUT ceases to energize the area EPS, and will return to service only after the area EPS has returned to a normal operating condition for not less than the minimum specified time in the return to service criteria in the SRD.

Note: This differs from momentary cessation in the intentional delay before return to service.

SA3.20 Uni-Grounded – A center ground referenced WYE configured source with a 3 wire output circuit.

SA3.21 Unintentional Island – An unplanned island.

SA3.22 Utility-Interactive Inverter – An inverter intended for use in parallel with an electric utility to supply common loads and sometimes deliver power to the utility and that fully complies with the applicable parts of IEEE 1547-2003 and IEEE 1547.1-2005.

Note: Products for general utility interactive applications are evaluated for compliance with IEEE 1547-2003 and IEEE 1547.1-2005. They may also include additional Grid Support and or Special Purpose Utility Interactive functions that may be enabled in accordance with local utility interconnection protection requirements. For example, products may be evaluated for compliance with Reliability Standard NERC PRC 024-1, Generator Frequency and Voltage Protective Relay Settings.

SA3.23 Widest ride-through settings – Unit settings that maximize the range for the ride through time and voltage or frequency parameter regions. This setting needs to account for the manufacturer’s stated accuracy.

SA4 Construction

SA4.1 Grid support utility interactive inverter or converter shall comply with all of the UL 1741 construction requirements defined for utility interactive products.

SA4.2 Grid support utility interactive inverter or converter may rely upon externally provided equipment to operate in compliance with these requirements. Such external equipment shall be evaluated to UL 1741 or other applicable component standard for its function and conditions of use.

SA5 Performance – Grid Support Utility Interactive

SA5.1 General

SA5.1.1 When performing the abnormal tests in Section 50, consideration shall be given to the worst case EUT grid support interactive operating parameters in the continuous and mandatory operating regions.

Note: In some cases it may be necessary to repeat the test under multiple settings to determine the worst case.

SA5.2 Grid support utility interconnection protection performance

SA5.2.1 Grid support utility interactive inverter or converter shall be evaluated and found compliant with the applicable test procedures within Part 2 of this Supplement that are not identified as optional. The test procedures within this Supplement that are identified as optional may be additionally evaluated.

SA5.2.2 Grid support utility interactive inverter or converters are required to be evaluated for compliance with this standard and Supplement requirements and shall additionally be evaluated for compliance with IEEE 1547-2003 and IEEE 1547.1-2005. In cases of requirement conflicts, such as but not limited to trip limits and trip times, this Supplement including the SRD takes precedence over the IEEE 1547-2003 and IEEE 1547.1-2005 requirements. The evaluated featured functions and limits are defined in the product’s ratings and markings as defined in SA6.

SA5.2.3 Grid support utility interactive inverter or converter may be evaluated for compliance with specific documents or requirements (outside of or in addition to IEEE 1547-2003 and IEEE 1547.1-2005 including amendments or IEEE 1547a-2014 (Amd. 1) and IEEE 1547.1a-2015 (Amd. 1) as defined and referenced in the product ratings.

SA5.2.4 When a grid support utility interactive inverter or converter requires additional interconnection protection devices to comply with these requirements, the devices shall be provided as part of the grid support utility interactive inverter or converter or shall be specified in the product installation instructions as required equipment for inclusion during installation

SA5.2.5 Grid support utility interactive inverter or converter may include functions that are intended to be enabled or disabled in accordance with local utility interconnection protection requirements. The special functions shall be explained in the installation instruction and/or operating manual as defined in SA6.4.

SA5.2.6 The inverter requirements in this Supplement address common operating and fault conditions for single phase and 3 phase EPS configurations. EUTs rated only for operation on 3 phase 3 wire systems, are to be evaluated for response to phase to phase voltages. EUT rated for operation on 3 phase 3 wire uni-grounded systems may be evaluated for both phase to ground and phase to phase voltages.

SA5.2.7 For the purposes of this document, testing shall be conducted in accordance IEEE 1547.1-2005, Clause 4, except as otherwise defined in the individual tests of this document. Measurement equipment shall have anti-aliasing filters and sampling frequencies appropriate to the measurement of the fundamental frequency component shall be applied.

SA5.2.8 Units that incorporate operating parameters with a range of adjustment are to be evaluated at the extremes of the adjustment range and another semi-central point between the extremes, (where required by the individual test procedures) to validate compliance across the range of adjustability.

SA5.2.9 EUT protective functions needed to prevent damage to the EUT shall be permitted to function during mandatory operation.

SA5.2.10 When measuring EPS events with changes in voltage and frequency the test equipment measurement time domain current and voltages shall be sampled at rate above 10,000 samples/sec. Longer duration tests with slower response e.g. RR and SPF may use a lower sampling rate.

SA5.3 Test parameter tolerances

SA5.3.1 Unless otherwise stated, the following tolerances shall apply to specified test parameters and or test setup operating conditions. These tolerances shall not be applied to minimum or maximum absolute specified limits.

Example: For a test procedure requirement that specifies to “set the AC input to nominal voltage”, per this requirement the actual voltage is allowed to be within a window of nominal voltage ±2 %.

SA5.3.2 This section is not applied to manufacturer stated accuracy of a EUT nor is it to be applied to equipment measurement accuracy.

SA5.3.3 If a setup or other criteria is expressed as a percentage of voltage, current, power, or time, the tolerance is to be calculated based on the base unit then application of the tolerances in Table SA5.1.

Table SA5.1
Test Parameter Tolerances

Parameter	Units	Default tolerance of measurement
Voltage (DC)	Volts	±2 %
Voltage (ac)	Volts rms	±2 %
Current (DC)	Amps	±3 %
Current (ac)	Amps rms	±2 %
Power	Watts / VA	±4 %
Power Factor	Displacement Power Factor	±3 %
Frequency	Hz	±0.05 Hz
Time	Seconds	±3 %
Temperature	Degrees C	±3c
Averaging Window		Not less than 100 averages over the duration of measurement
Averaging Window Weighting		Piecewise linear

SA5.4 Representative testing

SA5.4.1 When testing a product family that shares an identical physical construction of critical components and firmware, where the family members only differ in output power ratings, testing on the highest power EUT is considered representative of lower power units in the EUT family, unless otherwise specifically defined by a test protocol.

SA5.5 Abnormal tests

SA5.5.1 A grid support utility interactive inverter or converter shall not pose hazards defined in Section 50.1 for Abnormal Tests when performing grid support functions. The grid support utility interactive product shall be evaluated at its most extreme rated operational limits of voltage, frequency, and current.

SA6 Ratings, Markings and Instructions

SA6.1 Grid support utility interactive inverter or converter shall be rated, marked and include instructions in accordance with the applicable requirements for utility interactive inverters in accordance with Sections 65 through 69, and Section SA16. The actual markings ratings and instructions provided shall accurately represent the functions that were the subject of the product evaluation.

SA6.2 Grid support inverters or converters that have not been evaluated to and found compliant with the full set of applicable IEEE 1547-2003 and IEEE 1547.1-2005 interconnection protection function requirements (as defined for the specific product type) shall be permanently marked with the following markings:

a) "ATTENTION" and the following or equivalent: "This unit has not been evaluated for some of the IEEE 1547-2003 and IEEE 1547.1-2005 utility interconnection protective functions. This unit may need to be provided with external utility interconnection protection in accordance with local codes and local utility requirements." This marking is to be placed in a location that is readily visible adjacent or near the unit's ratings marking.

b) Grid support inverter or converter complying with a subset of the IEEE 1547-2003 and IEEE 1547.1-2005 requirements shall include details of the specific compliant portions or conversely the unevaluated portions of the standards. This information may be provided as part of the product ratings label, or the warning label in SA6.2(a), or it shall be marked in either of those locations as follows; "Product specific evaluation criteria and ratings are included in the product installation instructions and/or operating manuals."

SA6.3 Compliance with specific documents or requirements [outside of IEEE 1547-2003 and IEEE 1547.1-2005 IEEE 1547a-2014 (Amd.1) and IEEE 1547.1a-2015 (Amd. 1)] that include additional grid support utility interconnection settings and functions, shall be specifically defined and referenced in the product ratings, within the installation manual and/or operating instructions. This information shall be provided in the same locations as the information that is referenced in SA6.2 (a) or (b).

SA6.4 In accordance with SA5.2.5, the installation instructions for grid support utility interactive inverter or converter shall include the following details:

a) The specific grid connectivity requirements, documents or standards to which the product was designed and evaluated including the specific version or edition or publication date as adequate to identify the specific version.

b) Information about the type and characteristics of required external utility interconnection protection functions or devices.

c) Information clearly indicating limitations in product function availability or scope of operation due to incompatibility with other available product functions.

d) The means by which programmable settings can be accessed and programed as well as functions enabled or disabled, except those passwords related to changing the availability or settings of grid protection and support functions shall not be required to be published in the instructions or manuals.

SA6.5 Grid support utility interactive product functions referenced within the manuals and instructions that have been evaluated for compliance, shall be clearly differentiated within the installation instructions from grid support utility interactive product functions that have not been evaluated.

SA6.6 The equipment evaluated under this document shall include manufacturer’s stated accuracy in the product manual including at least: voltage current, frequency, power (active and reactive), power factor and time.

SA7 Manufacturing and Production Line Testing for Grid Support Utility Interactive Inverters

SA7.1 Grid support utility interactive inverter or converter shall be subjected to an evaluation to validate inverter firmware version(s) and default settings in addition to the production test requirements defined in Section 70, 71 and as defined in IEEE 1547.1-2005.

PART 2 – SPECIFIC REQUIREMENTS AND TESTS FOR GRID SUPPORT UTILITY INTERACTIVE INVERTERS

SA8 Anti-islanding Protection – Unintentional Islanding with Grid Support Functions Enabled

Since compliance with the Supplement SA series of tests in Sections SA9 – SA15 is required as a prerequisite for performing the following Anti-islanding test, the Anti-Islanding test should be run as the last test in the Supplement SA series of tests.

SA8.1 General

SA8.1.1 This unintentional islanding test procedure addresses unintentional islanding evaluation on the Equipment Under Test (EUT) with grid support functions enabled. This test differs from IEEE 1547.1-2005, Section 5.7.1, by including grid support functions, i.e. commanded active power level, commanded reactive power level, voltage/frequency ride-through functions, and autonomously implemented voltage and frequency grid support functions. This section is intended to address autonomous inverter anti-islanding functions and does not consider or account for other communications based schemes like permissive operating signals that may be incorporated.

SA8.1.2 This test is intended to verify that the EUT trips as specified by the applicable requirements document or manufacturer specification when a EUT is exposed to an unintentional islanded condition. The EUT is verified to be compliant with ride through functions enabled both with and without additional grid support functions enabled.

SA8.1.3 The IEEE 1547.1-2005 Unintentional Islanding test procedure in 5.7.1.2 shall be applied to the EUT with the following revision to 5.7.1.2(d):

Set and verify the EUT trip parameters are at maximum adjustable voltage and frequency ranges, maximum adjustable response durations as previously determined in the voltage and frequency ride-through sections, and grid support functions are set as described below. It is permitted to disable the grid support functions or widen deadband setting when tuning the test circuit provided doing so does not change the EUT active or reactive output power at nominal test conditions. After tuning the test circuit the deadband shall be returned to the worst case setting.

a) For each of the functions to be verified as compatible with unintentional islanding compliance, the manufacturer shall identify parameters that adversely affect islanding detection and state the worst-case condition for the EUT to be anti-islanding compliant. The worst-case conditions shall be identified and documented by the manufacturer and test laboratory for evaluation under this test program.

Note: This condition is likely to exist when the voltage and frequency ranges and detection times are adjusted to the maximum adjustable settings with L/HVRT and the L/HFRT functions enabled. (Time parameters are set to the largest value within their range of adjustability, the low voltage/frequency parameters are set to the minimum value within their range of adjustability, and the high voltage/frequency parameters are at the maximum value within their range of adjustability.) If a Volt-Var function is to be validated using this procedure, the worst-case parameter values are likely to minimize the deadband, maximize the var production, and maximize the slope of the volt-var curve. For example, if a var-priority volt-var function is to be validated, this function may need to be enabled instead of a watt-priority Volt-Var function.

b) Given the function configuration to be validated, unintentional islanding tests shall be performed to validate each unique combination of functions grouped together that can be simultaneously enabled as stated by the manufacturer. Functions, which may be grouped within unique function combination groupings, are not required to be retested.

c) For example, to test the EUT for hypothetical functions A, B, and C that can be enabled simultaneously, those functions shall be enabled and tested as a group. See Table SA8.1. If the EUT passes the test for this grouping then no additional tests or combinations of A, B, and C are required. However, to certify another function, D, which is mutually exclusive with C, then the grouping A, B, D must be tested as well.

SA8.2 Test procedure

SA8.2.1 Set up the EUT as described in IEEE 1547.1-2005 section 5.7.1.2 steps (a) through (l) with the following exceptions:

a) Where IEEE 1547.1-2005 section 5.7.1.2 states that “Any reactive power compensation by the EUT should remain on during the test” refer to Table SA8.1 for examples of how and when various active functions, including reactive power compensation are to be treated during the testing.

b) Before testing activate the appropriate function set for the test being conducted (see Table SA8.1 for reference), repeat all steps for each of the active function combinations in Table SA8.1 including modifications from SA8.1.3(a).

c) IEEE 1547.1-2005 section 5.7.1.2(d) states “Set (or verify) all EUT parameters to the nominal operating settings.” In place of this step, refer to the note in SA8.1.3(a) for details on EUT parameters settings.

d) When evaluating EUT output power factor values below 0.707, the Qf of the test circuit including the EUT will be higher than Qf=1. This is different than as defined in IEEE 1547.1-2005 section 5.7.1.2 step (h). Under those circumstances only one reactive load bank component is necessary to null the reactive output current of the EUT and test circuit.

Table SA8.1
Example Test Procedure

Functions active during anti-islanding test	Steps to be completed
L/HVRT, L/HFRT	IEEE 1547.1-2005 section 5.7.1.2 steps (d) through (l) and SA8.2.1(a)
L/HVRT, L/HFRT, SPF, RR, FW	IEEE 1547.1-2005 section 5.7.1.2 steps (d) through (l) and SA8.2.1(a)
L/HVRT, L/HFRT, Q(V), RR, FW	IEEE 1547.1-2005 section 5.7.1.2 steps (d) through (l) and SA8.2.1(a)
Note: RR for the purpose of this test, RR is considered to be the normal ramp up rate under normal operation as described in SA11.1.3. Also see SA8.3.8.	

SA8.2.2 Replace IEEE 1547.1-2005 section 5.7.1.2 steps (m) through (o) with the following (a) – (e):

a) Review the test results of IEEE 1547.1-2005 section 5.7.1.2 step (l) for the 1 % load increment settings. Identify the load setting that yielded the longest run on time before tripping.

1) Run two additional test iterations for those identified load settings.

2) The average trip time is to be taken of the three test iterations to determine the worst case trip time for the set of functions under test. Note that SA8.3.4 applies to the results of all iterations.

b) Repeat IEEE 1547.1-2005 section 5.7.1.2 steps (d) through (l) and sub-step SA8.2.2(a)(1), with the next appropriate EUT function set activated in accordance with Table SA8.1.

c) After collecting the 1 % load setting increments that yielded the longest average trip time for each function set detailed in Table SA8.1, determine which function set produced the longest average trip time.

1) For that function set, review the trip time results and the 1 % load setting increments that yielded the three longest trip times. The two settings that were not already subjected to three test iterations from sub-step (a)(1), shall be subjected to two additional test iterations.

2) If the three longest trip times [including the trip time already subjected to 3 test iterations from sub-step (a)(1)] occur at nonconsecutive 1 % load setting increments, the additional two iterations shall be run for all load settings in between.

d) For that function set identified in (c), repeat IEEE 1547.1-2005 section 5.7.1.2 step (n).

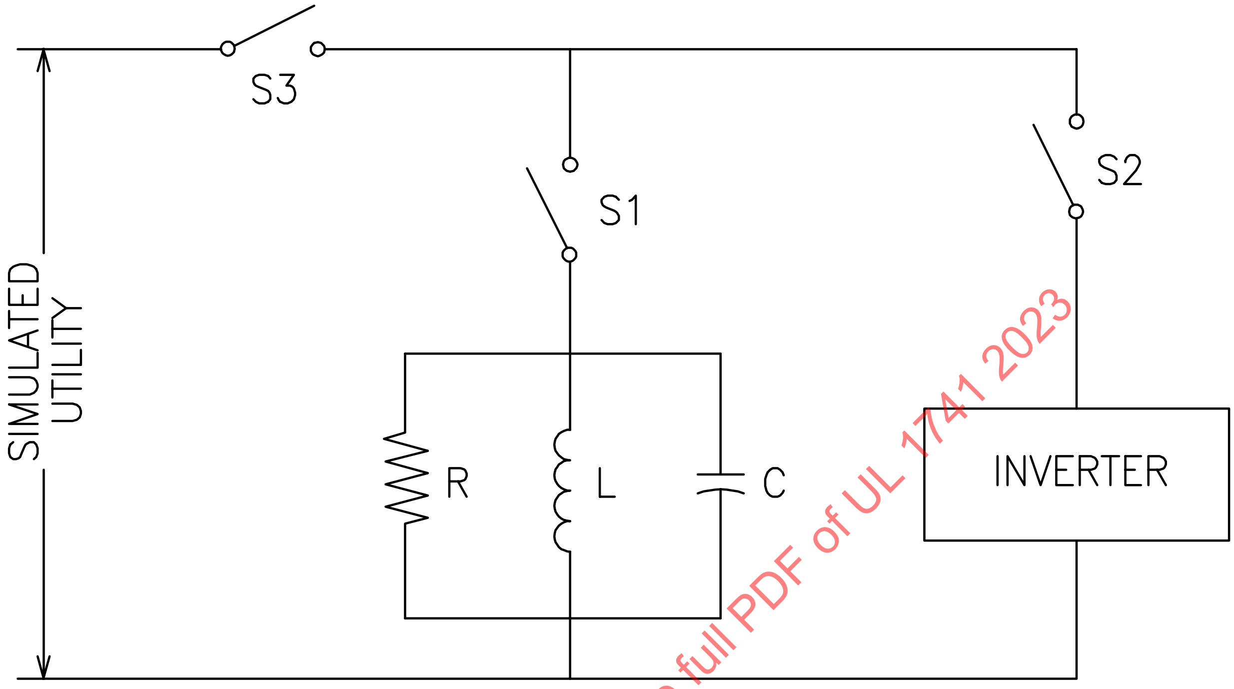
e) For that function set identified in (c), repeat IEEE 1547.1-2005 section 5.7.1.2 step (o).

SA8.3 Tests requirements

SA8.3.1 The test requirements in 5.7.1.3 of IEEE 1547.1-2005 shall be applied and additionally the actual EUT trip time for each test shall be recorded for each iteration of the test. The test circuit for the unintentional islanding tests is shown in Figure SA8.1 (or the test circuit in IEEE 1547.1-2005 Section 5.7.1.2, Figure 2). The following test criteria shall replace the criteria in 5.7.1.4 of IEEE 1547.1-2005.

Figure SA8.1

Unintentional Islanding Test Circuit



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SA8.3.2 The simulated area EPS shall meet the requirements of IEEE 1547.1-2005, Section 4.6.1. The measurement system shall meet the requirements of IEEE 1547.1-2005, Section 4.6.2. The input source shall be capable of supplying at least 125 % of the rated maximum input current of the EUT except as defined for the 33 % and 66 % power levels.

SA8.3.3 A test is successful when the EUT trips from and ceases to energize the test load within the timing requirements of IEEE 1547-2003 after switch S3 is opened. IEEE 1547-2003 and 1547a-2014 define compliance as ceasing to energize the area EPS within 2 seconds of the formation of the island.

SA8.3.4 If any of these tests results in islanding for longer than the specified time, the unit fails the test. A single failure of any of these tests is considered a failure of the entire test sequence.

SA8.3.5 If a non-compliant condition is discovered, this test may be repeated with the settings adjusted differently (e.g., less aggressively) for the Grid Support function causing non-compliance. If the adjustment of the grid support function produces compliant results, the rated EUT range of adjustment for the support function must be modified for the EUT.

SA8.3.6 Unevaluated combinations of functions and or unevaluated ranges of adjustments shall not be accessible to the end user or installer.

SA8.3.7 A grid support utility interactive inverter shall pass the unintentional islanding tests with the grid support functions enabled and disabled in accordance with Table SA8.2 and Table SA8.3, if applicable.

SA8.3.8 The grid support functions, examples of which are shown in Table SA8.2, shall be activated with the worst-case parameter sets, as defined by the manufacturer. The ramp rate (RR) function is not expected to support the Area EPS or reduce the EUT sensitivity to detect the island; however, if it is determined through testing that the ramp rate limitation can impact anti-islanding detection, it must also be enabled and tested, as shown in Table SA8.2 and/or Table SA8.3. If the EUT includes a Frequency-Watt function, it must be tested as well, as shown in Table SA8.3.

Note: Table SA8.2 depicts example of combinations of advanced functions that may be required to be simultaneously enabled to qualify a unit for Rule 21 SA compliance.

Table SA8.2
Example Test Matrix for Anti-Islanding Validation

Test	L/HVRT	L/HFRT	SPF	Q(V)	RR
1	X	X			
2	X	X	X		X[a]
3	X	X		X	X[a]

[a] If the RR function is shown to reduce island detection sensitivity, testing shall be performed with RR control set to worst case.

Legend:

- L/HVRT, Low/High Voltage Ride-Through
- L/HFRT, Low/High Frequency Ride-Through
- SPF, Specified Power Factor
- Q(V), Volt-Var Function with Watt or Var Priority as defined by source document
- RR, Normal Ramp Rate

Note: This table corresponds to the minimum requirements for CA Rule 21, 2015.

Table SA8.3
Test Matrix for Anti-Islanding Certification (with FW and VW Optional Functions Enabled)

Test	L/HVRT	L/HFRT	SPF	Q(V)	RR	FW	VW
1	X	X					
2	X	X	X		X[a]	OPT	OPT
3	X	X		X	X[a]	OPT	OPT

[a] If the RR function is shown to reduce island detection sensitivity, testing shall be performed with RR control set to worst case.

Legend:

- L/HVRT, Low/High Voltage Ride-Through
- L/HFRT, Low/High Frequency Ride-Through
- SPF, Specified Power Factor
- Q(V), Volt-Var Function with Watt or Var Priority as defined by source document
- RR, Normal Ramp Rate
- FW, Freq-Watt Function

SA8.3.9 The test comments in 5.7.1.5 of IEEE 1547.1-2005 shall be applied including the below text which is to be appended at the end of the section.

Note: For example, the worst-case parameter sets for the Rule 21 ride-through functions are when the operating and ride-through windows are maximized. There is no adjustability in the L/HVRT function described by the CPUC Electric Rule 21, 2015, but there is a range of adjustability for L/HFRT. The worst-case settings for L/HFRT are shown in Table SA8.4.

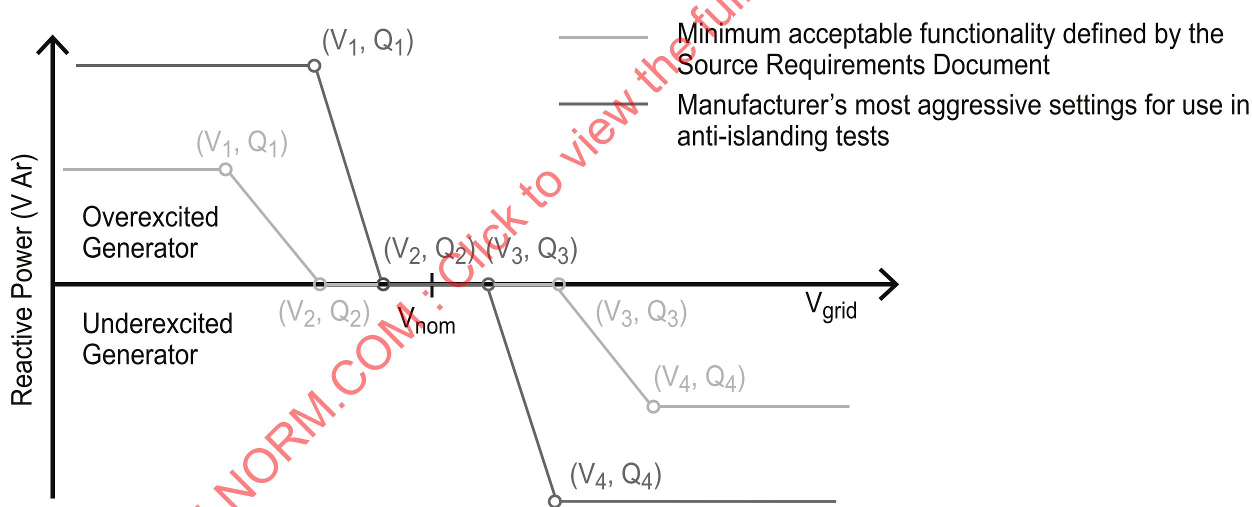
Table SA8.4
Example Settings for L/HFRT During Anti-Islanding Testing

System frequency	Ride-through until (s)	Ride-through operational mode	Trip time (s)
f > 64	No Ride-Through	Not Applicable	0.16
60.5 < f < 62	299	Mandatory Operation	300
58.5 < f < 60.5	Indefinite	Continuous Operation	Not Applicable
57.0 < f < 58.5	299	Mandatory Operation	300
f < 57.0	No Ride-Through	Not Applicable	0.16
Note: While these operating parameters correspond to the CPUC Rule 21 parameters and they may be substituted with other operating parameters for other area EPS requirements.			

SA8.3.10 The worst-case parameter settings for Volt-Var functions such as Q(V) are most likely from a minimized deadband, e.g., max(V_2) and min(V_3), maximized var production, e.g., max(Q_1) and min(Q_4), and maximize the slope of the volt-var curve, e.g., max(V_1) and min(V_4). An example of these settings is shown in Figure SA8.2. If an EUT response time is adjustable, it is to be set to the worst case defined by the mfr otherwise it is set to the fastest response time setting. Record the time domain response of the EUT.

Figure SA8.2

Example Q(V) Settings for AI Anti-Islanding Testing



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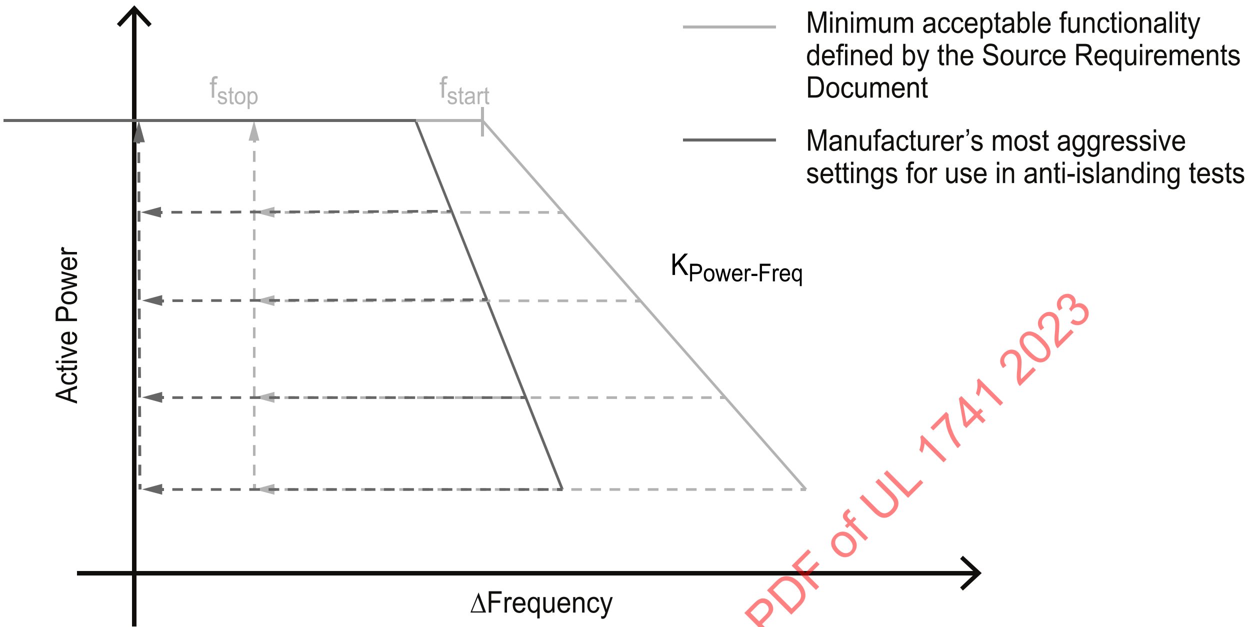
Note: The worst-case parameter settings (settings defined in IEC Technical Report IEC 61850-90-7, "Communication networks and systems for power utility automation – Part 90-7: Object models for power converters in distributed energy resources (DER) systems," Edition 1.0, Feb 2013) for Frequency-Watt functions such as FW are most likely from a minimized f_{Start}, maximized $K_{Power-Freq}$, and a minimized f_{Stop}. An example of these settings is shown in Figure SA8.3, Example FW settings for AI anti-islanding testing.

Figure SA8.3

Example FW Settings for AI Anti-Islanding Testing



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SA9 L/HVRT Low and High Voltage Ride-Through

SA9.1 Function L/HVRT – low and high voltage ride-through

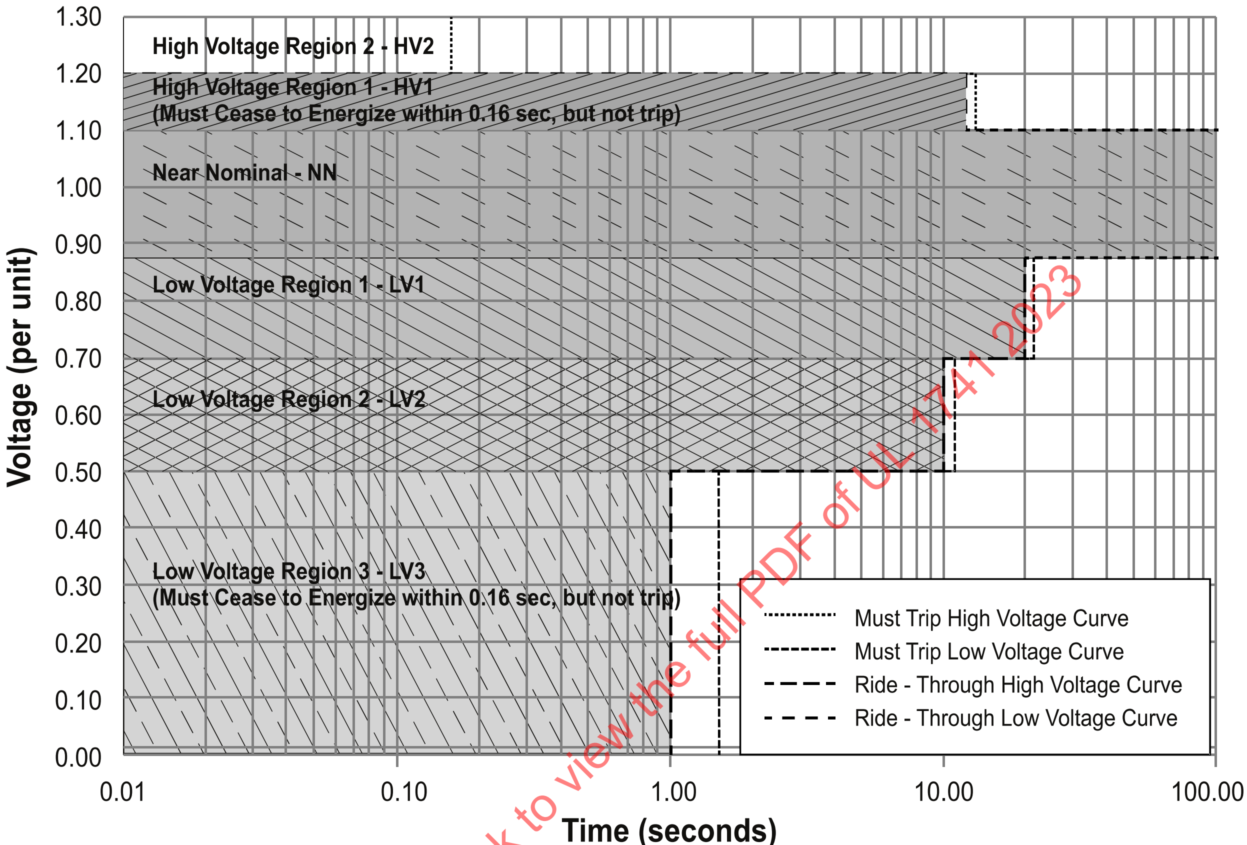
SA9.1.1 General

SA9.1.1.1 The purpose of this test is to verify the behavior of the system in response to low and high voltage excursions that are outside the normal range of operation of the area EPS. The test verifies behavior of the EUT in ride-through region.

Note: The ride-through behavior can either be Momentary Cessation (also known as gate blocking in some regions), where the EUT does not export power, Permissive Operation, where the EUT may or may not export power, or Mandatory Operation, where the EUT must continue to export power. An example of voltage ride-though and must trip regions is shown in Figure SA9.1 for Rule 21, 2015.

Figure SA9.1

Example Operating Parameters that Correspond to Rule 21 Ride-Through and Must Trip Regions in the Time-Voltage Domain



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Note: While these operating parameters correspond to the Rule 21 parameters they may be substituted with operating parameters for other area EPS requirements. The manufacturer’s stated accuracy for limit and time parameters are not addressed in this figure.

SA9.1.1.2 Table SA9.1 is an example of a SRD with defined operating parameters for L/HVRT.

Note: The Electric Rule 21, 2015 defines the L/HVRT requirements according to Table SA9.1 and the L/HFRT requirements. These operating parameters for limits and times are consistent with the Electric Rule 21, 2015. Other defined operating parameters for limits and times may be used to evaluate for compliance in other installation locations.

Table SA9.1
Example Operating Parameters that Correspond to Rule 21 L/HVRT[a]

Region	Voltage (% nominal voltage)	Ride-through until	Operating mode	Maximum trip time (s)
High Voltage 2 (HV2)	$V \geq 120$	Not Applicable	Not Applicable	0.16 s
High Voltage 1 (HV1)	$110 < V < 120$	12 s	Momentary Cessation	13 s
Near Nominal (NN)	$88 \leq V \leq 110$	Indefinite	Continuous Operation	Not Applicable
Low Voltage 1 (LV1)	$70 \leq V < 88$	20 s	Mandatory Operation	21 s
Low Voltage 2 (LV2)	$50 \leq V < 70$	10 s	Mandatory Operation	11 s
Low Voltage 3 (LV3)	$V < 50$	1 s	Momentary Cessation	1.5 s

[a] While these operating parameters correspond to the Rule 21 parameters, they may be substituted with operating parameters for other area EPS requirements.

Note 1: Manufacturer may evaluate product over wider ranges of adjustment than those within the table.

Note 2: The table voltage could be either at the PCC or equipment terminals.

Note 3: For LV3 or HV1 the EUT shall cease to energize in not more than 0.16 s (and not trip). This may differ in other SRD(s).

SA9.1.2 Test requirements

SA9.1.2.1 The simulated area EPS shall meet the requirements of IEEE 1547.1-2005, Section 4.6.1. The measurement system shall meet the requirements of IEEE 1547.1-2005, Section 4.6.2. The input source shall be capable of supplying at least 125 % of the rated maximum input current of the EUT.

SA9.1.2.2 A test is successful when the EUT rides through specified abnormal voltage conditions for the duration not less than the specified time defined by a SRD.

SA9.1.2.3 Other grid support functions may be enabled during this test as required by the SRD.

SA9.1.3 Ride through verification test procedure

SA9.1.3.1 This procedure uses the ride-through test signal (step function) defined in SA10.4. These tests shall be performed at the terminals of the EUT. Signal injection test methods shall not be used. The test circuit for the low/high voltage ride-though magnitude and duration tests is shown in Figure 11.2.

a) Record the voltage (magnitude) and time (duration) limits for each overvoltage and undervoltage operating region from the applicable SRD(s). This testing procedure assumes that the regions do not contain any non-rectangular regions (e.g., the mandatory operation and must trip curves do not contain sloped lines). In the event, that a jurisdiction has a non-rectangular testing region, an alternative testing method will be required. The manufacturer may specify the testing regions that encompass the widest regions from all SRDs. The SRD(s) will depend on the jurisdiction. For example, interconnecting to the CA IOU EPS requires compliance with the Electric Rule 21 Requirements Document. See SA1.3 for information on how to evaluate for products that are intended to comply with multiple SRDs. The tightest testing regions (where required) are addressed in (f). The regions may be tested in any order. These test regions encompass the SRD(s) being evaluated for the widest adjustable settings or other regions specified by the widest EUT ratings.

b) Determine and record the applicable EUT control parameters for each overvoltage and under voltage region.

c) Record manufacturer’s stated accuracy for AC voltage (magnitude) and time (duration) measurements for each overvoltage and undervoltage region.

d) Connect the EUT according to the instructions and specifications provided by the manufacturer.

e) Set all parameters for the input source to the nominal operating conditions for the EUT.

f) Set (or verify) all EUT parameters to the default rated operating conditions and set power output to maximum rated power.

If the ride-through setting is adjustable, set the EUT to the tightest (the tightest ride-through settings minimize the size of the over voltage and under voltage regions. The widest ride-through settings maximize the size of the overvoltage and undervoltage regions) ride-through voltage setting, but not within the range around nominal voltage ±1.5 times the manufacturer’s stated accuracy and with duration of not less than the shortest permitted ride-through time plus 1.5 times the manufacturer's stated accuracy.

Note: During the procedure, the settings of parameters for other functions, or voltage parameters for other voltage regions, shall be set so as not to influence the test results for the operating region being evaluated, or shall be disabled. In some cases this may be accomplished by disabling functions or setting the limits to levels outside the test parameters such that they do not interfere with this test.

g) For overvoltage tests:

1) Set the duration of the ride-through step function, t_{ex}, to maximum value of the region being tested.

2) Set the voltage magnitude, V_T, of the ride-through step function to the maximum value of the region being tested minus 1.5 times the manufacturer’s stated voltage accuracy for this region.

For undervoltage tests:

1) Set the duration of the ride-through step function, t_{ex}, to the maximum value of the region being tested.

2) Set the voltage magnitude, V_T, of the ride-through step function to the minimum value of the region being tested plus 1.5 times the manufacturer’s stated voltage accuracy for this region.

h) Record applicable settings.

i) The following shall apply:

1) For overvoltage tests: V_N shall be the minimum NN grid voltage magnitude plus 1.5 times the manufacturer’s stated voltage accuracy. This verifies the magnitude of the NN range and maximizes the voltage change during the test.

2) For undervoltage tests: V_N shall be the maximum NN grid voltage magnitude minus 1.5 times the manufacturer’s stated voltage accuracy. This verifies the magnitude of the NN range and maximizes the voltage change during the test.

j) For single-phase units, adjust voltage of the simulated utility to starting point V_N. The simulated utility source shall be held at this voltage for period of not less than t_d. At the end of this period, initiate the step ride-through function. The t_r and t_f values shall each be less than or equal to the larger of 1 cycle or 1 % of the ride-through region duration. Record the EUT output current over time relative to the simulated utility ride-through voltage change.

k) For multiphase units, adjust phase to neutral voltage (for any EUT rated for operation on a four wire EPS) or phase to phase voltage (for any EUT rated for operation only on a three wire local EPS) on the simulated utility to the starting point V_N. The simulated utility source shall be held at this voltage for period of not less than t_d. At the end of this period, initiate the step ride-through function. Ensure that remaining / unchanged phase(s) are held at nominal ±5 %. The t_r and t_f

values shall each be less than or equal to the larger of 1 cycle or 1 % of the ride-through region duration.

l) Record all voltage magnitudes, rise times, fall times, hold times and dwell times of the ride-through step function of the simulated test signal.

m) Repeat steps (g) through (k) four times for a total of N_r = five repetitions

n) For multiphase units, repeat steps (g) through (l) for each phase individually and all phases simultaneously. For EUTs rated for connection to 3 wire systems the test is repeated for a total of 4 different test configurations (each phase to phase voltage and all phases simultaneously). For EUTs rated for operation on 4 wire systems the test is repeated for a total of 7 different test configurations [for each phase (a, b and c) to neutral voltage, each phase to phase voltage and all phases simultaneously].

o) Repeat steps (g) through (n) for each of the remaining over/undervoltage regions.

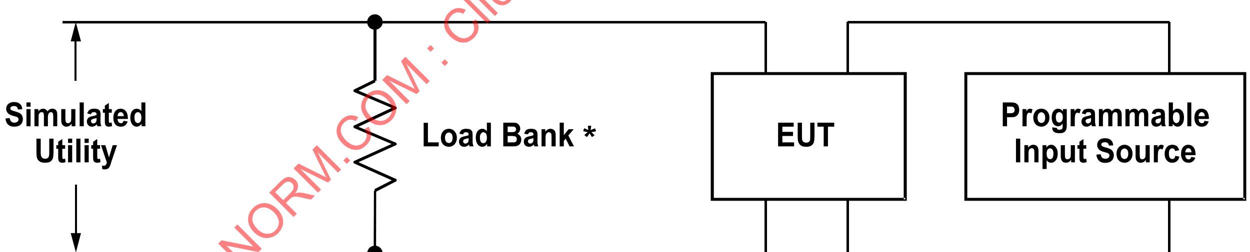
p) Repeat steps (g) though (o) with the EUT output set via the EUT input source parameters between 18 % and 22 % of the maximum continuous output current rating. For units that do not adjust output current as a function of their input such as units with energy storage or multimode products the output current is to be commanded. For units that will not function to export power between 18 % to 22 % if rated EUT output, these units shall be run at the lowest level for which it is capable.

Exception: Where it can be shown by testing or analysis that low output current does not affect the ability of the EUT to ride through the excursion, it is not required to repeat all test cases at both full and low output current. Only the test condition considered most likely to cause failure at low output current is required to be repeated at low output current.

q) Repeat steps (g) through (p) for the widest ride-through setting.

Figure SA9.2

Test Circuit



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*Note: Load bank required only for non-regenerative simulated utility sources. Some simulated utility sources are unidirectional sources and therefore require a load bank to absorb the active and reactive power produced by the EUT during testing.

SA9.1.3.2 Each region shall have the applicable ride-through magnitudes and durations verified. In the case of Rule 21 L/HVRT, four ride-through magnitudes will be verified: the upper bound of HV1, lower bound of LV1, lower bound of LV2, and lower bound of LV3.

The required behavior of the EUT, e.g., momentary cessation or mandatory operation, shall also be verified for all ride-through regions. For mandatory operation regions, the EUT shall be considered in compliance if it provides a an average current greater than or equal to 80 % of the pre-disturbance current or other percentage defined in the requirements documents during the ride-through event in each of the voltage ranges specified in the SRD(s), and returns to at least 80 % of the pre-disturbance current level within the time specified in the SRD(s). For momentary cessation regions, the EUT shall be considered in compliance if it provides an average active current less than or equal to 10 % of the EUT rated current during the ride-through event in each of the voltage ranges specified in the SRD(s), and returns to the pre-disturbance current level or percentage as defined in the requirements document within the time specified in the SRD(s). Where adjustable set points are used, the EUT shall be considered in compliance if it continues to energize the utility within the programmed setting ± manufacturer's stated accuracy.

Exception: For EUT's that are power limited at high grid voltage conditions, the permissible minimum EUT output current value may be based upon 80 % of the EUT pre-disturbance output power instead of the 80 % of the pre-disturbance current.

Note: Testing is necessary at high and low boundaries only if there are conflicting modes of operation in contiguous regions.

SA9.1.3.3 For the purpose of this test the input source current will be held constant so the maximum available current should be the same as the pre-disturbance current. These two current levels may be different in future SRD(s).

SA9.2 Must trip magnitude and duration

SA9.2.1 Test procedure

SA9.2.1.1 The EUT must trip functionality for L/HVRT is to be verified with the following procedure:

a) It is permitted to disable other grid support functions, so as not to influence the test results for the operating region being evaluated.

b) Turn the momentary cessation option off for all regions. In the event that the momentary cessation capabilities cannot be deactivated, the manufacturer shall provide a signal to indicate when a trip has occurred.

c) For all voltage must trip limits in all regions being evaluated, perform the must trip magnitude tests in accordance with IEEE 1547.1-2005, Section 5.2.1.2 and 5.2.2.2 Test for response to abnormal voltage conditions, as referenced in Section 43, Interactive Equipment.

d) The EUT is in compliance if it trips in the voltage range specified in SRD(s).

e) For all voltage must trip durations in all regions being evaluated, perform the trip duration tests in accordance with IEEE 1547.1-2005, Sections 5.2.1.3 and 5.2.2.3, Response to abnormal voltage conditions, as referenced in Section 43, Interactive Equipment, but evaluating the required trip point(s)/value(s) defined in the SRD(s). It is permitted to change the hold time, t_h, to a convenient value within the range of the max trip time provided it is confirmed the EUT has not crossed the limit.

f) The simulated area EPS shall meet the requirements of IEEE 1547.1-2005, Section 4.6.1. The measurement system shall meet the requirements of IEEE 1547.1-2005, Section 4.6.2. The input source shall be capable of supplying at least 125 % of the output power used for the trip magnitude and time testing of the EUT.

Note: For the purpose of this test, if the equipment under test is a bidirectional device that can transfer energy from the grid to the dc side and vice versa, the input source herein is declared to be on the EUT's DC-side.

SA9.2.2 Test requirement

SA9.2.2.1 As a result of SA9.2.1.1, the EUT shall trip within the clearing time specified in SRD(s).

SA10 L/HFRT Low and High Frequency Ride-Through

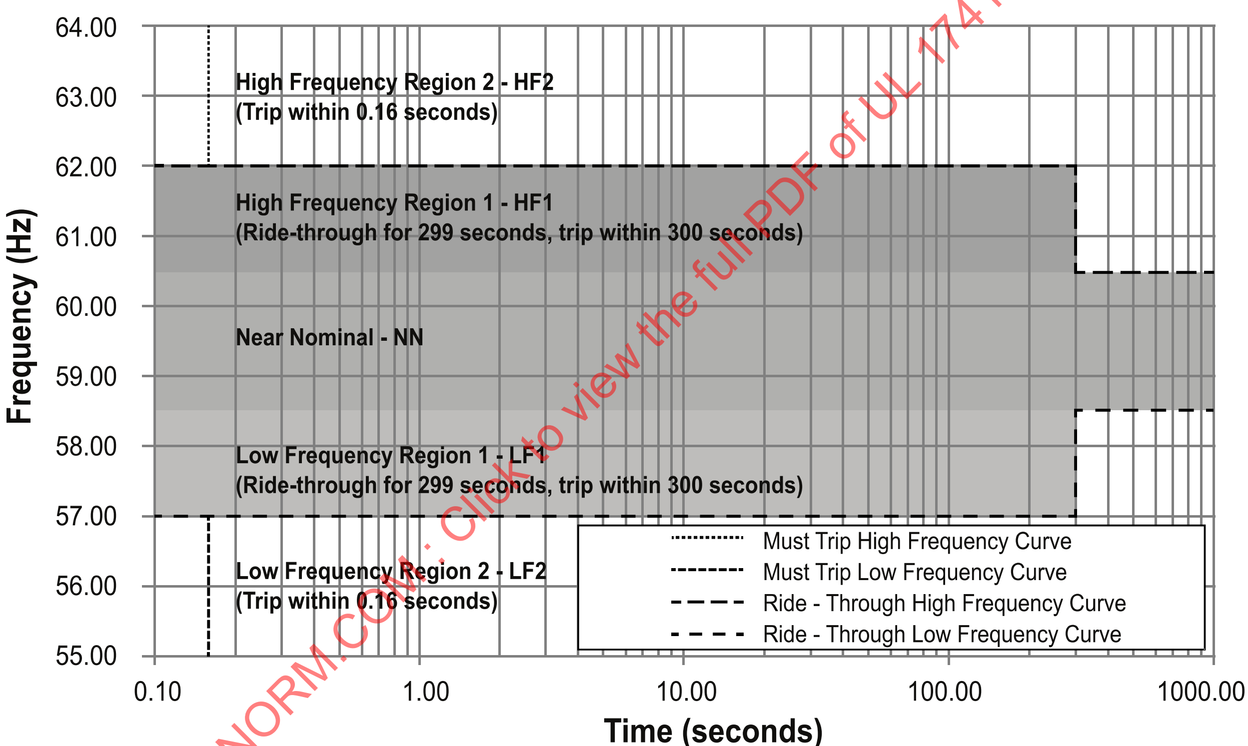
SA10.1 General

SA10.1.1 The purpose of this test is to verify the behavior of the system in response to low and high frequency excursions that are outside the normal range of operation of the area EPS. The test verifies behavior of the EUT in ride-through regions.

Note: The ride-through behavior can be Momentary Cessation, where the EUT does not export power, Permissive Operation, where the EUT may or may not export power, or Mandatory Operation, where the EUT must continue to export power. An example of frequency ride-through and must trip regions is shown in Figure SA10.1.

Figure SA10.1

Example Operating Parameters that Correspond to Rule 21 Default Ride-Through and Must Trip Regions in the Time-Frequency Domain



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Note: While these operating parameters correspond to Rule 21 parameters, they may be substituted with different operating parameters for other area EPS requirements. The manufacturer's stated accuracy for limit and time parameters are not addressed in this figure.

Table SA10.1
Example Operating Parameters that Correspond to Rule 21 L/HFRT[a]

Region	System frequency default settings	Minimum range of adjustability (Hz)	Ride-through until (s)	Ride-through operational mode	Trip time (s)
High Frequency 2 (HF2)	f > 62	62.0 – 64.0	No Ride-Through	Not Applicable	0.16
High Frequency 1 (HF1)	60.5 < f ≤ 62	60.1 – 62.0	299	Mandatory Operation	300
Near Nominal (NN)	58.5 < f ≤ 60.5	Not Applicable	Indefinite	Continuous Operation	Not Applicable
Low Frequency 1 (LF1)	57.0 < f ≤ 58.5	57.0 – 59.9	299	Mandatory Operation	300
Low Frequency 2 (LF2)	f ≤ 57.0	53.0 – 57.0	No Ride-Through	Not Applicable	0.16

[a] While these operating parameters correspond to the Rule 21, 2015 parameters they may be substituted with operating parameters for other area EPS requirements.

Note 1: Manufacturer may evaluate product over wider ranges of adjustment than those within the table.

Note 2: Frequency / Watt functionality is an option under the Rule 21, 2015 filing.

SA10.2 Test requirements

SA10.2.1 A test is successful when the EUT rides through specified abnormal frequency conditions for the duration not less than the specified time defined by a SRD.

SA10.3 Test procedure

SA10.3.1 This procedure uses the ride-through test signal (step function) defined in SA10.4. These tests shall be performed at the terminals of the EUT. Signal injection test methods shall not be used. The test circuit for the low/high frequency ride-though magnitude and duration tests is shown in Figure SA9.2.

a) Record the trip frequency (magnitude) and time (duration) limits for each overfrequency and underfrequency operating region from the applicable SRD(s). This testing procedure assumes that the regions do not contain any non-rectangular regions (e.g., the mandatory operation and must trip curves do not contain sloped lines). In the event, that a jurisdiction has a non-rectangular testing region, an alternative testing method will be required.

The manufacturer may specify the testing regions that encompass the widest regions from all SRDs. The tightest testing regions (where required) are addressed in (f). The regions may be tested in any order. These test regions encompass the SRD(s) being evaluated for the widest adjustable settings or other regions specified by the widest EUT ratings.

The SRD(s) will depend on the jurisdiction. For example, interconnecting to the CA IOU EPS requires compliance with the Electric Rule 21 SRD. See SA1.3 for information on how to evaluate for products that are intended to comply with multiple SRDs.

b) Determine and record the applicable EUT control parameters for each overfrequency and underfrequency region.

c) Record manufacturer's stated accuracy for frequency (magnitude) and time (duration) measurements for each overfrequency and underfrequency region.

d) Connect the EUT according to the instructions and specifications provided by the manufacturer. Set all parameters for the input source to the nominal operating conditions for the EUT.

e) Set (or verify) all EUT parameters to the default rated operating conditions and set power output to maximum rated power. If the must ride-through setting is adjustable, set the EUT to the tightest (the tightest ride-through settings minimize the size of the over-frequency and under-frequency regions in terms of magnitude and/or duration. The widest ride-through settings maximize the size of the over-frequency and under-frequency regions in terms of magnitude and duration) ride-through frequency setting, but not within the range around nominal frequency ± 1.5 times the manufacturer's stated accuracy and with duration of not less than the shortest permitted ride-through time plus 1.5 times the manufacturer's stated accuracy. During the procedure, the settings of parameters for other functions, or frequency parameters for other frequency regions, shall be set so as not to influence the test results for the operating region being evaluated, or shall be disabled.

f) For overfrequency tests:

1) Set the duration of the ride-through step function, t_{ex}, to the maximum value of the region being tested.

2) Set the frequency magnitude, f_T, of the ride-through step function to the maximum value of the region being tested, minus 1.5 times the manufacturer's stated frequency accuracy for this region.

For underfrequency tests:

1) Set the duration of the ride-through step function, t_{ex}, to the maximum value of the region being tested.

2) Set the frequency magnitude, f_T, of the ride-through step function to the minimum value of the region being tested, plus 1.5 times the manufacturer's stated frequency accuracy for this region.

g) Record applicable settings.

h) Adjust frequency of the simulated utility to starting point f_N. The simulated utility source shall be held at this frequency for period of not less than t_d. At the end of this period, initiate the step ride-through function. The values of t_r and t_f shall be selected such that the rate of change of frequency is at least 1.0 Hz/s. It should be noted that rates faster than 3Hz/s may result in undefined results that may indicate a false failure of ride through tests. Faster rate of change slopes are permitted when evaluating trip times.

For overfrequency tests:

f_N shall be the minimum NN grid frequency magnitude plus 1.5 times the manufacturer's stated frequency accuracy. This verifies the magnitude of the NN range and maximizes the frequency change during the test.

For underfrequency tests:

f_N shall be the maximum NN grid frequency magnitude minus 1.5 times the manufacturer's stated frequency accuracy.

i) Record all frequency magnitudes, rise times, fall times, hold times and dwell times of the ride-through step function.

j) Repeat steps (g) through (j) four times for a total of N_r = five repetitions.

Exception: Following at least one test at the SRD(s) maximum duration, the additional four repetitions may be tested with a shorter duration (not less than 10 % of the SRD(s) maximum duration).

k) Repeat steps (f) through (k) for each of the remaining over/underfrequency regions.

l) Repeat steps (f) though (l) with the EUT output set via the EUT input source parameters between 18 % and 22 % of the maximum continuous output current rating. For units that do not adjust output current as a function of their input such as units with energy storage or multimode products the output current is to be commanded.

Exception: Where it can be shown by testing or analysis that low output current does not affect the ability of the EUT to ride through the excursion, it is not required to repeat all test cases at both full and low output current. Only the test condition considered most likely to cause failure at low output current is required to be repeated at low output current.

m) Repeat steps (f) through (m) for the widest ride-through setting.

SA10.3.2 Each region shall have the applicable ride-through magnitudes and durations verified. In the event that the momentary cessation capabilities cannot be deactivated, the manufacturer shall provide a signal to indicate when the EUT has ceased to energize the EPS. The required behavior of the EUT, e.g., momentary cessation or mandatory operation, shall also be verified for all ride-through regions. For mandatory operation regions, the EUT shall be considered in compliance if it provides an average current greater than or equal to 80 %* of the pre-disturbance current (or other percentage as described in the requirements document) during the ride-through event in each of the frequency ranges specified in the SRD(s), and returns to at least 80 %* of the maximum available current level within the time specified in the SRD(s). For SRD(s) that require momentary cessation region(s), the EUT shall be considered in compliance if it provides an average current less than or equal to 10 %* of the EUT rated current during the ride-through event in each of the frequency ranges specified in the SRD(s), and returns to the pre-disturbance current level or percentage as defined in the requirements document within the time specified in the SRD(s). Where adjustable set points are used, the EUT shall be considered in compliance if it continues to energize the utility within the programmed setting ± manufacturer's stated accuracy.

*Note: Other value may be defined by the SRD.

SA10.3.3 For the purpose of this test the input source current will be held constant so the maximum available current should be the same as the pre-disturbance current. These two current levels may be different in future SRD(s).

SA10.3.4 The simulated area EPS shall meet the requirements of IEEE 1547.1-2005, Section 4.6.1. The measurement system shall meet the requirements of IEEE 1547.1-2005, Section 4.6.2. The input source shall be capable of supplying at least 125 % of the rated maximum input current of the EUT.

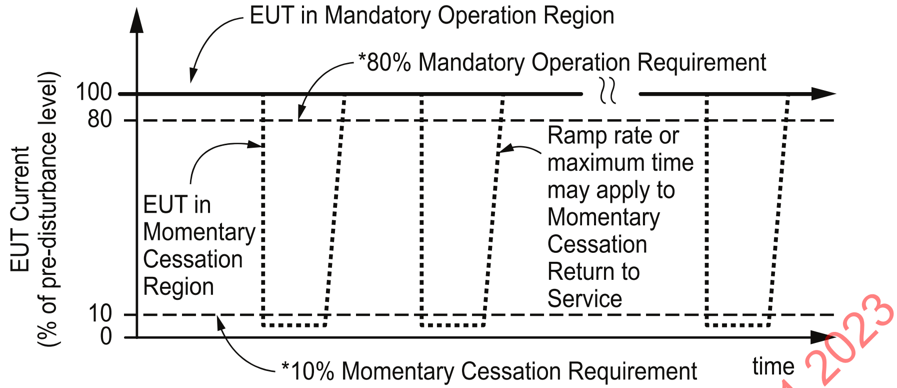
SA10.4 Ride-through test signal (step function)

SA10.4.1 The test signal described in this section is used to characterize the behavior of the EUT during ride-through events.

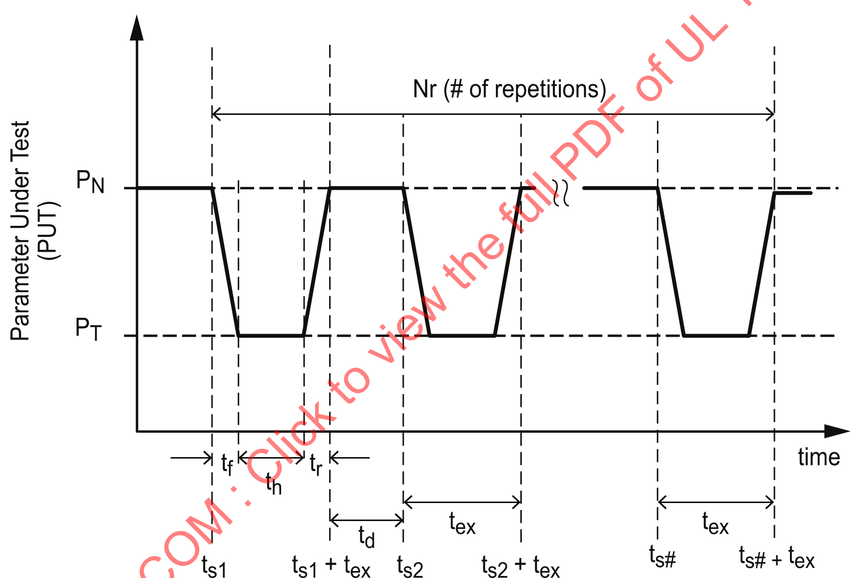
SA10.4.2 Vary the parameter under test (PUT) according to the magnitude step function envelope defined herein. The ride-through test signal shall take the form shown in Figure SA10.2.

Figure SA10.2

Graphical Representation of the Ride-Through Test Step Function



* Other value may be defined by the source document.



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where:

P is the magnitude of the PUT

t_h is hold time (s)

t_{ex} is the total excursion time (s) of the PUT $(t_{ex} = t_r + t_h + t_f)$

t_r is rise time (s)

t_f is fall time (s). This verifies the magnitude of the NN range and maximizes the magnitude change during the test.

t_d is dwell time (s) between pulses as specified by manufacturer

$t_{s\#}$ is the start time of the # repetition used for calculating the response time

N_r is the number of pulse repetitions per test sequence

P_N is the starting point of the step function (in units of the PUT)
P_T is the test value

SA10.5 Must trip magnitude and duration

SA10.5.1 The following procedure shall be used:

a) Disable all other grid support functions, so as not to influence the test results for the operating region being evaluated.

b) Turn the momentary cessation option off for all regions. In the event that the momentary cessation capabilities cannot be deactivated, the manufacturer shall provide a signal to indicate when the EUT has ceased to energize the EPS.

c) For all frequency must trip limits, perform the must trip tests in accordance with IEEE 1547.1-2005 Sections 5.3.1.2 and 5.3.2.2, Response to abnormal frequency conditions, as referenced in this standard, Section 43, Interactive Equipment.

d) The EUT is in compliance if it trips in the frequency range specified in SRD(s).

e) For all frequency must trip durations, perform the trip duration tests in accordance with IEEE 1547.1-2005 Sections 5.3.1.3 and 5.3.2.3, Response to abnormal frequency conditions, as referenced in this standard, Section 43, Interactive Equipment, but evaluating the required trip point(s) / value(s) defined in the SRD(s). It is permitted to change the hold time, t_h, to a convenient value within the range of the maximum trip time, provided it is confirmed the EUT has not crossed the limit.

SA10.5.2 With reference to SA10.5.1, the test requirements are:

a) The simulated area EPS shall meet the requirements of IEEE 1547.1-2005, Section 4.6.1. The measurement system shall meet the requirements of IEEE 1547.1-2005, Section 4.6.2. The input source shall be capable of supplying at least 125 % of the rated maximum input current of the EUT.

b) The EUT is in compliance if it trips within the clearing time specified in SRD(s).

SA11 RR – Normal Ramp Rate and SS – Soft-Start Ramp Rate

SA11.1 General

SA11.1.1 This test confirms that an inverter meets a given response characteristic for providing ramp rate responses for normal and/or soft-start ramp rate commands. An EUT can change the rate at which they increase their power output. These ramp rates are constrained by what the systems can physically do. For instance, if they are outputting their maximum power, they cannot ramp up, while a completely charged storage system may discharge power into the Area EPS, but cannot draw power from the area EPS as it is already completely charged.

SA11.1.2 The purpose of establishing ramp-up rates for systems is to help smooth transitions from one output level to another output level. Although a single system might not impact the grid through a single sharp transition, aggregated systems responding to a specific event could cause significant rapid jumps in overall output if they do not ramp to the new level. Such sharp transitions could cause power quality issues such as voltage spikes or dips, harmonics, or oscillations.

SA11.1.3 Multiple ramp rate characteristics are possible for inverters. This test verifies two types of ramp rates, although they may optionally be implemented as one general ramp rate. Manufacturers must indicate the following types of ramp rates provided in their products during testing:

– Normal ramp-up rate when the inverter is adjusting the output power, e.g., when a PV inverter is following the available power from the dc source.

– Soft-start ramp-up rate that defines the behavior of the device to ramp from zero to operating power after a trip.

SA11.1.4 Ramp rates are expressed as a percentage of nameplate ac current to the EPS per second. The ramp-up values for each of these may be defined independently or as a combined value.

Note: Where the voltage and phase angle are held constant during the test, active power may be used as a proxy for current during the test.

SA11.2 Procedure for normal ramp rate test

SA11.2.1 The manufacturer shall state the following parameters for the EUT:

a) Output Current Rating (A) – I_{rated}

b) Minimum normal ramp-up rate ($\%I_{rated}$ /sec) – $RR_{norm\_up\_min}$

c) Maximum normal ramp-up rate ($\%I_{rated}$ /sec) – $RR_{norm\_up\_max}$

d) Minimum output current, I_{low}

e) Ramp Rate Accuracy MSA_{RR} ($\%I_{rated}$ /sec)

SA11.2.2 The normal ramp rate test shall be carried out as follows:

a) Connect the EUT according to Test Requirements, Section SA11.3, and specifications provided by the manufacturer. Set the EUT to maximum power factor.

b) Set all AC source parameters to the nominal operating conditions for the EUT.

c) Set the input power level to provide I_{low} from the EUT. For units that do not adjust output current as a function of their input such as units with energy storage or multimode products the output power is to be commanded.

d) Turn on the EUT. Allow the EUT to reach steady state, e.g., maximum power point.

e) Set the EUT ramp rate parameters according to Test 1 in Table SA11.1.

f) Begin recording the time domain response of the EUT AC voltage and current and trigger signal.

g) Increase the available input power to provide I_{rated} from the EUT according to the step function described in Ramp Rate Test Profiles, Section SA11.6.

h) Stop recording the time domain response after the ramp duration plus a manufacturer-specified dwell time. Ramp duration is defined by $100/RR_{norm\_up}$ as appropriate for the test settings.

i) Repeat steps (c) – (h) two times for a total of 3 repetitions.

j) Repeat steps (c) – (i) for Tests 2 – 3 in Table SA11.1.

Table SA11.1
Normal ramp rate test parameters

Test	Ramp-up rate RR_{norm_up} ($\% I_{rated}$/sec)
1	$RR_{norm\_up\_min}$
2	$(RR_{norm\_up\_min} + RR_{norm\_up\_max})/2$
3	$RR_{norm\_up\_max}$

SA11.3 Test requirements

SA11.3.1 The inverter shall be connected into a test circuit similar to that shown in Figure SA9.2.

SA11.3.2 For each of the recorded time domain responses, the EUT ramp shall not exceed a region with the upper limit defined by the ramp rate setting plus the stated ramp rate accuracy and with the lower limit defined by the upper limit minus 5 % of I_{rated}. The EUT shall reach at least 95 % of I_{rated} at the end of the dwell time. See Figure SA11.1.

If the SRD defines a maximum and minimum ramp rates, they are treated as a limits without a tolerance and there is no need to specify an accuracy of the ramp rate. If the SRD defines an average ramp rate, the manufacturer shall define the ramp rate accuracy. During ramp rate testing the total ramp duration shall be defined as the open loop response time for the EUT output current to rise from 10 % to 90 % of the EUT's rated output current (I_{rated}). The EUT response data set shall be divided into time windows equal to 5 % of the total ramp duration from 10 % to 90 % I_{rated}. During the test the output current shall be measured at least 1000 samples per second and averaged across windows of 5 % total EUT ramp duration. The EUT shall be considered in compliance if it meets the following criteria in (a) – (d) while operating between 10 % and 90 % of rated active power:

a) The instantaneous current measured at any time shall not exceed 150 % of the current defined by the straight line approximation of the rated ramp rate specified in the SRD.

b) The average current measured during any 5 % time window shall not exceed 125 % of the average of the straight line current predicted by the rated ramp rate in that window.

c) The average current measured during any two consecutive 5 % windows shall not exceed 125 % of the average of the straight line current predicted by the rated ramp rate in those two consecutive windows.

d) The average current measured over the total duration of the ramp shall not exceed 100 % of the average of the straight line current predicted over the total duration of the ramp.

SA11.4 Procedure for soft-start ramp rate test

SA11.4.1 The manufacturer shall state the following parameters of the EUT:

a) Output Current Rating (A) – I_{rated}

b) Minimum soft start ramp-up rate (%I_{rated} /sec) – RR_{SS_min}

c) Maximum soft start ramp-up rate (%I_{rated} /sec) – RR_{SS_max}

d) Ramp Rate Accuracy MSA_{RR} (%I_{rated} /sec)

SA11.4.2 The soft-start test shall be carried out as follows:

a) Connect the EUT according to the instructions and specifications provided by the manufacturer.

b) Set all AC source parameters to the nominal operating conditions for the EUT.

c) Set the input source power level to provide I_{rated} from the EUT. For units that do not adjust output current as a function of their input such as units with energy storage or multimode products the output power is to be commanded.

d) Turn on the EUT. Set the EUT ramp rate parameters according to Test 1 in Table SA11.2.

e) Adjust the AC voltage or frequency outside the trip limits for longer than the must-trip duration.

f) Begin recording the time domain response of the EUT AC voltage and current and trigger signal.

g) Connect the EUT to the utility or simulated utility operating within the continuous operating regions for voltage and frequency. Monitor the EUT and record the time domain response staring at the point at which the EUT begins export of current.

h) Stop recording the time domain response after at least the reconnect time of the inverter (e.g. 30 s to 5 min), plus ramp duration plus a manufacturer-specified dwell time as shown in Figure SA11.2. Ramp duration is defined by $100/RR_{ss}$ as appropriate.

i) Repeat steps (e) – (h) for a total of 3 repetitions.

j) Repeat steps (d) – (i) for Tests 2 and 3 in Table SA11.2.

Table SA11.2
Soft-Start Ramp Rate Test Parameters

Test	Soft-start ramp rate RR_{ss} (% P_{rated}/sec)
1	RR_{ss_min}
2	$(RR_{ss\_min} + RR_{ss\_max})/2$
3	RR_{ss_max}

SA11.5 Test requirements

SA11.5.1 The inverter shall be connected into a test circuit similar to that shown in Figure SA9.2.

SA11.5.2 The EUT shall reach at least 95 % of I_{rated} at the end of the dwell time. See Figure SA11.2. The data shall be recorded with an averaging window of 30 mSec or less to allow for minor response excursions above the limit.

If the SRD defines a maximum ramp rate, it is to be treated as a limit without a tolerance and there is no need to specify an accuracy of the ramp rate. If the SRD defines an average ramp rate, the manufacturer shall define the ramp rate accuracy. During ramp rate testing the total ramp duration shall be defined as the open loop response time for the EUT output current to rise from 10 % to 90 % of the EUT's rated output current (I_{rated}). The EUT response data set shall be divided into time windows equal to 5 % of the total ramp duration from 10 % to 90 % I_{rated}. During the test the output current shall be measured at least 1000 samples per second and averaged across windows of 5 % total EUT ramp duration.

Where the SRD specifies maximum ramp rate, the EUT shall be considered in compliance if it meets the following criteria in (a) – (d) while operating between 10 % and 90 % of rated active power:

a) The instantaneous current measured at any time shall not exceed 150 % of the current defined by the straight line approximation of the rated ramp rate specified in the SRD.

b) The average current measured during any 5 % time window shall not exceed 125 % of the average of the straight line current predicted by the rated ramp rate in that window.

c) The average current measured during any two consecutive 5 % windows shall not exceed 125 % of the average of the straight line current predicted by the rated ramp rate in those two consecutive windows.

d) The average current measured over the total duration of the ramp shall not exceed 100 % of the average of the straight line current predicted over the total duration of the ramp.

Where the SRD specifies the average ramp rate, the EUT shall be in compliance if it does not exceed the average ramp rate ±MSA.

Note: This test method addresses ramp rates of 100 %/sec or slower.

SA11.6 Ramp rate test profiles

SA11.6.1 The following applies to Figure SA11.1 and Figure SA11.2.

t_d is dwell time (s) between test iterations as specified by the manufacturer

t_R is the reconnection time (s) as measured during the test

I_{low} is the minimum output current of ramp rate function (%I_{rated})

RR is the ramp rate (%I_{rated}/sec)

Upper RR limit, is a curve offset above the target RR, from the time the EUT reaches the I_{min}, defined by the following:

Upper RR limit (%I_{rated}) = RR + MSA_{RR}

Lower RR limit, is defined by a curve offset below the Upper RR limit by 5 % * I_{rated}.

The references to ramp rate current shall be the apparent current.

Figure SA11.1

Graphical Representation of the Normal ‘Up’ Ramp Rate Test Step Function

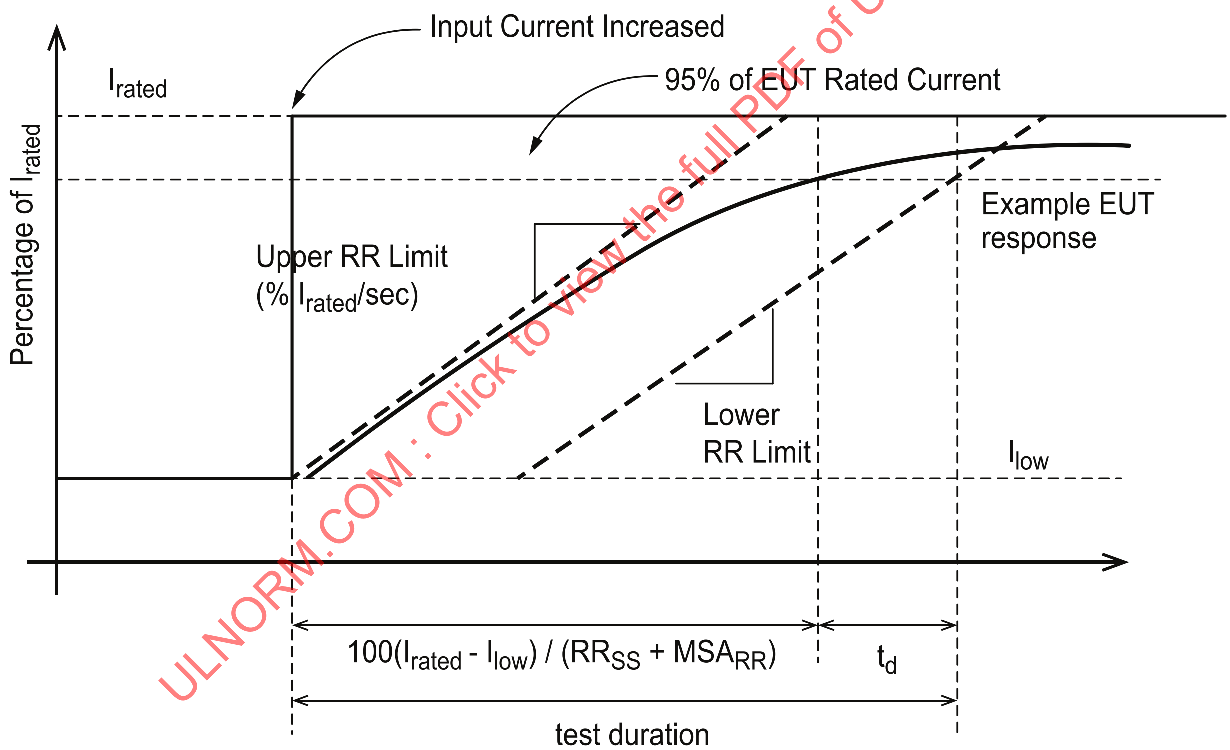

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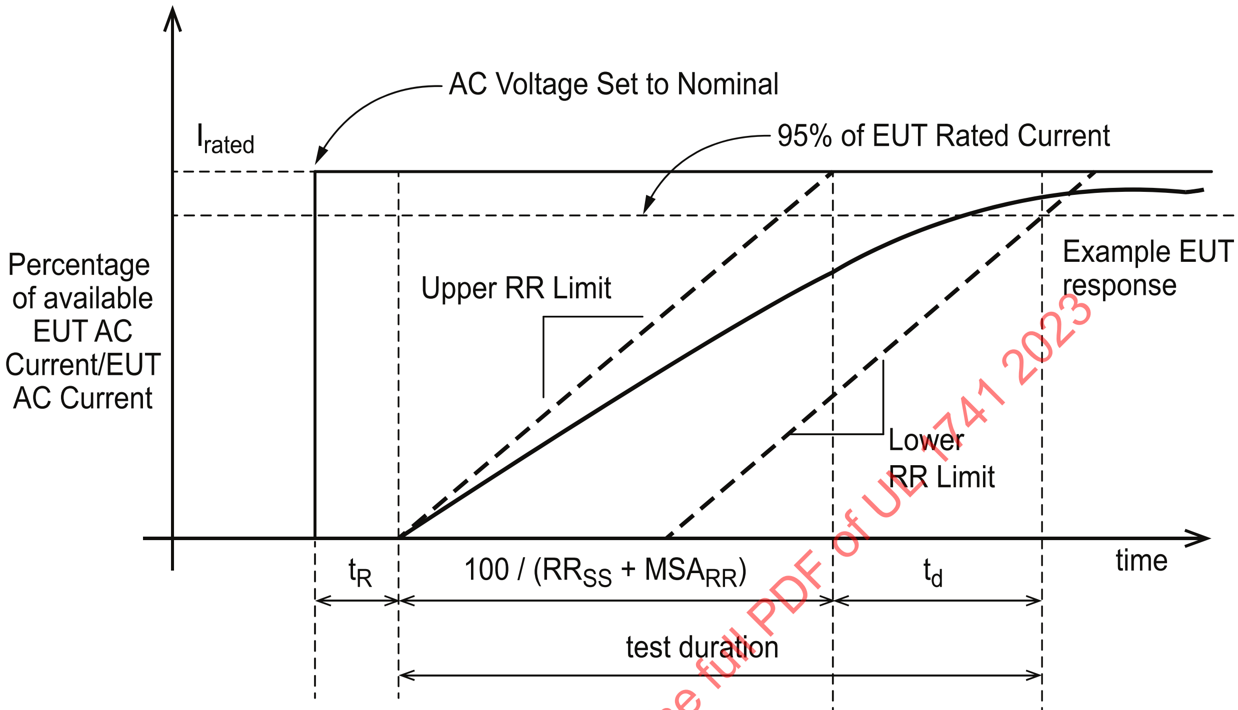
Figure SA11.2

Graphical Representation of the Soft Start Ramp Rate Test Step Function



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SA12 SPF – Specified Power Factor

SA12.1 General

SA12.1.1 In order to maintain a stable grid voltage, it is desired that inverters be able to supply reactive power to the grid. One way to do this is to have the inverter operate at a specified, non-unity power factor. This test verifies that an EUT operates at a fixed power factor.

Note: In general, FPF mode should be used to ensure availability of reactive power at all DER output power levels between 20 % and 100 %.

SA12.1.2 This test verifies the performance of a single inverter when connected to an area EPS. Performance of multi-inverter testing is beyond the scope of this test. This test verifies the inverter's power factor in response to changing active power levels, but does not address the voltage stability of the area EPS.

SA12.2 Procedure for specified power factor test

SA12.2.1 The manufacturer shall state the following parameters of the EUT for the purposes of this test:

a) Apparent Power Rating (VA) – S_{rated}

b) Output Power Rating (W) – P_{rated}

c) DC Input voltage range with function enabled (V)

d) Nominal AC voltage (V) – V_{nom}

e) AC voltage range with function enabled (V)

f) AC voltage measurement accuracy (V) – MSA_{Vac}

g) DC voltage measurement accuracy (V) – MSA_{Vdc}

h) Active power range of function, e.g., 20-100 % of nameplate – [P_{low}, P_{rated}]

Note: At a certain low input power level, the EUT may be unable to accurately produce a fixed power factor. This is a mathematical artifact associated with the calculation of PF.

i) Power Factor Accuracy – MSA_{PF}

j) Power Factor Settling Time (s)

k) Minimum Inductive (Underexcited) Power Factor – $PF_{min,ind}$

l) Minimum Capacitive (Overexcited) Power Factor – $PF_{min,cap}$

Additionally, the following parameters shall be defined:

m) PF, the inductive or capacitive signed power factor commanded for test

n) $PF_{mid,cap} = (1 + PF_{min,cap})/2$, middle of the EUT capacitive range.

o) $PF_{mid,ind} = (1 + PF_{min,ind})/2$, middle of the EUT inductive range.

p) $P_{Outlimit}$, the maximum output power either limited by the input supply or by a command to the inverter.

q) PF_{target}, the target power factor. This will differ from the commanded power factor in 'Active Power Priority' modes for input power greater than P_X.

SA12.2.2 The specified power factor test shall be carried out as follows:

1) Connect the EUT according to the requirements in Section 4 of IEEE 1547.1-2005 and specifications provided by the manufacturer.

2) Set all AC source parameters to the nominal operating conditions for the EUT. Frequency is held at nominal throughout this test. Set the EUT input power to P_{low}. For units that do not adjust output current as a function of their input such as units with energy storage or multimode products the output power is to be commanded.

3) Turn on the EUT. It is permitted to set all L/HVRT limits and abnormal voltage trip parameters to the widest range of adjustability possible with the SPF enabled in order not to cross the must trip magnitude threshold during the test.

4) Select 'Fixed Power Factor', operational mode.

5) Set the input source to produce P_{rated} for the EUT.

6) Set the EUT power factor to unity. Measure the AC source voltage and EUT current to measure the displacement power factor and record all data.

7) Set the EUT power factor to the value in Test 1 of Table SA12.1. Measure the AC source voltage and EUT current to measure the displacement power factor and record all data.

8) Repeat Steps (6) – (8) for two additional times for a total of three repetitions.

9) Repeat Steps (5) – (7) at two additional power levels. One power level shall be at P_{min} or 20 % of P_{rated} and the second at any power level between 33 % and 66 % of P_{rated}.

10) Repeat Steps (6) – (9) for Tests 2 – 4 in Table SA12.1.

11) In the case of bi-directional inverters, repeat Steps (6) – (10) for the second active power flow direction.

Table SA12.1
SPF Test Parameters

Test #	Power factor	P_X
1	$PF_{min,ind}$	$S_{rated} \cdot PF_{min,ind}$
2	$PF_{mid,ind}$	$S_{rated} \cdot PF_{mid,ind}$
3	$PF_{min,cap}$	$S_{rated} \cdot PF_{min,cap}$
4	$PF_{mid,cap}$	$S_{rated} \cdot PF_{mid,cap}$

SA12.3 Test requirements

SA12.3.1 The inverter shall be connected into a test circuit similar to that shown in Figure SA9.2.

SA12.3.2 The simulated area EPS shall meet the requirements of Clause 4.6.1 of IEEE 1547.1-2005. The measurement system shall meet the requirements of Clause 4.6.2 of IEEE 1547.1-2005. These tests shall be performed at the terminals of the EUT.

SA12.3.3 For three phase inverter tests, the simulated EPS voltage in these tests is balanced meaning each phase has the same magnitude and phases are separated by 120 degrees. For single-phase tests the voltage under consideration is the RMS voltage at the inverter terminals.

SA12.3.4 For each of the displacement power factor conditions recorded in Steps (5) and (6), compliance shall be verified when the EUT achieves the target power factor within stated accuracy of the power factor setting.

SA13 Volt/VAr Mode [Q(V)]

SA13.1 General

SA13.1.1 In order to maintain a stable grid voltage, it is desired that inverters be able to supply or absorb reactive power to/from the EPS. One way to achieve this is to have the inverter supply or absorb reactive power in response to fluctuations in EPS voltage. The inverter supplies or absorbs reactive power as a function of voltage known as a Q(V) function or Volt-VAr mode. This test verifies that the inverter's Volt-VAr mode implements the reactive power response to fluctuations in EPS voltage.

SA13.1.2 Inverters can be set to prioritize reactive or active power. This priority setting defines the inverter's behavior when the inverter reaches its kVA limits. Volt-VAr mode can function with active or reactive power priority. When an inverter is set in Volt-VAr mode with reactive power priority and the inverter's apparent power kVA limit is reached, active power is reduced to maintain reactive power production. When an inverter is set in Volt-VAr mode with active power priority and the inverter's apparent power kVA limit is reached, the reactive power is reduced to maximize active power production.

SA13.2 Procedure for Volt-VAr "Q(V)" test

SA13.2.1 The manufacturer shall state the following parameters of the EUT:

a) Apparent Power Rating (VA) – S_{rated}

b) Output Power Rating (W) – P_{rated}

c) EUT Input voltage range with function enabled (V)

d) Nominal AC EPS voltage (V) – V_{nom}