Subject 1699B

October 31, 2014

SUMMARY OF TOPICS

The Proposed First Edition of the Standard for Photovoltaic (PV) DC Arc-Fault Circuit Protection, UL 1699B, which covers DC photovoltaic arc-fault circuit protection devices intended for use in solar photovoltaic electrical energy systems, is being proposed:

> ***1. Proposed First Edition of the Standard for Photovoltaic (PV) DC Arc-Fault Circuit Protection, UL 1699B***

STP BALLOTS DUE: December 30, 2014

COMMENTS DUE: December 30, 2014

1. Proposed First Edition of the Standard for Photovoltaic (PV) DC Arc-Fault Circuit Protection, UL 1699B

BACKGROUND

The UL 1699B Outline of Investigation was originally developed as part of a research project to develop requirements for PV DC arc fault protection. This project included UL's research department as well as independent research organizations working on PV systems and their arc faults, inverter manufacturers, AFCI manufacturers and manufacturers of components used in PV systems. A number of ad-hoc meetings were held to develop the requirements.

Subsequently, industry representatives requested that the Outline be converted to a full Standard. As experience in the use of the Outline and field history of these devices was gained, a need arose to review aspects of the arc detection tests and also the unwanted tripping experience of these devices in the field. These issues needed to be addressed by those having technical expertise in these areas. The UL 1699B STP was formed and a collaborative project undertaken to develop a Standard from the Outline. UL worked on a draft that expanded the Outline into a full Standard.

A call for proposals went out to UL 1699B STP members and subscribers on February 5, 2013. Proposals to modify many of the requirements and tests in the outline were received. An STP meeting was held September 10-11, 2013 to review and consider the proposals. It became clear that many of these issues were interrelated and technically complex. As a result a number of task groups were formed to consider the proposals as well as the test methods and other issues.

These task groups completed their work and recommended modifications to the requirements currently in the Outline. The proposal presented here represents the combined work of the STP and the task groups.

RATIONALE

Proposal submitted by: Robert L. LaRocca, UL LLC, on behalf of the Task Groups of the 1699B STP.

The task groups for STP 1699B, Photovoltaic (PV) DC Arc-Fault Circuit Protection were formed as a result of the September 2013 STP 1699B meeting to further develop this proposed first edition of the Standard for Photovoltaic (PV) DC Arc-Fault Circuit Protection, UL 1699B, which covers DC photovoltaic arc-fault circuit protection devices intended for use in solar photovoltaic electrical energy systems. The STP members submitting proposal requests and the task groups used UL's Outline of Investigation for Photovoltaic (PV) DC Arc-Fault Circuit Protection, UL 1699B, as the baseline document and identified the changes needed to develop a final draft of the standard to present for ballot and comment.

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PROPOSAL

PART 1 - ALL DEVICES

INTRODUCTION

1 Scope

1.1 These requirements cover DC photovoltaic arc-fault circuit protection devices intended for use in solar photovoltaic electrical energy systems as described in Article 690 of the National Electrical Code, NFPA 70. This protection is intended to mitigate the effects of arcing faults that may pose a risk of fire ignition under certain conditions if the arcing persists.

1.2 These requirements cover devices including photovoltaic (PV) dc arc-fault circuit-interrupters (AFCI), arc-fault detectors (AFD), interrupting devices (ID) and inverters, converters, and charge controllers with integral arc-fault circuit-interrupter protection.

1.3 These requirements cover devices rated 1000 volts or less. They are intended for use in dc electrical systems that are supplied by a photovoltaic source, such as a module with solar cells designed to generate dc power when exposed to sunlight.

1.4 These devices are not intended to detect glowing connections.

1.5 In Part 1 of these requirements the term ″device″ is used generically to apply to all of the devices covered by these requirements and is modified when the requirement does not apply to all types. In Part 2 and Part 3 of these requirements the term ″device″ is used generically to apply to all devices covered by the particular part of this Standard, and is modified when the requirement does not apply to all types.

1.6 A device that is also intended to perform other functions, such as overcurrent protection, disconnects, combiner boxes, inverters, or other PV system functions or any combination thereof, shall additionally comply with the requirements of the applicable Standard or Standards that cover devices that provide those functions as intended for use in PV systems.

2 Glossary

2.1 For the purposes of this standard the following definitions apply.

2.2 ANNUNCIATOR – A feature of a device that gives an indication upon the functioning of a protective device.

2.3 ARCING – A luminous discharge of electricity across an insulating medium, usually accompanied by the partial volatilization of the electrodes.

2.4 ARCING FAULT – An unintentional arcing condition in a circuit.

2.5 CELL – The basic photovoltaic device that generates electricity when exposed to sunlight.

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

2.7 CONVERTER (DC) – A device that accepts dc power input and converts it to another form of dc power.

2.8 DUT – Device under test.

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

2.10 INTERRUPTING CONTACT – A contact device inserted in series with the source and/or load. It is intended to stop the flow of arcing current by opening the circuit and may be a mechanical contact set with an air gap or a solid state switching device.

2.11 MICROELECTRONICS – Monolithic, hybrid, or module circuits, where the internal circuit connections are not accessible exclusive of provided external connection pins or pads. The circuits are capable of functioning in the analogue mode, digital mode, or a combination of the two modes. Examples of microelectronics include: ASICs, ROMs, RAMs, PROMs, EPROMs, PALs, and PLDs. See 2.17.

2.12 OPERATION INHIBITION – Denotes the concealment of an arcing fault by the normal operation of certain circuit components.

2.13 PARALLEL ARCING – Arcing that is in parallel with the load, such as between the positive and negative conductors, or between any two conductors or ground.

2.14 PHOTOVOLTAIC (PV) DC ARC-FAULT CIRCUIT-INTERRUPTER (PV AFCI) – A device that is intended to be installed in a solar photovoltaic energy system to interrupt power delivered to an arcing fault when an arcing fault is detected by the AFCI. It is intended to provide arcing protection to the PV system and wiring against the unwanted effects of arcing.

2.15 PHOTOVOLTAIC (PV) DC ARC-FAULT DETECTOR (PV AFD) – A device that is intended to provide arcing protection to the PV system and wiring against the unwanted effects of arcing by enabling an interruption or shorting device to interrupt power delivered to an arcing fault.

2.16 PHOTOVOLTAIC (PV) DC INTERRUPTING DEVICE (PV ID) – A device that is intended for installation in a solar photovoltaic energy system to interrupt a detected arcing fault. The device is generally enabled by another device which detects arcing, such an arc-fault detector. The device can perform an interruption or shorting function as appropriate to interrupt power delivered to an arcing fault.

2.17 PROGRAMMABLE COMPONENT – Any microelectronic hardware that can be programmed in the design center, the factory, or in the field. Here the term ″programmable″ is taken to be ″any manner in which one can alter the software wherein the behavior of the component can be altered.″ The microelectronics defined in 2.11 are examples of programmable components.

2.18 PV MODULE – The smallest environmentally protected assembly of solar cells and ancillary parts, such as interconnects and terminals, intended to generate dc power under sunlight.

2.19 SERIES ARCING – Arcing that is in series with the load and is the result of a failure in the intended continuity of a conductor, connection, module or other system components in the direct current PV source and output circuits.

2.20 SHUNTING CONTACT – A contact device inserted in parallel with the source and/or load. It is intended to stop the flow of arcing current by short circuiting the supply or shunting current around the arcing fault location. It may be a mechanical contact set with an air gap or a solid state switching device.

2.21 TYPE 1 DEVICE – A solar photovoltaic device that is intended to detect or interrupt series arcing faults.

2.22 TYPE 2 DEVICE – A solar photovoltaic device that is intended to detect or interrupt both series arcing faults and parallel arcing faults.

2.23 UNWANTED TRIP – A tripping function in response to a condition that is not an arcing fault but a condition that occurs as part of the normal or anticipated operation of circuit components.

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 Appendix A for a list of standards covering components generally 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 Undated 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 All devices shall comply with the construction requirements in Sections 6 – 15 of this standard.

7 Corrosion Protection

7.1 Parts, in addition to enclosures, shall be protected against corrosion if failure of such parts would be likely to result in a hazardous condition such as the inability of the device to perform its intended function. Compliance is determined by the Corrosion Test, Section 41.

8 Current Carrying Parts

8.1 Current-carrying parts shall be of silver, a silver alloy, copper, a copper alloy or other metal acceptable for the application. Screws, nuts, or wire binding screws made of iron or steel and corrosion protected, shall be permitted to be used to secure live parts, but shall not be depended upon to carry current.

9 Internal Wiring

9.1 The gauge and insulation of wires shall withstand the mechanical and electrical stresses of service. Wires smaller than 24 AWG (0.21 mm^2) shall be investigated for the application.

10 Insulation

10.1 A device shall have at least functional insulation throughout. Materials shall be suitable for the temperature, voltage and conditions of service.

11 Inclined Plane Tracking

11.1 For devices rated greater than 600 volts, insulating materials that are in direct contact with live parts shall not track beyond one inch in less than 60 minutes using the time to track method of the Inclined-Plane Tracking Test specified in ASTM D 2303. The voltage for the test shall not be less than the maximum rated voltage of the equipment.

12 Power Supply

12.1 The power supply of a device shall be a commercial light and power source available in a building, dc power from a photovoltaic source, or both. The power supply shall be capable of allowing the device to function and provide protection at all times when the danger of an arcing fault is present.

12.2 When conducting tests in accordance with Part 2 or Part 3 of this standard, tests applicable to each intended power supply type as mentioned in 12.1 shall be conducted.

13 Operating Mechanism

13.1 Compliance with the provisions of arcing fault interruption shall not be prevented by manipulation or restraint of accessible levers, knobs, and the like of a device.

13.2 A device that has tripped in accordance with the provisions of arcing fault interruption shall not be capable of automatic reclosure.

14 Programmable Circuit Components

14.1 If a device employs a programmable circuit component such as a microprocessor in its arc fault detection or interruption system, or in its test circuits, that portion of the device shall be investigated in accordance with the Standard for Software in Programmable Components, UL 1998, as defined in 14.2 – 14.9.

14.2 All of the requirements of the Standard for Software in Programmable Components, UL 1998, apply to programmable components employed in a device as mentioned in 14.1, except as modified by 14.3 – 14.9.

14.3 The risks to be considered for the Risk Analysis portion of UL 1998 include the following scenarios:

a) Unwanted tripping;

b) Failure to trip under conditions where tripping should occur; and

c) Failure of a test circuit to complete evaluation.

14.4 The Tool Qualification requirements from UL 1998 are modified in 14.5 and 14.6.

14.5 All tools used in the design, implementation, and verification of software shall be documented. The documentation shall include:

a) The name of the tool supplier or developer;

b) The model, application, or trade name of the tool;

c) The tool version identification;

d) A description of the purpose for which the tool is used; and

e) A list of known errors, faults or failures of the tool performance, such as a ″bug list″.

14.6 Software tools are defined as software or hardware used in the development, testing, analysis, or maintenance of a program or its documentation. Examples include compilers, assemblers, timing analyzers, logic analyzers, test case generators, simulators, emulators, and similar tools.

14.7 Means shall be employed to address all microelectronic hardware failure modes identified in the Risk Analysis of 14.3. The analysis shall consider all possible combinations of microelectronic hardware failures, software faults, and other events that are capable of resulting in a risk. This includes, for example, microelectronic hardware failures that cause software faults that are capable of resulting in a risk. Detection of failure modes shall be at a frequency and adequacy suitable for the application.

14.8 One approach to comply with 14.7 is for the manufacturer to:

a) Identify failure modes;

b) Determine safety impact of failure modes;

c) Design and provide means to detect the failure modes that have an impact on safety;

d) Demonstrate that coverage provided by detection means is at a frequency and effective level suitable for the application; and

e) Provide evidence that the failure rate of microelectronic components is suitable for the application.

14.9 The requirements in UL 1998 addressing user interfaces do not apply.

15 Electronic Interruption

15.1 General

15.1.1 Solid state components used in place of air gap contacts to interrupt or shunt an arc fault shall comply with 15.2 – 15.4 as applicable.

15.2 ″Off″ state or stand-by mode current

15.2.1 When arcing is interrupted by an interrupting contact using electronic means, the available current with the system in the ″off″ state or stand-by mode after interruption shall not exceed 250 mA with the DC system at maximum rated voltage.

15.3 Reliability

15.3.1 Except as indicated in 15.3.2, solid-state components that function as an interrupting contact or shunting contact to terminate an arc fault shall be investigated in accordance with the Standard for Tests for Safety- Related Controls Employing Solid-State Devices, UL 991. This UL 991 investigation shall include the failure of any components between the interrupting or shunting components and the product's input and or output wiring connections that may prevent the interrupting or shunting devices from clearing an arc fault.

15.3.2 If degradation and/or failure of these components is detected and indicated by the test circuit, then only the test circuit shall be investigated in accordance with UL 991.

15.4 Programmable circuit components

15.4.1 If a device employs a programmable circuit component such as a microprocessor to implement the test circuit function mentioned above in 15.3.2, that portion of the circuit shall be investigated in accordance with Programmable Circuit Components, Section 14.

MANUFACTURING AND PRODUCTION LINE TESTS

16 General

16.1 Each device shall be subjected to the manufacturing and production-line tests described in Appendix B.

PART 2 - PV AFCI, PV AFD, AND PV ID DEVICES

CONSTRUCTION

17 General

17.1 A PV AFCI, PV AFD, or PV ID device shall comply with the construction requirements of Part 1 of this Standard as well as Sections 18 – 25.

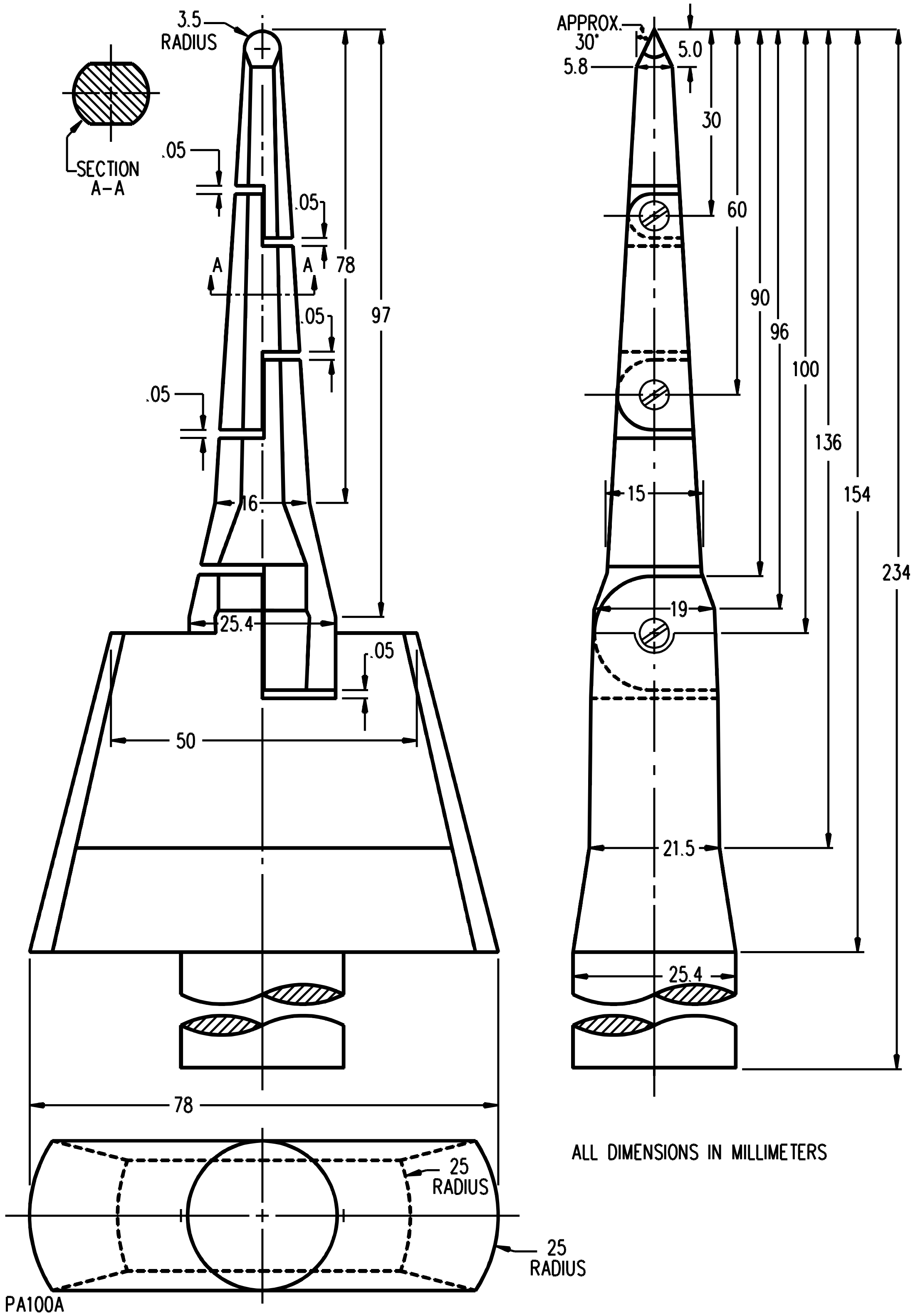
18 Accessibility of Energized Parts

18.1 Parts of a device shall not be accessible when they are installed as intended and energized.

18.2 Parts are considered to be accessible if they can be touched using the articulated probe shown in Figure 18.1.

18.3 Access to the trip mechanism shall not be attainable with ordinary tools.

Figure 18.1
Articulated probe



19 Current Carrying Parts

19.1 Current-carrying parts shall be of silver, a silver alloy, copper, a copper alloy or other metal acceptable for the application. Screws, nuts, or wire binding screws made of iron or steel and corrosion protected, shall be permitted to be used to secure live parts, but shall not be depended upon to carry current.

20 Spacings

20.1 Except as indicated in 20.2, a device shall comply with the requirements shown in Table 20.1.

Table 20.1
Spacing in inches (mm)[a,b]

Operating potential between parts					
0 – 200 V peak		201 – 400 V peak		401 – 1000 V peak	
Through air	Over surface	Through air	Over surface	Through air	Over surface
1/8 (3.2)	1/4 (6.4)	1/4 (6.4)	3/8 (9.5)	3/8 (9.5)	1/2 (12.7)

[a] Smaller spacings may be acceptable where they are inherent in a suitable component.

[b] For printed wiring boards with suitable conformal coating which have been determined to comply with the requirements for conformal coatings in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, spacings may be reduced to 1/32 inch (0.8 mm), and may be reduced further if the coating is determined to be suitable and it is evaluated in accordance with UL 746C for the reduced spacing.

20.2 At field-wiring terminals, the spacings between terminals with a potential difference between them shall be not less than 1/4 inch (6.4 mm) for devices rated 400 V and less, and not less than 1/2 inch (12.7 mm) for devices rated greater than 400 V.

20.3 Except as permitted in Note a of Table 20.1, if a groove or a slot in insulating material is less than 1/64 inch (0.4 mm) wide, the contour of the slot or groove is to be disregarded in measuring spacings over the surface.

20.4 Spacings measured along the boundary of insulating materials that have been joined together are considered to be spacings over surface unless it can be shown that the dielectric strength of the boundary is not less than that of any of the materials joined.

20.5 Film-coated magnet wire is considered to be uninsulated in determining spacings.

20.6 As an alternative to the requirements specified in 20.1 – 20.5, the minimum acceptable clearances (through air spacings) and creepage distances (over surface spacings) for a printed wiring board assembly may be evaluated as specified in 20.7 – 20.9 using the applicable requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840.

20.7 When applying the requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, the environment for a printed wiring board assembly within a device is considered to be:

a) Pollution degree 3 for an assembly without a conformal coating;

b) Pollution degree 2 for

1) An assembly with a coating,

2) An assembly without a coating when the printed wiring board is contained in a sealed housing that complies with the Dust Test, Section 48, or

c) Pollution degree 1 for an assembly with a conformal coating complying with the Printed Wiring Board Coating Performance Test, in UL 840.

20.8 For Clearance B (controlled overvoltage) requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, the applicable overvoltage category for line-voltage circuits is Category III for PV AFCIs, PV AFDs, and PV IDs. Category I is applicable to low-voltage circuits if short circuit between the parts involved may result in an increase in the risk of fire or electric shock. Any overvoltage protection device needed to achieve these categories shall be provided as an integral part of the device.

20.9 Where measurement of clearances and creepage distances is involved to establish the minimum spacings, the methods specified in Measurement of Clearance and Creepage Distances in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, shall be used.

21 Terminals

21.1 General

21.1.1 A device shall have terminals suitable for the application. Terminals that are intended to be wired in the field shall be in the form of terminal leads, wire binding screws or pressure-wire terminals. The terminals shall comply with 21.2, 21.3, or 21.4 as applicable.

21.1.2 A device may also be evaluated for use with PV wire, or other class and strand configurations as indicated by marking. See 50.9.

21.2 Terminal leads

21.2.1 Terminal leads shall differ by no more than two wire sizes from the size that would have an ampacity in accordance with the National Electrical Code (NEC), ANSI/NFPA 70 for the rating of the device.

21.2.2 The insulation of lead type terminals shall be rated for the application and be of a color that conforms with the requirements of the NEC, that is white or gray for the grounded conductor and green or green with a yellow stripe for the grounding conductor.

21.2.3 The free length of a terminal lead shall be at least 6 inches (152 mm).

21.2.4 A terminal lead shall be constructed so as to withstand the stress of normal handling without damage to itself or the device. See Mechanical Tests, Section 47.

21.3 Wire binding screw terminals

21.3.1 A wire binding screw shall be permitted to be used at a field wiring terminal intended for the connection of a 10 AWG (5.3 mm^2) or smaller wire if upturned lugs or the equivalent are provided to retain the wire under the head of the screw even though the screw becomes loosened.

21.3.2 A screw and washer construction used at a field wiring terminal shall not be smaller than No. 10 (4.8 mm) with no more than 32 threads per inch (25.4 mm).

21.3.3 A terminal plate tapped for a wire binding screw shall be of metal not less than 0.05 inch (1.27 mm) thick and shall have not less than 2 full threads in the metal; except that a plate made of a special alloy not less than 0.03 inch (0.76 mm) thick shall be permitted if the tapped threads have the necessary mechanical strength.

21.3.4 A terminal plate shall be permitted to have the metal extruded at the tapped hole so as to give the thickness necessary for at least 2 full threads provided that the thickness for the unextruded metal is not less than the pitch of the thread.

21.4 Pressure wire terminals

21.4.1 Pressure wire terminals provided with a device shall comply with the Standard for Wire Connectors, UL 486A-486Bor the Standard for Equipment Wiring Terminals for Use with Aluminum and/or Copper Conductors, UL 486E.

21.4.2 The tightening torque for a field wiring terminal shall be in accordance with the Standard for Wire Connectors, UL 486A-486B, the Standard for Equipment Wiring Terminals for Use with Aluminum and/or Copper Conductors, UL 486E, or as specified by the device manufacturer and the device shall be marked as required by 50.10. The specified tightening torque shall not be less than 90 percent and not more than 100 percent of the value used in the static heating test as specified in UL 486A-486B or UL 486E, for the wire size corresponding to the ampere rating of the device. See Mechanical Tests, Section 47. Torque values shall be permitted to be less than 90 percent if the connector is investigated in accordance with the lesser assigned torque value.

21.4.3 A pressure wire connector shall be prevented from moving (rotating) so as to strain connections or reduce spacings to unacceptable values.

22 Enclosure

22.1 When a device is provided with its own enclosure, the enclosure shall comply with the requirements in the Standard for Enclosures for Electrical Equipment, UL 50, for the designated Type. There shall not be any unused openings.

23 Grounding

23.1 All accessible parts of a PV AFCI, AFD or ID device that are likely to become energized if there should be arc-over, insulation failure or the like, shall be connected together and to the terminal intended for the equipment grounding conductor.

23.2 A device intended to be connected to multiple power sources, such as a PV power source and a commercial light and power source, shall incorporate terminals or provisions for connecting the equipment grounding conductor from each source.

24 Annunciator

24.1 A PV AFCI or AFD device shall be provided with an annunciator (local or remote) that provides a visual indication that the device has operated when an arc fault is detected. This indication shall not reset automatically.

24.2 It shall be permissible for the indication to be manually reset by remote means.

25 Test Circuits

25.1 A PV AFCI or AFD device shall be provided with a manual test circuit complying with 25.2 – 25.4, or an automatic test feature complying with 25.5, or both.

25.2 A manual test circuit shall simulate an arc such that the arc detection circuit or software is caused to detect the simulated arc. The test circuit shall allow for periodic testing of the device by manual means that does not require the use of a tool.

25.3 Operation of the manual test circuit shall cause the contacts of the PV AFCI device to open or a PV AFD device to activate its output such that an associated PV ID or other interruption device would open. The results of the test shall be made known to the user by a positive visual indication.

25.4 A device may be provided with a means to actuate the manual test remotely. If such a feature is provided, then the device shall include a remote visual indication of the results of the test and shall also provide means for remote manual reset.

25.5 An automatic self-test feature shall test the device each time the PV DC input to the device becomes active. Detection of a failure by the self-test circuit shall result in an AFCI opening or an AFD activating its output such that an associated PV ID or other interruption device would open. Detection of a failure by the self-test circuit shall also result in a visual indication of a failure. It shall be permissible for the device to include a remote visual indication of the results of the automatic test, if means is also provided for remote manual reset.

25.6 Any test circuit that employs a programmable circuit component shall comply with Section 14, Programmable Circuit Components.

PERFORMANCE

26 General

26.1 A PV AFCI, AFD or ID device shall comply with the applicable performance requirements in Sections 27 – 48, as detailed in Table 26.1.

Table 26.1
Test sequence

Test name	Section	Conditioning/ environmental [a]	Overload/ endurance [b]	Other [c]
Humidity	27	X		
Leakage[d]	28	X		
Voltage surge[e]	29	X		
Environmental sequence	30	X		
Arc fault detection	31	X		
Unwanted tripping	32			X
Inhibition	33			X
Normal Temperature	34			X
Overvoltage[d]	35		X	
Overload	36		X	
Endurance	37		X	
Dielectric voltage withstand	38	X	X	
Abnormal Operations	39			X
Short circuit	40			X
Corrosion	41			X
Surge current[d]	42			X
Abnormal overvoltage[d]	43			X
Supplemental voltage surge[d]	44			X
Resistance to environmental noise	45			X
Electrostatic discharge	45.2			X
Radiated EMI	45.3			X
Fast transients[d]	45.4			X
Voltage surge[d]	45.5			X
Conducted EMI[e]	45.6			X
Voltage dips[d]	45.7			X
Strain relief	46			X
Mechanical	47			X
Dust	48			X

[a] The same representative device shall be subject to the tests in the sequence shown.

[b] A new representative device shall be subject to all of the tests in the sequence shown.

[c] These tests need not be conducted in the sequence shown and may be conducted on new representative devices, except when the dielectric voltage withstand is required as part of another test.

[d] Only applicable to devices with built-in power supplies deriving their power from a commercial light or power source (devices with AC input).

[e] Conducted at the DC input of all devices plus the AC input of devices with built-in power supplies deriving their power from a commercial light or power source (devices with AC input).

26.2 An interrupting device, such as a PV ID, intended for use with a specific detection device, such as a PV AFD, shall be tested in combination with that device as intended.

26.3 When conducting tests in accordance with this Part, tests applicable to each intended power supply type as mentioned in 12.1 shall be conducted.

26.4 For tests requiring a source of PV power, the source shall consist of an array of PV modules connected in a series or series/parallel, or a simulated PV DC power source having characteristics similar to a PV array. An example of a simulated PV DC power source is shown in Appendix C. Since a simulated PV DC power source may produce unwanted tripping, or may inhibit the PV AFCI from detecting arcing, when deemed necessary, referee tests shall be made using a suitable array of PV modules.

26.5 Where tests are specified to be conducted at maximum power, the PV power source shall be adjusted for its Maximum Power Point (MPP) as follows:

a) The open circuit voltage of the PV supply shall be equal to the rated voltage of the device being tested, and

b) The short circuit current capability of the PV supply shall be equal to the rated current of the device being tested.

26.6 Where the use of a ballast resistor is specified in this standard, a noninductive resistor shall be used.

27 Humidity Conditioning

27.1 A representative device is to be exposed for 168 hours to air at a relative humidity of 93 ±2 percent at a temperature of 32.0 ±2.0°C (89.6 ±3.6°F). The device is to be exposed to ambient air at a temperature of at least 30°C (86°F) until thermal equilibrium is attained before being placed in the test chamber.

27.2 Following the conditioning, while still in the chamber or within 60 s after removal from the chamber, the sample shall be connected to an appropriate source of power. Operation of the sample shall be verified by actuating the test circuit.

28 Leakage Current Measurement

28.1 The leakage current of a device with a built-in power supply deriving its power from a commercial light or power source (device with an AC input), shall not be more than 0.5 mA when tested in accordance with 28.2 – 28.6.

28.2 All accessible parts of a device are to be tested for leakage currents. The accessible parts are to be tested individually, collectively, and from one part to another.

28.3 If a surface other than metal is used for the enclosure or part of the enclosure, the leakage current is to be measured using metal foil with an area of 10 by 20 cm in contact with the surface. Where the surface is less than 10 by 20 cm, the metal foil is to be the same size as the surface. The metal foil is not to be pressed into openings and is not to remain in place long enough to affect the temperature of the device.

28.4 The measurement circuit for leakage current of a cord connected device is to be as shown in Figure 28.1. The measurement instrument is defined in (a) – (d) below. The meter that is actually used for a measurement need only indicate the same numerical value for a measurement as would the defined instrument. The meter used need not have all the attributes of the defined instrument.

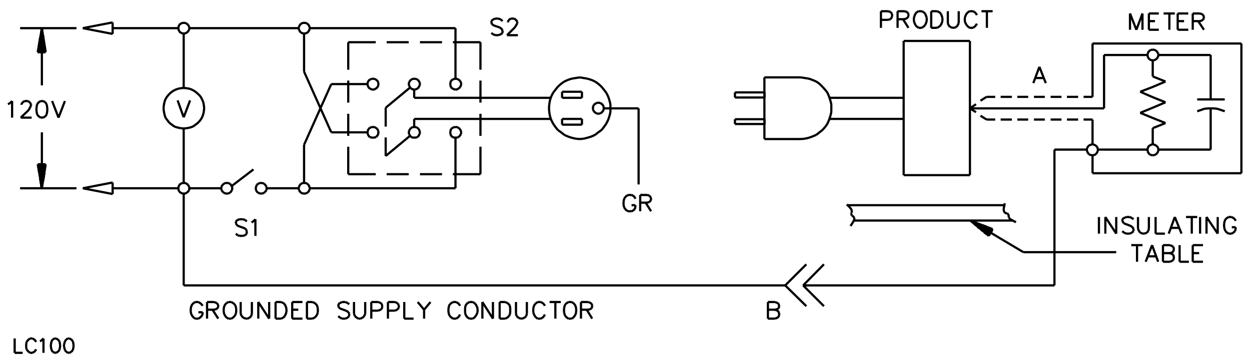
a) The meter is to have an input impedance of 1500 ohms resistive shunted by a capacitance of 0.15 µF.

b) The meter is to indicate 1.11 times the average of the full-wave rectified composite waveform of voltage across the resistance or current through the resistance.

c) Over a frequency range of 0 – 100 kHz, the measurement circuitry is to have a frequency response (ratio of indicated to actual value of current) that is equal to the ratio of the impedance of a 1500-ohm resistance, shunted by a 0.15-µF capacitance, to 1500 ohms. At an indication of 0.5 mA, the measurement is to have an error of not more than five percent at any frequency within the range of 0 – 100 kHz.

d) Unless the meter is being used to measure leakage from one part of the sample to another, the meter is to be connected between the accessible parts and the grounded supply conductor.

Figure 28.1
Leakage-current measurement circuit



NOTES:

A – Probe with shielded lead.

B – Separated and used as clip when measuring currents from one part of the device to another.

28.5 A permanently connected device is to be connected to the supply by way of the terminals of the device, and tested in the same manner as a cord connected device except that switches S1 and S2 are not to be employed.

28.6 A representative device is to be tested for leakage current after the conditioning described in Humidity Conditioning, Section 27. If removed from the humidity chamber, the testing is to start within one minute after its removal. The grounding conductor of a cord connected device is to be open at the supply receptacle and the grounding conductor of a permanently connected device unit is not to be used. The supply voltage is to be adjusted to 110 percent of the rated voltage. The test sequence, with reference to the measuring circuit in Figure 28.1, is as follows:

a) With switch S1 open, the device is to be connected to the measurement circuit. The leakage current is to be measured using both positions of switch S2 and with the sample switching devices in all their positions.

b) Switch S1 is then to be closed, energizing the device, and within a period of five seconds, the leakage current is to be measured using both positions of switch S2 and with the control settings varied throughout the operating range.

c) Leakage current is to be monitored at intervals necessary to determine the maximum leakage current, with additional measurements being taken until such time as thermal equilibrium is attained. Both positions of switch S2 are to be used in determining this measurement.

29 Voltage Surge Test

29.1 General

29.1.1 Devices deriving their power from a commercial light or power source shall be subjected to the tests described in 29.2 and 29.3. The surges shall be applied to the AC input of the device.

29.1.2 In addition to the tests of 29.1.1, devices deriving their power from a commercial light or power source shall also be subjected to the tests described in 29.2 and 29.3 with the surges applied to the PV DC input of the device.

29.1.3 Devices deriving their power from a photovoltaic DC source shall be subjected to the tests described in 29.2 and 29.3. with the surges applied to the PV DC input of the device.

29.1.4 When applying the surges to the PV DC input of a device, the following shall apply:

a) Surges shall be applied to the PV DC input of the device with no PV DC power applied.

b) If the device employs a contactor or other air gap device in its DC supply circuitry, it shall be placed in the ″on″ position or bypassed prior to the application of the surges.

29.2 Unwanted tripping test (Ring wave)

29.2.1 A representative device shall not trip when subjected to the surges described in 29.2.2 – 29.2.5.

29.2.2 All devices shall still be functional following the application of the ring wave surges. Functionality of a device shall be verified by connecting it to an appropriate power source and actuating the test circuit.

29.2.3 Devices deriving their power from a commercial light or power source shall be subjected to ten random applications or three controlled applications of a 3 kV surge applied at 60 second intervals. When three controlled applications are employed, one application is to be essentially at zero of the supply voltage wave, one at the positive peak, and one at the negative peak.

29.2.4 Devices deriving their power from a photovoltaic DC source shall be subjected to three random applications of the 3 KV surge applied at 60 second intervals.

29.2.5 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 essentially as follows:

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 microseconds; and

c) Each successive peak, 60 percent of the preceding peak.

29.3 Surge immunity test (Combination wave)

29.3.1 The same device subjected to the Unwanted Tripping Test shall be subjected to the Surge Immunity Test without demonstrating, either during or after testing:

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) Ignition of the enclosure; or

c) Creation of any opening in the enclosure that results in accessibility of energized parts, when judged in accordance with Accessibility of Energized Parts, Section 18.

29.3.2 The device is permitted to trip during surge immunity testing. If the device trips, it shall be reset prior to the next surge application.

29.3.3 Following the application of the Surge Immunity (Combination Wave) surges, the device shall be in a condition to continue the test sequence in Table 26.1. Functionality of the device shall be verified by connecting it to an appropriate power source and actuating the supervisory circuit.

29.3.4 The test method is to be conducted in accordance with the testing methods described in the Electromagnetic Compatibility (EMC) – Part 4-5: Testing and Measurement Techniques – Surge Immunity Test, IEC 61000-4-5. Except as indicated in 29.3.5, the surges shall be applied at phase angles of 90 and 270 electrical degrees.

29.3.5 For devices deriving their power from a photovoltaic DC source, five impulses shall be applied in the positive direction and five impulses shall be applied in the negative direction for a total of 10 impulses at each application point.

29.3.6 The surge impulse test levels in Table 29.1 shall be used.

Table 29.1
Surge impulse test levels

Impulse[a]	
Peak voltage (KV p)	**Peak current (KA p)**
4	2

[a] Combination 1.2/50 µs, 8/20 µs Voltage/Current surge waveform. For specifications and tolerances, refer to the IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits (ANSI/IEEE), IEEE C62.41.

30 Environmental Test Sequence

30.1 A device that has been conditioned by humidity, leakage current (when required), and voltage surge, shall comply with all of the applicable tests in Arc Fault Detection Tests, Section 31, while operating in ambient air at 25°C (77°F). The same representative device shall also respond to the presence of an arcing fault when subjected to a repeated Series Connection Arc Test, while in ambient air at 66°C (150.8°F), -35°C (-31°F), and 25°C (77°F) by following the sequence shown in Table 30.1.

Table 30.1
Environmental test sequence for arc fault detection tests

Ambient air temperature[a]		Operating parameters	Remarks
1.	25.0 ±5.0°C (77.0 ±9.0°F)	No voltage applied	Establish thermal equilibrium with at least two hours of exposure. Do not test.
2.	25.0 ±2.0°C (77.0 ±3.6°F)	Rated voltage	Test per Section 31 as soon as possible to minimize self-heating.
3.[b]	66.0 ±2.0°C (150.8 ±3.6°F)	Rated voltage and current	Establish thermal equilibrium with at least two hours of exposure. Do not test.
4.[b]	66.0 ±2.0°C (150.8 ±3.6°F)	Rated voltage	Test per 31.1.
5.[c]	40.0 ±2.0°C (104.0 ±3.6°F)	Rated voltage and current	Establish thermal equilibrium with at least two hours of exposure. Do not test.
6.[c]	40.0 ±2.0°C (104.0 ±3.6°F)	Rated voltage	Test per 31.1.
7.	25.0 ±5.0°C (77.0 ±9.0°F)	No voltage applied	Establish thermal equilibrium with at least two hours of exposure. Do not test.
8.[d]	-35.0 ±2.0°C (-31 ±3.6°F)	No voltage applied	Establish thermal equilibrium with at least two hours of exposure. Do not test.
9.[d]	-35.0 ±2.0°C (-31 ±3.6°F)	Rated voltage	Tests per 31.1 as soon as possible to minimize self-heating
10.	25.0 ±5.0°C (77.0 ±9.0°F)	Rated voltage and current	Establish thermal equilibrium with at least two hours of exposure. Do not test.
11.	25.0 ±5.0°C (77.0 ±9.0°F)	Rated voltage	Test per 31.1.

[a] The ambient air temperature is to be changed to each value shown without intentional delay.

[b] For devices specified for use in higher ambient air conditions, such as devices for mounting directly to some modules or some rooftops, the device shall be tested at the maximum specified temperature extreme. In the event that a device is self-protecting such that it trips or functions at this ambient temperature, lower values of load current are to be employed, until the device just continues to operate, if possible.

[c] This test is not to be performed if steps 3 and 4 have been performed employing rated current.

[d] For devices specified for use in lower ambient air conditions, the device shall be tested at the minimum specified temperature extreme.

30.2 Before starting the test sequence in Table 30.1, the mounting position of the device under test shall be studied to determine whether there is one position that is more adverse to correct operation than another position. This study is to be made by introducing faults or by injecting signals that simulate faults while the device is placed in different positions. The mounting position of a device that is marked to specify a mounting position is to be varied from the marked mounting position by not more than 10 degrees in any direction. A representative device that has not been conditioned or subjected to other tests is to be used for this study. The device that has been conditioned is to be subjected to the tests in Table 30.1 while mounted in the position determined to be most adverse. When no position is found to be most adverse, the test sequence is to be performed with the device mounted in any convenient position.

31 Arc Fault Detection Tests

Table 31.1
Arc fault detection test

Clause	Test	Type 1	Type 2
31.1	Series Connection Arcing Test	X	X
31.2	Parallel Path Arcing Test	–	X

31.1 Series connection arcing test

31.1.1 The series connection arcing test is required for Type 1 and Type 2 devices. The series connection arcing test shall be conducted as follows:

a) An arc generator, similar to that described in Figure 31.1, shall be used for this test. For this apparatus, the electrodes, one moveable and one stationary, are made of solid copper, 1/4 inch (6.35 mm) diameter. The electrodes shall be thinned approximately 0.010 inch (0.254 mm) to allow the arcing gasses to escape from the tube described in (b). The electrodes can be separated by using a lateral adjustment means to position the moveable electrode to a desired gap.

b) For test purposes, a polycarbonate tube, 3/4 inch (19 mm) long, is used for insertion over the electrodes. The tube has an outer diameter of 3/8 inch (9.5 mm), an inner diameter of 1/4 inch (6.35 mm), and a wall thickness of 1/16 inch (1.6 mm). The tube may be clear for ease of inspection of the electrodes. A single 1/8 inch (3.2 mm) hole may be drilled perpendicular to the tube wall to allow for the ingress of oxygen and release of expanding gasses.

c) The tube is to be placed halfway over the stationary electrode. A small tuft of very fine steel wool (for example, Size 00) is placed inside the tube just sufficient to bridge the final gap between the electrodes and trigger the arc when the test voltage is applied. See Figure 31.2. The moveable electrode is then moved into the opposite end of the tube, and adjusted to the appropriate gap distance from the stationary electrode.

d) For the 100 W arc-power test, the electrodes may start in a position in which they contact one another such that no gap exists. The arc is then initiated by separating the electrodes along the cylindrical axis of the electrodes. In this case, no steel wool is used, but the polycarbonate tube is still placed as in (c).

e) For the arcing test, the device under test and arc generator are connected to a source of PV power as described in 26.4 to achieve the desired circuit test arc voltage and arc current. No inverter or charge controller is used for these tests. A ballasting resistor may be included in the circuit to limit the test current to the desired value. The electrode gap can be adjusted to achieve the desired arc voltage. The test shall be conducted by connecting the arc generator in series with the device under test. With the electrode gap set to the desired separation, the PV power is applied to the device under test. See 31.1.2 and Figure 31.3.

f) The total arcing time before the device under test detects or interrupts arcing shall not exceed the lesser of the following:

1) 2 seconds; or

2) In seconds, 750 (Joules) divided by the product of the measured arcing current (amps) times the measured arcing voltage (volts). See Table 31.2.

Figure 31.1
Arc Generator

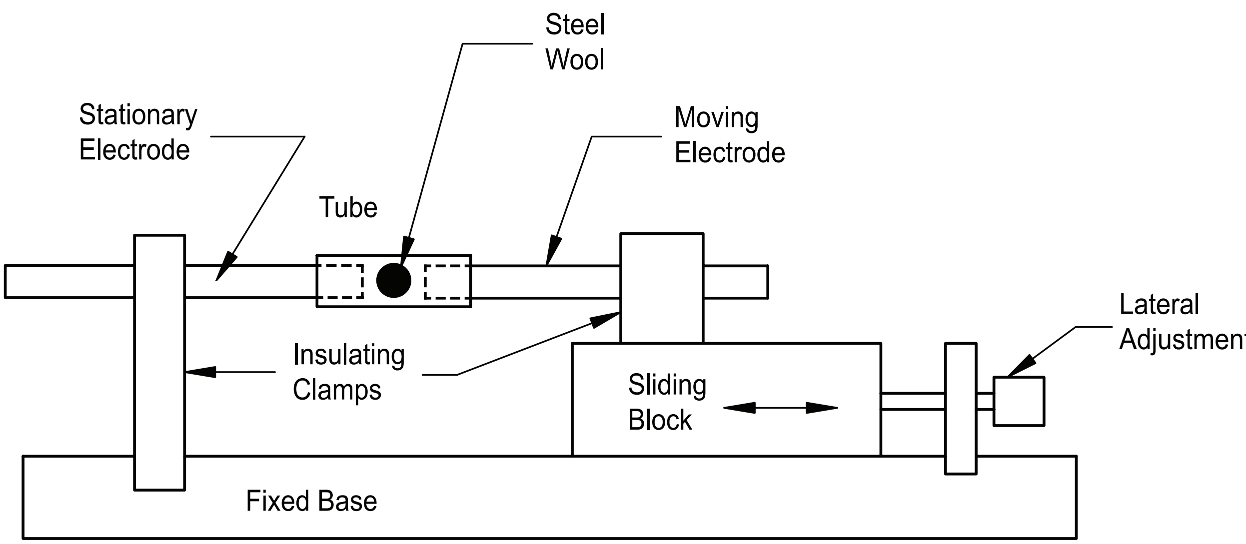


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Figure 31.2
Small tuft of steel wool placed inside tube

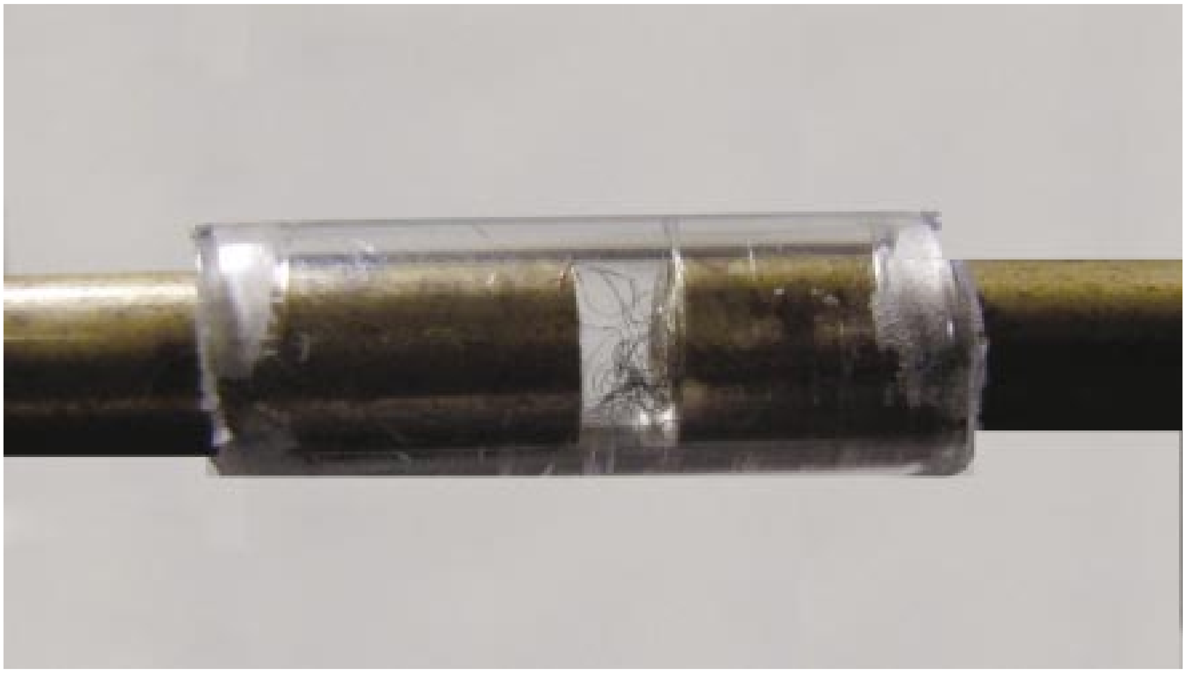

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Figure 31.3
Series connection arcing test circuit

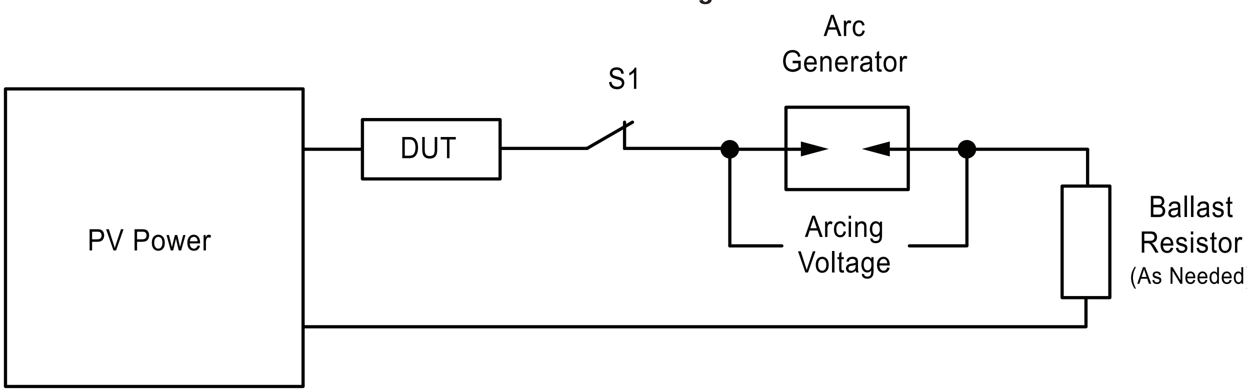

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Table 31.2
Arcing tests and clearing times

Arcing current (amps)[a, d]	Arcing voltage[b] (volts)	Average arcing watts[a]	Approximate electrode, inches (mm) [b]	Max time (sec)[c]
3	33	100[e]	1/32 (0.8)	2
7	43	300	1/16 (1.6)	2
7	71	500	3/16 (4.8)	1.5
14	46	650	1/8 (3.2)	1.2
14	64	900	1/4 (6.4)	0.8
Note: Arcing current may be reduced, while still achieving average Watts, where arcing current exceeds rated current of the device.				
[a] ±20% for arcing current. ±10% for average arcing Watts.				
[b] Approximate, as needed to achieve arcing Watts. Electrode gap can be adjusted to achieve needed arcing voltage.				
[c] Based on average Watts. See 31.1.1(f) for actual maximum detection or interruption times.				
[d] For devices rated less than arcing current, test current may be reduced to rated current and arcing watts calculated accordingly.				
[e] Tolerance of arcing Watts is relaxed to ±30% for this low power test.				

31.1.2 Each test shall be repeated three times at each voltage and current level shown in Table 31.2. For a device that provides circuit interruption, the device under test is to be closed on the fault and allowed to open the circuit or detect arcing. For all devices, the test is to be repeated by closing the switch S1 on the load side of the device under test. See Figure 31.3.

31.1.3 The above test shall be conducted in accordance with the Environmental Test Sequence, Section 30 and Table 30.1.

31.2 Parallel path arcing test

31.2.1 The parallel path arcing test is required for Type 2 devices. The parallel path arcing test shall be conducted as follows:

a) The arc generator described in 31.1.1 (a), (b), and (c) shall be used for the parallel path arcing test.

b) For the arcing test, the device under test, a ballast resistor, and arc generator are connected to a source of PV power as described in 26.4 to achieve the desired circuit test arc voltage and arc current. The test current is to be obtained by adjustment of the ballast resistor . An inverter, converter or charge controller is used as a load for these tests.

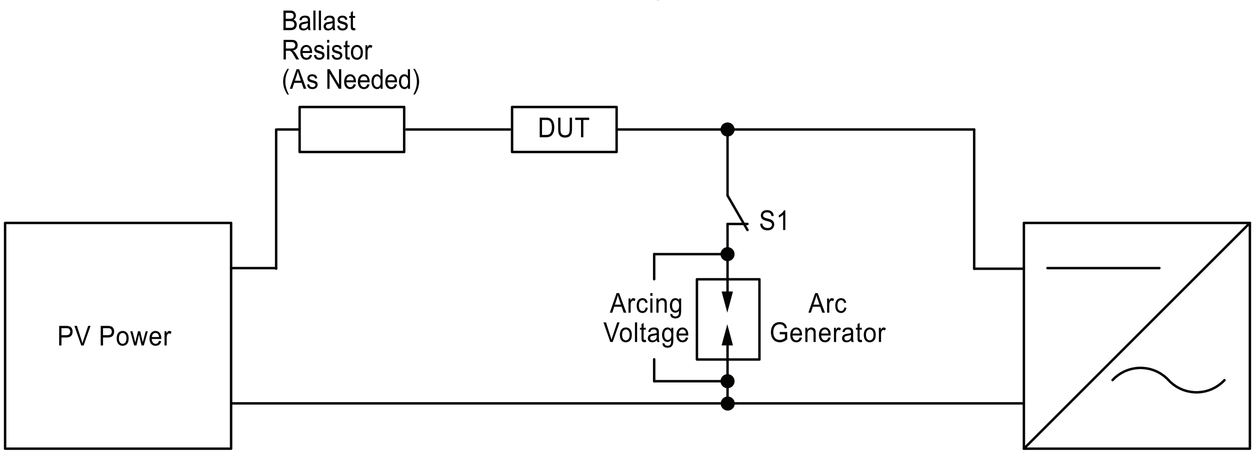
c) The switch, S1, and the arc generator shall be placed on the load side of the device under test, and in a parallel path between the positive and negative conductors of the PV power source as shown in Figure 31.4. With the electrode gap set to the desired separation and switch S1 open, the PV power is applied to the device under test. The test is to be initiated by closing the switch S1.

d) The total arcing time before the device under test detects or interrupts arcing shall not exceed the lesser of the following:

1) 2 seconds; or

2) In seconds, 750 (Joules) divided by the product of the measured arcing current (amps) times the measured arcing voltage (volts). See Table 31.2.

Figure 31.4
Parallel path arcing test circuit 1



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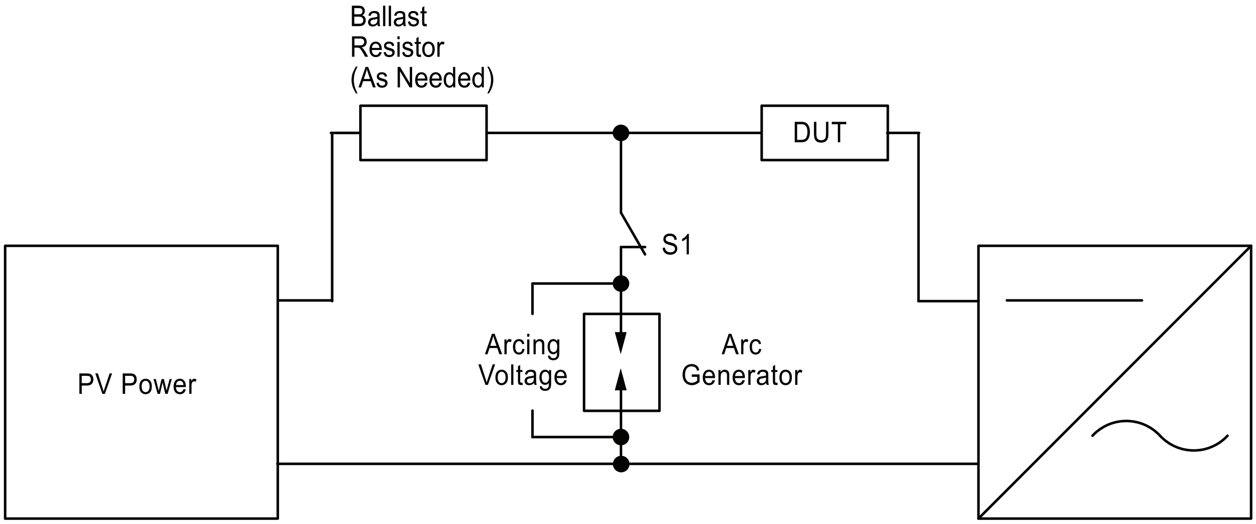
31.2.2 Each test shall be conducted three times at each voltage and current level shown in Table 31.2.

31.2.3 The test is to be repeated with the device under test located as shown in Figure 31.5.

Figure 31.5
Parallel path arcing test circuit 2



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32 Unwanted Tripping Tests

32.1 General

32.1.1 A representative device shall not trip after being tested under each of the following loading and sourcing conditions as described in this Section. When tripping occurs, an additional five representative devices of the rating under test shall be tested and shall not trip.

32.2 Loading condition I – Inverters, converters, and charge controllers

32.2.1 Loading condition I shall consist of one of the following load devices:

a) A single-phase inverter;

b) A three-phase inverter;

c) A converter;

d) A charge controller.

32.2.2 The device under test shall be installed two feet from the load device. With a PV power source operating at rated power of the unit under test, the load device shall be turned ″on″ for five minutes minimum and ″off″ for five minutes minimum. This sequence shall be repeated for a total of three operations.

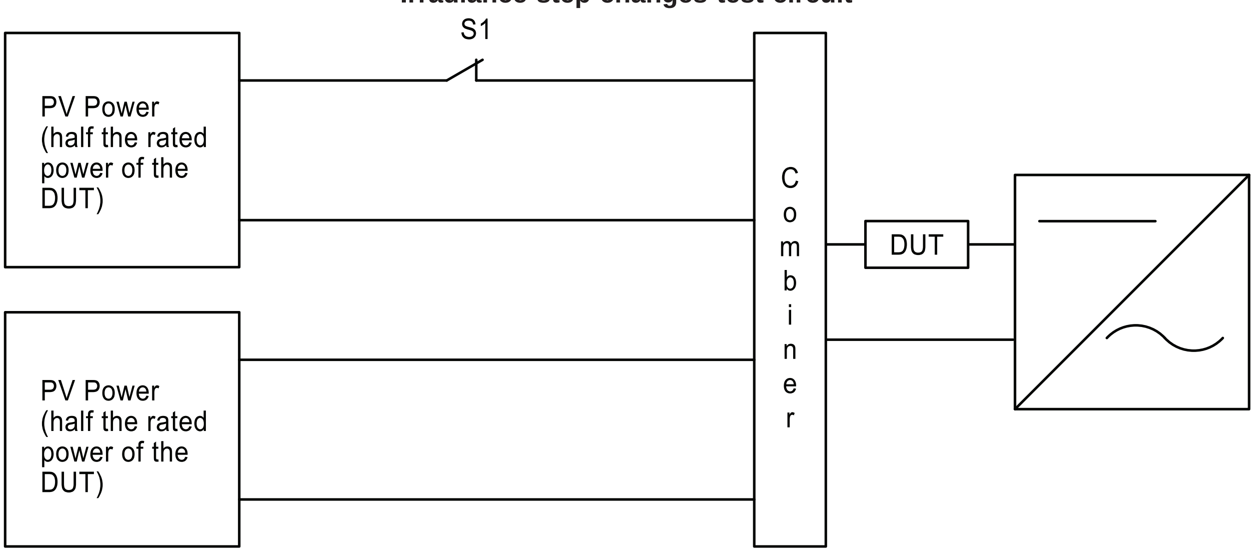
32.3 Loading condition II – DC switch operation

32.3.1 The device under test shall be installed in a test circuit with a PV power source and an inverter. A disconnect switch external to the inverter shall be installed two feet from the device under test. With the PV power source operating in a manner to supply the rated power of the device under test, the disconnect switch shall be operated ″on″ and then after the inverter has been exporting power for 30 seconds, ″off″. This sequence shall be repeated three times, with five minutes ″off″ time between each sequence.

32.4 Loading condition III – Irradiance step changes

32.4.1 The device under test shall be installed in a test circuit with a PV power source and an inverter as shown in Figure 32.1. A mechanical disconnect switch shall be installed on one half of the PV strings connected to the inverter. With the PV power source operating in a manner to supply the rated power of the device under test, the disconnect switch attached to half the PV source circuits shall be operated “on” and then after 30 seconds, “off”. This sequence shall be repeated three times, with five minutes “off” time between each sequence. This test is not performed when the device under test is designed for operation with only a single PV module.

Figure 32.1
Irradiance step changes test circuit



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33 Operation Inhibition Tests

33.1 General

33.1.1 The operation inhibition tests are to be conducted using the apparatus described in 31.1.

33.2 Masking the signal to operate

33.2.1 The device under test shall be tested with each of the following masking load conditions using the arc test in accordance with 31.1. The switch, S1, shown in Figure 31.3 for the Arc Generator Test Circuit is replaced with a shunting switch as shown in Figures 33.1 and 33.2 to bypass the arc generator and allow the inverter to attain a proper ″on″ state condition before initiating the arc fault test by opening the switch. Except as indicated in 33.2.2 and 33.2.3, the device shall interrupt or detect the arcing as described in Table 31.2 for the conditions of 300 and 900 Watts.

a) The device under test shall be installed in a test circuit with a PV power source and an inverter as shown in Figure 33.1.

b) The device under test shall be installed in a test circuit with a PV power source and an inverter as shown in Figure 33.2. The test shall be conducted with PV string 1, while PV string 2 is combined with PV string 1. PV string 2 shall have the same power as PV string 1.

Figure 33.1
Masking test with arcing and inverter

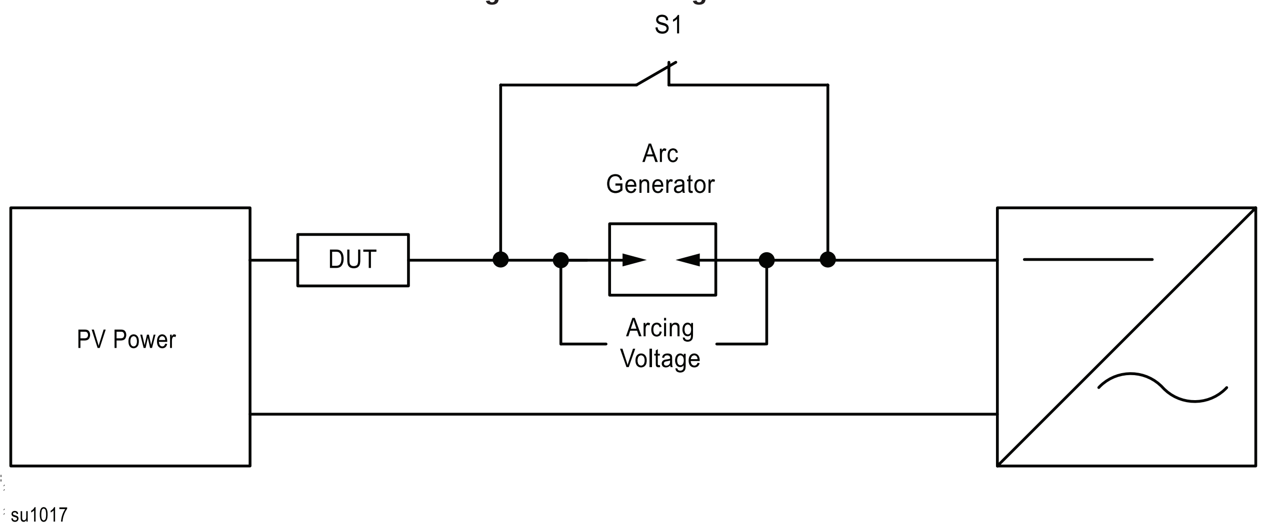
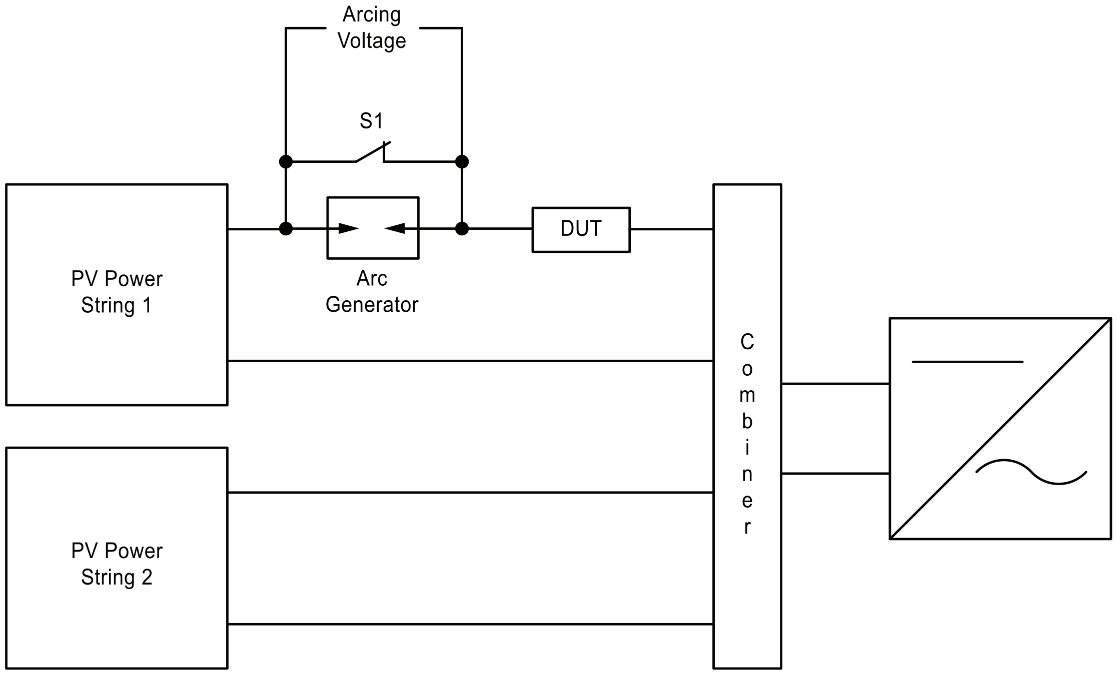


Figure 33.2
Masking test with arcing and multiple strings



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33.2.2 When conducting the tests of 33.2.1, if stable arcs of 900 Watts are not possible due to the rating of the device, operation at the maximum wattage possible shall be conducted and the required trip time calculated from the formula in 31.1.1(f)(2). Electrode gap and arcing current may be adjusted to obtain the required operating point.

33.2.3 When conducting the Masking Test using an inverter, the maximum power point tracking (MPPT) feature provided in the inverter may prevent the development of a stable arc. In this case, it shall be permissible to:

a) Increase the supply voltage, or

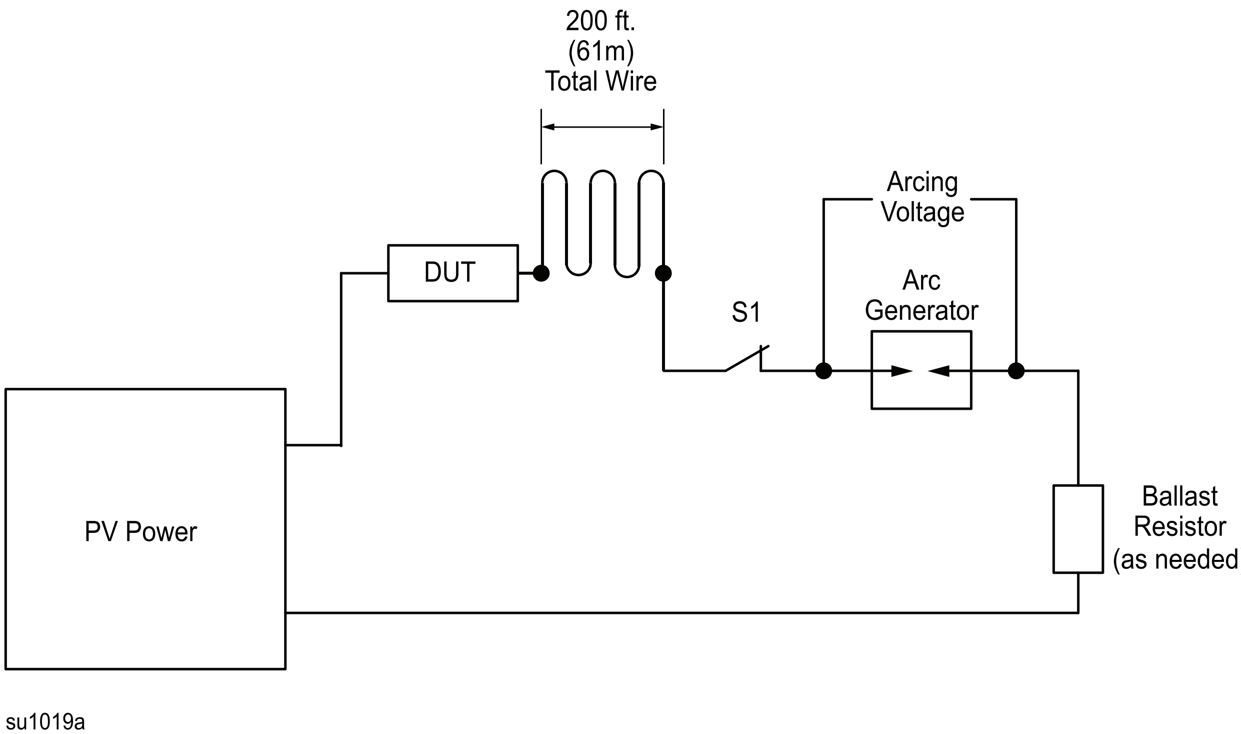
b) Increase the test current while reducing the arc gap, or

c) To modify the inverter MPPT operation so that a stable arc can be obtained for testing at the required operating points.

33.3 Line impedance

33.3.1 A representative device shall be tested in accordance with 31.1 for the series connection arcing test, with the exception that the length of the conductor shown in Figure 33.3 shall be a minimum of 200 ft of rated wire between the device under test and the switch S1. The 200 ft of wire shall be arranged with five 180 degree bends of six-inch radius. See Figure 33.3. Except as indicated in 33.3.2, the device under test shall interrupt or detect the arcing as described in Table 31.2 for the conditions of 300 and 900 Watts.

Figure 33.3
Arcing test with line impedance



33.3.2 When conducting the tests of 33.3.1, if stable arcs of 900 Watts are not possible due to the rating of the device due to the device rating, operation at the maximum wattage possible shall be conducted and the required trip time calculated from the formula in 31.1.1(f)(2). Electrode gap and arcing current may be adjusted to obtain the required operating point.

34 Normal Temperature Test

34.1 When carrying rated current and with rated voltage applied, a device shall not attain a temperature at any point that is sufficiently high to:

a) Constitute an increased risk of fire;

b) Affect injuriously any materials used in the device; or

c) Exhibit greater rises in temperature at specific points than indicated in Table 34.1, based on an assumed average ambient temperature in normal service of 25°C (77°F).

34.2 Coil or winding temperatures are to be measured by thermocouples unless access cannot be gained for mounting a thermocouple (for example, a coil enclosed in sealing compound) or unless the coil wrap includes thermal insulation or more than two layers (1/32 inch or 0.8 mm maximum) of cotton, paper, rayon, or the like. At a point on the surface of a coil where the temperature is affected by an external source of heat, the temperature rise measured by means of a thermocouple may be 10°C (18°F) more than the indicated maximum, provided that the temperature rise of the coil, as measured by the resistance method is no more than that specified in Table 34.1.

Table 34.1
Maximum acceptable temperature rises

Material and components	°C	°F
Wire insulation or insulating tubing	35	63
Electrical tape	55	99
Varnish-cloth insulation	60	108
Fiber employed as electrical insulation	65	117
Phenolic composition or melamine[a]	125	198
Urea composition[a]	75	108
Other insulating materials[a]	–	–

[a] The acceptability of insulating materials shall be determined with respect to properties – such as flammability, arc resistance, relative or generic temperature indices, and the like – based on the temperature rise plus 25°C (45°F).

34.3 Except at coils, temperature readings are to be obtained by means of thermocouples consisting of wires not larger than 24 AWG (0.21 mm^2), and a temperature is considered to be constant when three successive readings, taken at intervals of 10 percent of the previously elapsed duration of the test, but not less than 5-minute intervals, indicate no change. When thermocouples are used in the determination of temperatures in connection with the heating of electrical devices, it is common practice to employ thermocouples consisting of 30 AWG (0.05 mm^2) iron and constantan wires and a potentiometer type of indicating instrument. Such equipment is to be used whenever referee temperature measurements by thermocouples are necessary.

34.4 Ambient air is to be at any convenient temperature within the range of 20 – 30°C (68 – 86°F).

34.5 The thermocouples and related instruments are to be accurate and calibrated in accordance with accepted 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.

35 Overvoltage Test

35.1 A device shall operate continuously while connected to a supply set at 110 percent of rated voltage. The test shall continue for 4 hours or until thermal equilibrium is reached. During the 4 hours, the device shall not trip or become inoperative, and shall be in condition to continue the sequence at the end of the 4 hours.

36 Overload Test

36.1 Except as indicated in 36.2, a device that includes an interrupting or shunting contact function shall have the necessary capacity for overloads. See 36.7.

36.2 An interrupting or shunting device that complies with the requirements of the Outline of Investigation for Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures for Use with Photovoltaic (PV) Systems, UL 489B need not be subjected to this test.

36.3 In order to determine compliance with the provisions of 36.1, the same device previously subjected to the overvoltage test, is to be caused to switch a dc load adjusted for a value of load current equal to two times the ampere rating of the device at rated dc voltage.

36.4 The supply circuit for the test mentioned in 36.3 shall have the capacity to provide a closed-circuit voltage not less than 85 percent of the rated voltage of the device. Except as indicated in 36.5, the dc supply circuit shall have an inductive time constant of 1.0 – 3.0 ms. Except when a higher value is agreed to by those concerned, the open-circuit voltage shall be in the range of 100 – 105 percent of the rated voltage of the device. A 1A fuse shall be connected between the grounded conductor of a grounded supply circuit and accessible conductive parts of the device.

36.5 The DC inductive time constant may be less than 1.0 ms provided that the test circuit inductance is not less than 1mH.

36.6 In performing the test mentioned in 36.3 the device is to be switched ″on″ and, after not less than 20 ms switched ″off″. Each cycle of on/off operation is to be repeated for a total of 50 cycles of operation, at the rate of six cycles of operation per minute.

36.7 At the conclusion of the test, the 1A fuse mentioned in 36.4 shall not have opened, the circuit interrupting or shunting contacts shall still be capable of opening, and the device shall still be operational. A device with a solid state interrupting device shall additionally comply with 15.2.1.

37 Endurance Test

37.1 Except as indicated in 37.2, a device that that includes an interrupting or shunting contact function shall have the necessary capacity for normal operation. See 37.6.

37.2 An interrupting or shunting device that complies with the requirements of the Outline of Investigation for Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures for Use with Photovoltaic (PV) Systems, UL 489B need not be subjected to this test.

37.3 In order to determine compliance with 37.1, the same device as used for the overload test is to be caused to switch a dc load adjusted for a value of load current equal to the ampere rating of the device at rated voltage under the following conditions:

a) For devices rated less than 250 A, the device is to be switched ″on″ and, after one second, switched ″off″ at a rate of approximately 6 cycles of operation per minute for 1000 cycles, and then switched ″on″ and, after one second ″tripped″ off by using the test switch for an additional 1000 cycles. Ten percent of the latter 1000 operations shall be performed with the power supply voltage reduced to 85 percent of rated voltage.

b) For devices rated 250 A or greater, the device is to be switched ″on″ and, after one second, switched ″off″ at a rate of approximately 6 cycles of operation per minute for 400 cycles, and then switched ″on″ and, after one second ″tripped″ off by using the test switch for an additional 400 cycles. Ten percent of the latter 400 operations shall be performed with the power supply voltage reduced to 85 percent of rated voltage.

37.4 In performing the test described in 37.3, the supply circuit shall have the capacity to provide a closed-circuit voltage not less than 97.5 percent of the rated voltage of the device. Except as indicated in 37.5, the dc supply circuit shall have an inductive time constant of 1.0 – 3.0 ms. Except when a higher value is agreed to by those concerned, the open-circuit voltage is to be in the range of 100 – 105 percent of the rated voltage of the device. A 1-A fuse is to be connected between the grounded conductor of a grounded supply circuit and accessible conductive parts of the device.

37.5 The DC inductive time constant may be less than 1.0 ms provided that the test circuit inductance is not less than 1mH.

37.6 At the conclusion of the test, the 1A fuse mentioned in 37.4 shall not have opened, the circuit interrupting or shunting contacts shall still be capable of opening, and the device shall still be operational as demonstrated by compliance with the test of 37.7. A device with a solid state interrupting device shall additionally comply with 15.2.1.

37.7 After the endurance test, the same device shall be tested in accordance with 31.1. Except as indicated in 37.8, the device shall interrupt the arcing as described in Table 31.2 for the conditions of 300 and 900 Watts at room ambient.

37.8 When conducting the tests of 37.7, if stable arcs of 900 Watts are not possible due to the rating of the device, operation at the maximum wattage possible shall be conducted and the required trip time calculated from the formula in 31.1.1(f)(2). Electrode gap and arcing current may be adjusted to obtain the required operating point.

38 Dielectric Voltage-Withstand Test

38.1 The insulation and spacings shall withstand the application of a test voltage equal to two times the maximum rated voltage plus 1000 V between:

a) Line and load with the device open for a device that includes a circuit interrupting contact;

b) Line and load with the device tripped for a device that includes a circuit interrupting contact;

c) Live parts and parts that are grounded, including a ground terminal;

d) Live parts and accessible metal parts including an enclosure of insulating material wrapped in metal foil. See 38.7.

38.2 For a device deriving power from a commercial light or power source, the test voltage shall also be applied between the ac circuit and dc circuits, and between the ac circuit and parts that are grounded.

38.3 The test voltage across the dielectric of a capacitor shall be 900 volts DC.

38.4 Basic insulation and spacings inherent in a component need not withstand the test potentials mentioned in 38.1 if the component in question complies with the requirements applicable to the component.

38.5 In order to determine compliance with the provisions of 38.1, the insulation and spacings are to be subjected to application of a test potential increased from zero to the values specified and maintained for a period of one minute. The increase in the applied potential is to be at a substantially uniform rate and as rapid as is consistent with the value of the applied potential being correctly indicated by the voltmeter. The source of this test voltage shall be in accordance with (a) or (b) as follows:

a) For ac circuits, a 60 hertz essentially sinusoidal potential;

b) For a dc circuit, or between ac and dc circuits, a direct-current potential. It shall be permissible to use an alternating-current potential for these circuits. The ac RMS potential value is to be the required dc dielectric potential divided by 1.414.

38.6 Where the construction of the device is such as to deny access to the insulation to be tested, suitable subassemblies may be employed.

38.7 In the application of test potentials to insulating surfaces, metal foil may be used providing that care is taken to avoid flashover at the edge of the insulation.

38.8 In the application of the test potential specified by 38.1(c), any components in parallel with the applied potential shall be permitted to be disconnected before performing the dielectric voltage withstand test.

39 Abnormal Operations Test

39.1 A device shall not become a risk of fire, shock or injury when operating while in an abnormal condition, such as with a short-circuited or open-circuited component. See 39.4.

39.2 A single layer of cheesecloth is to be loosely draped over the device. In addition, a cord connected device is to rest on white tissue paper supported by a softwood surface. A 1-A fuse is to be connected between the grounded supply conductor and accessible conductive parts of the device.

39.3 The cheesecloth mentioned in 39.2 is to be bleached cheesecloth running 14 – 15 square yards per pound mass (approximately 26 – 28 square meters per kilogram mass) and having what is known in the trade as a ″count of 32 by 28″, that is, for any square inch, 32 threads in one direction and 28 threads in the other direction (for any square centimeter, 13 threads in one direction and 11 in the other direction).

39.4 A device operating under abnormal conditions will be considered to have become a risk of fire, shock or injury if:

a) There is glowing or flaming of the cheesecloth or tissue paper mentioned in 39.2;

b) There is emission of molten metal;

c) The fuse mentioned in 39.2 operates to open the circuit;

d) Except if the device is likely to be removed from service, there is dielectric failure. See 39.5 and 39.6;

e) It is possible to touch a part with the articulated probe shown in Figure 18.1 while there is a risk of shock at that part; or

f) There is any other evidence of a risk of injury.

39.5 Dielectric failure is considered to be failure to comply with the provisions of 38.1.

39.6 A device is considered likely to be removed from service if:

a) For an AFCI or ID it is no longer able to complete the electric circuit to the load; or

b) For an AFD it is no longer able to cause its corresponding ID to complete the circuit to the load.

40 Short Circuit Current Test

40.1 A device that includes an interrupting or shunting contact shall withstand short-circuit currents. See 40.7.

40.2 In order to determine compliance with the provisions of 40.1, the supply circuit shall have an open-circuit voltage in the range of 100 – 105 percent of the rating of the device. Except as indicated in 40.3, the dc supply circuit shall have an inductive time constant of 1.0 – 3.0 ms. The impedance of the supply is to be such as to provide a prospective current that shall be any of the following values as required for the application: 100, 400, 800, 1200, 1600, 2000, 3000, or 5000.

40.3 The DC inductive time constant may be less than 1.0 ms provided that the test circuit inductance is not less than 1mH.

40.4 Each line terminal of a device is to be connected to the supply mentioned in 40.2 using 4 ft (1.2 m) of insulated wire, sized for the rating of the device. A PV fuse complying with the Outline of Investigation for Low-Voltage Fuses – Fuses For Photovoltaic Systems, UL 2579, rated at the current rating of the PV DC arc-fault circuit-interrupter is to be connected in series with the ungrounded conductor. If the required fuse rating is not a standard fuse rating, the next higher standard value shall be used. The fuse shall have an interrupting rating equal to or greater than the test current. A 20-inch (508-mm) conductor is to be connected between the load terminals or for a single pole device, between the load terminal and the return terminal of the supply. The device is to be in any position considered to be normal in service. A 1-A fuse is to be connected between the supply terminal representing the grounded circuit conductor and accessible conductive parts of the device. Surgical cotton is to cover openings of the device where flame may be emitted.

40.5 The prospective current is to be initiated once by means of a switch in the supply circuit. The test is to be repeated with the prospective current initiated once by means of any control of the device. A single representative device is not required to experience more than one current initiation.

40.6 The short circuit current test described in 40.5 shall be repeated with reverse current by reversing the line and load connections to the device.

40.7 At the conclusion of the above tests the 1A fuse mentioned in 40.4 shall not have opened, there shall not be any flaming of the cotton mentioned in 40.4, the interrupting or shunting contacts shall still be capable of opening, and the device shall still be operational as demonstrated by compliance with the test of 40.8. A device with a solid state interrupting device shall additionally comply with 15.2.1.

40.8 After the short circuit current tests, each representative device shall be tested in accordance with 31.1. Except as indicated in 40.9, the device shall interrupt the arcing as described in Table 31.2 for the conditions of 300 and 900 Watts at room ambient.

40.9 When conducting the tests of 40.8, if stable arcs of 900 Watts are not possible due to the rating of the device, operation at the maximum wattage possible shall be conducted and the required trip time calculated from the formula in 31.1.1(e)(2). Electrode gap and arcing current may be adjusted to obtain the required operating point.

41 Corrosion Test

41.1 A device shall operate as intended after being subjected to the corrosive atmosphere test described in 41.2 – 41.3.

41.2 One representative device is to be placed in a 200 liter (52.8 gallon) or larger test chamber on a platform approximately 2 inches (50.8 mm) above the bottom of the chamber. The temperature in the chamber is to be maintained at 30 ±2°C (86 ±3°F) and the relative humidity at 70 ±2 percent (measured directly in the chamber). The temperature and humidity are to be checked daily. Because of the corrosive atmosphere a set of wet and dry bulb thermometers shall be used for measurement of relative humidity.

41.3 The following gas mixture in air is to be supplied to the chamber at a rate sufficient to achieve an air exchange in the chamber of about five times per hour, for a period of 3 weeks: 100 ±10 parts per billion (ppb) (parts per billion = parts per 10^9 by volume) hydrogen sulfide (H_2S) plus 20 ±5 ppb chlorine (Cl_2) plus 200 ±50 ppb nitrogen dioxide (NO_2). The air inside the chamber is to be circulated by a single fan, with flow upwards from the bottom.

41.4 After the corrosion test, the representative device shall be tested in accordance with 31.1 at the two lowest wattages specified in Table 31.2, and shall trip as required.

42 Surge Current Test

42.1 General

42.1.1 All devices with built-in power supplies deriving their power from a commercial light and power source (devices with AC input) shall be subjected to the Surge Current Test in 42.2.1 – 42.4.1, and shall comply with the requirements in 42.1.2.

42.1.2 During and following the Surge Current Test the following conditions shall not result:

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, when judged in accordance with Accessibility of Energized Parts, Section 18.

42.1.3 Three previously untested representative devices are to be subjected to the test.

42.2 Mounting and installation

42.2.1 Each representative device shall be placed on a softwood surface covered with a double layer of white tissue paper. Each device is to be loosely draped with a double layer of cheesecloth. The cheesecloth shall cover openings (for example, receptacle openings, ventilation openings) where flame, molten metal, or other particles may be expelled as a result of the test. However, the cheesecloth shall not be deliberately pushed into openings.

42.3 Surge parameters

42.3.1 A cord and plug connected device is to be subjected to a surge of 6 kV at 3 kA. A permanently-connected device is to be subjected to a minimum surge of 6 kV at 10 kA. The surge shall be a combination 1.2/50µs, 8/20µs voltage/current surge waveform.

42.4 Surge polarity

42.4.1 The polarity of the impulses shall be one positive applied at a phase angle of 90 degrees (+0, -15), one negative applied at a phase angle of 90 degrees (+0, -15).

43 Abnormal Overvoltage Tests

43.1 General

43.1.1 All devices with built-in power supplies deriving their power from a commercial light and power source (devices with AC input) shall be subjected to the Full Phase Voltage-High Current Abnormal Overvoltage Test, 43.2, and Limited Current Abnormal Overvoltage Test, 43.3. Testing shall not result in any of the following conditions:

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; and

d) Creation of any openings in the enclosure that results in accessibility of live parts, when judged in accordance with Accessibility of Energized Parts, Section 18.

43.1.2 The representative devices used for each of the tests described in 43.2 – 43.3 are to be previously untested.

43.1.3 The representative devices shall be placed on a softwood surface covered with a double layer of white tissue paper. The orientation of the representative device shall be such as to create the most severe conditions representative of normal installation. Each representative device is to be loosely draped with a double layer of cheesecloth. The cheesecloth shall cover openings (for example, receptacle openings, ventilation openings and any other similar openings) where flame, molten metal, or other particles may be expelled as a result of the test. However, the cheesecloth shall not be deliberately pushed into openings.

43.1.4 Cord connected devices shall be tested in accordance with the Limited Current Abnormal Overvoltage Test, 43.3, in both normal and reversed polarity.

43.1.5 When agreed upon by all concerned parties, fewer representative devices than those specified in 43.2 – 43.3 may be used for testing.

43.1.6 Following the tests described in the Full Phase Voltage – High Current Abnormal Overvoltage Test, 43.2, and the Limited Current Abnormal Overvoltage Test, 43.3, the same representative devices are to be subjected to and comply with Section 28, Leakage Current Measurement , and comply with the requirements of Section 23, Grounding. The leakage current test shall be conducted within five minutes of the end of the abnormal overvoltage tests.

43.1.7 Operation of the ac-power-line circuit breaker, a fuse internal or external to the device, or operation of an acceptable overcurrent or over temperature protective device provided as part of the device is considered acceptable.

43.2 Full phase voltage – high current abnormal overvoltage test

43.2.1 The test described in this section shall not result in any of the conditions described in 43.1.1. One previously untested device is to be subjected to the application of the test voltage as specified in Table 43.1 with a power factor as specified in Table 43.3. The ac power source shall have an available short-circuit (fault) current (I_{SC}) as specified in Table 43.2. The overvoltage is to be applied for 7 hours, or until current to, or temperatures within the device attain equilibrium, or until the device becomes disconnected from the ac supply (due, for example, to open circuiting of a thermal or overcurrent protective device). See Figure 43.1.

Exception: This testing is not required for an device employing a component or components that have been previously tested and shown not to conduct current nor to exhibit any condition in 43.1.1 when subjected to the maximum phase voltage or twice the conductor pair voltage rating of the device as specified in Table 43.1.

43.2.2 Connection of the test circuit in series with a circuit breaker or time delay non-current limiting fuse rated for the maximum ampacity of the circuit in which the AFCI is to be installed, as specified in the National Electrical Code, ANSI/NFPA 70, is not prohibited.

Figure 43.1
High current abnormal overvoltage

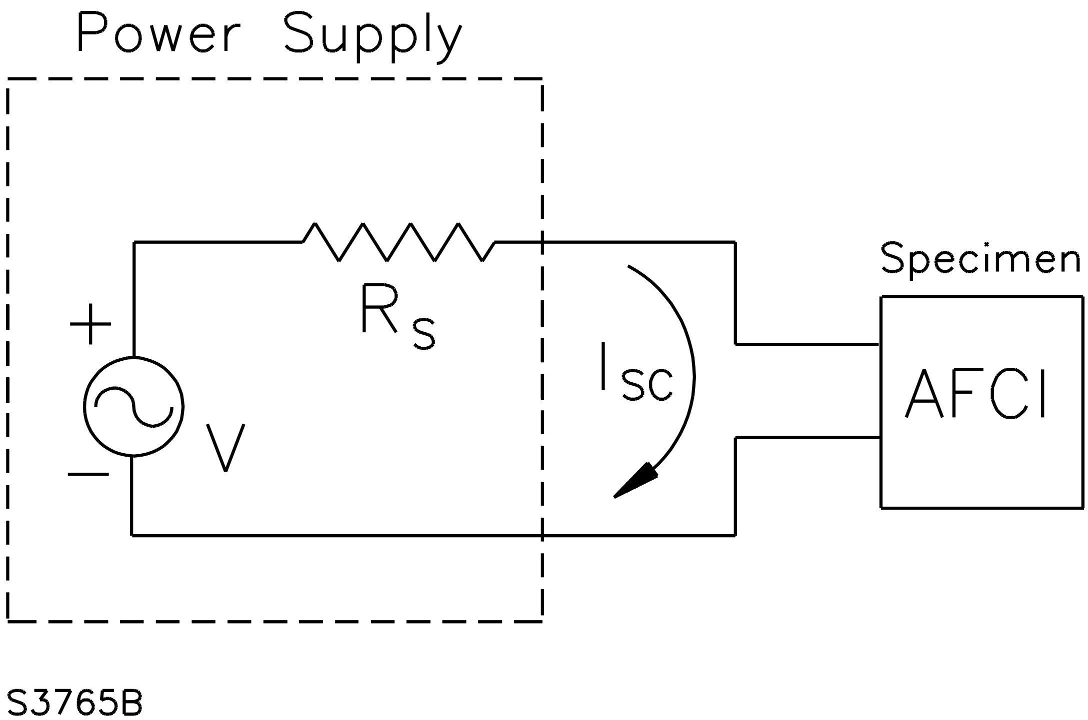


Table 43.1
Test voltage selection table

Device AC supply rating	Phase	Test voltage (Vac)[a]	Voltage rating of conductor pair to which the test voltage is to be applied
110 – 120 V	Single	240	All
110 – 120V/220 – 240V	Split	240	110 – 120V
120/208V	3-Wye	208	120V

[a] For device ratings not specified in this table, the test voltage shall be the maximum phase voltage (if available) or twice the conductor pair voltage rating.

Table 43.2
Available fault current from source of supply

Permanently connected devices		Cord connected devices		
Rating A	**Available fault current, amperes**	**Rating volts**	**Rating, volts times amperes**	**Available fault current, amperes**
100 A or less	5,000	250 ac or less	1175 or less	200
> 100 A	10,000		1176 to 1920	1000
			1921 to 4080	2000
			4081 to 9600	3500
			More than 9600	5000

Table 43.3
Power factor

Available fault current	Power factor
200 A	0.80 – 1.0
1000 A	0.70 – 0.80
2000 – 10,000 A	0.40 – 0.50

43.3 Limited current abnormal overvoltage test

43.3.1 The test described in this section shall not result in any of the conditions described in 43.1.1. Each of four previously untested representative devices is to be connected to an ac power supply having an open circuit voltage equal to the test voltage specified in Table 43.1. The power supply is to incorporate a series variable resistor that can be adjusted to obtain the short-circuit current (I_{sc}) specified below. See Figure 43.2. No load is to be connected. The variable resistor is to be adjusted such that Isc equals 5 A for the first representative device, 2.5 A for the second, 0.5 A for the third, and 0.125 A for the fourth. The four representative devices are to be energized for 7 hours, or until current to, or temperatures within the device attain equilibrium, or until the AFCI becomes disconnected from the ac supply (due, for example, to open circuiting of a thermal or overcurrent protective device). See Figure 43.2.

Exception No. 1: This test is not required for an end-product employing a component or components that have been previously tested and shown not to conduct current nor to exhibit any condition in 43.1.1 when subjected to the maximum phase voltage or twice the conductor pair voltage rating of the device as specified in Table 43.1.

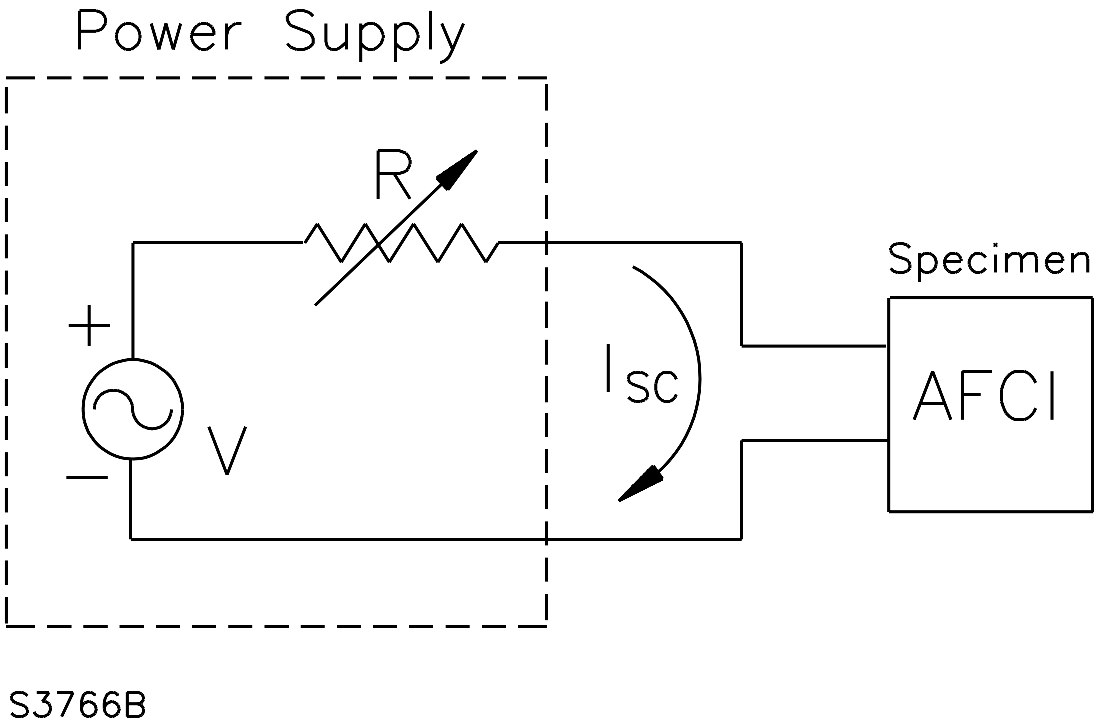
Exception No. 2: When this test is performed at any current level specified above and results in neither:

a) Any condition specified in 43.1.1; nor

b) Operation of any overcurrent or thermal device

then the test results are also representative of testing of the device at lower current levels.

Figure 43.2
Limited current abnormal overvoltage test circuit



44 Supplemental Voltage Surge Immunity Test

44.1 General

44.1.1 All devices with built-in power supplies deriving their power from a commercial light and power source (devices with AC input) shall be subjected to this test.

44.1.2 The ac terminals of the device shall be connected to a supply of rated voltage. The grounding lead or terminal of the device (if provided) is to be connected to the supply conductor serving as the neutral. The device is to be in the ″ON″ condition with no load connected. Devices that are intended only for use in enclosures shall be tested in their intended enclosure. The enclosure shall be representative of the worst case situation for the tests.

44.2 Surge immunity test (combination wave)

44.2.1 The AFCI shall be subjected to the Surge Immunity Test without demonstrating, either during or after testing:

a) Emission of flame, molten metal, glowing or flaming particles through any openings (preexisting or created as a result of the test) in the product;

b) Ignition of the enclosure; or

c) Creation of any opening in the enclosure that results in accessibility of energized parts, when judged in accordance with Accessibility of Energized Parts, Section 18.

44.2.2 The test method is to be conducted in accordance with the testing methods described in the Standard for Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test, IEC 61000-4-5.

44.2.3 The surges shall be superimposed on the ac power with the device energized and applied at phase angles of 90 and 270 electrical degrees.

44.2.4 The surge impulse test levels in Table 44.1 shall be used. Using a separate representative device for each surge impulse test level meets the intent of the requirement.

Table 44.1
Surge impulse test levels

Peak voltage (kV p)	Peak current (kA p)
2	1
6	3
NOTE: Combination 1.2/50 µs, 8/20 µs Voltage/Current surge waveform. For specifications and tolerances, refer to the Standard for Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test, IEC 61000-4-5.	

44.2.5 The device is permitted to trip during surge immunity testing. If the device trips, it shall be reset prior to the next surge application.

44.2.6 After the 2 kV test the same device shall be in condition to comply with the Series Connection Arcing Test of 31.1, see 44.2.8, and the Dielectric Voltage Withstand Test, Section 38.

44.2.7 After the 6 kV test, the same device shall comply with either (a) or (b):

a) The device shall be in condition to comply with the Series Connection Arcing Test of 31.1, see 44.2.8, and the Dielectric Voltage-Withstand Test, Section 38; or

b) The device shall trip as a result of the surge test and render itself incapable of delivering power after attempting reset. Reset shall be attempted 5 times as fast as possible with rated voltage applied.

44.2.8 Except as indicated in 44.2.9, when conducting the Series Connection Arcing Test of 31.1, after the application of surges, the device shall interrupt the arcing as described in Table 31.2 for the conditions of 300 and 900 Watts at room ambient.

44.2.9 When conducting the Series Connection Arcing Test of 31.1, if stable arcs of 900 Watts are not possible due to the rating of the device, operation at the maximum wattage possible shall be conducted and the required trip time calculated from the formula in 31.1.1(f)(2). Electrode gap and arcing current may be adjusted to obtain the required operating point.

45 Resistance to Environmental Noise Test

45.1 General

45.1.1 A device shall demonstrate immunity from false operation when exposed to the conditions described in this Section.

45.1.2 The same representative device shall be tested for all of the applicable tests as tabulated in Table 26.1 and described in 45.2 – 45.7.

45.1.3 Except as indicated in 45.1.4, the device shall not trip as a result of the electromagnetic event.

45.1.4 It shall be permissible for a device to trip as a result of any electromagnetic event, providing all of the following conditions are met:

a) The device automatically restores power after conducting an acceptable self-test;

b) The self-test system that allows restoration of power after an electromagnetic event also prevents the device from resetting automatically after tripping as a result of an arc fault; and

c) If the self-test system employs a programmable circuit component such as a microprocessor, it shall be included in the investigation required by Section 14, Programmable Circuit Components.

45.1.5 It shall be permissible for a device to trip during the Voltage dips, short interruptions and voltage variations immunity test if the device complies with 45.1.4 or 45.7.2.

45.1.6 After all of the tests involving the electromagnetic events, the representative device shall be tested in accordance with 31.1 using any two of the test conditions specified in Table 31.2, and shall trip as required.

45.2 Electrostatic discharge immunity

45.2.1 The Standard for Electromagnetic compatibility (EMC) Part 4; Testing and measurement techniques – Section 2: Electrostatic discharge immunity test – Basic EMC publication, IEC 61000-4-2, is to be used as the reference for testing and measuring techniques. The test limits are:

a) 4kV, positive and negative polarity, for direct contact discharge; and

b) 8kV, positive and negative polarity, for air discharge.

45.3 Radiated electromagnetic field immunity

45.3.1 The Standard for Electromagnetic compatibility (EMC) Part 4: Testing and measurement techniques – Section 3: Radiated, radio frequency, electromagnetic field immunity test, IEC 61000-4-3, is to be the test measurement reference. The frequency range to be investigated is to be from 80 MHz to 1 GHz. The exposure is to be level 2, 3 V/m modulated with 80 percent AM modulation at 1 kHz. The protective device shall not false trip when exposed to these fields. The frequencies to be used encompass the standard broadcast frequency ranges for commercial and amateur (″ham″) radio and television. The step size for the test frequency ranges is to be 1 percent of fundamental. In addition the device should be exposed to radiated electromagnetic fields that simulate those generated by digital radio telephones (commonly known as ″cell phones″). This test consists of exposure to 3 V/m field using a 200 Hz digital modulation technique with a 50 percent duty cycle on one frequency between 895 MHz and 905 MHz. Other frequency ranges that are used in the United States are to be considered.

45.4 Electrical fast transient immunity

45.4.1 The Standard for Electromagnetic compatibility (EMC) Part 4: Testing and measurement techniques – Section 4: Electrical fast transient/burst immunity test – Basic EMC publication, IEC 61000-4-4, is to be the standard for testing methods and to specify multiple levels of limits based on installation environment. Level 2 is to be the test limit.

45.5 Voltage surge

45.5.1 The Standard for Electromagnetic compatibility (EMC) Part 4: Testing and measurement techniques – Section 5: Surge immunity test – Basic EMC publication, IEC 61000-4-5, is to be the standard for testing methods and to specify multiple levels of limits based on installation environment. The test limit is to be level 3 at 2 kV line-to-ground and level 2 at 1kV line-to-line and line-to-neutral.

45.6 Immunity to conducted disturbances, induced by RF fields

45.6.1 The test method described in the Standard for Electromagnetic compatibility (EMC) Part 4: Testing and measurement techniques – Section 6, Immunity to conducted disturbances, induced by radio-frequency fields, IEC 61000-4-6, are to be followed. The representative product is to be subjected to a conducted disturbance at 3 V over a frequency range of 150 kHz to 80 MHz.

45.7 Voltage dips, short interruptions and voltage variations immunity

45.7.1 The Standard for Electromagnetic compatibility (EMC) Part 4: Testing and measuring techniques – Section 11: Voltage dips, short interruptions and voltage variations immunity tests, IEC 61000-4-11, is to be the standard for testing methods. The device shall be investigated under the following power line conditions:

a) 100 percent voltage dip for 10 mS;

b) 60 percent voltage dip for 200 mS; or

c) 30 percent voltage dip for 1 S.

45.7.2 A device turning OFF during the disturbances specified in 45.7.1 meets the intent of the requirement provided:

a) The power to the device output is removed, and

b) Operation is automatically restored when input power is restored to at least 85 percent of rated voltage

46 Strain-Relief Tests

46.1 Terminal lead strain-relief test

46.1.1 A device that is provided with terminal leads intended to be connected in the field shall be subjected to the test described in 46.1.2. Following the test there shall be no indication that either the device or the lead has sustained damage as a result of the test, or that the force would have been transmitted to the terminations.

46.1.2 The leads are to be disconnected from the internal point of termination. Each terminal lead shall be subjected to a tensile force increased gradually to 20 lbf (89 N), and maintained at that value for five minutes.

46.2 Power-supply cord strain-relief test

46.2.1 A device that is provided with a power-supply cord shall be subjected to the test described in 46.2.2. Following the test there shall not be any indication that the force was transmitted to the cord-conductor terminations.

46.2.2 The leads are to be disconnected from the internal point of termination. The cord shall be subjected to a tensile force increased gradually to 35 lbf (156 N) and maintained at that value for one minute.

47 Mechanical Tests

47.1 An interrupting device that is provided with pressure wire connectors or wire binding screw terminals intended for field wiring shall be subjected to the tests described in 47.2 or 47.3 as applicable.

47.2 There shall be no breakage or damage of any part of the device when 110 percent of the marked terminal tightening torque is applied to the wire securing means of a pressure wire connector.

47.3 A wire binding screw or nut is to be tightened on a conductor selected in accordance with the ampere rating of the device, but no less than 14 AWG (2.1 mm^2), to a torque of 20 lbf-in (2.3 N·m) without causing displacement of the wire or damage to the terminal assembly or the wire. Except where the configuration of the terminal assembly does not permit, or markings allow, the use of unformed wire, the wire is to be formed into a 3/4 loop that will just be accommodated by the assembly, before tightening.

48 Dust Test

48.1 To determine compliance with 20.7(b)(2), each of six devices, each mounted in a different mounting orientation, is to be placed, deenergized, in an air tight chamber having an internal volume of at least 0.09 m^3 (3 cubic feet).

48.2 A 0.06-kg (2-oz.) quantity of cement dust, maintained at a relative humidity of 20 – 50 percent, and capable of passing through a 200 mesh screen, is to be circulated for 15 minutes by means of compressed air or a blower so as to completely envelop the device in the chamber. The air flow is to be maintained at an air velocity of approximately 0.25 m/s (50 fpm).

48.3 Following the exposure to dust, the exterior of the device is to be cleaned carefully. The device is to be opened and examined for the presence of dust. To be considered as meeting Pollution Degree 2, there shall not be any evidence of dust in the interior of the device.

RATINGS

49 General

49.1 A device shall be rated in volts DC, and amperes DC.

49.2 The short circuit rating of a device intended to interrupt arcing shall not exceed that value of the prospective current used during the Short Circuit Current Test, Section 40.

MARKINGS

50 General

50.1 A device shall be marked with the manufacturer's name, trademark, or other suitable means of identification, a type or catalog designation, the electrical ratings in dc voltage, load capacity in dc amperes, and short circuit rating in dc amperes.

50.2 A device that is intended to receive power from a commercial light and power source shall also be marked with the intended voltage, frequency, and rating in amperes.

50.3 Except as indicated in 50.4, a device shall be legibly and permanently marked with the date or other dating period of manufacture not exceeding any three consecutive months.

50.4 The date of manufacture may be abbreviated, or may be in a nationally accepted conventional code, or in a code affirmed by the manufacturer, provided that the code:

a) Does not repeat in less than 20 years; and

b) Does not require reference to the production records of the manufacturer to determine when the product was manufactured.

50.5 If the device is manufactured in more than one location, the finished device shall have a distinctive marking, which may be in code, to identify the product of a particular factory.

50.6 Except as indicated in 50.8, a device shall be marked ″Photovoltaic DC Arc-Fault Circuit-Interrupter″, ″Photovoltaic DC AFCI″, ″PV DC AFCI″, Photovoltaic DC Arc-Fault Detector″, ″Photovoltaic DC AFD″, ″PV DC AFD″, ″Photovoltaic DC Interrupting Device″, ″Photovoltaic DC ID″, or ″PV DC ID″ as applicable. The marking shall be located where visible while the device is installed. An AFCI or AFD device shall additionally be marked ″Type 1″ or ″Type 2″ as appropriate.

50.7 When a device is integrated into a product that performs another function, such as overcurrent protection, a disconnect, a combiner box, or other PV system function, the product shall be marked ″Photovoltaic DC Arc-Fault Circuit-Protection″ or equivalent, where visible while the device is installed. The marking shall also include ″Type 1″ or ″Type 2″ as appropriate.

50.8 A device may be marked ″Suitable for Use in Photovoltaic DC Systems in Accordance with Article 690 of the NEC″. The word ″photovoltaic″ may be abbreviated ″PV″.

50.9 A device provided with wiring terminals shall be marked with the wire size or wire range, the type and/or class of wire and the stranding if different from Class B concentric and compressed, or Class C concentric. A device may also be marked with metric sizes ″PV wire″ or ″photovoltaic wire″ and/or other class and strand configurations in accordance with 21.1.2.

50.10 A device provided with wiring terminals shall be marked with a range of values or a nominal value of tightening torque to be applied to the clamping screws of all terminal connectors for field wiring.

50.11 A device that is required to be mounted in a specific orientation shall be marked to identify that orientation.

50.12 Controls on a device such as those provided for Test and Reset of the device shall be identified.

INSTRUCTIONS

51 Operating and Installation Instructions

51.1 The operating and installation instructions of an AFCI, AFD or ID device shall include the following:

a) Manufacturer’s name and complete address;

b) Specific designation (such as “PV DC AFCI Type 1” or equivalent) and catalog number or other specific identification;

c) Intended conductor material, wire type, and wire size;

d) Intended mounting instructions;

e) Cable preparation (strip length, required slack, tools, and the like);

f) Torque rating;

g) Wiring instructions;

h) Correct operation and test instructions;

i) Annunciator instructions; and

j) For devices with remote components or remote access features, instructions for remote wiring and correct operation, including proper interfacing with remote components.

PART 3 - INVERTERS, CONVERTERS, AND CHARGE CONTROLLERS WITH INTEGRAL PHOTOVOLTAIC DC ARC-FAULT CIRCUIT INTERRUPTER PROTECTION

GENERAL

52 General

52.1 Inverters, converters, and charge controllers with integral photovoltaic dc arc-fault circuit protection shall comply with the requirements of the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741.

CONSTRUCTION

53 General

53.1 Inverters, converters, and charge controllers with integral photovoltaic dc arc-fault circuit interrupter protection shall comply with the construction requirements of the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741. In addition, they shall also comply with Part 1 and Sections 54 – 56 of this standard.

54 Alternate Spacings – Clearances and Creepage Distances

54.1 When applying the requirements of Alternate Spacings – Clearances and Creepage Distances section of the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741, pollution degree 2 also applies to a printed wiring board assembly when the printed wiring board is contained in a sealed housing that complies with the Dust Test, Section 48.

55 Annunciator

55.1 An inverter, converter, or charge controller shall be provided with an annunciator (local or remote) that provides a visual indication that the inverter, converter, or charge controller has detected an arc fault. This indication shall not reset automatically. This visual indication is not required when the PV power source is inactive, but must be present when PV power is sufficient to activate the inverter or charge controller in an ″off″ or stand-by state.

55.2 It shall be permissible for the indication to be manually reset by remote means.

56 Test Circuits

56.1 A device shall be provided with a manual test circuit complying with 56.2 – 56.4, or an automatic test feature complying with 56.5, or both.

56.2 A manual test circuit shall simulate an arc such that the arc detection circuit or software is caused to detect the simulated arc. The test circuit shall allow for periodic testing of the device by manual means that does not require the use of a tool.

56.3 Operation of the manual test circuit shall cause the inverter, converter, or charge controller to turn off or go to a stand-by state. The results of the test shall be made known to the user by a positive visual indication. This visual indication is not required when the PV power source is inactive, but must be present when PV power is sufficient to activate the inverter or charge controller in an ″off″ or stand-by state.

56.4 An inverter, converter, or charge controller may be provided with a means to actuate the manual test circuit remotely. If such a feature is provided, then the device shall include a remote visual indication of the results of the test and shall also provide means for remote manual reset.

56.5 An automatic self-test feature shall test the device each time the PV DC input is activated. Detection of a failure by the self-test circuit shall prevent actuation of the device and shall result in a visual indication of a failure. It shall be permissible for the device to include a remote visual indication of the results of the automatic test, if means is also provided for remote manual reset.

56.6 Any test circuit that employs a programmable circuit component shall comply with Section 14, Programmable Circuit Components.

PERFORMANCE

57 General

57.1 Inverters, converters, and charge controllers with integral photovoltaic dc arc-fault circuit protection shall comply with the performance requirements of the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741.

57.2 Inverters, converters and charge controllers with integral photovoltaic dc arc-fault circuit protection also shall comply with the applicable performance requirements of Part 2 of this Standard as modified or supplemented by the requirements of Sections 57 – 62. See Table 57.1.

57.3 When conducting tests in accordance with this Part, tests applicable to each intended power supply type as mentioned in Section 12, Power Supply, shall be conducted.

Table 57.1
Test sequence

Test name	Section	Conditioning/ environmental [a]	Overload/ endurance [b]	Other [c]
Humidity	27	X		
Leakage[d]	28	X		
Voltage surge[e]	29, 58	X		
Environmental sequence	30	X		
Arc fault detection	59	X		
Unwanted tripping	60			X
Inhibition	61			X
Normal Temperature	34			X
Overvoltage[d]	35[f]		X	
Overload	36[f]		X	
Endurance	37[f]		X	
Dielectric voltage withstand	38	X	X	X
Abnormal operations	39[f]			X
Short circuit	40[f]			X
Corrosion	41			X

Table 57.1 Continued on Next Page

Table 57.1 Continued

Test name	Section	Conditioning/ environmental [a]	Overload/ endurance [b]	Other [c]
Surge current[d]	42			X
Abnormal overvoltage[d]	43			X
Supplemental voltage surge[d]	44			X
Resistance to environmental noise	45			X
Electrostatic discharge	45.2			X
Radiated EMI	45.3			X
Fast transients[d]	45.4			X
Voltage surge[d]	45.5			X
Conducted EMI [e]	45.6			X
Voltage dips[d]	45.7			X
Strain relief	46			X
Mechanical	47			X
Dust	48			X

[a] The same representative device shall be subject to the tests in the sequence shown.

[b] A new representative device shall be subject to all of the tests in the sequence shown.

[c] These tests need not be conducted in the sequence shown and may be conducted on new representative devices, except when the dielectric voltage withstand is required as part of another test.

[d] Only applicable to devices with built-in power supplies deriving their power from a commercial light or power source (devices with AC input).

[e] Conducted at the DC input of all devices plus the AC input of devices with built-in power supplies deriving their power from a commercial light or power source (devices with AC input).

[f] Test may be conducted per Section 62, Overvoltage, Overload, Endurance, Abnormal Operations, and Short Circuit Tests.

58 Voltage Surge Test

58.1 Devices deriving their power from a photovoltaic DC source and intended for use in stand-alone (not grid-connected) power systems shall be subjected to the tests of 29.2 and 29.3 with the surges applied to the PV DC input of the device.

58.2 Devices deriving their power from a commercial light or power source and utility-interactive equipment shall be subjected to the surge tests described in the Standard for Interconnecting Distributed Resources With Electric Power Systems, IEEE 1547. The surges shall be applied to the AC input of the device.

58.3 In addition to the test of 58.2, devices deriving their power from a commercial light or power source and utility-interactive equipment shall also be subjected to the tests of 29.2 and 29.3 with the surges applied to the PV DC input of the device.

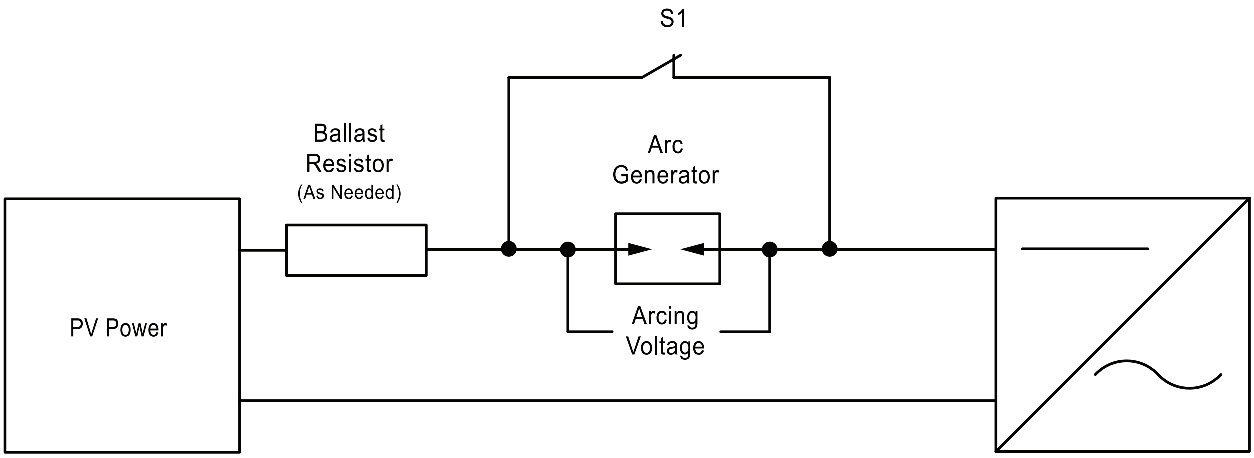
59 Arc Fault Detection Tests

59.1 Series connection arcing test

59.1.1 Except as described in 59.1.2 – 59.1.4, the series connection arcing test shall be conducted as described in 31.1.

59.1.2 When conducting the test, switch, S1, shown in Figure 31.3 for the arc generator test circuit is replaced with a shunting switch as shown in Figure 59.1 to bypass the arc generator and allow the inverter, converter, or charge controller to attain a proper ″on″ state condition before initiating the arc fault test. The arc generator shall be placed between the PV power source and the device under test. A ballasting resistor may be included in the circuit to limit the test current to the desired value.

Figure 59.1
Arc generator test circuit with inverter (converter or charge controller)



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59.1.3 When conducting the series connection arcing test, if stable arcs of 900 Watts are not possible due to the rating of the device, operation at the maximum wattage possible shall be conducted and the required trip time calculated from the formula in 31.1.1(e)(2). Electrode gap and arcing current may be adjusted to obtain the required operating point.

59.1.4 When conducting the series connection arcing test, the maximum power point tracking (MPPT) feature provided in the device may prevent the development of a stable arc. In this case, it shall be permissible to:

a) Increase the supply voltage; or

b) Increase the test current while reducing the arc gap; or

c) To modify the inverter MPPT operation so that a stable arc can be obtained for testing at the required operating points.

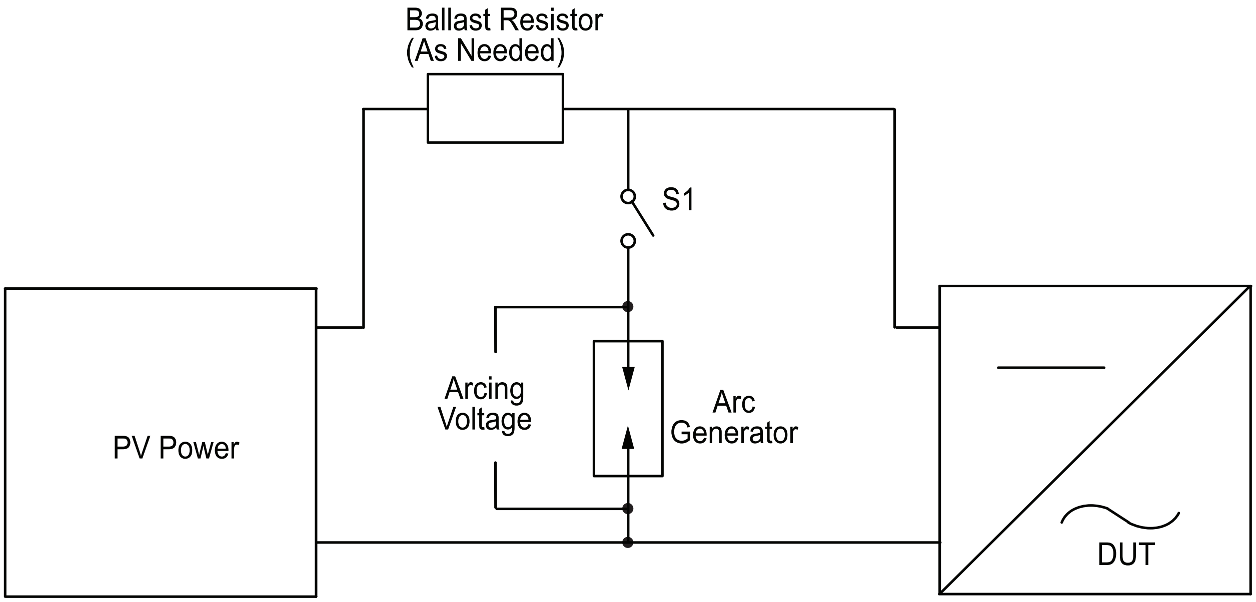
59.2 Parallel path arcing test

59.2.1 Except as described in 59.2.2 and 59.2.3, the parallel path arcing test shall be conducted as described in 31.2.

59.2.2 For the parallel path arcing test, the device under test, a ballast resistor, and arc generator are connected to a source of PV power, as described in 26.4,to achieve the desired circuit test arc voltage and arc current. The test current is to be obtained by adjustment of the ballast resistor. See Figure 59.2.

59.2.3 The switch, S1, and the arc generator shall be placed on the input side of the device under test, and in a parallel path between the positive and negative conductors of the PV power source as shown in Figure 59.2. With the electrode gap set to the desired separation and switch S1 open, the PV power is applied to the device under test and operation is allowed to stabilize. The test is to be initiated by closing the switch S1.

Figure 59.2
Parallel path arcing test circuit



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60 Unwanted Tripping Tests

60.1 General

60.1.1 A representative device of each rating shall not trip after being tested under each of the following loading and sourcing condition described in this Section. When tripping occurs, an additional five representative devices of the rating under test shall be tested and shall not trip.

60.2 Loading condition I – DC switch operation

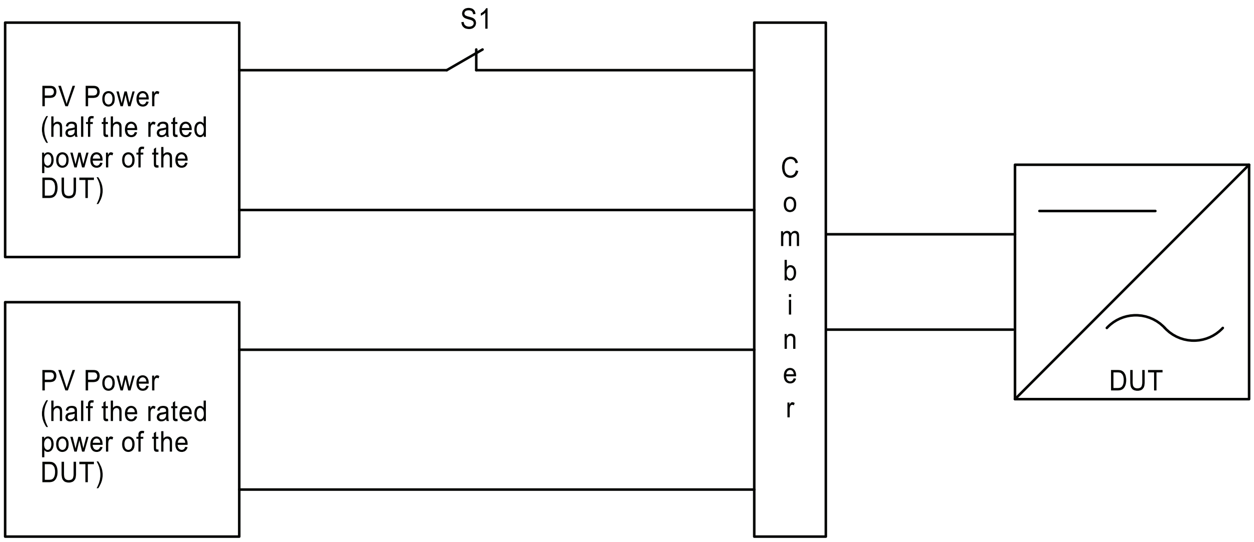
60.2.1 This test shall only be conducted on devices that derive their operating power from a commercial light or power source.

60.2.2 The device under test shall be installed as intended in a test circuit with a PV power source and a commercial light or power source. A DC disconnect switch shall be installed two feet from the device under test. With the PV power source operating in a manner to supply the rated power of the device under test, the disconnect switch shall be operated ″on″ and then after 30 seconds ″off″. This sequence shall be repeated three times, with the five minutes ″off″ time between each sequence.

60.3 Loading condition II – Irradiance step changes

60.3.1 The device under test shall be installed in a test circuit with a PV power source as shown in Figure 60.1. A mechanical disconnect switch shall be installed on one half of the PV strings connected to the inverter. With the PV power source operating in a manner to supply the rated power of the device under test, the disconnect switch attached to half the PV source circuits shall be operated “on” and then after 30 seconds, “off”. This sequence shall be repeated three times, with five minutes “off” time between each sequence. This test is not performed when the device under test is designed for operation with only a single PV module.

Figure 60.1
Irradiance step changes test circuit



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61 Operation Inhibition Tests

61.1 General

61.1.1 Except as indicated in 61.1.2 and 61.1.3, a device shall be tested under each of the conditions described in 61.2 and 61.3 using the series connection arcing test in accordance with 59.1.

61.1.2 These tests shall not be performed on a device:

a) Intended for installation directly on a PV panel; or

b) Intended for use with a single PV panel and intended to be installed such that the length of wiring between the PV panel and the device does not exceed 5 feet.

61.1.3 Except as indicated in 61.1.4 and 61.1.5, the device shall interrupt or detect the arcing as described in Table 31.2 for the conditions of 300 and 900 Watts.

61.1.4 When conducting the Operation Inhibition Tests, if stable arcs of 900 Watts are not possible due to the rating of the device, operation at the maximum wattage possible shall be conducted and the required trip time calculated from the formula in 31.1.1(e)(2). Electrode gap and arcing current may be adjusted to obtain the required operating point.

61.1.5 When conducting the Operation Inhibition Tests, the maximum power point tracking (MPPT) feature provided in the device may prevent the development of a stable arc. In this case, it shall be permissible to:

a) Increase the supply voltage; or

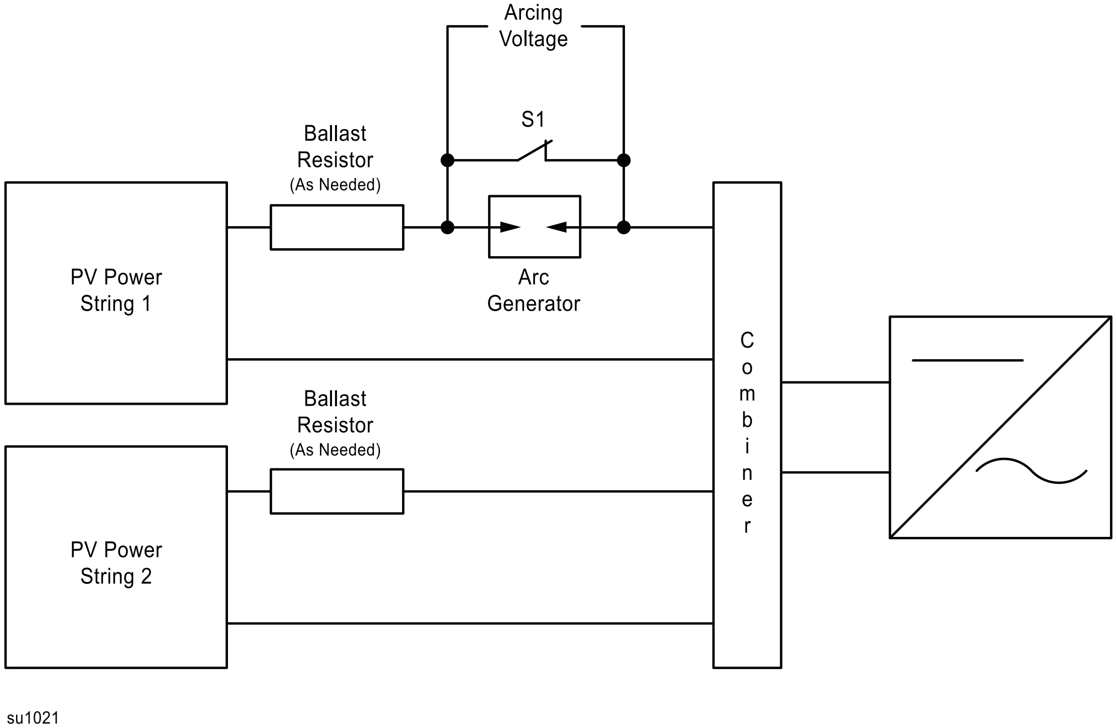
b) Increase the test current while reducing the arc gap; or

c) To modify the inverter MPPT operation so that a stable arc can be obtained for testing at the required operating points.

61.2 Masking the signal to operate – multiple strings

61.2.1 The device under test shall be installed in a test circuit with a PV power source as shown in Figure 61.1. The test shall be conducted with PV string 1, while PV string 2 is combined with PV string 1. PV string 2 shall have the same power as PV string 1.

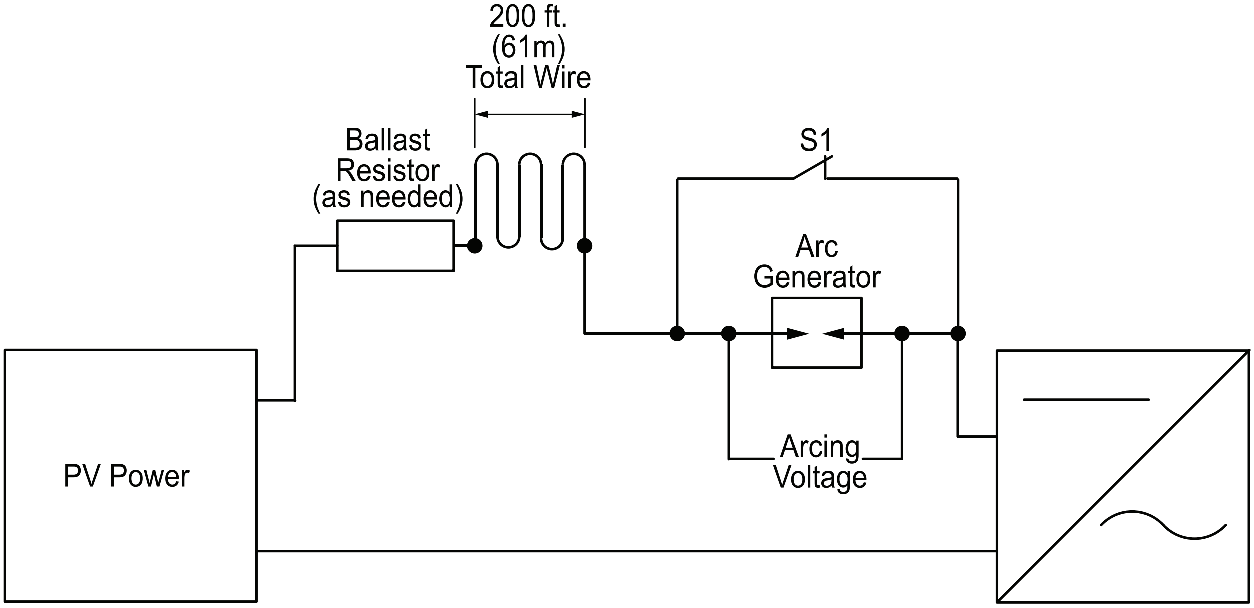
Figure 61.1
Masking test with arcing and multiple strings



61.3 Line impedance

61.3.1 The device under test shall be tested in accordance with 59.1 for the series connection arcing test, with the exception that the length of the conductor shown in Figure 59.1 shall be a minimum of 200 ft. of rated wire between the ballast resistor and the switch S1. The 200 ft. of wire shall be arranged with five 180 degree bends of six inch radius. See Figure 61.2.

Figure 61.2
Arcing test with line impedance



62 Overvoltage, Overload, Endurance, Abnormal Operations, and Short Circuit Tests

62.1 Switching devices in the power conversion circuits of inverters, converters, and charge controllers that are subjected to the Abnormal Tests, as applicable, of the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741 need not be subjected to the Overvoltage, Overload, Endurance, Abnormal Operations , and Short Circuit Tests from Table 57.1, provided that after the Abnormal Tests of UL 1741 each representative device complies with 15.2.1 and the applicable tests of Section 59, Arc Fault Detection Tests. See 62.2.

62.2 When applying the requirements of 62.1, the applicable tests of Section 59, Arc Fault Detection Tests, shall not be conducted after an Abnormal Test if all of the following conditions are met:

a) The sample is no longer functional, that is, has no inverter output; and

b) The sample provides an indication to the user that it has failed.

62.3 Except as indicated in 62.4, when conducting the applicable tests of Section 59, Arc Fault Detection Tests, the device shall interrupt the arcing as described in Table 31.2 for the conditions of 300 Watts and 900 Watts while at room ambient.

62.4 When conducting the applicable tests of Section 59, if stable arcs of 900 Watts are not possible due to the rating of the device, operation at the maximum wattage possible shall be conducted and the required trip time calculated from the formula in 31.1.1(e)(2). Electrode gap and arcing current may be adjusted to obtain the required operating point.

62.5 Redundant interrupting or shunting contact devices that supplement power conversion circuits of inverters, converters, and charge controllers that do not operate as part of the power conversion electronics shall be subjected to the Overvoltage, Overload, Endurance, and Short Circuit tests from Table 57.1.

MARKINGS

63 General

63.1 An inverter, converter, or charge controller shall comply with the marking requirements of the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741 and 63.2 – 63.4 of this Standard.

63.2 A device shall be marked ″Photovoltaic DC Arc-Fault Circuit-Protection″ or equivalent, where visible while the device is installed and shall also be marked ″Type 1″ or ″Type 2″ as appropriate.

63.3 A device that is required to be mounted in a specific orientation shall be marked to identify that orientation.

63.4 Controls on a device such as those provided for Test and Reset of the device shall be identified.

INSTRUCTIONS

64 Operating and Installation Instructions

64.1 An inverter, converter, or charge controller shall comply with the operating and installation instruction requirements of the Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources, UL 1741 and 64.2 of this Standard.

64.2 The operating and installation instructions of a device shall include the following:

a) Manufacturer’s name and complete address;

b) Specific designation (such as “Photovoltaic DC Arc-Fault Circuit-Protection Type 1” or equivalent) and catalog number or other specific identification;

c) Correct operation and test instructions;

d) Annunciator instructions; and

e) For devices with remote components or remote access features, instructions for remote wiring and correct operation, including proper interfacing with remote components.

APPENDIX A

Standards for Component

Standards under which components of the products covered by this standard are evaluated include the following:

Title of Standard − UL Standard Designation

Appliance Wiring Material – UL 758
Attachment Plugs and Receptacles – UL 498
Capacitors – UL 810
Capacitors and Suppressors for Radio- and Television-Type Appliances – UL 1414
Circuit Breakers, Molded-Case; Molded-Case Switches and Circuit-Breaker Enclosures – UL 489
Cord Sets and Power-Supply Cords – UL 817
Electromagnetic Interference Filters – UL 1283
Enclosures for Electrical Equipment – UL 50
Equipment Wiring Terminals for Use With Aluminum and/or Copper Conductors – UL 486E
Filter Units, Air – UL 900
Fittings, Conduit, Tubing, and Cable – UL 514B
Flexible Cords and Cables – UL 62
Fuseholders – Part 1: General Requirements – UL 4248-1
Fuseholders – Part 4: Class CC – UL 4248-4
Fuseholders – Part 5: Class G – UL 4248-5
Fuseholders – Part 6: Class H – UL 4248-6
Fuseholders – Part 8: Class J – UL 4248-8
Fuseholders – Part 9: Class K – UL 4248-9
Fuseholders – Part 11: Type C (Edison Base) and Type S Plug Fuse – UL 4248-11
Fuseholders – Part 12: Class R – UL 4248-12
Fuseholders – Part 15: Class T – UL 4248-15
Fuses, Low-Voltage – Part 1: General Requirements – UL 248-1
Fuses, Low-Voltage – Part 6: Class H Non-Renewable Fuses – UL 248-6
Fuses, Low-Voltage – Part 7: Class H Renewable Fuses – UL 248-7
Fuses, Low-Voltage – Part 9: Class K Fuses – UL 248-9
Fuses, Low-Voltage – Part 11: Plug Fuses – UL 248-11
Fuses, Low-Voltage – Part 12: Class R Fuses – UL 248-12
Fuses, Low-Voltage – Part 14: Supplemental Fuses – UL 248-14
Fuses, Low-Voltage – Part 15: Class T Fuses – UL 248-15
Ground-Fault Circuit Interrupters – UL 943
Ground-Fault Sensing and Relaying Equipment – UL 1053
Industrial Control Equipment – UL 508
Insulating Materials, Systems of – General – UL 1446
Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment – UL 840
Lampholders – UL 496
Marking and Labeling Systems – UL 969
Optical Isolators – UL 1577
Outlet Boxes, Flush-Device Boxes and Covers, Nonmetallic – UL 514C
Outlet Boxes, Metallic – UL 514A
Plastic Materials for Parts in Devices and Appliances, Tests for Flammability of – UL 94
Polymeric Materials – Fabricated Parts – UL 746D
Polymeric Materials – Long Term Property Evaluations – UL 746B

Polymeric Materials – Short Term Property Evaluations – UL 746A
Polymeric Materials – Use in Electrical Equipment Evaluations – UL 746C
Printed-Wiring Boards – UL 796
Protectors, Supplementary, for Use in Electrical Equipment – UL 1077
Software in Programmable Components – UL 1998
Surge Protective Devices – UL 1449
Switches, Special-Use – UL 1054 or
Switches for Appliances – Part 1: General Requirements – UL 61058-1
Switchgear and Controlgear, Low-Voltage – Part 1: General Rules – UL 60947-1
Switchgear and Controlgear, Low-Voltage – Part 4-1: Contactors and Motor-Starters – Electromechanical Contactors and Motor-Starters – UL 60947-4-1A
Switchgear and Controlgear, Low-Voltage – Part 5-2: Control Circuit Devices and Switching Elements – Proximity Switches – UL 60947-5-2
Tape, Polyvinyl Chloride, Polyethylene, and Rubber Insulating – UL 510
Terminal Blocks – UL 1059
Terminals, Electrical Quick-Connect – UL 310
Tests for Safety-Related Controls Employing Solid-State Devices – UL 991
Tests for Sharpness of Edges on Equipment – UL 1439
Thermal-Links – Requirements and Application Guide – UL 60691
Transformers, Low Voltage – Part 1: General Requirements – UL 5085-1
Transformers, Low Voltage – Part 2: General Purpose Transformers – UL 5085-2
Transformers, Low Voltage – Part 3: Class 2 and Class 3 Transformers – UL 5085-3
Transformers, Specialty – UL 506
Wire Connectors – UL 486A-486B
Wires and Cables, Thermoplastic-Insulated – UL 83

APPENDIX B

Manufacturing and Production Line Tests

B1 General

B1.1 Manufacturing and production line tests shall be performed on the products covered by this Standard in accordance with Sections B2 and B3.

B1.2 The testing and measuring equipment used in the manufacturing and production line tests shall be established with the agreement of all concerned parties.

B1.3 The manufacturer shall maintain a program to assure that testing and measuring equipment used in manufacturing and production line tests is clean, is maintained in proper working order, and is in calibration.

B2 Manufacturer’s Production Line Test Program

B2.1 The test program described in B2.2 and B2.3 shall be conducted on 100 percent of production of finished products covered by this Standard.

B2.2 Each finished product shall be subjected to one or more performance tests as described in the manufacturer’s Proprietary Inspection Program (PIP) of Section B3. The Manufacturer’s Production Line Test Program shall verify that the performance of each device is within specified tolerances.

B2.3 The Manufacturer’s Production Line Test Program shall be established with the agreement of all concerned parties.

B3 Manufacturer’s Proprietary Inspection Program (PIP)

B3.1 The manufacturer shall conduct a proprietary inspection program (PIP) on finished products covered by this Standard. The PIP shall describe the tests conducted, the frequency (100% or sampled) and the test equipment employed by the manufacturer to conduct those tests.

B3.2 As a minimum, the PIP shall include the Manufacturer’s Production Line Test Program on 100% of production as described in B2. The PIP shall describe the Manufacturer’s Production Line Test Program and any additional tests the manufacturer deems appropriate to ensure that a fully compliant product is consistently produced. The additional tests may be conducted on a sampling basis.

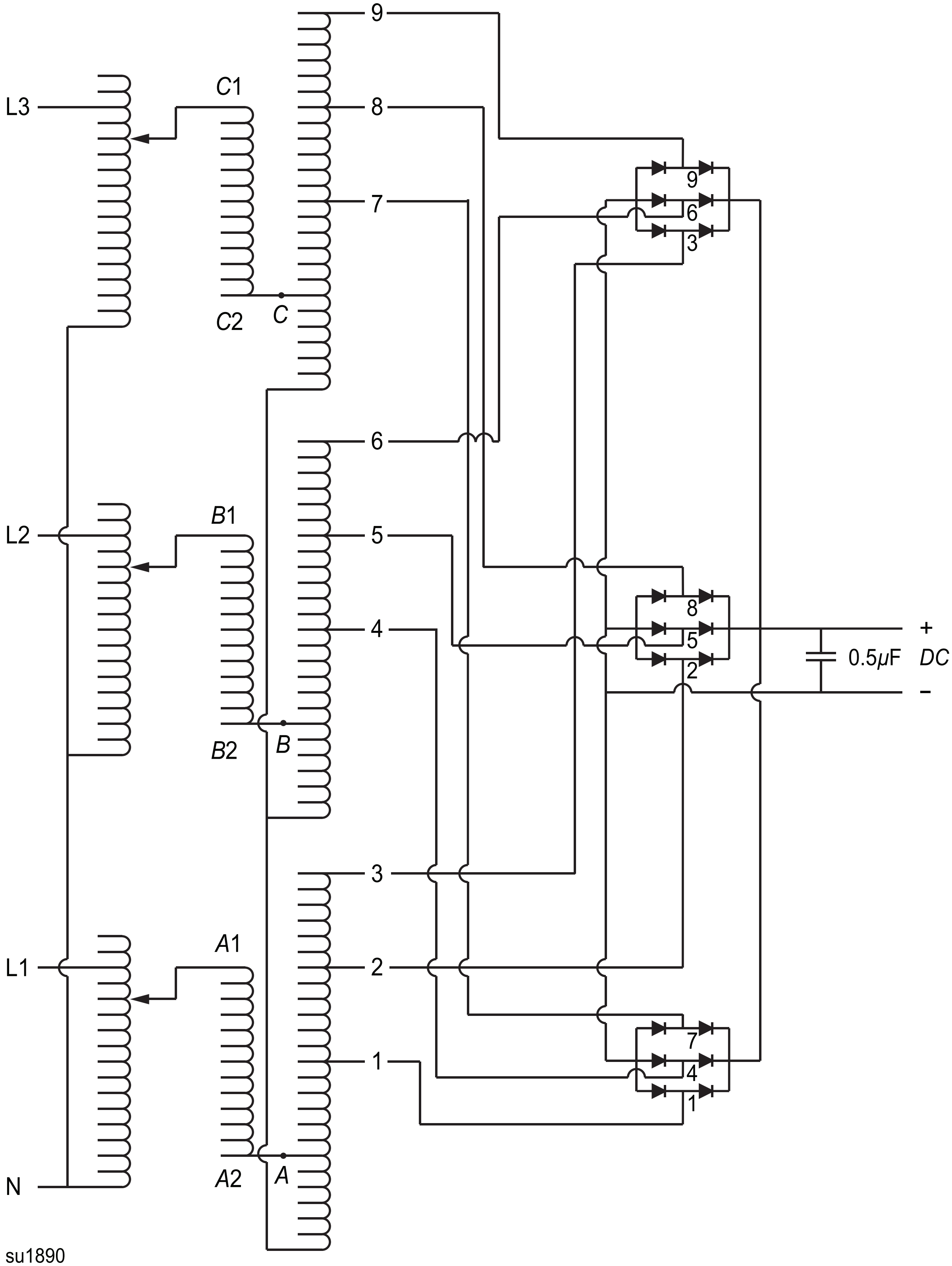
B3.3 The Manufacturer’s Proprietary Inspection Program shall be established with the agreement of all concerned parties.

APPENDIX C (Informative)

Example of Simulated PV DC Power Source

An example of an 18-pulse auto-transformer rectifier is shown in Figure C1.1. The input is 480 volts, three-phase, 60 Hz. The output is 247 volts, nine-phase, 60 Hz. The output is connected to three (3) three-phase rectifier bridges as shown. A 0.5 uF capacitor is connected across the DC output to reduce the AC ripple. The ± DC output is used as a simulated PV DC power source as indicated in 26.4.

Figure C1.1
18-pulse auto-transformer rectifier



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