UL 1699B

STANDARD FOR SAFETY

Photovoltaic (PV) DC Arc-Fault Circuit Protection

UL Standard for Safety for Photovoltaic (PV) DC Arc-Fault Circuit Protection, UL 1699B

First Edition, Dated August 22, 2018

Summary of Topics

This revision of ANSI/UL 1699B dated July 9, 2024 includes the following changes in requirements:

– Allowance of alternative test method according to an IEC standard; 38.1 and 38.4

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

The revised requirements are substantially in accordance with Proposal(s) on this subject dated May 31, 2024.

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Standard for Photovoltaic (PV) DC Arc-Fault Circuit Protection

First Edition

August 22, 2018

This ANSI/UL Standard for Safety consists of the First Edition including revisions through July 9, 2024.

The most recent designation of ANSI/UL 1699B as an American National Standard (ANSI) occurred on July 9, 2024. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

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

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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 1500 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 FUNCTIONAL INSULATION – Insulation that is necessary only for the functioning of the equipment.

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

2.11 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.

2.12 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 2.18.

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

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

2.15 PHOTOVOLTAIC (PV) DC ARC-FAULT CIRCUIT-INTERRUPTER (PV AFCI) – A device that is intended to be installed in a 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 protection to the PV system from unwanted effects of arcing.

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

2.17 PHOTOVOLTAIC (PV) DC INTERRUPTING DEVICE (PV ID) – A device that is intended for installation in a 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.

2.18 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 2.12 are examples of programmable components.

2.19 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.

2.20 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.

2.21 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.

2.22 TYPE 1 DEVICE – A photovoltaic device that is intended to detect or interrupt series 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 7 – 14 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 38.

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 Power Supply

11.1 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.

11.2 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 11.1 shall be conducted.

12 Operating Mechanism

12.1 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 Programmable Circuit Components

13.1 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 13.2 – 13.9. As an alternative to UL 1998 and the requirements as defined in 13.2 – 13.9, the Standard for Automatic Electrical Controls – Part 1: General Requirements, UL 60730-1, Annex H, or Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems, IEC 61508, may be used to evaluate functional safety. IEC 61508 evaluations shall be SIL2 or higher.

13.2 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 13.1, except as modified by 13.3 – 13.9.

13.3 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.

13.4 The Tool Qualification requirements from UL 1998 are modified in 13.5 and 13.6.

13.5 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".

13.6 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.

13.7 Means shall be employed to address all microelectronic hardware failure modes identified in the Risk Analysis of 13.3. 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.

13.8 One approach to comply with 13.7 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.

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

14 Electronic Interruption

14.1 General

14.1.1 Solid state components used in place of air gap contacts to interrupt or shunt an arc fault shall comply with 14.2 – 14.4 as applicable.

14.2 "Off" state or stand-by mode current

14.2.1 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.

14.3 Reliability

14.3.1 Except as indicated in 14.3.2, 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.

14.3.2 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.

14.3.3 When the Standard for Automatic Electrical Controls – Part 1: General Requirements, UL 60730-1, Annex H, or Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems, IEC 61508, are used as an alternative to UL 1998 in order to determine compliance with the requirements as defined in Programmable Circuit Components, Section 13, these standards may be used to evaluate the hardware requirements of UL 991.

14.4 Programmable circuit components

14.4.1 If a device employs a programmable circuit component such as a microprocessor to implement the test circuit function mentioned above in 14.3.2, that portion of the circuit shall be investigated in accordance with Programmable Circuit Components, Section 13.

MANUFACTURING AND PRODUCTION LINE TESTS

15 General

15.1 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

16 General

16.1 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 17 – 23.

17 Accessibility of Energized Parts

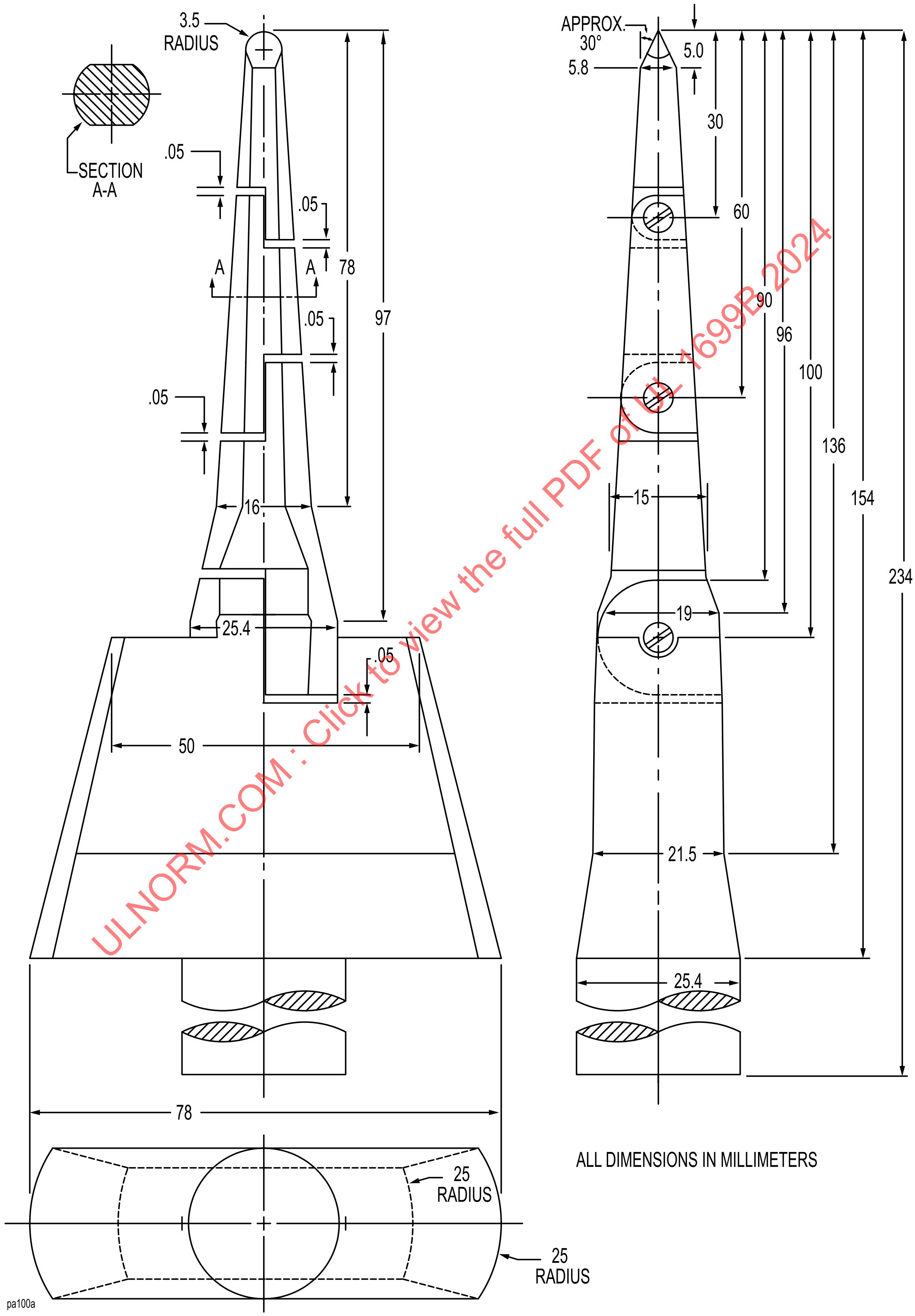
17.1 Parts of a device shall not be accessible when they are installed as intended and energized.

17.2 Parts are considered to be accessible if they can be touched using the articulated probe shown in Figure 17.1.

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

Figure 17.1

Articulated probe



18 Spacings

18.1 Except as indicated in 18.2, a device shall comply with the requirements shown in Table 18.1.

Table 18.1
Spacing in mm (inches)[a,b]

Operating potential between parts							
0 – 200 V peak		201 – 400 V peak		401 – 1000 V peak		1001 – 1500 V peak	
Through air	Over surface	Through air	Over surface	Through air	Over surface	Through air	Over surface
3.2 (1/8)	6.4 (1/4)	6.4 (1/4)	9.5 (3/8)	9.5 (3/8)	12.7 (1/2)	17.8 (0.70)	30.5 (1.20)

[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 0.8 mm (1/32 inch), 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.

18.2 At field-wiring terminals, the spacings between terminals with a potential difference between them shall be not less than 6.4 mm (1/4 inch) for devices rated 200 V and less, not less than 9.5 mm (3/8 inch) for devices rated 201 – 400 V, not less than 12.7 mm (1/2 inch) for devices rated 401 – 1000 V, and not less than 30.5 mm (1.20 inch) for devices rated over 1000V.

18.3 Except as permitted in Note a of Table 18.1, if a groove or a slot in insulating material is less than 0.4 mm (1/64 inch) wide, the contour of the slot or groove is to be disregarded in measuring spacings over the surface.

18.4 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.

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

18.6 As an alternative to the requirements specified in 18.1 – 18.5, 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 18.7 – 18.9 using the applicable requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840.

18.7 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 45, or

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

18.8 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.

18.9 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.

18.10 As an alternative to the requirements specified in this Section, Creepage and Clearance requirements may be evaluated in accordance with Tables 13 and 14 of the Standard for Power Converters for use in Photovoltaic Power Systems – Part 1: General Requirements, UL 62109-1.

19 Terminals

19.1 General

19.1.1 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 19.2, 19.3, or 19.4 as applicable.

19.1.2 A device may also be evaluated for use with PV wire, or other class and strand configurations as indicated by marking. See 47.9.

19.2 Terminal leads

19.2.1 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.

19.2.2 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.

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

19.2.4 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 44.

19.3 Wire binding screw terminals

19.3.1 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.

19.3.2 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). A minimum of two threads shall be engaged.

19.3.3 A terminal plate tapped for a wire binding screw shall be of metal not less than 1.27 mm (0.05 inch) 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 0.76 mm (0.03 inch) thick shall be permitted if the tapped threads have the necessary mechanical strength.

19.3.4 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.

19.4 Pressure wire terminals

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

19.4.2 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 44. Torque values shall be permitted to be less than 90 percent if the connector is investigated in accordance with the lesser assigned torque value.

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

20 Enclosure

20.1 When a device is provided with its own enclosure, the enclosure shall comply with the requirements in the Standard for Enclosures for Electrical Equipment, Non-Environmental Considerations, UL 50, and the applicable enclosure requirements for the intended environment in the Standard for Enclosures for Electrical Equipment, Environmental Considerations, UL 50E.

21 Grounding

21.1 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.

21.2 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.

22 Annunciator

22.1 A PV AFCI or AFD device exceeding the limits of region A as defined in Figure 29.9 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 after exceeding the limits defined in 29.1.8.

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

23 Test Circuits or Methods

23.1 A PV AFCI or AFD device shall be provided with a manual or automatic test circuit or method complying with 23.2 – 23.7.

23.2 The arc detection circuit or software shall be tested by simulating an arc or by other means that offer equivalent levels of protection. Equivalent methods or means shall be agreed upon by all concerned parties and documented in the test results. The manual test circuit or method shall allow for periodic testing of the device by manual means that does not require the use of a tool.

23.3 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.

23.4 Failure of a manual or automatic test 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.

23.5 A device may be provided with a means to actuate the 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.

23.6 An automatic self-test feature shall test the device each time prior to supplying current from the PVDC circuit.

23.7 Any test circuit or method that employs a programmable circuit component shall comply with Section 13, Programmable Circuit Components.

PERFORMANCE

24 General

24.1 A PV AFCI, AFD or ID device shall comply with the applicable performance requirements in Sections 25 – 45, as detailed in Table 24.1.

Table 24.1
Test sequence

Test name	Section	Conditioning / environmental[a]	Overload / endurance[b]	Other[c]
Humidity	25	X		
Leakage[d]	26	X		
Voltage surge[e]	27	X		
Environmental sequence	28	X		
Arc fault detection	29	X		
Unwanted tripping	30			X
Normal Temperature	31			X
Overvoltage[d]	32		X	

Table 24.1 Continued on Next Page

Table 24.1 Continued

Test name	Section	Conditioning / environmental[a]	Overload / endurance[b]	Other[c]
Overload	33		X	
Endurance	34		X	
Dielectric voltage withstand	35	X	X	
Abnormal Operations	36			X
Short circuit	37			X
Corrosion	38			X
Surge current[d]	39			X
Abnormal overvoltage[d]	40			X
Supplemental voltage surge[d]	41			X
Resistance to environmental noise	42			X
Electrostatic discharge	42.2			X
Radiated EMI	42.3			X
Fast transients[d]	42.4			X
Voltage surge immunity[d]	42.5			X
Conducted EMI[e]	42.6			X
Voltage dips[d]	42.7			X
Strain relief	43			X
Mechanical	44			X
Dust	45			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).

24.2 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.

24.3 When conducting tests in accordance with this Part, tests applicable to each intended power supply type as mentioned in 11.1 shall be conducted.

24.4 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 (or Solar Array/PV Simulator) having characteristics similar to a PV array. 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. When using an actual PV array or Solar Array/PV simulator, the following optional changes can be made according to the values in Table 29.3 and Table 30.1:

a) The impedance of the actual interconnection conductors shall be verified and the values for the Line Impedance model (L4, L5, R3, R4) may be altered to adjust for the measured conductor values. The total impedance shall not exceed the values specified in Table 29.3 and Table 30.1.

b) The DC source resistance (R1, R2) of the decoupling network may be removed.

24.5 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 within 10 percent of the rated voltage of the device being tested but less than the rating of the device, and

b) The total current capability of the PV supplies shall be at least 125 percent of the maximum DC source short circuit current rating of the DUT.

Note: If actual PV modules are used, it may be necessary to parallel two or more strings.

c) Power may be limited by the DC source or the inverter.

25 Humidity Conditioning

25.1 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.

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

26 Leakage Current Measurement

26.1 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 26.2 – 26.6.

26.2 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.

26.3 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.

26.4 The measurement circuit for leakage current of a cord connected device is to be as shown in Figure 26.1 and Figure 26.2. 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.

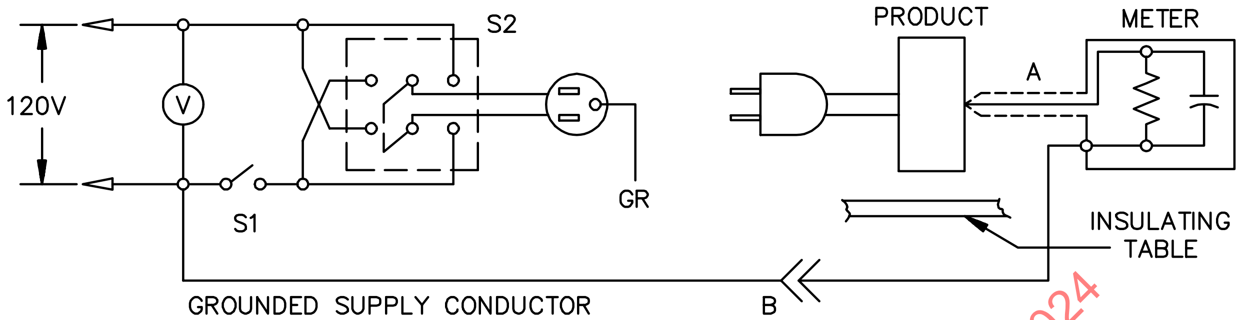
b) The meter is to indicate 1.11 times the average of the full-wave rectified composite waveform of voltage across the resistance or current through the resistance.

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 26.1

Leakage-current measurement circuit



LC100

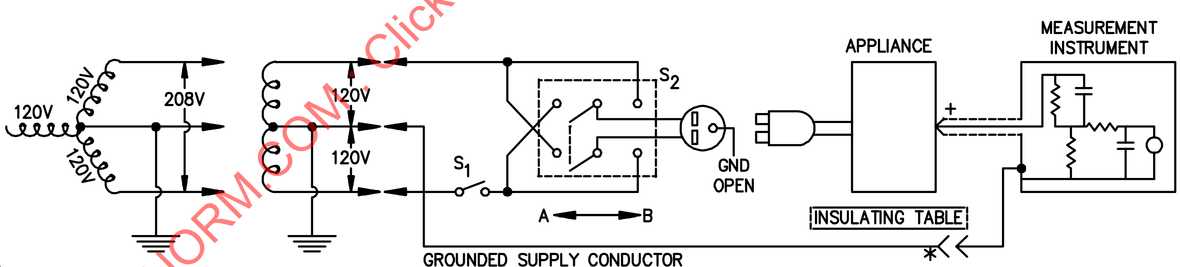
NOTES:

A – Probe with shielded lead.

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

Figure 26.2

Leakage current measurement circuit used for grounded or ungrounded 208 Vrms or 240 Vrms devices intended for connection to 3-wire neutral grounded circuits



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NOTES:

1) * Separated and used as clip when measuring currents from one part of the device to another.

2) + Probe with shielded lead.

3) All voltages shown in Figure 26.2 are nominal.

4) When it is not feasible to isolate the device from ground, the supply circuit shall be isolated from ground. It is possible that it will also be necessary to reverse the leads of the measurement instrument.

26.5 An AFCI that is deriving its power from the utility 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.

26.6 A representative device is to be tested for leakage current after the conditioning described in Humidity Conditioning, Section 25. 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 26.1, 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.

27 Voltage Surge Test

27.1 General

27.1.1 Devices deriving their power from a commercial light or power source shall be subjected to the tests described in 27.2 and 27.3. The surges shall be applied to the AC input of the device.

27.1.2 In addition to the tests of 27.1.1, devices deriving their power from a commercial light or power source shall also be subjected to the tests described in 27.2 and 27.3 with the surges applied to the PV DC input of the device.

27.1.3 Devices deriving their power from a photovoltaic DC source shall be subjected to the tests described in 27.2 and 27.3 with the surges applied to the PV DC input of the device.

27.1.4 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.

27.2 Unwanted tripping test (Ring wave)

27.2.1 A representative device shall not trip when subjected to the surges described in 27.2.2 – 27.2.5.

Note: For devices deriving their power from a photovoltaic DC source, this is a pre-conditioning test only.

27.2.2 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 or method.

27.2.3 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.

27.2.4 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.

Exception: Devices solely intended for use with ungrounded PV arrays are not required to be tested with surges applied between any of their PV inputs and ground.

27.2.5 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.

27.3 Surge immunity test (Combination wave)

27.3.1 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 17.

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

27.3.3 Following the application of the Surge Immunity (Combination Wave) surges, the device shall be in a condition to continue the test sequence in Table 24.1. Functionality of the device shall be verified by connecting it to an appropriate power source and actuating the supervisory circuit.

27.3.4 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 27.3.5, the surges shall be applied at phase angles of 90 and 270 electrical degrees.

27.3.5 For devices deriving their power from a photovoltaic DC source, the tests shall be conducted in accordance with Table 27.1 and Table 27.2.

Exception: Devices solely intended for use with ungrounded PV arrays are not required to be tested with surges applied between any of their PV inputs and ground.

27.3.6 For all other devices, the surge impulse test levels in Table 27.3 shall be used.

Table 27.1
PV input surge requirements

Surge type	Surge/impulse voltage	Surge test resistance	Number of impulses per polarity	Surge polarity for each test point
Combination wave (1.2/50 μsec)	Table 27.2	12 ohms	10	Negative
			10	Positive

Table 27.2
Surge values

Maximum dc input rating of equipment	Test Surge/impulse voltage
71 Vdc	500 V
141 Vdc	800 V
213 Vdc	1500 V
424 Vdc	2500 V
849 Vdc	4000 V
1500 Vdc	6000 V
Note: Interpolation is permitted	

Table 27.3
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.	

28 Environmental Test Sequence

28.1 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 29, 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 65°C (149°F), −35°C (−31°F), and 25°C (77°F) by following the sequence shown in Table 28.1.

Exception: Where the temperatures specified exceed or fall below the manufacturer's rated operating temperature, the device shall be tested at its specified operating temperature limit.

Table 28.1
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 29.1 as soon as possible to minimize self-heating.
3. [b]	65.0 ±2.0°C (149.0 ±3.6°F)	Rated voltage and current	Establish thermal equilibrium with at least two hours of exposure. Do not test.
4.[b]	65.0 ±2.0°C (149.0 ±3.6°F)	Rated voltage	Test per 29.1.
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 29.1.
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 29.1 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 29.1.

[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.

28.2 Before starting the test sequence in Table 28.1, 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 28.1 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.

28.3 All tests in step 1 of Table 24.1 shall be performed at 25°C ambient. For all other temperatures (steps) in the environmental sequence, it is permissible to choose only that test condition from Table 29.2 that dissipated the most arcing energy before the AFCI tripped at ambient temperature.

29 Arc Fault Detection Tests

29.1 General

29.1.1 The use cases described in Table 29.1 shall be identified and the DUT shall be tested per each use case as applicable. See Figure 29.2 – Figure 29.8A for typical examples of the use cases described in Table 29.1. The test set-ups shall use the component values shown in Table 29.3. Sections 29.2 – 29.7 include circuit requirements for the use cases. Figure 29.1 includes a legend applicable to all of the Figures in this Section and Unwanted Tripping Tests, Section 30.

Table 29.1
Use cases

Use cases	Description	Figure No.
1	DUT within the Inverter	Figure 29.2, Figure 29.3, Figure 29.8A
2	DUT embedded in Combiner Box	Figure 29.4
3	External DUT	Figure 29.2, Figure 29.3, or Figure 29.4 as appropriate
4	DC-DC converter based systems	Figure 29.5, Figure 29.6
5	DUT within the Inverter with integrated combiner box	Figure 29.4

Figure 29.1

Legend

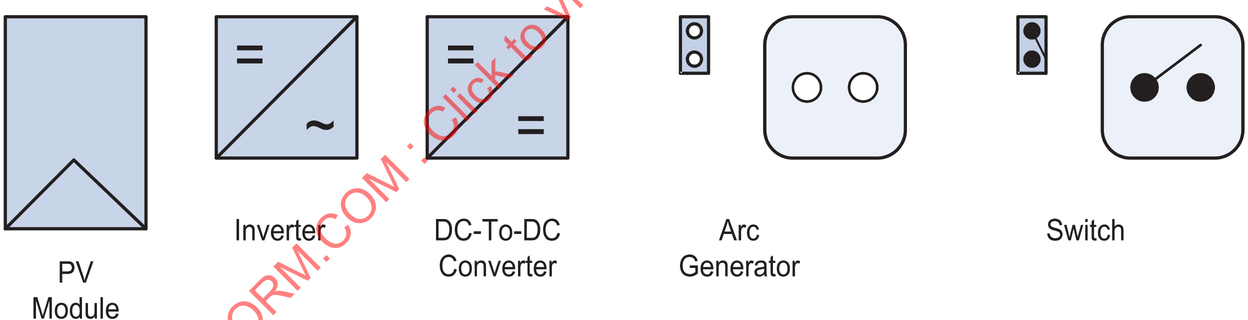

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Figure 29.2

One string, one MPPT

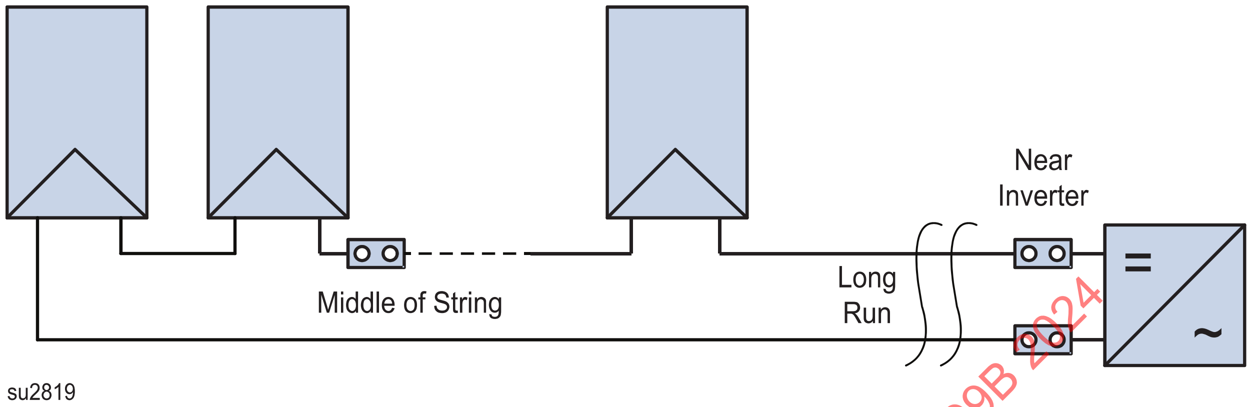

Figure 29.3

Two strings combined, one MPPT

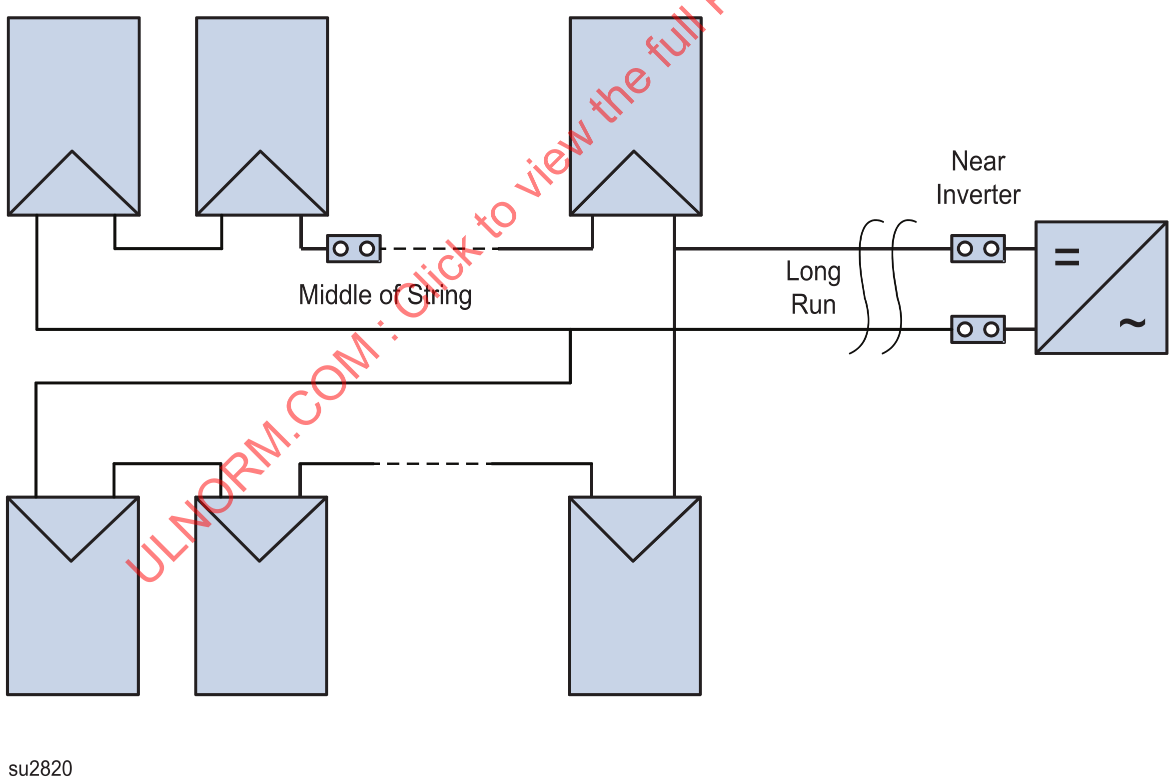

Figure 29.4

Combiner

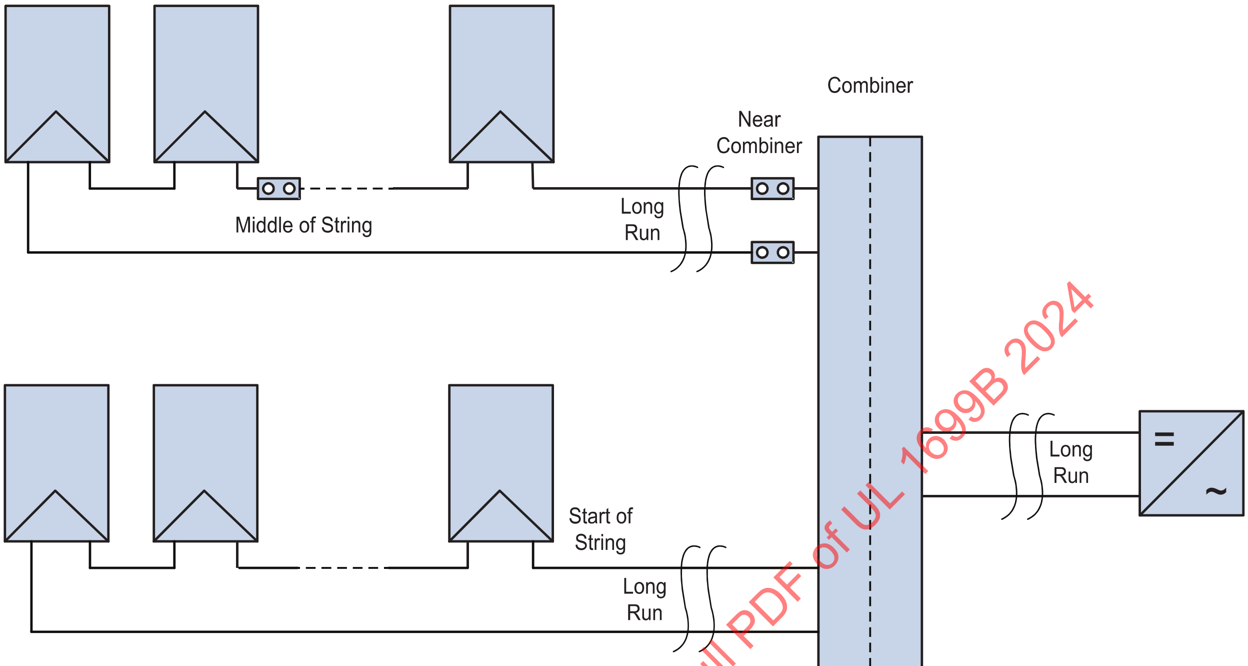

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Figure 29.5

DC-DC converter

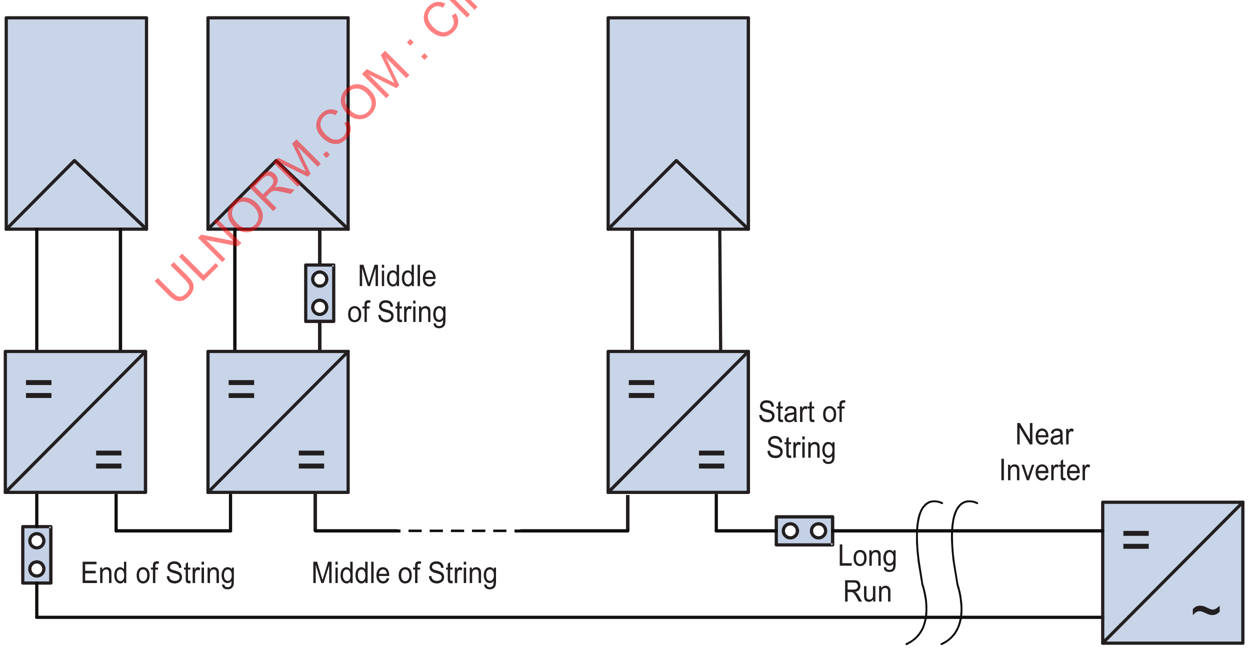

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Figure 29.6

DC-DC converter with two module input

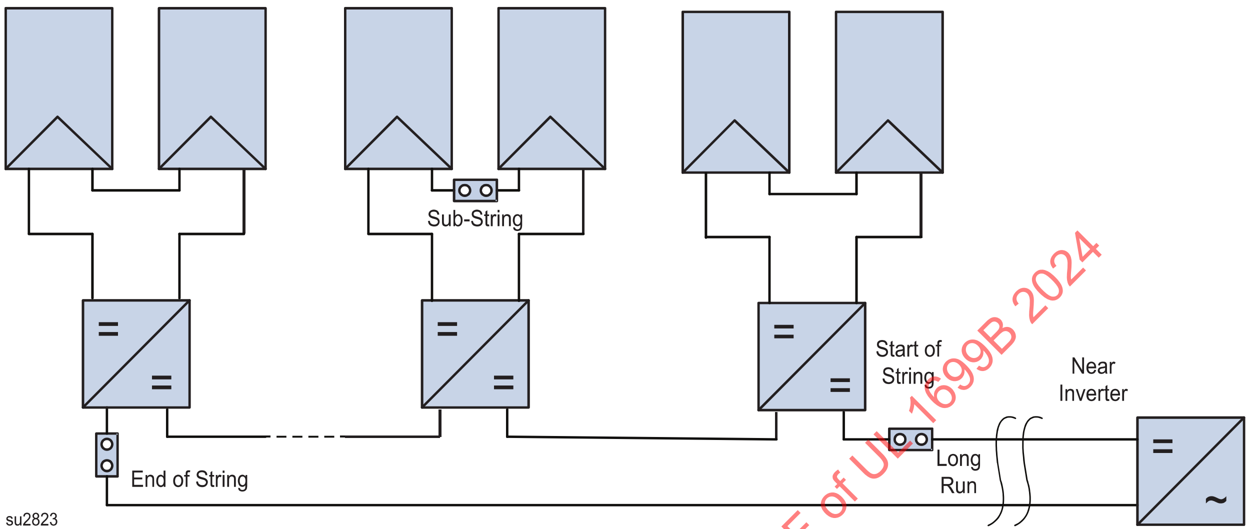

Figure 29.7

Microinverter with single module

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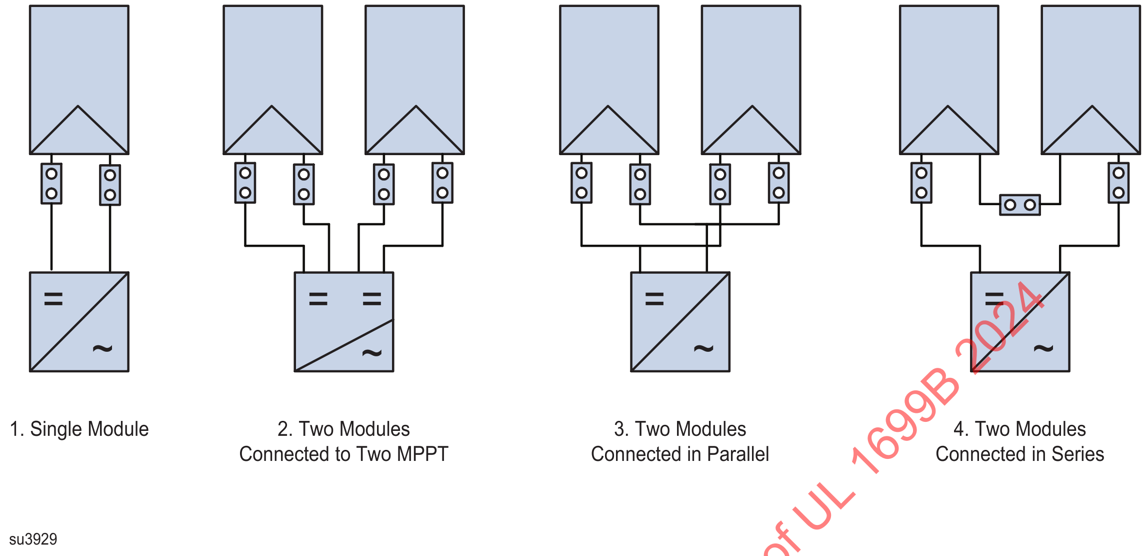
Figure 29.8

Microinverter with two modules

Figure deleted

Figure 29.8A

Electronic device with one or two modules



NOTES:

1. The arc locations shown in Figure 29.2 – Figure 29.8A are considered to be the worst case locations to verify the ability of the AFCI to detect an arc. This should be confirmed, and if a different worst case location in the circuit can be identified, it should also be included in the test sequence.

2. If multiple configurations are possible, refer to 29.1.3(c) exception.

29.1.2 An arc-fault circuit-interrupter shall be capable of detecting or interrupting arcing as described in the following and illustrated in Figure 29.9:

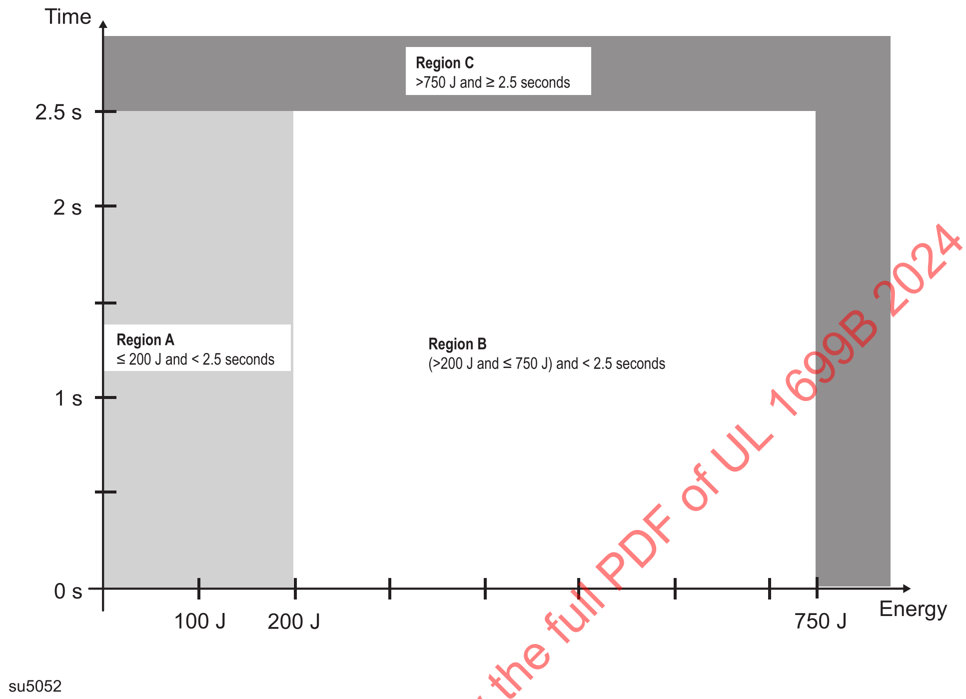
a) Region A: For all tests, disrupt arcing event in less than 2.5 seconds, and limit energy not to exceed 200 J;

b) Region B: For all tests, disrupt arcing event in less than 2.5 seconds, and limit energy that exceeds 200 J to not more than 750 J; and

c) Region C: For any test, arcing time equal to or greater than 2.5 seconds, or energy greater than 750 J, the device is considered non-compliant with the standard.

Figure 29.9

Arc energy regions



29.1.3 The series connection arcing test shall be conducted as follows:

a) An arc generator, similar to that described in Figure 29.10 or Figure 29.11 shall be used for this test. For this apparatus, the electrodes, one movable and one stationary, shall be constructed of copper or tungsten alloy. When using an apparatus as described in Figure 29.10, the electrodes shall be made of cylindrical copper rods with 6.35 mm (1/4 inch) diameter. When using an apparatus as described in Figure 29.11, tungsten alloy shall be used for the electrodes.The test is to begin with the electrodes in contact with each other (shorted) and then separated at a controlled rate to the specified gap, as defined in Table 29.2.

b) When the intended application consists of more than one module, the use of more power supplies or solar array/PV simulators is to allow the insertion of the arc gap in the middle of the "string." Each power supply or solar array/PV simulator shall be adjusted to the same voltage (within 10 percent), and the total supply voltage shall be within 10 percent of the rated voltage of the DUT.

c) The arc generator shall be placed one at a time in each position in the applicable figures. Each test condition defined in Table 29.2 shall be repeated 3 times. Each test must be performed 3 times at each of the two values of C4 (total of 6 tests at each arc location.) Testing the middle of the string location is mandatory.

Exception: If agreeable to all concerned parties and the most adverse condition is determined, the testing at the other positions is not required.

NOTE: Procedure for determining the "most adverse condition" parameters: Five measurements at each position are recorded. The most adverse condition shall be the arc location and C4 value resulting in the highest average trip time.

d) The voltage across the arc gap, arc time, and the current thru the arc shall be measured and recorded. These measurements are then used to calculate total energy generated in the arc prior to tripping.

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

1) 2.5 seconds of continuous arc power emission; or

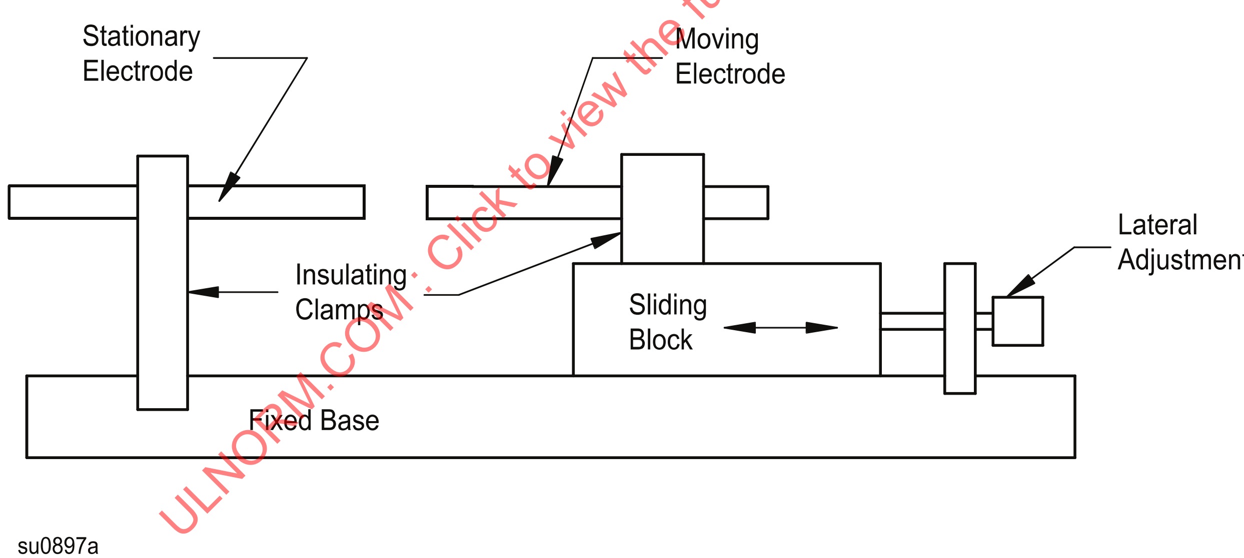
2) In seconds, calculated by dividing 750 (Joules) by the product of the measured arcing current (amps) times the measured arcing voltage (volts).

Exception No. 1: If a unit is rated for only a single PV string per AFCI, the tests at 16A in Table 29.2 are not required. A unit shall not be tested outside of its current ratings.

Exception No. 2: If voltage or current of one or more test cases described in Table 29.2 is outside the rated range of operation of the DUT, the point(s) of operation may be altered as agreed upon by all concerned parties. A unit shall not be tested outside of its voltage or current ratings. If the maximum rated voltage of the DUT is less than the value for V_{OC} in Table 29.2, V_{OC} shall be replaced by the maximum rated voltage of the DUT, and V_{mpp} shall be replaced by 0.65 times the maximum rated voltage.

Figure 29.10

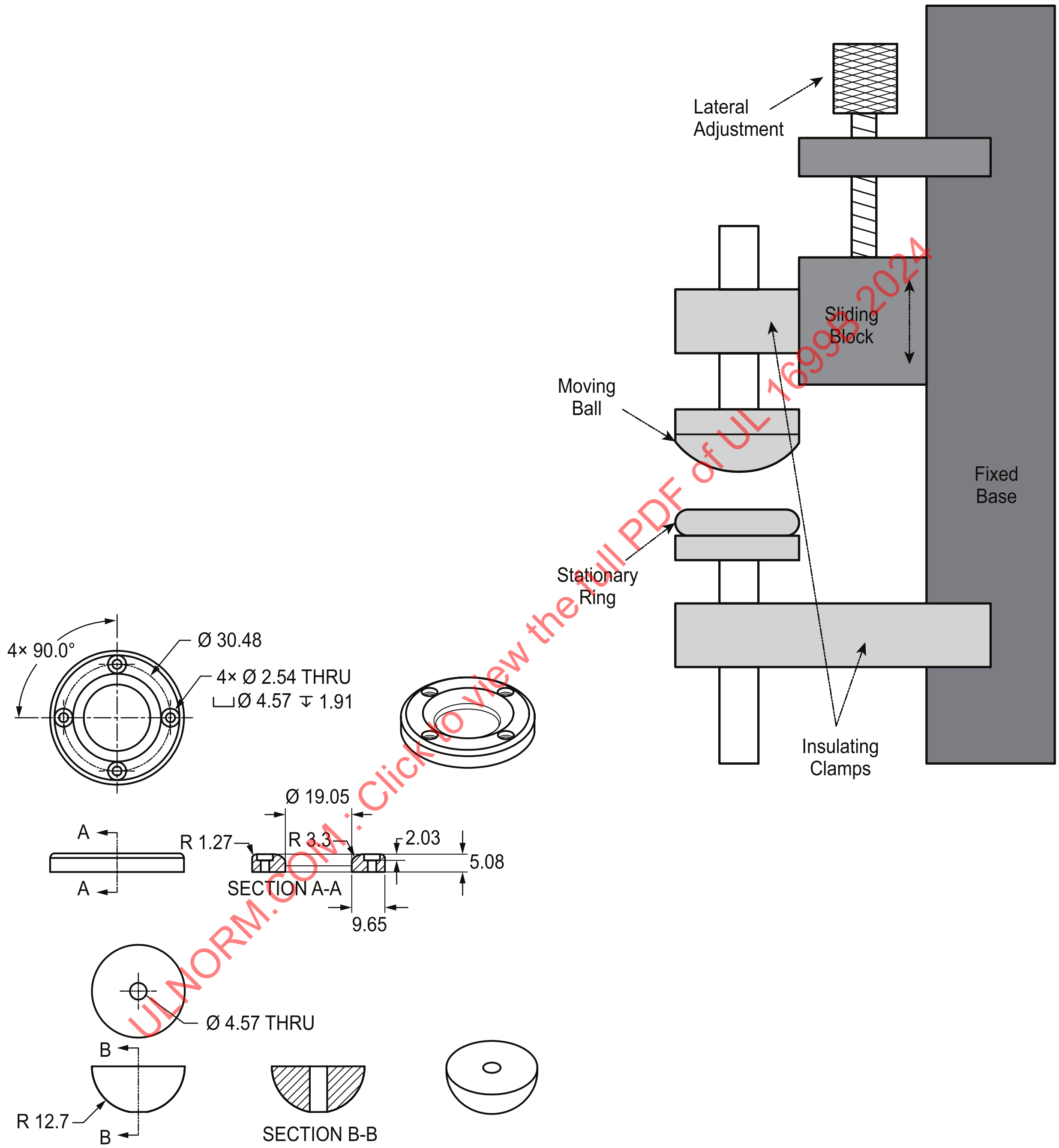
Arc generator



NOTE: For this apparatus, the electrodes, one moveable and one stationary, are made of solid copper, 6.35 mm (1/4 inch) diameter. The electrode mating surfaces shall be parallel, flat, and vertical.

Figure 29.11

Ball and ring



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NOTE 1: When using this apparatus, tungsten alloy shall be used for the electrodes.

NOTE 2: All dimensions are shown in mm.

mm	1.27	1.91	2.03	2.54	3.3	4.57	5.08	9.65	12.7	30.48
(inch)	(0.05)	(0.075)	(0.08)	(0.1)	(0.13)	(0.18)	(0.20)	(0.38)	(0.5)	(1.2)

Table 29.2
Arcing test conditions

Test no.	Minimum I_{arc} (A)[a]	Impp (A)	Sep. rate (mm/s)	Vmpp (V)[b]	Voc (V)[b]	R_{tot}(ohms)[b]	Gap (mm)
1	2.5	3.0	2.5	312.0	480.0	56.0	0.8
2	7.0	8.0	5.0	318.0	490.0	21.0	0.8
3[c]	14.0	16.0	5.0	318.0	490.0	11.0	1.1
4	7.0	8.5	5.0	607.0	810.0	24.0	2.5
Single module							
5	2.5	3.0	2.5	31.2	48.0	5.6	0.8
6	7.0	8.0	5.0	31.8	49.0	2.1	0.8

[a] I_{arc} values in Table 29.2 are representative of realistic arc events with one or two strings at full and low irradiance. It is expected that the AFCI shall meet compliance criteria below at intermediate current levels also.

[b] These values are approximate.

[c] Required for arcs in series with two parallel strings.

Table 29.3
Component values for arc-fault test circuits
Representing 80 meters of total conductor length, including PV module wiring for 10 modules in a string

Designator	Full string	Half string	Parallel string[1,2]	Single module	Details
C1	Minimum 20 uF				C1 shall be specified to dominate the output capacitance of the DC source
C2, C3	22 nF				
C4	150 nF and 10 uF	300 nF and 20 uF	150 nF * (n-1) and 10 uF * (n-1)	1.5 uF and 100 uF	See Note 3
C5, C6	1 nF	500 pF	1 nF * (n-1)	100 pF	
L1	12 mH				Common mode – minimal DC flux.
L2, L3	Minimum 60 uH				See Note 7.
L4, L5	50 uH + 0.7 uH per meter above 80 meters	25 uH	50 uH / (n-1)	2 uH + 0.7 uH per meter	See Note 7.
R1, R2	Use Formula 1 to calculate value				
R3, R4	Max. 1 Ω			Max. 0.5 Ω	
R5, R6	10 mΩ / meter				
L6, L7	0.7 uH / meter				See Notes 6 and 7.

Note 1: The “n” in the parallel string column is the total number of strings, including the string under test.

Note 2: The “Parallel String Value” column is the resulting value of each component when a single network is used to simulate multiple parallel strings.

Note 3: Two values are shown for C4. Depending on the detection method used in the DUT, one of these values may represent the worst case condition. If agreeable to all concerned, testing may be reduced to only one of these values if it can be determined which value represents the worst case. Procedure for determining the worst case condition: Five measurements at each of the two C4 capacitor values are recorded. The worst case condition shall be the capacitor value resulting in the highest average trip time.

Table 29.3 Continued on Next Page

Table 29.3 Continued

Designator	Full string	Half string	Parallel string[1,2]	Single module	Details
Note 4: Where a DUT comprises several identical AFCI sensors or inputs, only one representative sensor or input must be tested.					
Note 5: Calculations resulting in floating point numbers for component values shall be rounded up to the next commercially available component value.					
Note 6: Refer to 24.4 for selecting component values when using a solar array/PV simulator.					
Note 7: Shall be air core or constructed to avoid saturation. Different values determined by operating limitations and appropriate ratings of DUT may be used if agreeable to all concerned.					
Formula 1: R1 = R2 = Rtot / (2*k) – R3 with k being the number of decoupling networks used in the setup for one string and Rtot taken from Table 29.2. For a string composed of two half strings, k=2, for a single full string k=1.					
The Line Impedance network simulates the high frequency behavior of the module. The DC behavior is simulated by the decoupling network. Resistors shall be sized within 10% of the value calculated according to the formula 1.					
* I_limit shall be the current limit of the DC source					

29.1.4 *Deleted*

29.1.5 A compliant device shall:

a) Extinguish the arc before 750J of dissipated arc energy is exceeded, or before 2.5 seconds of arcing have elapsed, whichever occurs first; and

b) Meet the standby current requirement of 14.2.

29.1.6 After each arc is extinguished, the DUT shall delay no less than 5 minutes before resuming operation. The 5 minute delay is not required after a manual reset or if the arc is extinguished before exceeding Region A.

29.1.7 The DUT shall annunciate that an arc has been detected.

Exception: If the equipment can extinguish the arc before exceeding Region A (see Figure 29.9) for all tests, then annunciation is not required.

29.1.8 After 5 arc events in a 24 hour period in Region B (see Figure 29.9), the DUT shall open the circuit and shall require a manual reset before returning to operation. Once manual reset is required, annunciation shall occur and that annunciation shall be reset as specified in 22.1 and 22.2 or 52.1 and 52.2.

Exception: If the equipment can extinguish the arc before exceeding Region A (see Figure 29.9) for all tests, then manual reset is not required.

29.1.9 As an alternative to 29.1.7, a DUT may require manual reset after every arc event in Region B.

29.1.10 A device fails the test if for any test, for energy or time, it reaches Region C (see Figure 29.9).

29.1.11 Inductances shall be characterized over a frequency range of 10kHz to 300kHz. Inductance reference value is measured at 10kHz at the maximum specified test current and shall not decrease more than 40 percent at 300kHz. The nominal component value shall be ±10 percent.

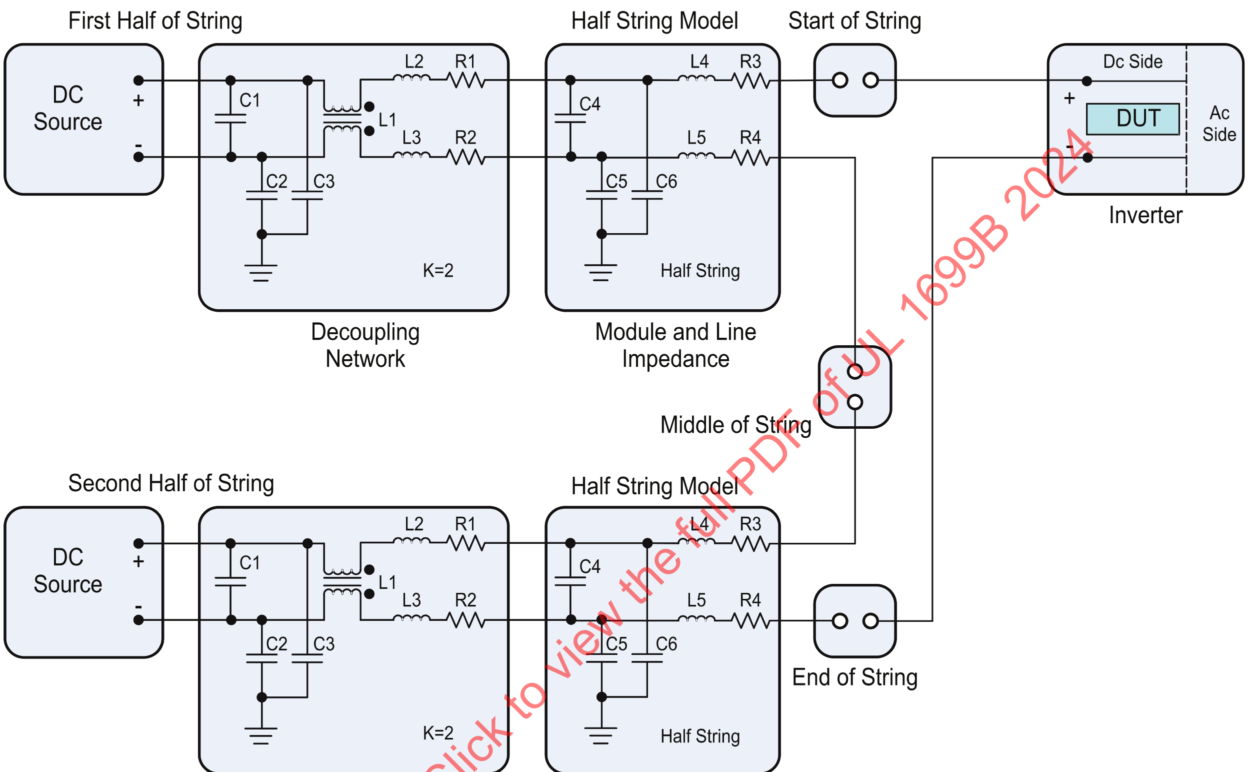
29.1.12 Capacitor and resistor values shall be ±10 percent.

29.2 One string, one MPPT

29.2.1 Test setup for one string, one MPPT shall be as shown in Figure 29.12.

Figure 29.12

Arc-fault circuit, one string, one MPPT



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NOTE: Component values are shown in Table 29.3.

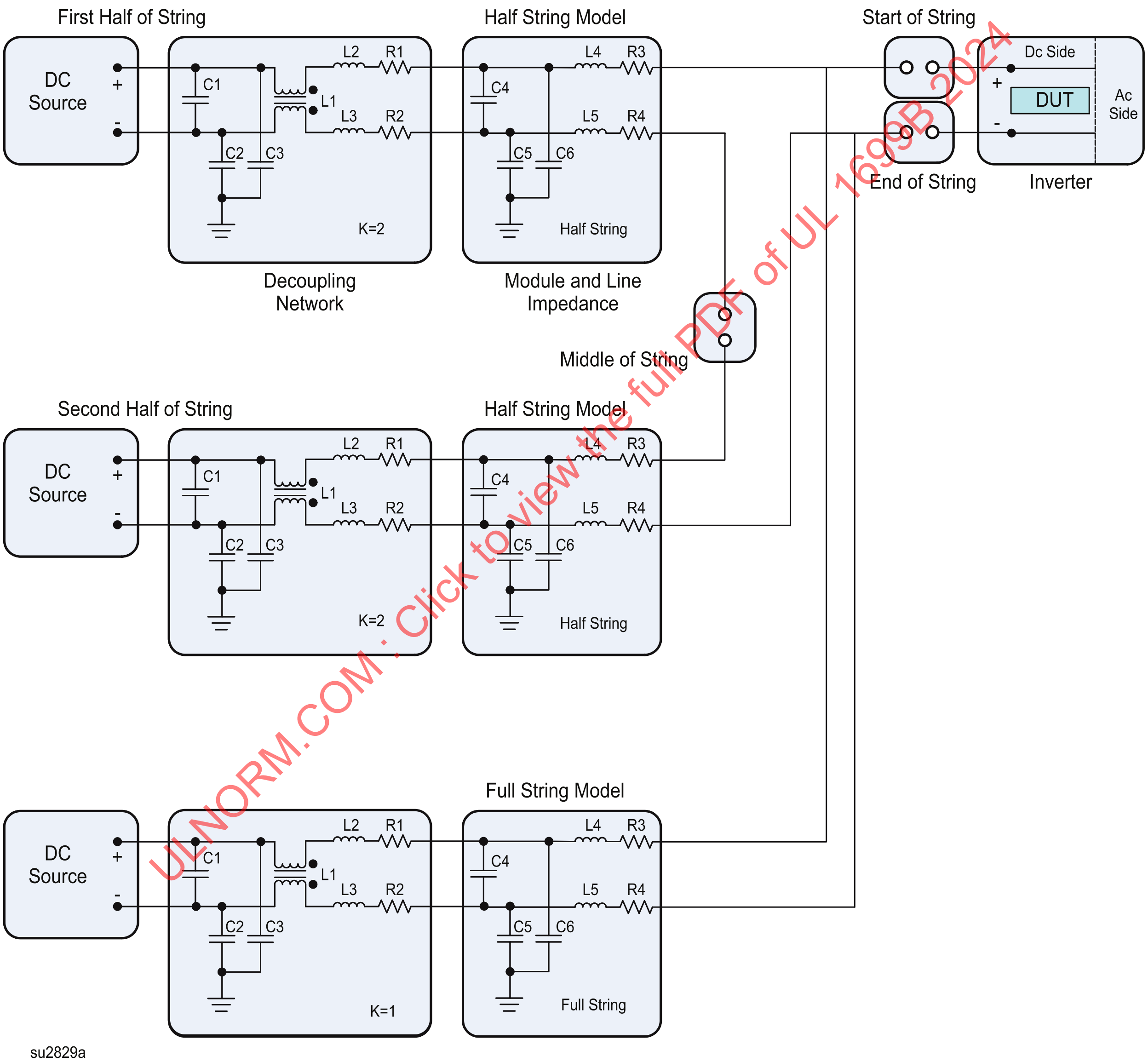
29.3 Two strings combined, one MPPT

29.3.1 Test setup for two strings combined, one MPPT shall be as shown in Figure 29.13.

29.3.2 The current in the parallel string shall be adjusted to that maximum value within the ratings of the DUT, at which the currents specified in Table 29.2 can be adjusted for the test string.

Figure 29.13

Arc-fault circuit, two string, one MPPT



NOTE: Component values are shown in Table 29.3.

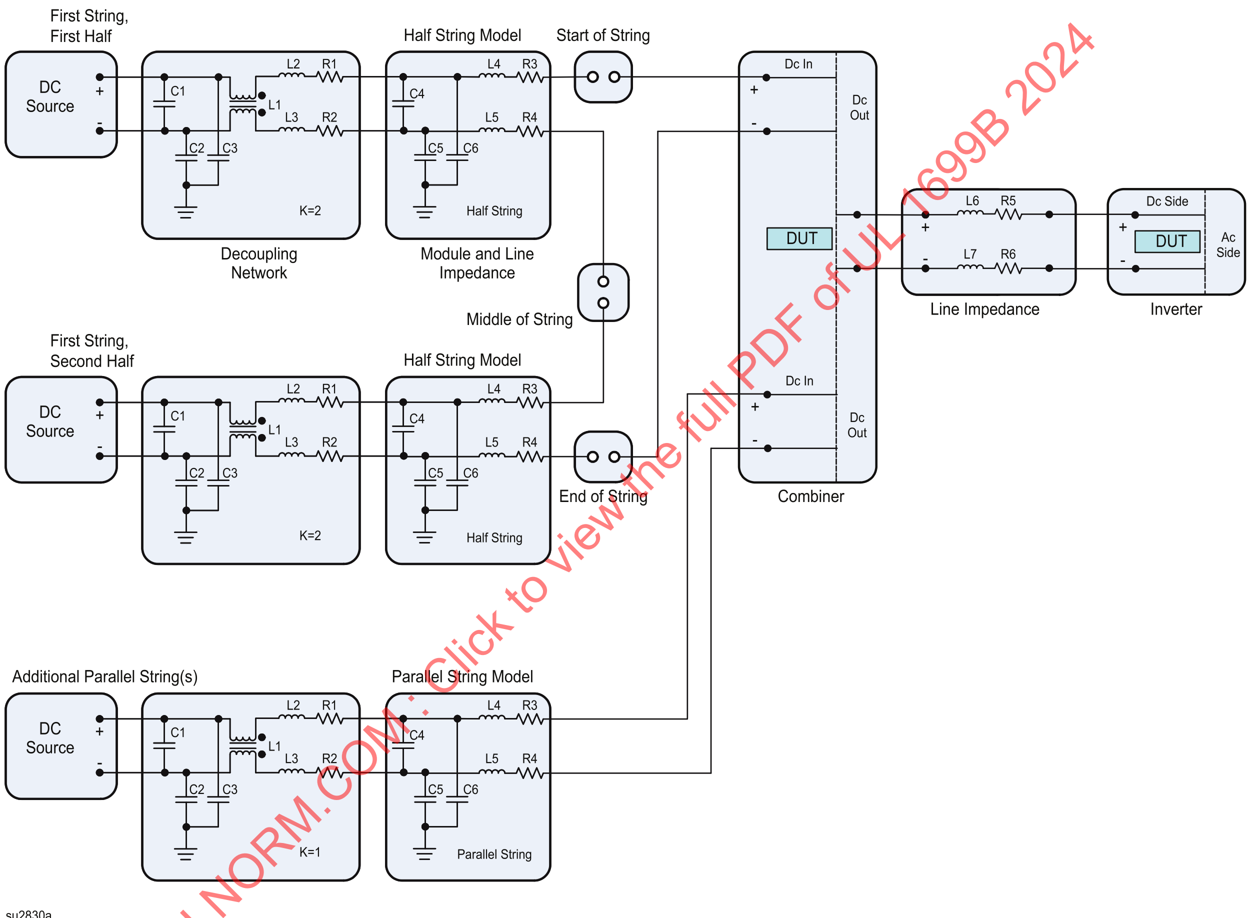
29.4 Combiner box

29.4.1 Test setup for a combiner box shall be as shown in Figure 29.14.

29.4.2 The current in the parallel string shall be adjusted to that maximum value within the ratings of the DUT, at which the currents specified in Table 29.2 can be adjusted for the test string.

Figure 29.14

Arc-fault circuit, combiner box/multiple strings



NOTES:

1. Component values are shown in Table 29.3.

2. If the combiner box is integrated in the inverter, R5, R6, L6 and L7 of the line impedance between combiner box and inverter are not required.

29.5 External AFCI

29.5.1 Test setup for an external AFCI is to reflect the intended installation location of the DUT. In general, the arc locations shall be as shown in Figure 29.2.

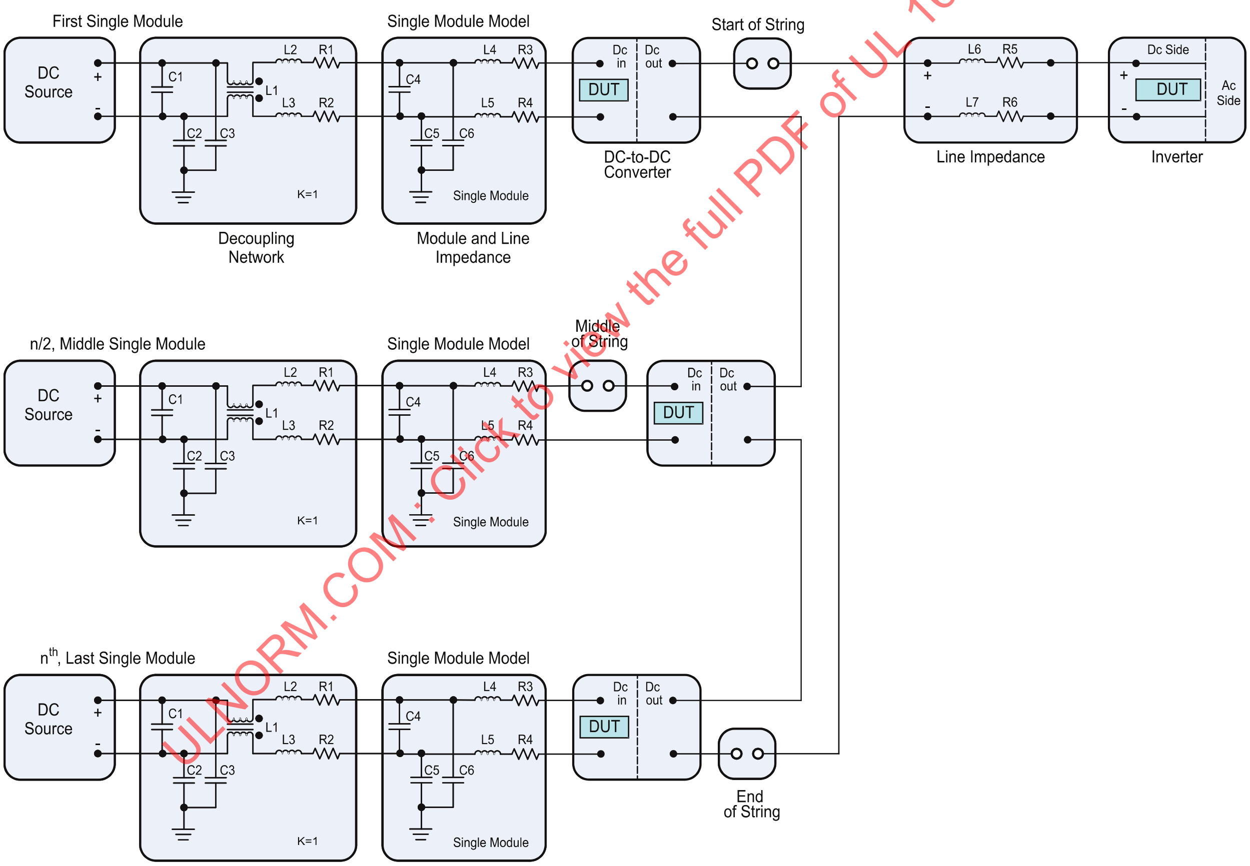
29.6 DC-DC converter systems

29.6.1 Test setup for a DC-DC converter system shall be as shown in Figure 29.15.

29.6.2 If more than one PV module can be placed in series on the DC-DC converter input, the points shown in Figure 29.16 shall be tested. The “Middle of String” arc detection test shall only be conducted if exposed wiring exists between the module and the DC-DC converter.

Figure 29.15

Arc-fault circuit, DC-DC converter

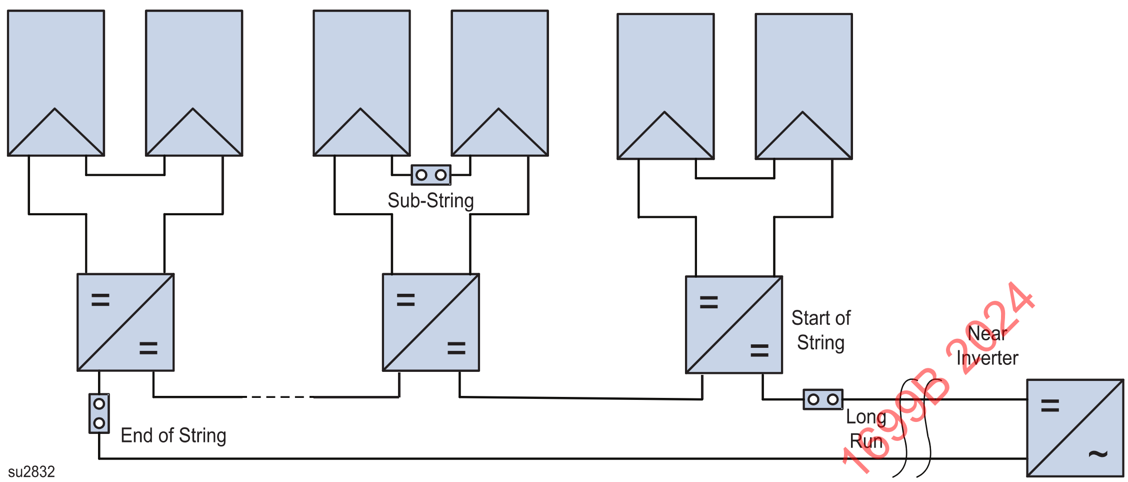


su2831

NOTE: Component values are shown in Table 29.3.

Figure 29.16

Arc-fault circuit, DC-DC converter with two module input



29.7 Electronic devices

29.7.1 Test setup for electronic devices shall be as shown in Figure 29.17A.1 – Figure 29.17A.4. For each module connected to the electronic device, a separate power supply or solar array/PV simulator shall be used. The power source shall be connected to a decoupling network and line impedance model. The model component values may be altered based on conditions specified in 24.4.

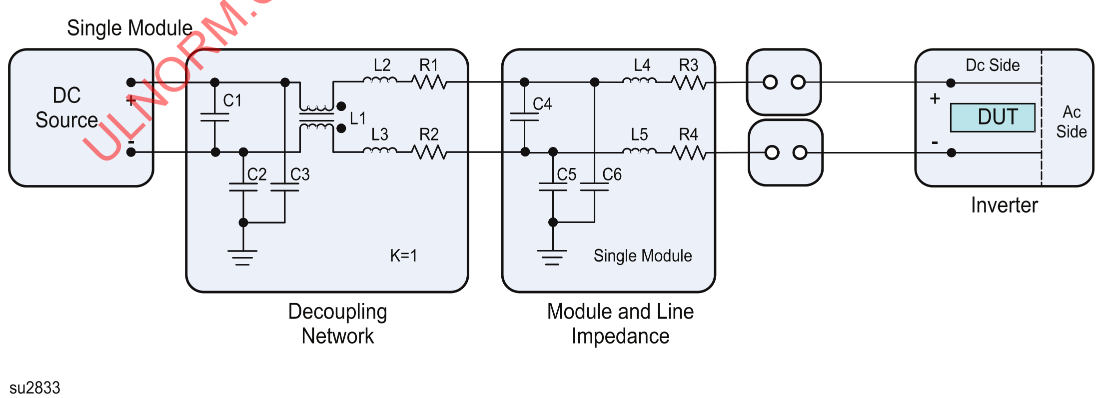
Figure 29.17

Arc-fault circuit, microinverter with single module

Figure deleted

Figure 29.17A.1

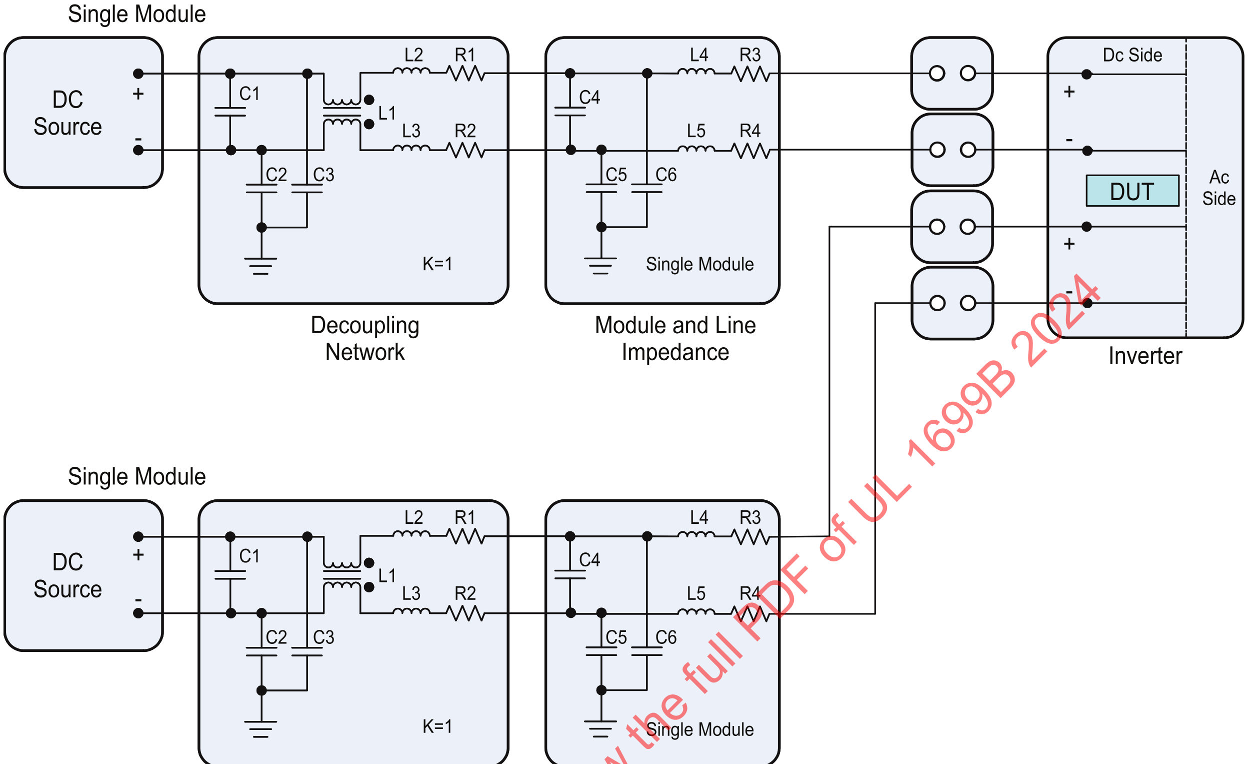
Arc-fault circuit, electronic device with single module



NOTE: Component values are shown in Table 29.3.

Figure 29.17A.2

Arc-fault circuit, electronic device connected to two MPPT



su3934

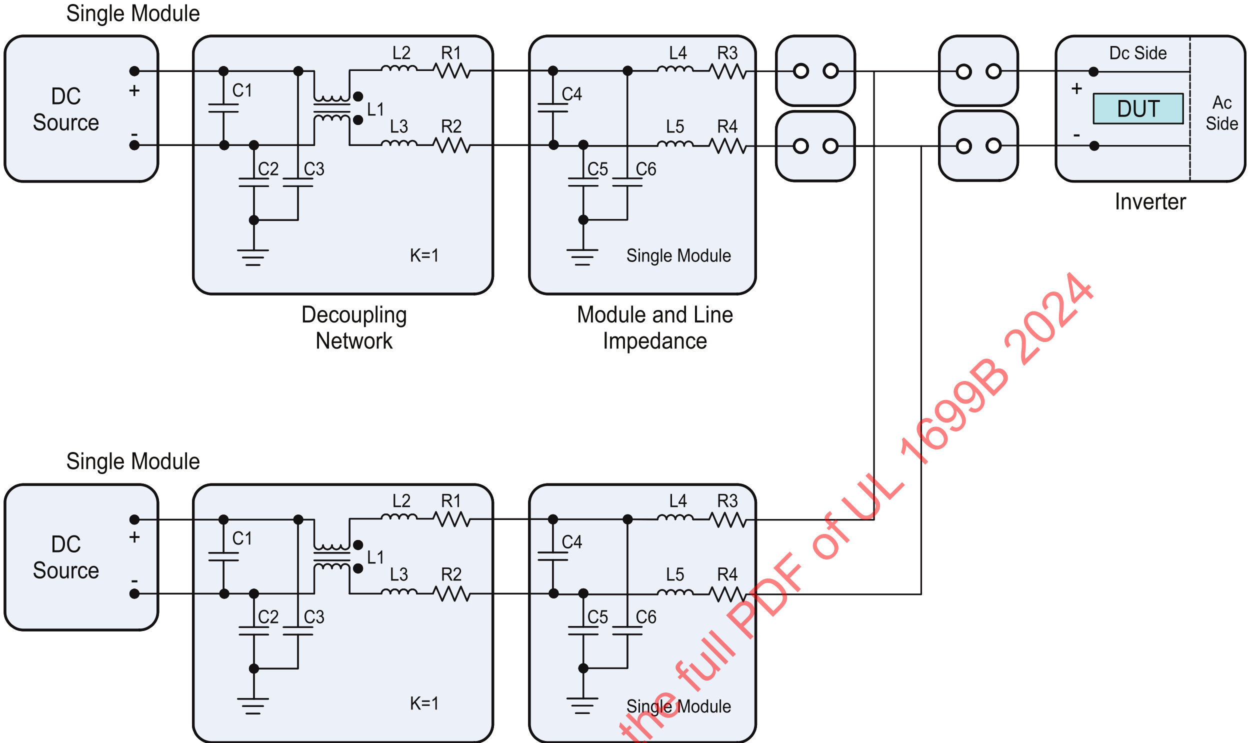
NOTES:

1. Component values are shown in Table 29.3.

2. Where a DUT comprises several identical AFCI sensors or inputs, only one representative sensor or input must be tested.

Figure 29.17A.3

Arc-fault circuit, electronic device connected to two modules in parallel

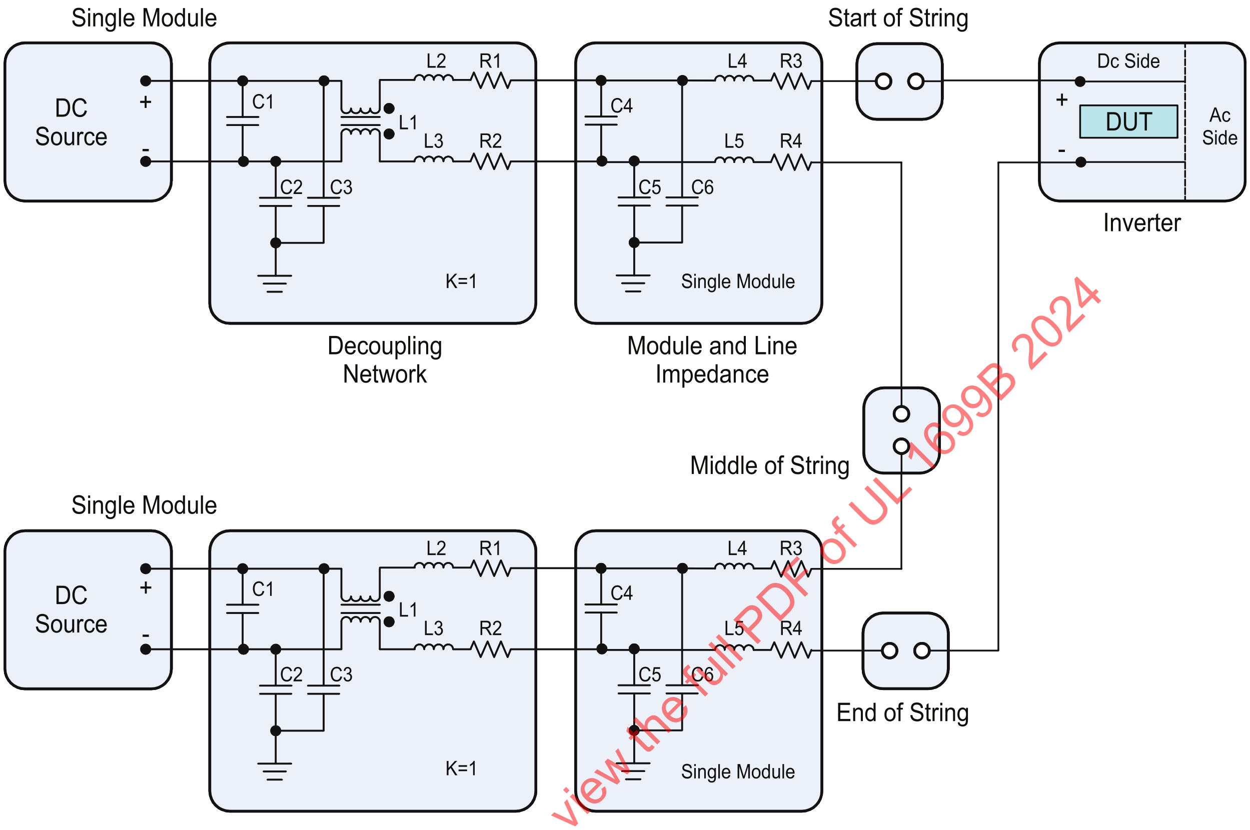


su3935

NOTE: Component values are shown in Table 29.3.

Figure 29.17A.4

Arc-fault circuit, electronic device connected to two modules in series



su3936

NOTE: Component values are shown in Table 29.3.

Figure 29.18

Arc-fault circuit, microinverter with two modules

Figure deleted

30 Unwanted Tripping Tests

30.1 General

30.1.1 A representative device shall be tested in accordance with Figure 30.1 – Figure 30.5A.4, using the values in Table 30.1 and the legend in Figure 29.1. The device shall not trip after being tested under each of the 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.

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

30.2.1 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.

30.2.2 The DUT shall be installed 0.6 m (2.0 ft) from the load device. With a PV power source operating at rated power and when agreed upon by all concerned parties, with one MPP-voltage from Table 29.2 representative 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.

30.2.3 The DUT shall NOT indicate an arc fault.

Table 30.1
Component values for unwanted tripping test circuits

Designator	Full string	Parallel string[1,2]	Single module	Comments
C1	Minimum 20 uF			C1 shall be specified to dominate the output capacitance of the DC source
C2, C3	22 nF			
C4	150 nF and 10 uF	150 nF * n and 10 uF * n	1.5 uF and 100 uF	
C5, C6	(180 nF * Inverter Power in kW) / (2n)	(180 nF * Inverter Power in kW) * (n-1) / (2n)	(180 pF * Inverter Power in W) / 2	See Note 3
L1	12 mH			Common mode – minimal DC flux.
L2, L3	Minimum 60 uH			See Note 6.
L4, L5	1 uH	1 uH / n	2 uH + 0.7 uH per meter	See Note 6.
R1, R2	Use Formula 1 to calculate value			
R3, R4	Max. 1 Ω		Max. 0.5 Ω	
R5, R6	10 mΩ / meter			
L6, L7	0.7 uH / meter			See Notes 5 and 6.
Note 1: The “n” represents the total number of strings, including the Full and the Parallel string.				

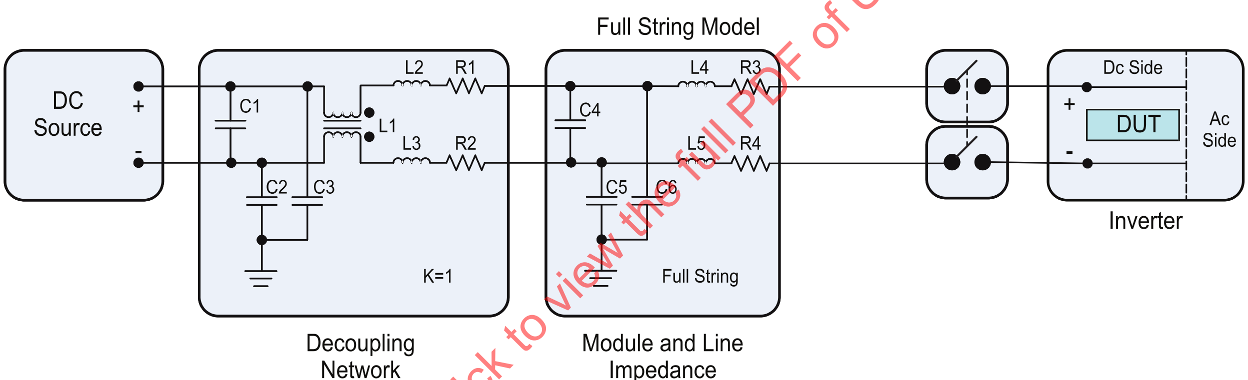
Table 30.1 Continued on Next Page

Table 30.1 Continued

<table>
<tr><th>Designator</th><th>Full string</th><th>Parallel string[1,2]</th><th>Single module</th><th>Comments</th></tr>
<tr><td colspan="5">Note 2: The “Parallel String Value” column is the resulting value of each component when a single network is used to simulate multiple parallel strings.</td></tr>
<tr><td colspan="5">Note 3: If the manufacturer specifies a total maximum common mode capacitance Cmax, then the following formulae may be used: C5 = C6 = Cmax / (2*n) for the full string; and C5 = C6 = (Cmax / 2) * (1 – (1 / n)) for the parallel string.</td></tr>
<tr><td colspan="5">Note 4: Calculations resulting in floating point numbers for component values shall be rounded up to the next commercially available component value.</td></tr>
<tr><td colspan="5">Note 5: Refer to 24.4 for selecting component values when using a solar array/PV simulator.</td></tr>
<tr><td colspan="5">Note 6: Shall be air core or constructed to avoid saturation. Different values determined by operating limitations and appropriate ratings of DUT may be used if agreeable to all concerned.</td></tr>
<tr><td colspan="5">Formula 1: R1 = R2 = [Rtot − k*(R3 + R4)] / (2*k) with k being the number of decoupling or PV-networks used in the setup for one string and Rtot taken from Table 29.2.</td></tr>
</table>

Figure 30.1

Unwanted tripping circuit, one string, one MPPT



su2835

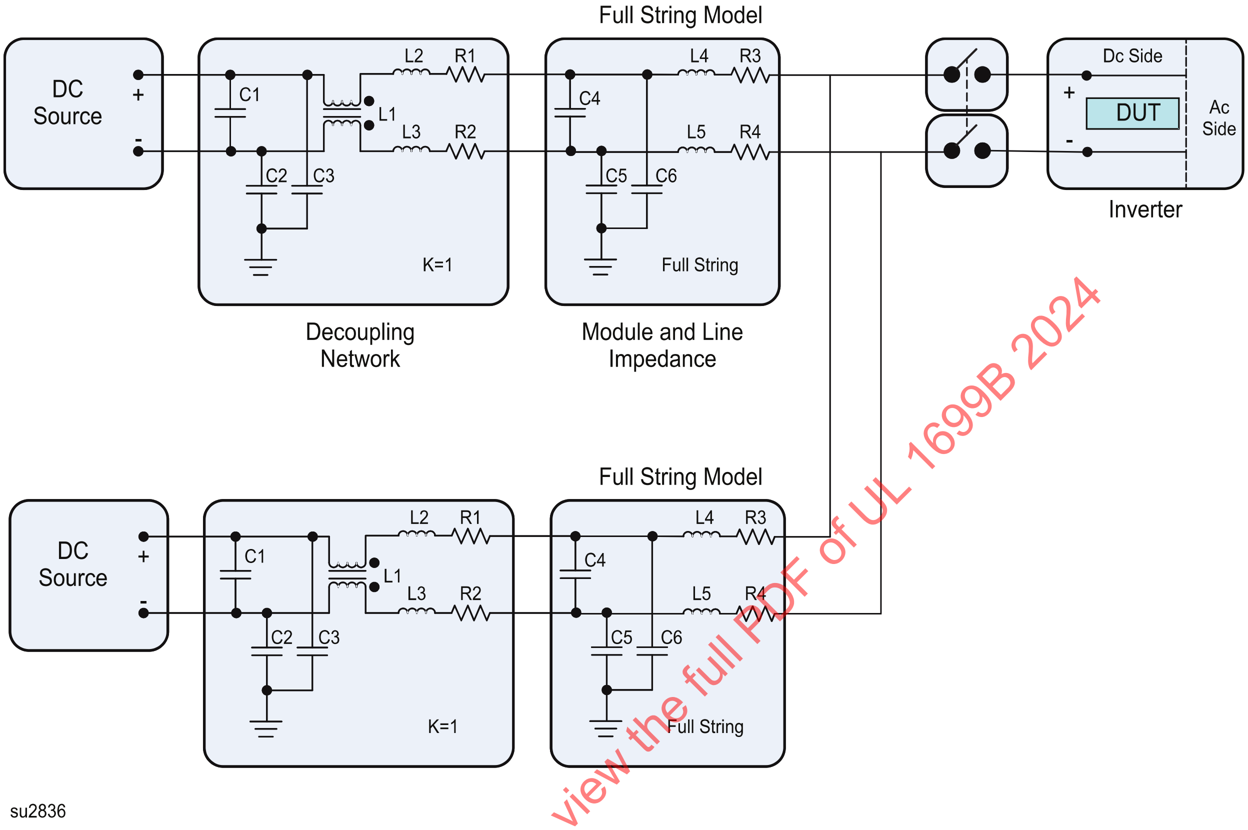
NOTES:

1. The disconnect switch is shown in both the + and the - DC lead. For grounded systems, a switch pole is only required in the ungrounded DC lead.

2. Component values are shown in Table 30.1.

Figure 30.2

Unwanted tripping circuit, two strings combined, one MPPT



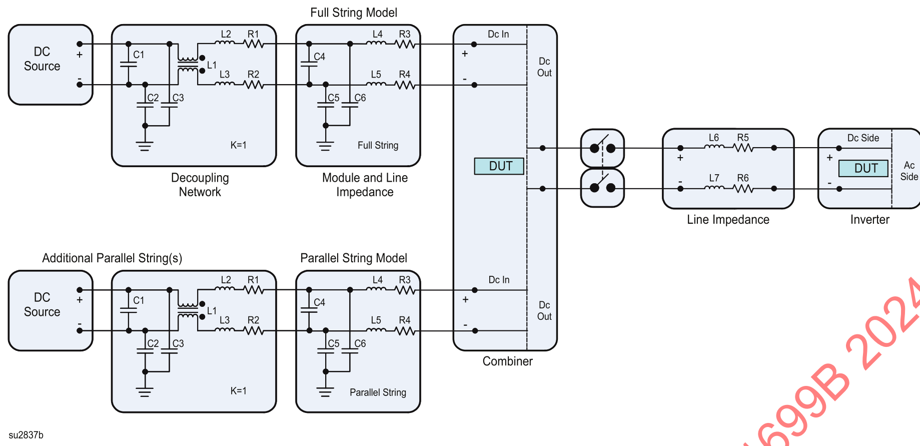
NOTES:

1. The disconnect switch is shown in both the + and the - DC lead. For grounded systems, a switch pole is only required in the ungrounded DC lead.

2. Component values are shown in Table 30.1.

Figure 30.3

Unwanted tripping circuit, combiner



NOTES:

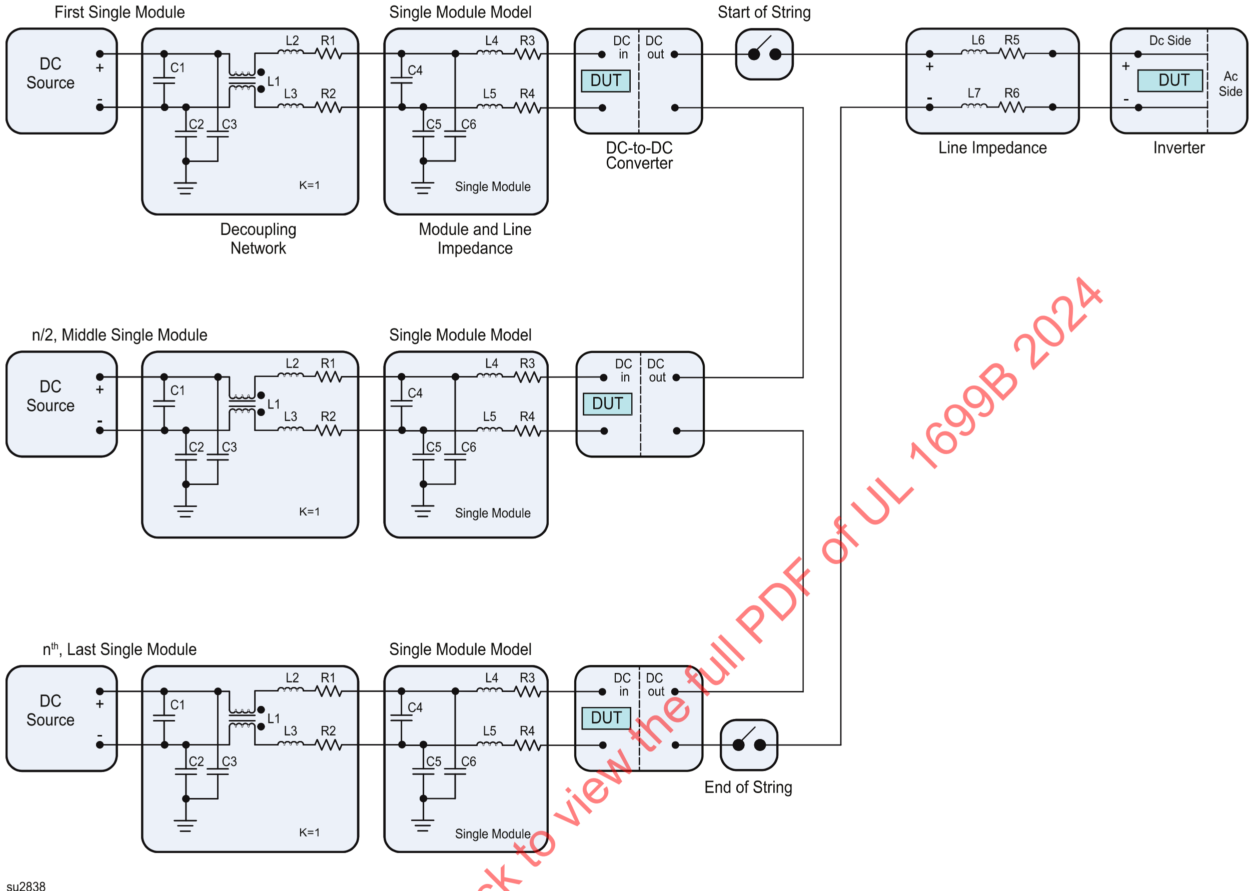
1. The disconnect switch is shown in both the + and the - DC lead. For grounded systems, a switch pole is only required in the ungrounded DC lead.

2. Component values are shown in Table 30.1.

3. If the combiner box is integrated in the inverter, R5, R6, L6 and L7 of the line impedance between combiner box and inverter are not required.

Figure 30.4

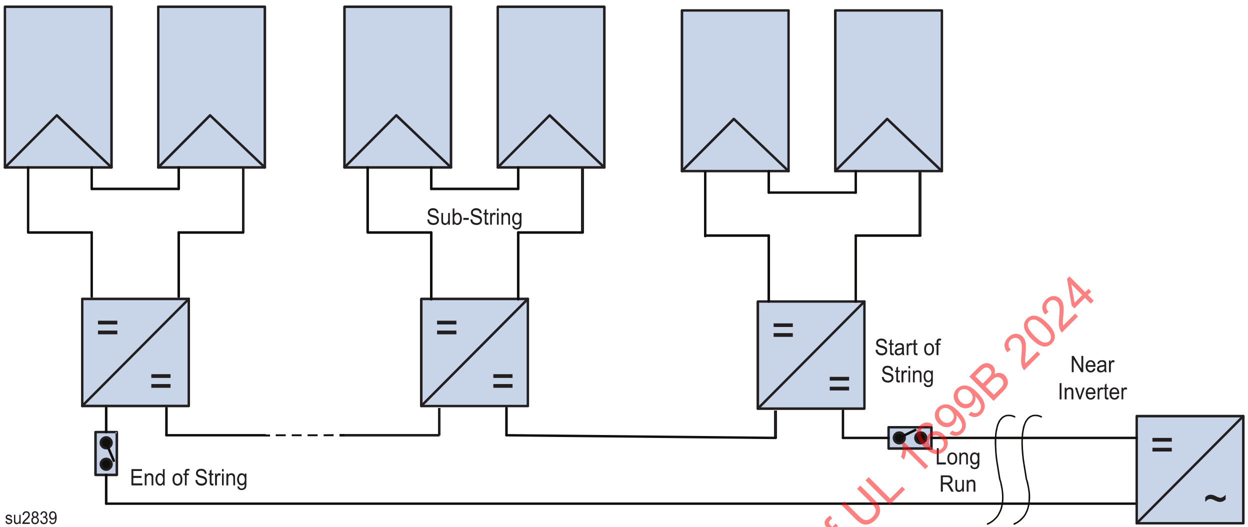
Unwanted tripping circuit, DC-DC converter



NOTE: Component values are shown in Table 30.1.

Figure 30.5

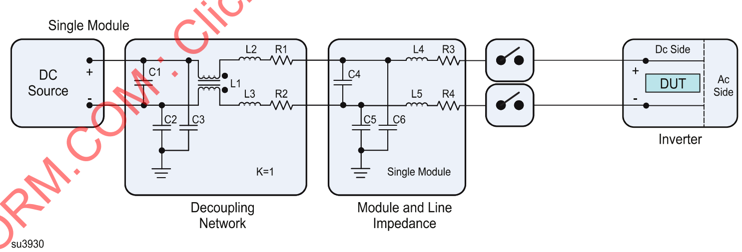
Unwanted tripping circuit, DC-DC converter, two module input



NOTE: The DUT can be located in the DC-DC converter, the inverter, or both. See Figure 30.4 for details.

Figure 30.5A.1

Unwanted tripping circuit, electronic device with single module



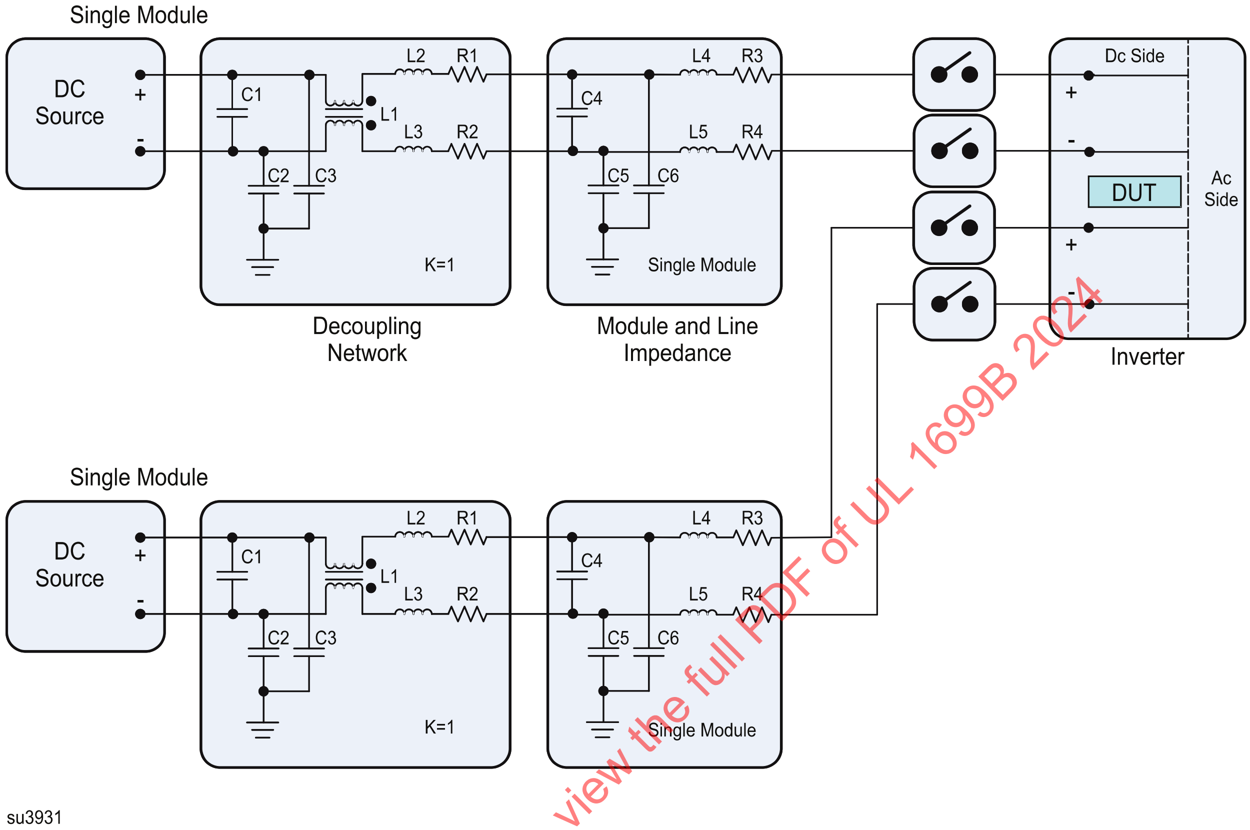
NOTES:

1. The disconnect switch is shown in both the + and the - DC lead. For grounded systems, a switch pole is only required in the ungrounded DC lead.

2. Component values are shown in Table 30.1.

Figure 30.5A.2

Unwanted tripping circuit, electronic device connected to two MPPT



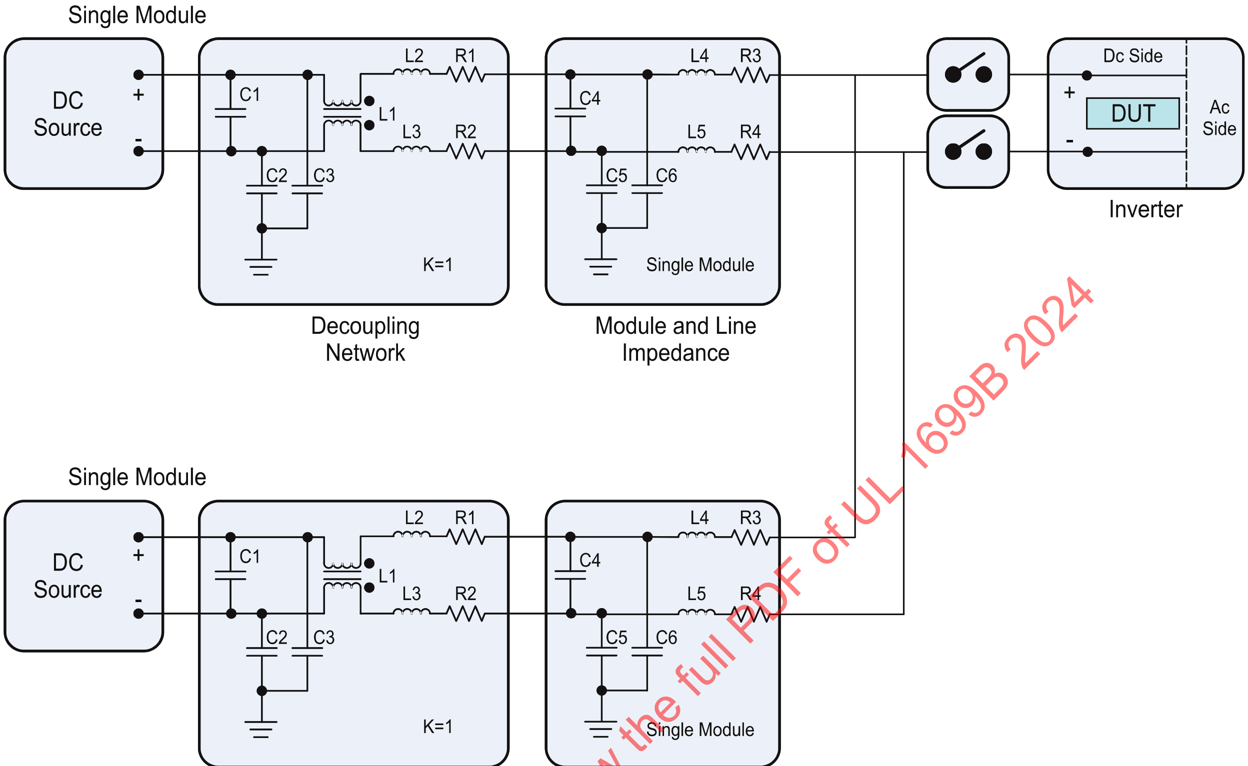
NOTES:

1. The disconnect switch is shown in both the + and the - DC lead. For grounded systems, a switch pole is only required in the ungrounded DC lead.

2. Component values are shown in Table 30.1.

Figure 30.5A.3

Unwanted tripping circuit, electronic device connected to two modules in parallel



su3932

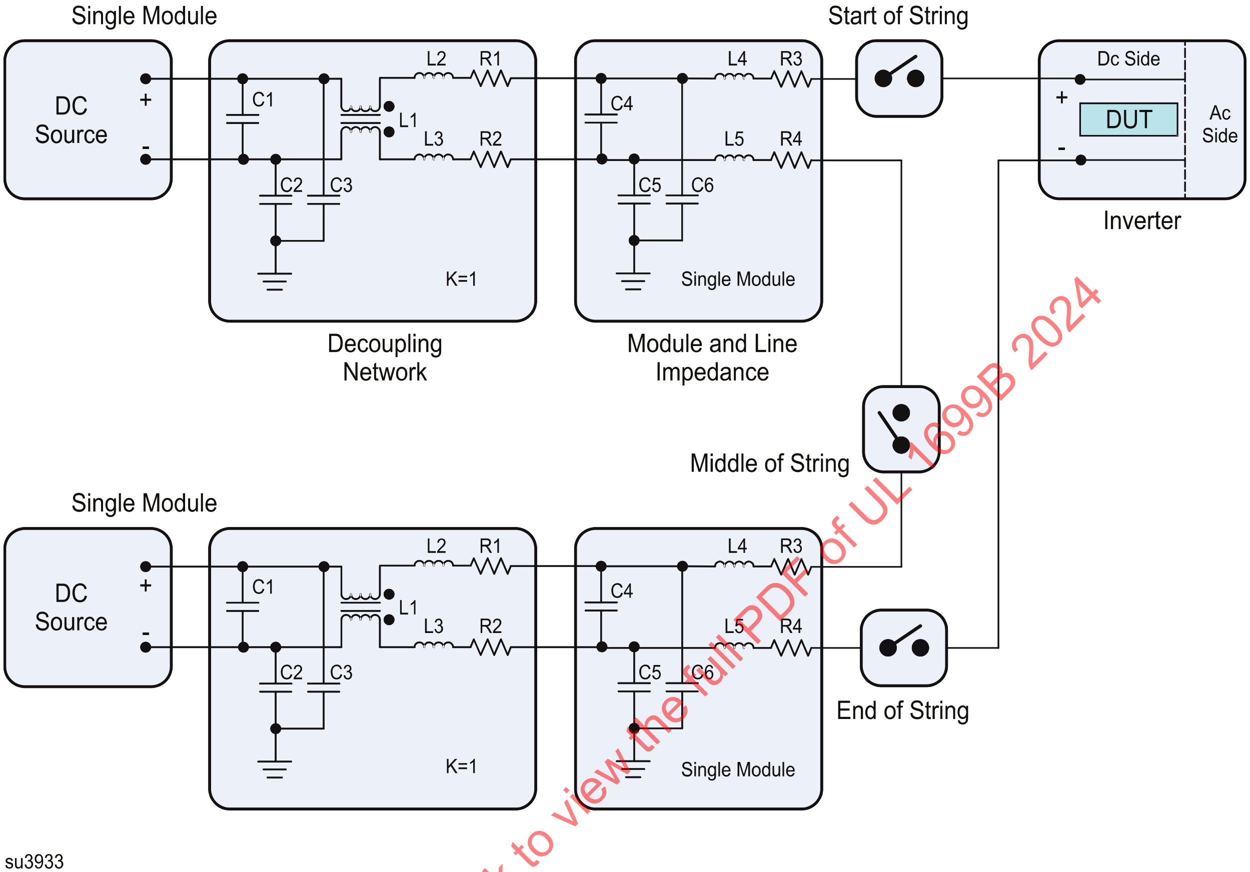
NOTES:

1. The disconnect switch is shown in both the + and the - DC lead. For grounded systems, a switch pole is only required in the ungrounded DC lead.

2. Component values are shown in Table 30.1.

Figure 30.5A.4

Unwanted tripping circuit, electronic device connected to two modules in series



NOTES:

1. The disconnect switch is shown in both the + and the - DC lead. For grounded systems, a switch pole is only required in the ungrounded DC lead.

2. Component values are shown in Table 30.1.

30.3 Loading condition II – DC switch operation

30.3.1 The DUT shall be installed in a test circuit with a PV power source and an inverter, converter, or charge controller. A disconnect switch external to the inverter shall be installed two feet from the device under test. With the PV power source set up 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, moved to the "off" position. This sequence shall be repeated three times, with five minutes "off" time between each sequence.

30.3.2 The DUT shall NOT indicate an arc fault.

30.4 Loading condition III – Irradiance step changes

30.4.1 The DUT shall be installed in a test circuit with a PV power source and an inverter as shown in Figure 30.6A and Figure 30.6B. 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. If a single power source is used this test must be performed by rapidly decreasing the supplied current to at least ½ of the test current in less than 5 seconds. After 30 seconds return to full initial current in less than 5 seconds. If using a module or array this may be achieved with a cover over the array or module. See Figure 30.1.

30.4.2 The DUT shall NOT indicate an arc fault.

Figure 30.6A

Arc-fault integrated inverter

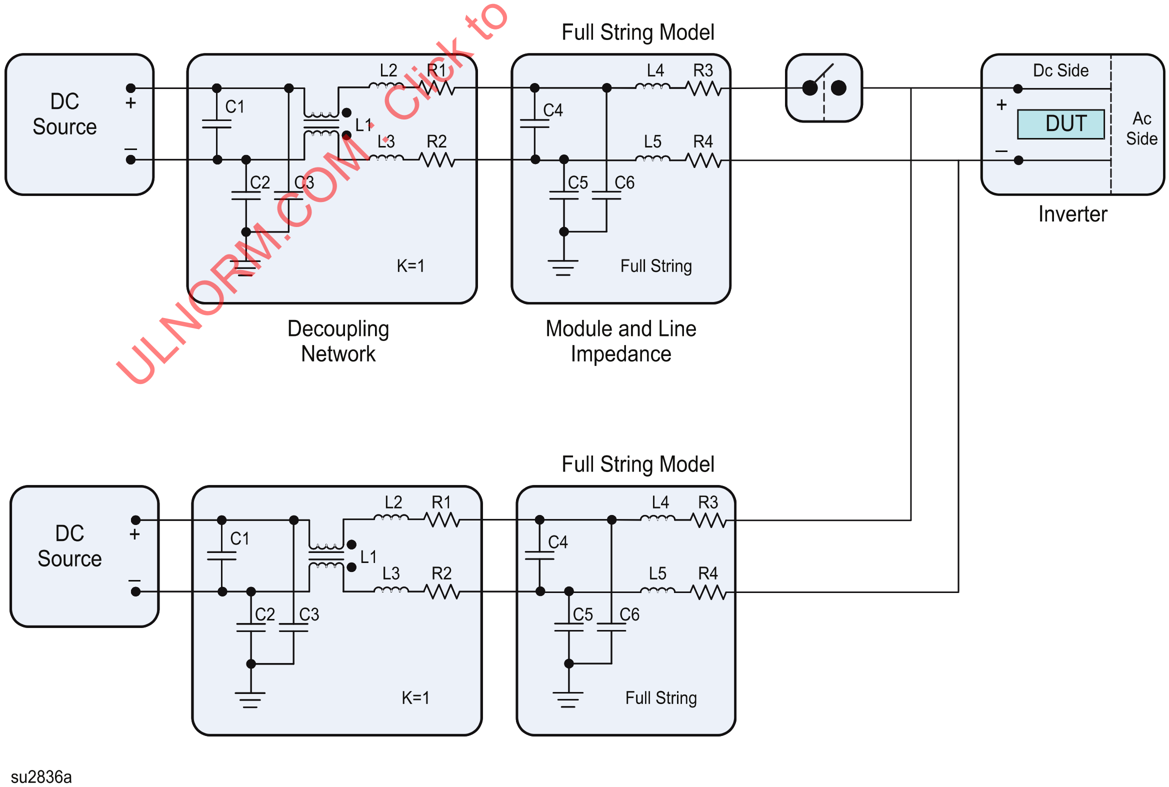
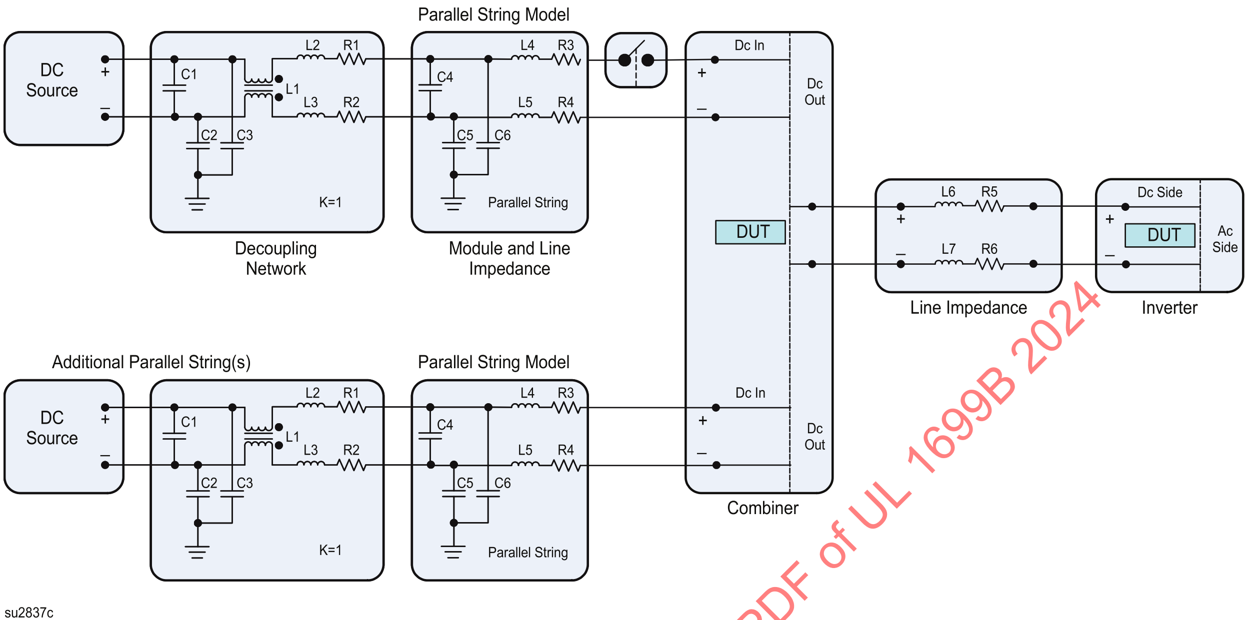


Figure 30.6B

Arc-fault combiner box



NOTE: If the combiner box is integrated in the inverter, R5, R6, L6 and L7 of the line impedance between combiner box and inverter are not required.

30.4.3 If the number of strings is odd, the mechanical disconnect switch shall be installed at the higher number of parallel strings, so that at least half of the strings are disconnected during the test.

30.4.4 If the number of strings is three, one Parallel String Model shall be replaced by a Full String Model. The mechanical disconnect switch shall be installed in the Parallel String Model.

31 Normal Temperature Test

31.1 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 31.1, based on an assumed average ambient temperature in normal service of 25°C (77°F).

31.2 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 (0.8 mm or 1/32 inch 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 31.1.

Table 31.1
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).

31.3 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.

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

31.5 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.

32 Overvoltage Test

32.1 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.

33 Overload Test

33.1 Except as indicated in 33.2, a device that includes an interrupting or shunting contact function shall have the necessary capacity for overloads. See 33.7.

33.2 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.

33.3 In order to determine compliance with the provisions of 33.1, 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.

33.4 The supply circuit for the test mentioned in 33.3 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 33.5, 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.

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

33.6 In performing the test mentioned in 33.3 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.

33.7 At the conclusion of the test, the 1A fuse mentioned in 33.4 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 14.2.1.

34 Endurance Test

34.1 Except as indicated in 35.2, a device that includes an interrupting or shunting contact function shall have the necessary capacity for normal operation. See 34.6.

34.2 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.

34.3 In order to determine compliance with 32.1, 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.

34.4 In performing the test described in 34.3, 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 34.5, 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.

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

34.6 At the conclusion of the test, the 1A fuse mentioned in 34.4 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 34.7. A device with a solid state interrupting device shall additionally comply with 14.2.1.

34.7 After the endurance test, the same device shall be tested in accordance with 29.1. Except as indicated in 34.8, the device shall interrupt the arcing as described in Table 29.2 for the conditions of Test no. 2 and 3 at room ambient.

34.8 When conducting the tests of 34.7, operation at the maximum wattage possible shall be conducted and the required trip time calculated from the formula in 29.1.3(e)(2). Electrode gap and arcing current may be adjusted to obtain the required operating point.

35 Dielectric Voltage-Withstand Test

35.1 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 35.7.

35.2 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.

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

35.4 Basic insulation and spacings inherent in a component need not withstand the test potentials mentioned in 35.1 if the component in question complies with the requirements applicable to the component.

35.5 In order to determine compliance with the provisions of 35.1, 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.

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

35.7 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.

35.8 In the application of the test potential specified by 35.1(c), any components in parallel with the applied potential shall be permitted to be disconnected before performing the dielectric voltage withstand test.

36 Abnormal Operations Test

36.1 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 36.4.

36.2 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.

36.3 The cheesecloth mentioned in 36.2 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).

36.4 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 36.2;

b) There is emission of molten metal;

c) The fuse mentioned in 36.2 operates to open the circuit;

d) Except if the device is likely to be removed from service, there is dielectric failure. See 36.5 and 36.6;

e) It is possible to touch a part with the articulated probe shown in Figure 17.1 while there is a risk of shock at that part; or

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

36.5 Dielectric failure is considered to be failure to comply with the provisions of 35.1.

36.6 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.

37 Short Circuit Current Test

37.1 A device that includes an interrupting or shunting contact shall withstand short-circuit currents. See 37.7.

37.2 In order to determine compliance with the provisions of 37.1, 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 37.3, 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: 50, 100, 400, 800, 1200, 1600, 2000, 3000, 5000, 7500, 10000, 14000, 18000, 20000, 22000, 25000, 30000, 35000, 42000, or 50000 amps.

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

37.4 Each line terminal of a device is to be connected to the supply mentioned in 37.2 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 508-mm (20-inch) 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.

37.5 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.

37.6 The short circuit current test described in 37.5 shall be repeated with reverse current by reversing the line and load connections to the device.

37.7 At the conclusion of the above tests the 1A fuse mentioned in 37.4 shall not have opened, there shall not be any flaming of the cotton mentioned in 37.4, 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 37.8. A device with a solid state interrupting device shall additionally comply with 14.2.1.

37.8 After the short circuit current tests, each representative device shall be tested in accordance with the Series Connection Arcing Test of 29.1. The device shall interrupt the arcing as described in Table 29.2 for the conditions of Test no. 2 and 3 at room ambient.

38 Corrosion Test

38.1 One representative DUT shall operate as intended after being subjected to the corrosive atmosphere test as specified in 38.2 and 38.3.

Exception: As an alternative to 38.2 and 38.3, the test may be performed with a non-energized DUT in accordance with IEC 60068-2-60, Environmental testing – Part 2-60: Tests – Test Ke: Flowing mixed gas corrosion test. Test procedure 2 with method 3 or 4 of IEC 60068-2-60 shall be applied for a duration of 21 days. The criteria in 38.4 shall apply.

38.2 One representative device is to be placed in a 200 liter (52.8 gallon) or larger test chamber on a platform approximately 50.8 mm (2 inches) 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.

38.3 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.

38.4 After the Corrosion Test, the DUT shall be tested in accordance with 29.1 at the two lowest wattages specified in Table 29.2, and shall trip as required.

39 Surge Current Test

39.1 General

39.1.1 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 39.2.1 – 39.4.1, and shall comply with the requirements in 39.1.2.

39.1.2 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 17.

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

39.2 Mounting and installation

39.2.1 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.

39.3 Surge parameters

39.3.1 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 1.2/50 µs, 8/20 µs voltage/current surge waveform.

39.4 Surge polarity

39.4.1 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).

40 Abnormal Overvoltage Tests

40.1 General

40.1.1 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, 40.2, and Limited Current Abnormal Overvoltage Test, 40.3. 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 17.

40.1.2 The representative devices used for each of the tests described in 40.2 – 40.3 are to be previously untested.

40.1.3 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.

40.1.4 Cord connected devices shall be tested in accordance with the Limited Current Abnormal Overvoltage Test, 40.3, in both normal and reversed polarity.

40.1.5 When agreed upon by all concerned parties, fewer representative devices than those specified in 40.2 – 40.3 may be used for testing.

40.1.6 Following the tests described in the Full Phase Voltage – High Current Abnormal Overvoltage Test, 40.2, and the Limited Current Abnormal Overvoltage Test, 40.3, the same representative devices are to be subjected to and comply with Section 26, Leakage Current Measurement , and comply with the requirements of Section 21, Grounding. The leakage current test shall be conducted within five minutes of the end of the abnormal overvoltage tests.

40.1.7 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.

40.2 Full phase voltage – high current abnormal overvoltage test

40.2.1 The test described in this section shall not result in any of the conditions described in 40.1.1. One previously untested device is to be subjected to the application of the test voltage as specified in Table 40.1 with a power factor as specified in Table 40.3. The ac power source shall have an available short-circuit (fault) current (I_{sc}) as specified in Table 40.2. 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 40.1.

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 40.1.1 when subjected to the maximum phase voltage or twice the conductor pair voltage rating of the device as specified in Table 40.1.

40.2.2 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 40.1

High current abnormal overvoltage (revised)

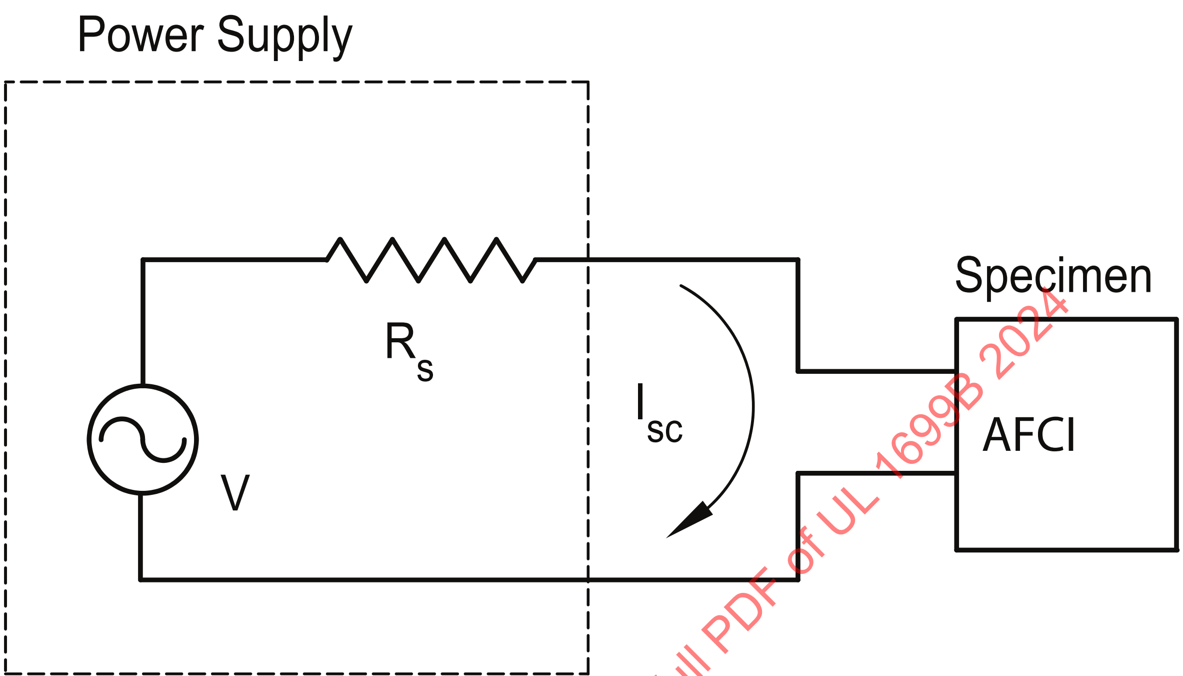


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Table 40.1
Test voltage selection table

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 40.2
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