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UL 1699B

OUTLINE OF INVESTIGATION
FOR
PHOTOVOLTAIC (PV) DC ARC-FAULT CIRCUIT PROTECTION

Issue Number 2

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Summary of Topics

This is the second issue of the Outline of Investigation for Photovoltaic (PV) DC Arc-Fault Circuit Protection, Subject 1699B, with revisions throughout to represent current practice.

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

1.4 These requirements are intended to be used with the Standard for Arc-Fault Circuit-Interrupters, UL 1699, as these requirements modify the requirements described in that standard.

1.5 These devices are not intended to detect glowing connections.

1.6 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 outline, and is modified when the requirement does not apply to all types.

1.7 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 Outline of Investigation, 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 CELL – The basic photovoltaic device that generates electricity when exposed to sunlight.

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

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

2.6 DUT – Device under test.

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

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

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

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

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

2.12 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.

2.13 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.

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

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

3 Components

3.1 Except as indicated in 3.2, a component of a product covered by this Outline of Investigation shall comply with the requirements for that component.

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

- a) Involves a feature or characteristic not needed in the application of the component in the product covered by this Outline of Investigation; or
- b) Is superseded by a requirement in this Outline of Investigation.

3.3 A component shall be used in accordance with its recognized rating established for the intended conditions of use.

3.4 Specific components are recognized as being 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 for which they have been recognized.

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 Outline of Investigation shall be interpreted as referring to the latest edition of that code or standard.

CONSTRUCTION

6 General

6.1 All devices shall comply with the construction requirements in Sections 6 - 14 of this Outline.

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 of Section 35

8 Internal Wiring

8.1 The gauge and insulation of wires shall withstand the mechanical and electrical stresses of service. Wires smaller than 24 AWG (0.21 mm²) shall be investigated for the application.

9 Insulation

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

10 Inclined Plane Tracking

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

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 Outline, 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.

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

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 circuit, 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.

13.2 All of the requirements of the Standard for Software in Programmable Components, UL 1998, apply to microprocessors 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 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 the circuit current when an arc fault is sensed shall comply with 14.2 - 14.4.

14.2 "Off" State or Stand-By Mode Current

14.2.1 When arcing current is interrupted by electronic means, the available current with the system in the "off" state or stand-by mode after detecting an arc-fault condition 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 to interrupt the circuit current in the event of 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 switching/interrupting components and the products input wiring connections that may prevent the switching interrupting 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.

14.4 Programmable Circuit Components

14.4.1 If a device employs a programmable circuit component such as a microprocessor to control the interruption of current during an arc-fault condition or to implement the test circuit function mentioned above in 14.3.2, that portion of the circuit shall be investigated in accordance with Section 13 of this Outline.

14.4.2 When conducting the investigation in accordance with Section 13, the additional risks to be considered for the Risk Analysis portion of UL 1998 include the following scenarios:

- a) Failure to trip under conditions where tripping should occur; and
- b) Failure of the supervisory circuit to complete evaluation.

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

CONSTRUCTION

15 General

15.1 A PV AFCI, PV AFD, or PV ID device shall comply with the construction requirements of Part 1 of this Outline as well as Sections 15 - 23.

16 Accessibility of Energized Parts

16.1 Parts of a PV AFCI, PV AFD, or PV ID shall not be accessible when they are installed as intended and energized.

16.2 Parts are considered to be accessible if they can be touched using the articulated probe. See Figure 16.1.

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

17 Current Carrying Parts

17.1 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.

18 Spacings

18.1 A PV AFCI, PV AFD, or PV ID shall comply with the requirements shown in Table 18.1 except that at field-wiring terminals the spacings shall be not less than 1/4 inch (6.4 mm) for devices rated 400 V and less, and not less than 1/2 inch (12.7 mm) for devices rated greater than 400 V between terminals not operating at the same potential.

Table 18.1
Spacing in inches (mm)^{a,b}

Operating potential between parts					
0 - 200 V peak		201 - 400 V peak		401 - 1000 V peak	
Through air	Over surface	Through air	Over surface	Through air	Over surface
1/8 (3.2)	1/4 (6.4)	1/4 (6.4)	3/8 (9.5)	3/8 (9.5)	1/2 (12.7)
^a Smaller spacings may be acceptable where they are inherent in a suitable component. ^b For printed wiring boards with suitable conformal coating which have been determined to comply with the requirements for conformal coatings in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, spacings may be reduced to 1/32 inch (0.8 mm), and may be reduced further if the coating is determined to be suitable and it is evaluated in accordance with UL 746C for the reduced spacing.					

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

18.3 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.

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

18.5 As an alternative to the requirements specified in 18.1 – 18.4, 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 18.6 – 18.8 using the applicable requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840.

18.6 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,