JOINT CANADA-UNITED STATES
NATIONAL STANDARD

ANSI/CAN/UL 3741:2020

STANDARD FOR SAFETY

Photovoltaic Hazard Control

ANSI/UL 3741-2020

SCC FOREWORD

National Standard of Canada

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UL Standard for Safety for Photovoltaic Hazard Control, ANSI/CAN/UL 3741

First Edition, Dated December 8, 2020

Summary of Topics

This First Edition of ANSI/CAN/UL 3741, Standard for Photovoltaic Hazard Control, has been issued to reflect the latest ANSI and SCC approval dates, and to incorporate the proposals dated March 6, 2020 and September 18, 2020.

The new requirements are substantially in accordance with Proposal(s) on this subject dated March 6, 2020 and September 18, 2020.

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Standard for Photovoltaic Hazard Control

First Edition

December 8, 2020

This ANSI/CAN/UL Safety Standard consists of the First Edition.

The most recent designation of ANSI/UL 3741 as an American National Standard (ANSI) occurred on December 8, 2020. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, Preface or SCC Foreword.

This standard has been designated as a National Standard of Canada (NSC) on December 8, 2020.

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Preface

This is the First Edition of ANSI/CAN/UL 3741 Standard for Photovoltaic Hazard Control.

UL is accredited by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC) as a Standards Development Organization (SDO).

This Standard has been developed in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization.

This ANSI/CAN/UL 3741 Standard is under continuous maintenance, whereby each revision is approved in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization. In the event that no revisions are issued for a period of four years from the date of publication, action to revise, reaffirm, or withdraw the standard shall be initiated.

In Canada, there are two official languages, English and French. All safety warnings must be in French and English. Attention is drawn to the possibility that some Canadian authorities may require additional markings and/or installation instructions to be in both official languages.

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

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This Edition of the Standard has been formally approved by the UL Standards Technical Panel (STP) on Photovoltaic Hazard Control, STP 3741.

This list represents the STP 3741 membership when the final text in this standard was balloted. Since that time, changes in the membership may have occurred.

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This Standard is intended to be used for conformity assessment.

The intended primary application of this standard is stated in its scope. It is important to note that it remains the responsibility of the user of the standard to judge its suitability for this particular application.

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INTRODUCTION

1 Scope

1.1 Introduction

1.1.1 Fire fighters (FF) performing operations involving buildings with attached or integrated Photovoltaic (PV) arrays may be exposed to electrical hazards from damaged PV equipment. These requirements provide a means for evaluation of PV Hazard Control components, equipment and systems that provide a reduced level of shock hazard from energized PV system equipment and circuits located within the PV array after the operation of hazard control initiation function(s) where required, such as but not limited to any PV Rapid Shutdown Equipment (PVRSE) or PV Rapid Shutdown Systems (PVRSS) that comply with UL 1741 in the United States and CSA C22.2 No 330 in Canada.

NOTE: Damaged PV equipment in arrays includes damage as a result of fire fighter (FF) interaction as identified throughout this standard and also common PV faults such as PV array ground faults.

1.1.2 This standard is based on the presupposition that the PV array is installed by qualified persons in accordance with the installation instructions and all applicable installation codes and standards. Evaluation to this standard should not replace other requirements addressing the control of power source(s) for the purposes of worker safety during installation or maintenance. Energized circuits can remain in some PV array equipment after any required hazard control initiation function is operated.

NOTE: Requirements for PV arrays addressed in this standard are intended for compliance with the National Electrical Code (NEC), NFPA 70, 2017 and 2020 editions and their requirements for controlling electrical shock hazards inside the array boundary as addressed in NEC section 690.12(B)(2), Rapid Shutdown of PV Systems on Buildings and with the Canadian Electrical Code (CE Code) C22.1. A PVHCS may or may not additionally comply with the 30V in 30 seconds requirements outside the PV array as required in 690.12 (B)(1).

1.1.3 This standard evaluates the hazards associated with potential exposure to DC currents through defined fire fighter (FF) interactions. Alternating current (AC) exposure is limited to not more than 15 Vac, 8A and 240VA for any circuit within the array boundary.

NOTE: This ac voltage limit is aligned with the PVRS requirements in UL 1741 and general electric shock limits.

1.2 Equipment and conditions included in scope

1.2.1 These requirements relate to conditions where PV array equipment or assemblies are subjected to a safety analysis considering potential fire fighter (FF) interactions while performing duties during an emergency.

NOTE: These conditions may result in degradation or damage from stresses beyond those covered in existing product safety standards.

1.2.2 The acceptable shock hazard risk established by these requirements is based on defined assumptions related to specific personal protective equipment (PPE) in serviceable condition worn by fire fighters (FF) during structural fire fighting operations on buildings.

NOTE: NFPA 1971 Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting and NFPA 1851 Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting specify the selection, care, and maintenance of fire fighter PPE.

1.2.3 Types of fire fighter (FF) tools and extinguishing agents, including certain water plus foam solutions, during specific fire fighter (FF) tasks are considered in this standard.

NOTE: Specifications for these items are outlined in FF PV Array Interactions, Section 12.3.

1.2.4 Body resistances of adult fire fighters (FF) are defined in this standard to set the criteria by which shock hazards are evaluated.

1.2.5 The materials and methods used to construct the PV array are included in the evaluation. The evaluation to this standard is intended to result in an identified list of PV Hazard Control Equipment (PVHCE) determined to be necessary for the PV hazard control means. The list of PVHCE, and any characteristics of other connected equipment or systems that are essential to maintain the operational integrity of the hazard control function are documented in the PVHCE and / or the PV Hazard Control System (PVHCS) installation instructions in accordance with this standard.

1.2.6 The evaluation is based on a risk assessment of the electrical shock hazards to fire fighters (FF) working in the vicinity of the PV array.

1.2.7 The evaluation addresses the electrical hazard potential of PV array equipment on or integrated into buildings.

1.3 Equipment and conditions excluded from scope[1]

1.3.1 The evaluation does not include equipment where the hazard control systems or functions have been rendered ineffective due to physical damage not specifically addressed in this standard. Examples of physical damage not addressed are the direct exposure of components to fire, smoke, high-pressure hose spray, or major systemic physical damage such as building collapse, destruction or removal of the array.

NOTE: See Section 12.3 for the fire fighter (FF) interactions, including handheld hose lines, specifically addressed by this standard. Firefighting Monitors are controllable high capacity water jets that operate at higher pressures and volumes which can result in mechanical or structural damage to equipment and are therefore excluded from the scope of this standard.

[1] Additional installation requirements addressing rapid shutdown of PV system circuits can be found in the National Electrical Code (NEC), NFPA 70, Section 690.12, Rapid Shutdown of PV Systems on Buildings, and the Canadian Electrical Code (CE Code) C22.1 64-218 requirements.

1.3.2 While this standard accounts for fire fighters (FF) wearing new or serviceable used PPE, it does not include consideration for any damage to PPE that occurred prior to fire fighter (FF) interaction with the PV array.

NOTE: Standard operating procedures is to replace damaged fire fighting PPE.

1.3.3 The use of extinguishing agents not specified in this standard, such as seawater or high foam concentrations, are not included in the evaluation.

NOTE: The requirements and resistance data in this standard are based on expected practices and are considered to provide information sufficient for performing a safety analysis.

1.3.4 These requirements do not replace any electrical safe work practices for persons installing, servicing or maintaining the PV system.

1.3.5 Though all components, equipment, and systems that could be used to construct the PV array are considered in the evaluation, not all array equipment and components are required to be identified to perform the PV hazard control function, or be specifically addressed in the installation instructions for the purposes of this standard.

NOTE: Examples for parts that are not required to be identified are parts such as nuts, bolts and other passive components not used directly to provide hazard reduction, as determined by the analysis in Section 12.

1.3.6 These requirements do not address any electrical shock hazards not covered by this standard or other hazards that PV arrays may present such as slip, trip or fall hazards.

1.3.7 This standard is not intended to address fire fighter (FF) interactions involving PV array equipment not installed on a building.

2 Components and Equipment

2.1 A component of a product covered by this standard and systems, including equipment evaluated by this standard, shall comply with the requirements for that component or equipment as specified in this Standard. A component and equipment shall comply with the CSA or UL standards as appropriate for the country where the product is to be installed.

3 Units of Measurement

3.1 Values and their respective units of measurement that are stated without parentheses constitute the requirement of the standard and those in parentheses constitute explanatory or approximate information.

4 Undated References

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

5 Referenced Publications

5.1 The following standards are referenced in this standard, and portions of these referenced standards may be essential for compliance. Some of the standard references are country specific depending upon whether or not the PV system is intended for installation in the Unites States, in Canada, or both.

UL Standards

UL 969 *Marking and Labeling Systems*
UL 1703 *Flat-Plate Photovoltaic Modules and Panels*
UL 1741 *Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources*
UL 2703 *Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels*
UL 4703 *Photovoltaic Wire*
UL 6703 *Connectors for Use in Photovoltaic Systems*
UL 61730-1 *Photovoltaic (PV) Module Safety Qualification – Part 1: Requirements for Construction*
UL 61730-2 *Photovoltaic (PV) Module Safety Qualification – Part 2: Requirements for Testing*
UL 840 *Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment*
UL 62109-1 *Power Converters for use in Photovoltaic Power Systems – Part 1: General Requirements*
UL 50 *Enclosures for Electrical Equipment, Non-Environmental Considerations*
UL 3003 *Distributed Generation Cables*
UL 1565 *Positioning Devices*
UL 62275 *Cable Management Systems – Cable Ties for Electrical Installations*

CSA Group Standards

C22.1 *Canadian Electrical Code, Part I Safety Standard for Electrical Installations*
C22.2 No. 330 *Photovoltaic Rapid Shutdown Systems*
C22.2 No. 0.15 *Adhesive Labels*

International Electrotechnical Commission (IEC) Standards

IEC 60812 *Standard for Analysis Techniques for System Reliability – Procedures for Failure Mode and Effects Analysis (FMEA)*
IEC 60479-1 *Effects of current on human beings and livestock – Part 1: General aspects*
IEC 60529 *Degrees of protection provided by enclosures (IP Code)*

International Standards Organization (ISO) Standards

ISO 3864-2 *Graphical Symbols – Safety Colours and Safety Signs – Part 2: Design Principles for Product Safety Labels*

National Fire Protection Association (NFPA) Codes and Standards

NFPA 70 *National Electrical Code*
NFPA 1001 *Standard for Fire Fighter Professional Qualifications*
NFPA 1851 *Standard on Selection, Care, and Maintenance of Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*
NFPA 1981 *Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services*
NFPA 1971 *Standard on Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting*

National Electrical Manufacturers Association (NEMA) Standards

NEMA Z535.1 *Safety Colors*
NEMA Z535.2 *Environmental and Facility Safety Signs*
NEMA Z535.3 *Criteria for Safety Symbols*
NEMA Z535.4 *Product Safety Signs and Labels*
NEMA Z535.5 *Safety Tags and Barricade Tapes (for Temporary Hazards)*
NEMA Z535.6 *Product Safety Information in Product Manuals, Instructions, and Other Collateral Materials*

6 Glossary

6.1 For the purpose of this standard, the following definitions apply.

6.2 ARRAY – A mechanically and electrically integrated grouping of PV modules with support structure including any mechanically attached system components such as inverter(s) or dc-to-dc converter(s) and combiner boxes.

6.3 ARRAY BOUNDARY – A zone extending 305 mm (1 ft) from the array in all directions.

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

6.5 BASIC INSULATION – Insulation that provides a single level of protection against electric shock under fault-free conditions. Basic insulation only applies to components in which there are not existing requirements for double or reinforced insulation.

6.6 DOUBLE INSULATION – Insulation comprising both basic insulation and supplementary insulation.

6.7 ENHANCED PROTECTION – An additional level of hazard control protection applied to PV array equipment or circuits as evaluated by this standard. This protection is added to basic, double or reinforced insulation. Examples may include: an added physical barrier, electrical insulation or barrier, high impedance semiconductor device or controlled air gap.

6.8 EQUIPMENT UNDER TEST (EUT) – Generic reference to the equipment, component or system being evaluated.

6.9 FAULT – An event that results in unintended current flow.

NOTE: Most fault current paths considered in this standard will include the FF body.

6.10 FAILURE – A condition in which a component's electrical safety function is compromised.

NOTE: See Informative Annex E for examples of typical failures considered in this standard.

6.11 FIRE FIGHTER (FF) – A person who has demonstrated the knowledge and skills to function as an integral member of a fire fighting team under direct supervision in hazardous conditions. A fire fighter is required to wear PPE and is trained in the use of that PPE.

NOTE 1: For the purposes of this standard, it is assumed that a fire fighter will have:

a) A base level of fire fighting training;

b) An established hierarchy of command and responsibility;

c) A minimum amount of PPE; and

d) A common set of fire fighting tools.

NOTE 2: See NFPA 1001 or appropriate equivalent standard for further information on qualifications of fire fighters.

6.12 FIRE FIGHTER (FF) INTERACTION – An action that may occur during the performance of a task that subjects the FF to contact with array equipment or components.

6.13 FUNCTIONAL SAFETY – Part of the hazard reduction for emergency responders, which depends on the correct execution of specific functions performed by mechanical assemblies, electrical circuits, components, or software.

NOTE: Mechanical assemblies may include inherent or passive construction features or hazard reduction means that may be part of the PVHCE or PVHCS.

6.14 HAZARD LEVEL (HL) – A defined criteria for reactions to exposure current as stated by IEC 60479-1 as modified for adult females as shown in Table 8.

6.15 NORMAL CONDITION – Un-faulted state, after the activation of an automatic RSS system.

6.16 PERSONAL PROTECTIVE EQUIPMENT (PPE) – The full complement of FF garments that are normally required for structural fire fighting, including turnout coat, protective trousers, fire fighting boots, fire fighting gloves, a protective hood, a helmet with eye protection, a self-contained breathing apparatus (SCBA) and a personal alert safety system (PASS) device.

NOTE 1: For the purposes of establishing baseline risk factors, the requirements of this standard assume that FF are equipped with standard and basic levels of PPE, and are trained in the following:

a) The proper use and maintenance of protective equipment;

b) An understanding of when personal protective equipment is necessary;

c) An understanding of the kind of protective equipment that is necessary;

d) An understanding of the limitations of personal protective equipment in protecting FF from injury; and

e) Proper procedures for putting on, adjusting, wearing, removing and maintaining personal protective equipment.

NOTE 2: See NFPA 1001, Chapter 3, or appropriate equivalent standard for further descriptions of personal protective clothing and equipment. See NFPA 1971 or appropriate equivalent standard for further information on protective ensembles for FFs. See NFPA 1981 or appropriate equivalent standard for further information on types of SCBA.

6.17 PV HAZARD CONTROL COMPONENT (PVHCC) – A component of a PVHCS. PVHCC are often incomplete but may serve a function related to compliance of PVHCS. Examples may include the physical barriers associated with Enhanced Protection.

6.18 PV HAZARD CONTROL EQUIPMENT (PVHCE) – A complete piece of equipment evaluated for compliance with this standard (in addition to other applicable normative standards in Section 5) that performs function (s) related to reduction of electric shock hazards for FFs performing their work in the vicinity of the PV array.

6.19 PV HAZARD CONTROL SYSTEM (PVHCS) – Systems of one or more PVHCE and other specific or generic specified PV array equipment that have been evaluated to comply with the system requirements of this standard when installed in accordance with the manufacturer's installation instructions.

6.20 VOLTAGE, PVHC MAXIMUM CIRCUIT (PVHC Maximum Circuit Voltage) – The highest voltage within a PVHCS that is available after PVHCS actuation which may take action to segment a PV string or array. Where applicable, this voltage includes temperature correction for photovoltaic module maximum open-circuit voltage based upon the lowest rated PVHCS operating temperature. If it is not otherwise defined in the specific PV module ratings the PVHC Maximum Circuit Voltage is 1.25 times the rated PV module Voc at Standard Test Conditions (STC).

NOTE: The PVHC Maximum Circuit Voltage will be the same as the NEC 690.7, PV maximum system voltage if the PVHCS does not segment the PV array. Some PVHCS partition an array or string into multiple segments which are less than the PV Maximum system voltage.

6.21 VOLTAGE, EXPOSURE (exposure voltage) – The highest voltage between two points to which a FF is available to contact through the specified interactions after PVHCS actuation including any applicable isolation or attenuation (where applicable). This voltage includes temperature correction (based upon the lowest rated PVHCS operating temperature) for photovoltaic module maximum open-circuit voltage or electronic device output voltages ratings, which may take action to segment a PV string or array. This maximum exposure voltage is used to calculate the exposure current considering the PV array, PVHC circuit characteristics, FF tool, PPE and FF body resistances.

NOTE: The exposure voltage value depends on the FF interaction and is equal to the PVHC maximum circuit voltage or lower if the PVHCS provides protection to limit exposure.

6.22 REINFORCED INSULATION – A single insulation system applied to live parts, which provides a degree of protection against electric shock equivalent to double insulation under the conditions specified.

NOTE: A single insulation system does not imply that the insulation must be one homogeneous piece. It may comprise several layers which cannot be tested singly as basic or supplementary insulation.

6.23 STRING – A circuit of one or more series connected PV modules including but not limited to interconnection conductors, wiring devices, UL 1741 compliant PVRSE or other equipment.

6.24 STRUCTURAL FIRE FIGHTING – The activities of rescue, fire suppression, and damage mitigation on or in buildings.

6.25 SUPPLEMENTARY INSULATION – Independent insulation applied in addition to basic insulation in order to provide protection against electric shock in the event of a failure of basic insulation.

6.26 WIRE MANAGEMENT / SECUREMENT SYSTEM – Methods within a PV array that do not involve enclosure of wires in raceway or conduit, such as wires or bundles of wires secured to a racking system, cable tray or channel by the use of clips, clamps, ties, or similar restraining components.

CONSTRUCTION

7 Array Component Requirements – PVHCS Requirements

7.1 PVHCS compliant with this standard are shown in a safety analysis to have sufficiently reduced shock hazard current exposure to FF during specific interactions by one or more of:

a) Limiting current flow between points of likely FF contact to within thresholds as defined in the standard, or

b) Limiting voltage between points of likely FF contact to within thresholds outlined in the standard, or,

c) Sufficiently demonstrating the low likelihood of FF contact between points that have higher thresholds of current or voltage.

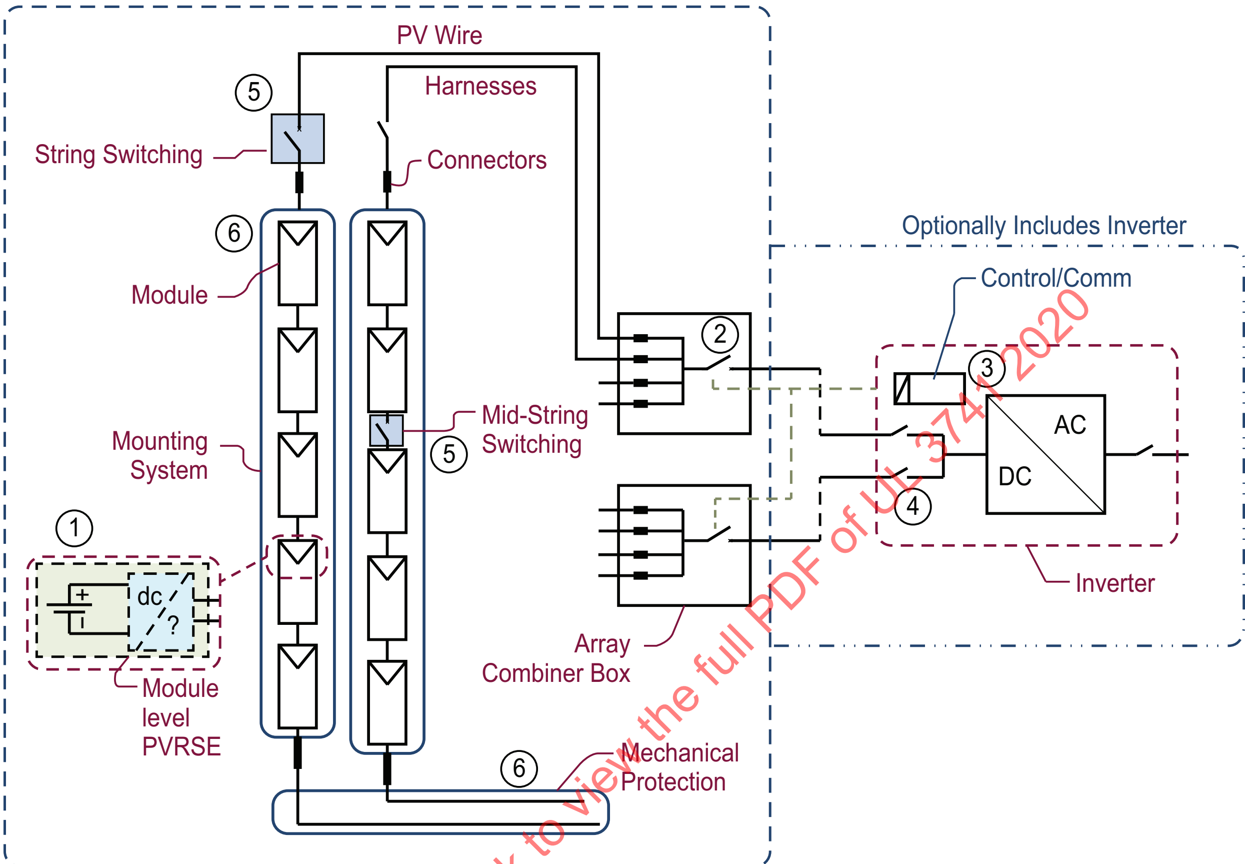
NOTE: This standard recognizes the limitation of equipment installed to provide electrical safety when that equipment may be subjected to damaging conditions exceeding those addressed by typical safety standards. Due to the nature of the scope of this standard therefore, a probabilistic assessment of risk is inherent in the evaluation. As such, there is no single set of component or equipment construction requirements. Systems relying on mechanical protection, separation, or isolation will rely more heavily on design/construction measures than those with an inherently low operating voltage, for example.

7.2 Figure 1 shows examples of potential PVHC implementations relative to the scope of this standard, including a collection of likely or possible components. This standard is intended to supplement the required applicable equipment and component standards. The PVHC evaluation under this standard is only required for the components and equipment identified as necessary to achieve the required level of shock hazard reduction.

7.3 A PV hazard control system may be comprised of either components or an individual piece of equipment that fulfills the necessary functions, or multiple pieces of equipment coordinated to perform the functions as defined in the installation instructions to reduce but not eliminate risk of electric shock hazard within a damaged PV array during fire fighting procedures.

Figure 1

Example PVHC implementations



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NOTE: Examples of array equipment that may provide hazard reduction as identified by numbers in Figure 1 include:

(1) Power electronic devices within the string, on or within module(s) that separate strings into lower voltage segments.

(2) PVRSE Combiner box level switching devices performing a PVHC function intended to isolate or attenuate PV output circuits from inverter, other strings and/or from intentional or unintentional ground potential reference.

(3) Control and communication devices that coordinate switching or attenuation.

(4) Inverter PV input circuit disconnection and isolation.

(5) String or sub-string level switching (electrical or electromechanical isolation or attenuation) devices inserted into the string wiring located within the array specifically for the PVHC function.

(6) Mechanical and or access prevention enhanced protection provided by mounting system hardware, enhanced physical protection/barrier of modules, wiring and wire management, separation of circuits, etc.

7.4 PVHC systems shall be built with equipment and components compliant with the applicable standards for the specific purpose. The component and equipment compliance standards shall be documented in the safety analysis.

NOTE: See Informative Annex E worksheets for common PV equipment and components compliance standards.

7.5 PVHCC and PVHCE that is not evaluated and rated for outdoor application in PV systems as required by 7.4 shall be evaluated under UL 1741 and using the environmental ratings from UL 1741, Table 88.1, for the rated installation location in the PVHCS. All roof top mounted PVHCC and PVHCE located within the array boundary that are relied upon to perform protective functions shall have a minimum 4x or IP65 rating or be subjected to the corresponding enclosure test on the component, equipment or assembly.

8 Protection Requirements

8.1 Basis of requirements

8.1.1 The requirements outlined in this Standard are intended to reduce the likelihood of muscle tetanization (involuntary contraction) and ventricular fibrillation from electrical shock by damaged or undamaged PV arrays during FF operations.

8.1.2 Under normal conditions and abnormal conditions evaluated under product safety standards, PV systems do not present a shock hazard. When properly installed in accordance with the manufacturer's instructions and installation codes, protection from access to live circuits, is incorporated in equipment and components and conductors. Insulation is the primary means to guard against the physiological effects described in 8.1.1. Other measures already required for PV systems, equipment and components address safety and fire-protection objectives but may not necessarily protect against these physiological effects accounting for the specific FF interactions. This standard defines additional evaluation of equipment within an array considering potential damage from FF interaction (s) to determine if additional enhanced protection mechanisms are required.

Exception: This requirement for enhanced protection does not apply for a PVHCS that does not exceed the shock hazard current limits defined in risk assessment.

8.1.3 For the purposes of reducing shock hazards in this standard, it is assumed that a FF as described in 6.11 will have training and PPE as described in 6.16.

8.2 Application of requirements

8.2.1 Protection Requirements, Section 8, applies to equipment and components of the PV array that have a potential to pose a risk of electric shock to FF. A safety analysis as defined in Section 12 shall be performed to select the components, foreseeable faults or failures, anticipated FF interactions, and performance tests in Section 13 to be evaluated for a specific PVHCS or PVHCE protection. The evaluation of a PVHCS begins with an analysis of the relevant array equipment and components as required in Section 12 of this standard:

a) Identify and list energized array equipment that can be contacted by the FF during interactions.

b) Analyze the identified equipment to determine if they pose a risk of electric shock as a result of FF interactions combined with array equipment and wiring fault conditions.

c) Determine a list of components and equipment that will be relied upon to provide protection from the shock hazard. These components and equipment shall be identified as PVHCC or PVHCE of the PVHCS.

NOTE: It is possible that several protective mechanisms will be required, in various combinations, on a single PV array to provide protection depending on the design.

8.2.2 The evaluation of a PVHC includes a determination of the effectiveness of each specific protective mechanism employed at each component of the PV array/system identified in 8.2.1.

8.2.3 The extent of performance testing required is dependent on the construction features. PVHCE that meet a minimum level of protection and/or have operational limits below the thresholds specified in this standard to reduce shock hazards can reduce or eliminate testing requirements.

9 Protective Elements

9.1 General

9.1.1 A wide range of protective elements may be employed as part of the PVHCS, including but not limited to those summarized in Referenced Publications, Section 5.

9.1.2 Electronic protective circuits and associated components of a PVHCE or PVHCS shall comply with the PVRSE and PVRSS requirements of UL 1741, including but not limited to the applicable Sections 87 – 97 for the specific functions that the equipment performs, and any applicable requirements in C22.2 No 330. This shall include the functional safety evaluation even if the electronic equipment is not designated PVRSE/PVRSS. UL 1741 requires compliance with functional safety requirements for the PVRSE and PVRSS.

9.2 PV circuit-interrupting device

9.2.1 PV circuit-interrupting devices shall revert to the isolated or attenuated condition upon activation of PVHC, upon loss of control power or upon loss of communication signal and shall interrupt power to the intended connected PV source circuitry within 30 seconds or less. The interrupting device's primary function may be to achieve one or both of the following:

a) Energized circuit segmentation (isolation).

b) Limit current flow to below thresholds defined in this standard (attenuation).

9.3 System or equipment ground circuit interrupting or attenuation

9.3.1 Circuit-interrupting (such as PV ground fault interrupters) and attenuation devices intended to disconnect or attenuate array circuits from grounded conductor(s) upon activation of PVHC, shall revert to the isolated or attenuated condition position upon loss of control power or upon loss of communication signal in 30 seconds or less.

NOTE: PV GFDI ground fault protection for ground referenced PV arrays is normally not intended to prevent shock, but this methodology to open the PV array ground bond/reference as a precaution could reduce electric shock hazards by electrically floating the array dc circuit.

9.4 Protection by enhanced protection from live parts

9.4.1 Enhanced protection measures may be achieved by the addition of another level of hazard control protection applied to PV array equipment or circuits as evaluated by this standard. This protection is added to basic, double or reinforced insulation.

NOTE: Examples may include an added physical barrier, electrical insulation or barrier, high impedance resistors or semiconductor device or controlled air gap. Some examples are shown in Table B.1 and Table B.2.

9.4.2 Protection measures comprising exposed conductive parts shall be evaluated in Section 12 for their likelihood to become energized under relevant single point failure and system level fault conditions.

9.4.3 Resistive and semiconductor devices intended to limit current to acceptable levels upon activation of PVHC, by inserting impedance into (rather than interrupting) circuits, shall comply with 9.1.2 including the requirements for PVRSE attenuation devices. These devices shall revert to the high impedance condition upon loss of control power or upon loss of communication signal within 30 seconds or less.

9.5 Limited access to live parts of different voltages

9.5.1 Protective measures to limit simultaneous access to live parts and/or circuits of different voltages, that could place a FF into a current path, may be achieved by designs placing distance between circuits, by controlled fixed spacing, by physical barriers, or equivalent means.

9.5.2 Circuits relying solely on distance between live parts of different potential that may be exposed through FF interactions that exceed defined hazard limits shall be separated by a minimum of 2.4 m (8 ft).

Exception: Live parts that may be exposed through FF interactions may be closer than 2.4 m (8 ft) if they do not exceed the PVHC shock hazard thresholds following the FF interaction evaluation in Fire fighter (FF) PV array interactions, Section 12.3.

9.5.3 Enhanced protection may be used to reduce the likelihood of contact with live parts or faults. Physical barriers may be used to limit access and prevent personnel from simultaneously contacting two or more circuits of different potentials.

9.5.4 Physical barriers comprising exposed conductive parts shall be evaluated in Section 12 for their likelihood to become energized under foreseeable single point failure and system level fault conditions.

10 Fire Fighter (FF) Current Path Resistance Determination

10.1 Body resistance

10.1.1 Annex D, Table D.1 and Table D.2, provide DC body resistance data for adult FF. This FF body resistance plus the PPE resistance is used in conjunction with the specific FF exposure voltage to calculate the potential current that could pass through the fire fighter's body during their fire fighting interactions with the damaged PV array. Annex D, Table D.2, provides a percentage multiplier for Annex D, Table D.1, values based upon the current path(s) through the body.

NOTE: The limits for adult females are roughly 2/3 of the limits for men so this standard will use the female limits.

10.2 Personal protective equipment (PPE) resistance

10.2.1 This section and the Annex D, Table D.3 and Table D.4, address the resistance of various FF PPE while it is wet with 1500μS/cm water which simulates being soaked in a higher conductivity liquid such as human sweat and or a fire fighting liquid such as water with a foam surfactant.

NOTE 1: While wetting of PPE with sea water will reduce the resistance of the PPE it was determined that fighting fires with salt water is exceedingly rare unless other freshwater alternatives are not available.

NOTE 2: FF boots are certified to provide electrical isolation and were excluded from the current pathway evaluation because new and used boots provide good electrical isolation. Once boots are worn or damaged to the point they leak water they lose isolation properties. FF boots that leak water should be taken out of service and are not considered to be serviceable PPE.

10.2.2 This standard utilizes water as the sole agent considered for testing and performance evaluation. Class A foam and water mixtures in percentages of less than 1% foam to water are sometimes used by fire departments since in low percentages, foam serves as a surfactant. Previous research has shown that the electrical conductivity of low concentration foam is higher than common tap water. Furthermore general fire service procedures for fighting fires involving PV arrays state that a foam should not be used. Blanketing or covering a PV array with a thick foam layer has not been found to have any reliable effect at blocking light and is not a recommended fire fighting practice, so has not been included in this standard.

NOTE: See https://ulfirefightersafety.org/research-projects/firefighter-safety-and-photovoltaic-systems.html for further information.

10.3 Water spray conductivity

10.3.1 Water resistance values (nozzle to electrically live target) calculated in Annex D, Table D.5, reference UL Fire Fighter Safety Report Table 6.1.4.1 with water conductivity of 1525 µS/cm, using a full stream of a distance of 3 m (10 ft).

NOTE: The UL Firefighter Safety and Photovoltaic Installations Research Project report included testing of hose spray at simulated energized PV system components. This practice has been incorporated into fire fighting training through distribution of the UL report. See https://ulfirefightersafety.org/research-projects/firefighter-safety-and-photovoltaic-systems.html for further information.

11 Indication Systems

11.1 Indication system equipment if provided, shall comply with 9.1.2.

12 Safety Analysis

12.1 General

12.1.1 PVHC systems shall have a safety analysis evaluation as described in this section that identifies key safety components and circuits of the system. The overall process is shown in Figure 2, and the steps to the safety analysis are shown in Annex A, Figure A.1 and Figure A.2. Annex F provides an additional explanation and examples.

Example documentation for the safety analysis can be found in Table A.1 and Table A.2. The analysis shall consider:

a) The compatibility of the parts of the PV system (e.g. modules, control devices, wire management systems, etc.) with regard to the hazard reduction efficacy of the overall system, and

b) The range of relevant single point failures, system level faults, FF interactions, and

NOTE: These conditions are beyond those of single point failures that are evaluated as part of equipment safety standards. Examples of some component single point failures are listed in Informative Annex E.

c) The performance tests to be conducted to assess potential hazard reduction

12.1.2 The analysis shall be performed by the manufacturer of the PVHC system, manufacturers of components of the PVHC system, or the entity that integrates the components and equipment that comprise the PVHC system. Guidance for the analysis can be found in IEC 60812, and Annex A.

NOTE: Analysis of a single components outside of a system will be limited and may or may not address all of the critical aspects of its use in the end PVHCS.

12.1.3 Electrical and electronic devices used for hazard reduction of the PV system shall comply with 9.1.2. Based upon the risk assessment for a PVHCS, the voltage and current limit inside the PV array for the PVHC identified through the application of this standard are allowed to be different than the 30 Vdc, 15

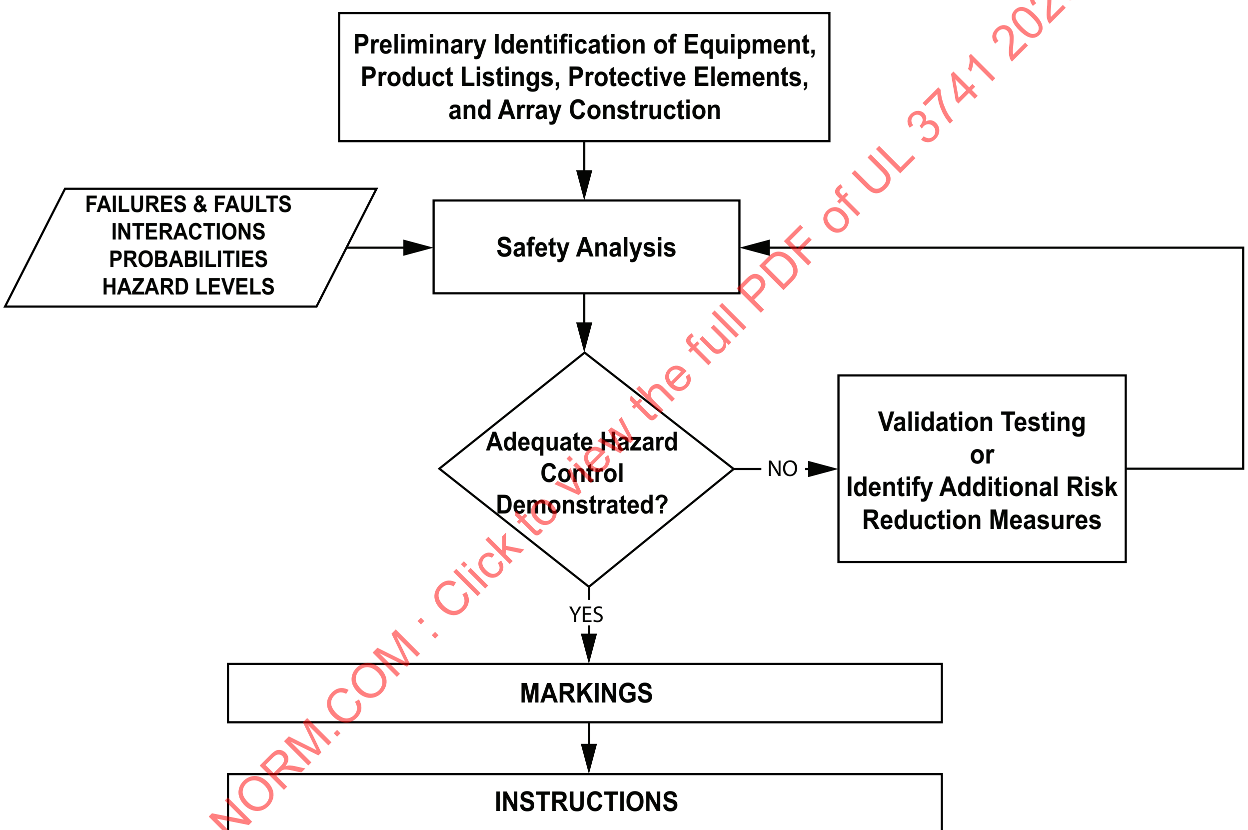
Vac and 240 VA required by UL 1741 for PVRSS and PVRSE for outside the PV array. PVRSE and PVRSS equipment, where used, shall be evaluated and rated in accordance with UL 1741 PVRSE and PVRSS requirements for the end use function and electrical conditions of the PVHCS.

NOTE: Equipment using a robust common communications protocol (such as but not limited to Sunspec PVRS communications) that have included the robust communications in the functional safety evaluation may form a reliable PVHCS provided all electronic components of the system use the same communications protocol.

12.1.4 Steps necessary to perform a comprehensive safety analysis are detailed in Section 12.2.

Figure 2

PVHC evaluation flowchart



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12.2 Safety analysis steps

12.2.1 Perform a safety analysis of the array in accordance with 12.2.2 and 12.2.3 to determine the PVHCC and PVHCE that make up the PV Hazard Control System (see Figure A.1 and Figure A.2 for flowcharts of steps).

12.2.2 Perform an analysis of the array in the normal condition in accordance with the following:

a) List array equipment located within the array boundary. All equipment with energized circuits must be included. All PVRSE or PVRSS shall be included, even where outside the array boundary. This list is expected to include wiring, raceways, mounting systems, wire management/securement systems, frames, connectors and assemblies (such as PV Modules, AC or DC combiner/wiring boxes, inverters or other power conversion equipment, disconnects, UL 1741 compliant PVRSE/PVRSS, module level electronics, module integrated electronics).

b) Identify and list equipment that is still energized or contains energized circuit components after the activation of the UL 1741 compliant PVRSS and record the associated PVHCS maximum circuit voltage for the energized circuit. Equipment under consideration includes metal surfaces, structures or components where it is likely that adjacent PV circuit conductors or components could become electrically referenced during a failure of insulation.

NOTE: See Table B.1, Common Construction Details, for guidance.

c) Of the equipment listed in (b), further identify the equipment exposed for contact by a FF body during the FF interactions identified in Table 9, FF Interactions. This requirement is related to FF body contact prior to the potential damage caused by the FF interactions and or other PV array component faults that can occur as defined by the safety analysis.

d) Determine the Hazard Level (HL) from Table 8 for all equipment identified in (c) and record associated FF contact path using Table 9, column 1. Wet conditions shall be assumed, unless the installations instructions for that equipment clearly identifies that it will only be used in dry conditions. The determination of HL is based on:

1) The product standard used for the equipment and the environmental protection evaluation that determines the insulation resistance value under wet conditions. If the product standard does not contain a test for wet insulation resistance after a preconditioning test such as ten cycles of humidity freeze (example UL1703), then such a test shall be performed. As an option to performing a wet insulation test after preconditioning, the leakage current test of 15.3 can be performed on the actual product in step 2 to determine the measured hazard level current when combined with the body and PPE resistances, and

2) The body resistances and PPE resistance from Annex D that represent the contact points previously determined in step (c) combined with the wet insulation resistance at the contact points of the equipment shall be used to calculate the current based on the PVHCS system voltage as determined by step (b). If the wet insulation resistance value is used to calculate, instead of the leakage current test of 15.3, then that value shall be the minimum value required by the product standard.

e) The hazard level shall be determined to be no higher than zero as identified in Table 8.

12.2.3 Perform an analysis of the array in the faulted condition in accordance with the following:

a) List each FF interaction identified in Table 9,

b) List array equipment from 12.2.2(b) where there is a risk of direct contact between energized circuit components and the FF body or held tool during that interaction.

NOTE: See Table 9 footnotes for further guidance.

c) For the equipment in 12.2.3(b) identify single point failure or fault that has the potential to expose a FF to energized circuits considering the following:

1) Moisture or water creating a leakage current path

2) The potential for damage from the FF interaction

3) Equipment consisting of metal surfaces, structures or components where based on the array construction, it is likely that adjacent PV circuit conductors or components could become electrically referenced during a failure of insulation.

NOTE: See Informative Annex E for guidance on equipment faults and root causes.

d) List the contact path associated with the corresponding FF interaction from column 1 of Table 9 for each of the failures identified in 12.2.3(c).

Exception: It is permitted to assume a single FF interaction using the glove to turnout gear covered hip contact path for any energized circuit component and any interaction.

e) Calculate the potential maximum exposure voltage for the energized circuit components identified in 12.2.3(b) for the corresponding FF interaction. The exposure voltage is calculated for contact points that are separated by less than 2.4 m (8 ft), unless the distance is modified by a specific interaction fault scenario.

f) Calculate or measure the source resistance and the FF current path resistance as shown in Figure A.3 and Figure A.4 from contact point 1 to contact point 2.

Exception: It is permitted to assume a source and circuit resistance value of zero for any energized circuit component and any interaction.

g) Where a secondary failure is required to create a fault current path related to the exposure voltage, document the secondary failure.

NOTE 1: See Informative Annex E for examples of equipment failures and root causes. Secondary failures can include those that may have occurred during a single FF interaction. See Annex B for guidance on fault protection and risk levels.

NOTE 2: PV dc circuit faults can occur due to wiring insulation damage that allows the conductor to come into contact with metal parts of the array (grounded or ungrounded). This type of fault may cause the dc circuit to become referenced to a metal part or parts of the array that will create a voltage potential between array metal part(s) and any circuit conductors of the opposite polarity. This fault by itself may not pose a hazard condition through FF interactions with the metal part, but needs to be considered when evaluating other failures or faults and FF interactions. A reference of the dc circuit to these metal parts may also occur due to water and moisture. Therefore, a resistive reference may also need to be considered.

h) Calculate or measure the return path resistance.

Exception: It is permitted to assume a return path resistance value of zero for any energized circuit component and any interaction.

i) For each potential fault path identified above, determine the fault current using either the worst case contact path resistance or the measured currents from the testing in Section 15. Determine the Hazard Level (HL) from Table 8. This step shall consider the following in the calculation (see Figure A.3 and Figure A.4 for examples):

1) Use the voltage value determined in 12.2.3(e)

2) Use the source and circuit resistance in 12.2.3(f)

3) Use resistance values listed in Annex D, Table D.1 – Table D.5, for the FF body model.

NOTE: The resistance values in Section 10 consider PPE to be in serviceable condition when wet.

4) Use the return path resistance in 12.2.3(h)

NOTE: The first time these calculations are performed, contact with the energized parts and a path through the body is assumed in order to identify the energized circuit components that could be hazardous to the FF. Calculations may be repeated in further stages of the safety analysis using known resistance values.

j) For any fault current path identified in 12.2.3(i) where HL is determined to be less than or equal to one, move to 12.2.3(q)

k) Using the descriptions in Table 6 calculate the Probability of Fault (Pf) by multiplying the Probability of First Failure (Pf_1) and Probability of Secondary Failure (Pf_2) together. Assign a risk level for each failure considering the following:

NOTE: The use of the terms “first” and “secondary” failures do not relate to the time of occurrence. Secondary failures will often have occurred prior to the FF interaction.

1) First failures are failures that can be caused during FF interactions. The risk for these failures are determined based on the following considerations:

i) Failures considered likely are those that lack a demonstrated hazard mitigation capability for the FF interaction.

ii) Failures considered unlikely are those where contact of the FF with the energized circuit is prevented through enhanced protection such as:

– The location of the energized circuit component prevents contact.

NOTE: See Table 9 column 3 for elevation values related to different FF interactions as examples.

– An enhanced protection component such as a physical barrier demonstrated to prevent contact.

– Components or assemblies with inherent protection demonstrated through performance testing as documented in this standard.

2) The risk level for secondary failures with root causes other than the FF interaction are determined based on:

i) System fault detection methods and maintenance procedures that will identify and correct the faults. These may be a risk level 1.

ii) Known and common failures in arrays that may not be detected. These shall be a risk level 3 unless testing or construction justifies reducing to a lower risk level. See Annex B for guidance on fault protection and risk levels.

iii) Less common failures combined with statistical probability of aligning with an event resulting in a FF interaction as identified in Table 9. These may be a risk level 2 unless testing or construction justifies a lower level. See Annex B for guidance on fault protection and risk levels.

iv) Failures that are not common or that cannot be contacted through fire fighting interactions. These may be a risk level 1. Testing or construction may also be used to justify considering these as “no action required” in Table 7.

Exception: It is permitted to use a Pf value of 3 for any component and any interaction.

l) Using Table 9 for Probability of Event (Pe), assign a risk level for each FF interaction also considering the following:

1) For the purposes of this standard it is allowed to assign a higher risk level other than the one shown in Table 9 for any FF interaction however a lower risk level number cannot be selected without a clear explanation documented in the evaluation.

2) For each applicable FF interaction where it has been determined that the FF body or tool can make direct contact with the component (Table 9 column 1), the contact path shown in Table 9 column 2 that corresponds to the interaction must be used when performing the safety analysis for that FF interaction.

3) For each applicable FF interaction in Table 9, column 3 provides the values for elevation (E) and slope (S) that are to be used for the risk level determination in columns 4 and 5. For components mounted at a fixed angle the highest elevation on that angled component shall be used for the analysis. For components that allow for multiple elevation or slope mounting methods, the minimum allowable elevation and slope values should be considered for this analysis as appropriate.

4) After determining the two risk level values for both elevation and slope (columns 4a or 4b and columns 5a or 5b) for the applicable interaction, the lower risk level value should be selected for that interaction. For arrays that do not have any restrictions on mounting (or that don't state any restrictions in their instructions) the highest risk factor must be selected for each interaction where elevation or slope impacts the risk level.

NOTE: The reason why the lower risk level is selected when there are two different numbers derived based on both elevation and slope can be best explained using some examples. Consider a PV module that can only be installed at a fixed steep angle mounted to a low-slope roof, such an component could be located close to the roof level (low elevation) however due to the steep angle of the module (high slope angle), the risk of damage from such interactions as stepping or walking on them is very low. If, however, the same mounting method is used but with the module mounted at a low slope angle, the risk for that same interaction would be higher. Similarly consider a PV patio structure installed high above a rooftop deck where the modules are installed at the same angle as the roof, though the slope of the module is low, the high elevation causes the risk of certain interactions such as stepping or walking to be low. In both examples the lower risk level overrides the higher one for each FF interaction.

Exception: It is permitted to use a Pe value of 3 for any component and any interaction.

m) Determine the frequency of occurrence (FO) level by adding Pf and Pe levels together.

n) Using Table 7, identify the cell that aligns with the FO row and the HL column for each fault current path. Determine necessary action based on the Hazard Reduction Description in Table 7.

o) For any component, including those where multiple interactions can apply to a single component, all "action required" or "action may be required" conclusions from Table 7 must be addressed.

p) Document protective elements or performance test results that lower hazard level or prevent current flow.

q) Document which components are PV Hazard Control Components or PV Hazard Control Equipment. This list shall include all PVRSE and PVRSS, as well as any components uses as protective elements identified in 12.2.3(l).

Table 6
Relative probability of events

<table>
<tr><th colspan="3">Description</th><th colspan="4">Risk Level</th></tr>
<tr><td rowspan="2">Pf = Probability of Fault Equals = (Pf_1 * Pf_2)</td><td>Pf_1 (failure 1)</td><td>Probability of First Failure – Relative probability of a component failure or fault, caused by a FF interaction, leading to the exposure of a potential hazard. (see Annex B for additional guidance)</td><td colspan="2">Unlikely = 0 : A failure is unlikely due to lack of contact by a FF body or tool, or due to demonstrable mitigation by enhanced protection.</td><td colspan="2">Likely = 1 : A failure plausibly caused by the FF interaction, and exposure to a hazard still remains despite enhanced protection, if present.</td></tr>
<tr><td>Pf_2 (failure 2)</td><td>Probability of Secondary Failure – Relative probability of a secondary component failure leading to a return fault current path shock hazard, whether due to a separate root cause or the same FF interaction that created Pf_1. (see Annex B for additional guidance)</td><td>Extremely Rare = 1 : a failure that has not been demonstrated on other arrays or is limited by more than one level of enhanced protection</td><td colspan="2">Plausible = 2 : a failure that has occurred on other arrays, but where a fault is limited by a single level of enhanced protection</td><td>Likely = 3 : a failure that has occurred on other arrays, or one that occurs during the same FF interaction that created Pf1, and where a fault is not limited by any enhanced protection</td></tr>
<tr><td>Pe = Probability of Event</td><td colspan="2">Probability of Event – Relative probability of events leading to FF exposure to hazard (FF operation puts FF in proximity or potential contact with the hazard created)</td><td>Extremely Rare = 1</td><td colspan="2">Plausible = 2 : a known condition that has occurred in the past</td><td>Likely = 3 : condition that could occur during FF duties even when following procedures (accident)</td></tr>
</table>

Table 7
Hazard reduction description

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="4">Hazard Level (HL) – see Table 8 for descriptions</td></tr>
<tr><td>Hazard Level 0</td><td>Hazard Level 1</td><td>Hazard Level 2</td><td>Hazard Level 3</td></tr>
<tr><td rowspan="3">Frequency of Occurrence: FO = (Pf + Pe)</td><td>Frequent
FO = (6)</td><td>No Action Required</td><td>No Action Required</td><td>Action Required</td><td>Action Required</td></tr>
<tr><td>Probable
FO = (5)</td><td>No Action Required</td><td>No Action Required</td><td>Action Required</td><td>Action Required</td></tr>
<tr><td>Occasional
FO = (4)</td><td>No Action Required</td><td>No Action Required</td><td>Action May Be Required</td><td>Action Required</td></tr>
</table>

Table 7 Continued on Next Page

Table 7 Continued

	Remote FO = (3)	No Action Required	No Action Required	Action May Be Required	Action Required
	Improbable FO = (2)	No Action Required	No Action Required	No Action Required	Action May Be Required
	Extremely Rare FO = (1)	No Action Required	No Action Required	No Action Required	No Action Required
The cell entries in the above table are based upon IEC 60812. Hazard Levels are based on Table 8					
Hazard Reduction Descriptions					
No action required	No additional risk reduction measures needed. IEC 60812 specifies this as “Negligible”.				
Action may be required	Additional risk reduction measures should be applied; if they are not applied, engineering rationale shall be provided, aligning with standard FF procedures; in addition, the probability of a second independent fault occurring shall be considered that could change the Hazard Level (HL). IEC 60812 specifies this as “Undesirable”.				
Action Required	Additional risk reduction measures are necessary . IEC 60812 specifies this as “Intolerable”.				

Table 8
Description of Hazard levels

Hazard Level (HL) Description (DC Current Limits for Adult Women derived from 1.33 times the IEC 60479-1 Figure 22 table values that include children)		
Hazard Level	**Range mA**	**Description**
0	0 – 2.67	Perception with slight pricking sensation. No risk of shock or reaction (Similar to IEC 60479-1 DC-1 modified for adult females.)
1	>2.67 – 40	Muscle Contraction. Insignificant threat to life or injury. May result in a reaction response. (Similar to IEC 60479-1 DC-2 modified for adult females.)
2	>40 – 100	Strong Involuntary Muscular Reaction. (Similar to IEC 60479-1 DC-3 modified for adult females.)
3	>100	For the purpose of this standard, this is the maximum allowed exposure current. This 100mA value was chosen to provide a safety factor and is 66% of the fibrillation threshold (Catastrophic – serious life or injury probable (Similar to IEC 60479-1 DC-4 modified for adult females) calculated for 5% of the adult women population.
NOTE: Level 1 and higher limits are not compliant under normal conditions as described in 12.2.2(e). Level 1, 2 and 3 limits may be compliant after accessing PVHCS abnormal conditions along with FF interactions with PVHCS as determined by following the steps in 12.2.3.		

12.3 Fire fighter (FF) PV array interactions

12.3.1 The potential interactions of FF with PV array equipment as outlined in Table 9 are considered in the standard. All interactions identified in Table 9 shall consider the following:

a) FF body contact with any tool or component is made through serviceable FF PPE as defined in Shock Hazard Thresholds for FF, Section 10.

b) For the purposes of this standard fire extinguishing agents applied on or in the vicinity of PV arrays include consideration for water with specific properties identified in Annex D see notes to Table D.3.

c) Common FF tools used for the interactions have been considered in the requirements in Section 14.

Table 9
FF interactions probability of event (Pe)

Columns	1	2	3	4a	4b	5a	5b
		Conditions		Risk Level[1]			
				Elevation		Slope[3]	
FF Interaction	FF contact path with array component to be used in the safety analysis[1]	Can FF directly contact component with body or tool? [2] Yes or No?	Elevation (E) and Slope (S) Values[3]	Component is <(E)" from roof surface	Component is ≥(E)" from roof surface	Component is <(S)° difference from the roof surface angle	Component is ≥(S)° difference from the roof surface angle
Stepping / Walking	Boot contacting component to Boot contacting component	If "No" then Risk Level =1 If "Yes" then consider elevation and slope to determine risk level	E=30.5 cm (12 in) S=10°	2	1	2	1
Crawling on	Glove contacting component to Glove contacting component		E=30.5 cm (12 in) S=10°	2	1	2	1
Falling onto	Glove contacting component to Glove contacting component		E=106.7 cm (42 in) S=0°	2	1	2	2
Falling onto with tool in belt	Tool contacting component through Turnouts to Glove contacting component		E=106.7 cm (42 in) S=0°	2	1	2	2
Falling onto with tool in hand	Glove contacting component to Glove through tool contacting component		E=106.7 cm (42 in) S=0°	2	1	2	2
Held hoseline spraying array	Knee to Glove contacting nozzle through water spray contacting component.		E=0 cm (0 in) S=0°	3	3	3	3
Ladder or ladder hooks contacts array[3]	Ladder contacting component through Glove to Glove		E=2.44 m (96 in) S=10°	2	1	2	1

Table 9 Continued on Next Page

Table 9 Continued

Columns	1	2	3	4a	4b	5a	5b
FF Interaction	FF contact path with array component to be used in the safety analysis[1]	Conditions		Risk Level[1]			
				Elevation		Slope[3]	
		Can FF directly contact component with body or tool? [2] Yes or No?	Elevation (E) and Slope (S) Values[3]	Component is <(E)" from roof surface	Component is ≥(E)" from roof surface	Component is <(S)° difference from the roof surface angle	Component is ≥(S)° difference from the roof surface angle
	contacting component						
FF holds tools and contacts array	Tool contacting component through Glove to Knee contacting component		E=2.44 m (96 in) S=0°	2	1	2	2

[1] Though several contact paths are possible for certain interactions, this table has selected one to be used in the safety analysis that is intended to represent the greatest risk for that interaction to the FF.

[2] Some array designs may allow contact with array components containing energized circuits from above or below equipment such as a PV module. This likelihood of contact may be reduced by the elevation or slope of the equipment compared to the work area (i.e. the roof) where the FF needs to perform their operations. Additionally, enhanced protection may be provided through the use of mechanisms such as physical guards or barriers may also prevent contact.

[3] Assessment of this interaction may consider any restrictions on the actual roof slope that are identified in the instructions when determining selected risk levels. For example a 10 degree or greater roof slope would make the use of a ladder probable but roof slopes below this value would generally mean that a ladder would not be used.

PERFORMANCE

13 General

13.1 PVHC equipment and systems shall be subjected to the tests described in Sections 14 and 15 as determined necessary by the Safety Analysis in Section 12.

NOTE: The safety analysis performed in Section 12 may determine that systems with inherently low shock hazard may avoid some or all of the tests defined in Sections 14 and 15.

14 PVHC System Conditioning

14.1 Potential damage from FF operations

14.1.1 The conditioning tests in this section are designed to simulate potential impacts to modules, enclosures, wireways, securement systems, and other array related equipment in the intended assembly resulting from rooftop operations by FFs. The selection and application of the EUT and applicable conditioning tests is determined in Section 12. More than one sample from a conditioning test may be required for subsequent tests of secondary failures, also defined in Section 12. A single sample is not required to be subjected to multiple conditioning tests.

14.1.2 The EUT for each of the procedures in this section shall include the equipment to be subjected to the conditioning test and any other component and/or equipment in the mechanical and electrical assembly that is relied upon for the hazard control system. The EUT shall be tested in the mechanical and electrical assembly that is representative of the intended system construction in its worst-case conditions as allowed by the installation instructions. Worst case conditions (that can most likely result in a failure) shall consider at a minimum:

a) Mechanical spacings (attachment points, securement devices);

b) Fastener and securement device types;

c) Maximum support spans (including cantilevered) and maximum component dimensions (e. g. modules);

d) Wireway or raceway fill;

e) Spacing, separation and securement of conductors; and

f) Access to circuits that may be installed along the mechanical assembly.

The tests conducted relate to worst case EUT conditions (including but not limited to the applicable items (a) – (f) above), and their rationale, shall be recorded in a table for each applicable test.

NOTE: Multiple test configurations may be required.

14.1.3 After each applicable test performed in Sections 14.1 – 14.4, the sample shall be subjected to the applicable electrical hazard exposure tests described in Section 15.

NOTE: Tests in Section 14 do not create any pass/fail criteria, as these will be results of tests in Section 15. Those test results are to be used in Section 12 to determine the potential current flow and corresponding hazard level for each FF interaction.

14.1.4 Unless otherwise specified, the tests in Section 14 shall be conducted at room temperatures of 20 to 40 °C (68 to 104°F). Deviations and their rationale shall be documented. All metrics used in testing such as distances, angles, weights, etc., shall be ±5% unless specified otherwise in the test practices.

14.2 Damage from FF tool

14.2.1 Purpose

14.2.1.1 The purpose of this test is to replicate damage imposed on a PV module, array equipment or assembly of equipment by a representative FF tool. This test is generalized sufficiently to replicate damage from the following FF interactions:

a) Fall onto exposed component(s) or equipment with attached tool;

b) Fall onto exposed component(s) or equipment with a held tool;

c) Held hose line with metallic fitting in contact with component or equipment;

d) Ladder or ladder hook on component surface; and

e) Contact with array components by FFs holding tools.

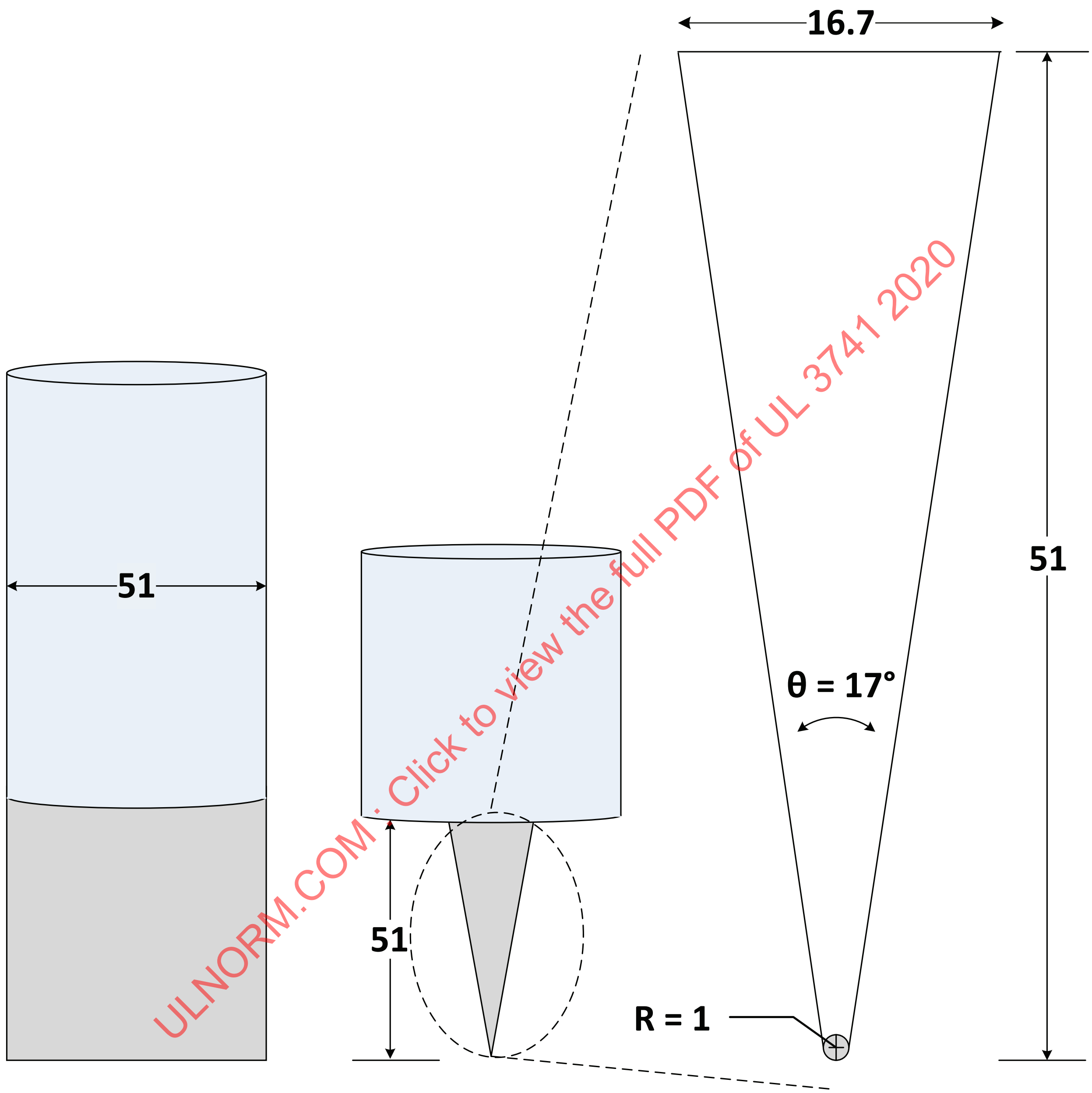
14.2.2 Apparatus

14.2.2.1 The impactor shall consist of a circular steel bar with a rectangular impactor point, dropped through a tube onto a module, component, or array assembly such that the blade edge of the tool falls perpendicular to the planar surface of the module or EUT. The component or assembly shall be mounted to a horizontal structure to maintain consistent impact energy normal to the EUT surface.

14.2.2.2 The impactor tool shown in Figure 3 shall have the following characteristics: circular bar of cold rolled steel, weighing 2.72 kg (6 lbs) with a 5.1 cm (2 in) wide impactor blade (+/-3%), a symmetric impactor angle with a blade edge radius of 1 mm +0/-0.2 mm (0.039 in +0/-0.008) The impactor tool is to be dropped from a height of 1 m (39.4 in) in order to achieve an impact energy of no less than 26.5 Joules. Variability in the weight and drop height is permitted as long as the required impact energy is maintained. The 17° angle in Figure 3 is approximate.

Figure 3

Impactor tool blade edge (all dimensions in mm)



su3683a

Conversion information:

51 mm (2 in)

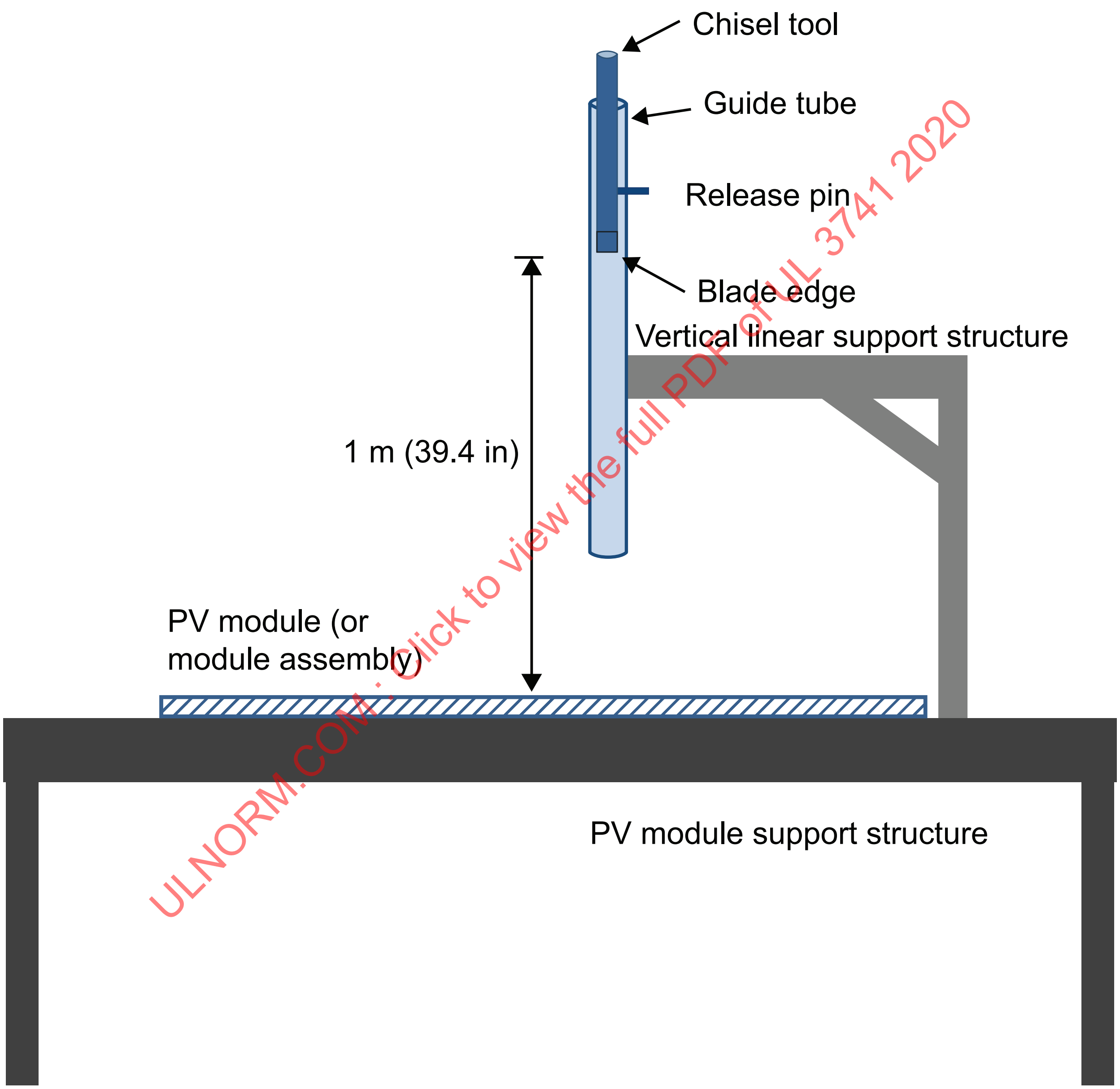
16.7 mm (0.66 in)

1 mm (0.04 in)

14.2.2.3 The impactor tool apparatus shown in Figure 4 shall be constructed such that the impactor tool is sufficiently guided by the tube to result in a consistent sharp edge impact on the EUT, without limiting the required impact energy through friction or air pressure The tool is permitted to impact the surface multiple times if it bounces off the test surface.

Figure 4

FF tool impact test apparatus



su3684a

NOTE: Figure 4 shows impact somewhat centered on the PV module, but it must be determined where the most vulnerable location(s) is. The most vulnerable impact point may be at an edge or corner of the panel.

14.2.3 Procedure

14.2.3.1 Mount the module, enclosure, or other equipment sample so that it is centered on a horizontal rigid test surface using the method and parts described by the manufacturer, including a defined torque if screws are used for mounting and any described racking system.

14.2.3.2 Select the most critical impact location or locations on the EUT. Selection of the location should consider factors such as location of module busbars, junction boxes, proximity to other equipment or components, etc., where the lowest impedance paths for current exist. Secure the impactor assembly relative to the EUT such that the blade edge falls normal to the planar surface. Lift the impactor to the nominal (subject to variation) drop height of 1 m (39.4 in) measured vertically to the EUT surface. Allow the impactor to stabilize and then release it to strike the EUT sample. The blade chisel point shall be rotated / oriented such that it is most likely to contact live parts.

14.2.3.3 Any visible evidence of damage, deformation or creation of sharp edges of the EUT shall be documented by the test laboratory, along with the impact location (s) and intended blade chisel point rotation angle(s) relative to the module orientation. See 14.1.3.

14.3 Damage from falling FF

14.3.1 Purpose

14.3.1.1 The purpose of this test is to replicate damage imposed on a PV module, array equipment or assembly from a FF falling on the equipment. The PV module, assembly or array equipment shall be tested either to 14.3.3 or 14.3.4. PV modules or array equipment that were tested to 14.3.3 do not need to be tested to 14.3.4.

14.3.2 Apparatus

14.3.2.1 The impactor shall be a circular, flexible but firm (canvas for example) bag made of a material capable of retaining the required fill weight (e. g. steel balls or pellets that do not have sharp points or irregular shapes) and maintain physical integrity throughout the test without loss of fill material. The bag shall not have hard protrusions such as metal hardware attachment points in the bottom impact area. When filled, the impactor bag shall have dimensions as described in Figure 5 and a weight of 125 ±0.5 kg (275 ±1 lb) (representing a large FF with FF equipment). The diameter of the bottom surface which impacts the EUT shall be no more than 0.3 m (1 ft), resulting in a surface area of no more than 0.071 m^2 (0.76 ft^2). Variability in the weight and drop height is permitted as long as the required impact energy of 1225 Joules is maintained.

NOTE: Impact Energy E (J) = Drop height (m) x bag weight (kg) x 9.81 m/s^2.

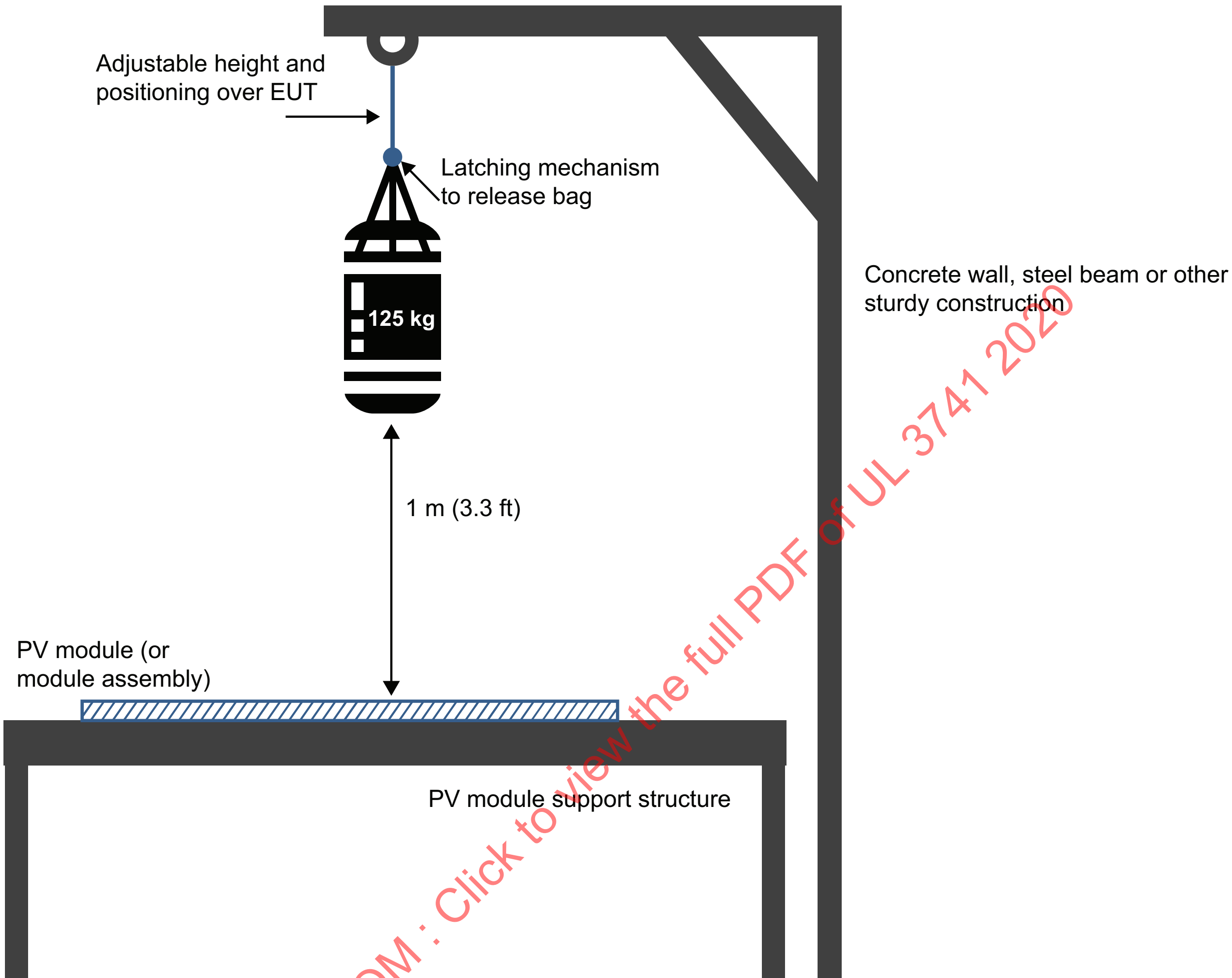
Figure 5

Impactor representative of a FF body

14.3.2.2 A test frame similar to that shown in Figure 6 shall be provided to minimize movement and deflection during testing. The structure framing and bracing shall be steel channel, approximately 100 mm (3.9 in) x 200 mm (7.9 in) or larger and shall have a minimum area moment of inertia of approximately 187 cm^4. The frame shall be welded or securely bolted at the corners to minimize twisting during impact. It shall also be bolted to a rigid floor to prevent movement during impact testing.

Figure 6

Test frame for impactor



su3685

Conversion information:

125 kg (275 lb)

14.3.3 Procedure – module or other array equipment test

14.3.3.1 This section is to be applied if the EUT is a single piece of equipment such as a PV module or electrical enclosure.

14.3.3.2 Mount the module, enclosure, or other equipment sample so that it is centered and rigid on a horizontal test frame using the method and parts described by the manufacturer, including a defined torque if screws are used for mounting.

14.3.3.3 Select the most critical impact location on the EUT as agreed upon by the manufacturer and the testing laboratory applying this standard.

14.3.3.4 Lift the impactor to a drop height of 1 m (3.3 ft) from the surface of the EUT sample, allow the impactor to stabilize, and then release it to strike the EUT. Variability in the weight and drop height is permitted as long as the required impact energy of 1225 Joules is maintained.

14.3.3.5 Any visible evidence of damage, deformation, or creation of sharp edges of the EUT shall be documented by the test laboratory, along with the impact location(s).

14.3.4 Procedure – mechanical assembly test

14.3.4.1 This section is to be applied if the EUT is an assembly e.g. consisting of a module and/or other electrical components along with a specific mounting structure.

14.3.4.2 Mount the module or equipment in the mechanical and electrical assembly that is representative of the intended system construction, as prescribed by the installation instructions and within the specified range of the product tilt angles. The orientation and tilt angle shall be representative of the worst case (typically the lowest angle) with respect to the potential damage and drop the bag vertically.

14.3.4.3 In the absence of a specified tilt range for the racking system, the assembly shall be mounted horizontally. If the EUT consists of modules in a racking assembly with an adjustable tilt angle, that racking assembly shall be tested at the minimum design tilt angle.

14.3.4.4 Where a module, array equipment or assembly is designed to be installed at a minimum tilt angle of the module surface relative to a horizontal plane greater than zero, that minimum tilt angle shall be specified in the manufacturer's instructions.

14.3.4.5 Select the most critical impact location on the EUT.

14.3.4.6 Lift the impactor to a drop height of 1 m (3.3 ft) measured from the center of impact to the EUT sample, allow the impactor to stabilize, and then release it to strike the EUT. Variability in the weight and drop height is permitted as long as the required impact energy of 1225 Joule is maintained.

14.3.4.7 Any visible evidence of damage, deformation, or creation of sharp edges of the EUT shall be documented by the test laboratory, along with the impact location(s).

14.4 Damage from FF step, walk or crawl

14.4.1 Purpose

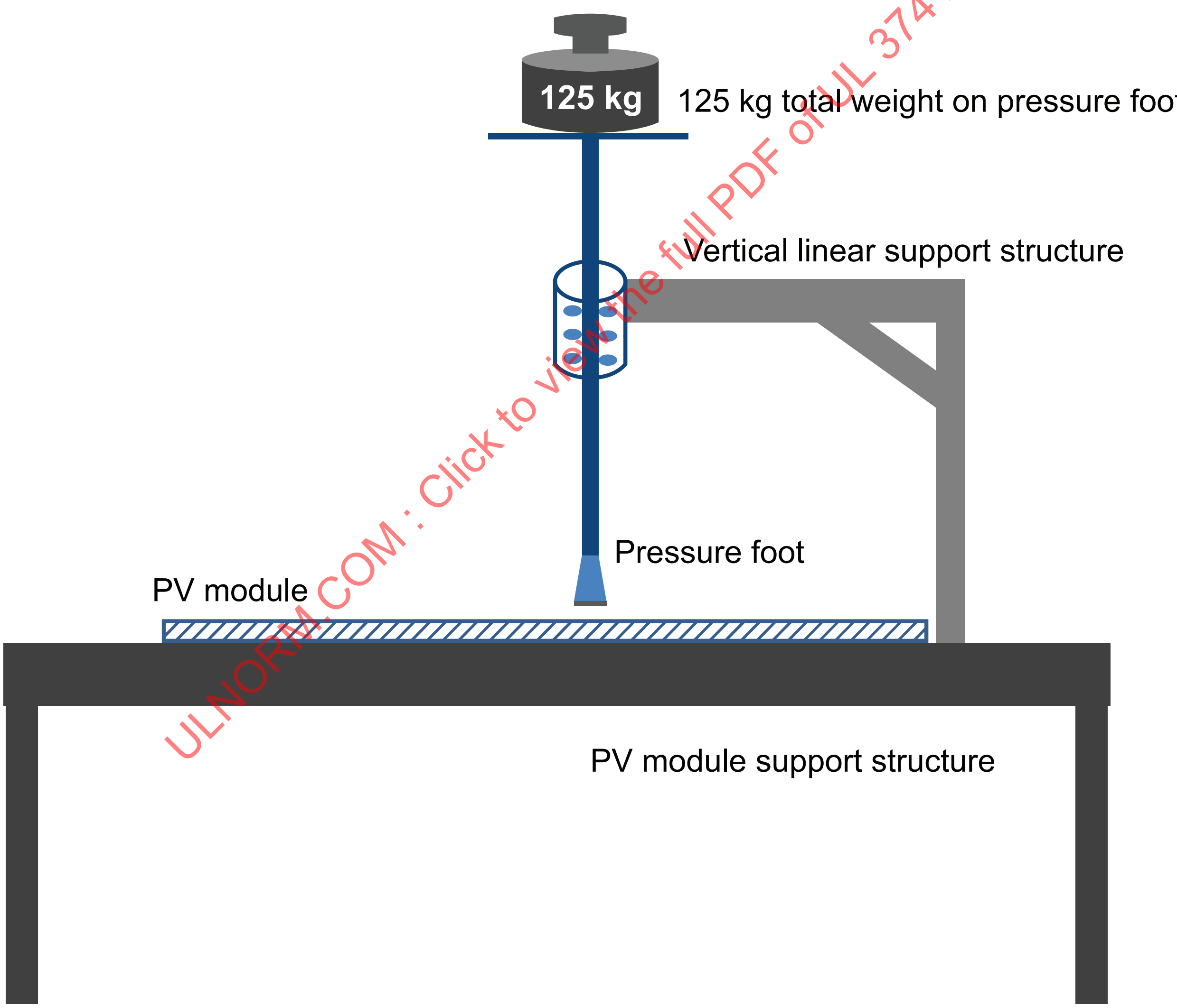
14.4.1.1 The purpose of this test is to replicate the impact on a PV module, array equipment or assembly of a FF walking or crawling on the equipment. Equipment or components intended for installation only in protected areas such as underneath modules or array mounting equipment need only be tested in the intended assembly, and not separately subjected to this test. Restrictions on mounting locations for exempted equipment shall be specified in the installation manual. PV modules mounted on a racking assembly with a minimum tilt angle of 20 degrees or more are exempt from this test provided that the applicable minimum tilt angle is specified in the instructions.

14.4.2 Apparatus

14.4.2.1 The pressure foot shall be a static loading device capable of applying a 1225 N (275 lbf) force on surface of the EUT, as illustrated in Figure 7. The pressure foot shall utilize a 7.6 cm (3 in) diameter circular steel plate adhered with a flat rubber or polymer pad. The pad shall be 9.5 mm (3/8 in) thick with a Shore A hardness ranging from 65 – 75 with beveled or chamfered edges.

Figure 7

Pressure foot



su3686

Conversion information:

125 kg (275 lb)

14.4.3 Procedure

14.4.3.1 Mount the module, enclosure, or other equipment sample so that it is centered and rigid on a horizontal test frame using the method and parts described by the manufacturer, including a defined torque if screws are used for mounting.

14.4.3.2 The load shall be applied 2 times at the most critical location on the EUT as agreed upon by the manufacturer and the testing laboratory applying this standard. While this is not a dynamic load test, weight, if added incrementally, shall achieve the full rated load within 60 seconds of the test initiation. The full load shall be applied for a minimum of 30 seconds, then removed for a minimum of 30 seconds. Any visible evidence of damage, deformation, or creation of sharp edges of the EUT shall be documented by the test laboratory, along with the impact location(s) after the 2 cycles are completed.

15 Hazard Exposure

15.1 FF impedance circuits

15.1.1 The current measurements made in this Section are to be used to determine the potential current flow and corresponding hazard level for each FF interaction covered in Section 12.

15.2 Source test circuits

15.2.1 Source circuits for leakage current measurements shall incorporate the following:

a) The PVHC maximum circuit voltage allowed by the hazard control system, e.g. module level, sectionalized strings, string level.

b) The exposure voltage under fault conditions identified in the safety analysis.

c) The source impedance of the PV module, string or array given the largest capacity allowed by the hazard control system.

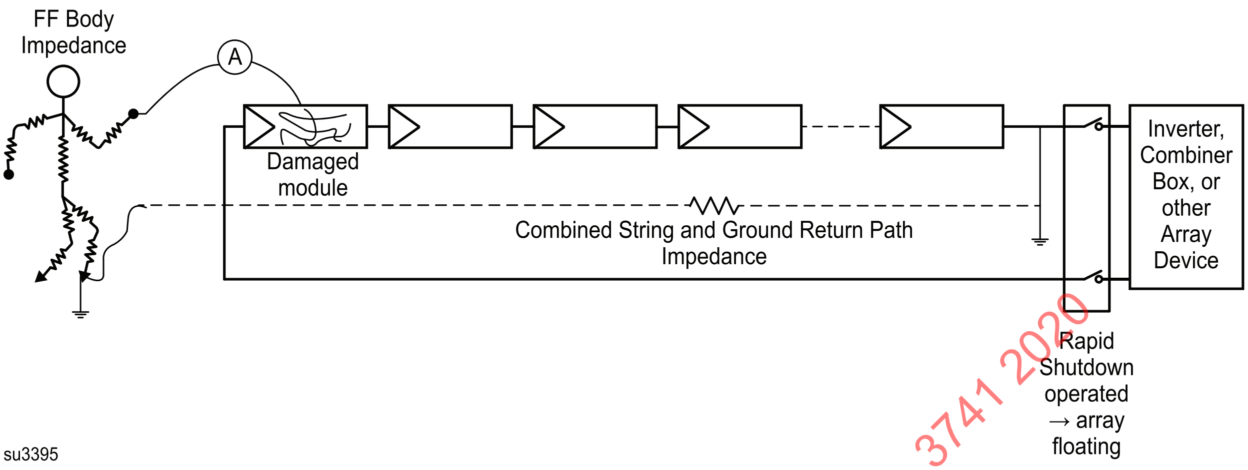
d) The combined applicable FF and PPE resistance from Section 10 for the interaction scenarios identified in the risk assessment.

e) Any additional impedances in the current path as determined by the safety analysis, such as ground fault return path impedances (See Figure 8).

NOTE: Unless expressed otherwise, all impedances are called out as resistances in the context of FF and FF PPE as all human body impedances are expressed as resistances.

Figure 8

Source circuit impedances



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15.3 Leakage current tests

15.3.1 Module leakage current test

15.3.1.1 Purpose

15.3.1.1.1 The purpose of this test is to quantify the potential leakage current from a PV module sample in a test array circuit that has been subjected to potential damage from the FF interaction impact tests in Section 14. Leakage current is measured across the module glass or polymer surface at a circuit voltage elevated to represent the PVHCS maximum circuit voltage provided by the intended hazard control system. Various resistive circuits are included to represent combined FF body and PPE resistance, fault resistances, and source series resistances shown as "Resistance network" in Figure 9.

NOTE: Consideration for PV module representative testing shall consider materials, construction methods and electrical ratings.

15.3.1.2 Apparatus

15.3.1.2.1 The test assembly is shown in Figure 9.

a) The module is to be secured in the same mounting system that complies with UL 2703 that was used when conducting the Section 14 impact tests.

b) The EUT glass is to be covered with a layer of cotton sheet with a minimum thread count of 300 threads per inch (600 threads per square inch), and a minimum weight of 120 g per square meter. For PV modules with conductive frames and or mounting structures, leave at least 20 mm (0.8 in) of clearance to metal frame or any mounting structure on all sides of the electrode described in d) so there is no direct conductivity between the frame and the wetted cloth. Alternatively, an insulating dam maybe placed between the frame and foil electrode to prevent a shunt current path for the measurement circuit.

NOTE: The cotton sheet is intended to retain the extinguishing water and conform to the contour of the broken PV module surface while providing a conductive path for the measurement circuit.

c) The cotton sheet is to be soaked with specified extinguishing water (the same water as specified in 15.3.2.2.1 for the Leakage Current Test) over the entire module surface to the point when water begins to run off and is to be applied between the module front glass and the electrode to provide a sufficient water film.

d) Cover cotton sheet with aluminum (or other recommended electrode) foil, again maintaining 20 mm (0.8 in) clearance to frame.

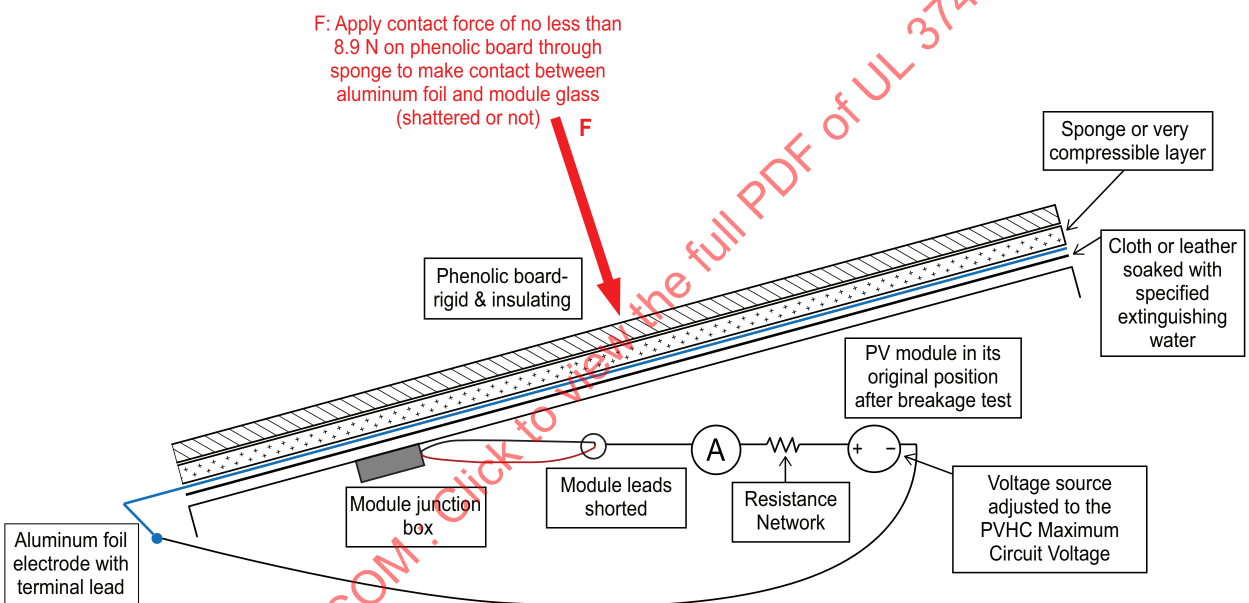
e) Cover aluminum foil with approximately 50 mm (2 in) thickness of compressible material (such as an open-cell polyurethane foam) suitable to maintain electrical contact between the foil and test surface.

f) Wipe any excess water for at least 20 mm (0.8 in) from the aluminum foil edges.

g) The final layer is to be a 10 or 15 mm (0.4 or 0.6 in) thick board of a hydrophobic material such as phenolic, polycarbonate, acrylic or other similar polymeric material which is insulating and rigid enough to transfer contact force on the aluminum foil even if glass is uneven.

Figure 9

Module assembly leakage current test



su3396c

15.3.1.3 Procedure

15.3.1.3.1 The following sequence of steps 15.3.1.3.2 through 15.3.1.3.6 are intended to be performed without interruption and initiated within 5 minutes of saturating the cotton sheet as described in 15.3.1.2.1 (C):

15.3.1.3.2 Connect the DC voltage supply, ammeter, and resistive circuit (representing FF body and PPE resistances, source and fault impedances) to the shorted PV connectors on one end, and the electrode foil on the other end.

15.3.1.3.3 Apply a minimum force to the board to provide uniform contact of the sponges to the glass around any damaged areas. Some means may be necessary to prevent the board from moving during the test.

15.3.1.3.4 The magnitude of pressure shall maintain electrical contact but not cause (additional) damage to the EUT.

15.3.1.3.5 Once the force is stabilized for a dwell time of 1 minute, raise the dc voltage source from zero to the PVHC maximum circuit voltage provided by the intended hazard control system and hold the voltage for 1 minute.

15.3.1.3.6 Record current values at a maximum interval of 1 second and record the stabilized current value and the length of time for the current to stabilize.

15.3.1.3.7 Repeat using other resistance circuit values as determined necessary by the risk analysis.

15.3.2 Enclosure or other component leakage test

15.3.2.1 Purpose

15.3.2.1.1 The purpose of this test is to quantify the potential leakage current from wetted PV system equipment or component(s) in a test array circuit that has been subjected to potential damage from the FF interaction impact tests in Section 14. Various resistive circuits may be included to represent combined FF body and PPE resistance, fault resistances, and source series resistances.

NOTE: Consider that certain components may contain sensitive protective equipment that may be damaged when subjected to these tests. Refer to the manufacturer in case of doubt.

15.3.2.2 Apparatus

15.3.2.2.1 The apparatus shall include the following:

a) A water/wetting agent solution meeting the following requirements:

1) Conductivity: 1500 μS/cm or more

2) Temperature: 22 ± 3°C (71.6 ± 5.4°F)

b) Cotton sheet as specified in 15.3.1.2.1 to wrap the DUT before wetting.

c) Sprayer to thoroughly wet the EUT.

d) A 127 mm x 229 mm (5 in x 9 in) and at least 25 mm (1 in) thick, open cell polyurethane foam wrapped in aluminum foil terminated with an alligator clip to make electrical contact

e) DC voltage source, with current limitation, capable of applying the PVHCS maximum system voltage or the PVHCS maximum circuit voltage if the PVHCS segments the PV array after actuation.

f) Resistive circuit representing FF body and PPE resistances, source and fault impedances.

g) Instrument to measure leakage current.

NOTE: Since the voltage driving any potential leakage current is purely DC, any potential capacities and inductances in the PV circuit can be neglected.

15.3.2.3 Procedure

15.3.2.3.1 The following sequence of Steps 1 – 7 are intended to be performed without interruption:

1. Connect the shorted terminals of the component to the positive terminal of a DC power supply with a current limitation. Set the current limit to 1 A.

2. Spray the cotton sheet with the solution to the point when water begins to run off.

3. Connect the foil wrapped sponge probe to the negative terminal of the DC power supply.

4. Increase the voltage applied by the tester at a rate not exceeding 500 V/s from zero to the PVHCS maximum circuit voltage.

5. Apply the foil wrapped sponge probe to surface cracks, gaps and other openings on the surface of the DUT as applicable. Use sufficient force on the foil wrapped sponge probe to make contact with the surface under test.

NOTE: Use appropriate voltage rated PPE to prevent electric shock during this test.

6. Record any resulting leakage current.

7. Repeat 5. and 6. using the foil wrapped sponge pressed on other damaged surfaces of the DUT enclosure.

8. Repeat using other resistance circuit values as determined necessary by the risk analysis.

15.3.3 Array leakage measurements within array assemblies

15.3.3.1 Where the EUT consists of array assemblies, test circuits defined in Sections 15.1 and 15.2 shall be used to measure leakage currents between points within the assembly and within 2.4 m (8 ft) of one another. The points shall consider the following criteria:

a) Where FF interaction tests in Section 14 result in two or more locations within the assembly that have sustained damage and/or led to additional circuit exposure,

b) Where FF interaction tests in Section 14 have disabled or compromised control circuits that are essential elements of the hazard control system.

c) Where failure or faults (such as ground faults) identified in the Safety Analysis, Section 12, create potential current paths between components damaged in the Section 14 interaction tests and specified surfaces.

MANUFACTURING AND PRODUCTION TESTS

16 General

16.1 The manufacturing and production testing shall be done in accordance with the applicable component or end product standard accounting for the functionality of the PVHCE or PVHCS.

MARKINGS

Advisory Note: In Canada, there are two official languages, English and French. Annex C provides translations in French of the English safety markings specified in this standard. Markings required by this standard may have to be provided in other languages to conform with the language requirements of the country where the product is to be used.

17 General

17.1 The markings including signage required for compliance to this standard shall be legible and permanent such as metal stamped, etched, adhesive labels, etc. An adhesive-backed label shall comply with the requirements in UL 969, or C22.2 No. 0.15, for the intended exposure conditions and surface adhered to.

17.2 Markings and signage shall be in lettering that is sized so that it is legible from the distance from which is must be read and shall have lettering in a color that contrasts with the background.

NOTE: Guidance for markings and signs can be found in standards such as the ISO 3864-2, NEMA Z535.1, NEMA Z535.2, NEMA Z535.3, NEMA Z535.4, and NEMA Z535.5.

17.3 PVHC equipment and components that are critical for compliance of the PVHCS, shall be marked with the manufacturer's name, trade name, trademark or other descriptive marking which identifies the organization responsible for the product, part number or model number.

Exception: PVHC components identified in the installation instructions need not be marked on the component.

17.4 The control devices and indicators required for operation or maintenance shall be marked with their function on or adjacent to the control.

17.5 Any applicable electrical or mechanical limits, such as maximum voltage, current, temperature limitations or number of units connected together, that apply to the installation of PVHC equipment or components shall be marked on the equipment or component. The maximum voltage shall be based on the conditions of use.

NOTE: Additional requirements for marking of PV systems utilizing PVHC can be found in the National Electrical Code (NEC), NFPA 70, requirements for identification of rapid shutdown systems as addressed in NEC section 690.56 (C), and with the Canadian Electrical Code (CE Code) C22.1.

INSTRUCTIONS

18 General

18.1 The PVHC system shall be provided with complete instructions for installation, operation and maintenance of the system. The installation instructions include a detailed description of the installation in accordance with the National Electrical Code (NEC), NFPA 70 and the Canadian Electrical Code (CE Code), C22.1.

NOTE: For additional guidance see the Standard for Product Safety Information in Product Manuals, Instructions, and Other Collateral Materials, NEMA Z535.6.

18.2 All cautionary markings and ratings unique to the PVHC function of the equipment or system, as well as system specifications needed for installation and operation of the system, shall be included in the instructions.

NOTE: These ratings would typically include but are not limited to: PVHC Maximum Circuit Voltage, Rated Temperature Operating Range and other markings from 17.5.

18.3 PVHC instructions shall include the following: "WARNING: To Reduce the Risk of Injury, read all instructions".

18.4 Instructions shall be provided as required by the individual PVHC system, equipment and components and as necessary for the proper installation of the PHVC equipment and components.

18.5 An identified list of PVHCE and PVHCC determined to be necessary for the PV hazard control function shall be provided in the instructions.

18.6 Restrictions on the characteristics of other equipment connected to the PV array that are essential to maintain the operational integrity of the hazard control function shall be documented in the instructions.

18.7 Any design constraints that must be placed on the equipment such as; a maximum or minimum slope or angle, limitations on quantities of equipment/components and limitations on the distances or clearances, shall be included in the instructions.

18.8 Where the presence of other equipment outside the array impacts PVHC functionality, any clearance requirements such as the minimum distance from grounded metal shall be included in the instructions.

18.9 All minimum mechanical requirements, including any tolerances, for the installation of PVHCE that are necessary to maintain the operational integrity of the hazard control function shall be documented in the instructions.

18.10 If the routing or separation of conductors or cables is necessary to maintain the operational integrity of the hazard control function, all restrictions with any tolerances shall be documented in the instructions.

18.11 If the installation location of the array with PVHC system has limitations (i.e. can only be located above specific roofing materials), these location limitations shall be indicated in the instructions.

18.12 The operating instructions shall contain instructions on the testing and maintenance of the PVHC if such operations are required.

18.13 The operating instructions shall contain warnings addressing the replacement of PV system equipment, including required specifications, if the replacement of such equipment impacts the operational integrity of the hazard control function.

18.14 Based on the considerations applied in 12.2.3(c)(3) and 12.2.3(g) instructions shall be provided to installers for proper placement and installation of conductors, materials or components that are critical for compliance of the PVHCS.

ANNEX A (Normative) – SAFETY ANALYSIS

Figure A.1

Safety Analysis Flow Chart

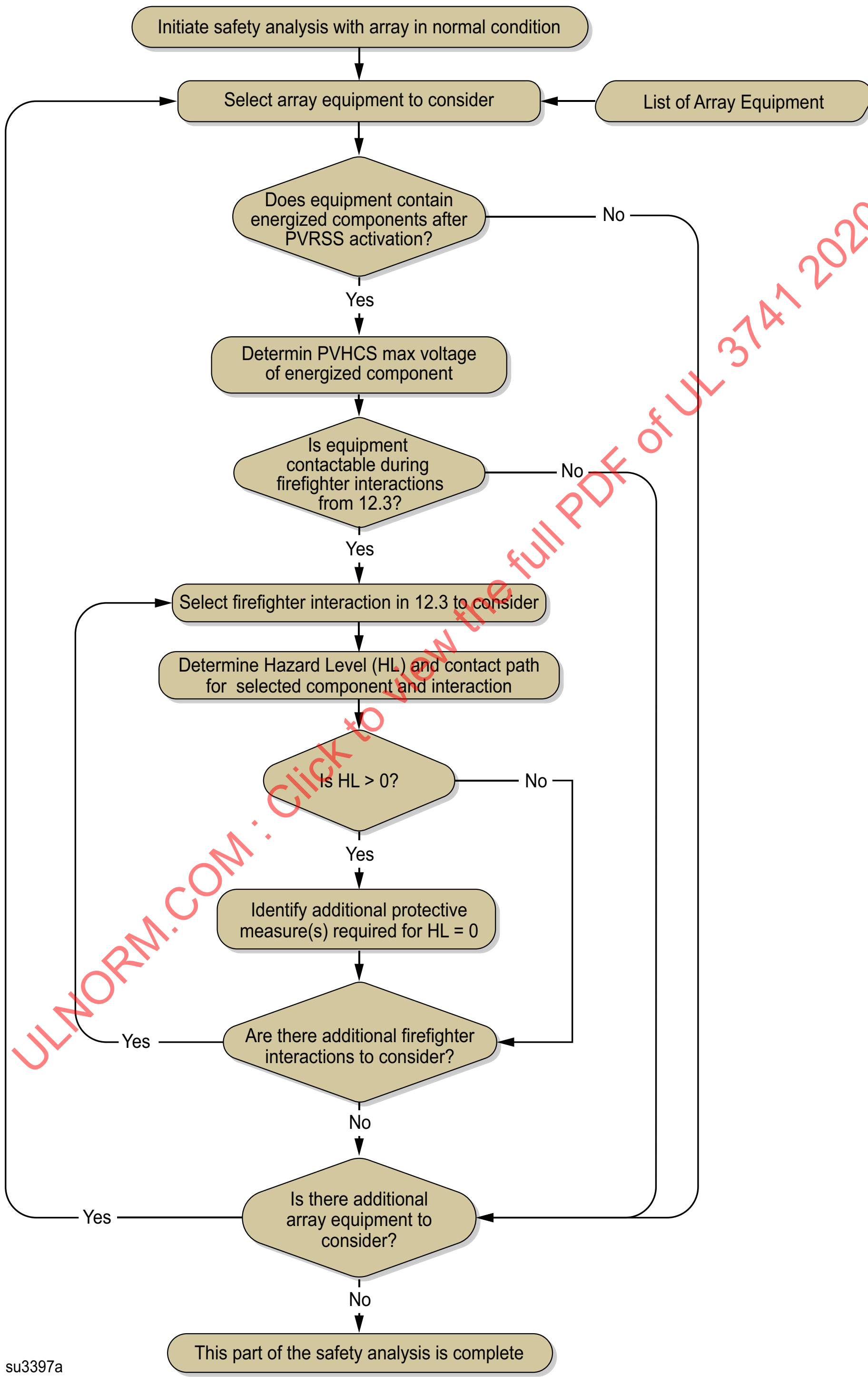


Figure A.2

Safety Analysis Flow Chart – FF Interaction Including Fault Condition

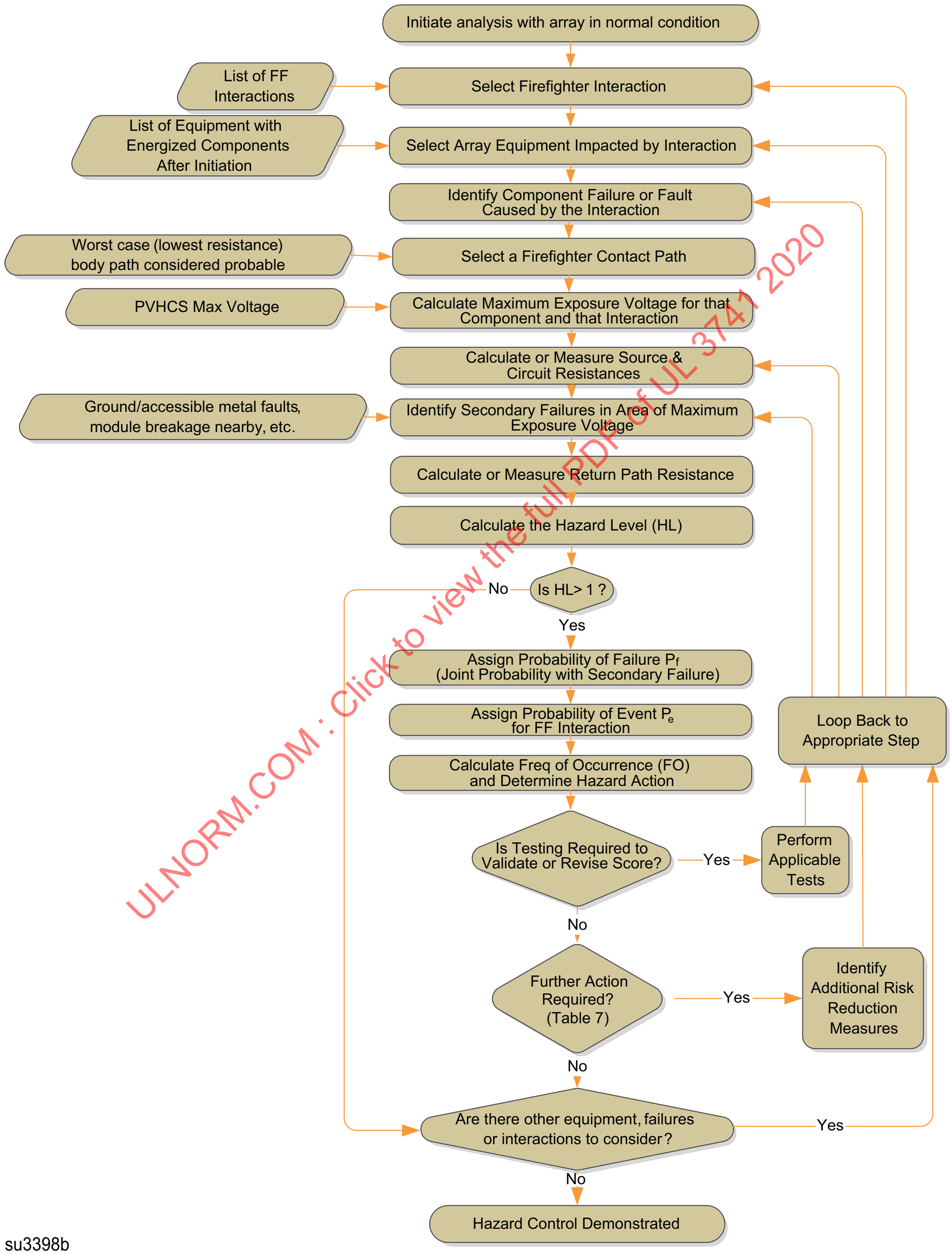


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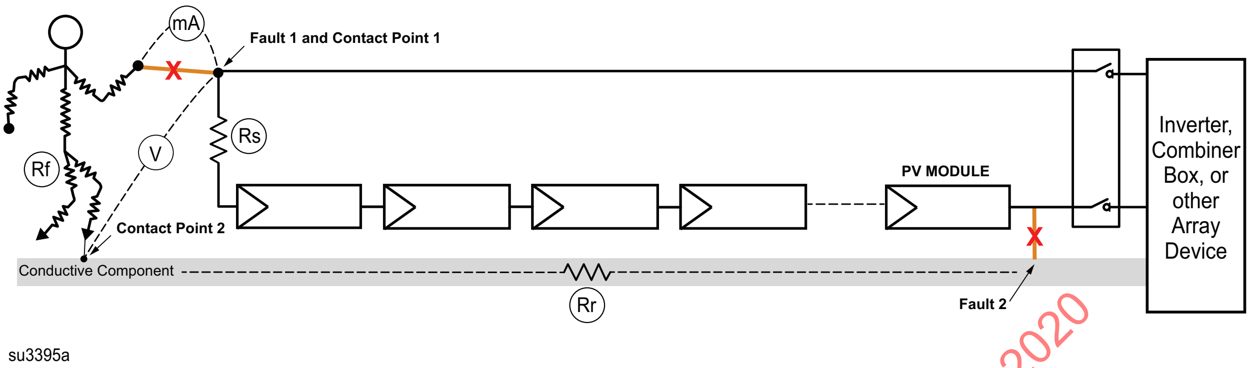
Figure A.3

Fault Current Path Example – FF Contacting Metallic Parts



CONDITIONS:

Shutdown has been initiated. Array is floating (with respect to ground/earth).

Firefighter contact with circuit conductor at contact point 1 (fault 1).

Firefighter contact with exposed conductive components at contact point 2.

New or pre-existing second fault between circuit conductor and exposed conductive component.

KEY:

mA = Calculated or measured current of entire fault current circuit path (in milliamps)

V = Calculated exposure voltage

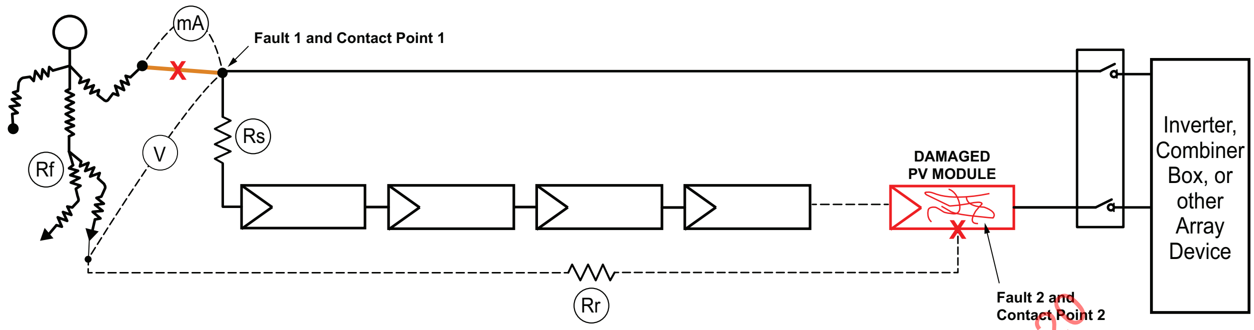
Rf = Resistance of path through FF body + resistance of PPE at contact point 1 + resistance of PPE at contact point 2

Rs = Source circuit resistance

Rr = Return path resistance

Figure A.4

Fault Current Path Example – FF Contacting Damaged Module



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CONDITIONS:

Shutdown has been initiated. Array is floating (with respect to ground/earth).

Firefighter contact with circuit conductor at contact point 1 (fault 1).

Firefighter in direct or indirect contact with damaged PV module (fault 2) through contact point 2.

KEY:

mA = Calculated or measured current of entire fault current circuit path (in milliamps)

V = Calculated exposure voltage

Rf = Resistance of path through FF body + resistance of PPE at contact point 1 + resistance of PPE at contact point 2

Rs = Source circuit resistance

Rr = Return path resistance

Table A.1
Array analysis in normal condition. Example risk analysis documentation.

Equipment within array boundary 12.2.2(a) and "Equipment list and fault/root cause worksheet" Annex E	Maximum internal voltage to ground or between circuits after activation of PVRSS 12.2.2 (b) and Annex E	List FF interaction(s) with equipment 12.2.2(c) and Table 9	Contact path 12.2.2(d)	Calculate resistance of contact path using Clause 10	Calculate current using Columns B and E	Determine Hazard level Clause 12.2.2 (d), (e) and Table 8

Table A.2
Array analysis in fault condition. Example risk analysis documentation

	FF interaction	Array Equipment	Component of energized equipment with risk of direct contact	Fault condition - pre-existing or due to FF interaction	FF Contact Path	Exposure Voltage	Calculate or Measure Source & Circuit Resistance	Identify Secondary Fault and root cause (s)	Calculate or Measure Return path resistance	Total Resistance of fault current path	Calculate fault current and determine Hazard Level (HL)	Probability of Fault (Pf)	Probability of Event (Pe)	Freq of Occurrence (FO = Pf + Pe)	HL Action	Is the equipment in "Array Equipment" required for PVHC (yes/no)
	Clause 12.2.3(a) and Table 9	**Clause 12.2.3(b) and Annex E**	**Clause 12.2.3(b) and Annex E**	**Clause 12.2.3(c) and Annex E**	**Clause 12.2.3(d) and Table 9**	**Clause 12.2.3(e), Figure A.3, Figure A.4, and Annex E**	**Clause 12.2.3(f) and Figure A.3 and Figure A.4**	**Clause 12.2.3(g), Annex B**	**Clause 12.2.3(h) and Figure A.3 and Figure A.4**	**Column "Calculate or Measure Source & Circuit Resistance" + Column "Calculate or Measure Return path resistance"**	**12.2.3(i) /12.2.3(j)**	**12.2.3(k)**	**12.2.3(l)**	**12.2.3(m)**	**12.2.3(n)**	**12.2.3(q)**
A	Stepping/-Walking	PV Module	Glass	Damaged Glass – cracked, shattered	Boot to Boot											
B	Crawling on	PV Module	Glass	Damaged Glass – cracked, shattered	Glove to Glove											
C	Falling onto	PV Module	Glass	Damaged Glass – cracked, shattered	Glove to Glove											
D	Falling onto with tool in belt	PV Module	Glass	Damaged Glass – cracked, shattered	Tool to Turnout gear to gloves											
E	Falling onto with tool in hand	PV Module	Glass	Damaged Glass – cracked, shattered	Tool to glove to glove											
F	Held Hoseline spraying array	PV Module	Glass	Damaged Glass – cracked, shattered	Water spray to nozzle to gloves to knees (turnout gear)	[Refer to Clause 10.3]	[Refer to Clause 10.3]	[Refer to Clause 10.3]	[Refer to Clause 10.3]	[Refer to Clause 10.3]	[Refer to Clause 10.3]	[Refer to Clause 10.3]	[Refer to Clause 10.3]	[Refer to Clause 10.3]	[Refer to Clause 10.3]	[Refer to Clause 10.3]
G	Ladder or hooks contact array	PV Module	Glass	Damaged Glass – cracked, shattered	Ladder to glove to glove											
H	FF holds tool and contacts array	PV Module	Glass	Damaged Glass – cracked, shattered	Tool to glove to knee (turnout gear)											
I	[List FF interactions – examples	PV Module	Junction Box	Enclosure damaged;	[List contact path											

Table A.2 Continued on Next Page

Table A.2 Continued

	FF interaction	Array Equipment	Component of energized equipment with risk of direct contact	Fault condition - pre-existing or due to FF interaction	FF Contact Path	Exposure Voltage	Calculate or Measure Source & Circuit Resistance	Identify Secondary Fault and root cause (s)	Calculate or Measure Return path resistance	Total Resistance of fault current path	Calculate fault current and determine Hazard Level (HL)	Probability of Fault (Pf)	Probability of Event (Pe)	Freq of Occurrence (FO = Pf + Pe)	HL Action	Is the equipment in "Array Equipment" required for PVHC (yes/no)
	Clause 12.2.3(a) and Table 9	**Clause 12.2.3(b) and Annex E**	**Clause 12.2.3(b) and Annex E**	**Clause 12.2.3(c) and Annex E**	**Clause 12.2.3(d) and Table 9**	**Clause 12.2.3(e), Figure A.3, Figure A.4, and Annex E**	**Clause 12.2.3(f) and Figure A.3 and Figure A.4**	**Clause 12.2.3(g), Annex B**	**Clause 12.2.3(h) and Figure A.3 and Figure A.4**	**Column "Calculate or Measure Source & Circuit Resistance" + Column "Calculate or Measure Return path resistance**	**12.2.3(i) /12.2.3(j)**	**12.2.3(k)**	**12.2.3(l)**	**12.2.3(m)**	**12.2.3(n)**	**12.2.3(q)**
	might be: Falling onto with tool in belt; Falling onto with tool in hand; Held hoseline spraying array; Ladder hooks contact array; FF holds tool and contacts array]			seal allows water inside	based on FF interac-tion]											
J	[List FF interactions – examples might be: Falling onto with tool in belt; Falling onto with tool in hand; Held hoseline spraying array; Ladder hooks contact array; FF holds tool and contacts array]	PV Module (includes wiring to other BOS equipment)	Wiring	Conductor shorted to metal parts; conductor exposed	[List contact path based on FF interac-tion]											
K	[List FF interactions – examples might be: Falling onto with tool in belt; Falling onto with tool in hand; Held hoseline spraying array; Ladder hooks contact array; FF	PV Module (includes wiring to other BOS equipment)	Connectors (ac or dc)	Sealing failed; exposed conductor;	[List contact path based on FF interac-tion]											

Table A.2 Continued on Next Page

Table A.2 Continued

	FF interaction	Array Equipment	Component of energized equipment with risk of direct contact	Fault condition - pre-existing or due to FF interaction	FF Contact Path	Exposure Voltage	Calculate or Measure Source & Circuit Resistance	Identify Secondary Fault and root cause (s)	Calculate or Measure Return path resistance	Total Resistance of fault current path	Calculate fault current and determine Hazard Level (HL)	Probability of Fault (Pf)	Probability of Event (Pe)	Freq of Occurrence (FO = Pf + Pe)	HL Action	Is the equipment in ”Array Equipment” required for PVHC (yes/no)
	Clause 12.2.3(a) and Table 9	**Clause 12.2.3(b) and Annex E**	**Clause 12.2.3(b) and Annex E**	**Clause 12.2.3(c) and Annex E**	**Clause 12.2.3(d) and Table 9**	**Clause 12.2.3(e), Figure A.3, Figure A.4, and Annex E**	**Clause 12.2.3(f) and Figure A.3 and Figure A.4**	**Clause 12.2.3(g), Annex B**	**Clause 12.2.3(h) and Figure A.3 and Figure A.4**	**Column ”Calculate or Measure Source & Circuit Resistance” + Column ”Calculate or Measure Return path resistance**	12.2.3(i) /12.2.3(j)	12.2.3(k)	12.2.3(l)	12.2.3(m)	12.2.3(n)	12.2.3(q)
	holds tool and contacts array]															
L	Worst case - identified as accessible for contact during various operations in Table 9		Example assumes metal used for racking and/or module frame: PV Module metal frame and Support Structure (racking). If array may be mounted on a metal roof, analysis must include metal roof contact.	Example 1: Metal provided with Enhanced insulation: No direct contact without damage to insulation. FF interaction would require intentional damage with a tool. Example 2: Exposed metal: Direct contact assumed without fault	worst case - hand to hand	Example 1: In order for an exposure voltage to exist on the metal, both enhanced insulation on the metal and insulation on the wiring would need to fail. Example 2: considered grounded (required by code) and would require FF contact with one side of dc PV circuit (risk evaluated in other rows of table) as well as opposite polarity fault to metal structure (grounded or ungrounded) for an exposure voltage to exist.	Interaction with the PV metal racking/-frame is not considered a shock hazard by itself. This interaction is not used for calculating the source and circuit resistance (skip to column ”Identify Secondary Fault and root cause (s)”).	This column should align with the return path secondary fault for other rows of the table.		N/A - this step is calculated as part of other rows of this table.	N/A - this step is calculated as part of other rows of this table.	Pf is probability of secondary fault in this row. See Table 6, Pf_1	Probability of event for this contact is the same as for the FF interaction considered for the first fault.	Calculated with the other FF interaction and first fault in other rows of this table.	Calculat-ed with the other FF interac-tion and first fault in other rows of this table.	For example 1, this would be a yes.
M	[List FF interactions]	DC Combiner Box			[List contact path											

Table A.2 Continued on Next Page

Table A.2 Continued

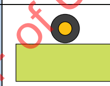
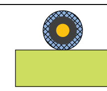
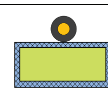
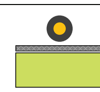
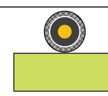
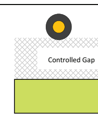
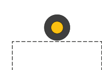
	FF interaction	Array Equipment	Component of energized equipment with risk of direct contact	Fault condition - pre-existing or due to FF interaction	FF Contact Path	Exposure Voltage	Calculate or Measure Source & Circuit Resistance	Identify Secondary Fault and root cause (s)	Calculate or Measure Return path resistance	Total Resistance of fault current path	Calculate fault current and determine Hazard Level (HL)	Probability of Fault (Pf)	Probability of Event (Pe)	Freq of Occurrence (FO = Pf + Pe)	HL Action	Is the equipment in ”Array Equipment” required for PVHC (yes/no)
	Clause 12.2.3(a) and Table 9	**Clause 12.2.3(b) and Annex E**	**Clause 12.2.3(b) and Annex E**	**Clause 12.2.3(c) and Annex E**	**Clause 12.2.3(d) and Table 9**	**Clause 12.2.3(e), Figure A.3, Figure A.4, and Annex E**	**Clause 12.2.3(f) and Figure A.3 and Figure A.4**	**Clause 12.2.3(g), Annex B**	**Clause 12.2.3(h) and Figure A.3 and Figure A.4**	**Column ”Calculate or Measure Source & Circuit Resistance” + Column ”Calculate or Measure Return path resistance**	**12.2.3(i) /12.2.3(j)**	**12.2.3(k)**	**12.2.3(l)**	**12.2.3(m)**	**12.2.3(n)**	**12.2.3(q)**
					based on FF interac-tion]											
N	[List FF interactions]	Disconnects (DC, remotely activated)			[List contact path based on FF interac-tion]											
O	[List FF interactions]	PVRSE/PV-RSS			[List contact path based on FF interac-tion]											
P	[List FF interactions]	Module or array level electronics			[List contact path based on FF interac-tion]											
Q	[List FF interactions - Note: Some Wiring Management devices may be evaluated based on contact path during a FF interaction while others may need to be considered for the secondary fault]	Wiring manage-ment devices (such as raceways, conduit, guards/barri-ers, cable guide-s/clamps)		[List potential fault condition(s) from worksheet]	[If evaluated for contact protection, then identify contact path based on FF interac-tion]											

ANNEX B (Normative) – COMMON CONSTRUCTION DETAILS INCLUDING ASSOCIATED RISK LEVELS

B.1 In accordance with 12.2.3 (c) (3) and 12.2.3 (g), Table B.1 shows common construction details including associated risk levels for the likelihood of PV circuit conductors becoming electrically referenced to adjacent metal surfaces, structures or equipment. Table B.2 shows common construction details including associated risk levels for circuits internal to equipment.

Table B.1

Common Construction Details

Metal Parts in Array	Basic Insulation on Conductor	Enhanced Protection Method to Mitigate Energized Conductor to Metal Contact					Secondary Fault Risk Level	Example Illustration
		Supplementary Insulation on Conductor	Supplementary Insulation on Metal	Barrier Between Conductor and Metal	Barrier Around Conductor	Controlled Air Gap		
Yes	Yes	No	No	No	No	No	3	
Yes	Yes	Yes	No	No	No	No	3[1]	
Yes	Yes	No	Yes	No	No	No	1	
Yes	Yes	No	No	Yes	No	No	1	
Yes	Yes	No	No	No	Yes	No	1	
Yes	Yes	No	No	No	No	Yes	1	
No	Yes	No	No	No	No	No	1	

su3399d

Illustrations Legend:

Gold = Conductor

Black = Basic insulation

Blue (hatched) = Supplemental insulation

Grey = Non-conductive barrier

Green = Conductive metal

[1] Supplemental insulation added to basic insulated conductors for double insulation or conductors with reinforced insulation where the insulated wiring is exposed (not protected by an enclosure or raceway from damage by rodents or mechanical abuse) is considered to be a higher risk level when in contact with metal parts. Even though other standards may consider double insulation or reinforced insulation as low risk of failure, for the purpose of this safety analysis, it is considered a higher risk level of failure based on known conditions that have existed in PV arrays with exposed dc wiring.

B.2 The illustrations provided are just examples. An acceptable fault-mitigation method must evaluate the risk of contact considering the presence of metal in the vicinity of conductors or other live parts (red) and any enhanced protection elements (green).

B.3 Any electrically insulative elements must meet the minimum voltage, environmental, and physical performance requirements for the application as defined by applicable standards.

B.4 A circuit is permitted to use different protective elements anywhere in that circuit. Where a system uses different protective elements within the same circuit, there shall be no portion of the circuit that is not protected by at least one protective element if the circuit is to be considered as having an acceptable method of fault-mitigation.

Table B.2
Common Construction Details, Internal Circuits

Insulation Type[1]	Ingress Protection[2]	Circuit Protection[3]	Additional Testing[4]	Risk Level
Reinforced/ double	Type4, 4x, 6, 6P, IP65, IP66, IP67, IP68, IP69	No	Yes	1
Reinforced/ double	Type4, 4x, 6, 6P, IP65, IP66, IP67, IP68, IP69	Yes	No	1
Reinforced/ double	Type4, 4x, 6, 6P, IP65, IP66, IP67, IP68, IP69	No	No	2
Basic/ functional	Type4, 4x, 6, 6P, IP65, IP66, IP67, IP68, IP69	No	Yes	2[5] 3[6]
Basic/ functional	Type4, 4x, 6, 6P, IP65, IP66, IP67, IP68, IP69	Yes	No	2[5] 3[6]
Basic/ functional	Type4, 4x, 6, 6P, IP65, IP66, IP67, IP68, IP69	No	No	3
Any	Type 3, 3R, 3S, IP34, < IP65[7]	No	No	3

[1] Insulation type used for circuit spacing, which includes any component ratings across the insulation.

[2] Enclosure environmental protection that provides a minimum of Pollution Degree 2 environment around the circuit. Enclosure protection rating to UL 50 or IEC 60529.

[3] Circuit provided with additional environmental protection using a coating or encapsulation tested to meet pollution degree 1 at the circuit. Refer to UL 840 or UL 62109-1.

[4] Additional environmental stress testing performed. At least temperature cycles and humidity freeze followed by a wet insulation resistance test or a functional test from one of the following standards: UL 1703, UL 61730-1, UL 61730-2, UL 1741 PVRSS/SE or UL 1741 MIE.

[5] Circuit with no components across the insulation or where a component fault analysis is performed to verify that there is no increase in leakage current and/or decrease in insulation resistance. Plus, the additional testing in Note 4 shall verify that there is no increase in leakage current and/or decrease in insulation resistance after the environmental stress testing using the wet insulation resistance test in UL 1703 and equivalent test in UL 61730-2.

[6] Does not meet the conditions noted in Note 5.

[7] IP rating where the first characteristic numeral is less than 6 or second characteristic numeral is less than 5.

ANNEX C (Informative) – FRENCH TRANSLATIONS FOR MARKING

C.1 In Canada, there are two official languages. Therefore, it is necessary to have CAUTION, WARNING, and DANGER instructions and markings in both English and French. This annex lists acceptable French translations of the CAUTION, WARNING, and DANGER instructions and markings specified in this Standard. When a product is not intended for use in Canada, instructions and markings may be provided in English only.

Table C.1
Safety marking translations

Clause	English	French
18.3	"WARNING: To Reduce the Risk of Injury, read all instructions"	« AVERTISSEMENT : Pour prévenir les blessures, lire toutes les instructions »

ANNEX D (Normative) – Resistance Tables

Table D.1
Adult FF body resistance in Ohms

Voltage (Volts dc) [4]	Hand to Hand Resistance in ohms (Ω) [2]	Hand to One Knee Resistance in ohms (Ω) [3]	Hand to One Foot Resistance in ohms (Ω) [1, 5]
25	3875	3409	4801
50	2900	2551	3593
75	2275	2001	2819
100	1900	1671	2354
125	1675	1473	2075
150	1475	1298	1828
175	1350	1188	1673
200	1275	1122	1580
225	1225	1078	1518
400	950	836	1177
500	850	748	1053
700	775	682	960
1000	775	682	960

[1] Table values are consistent with IEC 60479-1, Table 10, 50% column (which is considered representative of a significant majority of adult male and female FF). Interpolation is permitted between the values in adjacent rows based upon the voltage drop across that resistance. See Annex F for an example calculation including multiple iterations to determine the voltage drop across the individual resistance based upon the exposure voltage.

[2] The hand to hand resistance values are calculated from the hand to one foot values in the right column using the 80.7% multiplier from IEC 60479-1 Figure 2.

[3] This column is for reference purposes to calculate body resistances paths incorporating a knee.

[4] This is the maximum voltage across the body path.

[5] When the interactions in Table 9 result in multiple interactions that can occur, then the interaction that results in the lowest resistance path shall be used. For example, stepping or walking on the array will always result in other interactions with lower resistance path. Interactions and resistance models involving the feet are used as a reference for calculating other values. However, since the other interactions result in lower resistance, it is not necessary to include calculations of interactions involving feet.

Table D.2
(informative)
Relative body resistance for calculation of current pathway through body

Values are percentages of the "Hand to one foot" column of Table D.1. Not all FF contact paths in this table are required. See Table 9 for required FF contact paths.

	Hand	2 Hands	Foot	2 Feet	Knee	2 Knees	Forearm	Hip	Seat/Butt
Hand	80.7		100	74.3	71	59.8	56.1	57.2	27.5
2 Hands			76.4	50.6	47.4	36.2		33.6	15
Foot	100	76.4	101.5		72.5	35.6	80.5	58.7	48.2
2 Feet	74.3	50.6			25.3	17.8	47.9	50	25
Knee	71	47.4	72.5	25.3	43.5		44.6	29.7	15.9
2 Knees	59.8	36.2	35.6	17.8			33.4	21	10.5
Forearm	56.1		80.5	47.9	44.6	33.4	27.9	30.8	26.5
Hip	57.2	33.6	58.7	50	27.9	21	30.8		
Seat/Butt	27.5	15	48.2	25	15.9	10.5	26.5		

NOTE 1: This table is based on IEC 60479-1, column "Hand to One Foot", Figure 2, Internal partial impedances Zip of the human body.