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An American National Standard

Standard Guide for Fire Prevention for Photovoltaic Panels, Modules, and Systems[1]

This standard is issued under the fixed designation E2908; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide describes basic principles of photovoltaic module design, panel assembly, and system installation to reduce the risk of fire originating from the photovoltaic source circuit.

1.2 This guide is not intended to cover all scenarios which could lead to fire. It is intended to provide an assembly of generally accepted practices.

1.3 This guide is intended for systems which contain photovoltaic modules and panels as dc source circuits, although the recommended practices may also apply to systems utilizing ac modules.

1.4 This guide does not cover fire suppression in the event of a fire involving a photovoltaic module or system.

1.5 This guide does not cover fire emanating from other sources.

1.6 This guide does not cover mechanical, structural, electrical, or other considerations key to photovoltaic module and system design and installation.

1.7 This guide does not cover disposal of modules damaged by a fire, or other material hazards related to such modules.

1.8 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E772 Terminology of Solar Energy Conversion

E2481 Test Method for Hot Spot Protection Testing of Photovoltaic Modules

2.2 *Other Standards and Documents:*

IEC 61215 Crystalline silicon terrestrial photovoltaic (PV) modules—Design qualification and type approval

IEC 61730 Photovoltaic (PV) module safety qualification

North American Board of Certified Energy Practitioners (NABCEP) Study Guide for Photovoltaic System Installers

NFPA 70 U.S. National Electrical Code (article 690)

UL 1703 Standard for Flat-Plate Photovoltaic Modules and Panels

UL 1741 Inverters, Converters, and Controllers for Use in Independent Power Systems

3. Terminology

3.1 Definitions of terms used in this standard may be found in Terminology E772.

3.2 *Definitions:*

3.2.1 *ground fault, n*—a condition where there is an unintended electrical connection between the active PV circuit and ground.

4. Summary of Practice

4.1 Photovoltaic modules and panels should be designed to minimize the risk of fire and should be assembled with good quality control practices.

4.2 Photovoltaic systems should be designed to minimize the risk of fire, and installed with fire safety in mind. Installers should be aware of PV-related fires that have occurred and the cause of those fires.

[1] This guide is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.09 on Photovoltaic Electric Power Conversion.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

5. Significance and Use

5.1 Photovoltaic modules are electrical dc sources. dc sources have unique considerations with regards to arc formation and interruption, as once formed, the arc is not automatically interrupted by an alternating current. Solar modules are energized whenever modules in the string are illuminated by sunlight, or during fault conditions.

5.2 With the rapid increase in the number of photovoltaic system installations, this guide attempts to increase awareness of methods to reduce the risk of fire from photovoltaic systems.

5.3 This guide is intended for use by module manufacturers, panel assemblers, system designers, installers, and specifiers.

5.4 This guide may be used to specify minimum requirements. It is not intended to capture all conditions or scenarios which could result in a fire.

6. Arcing

6.1 *dc Arcing:*

6.1.1 An electrical arc can form where an electric potential exists between two neighboring conductors. Unlike ac arcs which may be extinguished during the alternating cycle of current, a dc arc will be maintained indefinitely until interrupted. A dc arc will be sustained until the voltage potential is reduced, an arc-detection device disrupts the flow of current, or the effective distance between the conductors becomes too large to sustain the arc. Even once the arc is eliminated, the arc may have been sufficient to cause burning or ignition of surrounding materials.

6.1.2 An arc may propagate across the surface of the module (for example, along the gap between rows of cells) as materials are burned away.

6.1.3 The arc may extinguish and re-ignite under variable environmental conditions or with expansion and contraction of affected materials, and may also extinguish at night and restart the next day.

6.1.4 Common sources of arcs in PV modules:

6.1.4.1 Cracks in solar cells (crystalline or thin film).

6.1.4.2 Inadequate spacing between parts of different voltage potentials.

6.1.4.3 Improper bonding of interconnects to cells.

6.1.4.4 Improper bonding of interconnects to bus bar.

6.1.4.5 Improper bonding of bus bar to wiring terminal or connector.

6.1.4.6 Insufficient allowance for thermal expansion and contraction of materials, which leads to mechanical fatigue. Common examples include cell interconnects and expansion joints in conduits.

6.1.4.7 Insufficient strain relief between parts, especially field wiring terminations, solder joints, and internal conductors.

6.2 *ac Arcing:*

6.2.1 Both ac and dc circuits may be present in a solar photovoltaic system, and both circuits contain potential arc sources. A dc arc may be sustained over a larger distance and longer duration than an ac arc due to the one-directional flow of the dc current, which is not easily interrupted. The current in an ac arc always goes to zero twice per cycle.

7. PV Modules and Panels

7.1 *Design Against Arcing*—Modules shall be designed to reduce the risk of arcing.

7.1.1 Modules shall meet the spacing requirements of IEC 61730 or UL 1703 to reduce the occurrence of arcing under both normal operating conditions and fault conditions.

7.1.2 Materials and processes used in the manufacture of PV modules shall be designed to be durable and reliable over the entire service life of the PV module.

7.1.3 Failure mechanisms, such as mismatch of thermal expansion coefficients, metal fatigue, corrosion or vibration, shall be considered during the selection of materials, module layout, and assembly.

7.1.4 Material selection shall include consideration of the operating temperatures of the material and aging characteristics of the material.

7.2 *Design for Arc and Fire Suppression:*

7.2.1 Materials in close contact to potential arc sources, such as junction boxes, shall have a minimum arc and flammability rating in accordance with IEC 61730 or UL 1703. This helps to reduce the risk of fire in the event of an arcing event.

7.2.2 According to the 2011 National Electrical Code, an arc detection device is required to disconnect the current flow in the event of arcing. Depending on the location of the device, it may protect an individual module or an entire string. Consideration shall be given to the reliability of such devices, to avoid nuisance trips and costly servicing.

7.3 *Operating Temperature:*

7.3.1 A PV module converts a portion of the sun's energy into electrical energy. The portion of the sun's energy that is not converted into electrical energy is either reflected, transmitted through the module, or transformed into heat energy. Therefore, a PV module usually operates at a temperature hotter than the surrounding ambient temperature.

7.3.2 *Operating Temperature Considerations*—The exact operating temperature of a module, and of any given component within a module, depends on a variety of factors.

7.3.2.1 *Environmental Factors*—Wind speed, wind direction, ambient temperature, solar irradiance, and cloud cover.

7.3.2.2 *Installation Factors*—Angle of installation, rack type, module spacing, location, wind obstructions, tracking versus non-tracking, ventilation, shading events.

7.3.2.3 *Module Factors*—Cell mismatch (leading to nonuniform heat generation), insulated sections (e.g. junction boxes), color, framing, transparency, material thermal conductivity, thermal convection characteristics, current-carrying limits of live parts.

7.3.3 *Shading*—Shading events can cause shaded cells to act as power sinks (resistors) as opposed to power generators. Therefore, shaded cells can run much hotter than neighboring cells. Although modules are designed to operate in unshaded conditions, some degree of localized shading is inevitable in most installations. Refer to Test Method E2481 for additional information.

7.3.3.1 The amount of heating of a cell depends on the shunt and series resistance characteristics of the shaded cells, the current flowing through the cell, and whether the cells are partially illuminated.

7.3.3.2 *Material Combustion*—Materials in contact with cells shall be able to withstand temperatures under the shaded condition without exceeding material ignition temperature ratings. The design may be tested to assess material suitability per UL 1703, Section 19, Temperature Test.

7.3.3.3 Modules shall have adequate protection in the event of shading.

7.3.3.4 *Diodes*—A common method for providing shading protection is through bypass diodes connected in parallel with the cells to be protected. As the forward and reverse characteristics of a PV cell are different, the diodes shall be sized to activate in the event of shading of part or all of one or more of the cells to prevent the formation of localized hot spots. The diodes must be able to safely handle the string current. Activation of the diode during a cell shading event shall not result in overheating of the diode, nor materials surrounding the diode. The diode shall be mounted and connected using a robust and reliable method, including strain relief as appropriate. Diode quality and the mounting method should be evaluated for durability. If diodes are mounted mechanically, they should be tested under simulated field conditions to ensure that adequate contact is maintained over time.

7.4 *Documentation:*

7.4.1 *Recognition*—The module should be certified by an approved organization to meet a minimum level of safety. Two standards that are commonly used to assess a minimum safety level are UL 1703 and IEC 61730.

7.4.2 *Quality System*—The PV manufacturer shall have an established quality system to ensure all modules manufactured meet a basic level of quality from a fire safety standpoint. Sources of dc arcing shall be given specific attention, as well as any material or process steps critical to module operating temperature.

7.4.3 *Installation Guide*—Any limitations on installation location or conditions critical to the safe operating state of a PV system shall be indicated in the installation guide. This may include ambient conditions, mounting configuration, wiring requirements, over-current protection devices, and fuse ratings.

8. PV Systems

8.1 *System Design Considerations:*

8.1.1 *Series Fuse Protection*—In most cases where two or more strings of photovoltaic modules are connected in parallel, the branch or sub-string shall be protected by a fuse. The fuse protects the modules and other electrical components in the system from over-current in the event of a fault condition. The total available current and fuse rating shall not exceed that recommended by the module or panel manufacturer.

8.1.2 *Module-to-Module Connections*—All wiring and connectors used shall be of the type and sizing recommended by the module manufacturer and in accordance with local codes. Wiring shall be suitable for the intended application, including temperature range, wire gauge, UV resistance, water resistance, and system voltage. Consideration shall be given to the extreme and nominal conditions expected throughout the module lifetime. The means for connection shall be in accordance with the module and connector installation guides or any applicable local codes. Wiring shall be mechanically secured, if required, to prevent strain on the electrical connections, with adequate slack to allow for thermal expansion and contraction of the wiring.

8.1.3 *Other Wiring*—All other wiring in the PV system shall be suitable for the intended application and secured if required, with consideration given to the same factors as described for module-to-module wiring. Wiring securement means must be able to withstand outdoor conditions, including UV radiation, over the expected service life of the system, and should be checked routinely as part of regular system maintenance. If wiring is in metallic conduit, particular attention should be given to proper installation and wire management techniques to reduce the possibility of ground faults.

8.1.4 *dc Disconnects*—dc disconnects shall be used to allow safe disconnection of a dc string from an inverter, combiner box, charge controller, or other electrical components in the system. The disconnect shall be rated appropriately for the dc current and voltage of the system, in accordance with local codes. Note that an ac-only disconnect may or may not be suitable for a dc circuit, as it relies on the alternating nature of ac current to disrupt the current flow.

8.1.5 *Inverters*—Inverters shall be appropriately sized for the intended location, be approved to the local standard, such as UL 1741, and meet local code requirements for connection to the grid. Inverters may have built-in arc detection capability, which disconnects the system in the event of an arc to reduce damage to the system and supporting structures.

8.1.6 *Ground Fault Protection*—Consideration shall be given to the grounding scheme, to minimize arcing and potential current pathways between live parts and ground potential.

8.2 *Operating Temperature:*

8.2.1 The operating temperature of a PV module is highly dependent upon the installation location and installation methods used.

8.2.2 The design of a PV system shall be such that the operating temperatures of the PV modules and all components fall within the rated values. Materials suitable for the installation location and operating temperatures under both normal and fault conditions (such as shading and reverse current) shall be used.

8.2.3 Do not allow concentrated sunlight to fall on the modules, unless explicitly permitted by the PV manufacturer.

8.2.4 Mount the PV modules in accordance with the recommended mounting procedure.

8.2.5 Ensure adequate ventilation of the PV module, per the manufacturer's recommended practice. Note that in the case of solar shingles, tiles, or other building-integrated photovoltaic products (BIPV), the manufacturer may recommend minimal ventilation to be consistent with the aesthetic requirements of the design, or the specific details of the module's fire rating. The resultant operating temperatures must still remain within rated values for the module and the supporting materials.