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Standard Test Method for Hot Spot Protection Testing of Photovoltaic Modules[1]

This standard is issued under the fixed designation E 2481; 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 test method provides a procedure to determine the ability of a photovoltaic (PV) module to endure the long-term effects of periodic "hot spot" heating associated with common fault conditions such as severely cracked or mismatched cells, single-point open circuit failures (for example, interconnect failures), partial (or non-uniform) shadowing or soiling. Such effects typically include solder melting or deterioration of the encapsulation, but in severe cases could progress to combustion of the PV module and surrounding materials.

1.2 There are two ways that cells can cause a hot spot problem; either by having a high resistance so that there is a large resistance in the circuit, or by having a low resistance area (shunt) such that there is a high-current flow in a localized region. This test method selects cells of both types to be stressed.

1.3 This test method does not establish pass or fail levels. The determination of acceptable or unacceptable results is beyond the scope of this test method.

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1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E 772 Terminology Relating to Solar Energy Conversion

E 927 Specification for Solar Simulation for Photovoltaic Testing

E 1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells

E 1328 Terminology Relating to Photovoltaic Solar Energy Conversion

E 1799 Practice for Visual Inspections of Photovoltaic Modules

E 1802 Test Methods for Wet Insulation Integrity Testing of Photovoltaic Modules

3. Terminology

3.1 *Definitions*—definitions of terms used in this test method may be found in Terminology E 772 and Terminology E 1328.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *hot spot*—a condition that occurs, usually as a result of shadowing, when a solar cell or group of cells is forced into reverse bias and must dissipate power, which can result in abnormally high cell temperatures.

4. Significance and Use

4.1 The design of a photovoltaic module or system intended to provide safe conversion of the sun's radiant energy into useful electricity must take into consideration the possibility of partial shadowing of the module(s) during operation. This test method describes a procedure for verifying that the design and construction of the module provides adequate protection against the potential harmful effects of hot spots during normal installation and use.

4.2 This test method describes a procedure for determining the ability of the module to provide protection from internal defects which could cause loss of electrical insulation or combustion hazards.

[1] This test method 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.

4.3 Hot-spot heating occurs in a module when its operating current exceeds the reduced short-circuit current (Isc) of a shadowed or faulty cell or group of cells. When such a condition occurs, the affected cell or group of cells is forced into reverse bias and must dissipate power, which can cause overheating.

NOTE 1—The correct use of bypass diodes can prevent hot spot damage from occurring.

4.4 Fig. 1 illustrates the hot-spot effect in a module of a series string of cells, one of which, cell *Y*, is partially shadowed. The amount of electrical power dissipated in *Y* is equal to the product of the module current and the reverse voltage developed across *Y*. For any irradiance level, when the reverse voltage across *Y* is equal to the voltage generated by the remaining (*s*-1) cells in the module, power dissipation is at a maximum when the module is short-circuited. This is shown in Fig. 1 by the shaded rectangle constructed at the intersection of the reverse I-V characteristic of *Y* with the image of the forward I-V characteristic of the (*s*-1) cells.

4.5 By-pass diodes, if present, as shown in Fig. 2, begin conducting when a series-connected string in a module is in reverse bias, thereby limiting the power dissipation in the reduced-output cell.

NOTE 2—If the module does not contain bypass diodes, check the manufacturer's instructions to see if a maximum number of series modules is recommended before installing bypass diodes. If the maximum number of modules recommended is greater than one, the hot spot test should be preformed with that number of modules in series. For convenience, a constant current power supply may be substituted for the additional modules to maintain the specified current.

4.6 The reverse characteristics of solar cells can vary considerably. Cells can have either high shunt resistance where the reverse performance is voltage-limited or have low shunt resistance where the reverse performance is current-limited. Each of these types of cells can suffer hot spot problems, but in different ways.

4.6.1 *Low-Shunt Resistance Cells* :

4.6.1.1 The worst case shadowing conditions occur when the whole cell (or a large fraction) is shadowed.

4.6.1.2 Often low shunt resistance cells are this way because of localized shunts. In this case hot spot heating occurs because a large amount of current flows in a small area. Because this is a localized phenomenon, there is a great deal of scatter in performance of this type of cell. Cells with the lowest shunt resistance have a high likelihood of operating at excessively high temperatures when reverse biased.

4.6.1.3 Because the heating is localized, hot spot failures of low shunt resistance cells occur quickly.

4.6.2 *High Shunt Resistance Cells* :

4.6.2.1 The worst case shadowing conditions occur when a small fraction of the cell is shadowed.

4.6.2.2 High shunt resistance cells limit the reverse current flow of the circuit and therefore heat up. The cell with the highest shunt resistance will have the highest power dissipation.

4.6.2.3 Because the heating is uniform over the whole area of the cell, it can take a long time for the cell to heat to the point of causing damage.

4.6.2.4 High shunt resistance cells define the need for bypass diodes in the module's circuit, and their performance characteristics determine the number of cells that can be protected by each diode.

4.7 The major technical issue is how to identify the highest and lowest shunt resistance cells and then how to determine the worst case shadowing for those cells. If the bypass diodes are removable, cells with localized shunts can be identified by reverse biasing the cell string and using an IR camera to observe hot spots. If the module circuit is accessible the current flow through the shadowed cell can be monitored directly. However, many PV modules do not have removable diodes or accessible electric circuits. Therefore a non-intrusive method is needed that can be utilized on those modules.

4.8 The selected approach is based on taking a set of I-V curves for a module with each cell shadowed in turn. Fig. 3 shows the resultant set of I-V curves for a sample module. The curve with the highest leakage current at the point where the diode turns

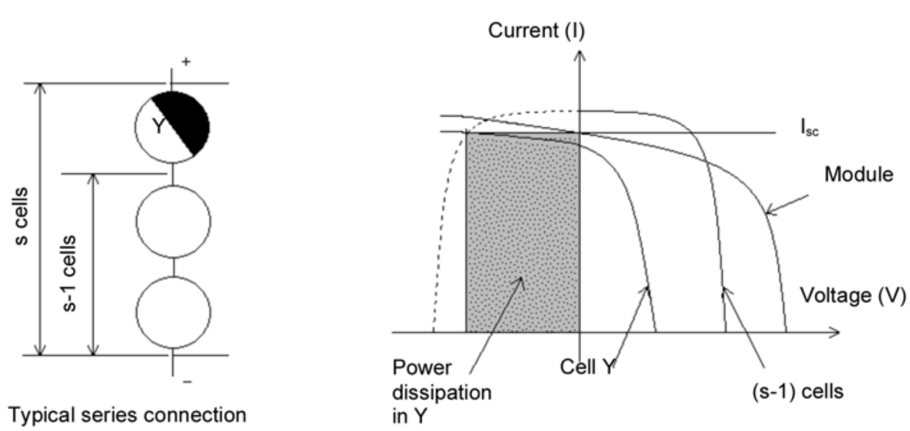

FIG. 1 Hot Spot Effect