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Standard Test Method for Wet Insulation Integrity Testing of Photovoltaic Arrays[1]

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1. Scope

1.1 This test method covers a procedure to determine the insulation resistance of a photovoltaic (PV) array (or its component strings), that is, the electrical resistance between the array's internal electrical components and is exposed, electrically conductive, non-current carrying parts and surfaces of the array.

1.2 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.

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

1.4 *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]

E772 Terminology of Solar Energy Conversion

E1328 Terminology Relating to Photovoltaic Solar Energy Conversion (Withdrawn 2012)[3]

E1462 Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules

3. Terminology

3.1 *Definitions*—Definitions of terms used in this test method may be found in Terminologies E772 and E1328.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *insulation resistance, n*—the electrical resistance of a photovoltaic array's insulation, measured between the photovoltaic circuit and exposed, electrically conductive non-current-carrying parts and surfaces of the array.

3.2.2 *metal oxide varistor MOV, n*—a surge protection device.

3.2.3 *photovoltaic circuit*—the active electrical circuit that conducts the photovoltaic generated power.

4. Summary of Test Method

4.1 A procedure is provided for testing the electrical isolation between the array's internal electrical components and its exposed, electrically conductive, non-current carrying parts and surfaces of the array.

4.2 The procedure offers two ways to connect the array during the test, either open-circuited or short-circuited. Each option has advantages and disadvantages (see 5.5).

4.3 A wetting solution is applied to the array, then a voltage is applied between the PV circuit and the exposed, electrically conductive, non-current carrying parts and surfaces of the array, while monitoring the current or resistance, to find localized regions where the insulation resistance is significantly reduced by the wetting solution. The array is then inspected for evidence of possible arcing.

5. Significance and Use

5.1 The design of a PV module or system intended to provide safe conversion of the sun's radiant energy into useful electricity must take into consideration the possibility of hazard should the user come into contact with the electrical potential of the array. In addition, the insulation system provides a barrier to electrochemical corrosion, and insulation flaws can result in increased corrosion and reliability problems. This test method describes a procedure for verifying that the design and construction of the array provides adequate electrical isolation through normal installation and use. At no location on the array should the PV-generated electrical potential be accessible, with the obvious exception of the output leads. The isolation is necessary to provide for safe and reliable installation, use, and service of the PV system.

5.2 This test method describes a procedure for determining the ability of the array to provide protection from electrical

[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.

[3] The last approved version of this historical standard is referenced on www.astm.org.

hazards. Its primary use is to find insulation flaws that could be dangerous to persons who may come into contact with the array. Corrective action taken to address such flaws is beyond the scope of this test method.

5.3 This procedure may be specified as part of a series of acceptance tests involving performance measurements and demonstration of functional requirements. Large arrays can be tested in smaller segments. The size of the array segment to be tested (called "circuit under test" in this test method) is usually selected at a convenient break point and sized such that the expected resistance or current reading is within the middle third of the meter's range.

5.4 Insulation leakage resistance and insulation leakage current leakage are strong functions of array dimensions, ambient relative humidity, absorbed water vapor, and other factors. For this reason, it is the responsibility of the user of this test method to specify the minimum acceptable leakage resistance for this test.

5.4.1 Even though a numerical quantity is specified, actual results are often pass-fail in that when a flaw is found, the leakage current changes from almost nothing to the full scale value on the meter.

5.5 The user of this test method must specify the option used for connection to the array during the test. The short-circuited option requires a shorting device with leads to connect the positive and negative legs of the circuit under test. For larger systems, where the shorting device may have to be rated for high current and voltage levels, the open-circuited option may be preferred. The open-circuited option requires the user to correct readings to account for the PV-generated voltage, and the procedure for making such corrections is beyond the scope of this test method. The short-circuited option may be easier for small systems where the voltage and current levels are low and the distance between the plus and minus leads of the circuit under test are small. The short-circuited option minimizes the chance of exposing array components to voltage levels above those for which they are rated.

6. Apparatus

6.1 Choose one of the following, depending on the option selected (see 4.2 and 5.5):

6.1.1 *Variable dc Voltage Power Supply*—A dc voltage power supply capable of providing a nominal test voltage of 500 V, as specified in Test Method E1462. A common term for this apparatus is insulation tester.

6.1.2 *Megohmmeter*—A high-impedance ohmmeter, or similar device, capable of adequately measuring leakage resistance in the range of anticipated readings, and that can provide a nominal test voltage of 500 V.

6.2 *Wetting Solution*—A solution of tap water and a wetting agent[4], with a surface tension of 0.03 N/m or less at 23°C.

6.3 *Spray Apparatus*—A system for applying the wetting solution to the array, capable of providing a water pressure of 35 kPa.[5] The force and flow rate of the wetting solution must be sufficient to reach all of the test segment surfaces and maintain wetted surfaces, front and back.

NOTE 1—The spray pressure is only enough to completely wet the exposed surfaces; it is not intended to penetrate enclosed spaces such as the interiors of junction boxes. It is not necessary to use a forceful stream because the wetting agent helps to penetrate small crevices.

6.4 *Array Shorter*—A dc-rated switch, circuit beaker or other device capable of interrupting the maximum short circuit current of the circuit under test. The array shorter is only required if the short-circuited option is used.

6.4.1 The array shorter must be rated for the maximum open-circuit voltage of the circuit under test plus the insulation tester or ohmmeter.

6.4.2 The wiring between the array shorter and the positive and negative terminals of the circuit under test must also be rated for the continuous maximum short-circuit current of the circuit under test.

7. Hazards

7.1 Touching the modules or array during the testing may be hazardous because of the high voltage applied.

7.2 Use caution whenever short circuiting any high voltage PV array. It may be advisable to reduce the risk involved by short-circuiting the array at night, when the current and voltage are minimized.

7.3 The megohmmeter or insulation tester should be turned off while wetting the array. This may not always be desirable, such as when trying to pinpoint the location of an insulation flaw. In these cases, appropriate personnel protection (electrical gloves with keepers, safety glasses, etc.) should be worn and care should be taken to keep the wetting solution from entering the gloves, boots, etc.

8. Procedure

8.1 Assemble the requisite equipment and personnel at the array to be tested.

8.2 Prepare the wetting solution.

8.3 Measure and record the site meteorological conditions (irradiance, ambient temperature, wind speed) or arrange for the data to be measured by the site data acquisition system.

NOTE 2—It is recommended that this test not be performed under conditions where the ambient temperature is greater than 40°C or the wind speed is greater than 7.5 m/s, since high values of either make it difficult to keep the array wet long enough to make the necessary measurements. If the short-circuited option is used, it may be necessary to conduct the test at a reduced irradiance to ensure that the currents produced in the short-circuited PV components are within manufacturer's requirements. Refer to the manufacturer's recommendations concerning shorting of modules and other array components at high irradiance.

8.4 Isolate the circuit(s) to be tested prior to the start of spraying. Depending on the design of the PV system, this may

[4] An acceptable wetting solution that has been found to produce adequate sheeting action is 1 part Liqui-nox detergent in 500 parts water. Liqui-Nox is available from Alconox, Inc., 9T East 40th St., New York, NY 10016, as part number C6308–2.

[5] Molded nylon Rain-Test spray heads are available from Underwriters' Laboratories, Inc., 333 Pfingsten Rd., Northbrook, IL 60062, as part number SA0820B.

involve opening source circuit switches, taking out removable links, or disconnecting bolted connections or connectors. All poles of the circuit to be tested (positive, negative and neutral) must be isolated. Disconnect positive and negative monopoles from each other. Ground connections among module frames, panels, array structures and system/earth ground must be left in place.

NOTE 3—The size of the array segment to be tested (circuit under test) may be limited to the area that can be kept wet at any given time. In certain situations for example, attempting to locate specific fault locations, it may be desirable to apply the test voltage first, and then apply the wetting solution.

8.5 Verify that MOVs or similar voltage surge protection devices are disconnected and are not part of the isolated circuits. If such devices are connected between the active array circuit and ground, they must be disconnected as they may invalidate the tests or be damaged by the test voltage.

8.6 Set the insulation tester or megohmmeter on an appropriate scale for the size of the circuit under test. Ensure that the insulation tester or megohmmeter is turned off before any electrical connections are made.

8.7 There are two acceptable options for performing this test: with the output leads of the circuit under test either short-circuited or open-circuited. Specify the option according to the criteria described in 4.2.

8.7.1 *Short-Circuited* —Short the output leads of the array together, using the array shorter (unless already done, see 7.2). Connect the shorted output terminals of the string(s) to the high-potential (positive) terminal of the insulation tester.

8.7.2 *Open-Circuited* —Connect the positive lead of the insulation tester to the negative terminal of the circuit under test. The positive terminal of the circuit under test is left unconnected and protected so that it will not become wet and interfere with the test.

NOTE 4—Depending on the circuit under test, it is acceptable and may be more convenient to connect the negative lead of the megohmmeter to the positive terminal of the circuit under test, leave the circuit's negative terminal unconnected, and connect the positive lead of the megohmmeter to earth ground.

8.8 Connect the grounded (negative) terminal of the insulation tester or megohmmeter to the grounding point of the array, or subarray string, being tested.

8.8.1 If there is no common array ground, the procedure may need to be repeated to measure the insulation resistance between the circuit under test and each separate and unconnected electrically conductive component.

8.8.2 Any connections to electrically conductive components must be made to uninsulated points for the test results to be valid. For example, an anodized aluminum frame would not qualify unless the anodization was removed at the test point.

8.9 Apply the test voltage. Measure and record the dry insulation resistance in megohms after the capacitive charging effect has subsided and the reading has established (perhaps 30 s or more). For insulation testers that indicate leakage current, divide the voltage applied by the tester, in volts, by the tester reading, in microamperes. Also note any instability in the reading which may indicate shorting or arcing.

NOTE 5—The capacitance of the circuit under test may be large enough to cause large currents to flow while the insulation capacitance is charging. When using the open-circuited option, the wetting of the circuit under test can cause changes in system voltage as the array temperature changes. The operator must be aware of such possibilities and allow time for the conditions to stabilize.

8.10 Thoroughly wet the back (away from the sun) side of the circuit under test. Take care not to get water into the interior of the interface junction boxes, the power-conditioning unit, the insulation tester or megohmmeter, or similar items that are not under test. Also, try to avoid wetting adjacent modules and panels in segments not yet tested, as this would interfere with subsequent dry resistance measurements (see 8.9).

8.11 While the entire test segment is wet, measure and record the wet leakage current or resistance reading after the capacitive charging effect has subsided (perhaps 30 s or more). Also, note any instability in the reading and the areas being sprayed at that time to provide an indication of the location of defects. Especially note any large changes in resistance, which indicate regions where the insulation integrity is compromised.

NOTE 6—Defects can be located more precisely by watching the insulation tester or megohmmeter reading while spraying small areas of the circuit under test using a small garden sprayer or spray bottle filled with the wetting solution.

8.12 Observe and listen to the array during the test for evidence of arcing or flashover.

8.13 Reduce the applied voltage to zero. Repeat 8.9 – 8.12, while wetting the front (sun) side of the test segment.

8.14 Reduce the applied voltage to zero. Short-circuit the terminals of the insulation tester or megohmmeter before disconnecting it from the array.

8.15 Inspect the array for any visual evidence of arcing or flash-over.

8.16 Repeat 8.7 – 8.15 for the remaining test segments. Observe appropriate polarities for the insulation tester or megohmmeter connection.

8.17 Replace wiring disconnected for the test. Circuits found to have defects may be left isolated, pending repairs. If the short-circuited option was used, remove the short circuit from the array terminals.

8.18 The spray may leave a thin residual film. If necessary, rinse residual from the face of the modules after completing the test.

9. Report

9.1 Report the following items as a minimum:

9.1.1 A complete description of the PV array,

9.1.2 A description of the measurement equipment and measurement conditions or parameters, including ambient weather conditions,

9.1.3 The insulation resistance values obtained in 8.9 and 8.11,

9.1.4 A description of any apparent changes as a result of the testing,

9.1.5 Observations or indications of any shorting, arcing, or other failures, 9.1.6 Identification of areas of the array where problems were found, and

9.1.7 Any deviations from the procedure.

10. Precision and Bias

10.1 Several factors make a determination of the precision and bias from the results of an interlaboratory study not practicable for this test method:

10.1.1 This test method requires the measurement of an installed PV array. It would be impractical to circulate such an array between laboratories for testing.

10.1.2 Insulation resistance and insulation current leakage can depend on ambient relative humidity, absorbed water vapor, temperature, construction and age of the array, and other factors.

10.1.3 The test method is affected strongly by the location, size, shape, and attachment methods of the array and test leads, as well as module construction and installation details.

10.2 Precision and bias will be a function of the precision and bias limits of the electrical instruments. Therefore, these electrical measurements should be made in accordance with sound engineering practices using instruments that have recent calibrations traceable to national and international standards.

11. Keywords

11.1 electrical testing; insulation integrity; insulation resistance; photovoltaics; solar energy