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Edition 1.0 2015-08

TECHNICAL SPECIFICATION

colour inside

Photovoltaic (PV) modules – Test methods for the detection of potential-induced degradation – Part 1: Crystalline silicon

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Part 1: Crystalline silicon

FOREWORD

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62804-1, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this standard is based on the following documents:

DTS	Report on voting
82/885/DTS	82/921A/RVC

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62804 series, published under the general title *Photovoltaic (PV) modules – Test methods for the detection of potential-induced degradation,* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This part of IEC 62804 is for testing and evaluating the durability of crystalline silicon photovoltaic modules to stresses that induce potential-induced degradation (PID). The applied stresses, mainly system voltage, manifest themselves in different degradation mechanisms depending on the module technology. A series of Technical Specifications is therefore proposed to define PID tests for different photovoltaic module technologies.

IEC TS 62804-1 defines test methods for evaluating PID in crystalline silicon PV modules.

IEC TS 62804-2 defines test methods for evaluating PID in thin-film PV modules.

Additional Technical Specifications in the series may be introduced in the future for emerging module technologies.

Voltage potential that exists between the active circuit and the grounded module surfaces can lead to module degradation by multiple mechanisms including ionic transport in the encapsulant, superstrate or substrate; hot carriers in the cell; redistribution of charges that degrade the active layer of the cell or its surfaces; failure of adhesion at interfaces, and corrosion of module components. These degradation mechanisms in crystalline silicon photovoltaic modules caused by voltage stress and promoted by high temperature and humidity have been labeled potential-induced degradation, polarization, electrolytic corrosion, and electrochemical corrosion. They are most active in wet or damp environments, and in environments prone to soiling of modules with conductive, acidic, caustic, or ionic species that lead to increased conduction on the module surfaces. In the field, modules have been observed to degrade in positive as well as negative polarity strings depending on the cell construction, module materials, and design. The testing in this Technical Specification therefore specifies the evaluation of the effects of voltage stress in both polarities for modules that may be operated in either polarity, or in the polarity defined by the manufacturer's documented specifications. Some crystalline silicon module designs undergoing system voltage bias stress have shown degradation manifested by junction failure, leading to changes in the reverse-bias breakdown characteristics and a resulting degradation in safety because of the increased potential for development of hot spots in the module. This Technical Specification describes two methods to measure the ability of a module to withstand degradation from system voltage effects that manifest in the relatively short term.

The stress-test levels in this Technical Specification have not been related to those of the natural environment. Modules types undergoing damp heat chamber testing with a 60 °C and 85 % relative humidity stress level with the temperature, humidity, and bias voltage ramped simultaneously at the start of a 96 h stress test were found resistant to PID in outdoor tests in Florida, USA. However, to improve reproducibility, test details including environmental chamber temperature and humidity ramps and tolerances have been tightened, which very significantly reduce the total stress applied and invalidate the correspondences previously found. The relevance to real outdoor stress conditions of the test contained herein using foil as the ground conductor is also not proven. Alternative levels beyond the basic stress levels in this Technical Specification are thus included.

It is known that variability in manufacturing processes can affect the susceptibility of modules to system voltage stress. Retesting of module samples by the test protocols contained herein and according to sampling plans of IEC 60410, internal quality assurance programs, or external audits will aid in verifying not only the durability of the design of the module to system voltage stress, but also the effects of variability of the materials and manufacturing processes.

PHOTOVOLTAIC (PV) MODULES – TEST METHODS FOR THE DETECTION OF POTENTIAL-INDUCED DEGRADATION –

Part 1: Crystalline silicon

1 Scope

This part of IEC 62804 defines procedures to test and evaluate the durability of crystalline silicon photovoltaic (PV) modules to the effects of short-term high-voltage stress including potential-induced degradation (PID). Two test methods are defined that do not inherently produce equivalent results. They are given as screening tests—neither test includes all the factors existing in the natural environment that can affect the PID rate. The methods describe how to achieve a constant stress level.

The testing in this Technical Specification is designed for crystalline silicon PV modules with one or two glass surfaces, silicon cells having passivating dielectric layers, for degradation mechanisms involving mobile ions influencing the electric field over the silicon semiconductor, or electronically interacting with the silicon semiconductor itself. This Technical Specification is not intended for evaluating modules with thin-film technologies, tandem, or heterostructure devices.

This Technical Specification describes methods to measure the module design's ability to withstand degradation from system voltage effects that manifest in the relatively short term. The testing in this Technical Specification does not purport to examine certain combined effects that may occur over longer periods of time in modules such as encapsulation failure, which could lead in turn to rapid moisture ingress and electrochemical corrosion. This Technical Specification does not incorporate illumination of the module that can affect the rate of degradation.

The test methods are designed to measure PID sensitivity and will give results according to the stress levels and the module grounding configuration inherent to the respective tests. Because stress method (a), testing in an environmental chamber, employs a non-condensing humidity level to serve as a conductive pathway to electrical ground, it frequently applies less stress toward the centre of the module face and the PID effect is concentrated toward the module edges as a result. Stress method (b), contacting the surfaces with a grounded conductive electrode, evaluates cell sensitivity and some effects of the component packaging materials such as glass and encapsulant resistivity, but does not differentiate the effects of some construction methods of mitigating PID, for example, the use of rear rail mounts, edge clips, and insulating frames.

The actual durability of modules to system voltage stress will depend on the environmental conditions under which they are operated. These tests are intended to assess PV module sensitivity to PID irrespective of actual stresses under operation in different climates and systems.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2-78:2012, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state*

IEC 60410, *Sampling plans and procedures for inspection by attributes*

IEC 61215:2005, *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61730-2:2004, *Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Samples

Four representative and identical samples (two for each polarity of the system voltage that is specified or allowed in the module documentation) shall be procured for each test. Modules not explicitly requiring string connections with one terminal grounded shall be tested in both polarities. The modules for test shall be constructed with the same process and design as the model type to be evaluated—it shall contain components including cells, encapsulant, backsheet, glass, and frame made with the same manufacturing process (process tools, materials, design, and process conditions).

Modules shall be taken at random from a production batch or batches in accordance with IEC 60410. The modules shall have been manufactured from specified materials and components in accordance with the relevant drawings and process sheets and have been subjected to the manufacturer's normal inspection, quality control, and production acceptance procedures. A control module of equivalent size and design that will not be stress tested shall be additionally procured.

When submitted to another party for testing, the submitted modules shall be complete in every detail and shall be accompanied by the manufacturer's handling, mounting and connection instructions, including the maximum permissible system voltage. Markings on the module shall conform to the requirements of IEC 61215:2005, Clause 4. If the modules tested are prototypes of a new design and not from production, this fact shall be noted in the test report (see Clause 5).

The test results relate only to the module construction tested. If a module manufacturer uses several sources for PV module components, module designs, cell designs, process designs, or differing process set points and tolerances, then four modules per permutation shall be tested. Changes of the junction boxes, cables, and connectors do not indicate retest however. In cases where the cell, module, or materials process variability or tolerances are large, testing of more than two samples per polarity will be useful for improving the confidence in the results.

If the module documentation and the nameplate specify usage of the module in strings of only one voltage polarity with respect to earth ground (one terminal of the module string tied to earth ground), then the number of modules selected for test shall be halved and stressed only in that specified polarity.

If the PV module is provided with or is specified for use with a specific means for grounding, then the grounding means shall be included and considered a part of the test sample. If the PV module is provided with or is specified for use with means for mounting that could additionally influence the module grounding, then the means for mounting shall be included and considered a part of the test sample.

4 Test procedures

4.1 General

The procedures given in the following subclauses shall be performed in the order given. Any intended or unintended changes and deviations shall be recorded and reported in detail, as indicated in Clause 5 i).

There are two methods described in this Technical Specification for application of the voltage stress as follows (see Figure 1):

a) Testing in an environmental chamber, which is based on providing an electrical contact on the module surfaces with elevated relative humidity of 85 % and temperature;

b) Contacting the surface by covering it with a grounded, electrically conducting electrode in a temperature-controlled environment with a relative humidity less than 60 %.

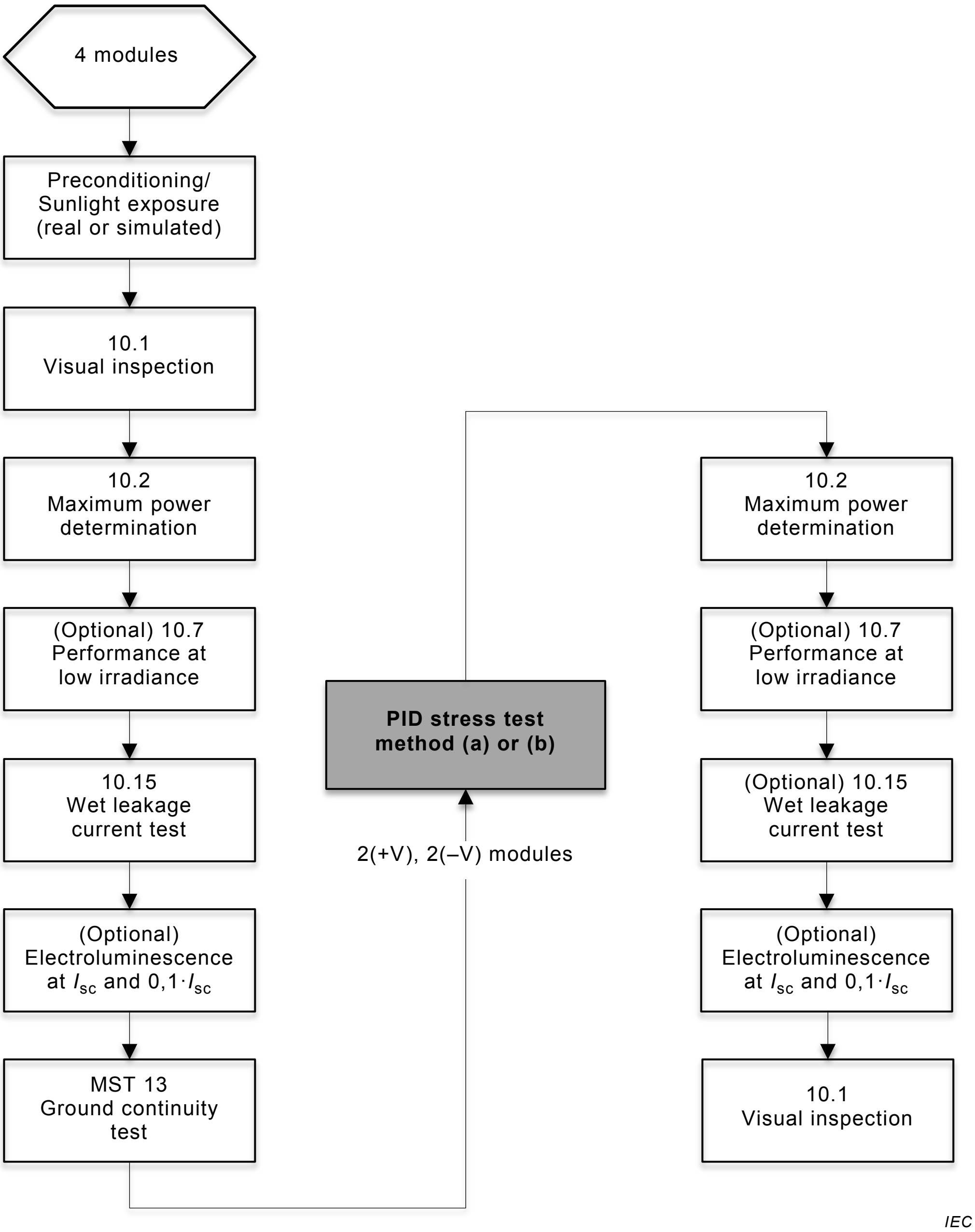

Figure 1 – PID test flow

NOTE 10.x and MST references are to clauses in IEC 61215:2005 and 61730-2:2004, respectively.

4.2 Pre-stress tests

a) All modules shall be exposed to sunlight (either real or simulated) to a target irradiation level according to the procedure for stabilization for crystalline Si modules within IEC 61215:2005, Clause 5.

b) Perform IEC 61215:2005, 10.1, Visual inspection.

c) Perform IEC 61215:2005, 10.2, Maximum power determination, including on the control module.

d) Optional: Perform IEC 61215:2005, 10.7, Performance at low irradiance, including on the control module.

NOTE 1 Loss of module power due to PID is frequently more apparent at low irradiance.

e) Perform IEC 61215:2005, 10.15, Wet leakage current test. If a wetting agent is used in the wet leakage current test, all surfaces of the modules shall be immediately and thoroughly rinsed following the wet leakage current test with water of resistivity not less than 0,05 MΩ cm that is used to generate humidity for the testing described in 4.3.2.3 (below) and according to IEC 60068-2-78:2012, 4.1. In all cases, all surfaces of the module should be wiped dry with clean cotton or paper towels and not evaporatively air-dried as the final step for the goal of avoiding sediments on the module face. This test procedure shall be terminated at this point if the module does not meet the requirements of IEC 61215:2005, 10.15, Wet leakage current test.

f) Optional: Perform electroluminescence imaging at 1 and 0,1 short circuit current (I_{sc}).

NOTE 2 Electroluminescence images are useful to identify degraded cells, which appear darker than the others.

g) Perform IEC 61730-2 MST 13, Ground continuity test, if the module has exposed conductive parts. The current for determining the resistance between conductive parts is however not specified; any current or voltage such that resistance can be evaluated may be applied.

4.3 Voltage stress test procedures

4.3.1 Apparatus

a) DC voltage power source capable of applying the maximum system voltage in the designated polarity of the modules under test with sufficient current to maintain the set-point voltage with tolerance of 0,5 % and an appropriate device for resolving and monitoring the leakage current from the module to ground.

b) Insulated wire rated for the intended test voltage, temperature, and humidity; module manufacturer-specified or stainless steel hardware for electrical connection to the modules.

c) Sensors and data logger for recording the environmental conditions (chamber air temperature, relative humidity), module temperatures to an accuracy of ±1,0 °C in a manner that demonstrates uniformity over the modules and testing space, and leakage currents (optional: applied bias voltage) of each module in 1 min or lesser intervals. Temperature sensors and their wires mounted to the module shall be electrically insulating at all applied temperatures and humidity levels so that they do not impact the voltage bias and leakage current from the module.

NOTE Current and voltage measurement and their recording are intended as indicators of stability, uniformity, and continuity of the stress test conditions and not intended as performance criteria for the module under test.

d) For procedure a) in 4.3.2, an environmental chamber capable of controlling temperature and humidity independently to achieve the stress levels for the test; non-porous, electrically insulating module support; or for procedure b) in 4.3.3, a material (e.g., aluminium or copper foil 8 µm to 150 µm in thickness) and a flexible polymeric mat to provide weighting on the foil to follow the surface morphology of the module glass to achieve a uniform electrical conducting electrode.

4.3.2 Stress method a), testing in damp heat using an environmental chamber

4.3.2.1 General

Application of heat and humidity in an environmental chamber promotes ionic conduction in some module packages and the adsorbed humidity provides electrical connections in declivities and pores on the module surface. The humidity functions to extend the ground potential over the face of module glass thereby introducing voltage stress. The potential frequently does not extend uniformly over the module face.

4.3.2.2 Severity

These severities represent the minimal stress levels for detection of PID.

- Module temperature: 60 °C ± 2 °C.
- Chamber relative humidity: 85 % ± 3 % relative humidity.
- Dwell: 96 h at the above stated temperature and relative humidity (not including stabilization).
- Voltage: module rated system voltage and polarities applied for the above given dwell duration and during ramp down of temperature to ambient conditions.

Suggested common temperatures to use for the detection of PID in modules that do not display degradation at 60 °C or when further acceleration is sought are 65 °C and 85 °C. The applied severities and test durations should be clearly marked in the test report according to Clause 5 h).

4.3.2.3 Environmental chamber

The test shall be carried out in an environmental chamber for damp heat in accordance with IEC 60068-2-78:2012; however, this Technical Specification shall supersede where conditions and specifications differ. The ramps to and from the stress conditions and the stress test itself shall be performed in a continuous and uninterrupted manner.

The total temperature tolerance of ± 2 °C is intended to take account of absolute errors in the measurement, slow changes of temperature, and temperature variations of the working space. However, to maintain the relative humidity within the required tolerances, it is necessary to keep the temperature difference between any two points in the working space at any moment within narrower limits. The required humidity conditions will not be achieved if such temperature differences exceed 1 °C. It may also be necessary to keep short-term fluctuations within ± 0,5 °C to maintain the required humidity. The chamber and module loading configurations within the chamber shall be characterized for achieving the required severities and tolerances at the various positions within the test space.

4.3.2.4 Procedure

a) The module shall be placed into an environmental chamber supported by a non-porous electrically insulating mounting material. Modules shall be placed by default in any upright position; however, this placement may be changed if it is helpful to better achieve the intended goals of this test method, including improved air circulation, temperature and relative humidity uniformity, tolerances, and set points, or implementation of the module's specifically documented mounting or grounding instructions.

   NOTE Insulator mounts are used to prevent alternative paths for leakage current between the biased active cell circuit and the manufacturers intended ground points, if any are provided, and for the safety of personnel and equipment. The insulation of the individual modules from each other may also be required to control the path to ground.

b) The method of the connection at the grounding point shall be based on the installation manual. For continuous metallic frames encasing the perimeter of the module that have grounding points or that have points for mounting the module that are not specified to be used on insulating mounting structures, the ground terminal of the voltage power supply shall be connected to a grounding point of the module with the manufacturer-specified grounding hardware, or if not specified, an insulated wire terminated with a crimped-on ring terminal attached with a stainless steel nut, bolt, and star washer. Thin layer coatings on the metallic frame shall be removed by abrasion to achieve metal-to-metal contact between the connector and the module frame.

In the case of modules with frames that are not continuous or compliant with IEC 61730-2 MST 13, non-metallic frames, and metallic frames with insulating surfaces that cannot be reasonably penetrated anywhere by abrasion, all module mounting points and grounding points available on the module shall be connected at those points of attachment to one another and to the ground terminal of the DC voltage supply with insulated wire terminated with a crimped-on screw connector and stainless steel annulus washers in contact with the module.

Modules without frames (frameless modules) should be tested with the supplied mounting brackets that are consistent in every way with that specified in the module installation manual. If none are specified in the installation manual or if the specifications do not indicate a specific bracket model or materials and dimensions of mounting brackets, then the stress test shall include a conductively adhered conductive foil on the perimeter of the module that spans from the module edges to the active cell circuit. The foil, which simulates a grounded module frame, is connected to the ground terminal of the DC voltage supply.

The testing shall reasonably accommodate requests by the module manufacturer to reproduce manufacturer-specified mounting configurations that could influence the electrical resistance between the module surfaces and ground. Specifically, if

1) the PV module is provided or is specified for use with an insulating structure for mounting, and
2) the module is designed and specified not to be connected to ground,

then such method of mounting the module shall be implemented to the extent possible. The base of that structure or portion designed to be mounted to a building structure or on the ground shall be thoroughly grounded and connected to the ground terminal of the DC voltage power supply during the course of the test.

c) Positive and negative electrical terminal wires (leads, tags, studs, screws, connectors) of the module shall be connected to one another and to the appropriate energized DC voltage terminal of the power supply with insulated wire rated for the intended test voltage.

d) Stresses are applied to the module in chamber according to the severities listed in 4.3.2.2 referencing the example profile in Figure 2. Recording of sensor data shall be commenced. The chamber temperature shall be ramped from ambient to the specified stress temperature. When the chamber air temperature and the module temperature reach the set point within tolerance, increase the relative humidity to arrive at the prescribed severity. When the temperature and relative humidity set points are reached within the prescribed tolerances, start the 12 h to 24 h stabilization period for the environmental conditions. At the end of this period, switch on the voltage to the prescribed stress level (rated maximum system voltage and polarity). The prescribed dwell period begins when the voltage has arrived at the prescribed severity.

e) For the cooling phase to ambient temperature (25 °C or less) at the end of the damp heat dwell, turn off the humidity generation and simultaneously begin to cool the chamber so that the modules reach the ambient temperature in a maximum of 1 h. The specified applied voltage shall be switched off when the module temperature reaches 25 °C ± 5 °C.

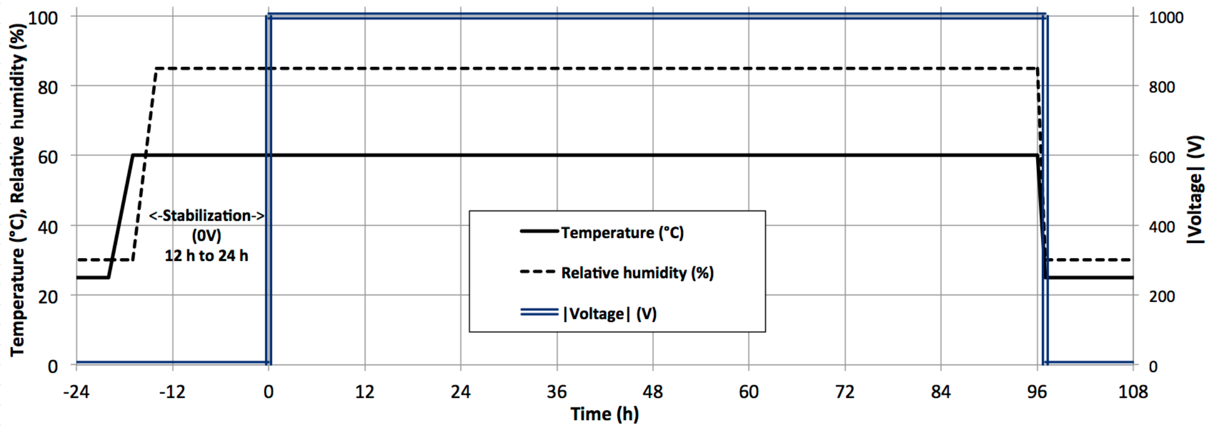

Figure 2 – Example test time-temperature-humidity-voltage profile for application of stress in an environmental chamber

4.3.3 Stress method b), contacting the surfaces with a conductive electrode

4.3.3.1 General

This test method grounds all glass module surfaces, thereby introducing a constant ground potential across the glass module face. It does not account for module-level designs intended to mitigate degradation by reducing leakage current pathways to ground. For example, it defeats protections that may be placed in the module construction to minimize metal contact to the module.

4.3.3.2 Severity

These severities represent the minimal stress levels for detection of PID.

– Module temperature: 25 °C ± 1 °C.
– Relative humidity: less than 60 %.
– Dwell duration: 168 h.
– Voltage: module rated system voltage and polarities applied for the above given dwell duration.

Suggested common temperatures to use for the detection of PID in modules that do not display degradation at 25 °C or when further acceleration is sought are 50 °C and 60 °C. The applied severities and test durations should be clearly marked in the test report according to Clause 5 h).

4.3.3.3 Procedure

a) Cover the PV module surfaces with the electrically conductive medium (e.g., aluminium foil or copper foil) to achieve contact to the surfaces and the frame (if applicable). The foil shall be compressed onto a module grounding point of the module frame with a stainless steel annulus washer and bolt and/or nut and connected at this point to the ground terminal of the DC voltage supply. Any coatings on a metallic module frame shall be abraded off under the area of the annulus washer. Apply a homogeneous load of 30 Pa minimum to the electrically conductive medium on the light-facing surfaces of the module using a flexible polymeric mat. Apply the ground-connected conductive foil also to the substrates or rear surfaces that are made of glass and place the module on a conforming, soft polymeric surface so that the foil is pressed to the glass by the module’s weight on at least 95 % of the exposed rear-surface glass area.

b) In the case of modules with frames that are not continuous or compliant with IEC 61730-2 MST 13 and module frames, clamps, or mounting brackets with insulating surfaces that cannot be reasonably penetrated anywhere by abrasion, all module mounting points and grounding points available on the module shall be connected and fixed at those points of attachment to the ground terminal of the DC voltage supply with insulated wire and stainless steel annulus washers in stable electrical contact with the foil and the module surface(s). Any coatings on metal shall be abraded off under the area of the annulus washers.

c) Recording of sensor data shall be commenced and prescribed stresses shall be applied to the modules according to the severities listed in 4.3.3.2 referencing the example profile in Figure 3 if performed in a 25 °C ambient room with less than 60 % relative humidity. Voltage shall be switched on at the start of the stress test to the shorted module leads, applied continuously over the course of the test, and switched off at the end of the stress test. The test duration shall correspond to the time that the prescribed voltage severity was applied. If performed in an environmental chamber requiring ramps to and from ambient conditions, the example in Figure 2 and 4.3.2.4 d) and e) shall be used in conjunction with the severities listed in 4.3.3.2.

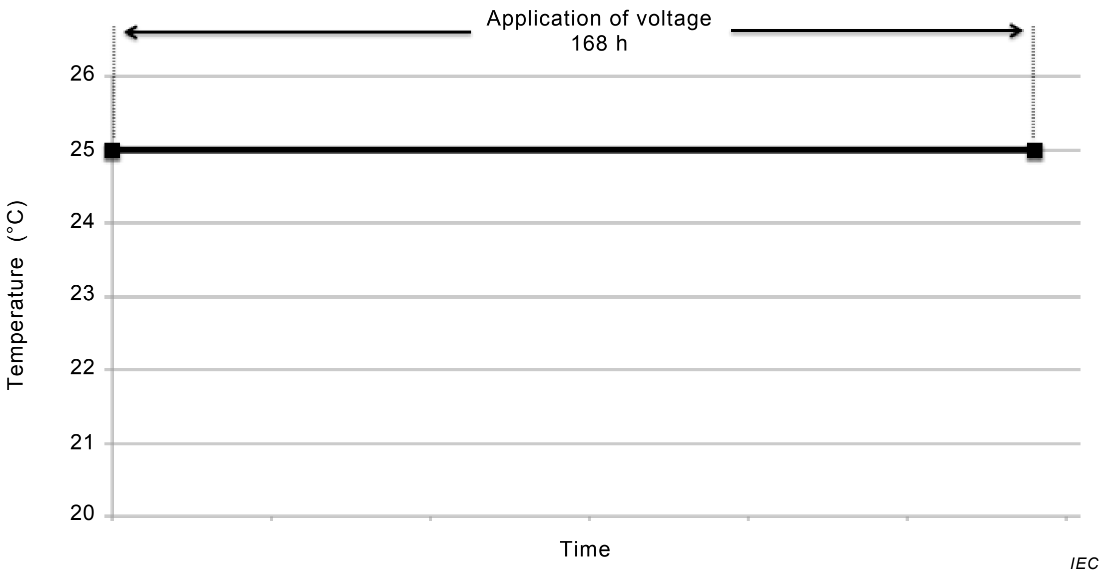

Figure 3 – Test time-temperature-voltage profile for stress method performed in 25 °C ambient

4.4 Post-stress tests

a) Perform IEC 61215:2005, 10.2, Maximum power determination between 2 h and 6 h after completion of 4.3.2 or 4.3.3, including the control module. Maintain the modules indoors at 25 °C or below and out of direct sunlight until ready for the maximum power determination.

b) Optional: Perform IEC 61215:2005, 10.7, Performance at low irradiance, including on the control module.

c) Optional: Perform IEC 61215:2005, 10.15, Wet leakage current test within 8 h after completion of 4.3.2 or 4.3.3.

NOTE The decision to perform IEC 61215:2005, 10.15, Wet leakage current test after stress testing may be based on observations of, for example, large increases in leakage current from the module during stress testing.

d) Optional: Perform electroluminescence imaging at 1 and 0,1 I_{sc} within two days of completion of 4.3.2 or 4.3.3.

e) Perform IEC 61215:2005, 10.1, Visual inspection.

5 Test report

A test report with measured performance characteristics and test results if prepared by a test agency shall be in accordance with ISO/IEC 17025. The test report shall contain the following data and information:

a) a title;

b) name and address of the test laboratory and location where the tests were carried out;

c) unique identification of the certification or report and of each page, and a clear identification of the purpose of the test report;

d) name and address of client, where appropriate;

e) a serial number and production date such that the bill of materials can be traced; reference to sampling procedure; for prototype modules, modules made on alternate or pilot production tools, or not randomly selected, such details of the deviation from the standard test method shall be noted;

f) date of receipt of test items and date(s) of test, where appropriate;

g) description, photographs, and identification of the items tested including test procedure, grounding and mounting methods utilized during the test, referencing (document, model, date, page) the specifications in the module manufacturer's documentation (where relevant);

h) characterizations, conditions, and the results obtained of the test items; this includes:

  - a clear statement of the stress method used (environmental chamber method or conductive electrode method) and the nominal stress parameters (temperature, relative humidity, voltages) and durations applied;
  - wet leakage current test results of each module (stress voltage polarities of each sample tested shall also be indicated);
  - visual inspection results, photographs, and, optionally, electroluminescence imaging results obtained before and after stress testing for each module (stress voltage polarities of each sample tested shall also be indicated);
  - maximum power at standard test conditions according to IEC 61215:2005, 10.2, determined initially and after stress testing (including the control module) and the extent to which each module degraded expressed as a relative percent change from the initial value (stress voltage polarities of each sample tested shall also be indicated). This reporting procedure shall also be applied for performance at low irradiance, if tested;
  - data files that include test voltage, module leakage current, module temperature, chamber temperature, and chamber relative humidity;
  - statement of the measured average, minimum, and maximum of module temperatures, relative humidities, and leakage currents during the test. Also include a time-parameter diagram;

i) a description, including photographs, of any deviations from, additions to, or exclusions from the testing or test method such as polarities not tested and any other information relevant to a specific test, such as special test conditions, with reference to the specifications in the module's documentation (where relevant);

j) measurements, examinations, and derived results supported by tables, graphs, sketches, and photographs (including optional electroluminescence images), as appropriate;

k) a statement of the estimated uncertainty of the test results (where relevant);

l) a signature and title, or equivalent identification, of the person(s) accepting responsibility for the content of the certificate or report, and the date of issue;

m) a statement about the domain of products (modules) to which the test result applies;

n) a statement whether the module tested is certified to IEC 61215 and IEC 61730-2;

o) a statement that the report shall not be reproduced except in full, without the written approval of the laboratory.

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