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INTERNATIONAL ELECTROTECHNICAL COMMISSION

THIN-FILM TERRESTRIAL PHOTOVOLTAIC (PV) MODULES –
DESIGN QUALIFICATION AND TYPE APPROVAL

FOREWORD

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International Standard IEC 61646 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This second edition cancels and replaces the first edition published in 1996. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

The major change is in the pass/fail criteria. It no longer relies on meeting a plus/minus criterion before and after each test, but rather on meeting the rated power after all of the tests have been completed and the modules have been light-soaked. This was done to eliminate the technology-specific preconditioning necessary to accurately measure the changes caused by the test. (Some modules lose power in light while others lose power during dark heat.) Since all modules must work after exposure to light, this seemed like a good approach and will streamline the test procedure, hopefully reducing the testing cost.

- Updated Normative references.
- Added a definition of "minimum value of maximum output power".

- Modified the wording in Major visual defects to allow some bending and misalignment without failure.
- Added requirements to the report from ISO/IEC 17025.
- Removed the "Twist Test" as was done from IEC 61215, since no one has ever failed this test.
- Made the pass/fail criteria for insulation resistance and wet leakage current dependent on the module area.
- Added the temperature coefficient of power (δ) to the required measurements.
- Modified temperature coefficient section to allow for measurements under natural sunlight or a solar simulator.
- Deleted reference plate method from NOCT.
- Added apparatus sections to those test procedures that did not have apparatus sections in edition 1.
- Rewrote the hot-spot test.
- Eliminated edge dip method from wet leakage current test.
- Changed mechanical load test to 3 cycles to be consistent with other standards.
- Added bypass diode thermal test.

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

FDIS	Report on voting
82/512/FDIS	82/528/RVD

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.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site 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.

THIN-FILM TERRESTRIAL PHOTOVOLTAIC (PV) MODULES – DESIGN QUALIFICATION AND TYPE APPROVAL

1 Scope and object

This International Standard lays down requirements for the design qualification and type approval of terrestrial, thin-film photovoltaic modules suitable for long-term operation in general open-air climates as defined in IEC 60721-2-1. This standard is intended to apply to all terrestrial flat plate module materials not covered by IEC 61215.

The test sequence is derived from IEC 61215 for the design qualification and type approval of terrestrial crystalline silicon PV modules. However, it no longer relies on meeting a plus/minus criterion before and after each test, but rather on meeting a specified percentage of the rated minimum power after all of the tests have been completed and the modules have been light-soaked. This eliminates the technology-specific preconditioning necessary to accurately measure the changes caused by the test.

This standard does not apply to modules used with concentrators.

The object of this test sequence is to determine the electrical and thermal characteristics of the module and to show, as far as possible within reasonable constraints of cost and time, that the module is capable of withstanding prolonged exposure in climates described in the scope. The actual life expectancy of modules so qualified will depend on their design, their environment and the conditions under which they are operated.

2 Normative references

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

IEC 60068-1: *Environmental testing – Part 1: General and guidance*

IEC 60068-2-21: *Environmental testing – Part 2-21: Tests – Test U: Robustness of terminations and integral mounting devices*

IEC 60068-2-78:2001, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state*

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

IEC 60721-2-1, *Classification of environmental conditions – Part 2-1: Environmental conditions appearing in nature – Temperature and humidity*

IEC 60891, *Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic (PV) devices*

IEC 60904-1:2006, *Photovoltaic devices – Part 1: Measurements of photovoltaic current-voltage characteristics*

IEC 60904-2, *Photovoltaic devices – Part 2: Requirements for reference solar devices*

IEC 60904-3, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

IEC 60904-7, *Photovoltaic devices – Part 7: Computation of spectral mismatch error introduced in the testing of a photovoltaic device*

IEC 60904-9, *Photovoltaic devices – Part 9: Solar simulator performance requirements*

IEC 60904-10, *Photovoltaic devices – Part 10: Methods of linearity measurements*

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

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

3 Sampling

Eight modules for qualification testing (plus spares as desired) shall be taken at random from a production batch or batches, in accordance with the procedure given in IEC 60410. The modules shall have been manufactured from specified materials and components in accordance with the relevant drawings and process sheets and shall have been subjected to the manufacturer's normal inspection, quality control and production acceptance procedures. The 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.

If the bypass diodes are not accessible in the standard modules, a special sample can be prepared for the bypass diode thermal test (see 10.18). The bypass diode should be mounted physically as it would be in a standard module, with a thermal sensor placed on the diode as required in 10.18.2. This sample does not have to go through the other tests in the sequence.

When the modules to be tested are prototypes of a new design and not from production, this fact shall be noted in the test report (see Clause 8).

4 Marking

Each module shall carry the following clear and indelible markings:

- name, monogram or symbol of manufacturer;
- type or model number;
- serial number;
- polarity of terminals or leads (colour coding is permissible);
- maximum system voltage for which the module is suitable;
- nominal and minimum values of maximum output power at STC, as specified by the manufacturer for the product type.

The minimum value of maximum output power refers to the lowest stabilized power that the manufacturer specifies for the product type (for example after any light induced degradation or recovery).

NOTE If the modules to be tested are prototypes of a new design and not from production, the results of this test sequence may be used to establish the module minimum power rating.

The date and place of manufacture shall be marked on the module or be traceable from the serial number.

5 Testing

The modules shall be divided into groups and subjected to the qualification test sequences in Figure 1, carried out in the order laid down. Each box refers to the corresponding subclause in this standard. Test procedures and severities, including initial and final measurements where necessary, are detailed in Clause 10. However, with regard to the tests of 10.2, 10.4, 10.6 and 10.7, it should be noted that the procedures laid down in IEC 60891 for temperature and irradiance corrections to measured I-V characteristics apply only to linear modules. Use IEC 60904-10 to assess linearity. If the module is non-linear, these tests shall be carried out within ± 5 % of the specified irradiance and within ± 2 °C of the specified temperature.

NOTE 1 Where the final measurements for one test serve as the initial measurements for the next test in the sequence, they need not be repeated. In these cases, the initial measurements are omitted from the test.

For diagnostic purposes, intermediate measurements of maximum power (10.2) may be undertaken before and after individual tests.

NOTE 2 The control module should be stored in accordance with the manufacturer's recommendation.

Any single test, executed independently of a test sequence, shall be preceded by the initial tests of 10.1, 10.2 and 10.3.

In carrying out the tests, the tester shall strictly observe the manufacturer's handling, mounting and connection instructions. Tests given in 10.4, 10.5, 10.6 and 10.7 may be omitted if future IEC 61853 has been or is scheduled to be run on this module type.

Thin film technologies can have different stabilization characteristics. It is impossible to define a single stabilisation procedure applicable to all thin film technologies. This procedure tests the modules "as received" and attempts to reach a stabilised condition before final test.

Test conditions are summarized in Table 1.

NOTE 3 The test levels in Table 1 are the minimum levels required for qualification. If the laboratory and the module manufacturer agree, the tests may be performed with increased severities.

6 Pass criteria

A module design shall be judged to have passed the qualification tests, and therefore, to be IEC type approved, if each test sample meets all the following criteria:

- a) after the final light soaking, the maximum output power at STC is not less than 90 % of the minimum value specified by the manufacturer in Clause 4;

NOTE The pass/fail criteria must consider the laboratory uncertainty of the measurement. As an example, if the laboratory extended uncertainty, 2 sigma of the STC measurement, is ± 5 %, then a maximum power measurement greater than 85,5 % of the minimum specified value would be the pass criteria.

- b) no sample has exhibited any open-circuit during the tests;
- c) there is no visual evidence of a major defect, as defined in Clause 7;
- d) the insulation test requirements are met after the tests;
- e) the wet leakage current test requirements are met at the beginning and the end of each sequence and after the damp heat test;
- f) specific requirements of the individual tests are met.

If two or more modules do not meet these test criteria, the design shall be deemed not to have met the qualification requirements. Should one module fail any test, another two modules meeting the requirements of Clause 3 shall be subjected to the whole of the relevant

test sequence from the beginning. If one or both of these modules also fail, the design shall be deemed not to have met the qualification requirements. If, however, both modules pass the test sequence, the design shall be judged to have met the qualification requirements.

7 Major visual defects

For the purposes of design qualification and type approval, the following are considered to be major visual defects:

- a) broken, cracked, or torn external surfaces, including superstrates, substrates, frames and junction boxes;
- b) bent or misaligned external surfaces, including superstrates, substrates, frames and junction boxes to the extent that the installation and/or operation of the module would be impaired;
- c) voids in, or visible corrosion of any of the thin film layers of the active circuitry of the module, extending over more than 10 % of any cell;
- d) bubbles or delaminations forming a continuous path between any part of the electrical circuit and the edge of the module;
- e) loss of mechanical integrity, to the extent that the installation and/or operation of the module would be impaired;
- f) Module markings (label) is no longer attached or the information is unreadable.

8 Report

Following type approval, a certified report of the qualification tests, with measured performance characteristics and details of any failures and re-tests, shall be prepared by the test agency in accordance with ISO/IEC 17025. Each certificate or test report shall include at least the following information.

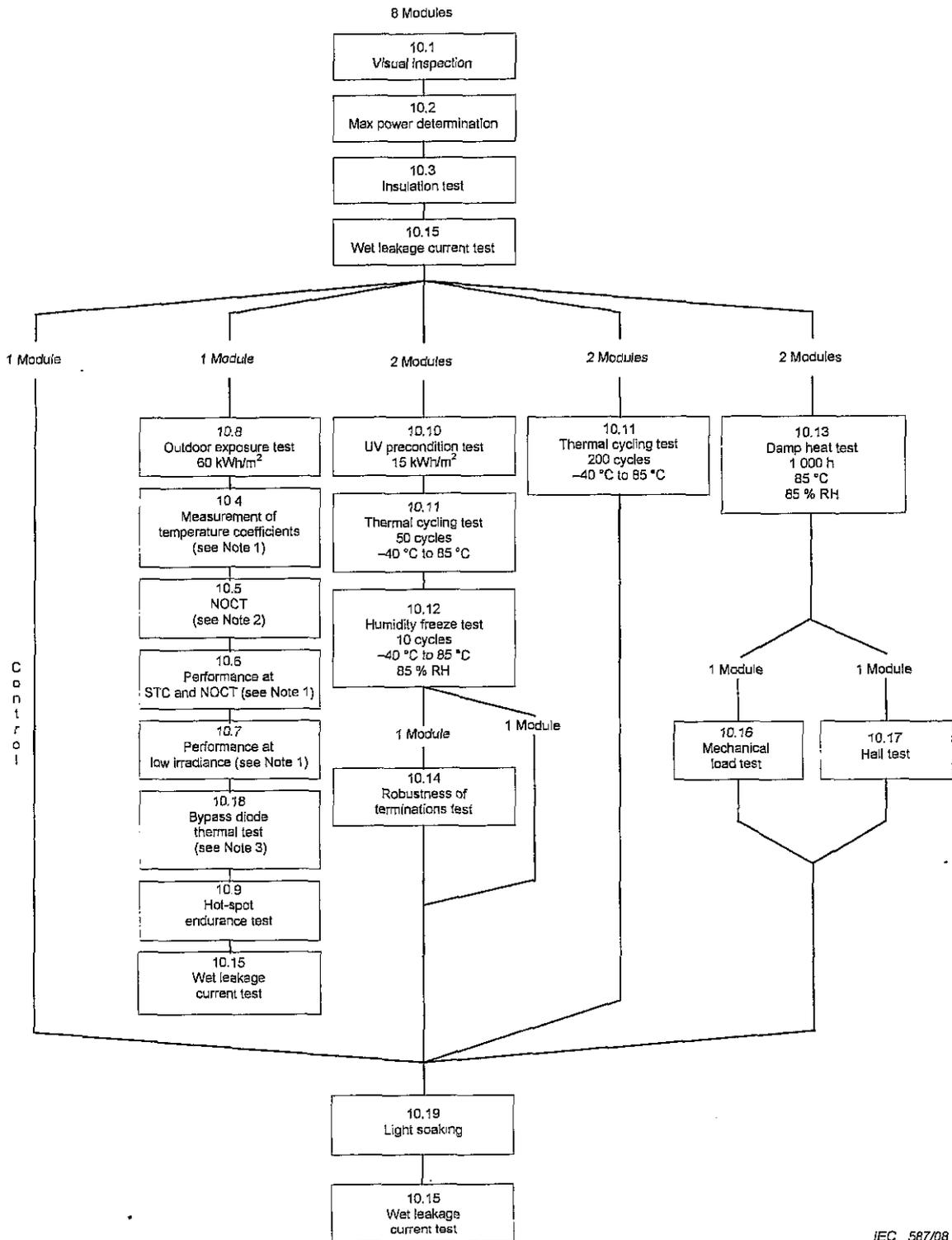
- a) A title.
- b) Name and address of the test laboratory and location where the tests were carried out.
- c) Unique identification of the certification or report and of each page.
- d) Name and address of client, where appropriate.
- e) Description and identification of the item tested.
- f) Characterization and condition of the test item.
- g) Date of receipt of test item and date(s) of test, where appropriate.
- h) Identification of test method used.
- i) Reference to sampling procedure, where relevant.
- j) Any deviations from, additions to or exclusions from the test method, and any other information relevant to a specific tests, such as environmental conditions.
- k) Measurements, examinations and derived results supported by tables, graphs, sketches and photographs as appropriate including temperature coefficients of short circuit current, open circuit voltage and peak power, NOCT, power at NOCT, STC and low irradiance, the maximum shaded cell temperature observed during the hot-spot test, spectrum of the lamp used for the UV prescreening test, minimum power observed after light soaking and any failures observed. If the maximum power loss observed after each of the tests has been measured it should also be reported.
- l) A statement of the estimated uncertainty of the test results (where relevant).
- m) 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.
- n) Where relevant, a statement to the effect that the results relate only to the items tested.

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

A copy of this report shall be kept by the laboratory and manufacturer for reference purposes.

9 Modifications

Any change in the design, materials, components or processing of the module may require a repetition of some or all of the qualification tests to maintain type approval.



IEC 587/08

NOTE 1 May be omitted if future IEC 61853 has been performed.

NOTE 2 In the case of modules not designed for open-rack mounting, the NOCT may be replaced by the equilibrium mean solar cell junction temperature in the standard reference environment, with the module mounted as recommended by the manufacturer.

NOTE 3 If the bypass diodes are not accessible in the standard modules, a special sample can be prepared for the bypass diode thermal test (10.18). The bypass diode should be mounted physically as it would be in a standard module, with a thermal sensor placed on the diode as required in 10.18.2. This sample does not have to go through the other tests in the sequence.

NOTE 4 For diagnostic purposes intermediate measurements of maximum power (10.2) may be undertaken before and after individual tests. If the control module is used for these measurements make sure it has been pre-conditioned per the manufacturers recommendation.

Figure 1 – Qualification test sequence

Table 1 – Summary of test levels

Test	Title	Test conditions
10.1	Visual inspection	See detailed inspection list in 10.1.2
10.2	Maximum Power Determination	See IEC 60904-1
10.3	Insulation test	Dielectric withstand at 1 000 V d.c. + twice the maximum system voltage for 1 min. For modules with an area less than 0,1 m ² the insulation resistance shall not be less than 400 MΩ. For modules with an area larger than 0,1 m ² , the measured insulation resistance times the area of the module shall not be less than 40 MΩ·m ² . Measured at 500 V or maximum system voltage, whichever is greater.
10.4	Measurement of temperature coefficients	See detail in 10.4 See IEC 60904-10 for guidance.
10.5	Measurement of NOCT	Total solar irradiance: 800 W·m ⁻² Ambient temperature: 20 °C Wind speed: 1 m·s ⁻¹
10.6	Performance at STC and NOCT	Cell temperature: 25 °C and NOCT Irradiance: 1 000 and 800 W·m ⁻² with IEC 60904-3 reference solar spectral irradiance distribution
10.7	Performance at low irradiance	Cell temperature: 25 °C Irradiance: 200 W·m ⁻² with IEC 60904-3 reference solar spectral irradiance distribution
10.8	Outdoor exposure test	60 kWh·m ⁻² total solar irradiation under resistive load
10.9	Hot-spot endurance test	One hour exposure to 1 000 W·m ⁻² irradiance in worst-case hot-spot condition
10.10	UV Preconditioning	15 kWh·m ⁻² total UV irradiation in the wavelength range from 280 nm to 385 nm with 5 kWh·m ⁻² UV irradiation in the wavelength range from 280 to 320 nm under resistive load.
10.11	Thermal cycling test	50 and 200 cycles from - 40 °C to +85 °C
10.12	Humidity freeze test	10 cycles from +85 °C, 85 % RH to -40 °C
10.13	Damp heat test	1 000 h at +85 °C, 85 % RH
10.14	Robustness of terminations test	As in IEC 60068-2-21
10.15	Wet leakage current test	See detail in 10.15 Test performed at test voltage 500 V or maximum systems voltage, whichever is higher for 1 min. For modules with an area less than 0,1 m ² the insulation resistance shall not be less than 400 MΩ. For modules with an area larger than 0,1 m ² the measured insulation resistance times the area of the module shall not be less than 40 MΩ·m ² .
10.16	Mechanical load test	Three cycles of 2 400 Pa uniform load, applied for 1 h to front and back surfaces in turn. Optional snow load of 5 400 Pa during last front cycle.
10.17	Hail test	25 mm diameter ice ball at 23,0 m·s ⁻¹ , directed at 11 impact locations
10.18	Bypass diode thermal test	One hour at I_{sc} and 75 °C One hour at 1,25 times I_{sc} and 75 °C
10.19	Light-soaking	Light exposure of 800 W·m ⁻² to 1 000 W·m ⁻² under resistive load until P_{max} is stable within 2 %.

10 Test procedures

10.1 Visual inspection

10.1.1 Purpose

To detect any visual defects in the module.

10.1.2 Procedure

Carefully inspect each module under an illumination of not less than 1 000 lux for the following conditions:

- cracked, bent, misaligned or torn external surfaces;
- faulty interconnections or joints;
- voids in, and visible corrosion of any of the thin film layers of the active circuit;
- visible corrosion of output connections, interconnections and busbars;
- failure of adhesive bonds;
- bubbles or delaminations forming a continuous path between a cell and the edge of the module;
- tacky surfaces of plastic materials;
- faulty terminations, exposed live electrical parts;
- any other conditions which may affect performance.

Make note of and/or photograph the nature and position of any cracks, bubbles or delamination, etc., which may worsen and adversely affect the module performance in subsequent tests.

10.1.3 Requirements

Visual conditions other than the major visual defects listed in Clause 7 are acceptable for the purpose of type approval.

10.2 Maximum power determination

10.2.1 Purpose

To determine the maximum power of the module before and after the various environmental tests. Repeatability of the test is the most important factor.

10.2.2 Apparatus

- a) A radiant source (natural sunlight or a solar simulator Class BBA or better in accordance with IEC 60904-9).
- b) A PV reference device in accordance with IEC 60904-2. If a Class BBA simulator is used, the reference device shall be a reference module of the same size with the same cell technology (to match spectral response) as the test specimen.
- c) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.
- d) Apparatus for measuring an I-V curve in accordance with IEC 60904-1.

10.2.3 Procedure

Determine the current-voltage characteristic of the module in accordance with IEC 60904-1 at a specific set of irradiance and temperature conditions (a recommended range is a cell

temperature between 25 and 50 °C and an irradiance between 700 W·m⁻² and 1100 W·m⁻²) using natural sunlight or a class BBA or better simulator conforming to the requirements of IEC 60904-9. In special circumstances when modules are designed for operation under a different range of conditions, the current-voltage characteristics can be measured using temperature and irradiance levels similar to the expected operating conditions. For linear modules temperature and irradiance corrections can be made in accordance with IEC 60891. For nonlinear modules the measurement shall be performed within ±5 % of the specified irradiance and within ±2 °C of the specified temperature. Every effort should be made to assure that peak power measurements are made under similar operating conditions, that is, minimize the magnitude of the correction by making all peak power measurements on a particular module at approximately the same temperature and irradiance.

NOTE The control module may be used as a check every time the test modules are measured.

10.3 Insulation test

10.3.1 Purpose

To determine whether or not the module is sufficiently well insulated between current carrying parts and the frame or the outside world.

10.3.2 Apparatus

- a) A d.c. voltage source, with current limitation, capable of applying 500 V or 1 000 V plus twice the maximum system voltage of the module (as marked on the module – see Clause 4) according to item c) of 10.3.4.
- b) An instrument to measure the insulation resistance.

10.3.3 Test conditions

The test shall be made on modules at ambient temperature of the surrounding atmosphere (see IEC 60068-1) and in a relative humidity not exceeding 75 %.

10.3.4 Procedure

- a) Connect the shorted output terminals of the module to the positive terminal of a d.c. insulation tester with a current limitation.
- b) Connect the exposed metal parts of the module to the negative terminal of the tester. If the module has no frame or if the frame is a poor electrical conductor, wrap a conductive foil around the edges and over the back of the module. If the module does not have a glass superstrate, also wrap the foil around the front of the module. Connect the foil to the negative terminal of the tester.
- c) Increase the voltage applied by the tester at a rate not exceeding 500 V·s⁻¹ to a maximum equal to 1 000 V plus twice the maximum system voltage (i.e. the maximum system voltage marked on the module by the manufacturer, see Clause 4). If the maximum system voltage does not exceed 50 V, the applied voltage shall be 500 V. Maintain the voltage at this level for 1 min.
- d) Reduce the applied voltage to zero and short-circuit the terminals of the test equipment to discharge the voltage build-up in the module.
- e) Remove the short circuit.
- f) Increase the voltage applied by the test equipment at a rate not to exceed 500 V·s⁻¹ to 500 V or the maximum system voltage for the module, whichever is greater. Maintain the voltage at this level for 2 min. Then determine the insulation resistance.
- g) Reduce the applied voltage to zero and short-circuit the terminals of the test equipment to discharge the voltage build-up in the module.
- h) Remove the short circuit and disconnect the test equipment from the module.

10.3.5 Test requirements

- no dielectric breakdown or surface tracking during step c);
- for modules with total area less than 0,1 m², the insulation resistance shall not be less than 400 MΩ;
- for modules with total area larger than 0,1 m² the measured insulation resistance times the area of the module shall not be less than 40 MΩ·m².

10.4 Measurement of temperature coefficients

10.4.1 Purpose

To determine the temperature coefficients of current (α) and voltage (β) and peak power (δ) from module measurements. The coefficients so determined are valid at the irradiance at which the measurements were made. For linear modules, they are also valid over an irradiance range of $\pm 30\%$ of this level. This procedure supplements that in IEC 60891 for measuring these coefficients from a representative set of single cells. The temperature coefficients of a thin-film module may depend upon the irradiation and the thermal history of the module. When temperature coefficients are referred to, the history concerning the conditions and the results of irradiation along with thermal tests shall be indicated.

10.4.2 Apparatus

The following apparatus is required to control and measure the test conditions:

- a) a radiant source (natural sunlight or solar simulator, class BBB or better in accordance with IEC 60904-9) of the type to be used in subsequent tests;
- b) a PV reference device having a known short-circuit current versus irradiance characteristic determined by calibrating against an absolute radiometer in accordance with IEC 60904-2;
- c) any equipment necessary to change the temperature of the test specimen over the range of interest;
- d) a suitable mount for supporting the test specimen and the reference device in the same plane normal to the radiant beam;
- e) apparatus for measuring an I-V curve in accordance with IEC 60904-1.

10.4.3 Procedure

There are two acceptable procedures for measuring the temperature coefficients.

10.4.3.1 Procedure in natural sunlight

- a) Measurement in natural sunlight shall only be made when:
 - the total irradiance is at least as high as the upper limit of the range of interest;
 - the irradiance variation caused by short-term oscillations (clouds, haze, or smoke) is less than $\pm 2\%$ of the total irradiance as measured by the reference device;
 - the wind speed is less than 2 m·s⁻¹.
- b) Mount the reference device co-planar with the test module so that both are normal to the direct solar beam within $\pm 5^\circ$. Connect to the necessary instrumentation.

NOTE The measurements described in the following subclauses should be made as expeditiously as possible within a few hours on the same day to minimize the effect of changes in the spectral conditions. If not, spectral corrections may be required.

- c) If the test module and reference device are equipped with temperature controls, set the controls at the desired level.
- d) If temperature controls are not used, shade the specimen and the reference device from the sun and wind until its temperature is uniform within $\pm 1^\circ\text{C}$ of the ambient air temperature, or allow the test specimen to equilibrate to its stabilized temperature, or cool

the test specimen to a point below the required test temperature and then let the module warm up naturally. The reference device should also stabilize within ± 1 °C of its equilibrium temperature before proceeding.

- e) Record the current-voltage characteristic and temperature of the specimen concurrently with recording the short-circuit current and temperature of the reference device at the desired temperatures. If necessary, make the measurements immediately after removing the shade.
- f) The irradiance G_0 shall be calculated in accordance with IEC 60891 from the measured current (I_{sc}) of the PV reference device, and its calibration value at STC (I_{rc}). A correction should be applied to account for the temperature of the reference device T_m using the specified temperature coefficient of the reference device α_{rc} .

$$G_0 = \frac{1000 \times I_{sc}}{I_{rc}} \times [1 - \alpha_{rc}(T_m - 25)]$$

Where α_{rc} is the relative temperature coefficient [$^{\circ}\text{C}^{-1}$] at 25 °C and 1 000 $\text{W}\cdot\text{m}^{-2}$.

- g) Adjust the temperature by means of a controller or alternately exposing and shading the test module as required to achieve and maintain the desired temperature. Alternately, the test module may be allowed to warm-up naturally with the data recording procedure of item d) performed periodically during the warm-up.
- h) Ensure that the test module and reference device temperature are stabilized and remain constant within ± 1 °C and that the irradiance as measured by the reference device remains constant within ± 1 % during the recording period for each data set. All data must be taken at 1 000 $\text{W}\cdot\text{m}^{-2}$ or be translated to that irradiance level using IEC 60891. The translation can only be performed within the range of irradiance where the module is linear as defined in IEC 60904-10.
- i) Repeat steps d) through h). Module temperatures shall be such that the range of interest is at least 30 °C and that it is spanned in at least four approximately equal increments. A minimum of three measurements shall be made at each of the test conditions.

10.4.3.2 Procedure with a solar simulator

- a) Determine the short-circuit current of the module at the desired irradiance at room temperature, in accordance with IEC 60904-1.
- b) Mount the test module in the equipment used to change the temperature. Connect to the instrumentation.
- c) Set the irradiance so that the test module produces the short-circuit current determined in item a).
- d) Heat or cool the module to a temperature of interest. Once the module has reached the desired temperature, measure I_{sc} , V_{oc} and peak power. Change the module temperature in steps of approximately 5 °C over a range of interest of at least 30 °C and repeat measurements of I_{sc} , V_{oc} and peak power.

NOTE 1 The complete current-voltage characteristic may be measured at each temperature to determine the temperature change in voltage at peak power and current at peak power.

NOTE 2 Care should be taken to assure that the test module is correctly pre-conditioned before each measurement.

10.4.3.3 Calculation of temperature coefficients

- a) Plot the values of I_{sc} , V_{oc} and P_{max} as functions of temperature and construct a least-squares-fit curve through each set of data.
- b) From the slopes of the least squares, fit straight lines for current, voltage and P_{max} . Calculate α , the temperature coefficient of short circuit current, β , the temperature

coefficient of open circuit voltage, and δ , the temperature coefficient of P_{\max} , for the module.

NOTE 1 See IEC 60904-10 to determine if the test modules can be considered to be linear devices.

NOTE 2 The temperature coefficients measured in this procedure are only valid at the irradiance level and spectrum at which they were measured. Relative temperature coefficients expressed as percentages can be determined by dividing the calculated α , β , and δ by the values of current, voltage and peak power at 25 °C.

NOTE 3 Because the fill factor of the module is a function of temperature, it is not sufficient to use the product of α and β as the temperature coefficient of peak power.

10.5 Measurement of nominal operating cell temperature (NOCT)

10.5.1 Purpose

To determine the NOCT of the module.

10.5.2 Introduction

NOCT is defined as the equilibrium mean solar cell junction temperature within an open-rack mounted module in the following standard reference environment (SRE):

- tilt angle: at 45° tilt from the horizontal
- total irradiance: 800 W·m⁻²
- ambient temperature: 20 °C
- wind speed: 1 m·s⁻¹
- electrical load: nil (open circuit)

NOCT can be used by the system designer as a guide to the temperature at which a module will operate in the field and it is therefore a useful parameter when comparing the performance of different module designs. However, the actual operating temperature at any particular time is affected by the mounting structure, irradiance, wind speed, ambient temperature, sky temperature and reflections and emissions from the ground and nearby objects. For accurate performance predictions, these factors shall be taken into account.

In the case of modules not designed for open-rack mounting, the method may be used to determine the equilibrium mean solar cell junction temperature in the SRE, with the module mounted as recommended by the manufacturer.

10.5.3 Principle

This method is based on gathering actual measured cell temperature data under a range of environmental conditions including the SRE. The data are presented in a way that allows accurate and repeatable interpolation of the NOCT.

The temperature of the solar cell junction (T_J) is primarily a function of the ambient temperature (T_{amb}), the average wind speed (V) and the total solar irradiance (G) incident on the active surface of the module. The temperature difference ($T_J - T_{\text{amb}}$) is largely independent of the ambient temperature and is essentially linearly proportional to the irradiance at levels above 400 W·m⁻². The procedure calls for plotting ($T_J - T_{\text{amb}}$) against G for a period when wind conditions are favourable. A preliminary NOCT value is then determined by adding 20 °C to the value of ($T_J - T_{\text{amb}}$) interpolated at the SRE irradiance of 800 W·m⁻². Finally, a correction factor, dependent on the average temperature and wind speed during the test period, is added to the preliminary NOCT to correct it to 20 °C and 1 m·s⁻¹.

10.5.4 Apparatus

The following apparatus is required:

- a) An open rack to support the test module(s) and pyranometer in the specified manner (see 10.5.2). The rack shall be designed to minimize heat conduction from the modules and to interfere as little as possible with the free radiation of heat from their front and back surfaces.

NOTE In the case of modules not designed for open-rack mounting, the test module(s) should be mounted as recommended by the manufacturer.

- b) A pyranometer, mounted in the plane of the module(s) and within 0,3 m of the test array.
- c) Instruments to measure wind speed down to $0,25 \text{ m}\cdot\text{s}^{-1}$ with an accuracy of $\pm 10 \%$ or $0,2 \text{ m}\cdot\text{s}^{-1}$ whichever is greater and wind direction with an accuracy of $\pm 10^\circ$, installed approximately 0,7 m above the top of the module(s) and 1,2 m to the east or west.
- d) An ambient temperature sensor, with a time constant approaching that of the module(s), installed in a shaded enclosure with good ventilation near the wind sensors.
- e) Cell temperature sensors, attached by solder or thermally conductive adhesive to the backs of two solar cells near the middle of each test module, or other equipment necessary for IEC-approved measurement of cell temperature.
- f) A data acquisition system with temperature measurement accuracy of $\pm 1^\circ\text{C}$ to record the following parameters within an interval of no more than 5 s:
- irradiance;
 - ambient temperature;
 - cell temperature;
 - wind speed;
 - wind direction.

10.5.5 Test module mounting

Tilt angle: the test module(s) shall be positioned so that it is tilted at $45^\circ \pm 5^\circ$ to the horizontal with the front side pointed toward the equator.

Height: the bottom edge of the test module(s) shall be 0,6 m or more above the local horizontal plane or ground level.

Configuration: to simulate the thermal boundary conditions of modules installed in an array, the test module(s) shall be mounted within a planar surface that extends at least 0,6 m beyond the module(s) in all directions. For modules designed for free-standing, open-back installations, black aluminium plates or other modules of the same design shall be used to fill out the remaining open area of the planar surface.

Surrounding area: there shall be no obstructions to prevent full irradiance of the test module(s) during the period from 4 h before local solar noon to 4 h after local solar noon. The ground surrounding the module(s) shall not have an abnormally high solar reflectance and shall be flat and level or sloping away from the test fixture in all directions. Grass, other types of vegetation, black asphalt or dirt are acceptable for the local surrounding area.

10.5.6 Procedure

- a) Set up the apparatus with the test module(s), as described in 10.5.4. Ensure that the test module(s) are open-circuited.
- b) On a suitable, clear, sunny day with little wind, record, as a function of time, the cell temperature, the ambient temperature, the irradiance, wind speed and wind direction.
- c) Reject all data taken during the following conditions:
- irradiance below $400 \text{ W}\cdot\text{m}^{-2}$;
 - in a 10 min interval after the irradiance varies by more than 10 % during a data collection run;

- wind speeds outside the range $1,0 \text{ m}\cdot\text{s}^{-1} \pm 0,75 \text{ m}\cdot\text{s}^{-1}$;
 - ambient temperatures outside the range $20 \text{ }^\circ\text{C} \pm 15 \text{ }^\circ\text{C}$ or varying by more than $5 \text{ }^\circ\text{C}$;
 - a 10 min interval after a wind gust of more than $4 \text{ m}\cdot\text{s}^{-1}$;
 - wind direction within $\pm 20^\circ$ of east or west.
- d) From a minimum of 10 acceptable data points covering an irradiance range of at least $300 \text{ W}\cdot\text{m}^{-2}$, making sure that data points are from both before and after solar noon, plot $(T_J - T_{\text{amb}})$ as a function of irradiance. Use regression analysis to fit the data points.
- e) Determine the value of $(T_J - T_{\text{amb}})$ at $800 \text{ W}\cdot\text{m}^{-2}$ and add $20 \text{ }^\circ\text{C}$ to give the preliminary value of NOCT.
- f) Calculate the average ambient temperature, T_{amb} , and the average wind speed, V , associated with the acceptable data points and determine the appropriate correction factor from Figure 2.
- g) Add the correction factor to the preliminary NOCT to correct it to $20 \text{ }^\circ\text{C}$ and $1 \text{ m}\cdot\text{s}^{-1}$. This sum is the NOCT of the module.
- h) Repeat the entire procedure on a different day and average the two values of NOCT if they are within $0,5 \text{ }^\circ\text{C}$. If the difference is more than $0,5 \text{ }^\circ\text{C}$, repeat the procedure on a third day and average all three values of NOCT.

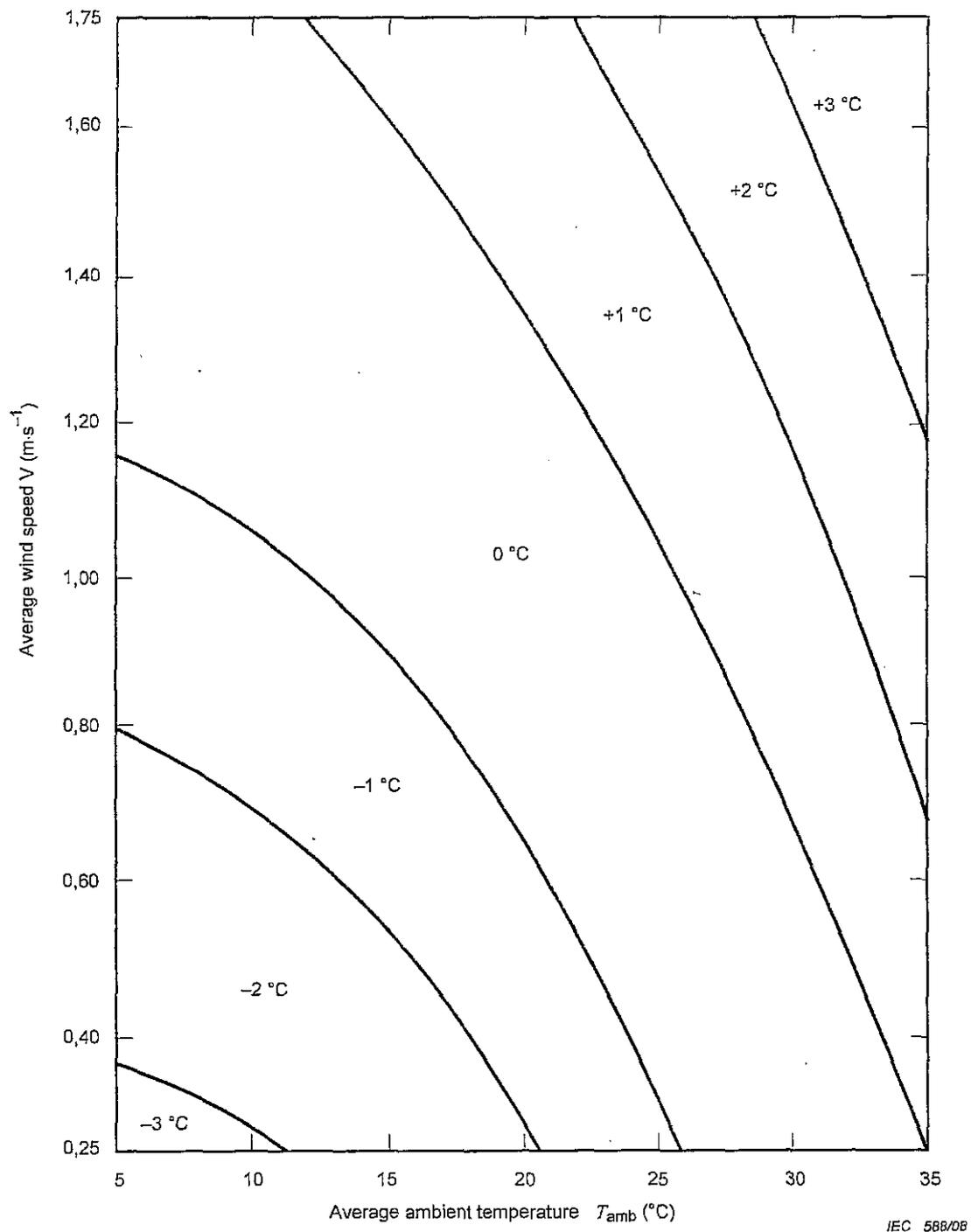


Figure 2 – NOCT correction factor

10.6 Performance at STC and NOCT

10.6.1 Purpose

To determine how the electrical performance of the module varies with load at STC ($1\,000\text{ W}\cdot\text{m}^{-2}$, $25\text{ }^{\circ}\text{C}$ cell temperature, with the IEC 60904-3 reference solar spectral irradiance distribution) and at NOCT, an irradiance of $800\text{ W}\cdot\text{m}^{-2}$, with the IEC 60904-3 reference solar spectral irradiance distribution.

10.6.2 Apparatus

- a) A radiant source (natural sunlight or a solar simulator Class BBB or better) in accordance with IEC 60904-9.
- b) A PV reference device in accordance with IEC 60904-2. If a Class BBB simulator is used, the reference device shall be a reference module of the same size with the same cell technology to match spectral response.
- c) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.
- d) Apparatus for measuring an I-V curve in accordance with Clause 4 of IEC 60904-1:2006.
- e) Equipment necessary to change the temperature of the test specimen to the NOCT temperature measured in 10.5.

10.6.3 Procedure

10.6.3.1 Standard Test Conditions (STC)

Maintain the module at 25 °C and trace its current-voltage characteristic at an irradiance of 1 000 W·m⁻² (as measured by a suitable reference device), in accordance with IEC 60904-1, using natural sunlight or a class BBB or better simulator conforming to the requirements of IEC 60904-9.

10.6.3.2 Nominal Operating Cell Temperature (NOCT)

Heat the module uniformly to NOCT and trace its current-voltage characteristic at an irradiance of 800 W·m⁻² (as measured by a suitable reference device), in accordance with IEC 60904-1, using natural sunlight or a class B or better simulator conforming to the requirements of the IEC 60904-9.

If the reference device is not spectrally matched to the test module, use IEC 60904-7 to calculate the spectral mismatch correction.

10.7 Performance at low irradiance

10.7.1 Purpose

To determine how the electrical performance of the module varies with load at 25 °C and an irradiance of 200 W·m⁻² (as measured by a suitable reference device), in accordance with IEC 60904-1 using natural sunlight or a class BBB simulator conforming to IEC 60904-9.

10.7.2 Apparatus

- a) A radiant source (natural sunlight or a solar simulator Class BBB or better) in accordance with IEC 60904-9.
- b) Equipment necessary to change the irradiance to 200 W·m⁻² without affecting the relative spectral irradiance distribution and the spatial uniformity in accordance with IEC 60904-10.
- c) A PV reference device in accordance with IEC 60904-2.
- d) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.
- e) Apparatus for measuring an I-V curve in accordance with IEC 60904-1.

10.7.3 Procedure

Determine the current-voltage characteristic of the module at 25 °C ± 2 °C and an irradiance of 200 W·m⁻² (as measured by a suitable reference device), in accordance with IEC 60904-1 using natural sunlight or a class BBB simulator conforming to IEC 60904-9. The irradiance shall be reduced to the specified level by using neutral filters or some other technique which

does not affect the spectral irradiance distribution. (See IEC 60904-10 for guidance on reducing the irradiance without changing the spectral irradiance distribution.)

10.8 Outdoor exposure test

10.8.1 Purpose

To make a preliminary assessment of the ability of the module to withstand exposure to outdoor conditions and to reveal any synergistic degradation effects which may not be detected by laboratory tests.

NOTE Caution should be taken in making absolute judgments about module life on the basis of passing this test because of the shortness of the test and the environmental variability of the test conditions. This test should only be used as a guide or indicator of possible problems.

10.8.2 Apparatus

- a) A device capable of measuring solar irradiance, with an uncertainty of less than $\pm 50 \text{ W}\cdot\text{m}^{-2}$.
- b) Means to mount the module, as recommended by the manufacturer, co-planar with the irradiation measuring device.
- c) A load sized such that at STC the module will operate near the maximum power point.

10.8.3 Procedure

- a) Attach the resistive load to the module and mount it outdoors, as recommended by the manufacturer, co-planar with the irradiation monitor. Any hot-spot protective devices recommended by the manufacturer shall be installed before the module is tested.
- b) Subject the module to an irradiation totaling $60 \text{ kWh}\cdot\text{m}^{-2}$, as measured by the monitor, under conditions conforming to general open-air climates, as defined in IEC 60721-2-1.

10.8.4 Final measurements

Repeat tests 10.1, 10.2, and 10.3.

10.8.5 Requirements

- no evidence of major visual defects, as defined in Clause 7;
- the maximum output power at STC shall exceed the manufacturer's minimum power rating;
- insulation resistance shall meet the same requirements as for the initial measurements.

10.9 Hot-spot endurance test

10.9.1 Purpose

To determine the ability of the module to withstand hot-spot heating effects, e.g. solder melting or deterioration of the encapsulation. This defect could be provoked by faulty cells, shadowing or soiling.

10.9.2 Hot-spot effect

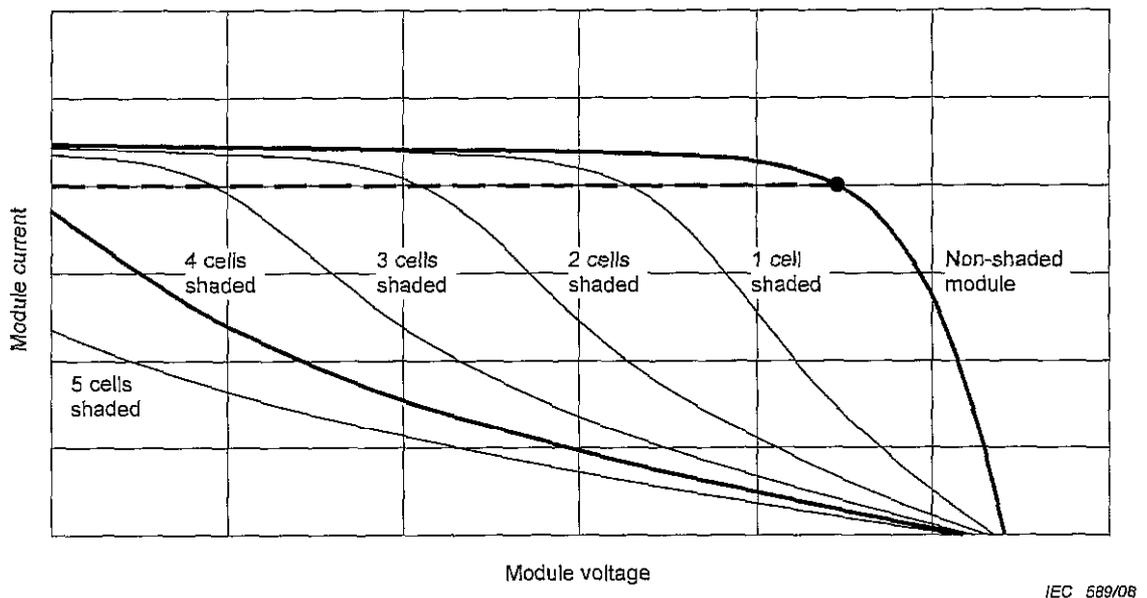
Hot-spot heating occurs in a module when its operating current exceeds the reduced short-circuit current (I_{sc}) of a shadowed or faulty cell or a group of cells. When such a condition occurs, the affected cell or group of cells is forced into reverse bias and dissipates power, which can cause overheating.

NOTE 1 Normally no bypass diodes are included in the interconnection circuit of the serially connected thin-film cells. Therefore, reverse voltage of shaded cells is not limited and module voltage can force a group of cells into reverse bias.

NOTE 2 The electrical performance of a thin-film module can already be negatively affected by short-term shading. Care must be taken that effects caused by setting worst case conditions and hot-spot endurance testing are clearly separated. The values of P_{max1} , P_{max2} and P_{max3} are collected for this purpose,

NOTE 3 While absolute temperature and relative power loss are not criteria of this test, the most severe hot-spot conditions are utilized to ensure safety of the design.

Figure 3 illustrates the hot-spot effect in a thin-film module consisting of a serial connection of cells, when a different number of cells is totally shadowed. The amount of power dissipated in the shaded cells is equal to the product of the module current and the reverse voltage developed across the group of shaded cells. For any irradiance level, maximum power is dissipated, when the reverse voltage across the shaded cells is equal to the voltage generated by the remaining illuminated cells in the module (worst case shading condition). This is the case when the short circuit current of the shaded module equals the maximum power current of the non-shaded module.



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**Figure 3 – Hot-spot effect in a thin-film module with serially connected cells.
The worst case shading condition is shading of 4 cells at the same time**

10.9.3 Classification of cell interconnection

Solar cells in a thin-film module are connected in one of the following ways:

- Case S: Series connection of all cells in a single string (most common case). A bypass diode can only be used between the module terminals.
- Case PS: Parallel-Series connection, i.e. a parallel connection of blocks, where each block consists of a series connection of a certain number of cells. Bypass diodes can be used for each block.
- Case SP: Series-Parallel connection, i.e. a series connection of blocks, where each block consists of a parallel connection of a certain number of cells. Bypass diodes can be used for each block.

Each configuration requires a particular hot-spot testing procedure.

10.9.4 Apparatus

- a) Radiant source: Natural sunlight, or a class CCB (or better) steady-state solar simulator conforming to IEC 60904-9 with an irradiance of $1\ 000\ \text{W}\cdot\text{m}^{-2}$.
- b) Module I-V curve tracer.
- c) Equipment for current measurement.
- d) Opaque covers suitably sized to completely shadow a group of neighbouring test cells.
- e) An appropriate temperature detector, if required.

10.9.5 Procedure

The hot-spot test is performed with the module is exposed to 800 to $1\ 000\ \text{W}\cdot\text{m}^{-2}$. Any hot-spot protective devices recommended by the manufacturer shall be installed before the module is tested.

10.9.5.1 Case S

- a) Expose the unshaded module to the radiant source at 800 to $1\ 000\ \text{W}\cdot\text{m}^{-2}$. When thermal stabilization is attained, measure the module I-V characteristic and determine the maximum power current range where $P > 0,99 P_{\text{max}1}$. (The module power measured after preconditioning).
- b) Short-circuit the module and monitor the short-circuit current.
- c) Starting from one edge of the module, use an opaque cover to shade one cell completely. Move the cover parallel to the cells and increase the shaded module area (number of shaded cells) until the short-circuit current falls within the maximum power current range of the non-shaded module. In these conditions, the maximum power is dissipated within the selected group of cells.
- d) Move an opaque cover (of the dimensions found in c) slowly across the module and monitor the module short-circuit current. If at a certain position the short-circuit current falls outside of the maximum power current of the non-shaded module range, reduce the size of the cover in small increments until the maximum power current condition is attained again. During this process, the irradiance shall not change by more than $\pm 2\%$.
- e) The final width of the cover determines the minimum area of shading that results in the worst case shading condition. This is the shaded area to be used for hot-spot testing.
- f) Remove the cover and visually inspect the module.

NOTE Reverse bias operation of the cells in step d) can cause junction breakdown and lead to visible spots irregularly spread across the module area. These defects can cause a degradation of maximum output power.

- g) Re-measure the module I-V characteristic and determine maximum power $P_{\text{max}2}$.
- h) Place the cover on the candidate module area and short-circuit the module.
- i) Expose the module again to 800 to $1\ 000\ \text{W}\cdot\text{m}^{-2}$. This test shall be performed at a module temperature in the range $50\ ^\circ\text{C} \pm 10\ ^\circ\text{C}$. Note the value of I_{sc} and keep the module in the condition of maximum power dissipation. If necessary, re-adjust the shadow to maintain the I_{sc} within the specified level determined in step a).
- j) Maintain these conditions for a total exposure time of $1\ \text{h}$.
- k) At the end of the endurance test, determine the hottest area on the shaded cells using an appropriate temperature detector.

10.9.5.2 Case PS

- a) Expose the unshaded module to 800 to $1\ 000\ \text{W}\cdot\text{m}^{-2}$. When thermal stabilisation is attained, measure the module I-V characteristic and determine the maximum power $P_{\text{max}1}$.

- b) Short-circuit the module and take at random at least 10 % of the parallel blocks in the module, shadow an increasing area of the block until the maximum temperature is determined using thermal imaging equipment or other appropriate means.
- c) Re-measure the module I-V characteristic and determine maximum power $P_{\max 2}$.
- d) Apply the shadow found in step b) and maintain these conditions for a total exposure time of 1 h.
- e) At the end of the endurance test, determine the hottest area on the shaded cells using an appropriate temperature detector.

10.9.5.3 Case SP

- a) Expose the unshaded module to the radiant source at 800 to 1 000 W·m⁻². When thermal stabilization is attained, measure the module I-V characteristic and determine the maximum power current range ($I_{\min} < I < I_{\max}$) where $P > 0,99 P_{\max 1}$.
- b) Then calculate the maximum power current range to be applied ($I(*)$) according to the following formula.

$$I_{\min} / P + I_{sc} \times (P - 1) / P < I(*) < I_{\max} / P + I_{sc} \times (P - 1) / P$$

P : number of parallel strings of the module

- c) Short-circuit the module and monitor the short-circuit current.
- d) Starting from one edge of one string of the module, use an opaque cover to shade one cell completely. Move the cover parallel to the cells and increase the shaded module area (number of shaded cells) until the short-circuit current falls in the maximum power current range ($I(*)$) of the non-shaded module. In these conditions, the maximum power is dissipated within the selected group of cells.
- e) Cut the opaque cover to the experimentally found size.
- f) Move the cover slowly across the module and monitor the module short-circuit current. If at a certain position, the short-circuit current falls outside of the maximum power current range ($I(*)$) of the non-shaded module, cut the cover in increments of one cell until the maximum power current condition is attained again. During this process, the irradiance shall not change by more than ± 2 %.
- g) Re-measure the module I-V characteristic and determine maximum power $P_{\max 2}$.
- h) Place the cover on the candidate module area and short-circuit the module.
- i) Expose the module again to 800 to 1 000 W·m⁻². This test shall be performed at a module temperature in the range 50 °C \pm 10 °C. Note the value of I_{sc} and keep the module in the condition of maximum power dissipation. If necessary, re-adjust the shadow to maintain the I_{sc} within the specified level determined in step a).
- j) Maintain these conditions for a total exposure time of 1 h.
- k) At the end of the endurance test, determine the hottest area on the shaded cells using an appropriate temperature detector.

10.9.6 Final measurements

Repeat tests 10.1 and 10.3.

NOTE The power after hot-spot testing may be measured for diagnostic purposes.

10.9.7 Requirements

- No evidence of major visual defects, as defined in Clause 7.
- Insulation resistance shall meet the same requirements as for the initial measurements.

NOTE 1 There is no pass/fail requirement for power loss during the hot-spot test.

NOTE 2 Cell damage caused by reverse bias in the hot-spot test is not considered a void or corrosion of the thin film layers.

10.10 UV preconditioning test

10.10.1 Purpose

To precondition the module with ultra-violet (UV) radiation before the thermal cycle/humidity freeze tests to identify those materials and adhesive bonds that are susceptible to UV degradation.

10.10.2 Apparatus

- a) Equipment to control the temperature of the module while it is irradiated by UV light. The equipment must be capable of maintaining the module temperature at $60\text{ °C} \pm 5\text{ °C}$.
- b) Means for measuring and recording the temperature of the module(s) to an accuracy of $\pm 2\text{ °C}$. The temperature sensors shall be attached to the front or back surface of the module, near the middle. If more than one module is tested simultaneously, it will suffice to monitor the temperature of one representative sample.
- c) Instrumentation capable of measuring the irradiation of the UV light produced by the UV light source at the test plane of the module(s), within the wavelength ranges of 280 nm to 320 nm and 320 nm to 400 nm with an uncertainty of $\pm 15\%$.
- d) A UV light source capable of producing UV irradiation with an irradiance uniformity of $\pm 15\%$ over the test plane of the module(s) with no appreciable irradiance at wavelengths below 280 nm and capable of providing the necessary irradiation in the different spectral regions of interest as defined in 10.10.3.
- e) A load sized such that at STC the module will operate near the maximum power point.

10.10.3 Procedure

- a) Using the calibrated radiometer, measure the irradiance at the proposed module test plane and ensure that at wavelengths between 280 nm and 400 nm, it does not exceed $250\text{ W}\cdot\text{m}^{-2}$ (i.e. about five times the natural sunlight level) and that it has a uniformity of $\pm 15\%$ over the test plane.
- b) Attach the resistive load to the module and mount it in the test plane at the location selected in a), normal to the UV irradiance beam. Make sure that the module temperature is $60\text{ °C} \pm 5\text{ °C}$.
- c) Subject the module(s) to a total UV irradiation of $15\text{ kWh}\cdot\text{m}^{-2}$ in the wavelength range between 280 nm and 400 nm, with 3 % to 10 % of the total energy within the wavelength band between 280 nm and 320 nm, while maintaining the module temperature within the prescribed range.

10.10.4 Final measurements

Repeat tests 10.1 and 10.3.

10.10.5 Requirements

- no evidence of major visual defects, as defined in Clause 7;
- insulation resistance shall meet the same requirements as for the initial measurements.

10.11 Thermal cycling test

10.11.1 Purpose

To determine the ability of the module to withstand thermal mismatch, fatigue and other stresses caused by repeated changes of temperature.

10.11.2 Apparatus

- a) A climatic chamber with automatic temperature control, means for circulating the air inside and means to avoid condensation on the module during the test, capable of subjecting one or more modules to the thermal cycle in Figure 4.
- b) Means for mounting or supporting the module(s) in the chamber, so as to allow free circulation of the surrounding air. The thermal conduction of the mount or support shall be low, so that, for practical purposes, the module(s) are thermally isolated.
- c) Means for measuring and recording the temperature of the module(s) to an accuracy of ± 1 °C.
- d) Means for monitoring, throughout the test, the continuity of the internal circuit of each module.

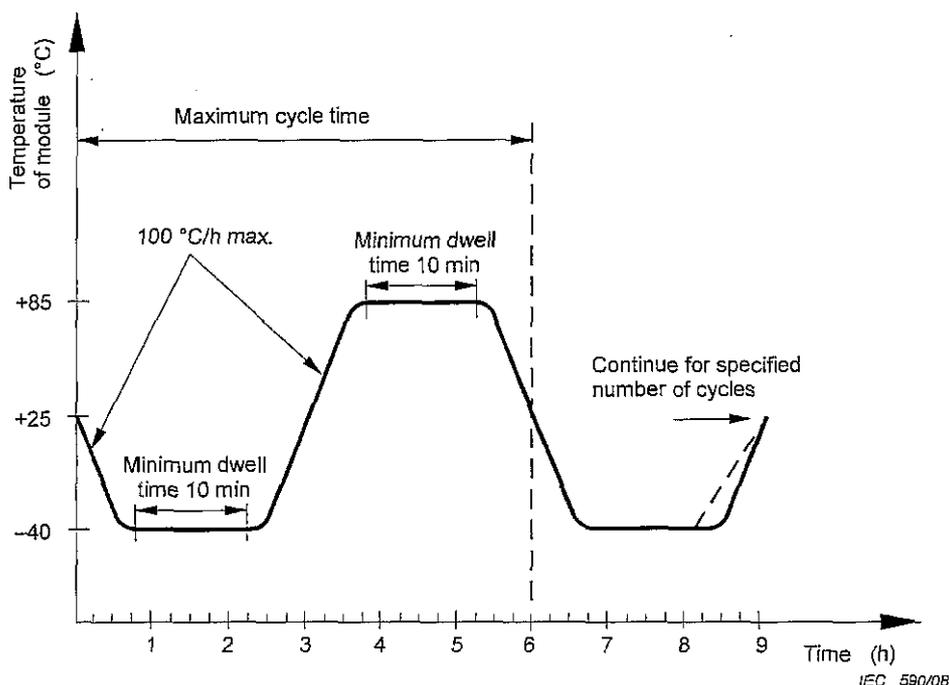


Figure 4 – Thermal cycling test

10.11.3 Procedure

- a) Install the module(s) at room temperature in the chamber.
- b) Connect the temperature monitoring equipment to the temperature sensor(s). The temperature sensors shall be attached to the front or back surface of the module, near the middle. If more than one module is tested simultaneously, it will suffice to monitor the temperature of one representative sample.
- c) Close the chamber and, subject the module(s) to cycling between module temperatures of -40 °C ± 2 °C and $+85$ °C ± 2 °C, in accordance with the profile in Figure 4. The rate of change of temperature between the low and high extremes shall not exceed 100 °C/h and the module temperature shall remain stable at each extreme for a period of at least 10 min. The cycle time shall not exceed 6 h. The number of cycles shall be as shown in the relevant blocks in Figure 1.
- d) Throughout the test, record the module temperature and monitor the continuity of the modules.

10.11.4 Final measurements

After a minimum recovery time of 1 h, repeat test 10.1 and 10.3.

10.11.5 Requirements

- No evidence of major visual defects, as defined in Clause 7.
- Insulation resistance shall meet the same requirements as for the initial measurements.
- No open circuits during the course of the test.

10.12 Humidity-freeze test

10.12.1 Purpose

To determine the ability of the module to withstand the effects of high temperature and humidity followed by sub-zero temperatures. This is not a thermal shock test.

10.12.2 Apparatus

- a) A climatic chamber with automatic temperature and humidity control, capable of subjecting one or more modules to the humidity-freeze cycle specified in Figure 5.
- b) Means for mounting or supporting the module(s) in the chamber, so as to allow free circulation of the surrounding air. The thermal conduction of the mount or support shall be low, so that, for practical purposes, the module(s) are thermally isolated.
- c) Means for measuring and recording the module temperature to an accuracy of $\pm 1^\circ\text{C}$. (It is sufficient to monitor the temperature of one representative sample, if more than one module is being tested.)
- d) Means for monitoring, throughout the test, the continuity of the internal circuit of each module.

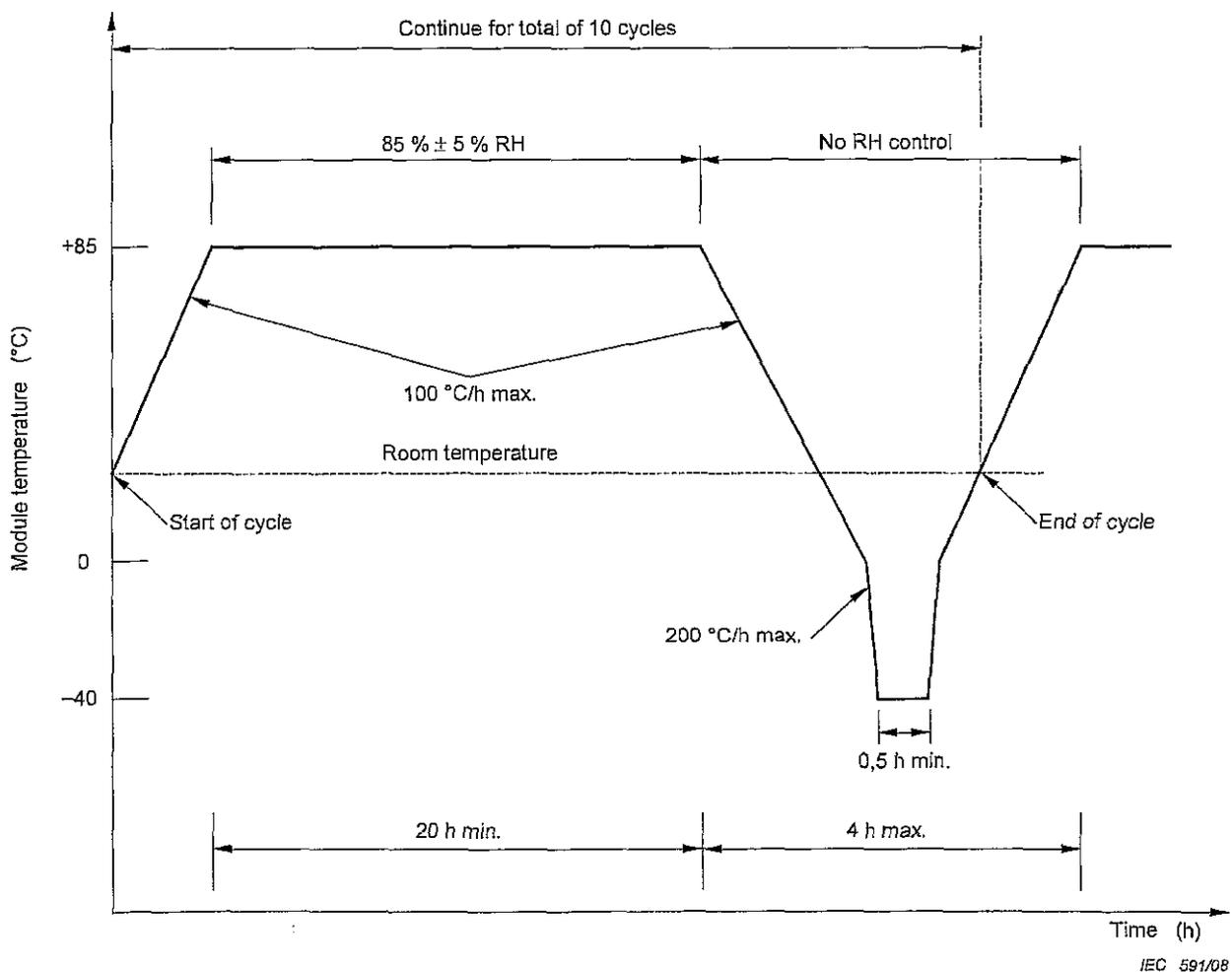


Figure 5 – Humidity-freeze cycle

10.12.3 Procedure

- a) Attach a suitable temperature sensor to the front or back surface of the module(s) near the middle.
- b) Install the module(s) at room temperature in the climatic chamber.
- c) Connect the temperature monitoring equipment to the temperature sensor(s).
- d) After closing the chamber, subject the module(s) to 10 complete cycles in accordance with Figure 5. The maximum and minimum temperatures shall be within ± 2 °C of the specified levels and the relative humidity shall be maintained within ± 5 % of the specified value at the maximum temperature (85 °C).
- e) Throughout the test, record the module temperature and monitor the continuity of the module(s).

10.12.4 Final measurements

Repeat tests 10.1, and 10.3 within two to four hours after the completion of the test.

10.12.5 Requirements

- No evidence of major visual defects, as defined in Clause 7.
- Insulation resistance shall meet the same requirements as for the initial measurements.
- No open circuits during the course of the test.

10.13 Damp heat test

10.13.1 Purpose

To determine the ability of the module to withstand the effects of long-term penetration of humidity.

10.13.2 Procedure

The test shall be carried out in accordance with IEC 60068-2-78 with the following provisions:

- a) Preconditioning
The module(s), being at room temperature, shall be introduced into the chamber without preconditioning.
- b) Severities
The following severities are applied:

Test temperature:	85 °C \pm 2 °C
Relative humidity:	85 % \pm 5 %
Test duration:	1 000 h

10.13.3 Final measurements

After a recovery time of between 2 h and 4 h, repeat tests 10.3 and 10.15. Repeat test 10.1.

10.13.4 Requirements

- No evidence of major visual defects, as defined in Clause 7.
- Insulation resistance shall meet the same requirements as for the initial measurements.
- Wet leakage current test shall meet the same requirements as the initial measurements.

10.14 Robustness of terminations test

10.14.1 Purpose

To determine that the terminations and the attachment of the terminations to the body of the module will withstand such stresses as are likely to be applied during normal assembly or handling operations.

10.14.2 Types of terminations

Three types of module terminations are considered:

- type A: wire or flying lead;
- type B: tags, threaded studs, screws, etc.;
- type C: connector.

10.14.3 Procedure

Preconditioning: 1 h at standard atmospheric conditions for measurement and test.

10.14.3.1 Type A terminations

Tensile test: as described in IEC 60068-2-21, test Ua, with the following provisions:

- all terminations shall be tested;
- tensile force shall never exceed the module weight.

Bending test: as described in IEC 60068-2-21, test Ub, with the following provisions:

- all terminations shall be tested;
- method 1-10 cycles (one cycle is one bend in each opposite direction).

10.14.3.2 Type B terminations

Tensile and bending tests:

- a) for modules with exposed terminals, each termination shall be tested as for type A terminations;
- b) if the terminations are enclosed in a protective box, the following procedure shall be applied:

A cable of the size and type recommended by the module manufacturer, cut to a suitable length, shall be connected to the terminations inside the box using the manufacturer's recommended procedures. The cable shall be taken through the hole of the cable gland, taking care to utilize any cable clamp arrangement provided. The lid of the box shall be securely replaced. The module shall then be tested as for type A terminations.

Torque test: as described in IEC 60068-2-21, test Ud, with the following provisions:

- all terminations shall be tested;
- severity 1.

The nuts or screws should be capable of being loosened afterwards, unless they are specifically designed for permanent attachment.

10.14.3.3 Type C terminations

A cable of the size and type recommended by the module manufacturer, cut to a suitable length, shall be connected to the output end of the connector, and the tests for type A terminations shall be carried out.

10.14.4 Final measurements

Repeat tests 10.1 and 10.3.

10.14.5 Requirements

- No evidence of major visual defects, as defined in Clause 7.
- Insulation resistance shall meet the same requirements as for the initial measurements.

10.15 Wet leakage current test

10.15.1 Purpose

To evaluate the insulation of the module under wet operating conditions and verify that moisture from rain, fog, dew or melted snow does not enter the active parts of the module circuitry, where it might cause corrosion, a ground fault or a safety hazard.

10.15.2 Apparatus

- a) A shallow trough or tank of sufficient size to enable the module with frame to be placed in the solution in a flat, horizontal position. It shall contain a water/wetting agent solution sufficient to wet the surfaces of the module under test and meeting the following requirements:

Resistivity: 3 500 Ω -cm or less

Temperature: 22 °C \pm 3 °C

The depth of the solution shall be sufficient to cover all surfaces except junction box entries not designed for immersion.

- b) Spray equipment containing the same solution.
- c) DC voltage source, with current limitation, capable of applying 500 V or the maximum rated system voltage of the module, whichever is more.
- d) Instrument to measure insulation resistance.

10.15.3 Procedure

NOTE 1 All connections shall be representative of the recommended field wiring installation and precautions shall be taken to ensure that leakage currents do not originate from the instrumentation wiring attached to the module.

- a) Immerse the module in the tank of the required solution to a depth sufficient to cover all surfaces except junction box entries not designed for immersion. The cable entries shall be thoroughly sprayed with solution. If the module is provided with a mating connector, the connector should be immersed during the test.
- b) Connect the shorted output terminals of the module to the positive terminal of the test equipment. Connect the liquid test solution to the negative terminal of the test equipment using a suitable metallic conductor.
- c) Increase the voltage applied by the test equipment at a rate not to exceed 500 V·s⁻¹ to 500 V or the maximum system voltage for the module (see marking Clause 4), whichever is greater. Maintain the voltage at this level for 1 min. Then determine the insulation resistance.
- d) Reduce the applied voltage to zero and short-circuit the terminals of the test equipment to discharge the voltage build-up on the module.

NOTE 2 Ensure that all of the wetting agent has been rinsed off the modules before continuing additional tests.

10.15.4 Requirements

- For modules with an area less than 0,1 m², the insulation resistance shall not be less than 400 M Ω ;

- for modules with an area larger than 0,1 m², the measured insulation resistance times the area of the module shall not be less than 40 MΩ·m².

10.16 Mechanical load test

10.16.1 Purpose

To determine the ability of the module to withstand wind, snow, static or ice loads.

10.16.2 Apparatus

- A rigid test base which enables the modules to be mounted front-side up or front-side down. The test base shall enable the module to deflect freely during the load application.
- Instrumentation to monitor the electrical continuity of the module during the test.
- Suitable weights or pressure means that enable the load to be applied in a gradual, uniform manner.

10.16.3 Procedure

- Equip the module so that the electrical continuity of the internal circuit can be monitored continuously during the test.
- Mount the module on a rigid structure using the method prescribed by the manufacturer. (If there are different possibilities, use the worst one, where the distance between the fixing points is at maximum).
- On the front surface, apply gradually a load corresponding to 2 400 Pa, spread uniformly. Maintain this load for 1 h.
- Without removing the module from the rigid structure, apply the same load on the back surface of the module.
- Repeat steps c) and d) for a total of three cycles.

NOTE 1 2 400 Pa correspond to a wind pressure of 130 km·h⁻¹ (approximately ±800 Pa) with a safety factor of 3 for gusty winds. If the module is to be qualified to withstand heavy accumulations of snow and ice, the load applied to the front of the module during this test is increased from 2 400 Pa to 5 400 Pa.

NOTE 2 Test conditions higher than 2 400 Pa might become necessary if the module is to be qualified for general use in areas with snow or wind loads exceeding 2 400 Pa. For example, snow load requirements can be concluded from relevant national standards or snow load maps.

NOTE 3 If different mounting methods for the module are permitted, the test is to be performed with different test configurations representing the range of envisaged mounting methods.

10.16.4 Final measurements

Repeat tests 10.1 and 10.3.

10.16.5 Requirements

- No evidence of major visual defects, as defined in Clause 7.
- Insulation resistance shall meet the same requirements as for the initial measurements.

10.17 Hail test

10.17.1 Purpose

To verify that the module is capable of withstanding the impact of hailstones.

10.17.2 Apparatus

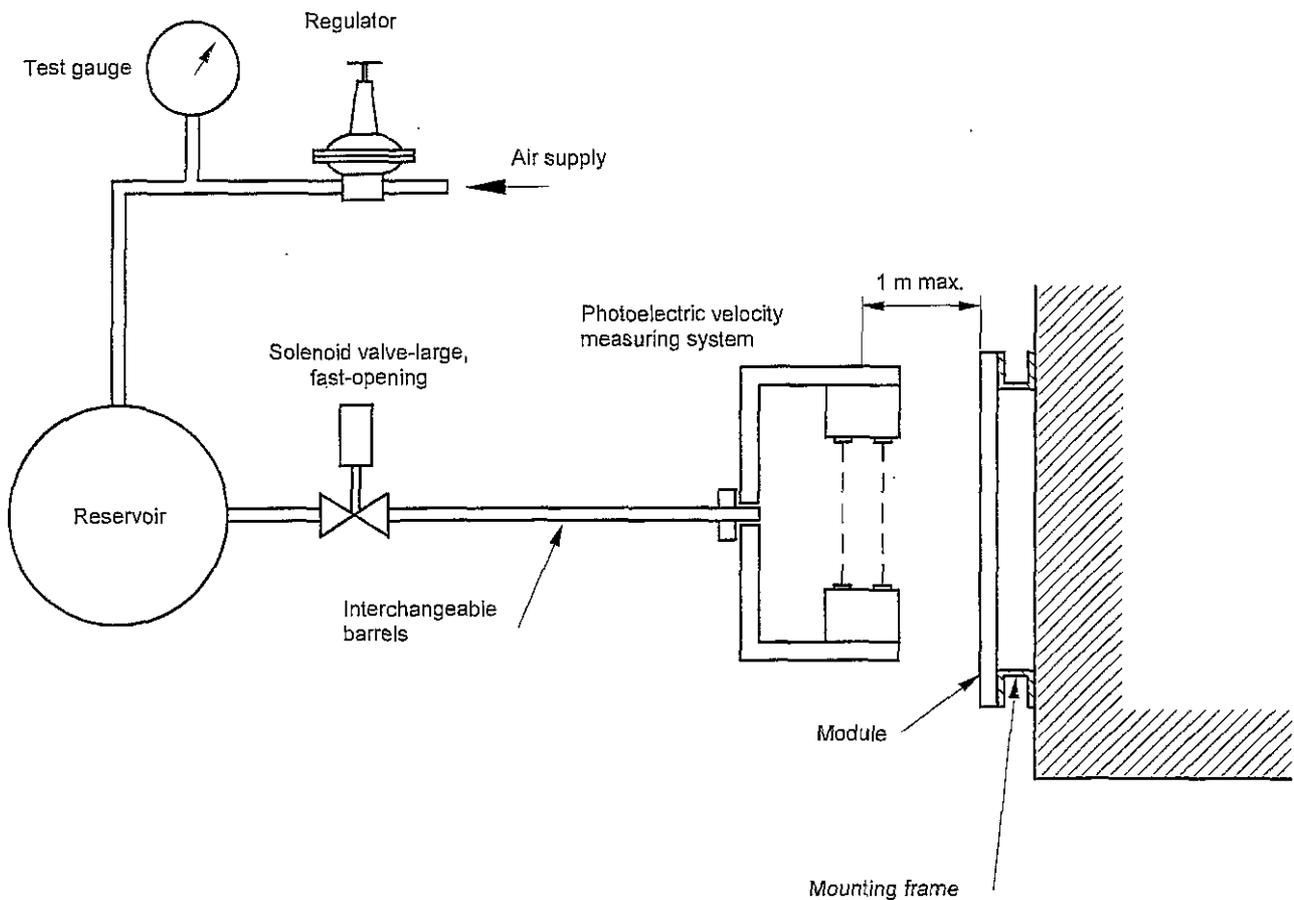
- Moulds of suitable material for casting spherical ice balls of the required diameter. The standard diameter shall be 25 mm, but any of the other diameters listed in Table 2 may be specified for special environments.

- b) A freezer, controlled at $-10\text{ °C} \pm 5\text{ °C}$.
- c) A storage container for storing the ice balls at a temperature of $-4\text{ °C} \pm 2\text{ °C}$.
- d) A launcher capable of propelling an ice ball at the specified velocity, within $\pm 5\%$, so as to hit the module within the specified impact location. The path of the ice ball from the launcher to the module may be horizontal, vertical or at any intermediate angle, so long as the test requirements are met.
- e) Rigid mount for supporting the test module by the method prescribed by the manufacturer, with the impact surface normal to the path of the projected ice ball.
- f) A balance for determining the mass of an ice ball to an accuracy of $\pm 2\%$.
- g) An instrument for measuring the velocity of the ice ball to an accuracy of $\pm 2\%$. The velocity sensor shall be no more than 1 m from the surface of the test module.

As an example, Figure 6 shows in schematic form a suitable apparatus comprising a horizontal pneumatic launcher, a vertical module mount and a velocity meter which electronically measures the time it takes the ice ball to traverse the distance between two light beams.

Table 2 – Ice ball masses and test velocities

Diameter mm	Mass g	Test velocity m·s ⁻¹	Diameter mm	Mass g	Test velocity m·s ⁻¹
12,5	0,94	16,0	45	43,9	30,7
15	1,63	17,8	55	80,2	33,9
25	7,53	23,0	65	132,0	36,7
35	20,7	27,2	75	203,0	39,5



IEC 591/08

Figure 6 – Hail test equipment

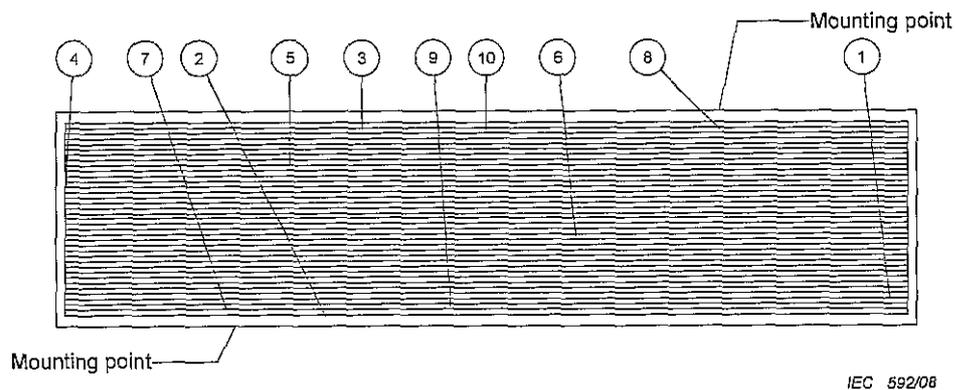
10.17.3 Procedure

- a) Using the moulds and the freezer, make enough ice balls of the required size for the test, including some for the preliminary adjustment of the launcher.
- b) Examine each one for cracks, size and mass. An acceptable ball shall meet the following requirements:
 - no cracks visible to the naked eye;
 - diameter within $\pm 5\%$ of that required;
 - mass within $\pm 5\%$ of the appropriate nominal value in Table 2.
- c) Place the balls in the storage container and leave them there for at least 1 h before use.
- d) Ensure that all surfaces of the launcher likely to be in contact with the ice balls are near room temperature.
- e) Fire a number of trial shots at a simulated target in accordance with step g) below and adjust the launcher until the velocity of the ice ball, as measured with the velocity sensor in the prescribed position, is within $\pm 5\%$ of the appropriate hailstone test velocity in Table 2.
- f) Install the module at room temperature in the prescribed mount, with the impact surface normal to the path of the ice ball.
- g) Take an ice ball from the storage container and place it in the launcher. Take aim at the first impact location specified in Table 3 and fire. The time between the removal of the ice ball from the container and impact on the module shall not exceed 60 s.

- h) Inspect the module in the impact area for signs of damage and make a note of any visual effects of the shot. Errors of up to 10 mm from the specified location are acceptable.
- i) If the module is undamaged, repeat steps g) and h) for all the other impact locations shown in Table 3, as illustrated in Figure 7.

Table 3 – Impact locations

Shot Number	Location
1	A corner of the module window, not more than 50 mm from the frame.
2	An edge of the module, not more than 12 mm from the frame.
3,4	Over the edge of the circuit.
5,6	Over the circuit near cell interconnects.
7,8	Near the point of mounting on the circuit.
9,10	In the center of the circuit, farthest from the mounting points.
11	Any point which may prove especially vulnerable to hail impact.



IEC 592/08

Figure 7 – Impact locations

10.17.4 Final measurements

Repeat tests 10.1 and 10.3.

10.17.5 Requirements

- No evidence of major visual defects, as defined in Clause 7.
- Insulation resistance shall meet the same requirements as for the initial measurements.

10.18 Bypass diode thermal test

10.18.1 Purpose

To assess the adequacy of the thermal design and relative long-term reliability of the bypass diodes used to limit the detrimental effects of module hot-spot susceptibility.

If the bypass diodes are not accessible in the module type under test, a special sample can be prepared for this test. This sample shall be fabricated to provide the same thermal environment for the diode as a standard production modules under test and does not have to

be an active PV module, but must have access to measure the temperature of the diode(s) during the test. The test shall then proceed as normal. This special test sample shall be used only for the bypass diode thermal test and not for the other tests in the sequence.

10.18.2 Apparatus

- a) Means for heating the module to a temperature of $75\text{ °C} \pm 5\text{ °C}$.
- b) Means for measuring and recording the temperature of the module(s) to an accuracy of $\pm 1\text{ °C}$.
- c) Means for measuring the temperature of any bypass diodes provided with the module. Measurement of the diode temperature can be made directly using a temperature sensor or by measuring the temperature coefficient of voltage drop across the diodes. Care should be taken to minimize any alteration of the properties of the diode or its heat transfer path.
- d) Means for measuring the junction voltage of the bypass diodes to an accuracy of 0,2 %.
- e) Means for applying a current equal to 1,25 times the STC short-circuit current of the module under test and means for monitoring the flow of current through the module, throughout the test.

10.18.3 Procedure 1

- a) Electrically short any blocking diodes incorporated in the module.
- b) Determine the rated STC short circuit current of the module from its label or instruction sheet.
- c) Measure the temperature and voltage of the bypass diodes during the test.
- d) Connect wires of the manufacturer's minimum recommended wire gauge to the output terminals of the module. Follow the manufacturer's recommendations for wire entry into the wiring compartment and replace the wire compartment cover.

NOTE 1 Some modules have overlapping bypass diode circuits. In this case, it may be necessary to install a jumper cable to assure that all of the current is flowing through one bypass diode.

- e) Heat the module to $75\text{ °C} \pm 5\text{ °C}$. Apply a current to the module equal to the short circuit current of the module as measured at STC $\pm 2\%$. After 1 h measure the temperature and voltage of each bypass diode.
- f) Using the information provided by the diode manufacturer, calculate the junction temperature from the measured case temperature and the power dissipated in the diode using the following formula.

$$T_j = T_{\text{case}} + R_{\text{THjc}} \times V_D \times I_D$$

where

- T_j = Diode junction temperature
 T_{case} = Measure diode case temperature
 R_{THjc} = Manufacturer's value relating junction temperature to case temperature
 V_D = Diode voltage
 I_D = Diode current

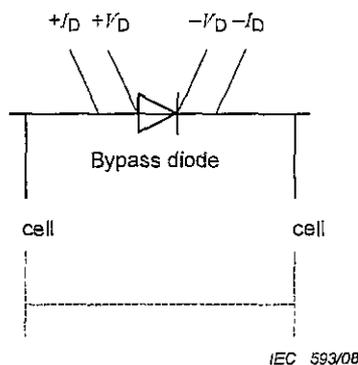
NOTE 2 If the module contains a heat sink specifically designed to reduce the operating temperature of the diode, this test may be performed at the temperature the heat sink reaches under conditions of $1\ 000\text{ W}\cdot\text{m}^{-2}$, $43\text{ °C} \pm 3\text{ °C}$ ambient with no wind rather than at 75 °C .

- g) Increase the applied current to 1,25 times the short-circuit current of the module as measured at STC while maintaining the module temperature at $75\text{ °C} \pm 5\text{ °C}$. Maintain the current flow for 1 h.
- h) Verify that the diode is still operational.

NOTE 3 Diode operation can be verified by subsequently using the hot-spot test (10.9).

10.18.4 Procedure 2

- a) Electrically short any blocking diodes incorporated in the module.
- b) Determine the rated STC short circuit current of the module from its label or instruction sheet.
- c) Connect the lead wire for V_D and I_D on both diode terminals as shown in Figure 8.
- d) It is recommended that the connections be made by the module manufacturer



NOTE The lead wire should not cause heat dissipation from the terminal box.

Figure 8 – Bypass Diode Thermal Test

- e) Put the module into the chamber set up to $30\text{ °C} \pm 2\text{ °C}$ until the module temperature reaches saturation.
- f) Apply the pulsed current (pulse width 1 ms) equal to the STC short circuit current of the module, measure the forward voltage V_{D1} of diode.
- g) As the same procedure, measure V_{D2} at $50\text{ °C} \pm 2\text{ °C}$.
- h) As the same procedure, measure V_{D3} at $70\text{ °C} \pm 2\text{ °C}$.
- i) As the same procedure, measure V_{D4} at $90\text{ °C} \pm 2\text{ °C}$.
- j) Then, obtain the V_D versus T_j characteristic by a least-squares-fit curve from V_{D1} , V_{D2} , V_{D3} and V_{D4} .

NOTE This V_D versus T_j characteristic may be provided by diode manufacturer with a manufacturer's certification.

- k) Heat the module to $75\text{ °C} \pm 5\text{ °C}$. Apply a current to the module equal to the short circuit current of the module as measured at STC $\pm 2\%$. After one hour measure the forward voltage of the each diodes.
- l) Using the V_D versus T_j characteristic obtained in item j), obtain T_j of the diode during the test in k).
- m) Increase the applied current to 1,25 times the short-circuit current of the module as measured at STC while maintaining the module temperature at $75\text{ °C} \pm 5\text{ °C}$.
- n) Maintain the current flow for 1 h.
- o) Verify that the diode is still operational after completing this test.

10.18.5 Final Measurements

Repeat tests 10.1 and 10.3.

10.18.6 Requirements

- The diode junction temperature as determined in 10.18.3.f) or 10.18.4.l) shall not exceed the diode manufacturer's maximum junction temperature rating "for continuous operation".
- No evidence of major visual defects, as defined in Clause 7.
- Insulation resistance shall meet the same requirements as for the initial measurements.
- The diode shall still function as a diode after the conclusion of the test.

10.19 Light-soaking

10.19.1 Purpose

To stabilise the electrical characteristics of thin-film modules by means of natural sunlight or simulated solar irradiation.

10.19.2 Apparatus

- a) A class CCC solar simulator, in accordance with the IEC 60904-9, or natural sunlight.
- b) A suitable reference device, with integrator, for monitoring the irradiation.
- c) Means to mount the modules, as recommended by the manufacturer, co-planar with the reference device.
- d) Means for measuring the temperature of the module(s) to an accuracy of ± 1 °C.
- e) Resistive loads sized such that at STC the modules will operate near their maximum power point.

10.19.3 Procedure

- a) Attach the resistive loads to the modules and mount them, as recommended by the manufacturer, with the reference device in the test plane of the simulator.
- b) When using a solar simulator, use the reference device to set the irradiance between $600 \text{ W}\cdot\text{m}^{-2}$ and $1\,000 \text{ W}\cdot\text{m}^{-2}$. Record the irradiance.
- c) During the simulator exposure, module temperatures must stay in the range $50 \text{ °C} \pm 10 \text{ °C}$.
- d) Subject each module to irradiation until its maximum power value stabilizes. Stabilization occurs when measurements from two consecutive periods of at least $43 \text{ kWh}\cdot\text{m}^{-2}$ each integrated over periods when the temperature is between 40 °C and 60 °C , meet the following criteria: $(P_{\max} - P_{\min})/P_{\text{average}} < 2 \%$. All intermediate maximum power measurements shall be performed at any convenient module temperature reproduced within $\pm 2 \text{ °C}$.
- e) Report the irradiation at which this stability is reached.

10.19.4 Final measurements

Repeat tests 10.1, 10.3 and 10.6 (Performance at STC).

10.19.5 Requirements

- No evidence of major visual defects, as defined in Clause 7.
- Insulation resistance shall meet the same requirements as for the initial measurements.
- After the final light-soaking, the maximum output power at STC shall be not less than 90 % of the minimum value specified by the manufacturer in Clause 4. (See Clause 6.)