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INTERNATIONAL STANDARD

colour
inside

Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures

IEC 61215-2:2021-02 RLV(en)

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

Part 2: Test procedures

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 61215-2:2016. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 61215-2 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This second edition of IEC 61215-2 cancels and replaces the first edition of IEC 61215-2 issued in 2016; it constitutes a technical revision.

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

a) Addition of cyclic (dynamic) mechanical load testing (MQT 20).
b) Addition of a test for detection of potential-induced degradation (MQT 21).
c) Addition of test methods required for bifacial PV modules.
d) Addition of test methods required for flexible modules. This includes the addition of the bending test (MQT 22).
e) Revision of simulator requirements to ensure uncertainty is both well-defined and minimized.
f) Correction to the hot spot endurance test, where the procedure for monolithically integrated (MLI) thin film technologies (MQT 09.2) previously included two sections describing a procedure only appropriate for silicon modules.
g) Selection of three diodes, rather than all, for testing in the bypass diode thermal test (MQT 18).
h) Removal of the nominal module operating test (NMOT), and associated test of performance at NMOT, from the IEC 61215 series.

Informative Annex A of IEC 61215-1:2021 explains the background and reasoning behind some of the more substantial changes that were made in the IEC 61215 series in progressing from edition 1 to edition 2.

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

FDIS	Report on voting
82/1829/FDIS	82/1853/RVD

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

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

A list of all parts in the IEC 61215 series, published under the general title *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*, can be found on the IEC website.

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

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

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

Whereas Part 1 of this standards series describes requirements (both in general and specific with respect to device technology), the sub-parts of Part 1 define technology variations and Part 2 defines a set of test procedures necessary for design qualification and type approval. The test procedures described in Part 2 are valid for all device technologies.

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

Part 2: Test procedures

1 Scope ~~and object~~

~~This International Standard series lays down IEC requirements for the design qualification and type approval of terrestrial photovoltaic modules suitable for long-term operation in general open-air climates, as defined in IEC 60721-2-1. This part of IEC 61215 is intended to apply to all terrestrial flat plate module materials such as crystalline silicon module types as well as thin-film modules.~~

This document lays down requirements for the design qualification of terrestrial photovoltaic modules suitable for long-term operation in open-air climates. The useful service life of modules so qualified will depend on their design, their environment and the conditions under which they are operated. Test results are not construed as a quantitative prediction of module lifetime.

In climates where 98th percentile operating temperatures exceed 70 °C, users are recommended to consider testing to higher temperature test conditions as described in IEC TS 63126[1]. Users desiring qualification of PV products with lesser lifetime expectations are recommended to consider testing designed for PV in consumer electronics, as described in IEC TS 63163 (under development). Users wishing to gain confidence that the characteristics tested in IEC 61215 appear consistently in a manufactured product may wish to utilize IEC 62941 regarding quality systems in PV manufacturing.

This document is intended to apply to all terrestrial flat plate module materials such as crystalline silicon module types as well as thin-film modules.

This document does not apply to modules used with concentrated sunlight although it may be utilized for low concentrator modules (1 to 3 suns). For low concentration modules, all tests are performed using the irradiance, current, voltage and power levels expected at the design concentration.

~~The objective 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 general open-air climates. The actual lifetime expectancy of modules so qualified will depend on their design, their environment and the conditions under which they are operated.~~

The objective of this test sequence is to determine the electrical 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 outdoors. Accelerated test conditions are empirically based on those necessary to reproduce selected observed field failures and are applied equally across module types. Acceleration factors may vary with product design and thus not all degradation mechanisms may manifest. Further general information on accelerated test methods including definitions of terms may be found in IEC 62506.

Some long-term degradation mechanisms can only reasonably be detected via component testing, due to long times required to produce the failure and necessity of stress conditions that are expensive to produce over large areas. Component tests that have reached a sufficient

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[1] Information on 98th percentile operating temperature as a function of system location and mounting configuration is included in IEC TS 63126.

level of maturity to set pass/fail criteria with high confidence are incorporated into the IEC 61215 series via addition to Table 1 in IEC 61215-1:2021. In contrast, the tests procedures described in this series, in IEC 61215-2, are performed on modules.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60050, *International Electrotechnical Vocabulary* (available at http://www.electropedia.org)~~

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

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

IEC 60891, *Photovoltaic devices – Procedures for temperature and irradiance corrections to measured I-V characteristics*

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

IEC 60904-1-1, *Photovoltaic devices – Part 1-1: Measurement of current-voltage characteristics of multi-junction photovoltaic (PV) devices*

IEC TS 60904-1-2, *Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices*

IEC 60904-2, *Photovoltaic devices – Part 2: Requirements for photovoltaic reference 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 the spectral mismatch correction for measurements of photovoltaic devices*

IEC 60904-8, *Photovoltaic devices – Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device*

IEC 60904-9:2020, *Photovoltaic devices – Part 9: Classification of solar simulator ~~performance requirements~~ characteristics*

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

IEC TR 60904-14: *Photovoltaic devices – Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions*

IEC 61140, *Protection against electric shock – Common aspects for installation and equipment*

IEC 61215-1:2021, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements*

IEC 61215-1-1, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules*

IEC 61730-1:2016, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*

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

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

~~IEC 61853-2, *Photovoltaic (PV) module performance testing and energy rating – Part 2: Spectral response, incidence angle, and module operating temperature measurements*~~~~[2]~~

IEC TS 62782, *Photovoltaic (PV) modules – Cyclic (dynamic) mechanical load testing*

IEC 62790, *Junction boxes for photovoltaic modules – Safety requirements and tests*

IEC TS 62804-1:2015, *Photovoltaic (PV) modules – Test methods for the detection of potential-induced degradation – Part 1: Crystalline silicon*

IEC TS 63163: –[3] *Terrestrial photovoltaic (PV) modules for consumer products – Design qualification and type approval*

~~ISO 868, *Plastics and ebonite – Determination of indentation hardness by means of a durometer (Shore hardness)*~~

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ~~IEC 60050 and~~ IEC TS 61836 and IEC 61215-1:2021 apply, as well as the following.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
accuracy <of a measuring instrument>
quality which characterizes the ability of a measuring instrument to provide an indicated value close to a true value of the measurand [consistent with the International Vocabulary of Metrology (VIM), 5.18]

Note 1 to entry: This term is used in the "true value" approach.

Note 2 to entry: Accuracy is all the better when the indicated value is closer to the corresponding true value.

~~[2] To be published.~~

[3] Under preparation. Stage at the time of publication: ADTS.

[SOURCE: IEC 60050-311:2001, 311-06-08]

3.2
control device
irradiance sensor (such as a reference cell or module) that is used to detect drifts and other problems of the solar ~~sun~~ simulator

3.3
electrically stable power output level
state of the PV module where it will operate under long-term natural sunlight ~~exposure in general open-air climates, as defined in IEC 60721-2-1~~

3.4
repeatability <of results of measurements>
closeness of agreement between the results of successive measurements of the same measurand, carried out under the same conditions of measurement, i.e.:

- by the same measurement procedure,
- by the same observer,
- with the same measuring instruments,
- used under the same conditions,
- in the same laboratory,

at relatively short intervals of time [≈ VIM, 3.6].

Note 1 to entry: The concept of "measurement procedure" is defined in VIM, 2.5.

[SOURCE: IEC 60050-311:2001, 311-06-06]

~~3.5~~
~~**reproducibility <of measurements>**~~
~~closeness of agreement between the results of measurements of the same value of a quantity, when the individual measurements are made under different conditions of measurement:~~

- ~~principle of measurement,~~
- ~~method of measurement,~~
- ~~observer,~~
- ~~measuring instruments,~~
- ~~reference standards,~~
- ~~laboratory,~~
- ~~under conditions of use of the instruments, different from those customarily used,~~

~~after intervals of time relatively long compared with the duration of a single measurement [≈ VIM 3.7].~~

~~Note 1 to entry: The concepts of "principle of measurement" and "method of measurement" are respectively defined in VIM 2.3 and 2.4.~~

~~Note 2 to entry: The term "reproducibility" also applies to the instance where only certain of the above conditions are taken into account, provided that these are stated.~~

~~[SOURCE: IEC 60050-311:2001, 311-06-07]~~

3.5
Gate No. 1
a pass / fail comparison between the performance of a module and its nameplate specifications, as described in IEC 61215-1:2021

3.6
Gate No. 2

a pass / fail comparison between the performance of a module before versus after stress, as described in IEC 61215-1:2021

4 Test procedures

The subclauses below provide detailed instructions for performing each module quality test (MQT). Reporting and test sequence requirements for qualification are described in IEC 61215-1.

4.1 Visual inspection (MQT 01)

4.1.1 Purpose

To detect any visual defects in the module.

4.1.2 Procedure

Carefully inspect each module under an illumination of not less than 1 000 lux for conditions and observations as defined in IEC 61215-1:2021.

Make note of and/or photograph any defects that may be major visual defects as defined in IEC 61215-1. Also make note of and/or photograph the nature and position of any cracks, bubbles or delaminations, etc., which may worsen and adversely affect the module performance in subsequent tests. Record any other relevant information regarding origin of failure and associated test or lab conditions.

4.1.3 Requirements

No evidence of major visual defects permitted, as defined in IEC 61215-1:2021.

4.2 Maximum power determination (MQT 02)

4.2.1 Purpose

To determine the maximum power of the module after stabilization as well as before and after the various environmental stress tests. ~~For determining the power loss from the stress tests, reproducibility of the test is a very important factor.~~

4.2.2 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 or better is used, the reference device shall be a reference module of the same size with the same cell technology to match spectral responsivity. If such a matched reference device is not available one of the following two options need to be followed:~~

  ~~1) a Class AAA simulator shall be utilized, or~~

  ~~2) the spectral responsivity of the module according to IEC 60904-8 and the spectral distribution of the solar simulator need to be measured and the module data corrected according to IEC 60904-7.~~

~~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.~~

a) Apparatus for measuring I-V characteristics in accordance with IEC 60904-1.

b) A PV reference device in accordance with IEC 60904-2.

c) At least one of the following two options to reduce the spectral mismatch component of uncertainty shall be utilized:

   - Perform a spectral mismatch correction. The spectral responsivity of the module shall be measured according to IEC 60904-8. The spectral response data may originate from the same lab that is performing IEC 61215-2:2021, or from a different lab. The sample used to obtain the spectral response data may be the test module or may be a reference cell made with the same bill of materials as the test module. The spectral distribution of the solar simulator shall then be utilized to correct for spectral mismatch according to IEC 60904-7.
   - Use a matched reference cell or module. The reference device shall be of the same cell technology as the test module, to match spectral responsivity. There is no requirement on the cell or module size.

d) A radiant source: natural sunlight or a solar simulator of class CAA or better in accordance with IEC 60904-9. For very large modules, as defined in IEC 61215-1:2021, a class CBA simulator may be used.

   NOTE 1 Class CBA is defined according to IEC 60904-9: The AM1.5 spectral match is categorized as C, non-uniformity of irradiance for the module size categorized as B, and temporal stability of irradiance categorized as A.

   To achieve a high accuracy of power measurement, the spectral irradiance distribution of the solar simulator should cover the whole wavelength range that is spanned by the spectral responsivity of the PV device under test. See IEC TR 60904-14 and IEC 60904-9:2020.

e) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.

NOTE 2 MQT 02 measurement procedures are intended for minimal uncertainty, for example as performed by an accredited testing laboratory. Lesser requirements, such as use of CAB class simulators, may be appropriate for other applications, such as quality control in the factory. Applications that only require repeatability, such as comparing module performance before and after an extended stress, may wish to relax spectral mismatch correction requirements.

4.2.3 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~~ 20 °C and 50 °C and an irradiance between 700 W/m^2 and 1 100 W/m^2) using ~~natural sunlight or a class BBA or better simulator conforming to the requirements of IEC 60904-9~~ the apparatus described in 4.2.2. 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 (as defined in IEC 60904-10) temperature and irradiance corrections can be made in accordance with IEC 60891 in order to compare sets of measurements made on the same module before and after environmental tests. For nonlinear modules (as defined in IEC 60904-10) the measurement shall be performed within ±5 % of the specified irradiance and within ±2 °C of the specified temperature. However, every effort should be made to ensure 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.

For flexible modules, the maximum power determination shall be measured with the flexible module in the flat position.

4.3 Insulation test (MQT 03)

4.3.1 Purpose

To determine whether or not the module is sufficiently well insulated between live parts and accessible parts.

4.3.2 Apparatus

a) DC voltage source, with current limitation, capable of applying ~~500 V or 1 000 V plus twice the maximum system voltage of the module (IEC 61215-1)~~ the voltage as specified in the third column of Table 1 for the various module classes.

b) An instrument to measure the insulation resistance.

4.3.3 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 %.

The voltage stress levels applied to the module are determined by the module's maximum system voltage (V_{sys}), the module class, and whether or not cemented joints are present. The definitions of module classes are taken from IEC 61140, and are discussed as related to PV modules in IEC 61730-1:2016, Clause 4. The definition of cemented joints is given in IEC 61730-1:2016, 3.4.2, and is further discussed in IEC 61730-1:2016, Clauses B.5 and B.9. The voltage stress levels applied in this test are the same as those applied for IEC 61730-2 MST 16.

4.3.4 Procedure

a) Connect the shorted output terminals of the module to the positive terminal of a DC insulation tester with a current limitation.

b) Connect the exposed metal parts of the module~~s~~ to the negative terminal of the tester. If the module~~s~~ has no frame or if the frame is a poor electrical conductor, wrap a conductive foil around the edges. ~~Cover all polymeric surfaces (front- / backsheet, junction box) of the module with conductive foil.~~ Connect all foil covered parts ~~also~~ to the negative terminal of the tester.

c) Some module technologies may be sensitive to static polarization if the module is maintained at positive voltage to the frame. In this case, the connection of the tester shall be done in the opposite way. If applicable, information with respect to sensitivity to static polarization shall be provided by the manufacturer and documented in the test report.

d) Read the "one-minute preconditioning" voltage, V_{Test1} from the third column of Table 1. Increase the voltage applied by the tester at a rate not exceeding 500 V/s to a maximum equal to ~~1 000 V plus twice the maximum system voltage (IEC 61215-1)~~ V_{Test1}. ~~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.

e) Reduce the applied voltage to zero and short-circuit the terminals of the test equipment to discharge the voltage build-up in the module.

f) Remove the short-circuit.

g) Read the "two-minute stress" voltage, V_{Test2} from the fourth column of Table 1. Increase the voltage applied by the test equipment at a rate not exceeding 500 V/s to ~~500 V or the maximum system voltage for the module, whichever is greater~~ V_{Test2}. Maintain the voltage at this level for 2 min. Then determine the insulation resistance.

h) Reduce the applied voltage to zero and short-circuit the terminals of the test equipment to discharge the voltage build-up in the module.

i) Remove the short-circuit and disconnect the test equipment from the module.

Table 1 – Voltage stress levels

Module class	Are cemented joints present?	1 min preconditioning V_{Test1} V	2 min stress for measuring insulation resistance, V_{Test2} V
0	No	1 000 + 2 x V_{sys}	Greater of 500 or V_{sys}
II	No	2 000 + 4 x V_{sys}	Greater of 500 or V_{sys}
III	No	500	500
0	Yes	1,35 x (1 000 + 2 x V_{sys})	Greater of 500 or V_{sys}
II	Yes	1,35 x (2 000 + 4 x V_{sys})	Greater of 500 or V_{sys}
III	Yes	1,35 x (500)	500

4.3.5 Test requirements

a) No dielectric breakdown or surface tracking ~~during 4.3.4 c)~~.

b) For modules with an area of less than 0,1 m^2 the insulation resistance shall not be less than 400 MΩ.

c) 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.

4.4 Measurement of temperature coefficients (MQT 04)

Determine the temperature coefficients of current (α), voltage (β) and peak power (δ) from module measurements as specified in IEC 60891. The coefficients so determined are valid at the irradiance at which the measurements were made. See IEC 60904-10 for evaluation of module temperature coefficients at different irradiance levels. For bifacial modules determine the temperature coefficients utilizing the same procedure, but insuring no backside irradiation. The backside shall be covered such that the contribution from the non-exposed side of the module is limited to or below the levels specified for "non-irradiated background" in IEC TS 60904-1-2. If open-circuit voltage or short-circuit current cannot be measured due to module-integrated electronics, the associated temperature coefficient shall be reported as "not measurable due to module-integrated electronics." Open-circuit voltage or short-circuit current shall not be determined by any method other than direct measurement, such as extrapolation.

NOTE For linear modules in accordance to IEC 60904-10, temperature coefficients are valid over an irradiance range of ±30 % of this level.

4.5 ~~Measurement of nominal module operating temperature (NMOT) (MQT 05)~~ Placeholder section, formerly NMOT

~~4.5.1 General~~

~~The power of PV-modules depends on the cell temperature. The cell temperature is primarily affected by the ambient temperature, the solar irradiance, and the wind speed.~~

~~NMOT is defined as the equilibrium mean solar cell junction temperature within an open-rack mounted module operating near peak power in the following standard reference environment (SRE):~~

- ~~Tilt angle: (37 ± 5)°~~
- ~~Total irradiance: 800 W/m²~~
- ~~Ambient temperature: 20 °C~~
- ~~Wind speed: 1 m/s~~
- ~~Electrical load: A resistive load sized such that the module will operate near its maximum power point at STC or an electronic maximum power point tracker (MPPT).~~

~~NOTE NMOT is similar to the former NOCT except that it is measured with the module under maximum power rather than in open circuit. Under maximum power conditions (electric) energy is withdrawn from the module, therefore less thermal energy is dissipated throughout the module than under open-circuit conditions. Therefore NMOT is typically a few degrees lower than the former NOCT.~~

~~NMOT 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, distance from ground, 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.~~

~~4.5.2 Principle~~

~~This method is based on gathering actual measured module 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 NMOT.~~

~~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 ($T_J - T_{amb}$) is largely independent of the ambient temperature and is essentially linearly proportional to the irradiance at levels above 400 W/m^2.~~

~~The module temperature is modelled by: $T_J - T_{amb} = G / (u_0 - u_1 v)$~~

~~The coefficient u_0 describes the influence of the irradiance and u_1 the wind impact.~~

~~The NMOT value for T_J is then determined from the model formula above by using T_{amb} = 20 °C, irradiance G of 800 W/m^2 and a wind speed v of 1 m/s.~~

~~4.5.3 Test procedure~~

~~The data for calculating NMOT shall be acquired using the test method (Methodology for determining module operating temperature) in IEC 61853-2.~~

~~NOTE This test can be performed simultaneously with the outdoor exposure test in 4.8.~~

The nominal module operating temperature (NMOT) test, formerly MQT 05, is no longer a part of this document. This subclause is preserved so that, in the following subclauses of the document, the MQT numbers match the subclause numbers.

4.6 Performance at STC ~~and NMOT~~ (MQT 06.1)

4.6.1 Purpose

To determine how the electrical performance of the module varies with load at STC (1 000 W/m², 25 °C cell temperature, with the IEC 60904-3 reference solar spectral irradiance distribution) ~~and at NMOT (an irradiance of 800 W/m² and an ambient temperature of 20 °C with the IEC 60904-3 reference solar spectral irradiance distribution)~~. ~~The measurement at STC is used to verify the name plate information of the module).~~ MQT 06.1 is a case of maximum power determination (MQT 02) performed at STC. MQT 06.1 is used to verify the name plate information of the module, and for determining power loss from the stress tests. Uncertainty, m_1, shall include a component from spectral mismatch, based either on measured spectral response or the worst-case possibility for a given technology type, and the method used to set the simulator intensity. For nameplate verification, the uncertainty m_1 is subject to the limits specified in the technology-specific parts. For determining the power loss from the stress tests, reproducibility of the test, r, is subject to the limits specified in the technology-specific parts.

4.6.2 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 or better is used, the reference device shall be a reference module of the same size with the same cell technology to match spectral responsivity. If such a matched reference device is not available one of the following two options need to be followed:~~

  ~~1) a Class AAA simulator shall be utilized, or~~

  ~~2) the spectral responsivity of the module according to IEC 60904-8 and the spectral distribution of the solar simulator need to be measured and the module data corrected according to IEC 60904-7.~~

~~c) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.~~

~~d) A means for monitoring the temperature of the test specimen and the reference device to an accuracy of ± 1 °C and repeatability of ± 0,5 °C.~~

~~e) Apparatus for measuring an I-V curve in accordance with IEC 60904-1.~~

~~f) If necessary, equipment to change the temperature of the test specimen to the NMOT temperature defined in 4.5.~~

a) The apparatus shall be as described in 4.2.2 (MQT 02).

b) It shall also be equipped with a means for monitoring the temperature of the test specimen and the reference device to an accuracy of ±1 °C and repeatability of ±0,5 °C.

c) For measurement of bifacial modules the following capability is also necessary: The radiant source utilized as specified in 4.6.2a shall be operable with adjustable irradiance levels and/or rear-side irradiance such that BNPI (as defined in IEC 61215-1:2021) can be applied by at least one method allowed by IEC TS 60904-1-2.

d) For measurement of multi-junction modules, the simulator and reference device shall meet the additional requirements imposed by IEC 60904-1-1.

4.6.3 Procedure for measuring at STC (MQT 06.1)

~~4.6.3.1 Measuring at STC (MQT 06.1)~~

~~Maintain the module at (25 ± 2) °C and trace its current-voltage characteristic at an irradiance of (1 000 ± 100) W/m² (as measured by a suitable reference device), in accordance with IEC 60904-1, using natural sunlight, or at least a class BBA simulator conforming to the requirements of IEC 60904-9.~~

~~Module temperature outside (25 ± 2) °C can be corrected to 25 °C using temperature coefficients and IEC 60904 series and IEC 60891.~~

~~4.6.3.2 Measuring at NMOT (MQT 06.2)~~

~~Heat the module uniformly to (NMOT ± 2) °C and trace its current-voltage characteristic at an irradiance of (800 ± 80) W/m^2 (as measured by a suitable reference device), in accordance with IEC 60904-1, using natural sunlight or a class BBA or better simulator conforming to the requirements of the IEC 60904-9.~~

~~Module temperature outside (NMOT ± 2) °C can be corrected to NMOT using temperature coefficients and IEC 60904 series and IEC 60891.~~

~~In both 4.6.3.1 and 4.6.3.2, if the reference device is not spectrally matched to the test module, use IEC 60904-7 to calculate the spectral mismatch correction.~~

Maintain the module at (25 ± 2) °C and trace its current-voltage characteristic at an irradiance of (1 000 ± 100) W/m^2 (as measured by a suitable reference device), in accordance with IEC 60904-1, using the apparatus described in 4.6.2.

Module temperature shall be corrected to 25 °C using temperature coefficients and IEC 60904 series and IEC 60891.

For bifacial modules, measurements shall proceed as specified in IEC TS 60904-1-2. MQT 06 shall be performed at STC and at elevated irradiance BNPI for Gate No 1. Each time MQT 06 is performed at STC, the STC bifaciality coefficients of short-circuit current ($\varphi_{I\mathrm{sc}} = I_{\mathrm{scr}} / I_{\mathrm{scf}}$), of open circuit voltage ($\varphi_{V\mathrm{oc}} = V_{\mathrm{ocr}} / V_{\mathrm{ocf}}$), and of power ($\varphi_{P\mathrm{max}} = P_{\mathrm{maxr}} / P_{\mathrm{maxf}}$) shall be measured according to IEC TS 60904-1-2. Full definition of these quantities, the method to measure them, and the symbols used to describe them are specified in IEC TS 60904-1-2. When evaluating Gate No 2 (i.e. post-stress), MQT 06 shall only be performed at BNPI. Post-stress, bifaciality coefficients need not be remeasured. unless specifically noted in the MQT stress test procedure. The bifaciality coefficients measured pre-stress may be utilized to calculate the appropriate equivalent intensity in a single-sided illumination measurement. When performing MQT 06 at BNPI, any method described in IEC 60891 may be used to correct the applied irradiance to desired equivalent front-side irradiance, as long requirements on maximum uncertainty m_1 are met.

NOTE 1 Using methods from IEC 60891 to correct the applied irradiance to desired equivalent front-side irradiance can help the tester avoid using a different simulator calibration for every module with a slightly different bifaciality coefficient.

NOTE 2 Measurement of performance at BSI is not required. Where stress levels are set according to BSI, currents may be extrapolated from lower intensities, as described specifically in the MQTs utilizing BSI for bifacial modules.

For flexible modules, the maximum power determination shall be measured with the flexible module in the flat (i.e. completely unfolded) position. For very large modules (as defined in IEC 61215-1:2021), testing by the testing entity may be performed at the manufacturer’s facility, but shall still meet the requirements stated in 4.6.2.

For multi-junction modules, measurements shall proceed as specified in IEC TS 60904-1-1.

4.7 Performance at low irradiance (MQT 07)

4.7.1 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 simulator class BBA or better conforming to the requirements of IEC 60904-9~~.

4.7.2 Apparatus

~~a) A radiant source (natural sunlight or a solar simulator class BBA or better in accordance with IEC 60904-9).~~

~~b) Equipment necessary to change the irradiance to 200 W/m² 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. If a class BBA simulator or better is used, the reference device shall be a reference module of the same size with the same cell technology to match spectral responsivity. If such a matched reference device is not available one of the following two options need to be followed:~~

  ~~1) a Class AAA simulator shall be utilized, or~~

  ~~2) the spectral responsivity of the module according to IEC 60904-8 and the spectral distribution of the solar simulator need to be measured and the module data corrected according to IEC 60904-7.~~

~~d) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.~~

~~e) A means for monitoring the temperature of the test specimen and the reference device to an accuracy of ± 1 °C and repeatability of ± 0,5 °C.~~

~~f) Apparatus for measuring an I-V curve in accordance with IEC 60904-1.~~

a) The apparatus shall be as described in 4.2.2 (MQT 02).

The apparatus shall also have the following capabilities:

b) Equipment necessary to change the irradiance to 200 W/m² without affecting the relative spectral irradiance distribution and the spatial uniformity in accordance with IEC 60904-10.

c) A means for monitoring the temperature of the test specimen and the reference device to an accuracy of ±1 °C and repeatability of ±0,5 °C.

d) For measurement of bifacial modules the following equipment is also necessary: Baffles that can be arranged around the modules edges, as well as a non-reflective cover allowing for temporarily blocking the irradiance to the opposite module side, to evaluate the front- and back-side performance of bifacial modules individually.

e) For measurement of multi-junction modules, the simulator and reference device shall meet the additional requirements imposed by IEC 60904-1-1.

4.7.3 Procedure

Determine the current-voltage characteristic of the module at (25 ± 2) °C and an irradiance of (200 ± 20) W/m² controlled by an appropriate reference device, in accordance with IEC 60904-1 using ~~natural sunlight or at least a class BBA simulator conforming to the requirements of IEC 60904-9~~ the apparatus specified in section 4.7.2. The irradiance shall be reduced to the specified level by using neutral density 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.)

Module temperature ~~outside (25 ± 2) °C can~~ shall be corrected to 25 °C using temperature coefficients and IEC 60904 series and IEC 60891.

For flexible modules, the maximum power determination shall be measured with the flexible module in the flat (i.e. completely unfolded) position. For very large modules (as defined in IEC 61215-1:2021), testing by the testing entity may be performed at the manufacturer's facility, but shall still meet the requirements stated in 4.7.2.

For bifacial modules make two single-sided measurements at 200 W/m², one on the front-side and one on the rear-side using baffles and back-cover screen. Calculate the bifaciality coefficients at low irradiance according to the procedure specified in IEC TS 60904-1-2, except utilizing an irradiance of 200 W/m² instead of 1000 W/m².

For multi-junction modules, measurements shall proceed as specified in IEC TS 60904-1-1.

4.8 Outdoor exposure test (MQT 08)

4.8.1 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.

4.8.2 Apparatus

a) An open rack to support the test module(s) and solar irradiation monitor in the specified manner. 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.

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

b) A solar irradiation monitor accurate to ±5 %, mounted in the plane of the module(s) within 0,3 m of the test array.

c) Means to mount the module, as recommended by the manufacturer, co-planar with the irradiation monitor.

d) A resistive load sized such that the module will operate near its maximum power point or an electronic maximum power point tracker (MPPT).

4.8.3 Procedure

a) The test module(s) shall be positioned so that it (they) are normal to the local latitude ±5°. Note the angle of tilt of the test module in the test report.

b) Attach the resistive load or electronic maximum power point tracker 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.

c) Subject the module to an irradiation totalling at least 60 kWh/m^2, as measured by the monitor~~, under conditions conforming to general open-air climates, as defined in IEC 60721-2-1~~.

~~Outdoor exposure and NMOT determination may be performed simultaneously on the same module. In this case follow the mounting procedure in IEC 61853-2.~~

The test modules may be cleaned according to manufacturer instructions during or after the test.

4.8.4 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.8.5 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.9 Hot-spot endurance test (MQT 09)

4.9.1 Purpose

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

4.9.2 Hot-spot effect

Reverse bias 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 group of cells. When such a condition occurs, the affected cell or group of cells is forced into reverse bias and shall dissipate power, which can cause overheating.

If the power dissipation is high enough or localized enough, the reverse biased cell(s) can overheat resulting in – depending on the technology – melting of solder, deterioration of the encapsulant, front and/or backsheet, cracking of the superstrate, substrate and/or cover glass. The correct use of bypass diodes can prevent hot spot damage from occurring.

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

Low shunt resistance cells:

- The worst case shadowing conditions occur when the whole cell (or a large fraction) is shadowed.
- Often low shunt ~~resistant~~ resistance cells are this way because of localized shunts. In this case hot spot heating occurs because a large amount of current flows in a small area. Because this is a localized phenomenon, there is a great deal of scatter in performance of this type of cell. Cells with the lowest shunt resistance have a high likelihood of operating at excessively high temperatures when reverse biased.
- Because the heating is localized, hot spot failures of low shunt resistance cells occur quickly.

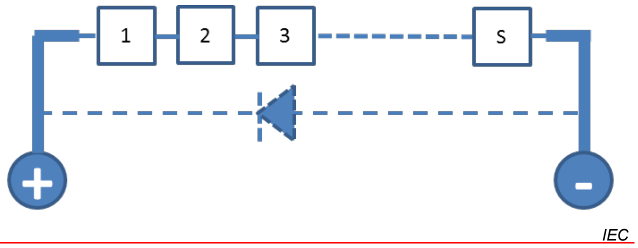
The major technical issue is how to identify the lowest shunt resistance cells and subsequently how to determine the worst case shadowing for those cells. This process is technology dependent and will be addressed in the technology specific parts of this standards series.

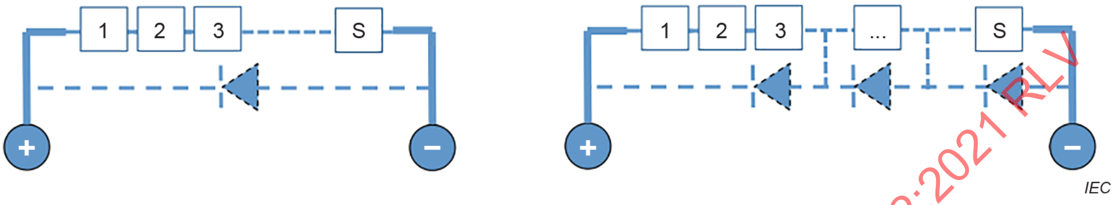
High shunt resistance cells:

- The worst case shadowing conditions occur when the cell is partially ~~shaded~~ shadowed.
- Junction breakdown and high temperatures occur more slowly. The ~~shading~~ shadowing needs to stay in place for some time to create worst case hot-spot heating.

4.9.3 Classification of cell interconnection

Case S: Series connection of all cells in a single string. Refer to Figure 1. Modules with series-connected cells may be protected by a single (Figure 1, left) or multiple (Figure 1, right) bypass diodes.





For the example a module protected by one bypass diode (left) or three bypass diodes (right).

Figure 1 – Case S, series connection with optional bypass diode

Case PS: Parallel-series connection, i.e. a series connection of (S) blocks, where each block consists of a parallel connection of a certain number (P) of cells. Refer to Figure 2.

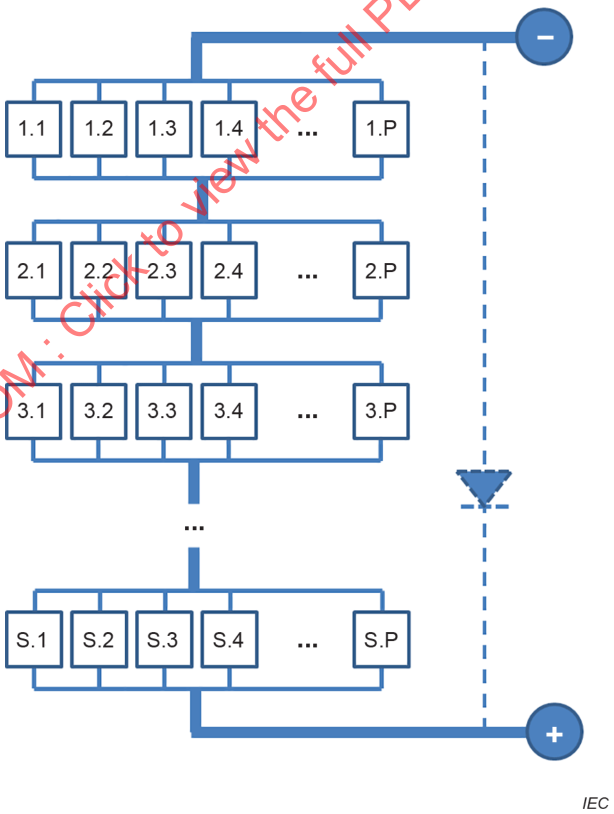


Figure 2 – Case PS, parallel-series connection with optional bypass diode

Case SP: Series-parallel connection, i.e. a parallel connection of (P) blocks, where each block consists of a series connection of a certain number of (S) cells. Refer to Figure 3.

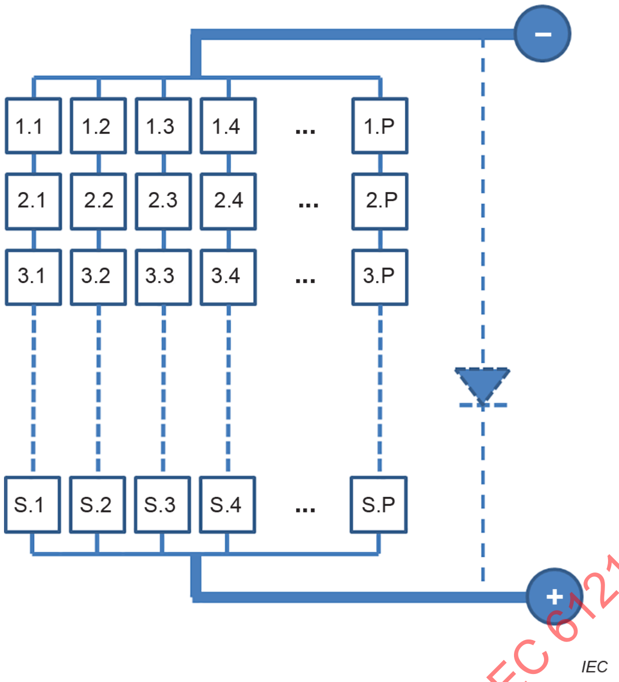


Figure 3 – Case SP, series-parallel connection with optional bypass diode

Each configuration requires a particular hot-spot testing procedure.

4.9.4 Apparatus

a) Radiant source: Natural sunlight, or a class BBB (or better) steady-state solar simulator conforming to IEC 60904-9 ~~with an irradiance of 800 W/m^2 to 1 100 W/m^2~~. Either type of radiant source shall have an irradiance of (1 000 ± 100) W/m^2. This radiant source will be used for applying long-duration stress when worst case shadowing has been applied to the module. This radiant source may be used in the selection of cells for shadowing, or the optional pulsed simulator (described in 4.9.4g) may be used for cell selection.

For bifacial modules, the radiant source used for prolonged exposure shall be operable with adjustable irradiance levels and/or rear-side irradiance such that BSI (as defined in IEC 61215-1:2021) can be applied by at least one method allowed by IEC TS 60904-1-2. Tolerance in the total irradiance, whether applied in a single-sided or double-sided configuration, shall be no larger than ±50 W/m^2.

b) Module I-V curve tracer.

c) Equipment for current measurement.

d) Completely opaque covers for test cells shadowing ~~according to the technology specific parts of IEC 61215~~.

e) An ~~appropriate temperature detector (preferably an~~ IR camera~~)~~ to measure and record module temperatures. The camera shall be operable in a manner that allows resolution of features smaller than one cell.

f) Equipment to record irradiance levels, integrated irradiance and ambient temperature.

Optional:

g) For selecting cells most sensitive to hot spot heating, a pulsed simulator of class BBB or better conforming to IEC 60904-9 with an irradiance of 800 W/m^2 to ~~1 000~~ 1 100 W/m^2 for measuring I-V performance ~~can~~ may be used.

4.9.5 Procedure

4.9.5.1 General

Depending on the solar cell technology and the manufacturing process two different procedures exist. MQT 09.1 is typically applicable to wafer-based technologies like standard crystalline silicon. For most common, monolithically integrated, thin film technologies (CdTe, CIGS, a-Si) the procedure MQT 09.2 is applicable. Bifacial modules are also to be tested using MQT 09.1.

If MQT 09.1 is performed using a representative sample, the representative sample shall have the same number of cells per bypass diode as the full-size product. Depending on the resulting sample size, this requirement can affect the choice of radiant source needed to perform the test.

For all technologies, selection of the shadowing dimensions and location is performed in the irradiance range of 800 W/m^2 to 1 100 W/m^2. Application of the extended stress is performed with the tighter irradiance specifications described in 4.9.4 a).

4.9.5.2 Procedure for wafer-based technologies (WBT) MQT 09.1

~~If the bypass diodes are removable, cells with localized shunts can be identified by reverse biasing the cell string and using an IR camera to observe hot spots.~~ The first step of the procedure is to select cells with the lowest and highest shunt resistances, (as detailed further in steps c), d) and e) below). If the module circuit is accessible the current flow through the shadowed cell can be monitored directly. If the PV modules to be tested do not have removable diodes or accessible electric circuits, the following non-intrusive method can be utilized.

The selected approach is based on taking a set of I-V curves for a module with each cell shadowed in turn. Figure 4 shows the resultant set of I-V curves for a sample module. The curve with the highest leakage current at the point where the diode turns on was taken when the cell with the lowest shunt resistance was shadowed. The curve with the lowest leakage current at the point where the diode turns on was taken when the cell with the highest shunt resistance was shadowed.

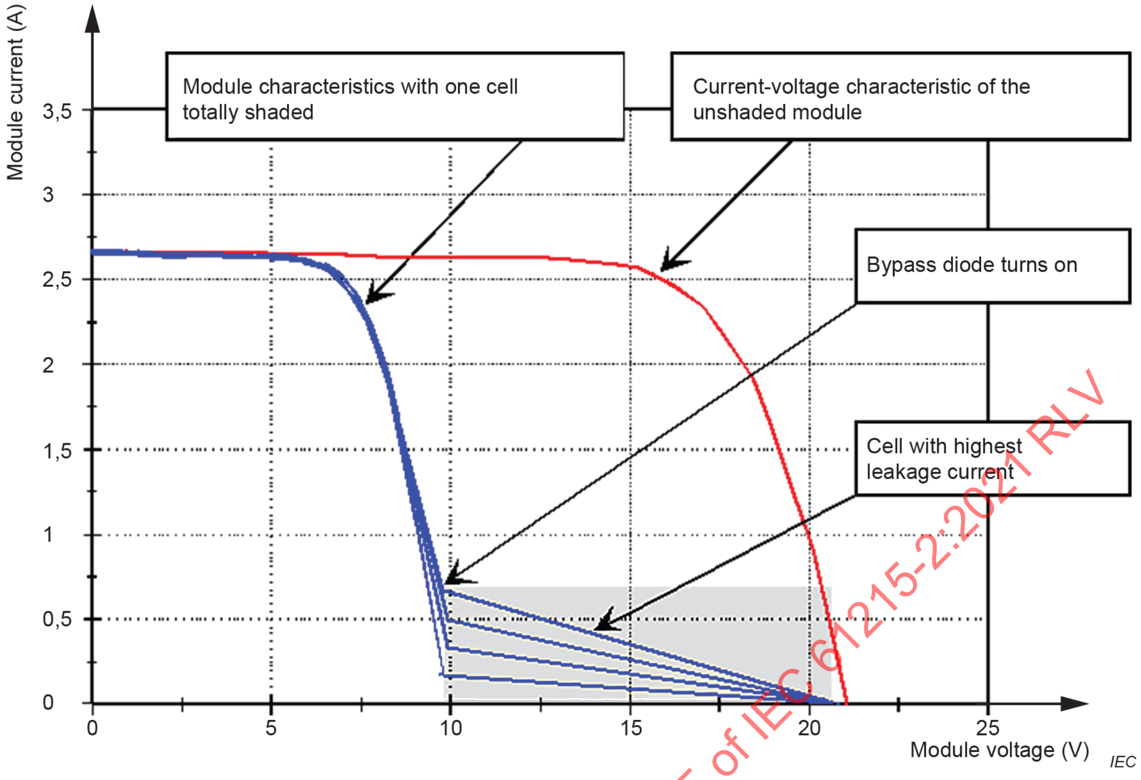


Figure 4 – Module I-V characteristics with different cells totally shadowed

Use the following procedure to identify hot spot sensitive cells:

a) ~~Expose the unshaded module to the radiant source at 800 W/m^2 to 1 000 W/m^2. This can be done using:~~

Expose the unshadowed module to the radiant source with irradiance between 800 W/m^2 and 1 100 W/m^2 using one of the following:

- A pulsed solar simulator where the module temperature will be close to room temperature (25 ± 5) °C.
- A steady-state solar simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
- Sunlight where the module temperature shall be stabilised within ±5 °C before beginning the measurements.

For bifacial modules, exposure for cell selection is to the module front, with the module back side covered to sufficiently limit the contribution from the non-exposed side of the module to or below the levels specified for "non-irradiated background" in IEC TS 60904-1-2.

~~After thermal stabilisation is attained, measure the module I-V characteristic and determine the maximum power current I_{MP1} (initial performance P_{MP1}).~~

b) Shadow each cell completely in turn, measure the resultant I-V curve and prepare a set of curves like Figure 4. For bifacial modules, if double-side illumination is utilized, both the front and the back of the cell shall be shadowed entirely. If single-side illumination is utilized, the rear shadowing is accomplished by the requirement of non-irradiated background defined in IEC TS 60904-1-2.

NOTE For the SP case the deformation of the module I-V curve is added to the sectional I-V curve of the fully illuminated parallel sub-section and so does not ~~start at~~ continue to V_{oc}.

c) Select the cell adjacent to the edge of the module that has the lowest shunt resistance, i.e. the one with the highest leakage current.

d) Select the two lowest shunt ~~resistant~~ resistance cells (in addition to the cell in c), those with the highest leakage current.

e) Select the cell with the highest shunt resistance.

~~f) Cell testing procedure:~~

~~For each of the selected cells determine the worst case shadowing condition by one of the following methods.~~

~~1) If the cell circuit is accessible, short circuit the module and attach the current measuring equipment such that it is reading only the current through the cell string under test. Expose the module to steady state irradiance of 800 W/m² to 1 000 W/m². Shadow each of the test cells and determine what shadow level results in the current through the shadowed cell being equal to the unshaded~~ ~~I_{MP1}~~ ~~determined in a). This is the worst case shadowing for that cell.~~

~~2) If the cell circuit is not accessible, take a set of I-V curves with each of the test cells shadowed at different levels as shown in Figure 5. Determine the worst case shadowing condition, which occurs when the current through the shadowed cell (the point where the by-pass diode turns on) coincides with the original unshaded~~ ~~I_{MP1}~~ ~~determined in a), like curve c) in Figure 5.~~

~~3) Shade each of the selected test cells in turn at 100 % and measure the cell temperature. Decrease the shading by 10 %. If the temperature decreases 100 % shading produces the worst case. If the temperature increases or stays the same continue to decrease the shading by 10 % until the temperature does decrease. Go back and use the previous shading level as worst case shading.~~

~~4) For the SP case if the bypass diode does not turn on when the selected cell is fully shadowed, worst case hot-spot condition is completely shading the cell. If the bypass diode does turn on when the selected cell is fully shadowed, use the procedure given in either f) 2) or f) 3) to determine the worst case shadowing condition.~~

~~5) Select the cell selected in c). Use the IR camera to determine the hottest spot on the cell when it is shaded 100 %. Shadow that cell to the worst case condition as determined in f) 1) to f) 4). Short-circuit the module. If possible make sure that this hottest spot is within the illuminated area.~~

~~g) Shadow each selected cell to the worst case condition as determined in f).~~

~~h) Short circuit the module. Expose the module to (1 000 ± 100) W/m². This test shall be performed at a module temperature in the range of (50 ± 10) °C.~~

~~i) Maintain the worst case shading condition determined in f) for 1 h for each of the selected cells. If the temperature of the shadowed cell is still increasing at the end of 1 h continue for a total exposure time of 5 h.~~

f) For bifacial modules, if some cells are permanently shadowed by design (e.g. junction box or back rails), those cells shall also be selected for hot-spot testing.

g) Begin cell testing procedure by determining the worst case shadowing condition for each of the selected cells:

   1) Expose the unshadowed module to a single-sided irradiance in the range of 800 W/m² to 1 100 W/m². The exposure shall meet the requirements described in 4.9.5.2 a).

   2) After thermal stabilisation of ±5 °C is attained, measure the module I-V characteristic and determine the maximum power current I_{MP1} (initial performance P_{MP1}).

   3) Expose the module to irradiance meeting the requirements of 4.9.5.2 a). Then use one of the methods in step 4) below to determine the worst case shadowing for each selected cell.

   4) Determine the worst-case shadowing for each of the selected test cells use one of the methods i) to iii) below.

      i) If the cell circuit is accessible, short-circuit the module and attach the current measuring equipment such that it is reading only the current through the cell string under test. For each selected test cell, shadow that cells and determine what shadow level results in the current through the shadowed cell being equal to the unshadowed I_{MP1} determined in step g)2). This is the worst case shadowing for that cell.

ii) If the cell circuit is not accessible, the first option for determining worst case shadowing involves taking I-V curves. Take a set of I-V curves with each of the selected test cells shadowed at different levels as shown in Figure 5. Determine the worst case shadowing condition, which occurs when the current through the shadowed cell (the point where the by-pass diode turns on) coincides with the original unshadowed I_{MP1} determined in a), like curve c) in Figure 5, at the same irradiance level as used in a). If the bypass diode does not turn on when the selected cell is fully shadowed, the worst case hot-spot condition is achieved by completely shadowing the cell.

iii) If the cell circuit is not accessible, the second option for determining worst case shadowing involves temperature measurements. Short-circuit the module. Shadow each of the selected test cells in turn at 100 % and measure the cell temperature. Decrease the shadowing by 10 %. If the temperature decreases, then 100 % shadowing produces the worst case. If the temperature increases or stays the same, continue to decrease the shadowing by 10 % until the temperature does decrease. Use the previous shadowing level as worst case shadowing.

5) For the cell selected in c), (i.e. the edge cell with the lowest shunt resistance), the positioning of the mask applied during prolonged exposure shall be further specified. Short-circuit the module. Use an IR camera to determine the hottest spot on the cell when it is 100 % shadowed. If possible make sure that this hottest spot is within the illuminated area during the prolonged exposure of step i).

h) Shadow one selected cell that was identified in steps c) through f) to the worst case condition as determined in g). If double-side illumination will be used in step i) for a bifacial module, the cell shall be masked identically on the rear side.

i) Short-circuit the module. Expose the module to steady state irradiance. For monofacial modules, the irradiance shall be (1 000 ± 100) W/m^2. For bifacial modules, the irradiance shall be BSI ± 50 W/m^2. This test shall be performed at a module temperature in the range of (55 ± 15) °C.

j) Maintain the worst case shadowing condition determined in g) for 1 h for the selected cell. If the temperature of the shadowed cell is still increasing at the end of 1 h continue for a total exposure time of 5 h.

k) Repeat steps h) through j) for each cell selected in steps c) through f).

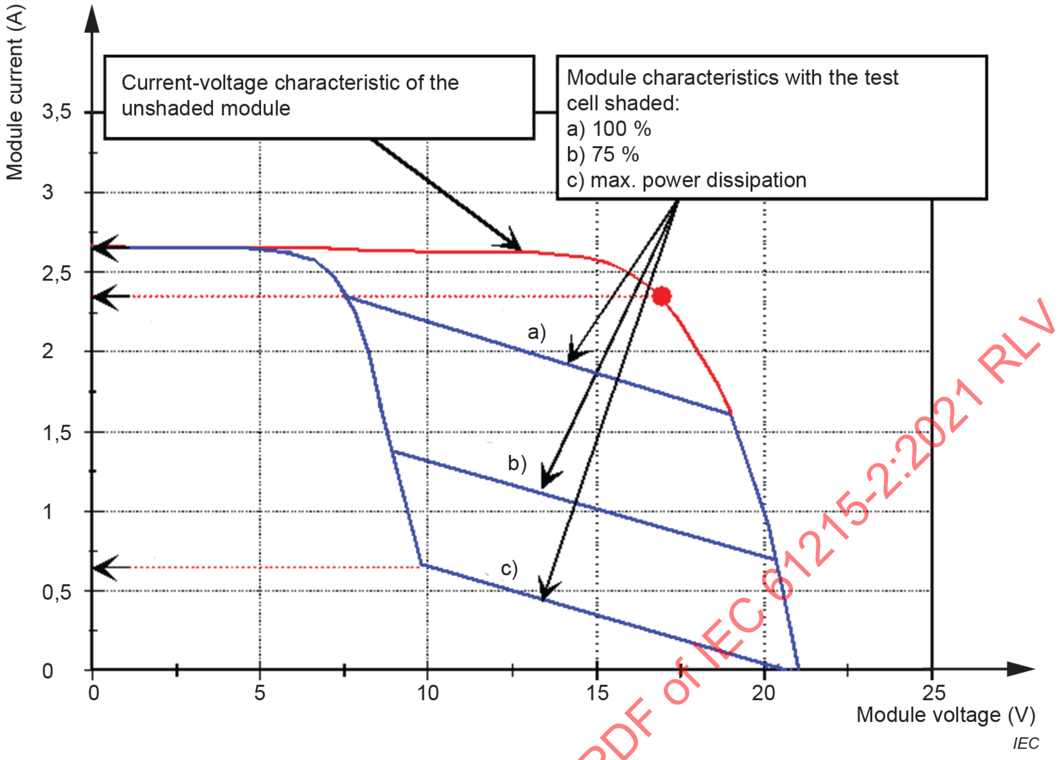


Figure 5 – Module I-V characteristics with the test cell shadowed at different levels

4.9.5.3 Procedure for monolithically integrated (MLI) thin film technologies MQT 09.2

4.9.5.3.1 General

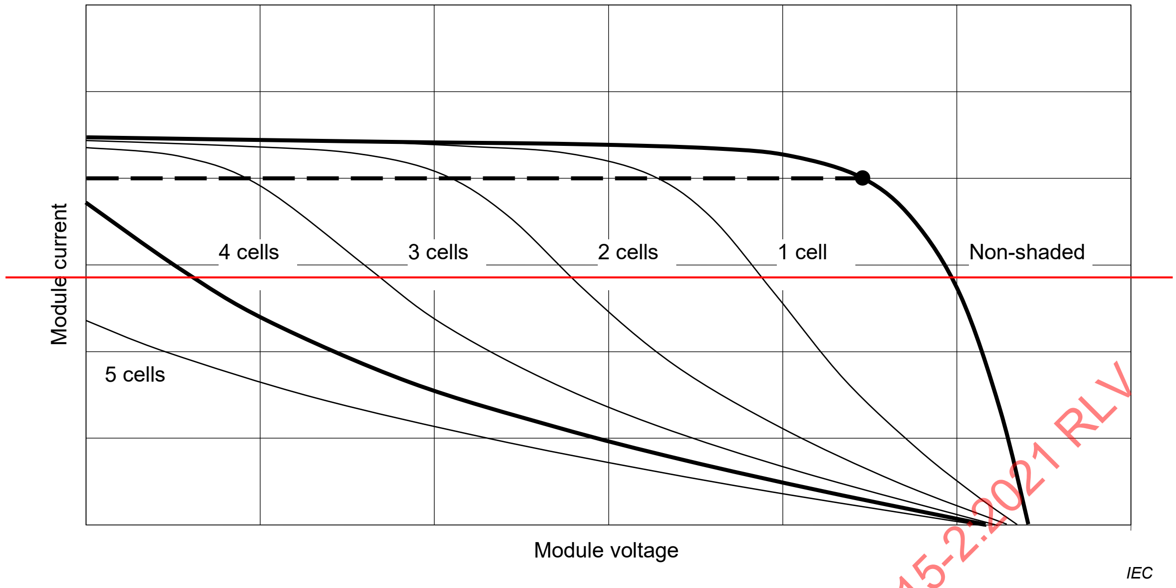
The hot-spot test is performed with the module exposed to (1 000 ± 100) W/m^2 during the extended exposure.

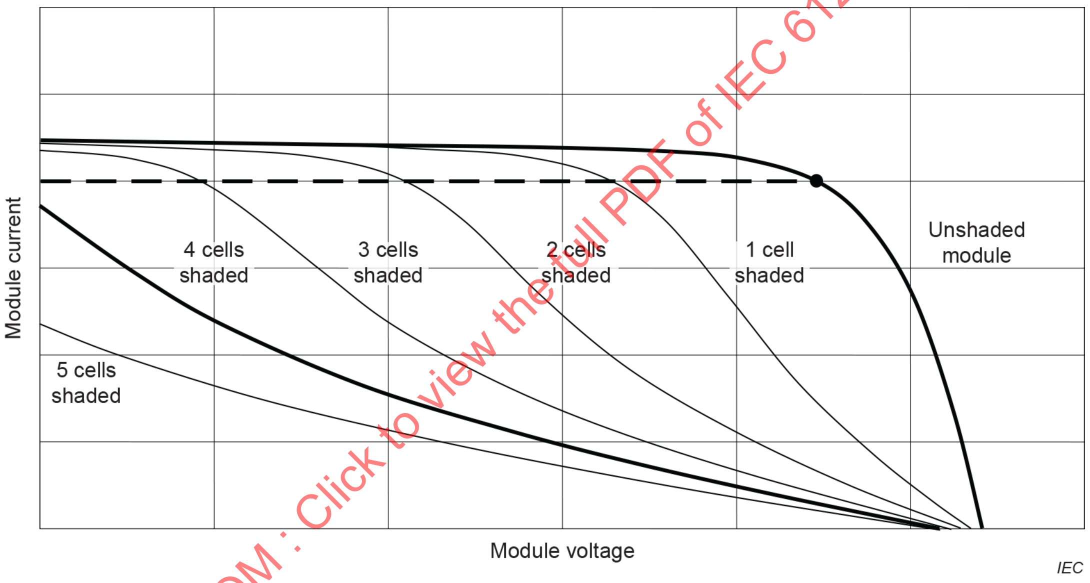
NOTE Typically no bypass diodes are included in the interconnection circuit of the serially connected MLI thin-film cells. Therefore, reverse voltage of ~~shaded~~ shadowed cells is not limited and module voltage can force a group of cells into reverse bias.

The electrical performance of a MLI thin-film module can already be negatively affected by short-term ~~shading~~ shadowing. Care shall be taken that effects caused by setting worst-case conditions and hot-spot endurance testing are clearly separated. The values of P_{max1} (before any shadowing has been applied), P_{max2} (after worst case conditions have been identified via shadowing) and P_{max3} (after extended stress has been applied) are collected for this purpose.

4.9.5.3.2 Case S

Figure 6 illustrates the hot-spot effect in a MLI thin-film module consisting of a serial connection of cells, when a different number of cells are totally shadowed. The amount of power dissipated in the ~~shaded~~ shadowed cells is equal to the product of the module current and the reverse voltage developed across the group of ~~shaded~~ shadowed cells. For any irradiance level, maximum power is dissipated when the reverse voltage across the ~~shaded~~ shadowed cells is equal to the voltage generated by the remaining illuminated cells in the module (worst case ~~shading~~ shadowing condition). This is the case when the short-circuit current of the ~~shaded~~ shadowed module equals the maximum power current of the ~~non-shaded~~ unshadowed module.





NOTE In this example, the worst case ~~shading~~ shadowing condition is ~~shading~~ shadowing of 4 cells at the same time.

Figure 6 – Hot-spot effect in a MLI thin-film module with serially connected cells

~~Steps a) through g) are best conducted using either a pulsed simulator or non-continuous illumination as opposed to a steady-state simulator or natural sunlight. When determining the size and location of the shaded area, the use of a non-continuous light source minimizes the potential for damage to the module prior to extended exposure in steps i), j), k).~~

a) ~~Employing a pulsed or non-continuous simulator where the module temperature will be close to room temperature (25 ± 5) °C expose the un-shaded module to a total irradiance of 800 W/m^2 to 1 000 W/m^2 at the module surface. Optional a steady-state simulator or sunlight can be used where the module temperature shall be stabilised within ± 5 °C before beginning the measurements. 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_{max1}. (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 (see Figure 6).~~

~~d) Move an opaque cover (of the dimensions found in c) above) 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 ± 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 steps c) and 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_{max2}.~~

~~h) Place the cover on the candidate module area and short-circuit the module.~~

~~i) Expose the module to the steady-state radiant source providing a total irradiance of (1 000 ± 100) W/m^2 at the module surface. This can be done using:~~

- ~~A steady-state simulator where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.~~
- ~~Sunlight where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.~~

~~This test shall be performed at a module temperature in the range (50 ± 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 IR camera or appropriate temperature detector.~~

The following method shall be used to select the cell(s) to be shadowed and to determine the worst case shadowing condition for module connected in series-only (case S).

a) Expose the un-shadowed module to a radiant source providing a total irradiance of 800 W/m^2 to 1 100 W/m^2 at the module surface, using one of the following:

- A pulsed simulator where the module temperature will be close to room temperature (25 ± 5) °C.
- A steady-state simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
- Sunlight where the module temperature shall be stabilised within ±5 °C before beginning the measurements.

b) After thermal stabilisation is attained, measure the module I-V characteristic and determine the maximum power current I_{MP1} and maximum power P_{max1}. Determine the maximum power current range ($I_{min} < I < I_{max}$) where I_{max} is the maximum power current of the unshadowed module, and I_{min} is 0,95 I_{max}. This current range is named $I(*)$.

c) Measure the short-circuit current at each position described in the next step.

d) Starting from one edge of the module, use an opaque cover to shadow one cell completely. Move the cover parallel to the cells and increase the shadowed module area (number of shadowed cells) until the short-circuit current falls within the current range of the non-shadowed module. In these conditions, the maximum power is dissipated within the selected group of cells (see Figure 6). The maximum step size between short-circuit current measurements is one cell width. The minimum mask width is two cell widths. If shadowing less than two cells is required to obtain a current within the specified range, then the mask width shall be fixed at the minimum. If shadowing some number of "n" cells results in a current that is too high, and if shadowing n+1 cells causes a current that is too low, then the narrower mask width (n cells) shall be chosen.

e) Move an opaque cover (of the dimensions found in d) above) slowly across the module and measure the short-circuit current at each position. The maximum step size between short-circuit current measurements is the mask width. (Thus, each cell in the module shall be shadowed at some point during this step.) If at a certain position the short-circuit current falls below the specified current range $I(*)$, reduce the size of the cover in increments of one cell width until the current is within the desired range again. If at any point during this process, the mask width is reduced to its minimum value of two cell widths, its size shall not be reduced further, and the process of moving the mask across the module is complete. If shadowing some number of "n" cells results in a current that is too high, and if shadowing n+1 cells causes a current that is too low, then the narrower mask width (n cells) shall be chosen. During this process, the irradiance shall not change by more than ± 2 %. The mask is not to be made larger at any point, i.e. if, during step g), the short-circuit current exceeds the higher limit of $I(*)$, the mask width shall be kept the same.

f) The final width of the cover, together with the position that exhibited the lowest current of each area subjected to the final mask width, determines the minimum area of shadowing that results in the worst case shadowing condition. This is the shadowed area to be used for hot-spot testing.

g) Remove the cover and visually inspect the module.

NOTE Reverse bias operation of the cells in steps d) and e) 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.

h) Re-measure the module I-V characteristic and determine maximum power P_{max2}.

i) Place the cover on the module. Put the cover on the position determined during steps e) and f).

j) Short-circuit the module, including a means to monitor the module current, such as an ammeter.

k) Expose the module to the steady-state radiant source providing a total irradiance of (1 000 ± 100) W/m^2 at the module surface, using one of the following:

  - A steady-state simulator where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.
  - Sunlight where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.

l) This test shall be performed at a module temperature in the range (55 ± 15) °C. Note the value of I_{sc} and keep the module current above the lower limit for $I(*)$. If I_{sc} falls below the lower limit for $I(*)$, decrease the mask width in increments of one cell width until I_{sc} once again exceeds the lower limit for $I(*)$. If the current falls below the desired range but the mask is already the minimum width, no adjustment shall be made.

m) Maintain these conditions for a total exposure time of 1 h.

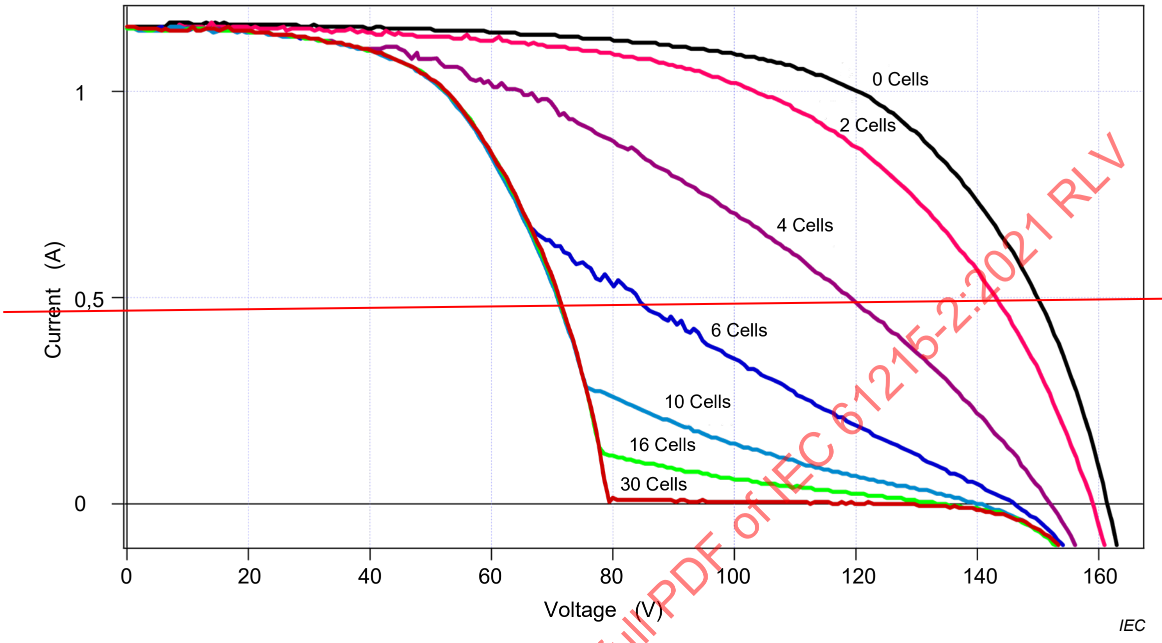
n) At the end of the endurance test, determine the hottest area on the shadowed cells using an IR camera or appropriate temperature detector.

4.9.5.3.3 Case SP

Figure 3 illustrates a series-parallel connection, i.e. a parallel connection of P strings each with S cells in series.

~~If the bypass diodes are removable, cells with localized shunts can be identified by reverse biasing the cell string and using an IR camera to observe hot spots. If the module circuit is accessible the current flow through the shadowed cell can be monitored directly. However, today many PV modules do not have removable diodes or accessible electric circuits. Therefore a non-intrusive method is needed that can be utilized on those modules.~~

~~The selected approach is based on taking a set of I-V curves for a module with each cell shadowed in turn. Figure 7 shows the resultant set of I-V curves for a sample module. The curve with the highest leakage current at the point where the diode turns on was taken when the cell with the lowest shunt resistance was shadowed. The curve with the lowest leakage current at the point where the diode turns on was taken when the cell with the highest shunt resistance was shadowed.~~



~~NOTE 1 Number of shadowed cells will depend on cell technology, efficiency and number of cells in series (here the module contains ~200 cells with 2 bypass diodes).~~

~~NOTE 2 The oscillations in “4 Cells” and “6 Cells” are a response of the module where tiny with spots where created. This phenomenon will also depend on cell technology.~~

~~Figure 7 – Module I-V characteristics with different cells totally shadowed where the module design includes bypass diodes~~

If a module is of the series-parallel type (case SP), the following method shall be used to select the cell(s) to be shadowed and to determine the worst case shadowing condition.

a) Expose the un-shadowed module to a radiant source providing a total irradiance of 800 W/m^2 to 1 100 W/m^2 at the module surface, using one of the following:
  - A pulsed simulator where the module temperature will be close to room temperature (25 ± 5) °C.
  - A steady-state simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
  - Sunlight where the module temperature shall be stabilised within ±5 °C before beginning the measurements.

b) After thermal stabilisation is attained, measure the module I-V characteristic and determine the maximum power current I_{MP1} and maximum power P_{max1}. Determine the maximum power current range ($I_{\mathrm{min}} < I < I_{\mathrm{max}}$) where I_{max} is the maximum power current of the unshadowed module, and I_{min} is 0,95 I_{max}.

c) Then calculate the acceptable maximum power current range to be applied I(*) according to the following formula.

$$I_{\mathrm{min}} / N + I_{\mathrm{sc}} \cdot (N - 1) / N < I\,(*) < I_{\mathrm{max}} / N + I_{\mathrm{sc}} \cdot (N - 1) / N$$

where N is the number of parallel strings of the module.

d) Select the substring to be measured. The following criteria are used to select the substring that is likely to experience hotter temperatures during extended stress. If some of the junction box is behind a power-generating area of the module, choose the substring that is in front of the largest fraction of the junction box area. If the junction box area is equally-divided between two substrings, or the module contains two junction boxes on two different sub-strings, choose either substring that is in front of half the junction box area. If the junction box is not located behind a power-generating portion of the module (e.g. the junction box is located in an edge-delete area) select the substring that is in front of the largest fraction of the module label. If no portion of the junction box or label is located behind a power-generating area of the module, choose the substring closest to the geometric centre of the module.

e) Measure the short-circuit current at each position described in the next step.

f) Starting from one edge of the module, use an opaque cover to shadow one cell of a selected substring completely. Move the cover parallel to the cells and increase the shadowed substring module area (number of shadowed cells) until the short-circuit current falls within the current range $I(*)$. In these conditions, the maximum power is dissipated within the selected group of cells (see Figure 6). The maximum step size between short-circuit current measurements is one cell width. The minimum mask width is two cell widths. If shadowing less than two cells is required to obtain a current within the specified range, then the mask width shall be fixed at the minimum. If shadowing some number of "n" cells results in a current that is too high, and if shadowing n+1 cells causes a current that is too low, then the narrower mask width (n cells) shall be chosen.

g) Move an opaque cover (of the dimensions found in f) above) slowly across the module and measure the short-circuit current at each position. The maximum step size between short-circuit current measurements is the mask width. (Thus, each cell in the module shall be shadowed at some point during this step.) If, at a certain position, the short-circuit current falls below the specified current range $I(*)$, reduce the size of the cover in small increments until the current is within the desired range again. If at any point during this process, the mask width is reduced to its minimum value of two cell widths, its size shall not be reduced further, and the process of moving the mask across the module is complete. If shadowing some number of "n" cells results in a current that is too high, and if shadowing n+1 cells causes a current that is too low, then the narrower mask width (n cells) shall be chosen. During this process, the irradiance shall not change by more than ± 2 %. The mask is not to be made larger at any point, i.e. if, during step g), the short-circuit current exceeds the higher limit of $I(*)$, the mask width shall be kept the same.

h) The final width of the cover, together with the position within the substring that exhibited the lowest current of each area subjected to the final mask width, determine the minimum area of shadowing that results in the worst case shadowing condition. This is the shadowed area to be used for hot-spot testing.

i) Remove the cover and visually inspect the module.

NOTE Reverse bias operation of the cells in step f) and g) 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.

j) Re-measure the module I-V characteristic and determine maximum power P_{max2}.

k) Place the cover on the module. Put the cover on the position determined during steps g) and h).

l) Short-circuit the module, including a means to monitor the module current, such as an ammeter.

m) Expose the module to the steady-state radiant source providing a total irradiance of (1 000 ± 100) W/m^2 at the module surface. This can be done using:

- A steady-state simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
- Sunlight where the module temperature shall be stabilised within ±5 °C before beginning the measurements.

This test shall be performed at a module temperature in the range (55 ± 15) °C. Note the value of I_{sc} and keep the module current above the lower limit for $I(*)$. If I_{sc} falls below the lower limit for $I(*)$, decrease the mask width in increments of one cell width until I_{sc} once again exceeds the lower limit for $I(*)$. If the current falls below the desired range but the mask is already the minimum width, no adjustment shall be made.

n) Maintain these conditions for a total exposure time of 1 h.

o) At the end of the endurance test, determine the hottest area on the shadowed cells using an IR camera or appropriate temperature detector.

~~4.9.5.3.4 Case SP with inaccessible cell circuit and internal reverse bias protection~~

~~If a module of the series-parallel type (case SP) has an inaccessible internal cell circuit and internal bypass diodes or an equivalent means of reverse bias protection that cannot be defeated, the following method shall be used to select the cell(s) to be shaded and to determine the worst case shadowing condition.~~

~~a) Expose the un-shaded module to a radiant source providing a total irradiance of 800 W/m^2 to 1 000 W/m^2 at the module surface. This can be done using:~~

- ~~A pulsed simulator where the module temperature will be close to room temperature (25 ± 5) °C.~~
- ~~A steady-state simulator where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.~~
- ~~Sunlight where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.~~

~~After thermal stabilisation is attained, measure the module I-V characteristic and determine the maximum power current I_{MP1} and maximum power P_{max1}.~~

~~b) Shadow each cell completely in turn, measure the resultant I-V curve and prepare a set of curves like Figure 7.~~

~~For the SP case the deformation of the module I-V curve is added to the sectional I-V curve of the fully illuminated parallel sub-section and so does not start at V_{oc}.~~

~~c) Select the cell adjacent to the edge that has the lowest shunt resistance, the one with the highest leakage current.~~

~~d) Select the two lowest shunt resistant cells (in addition to the cell selected in step c) above), those with the highest leakage current.~~

~~e) Select the cell with the highest shunt resistance.~~

~~f) For each of the selected cells determine the worst case shadowing condition by one of the following methods.~~

- ~~Take a set of I-V curves with each of the test cells shadowed at different levels as shown in Figure 8. Determine the worst case shadowing condition, which occurs when the current through the shadowed cell (the point where the by-pass diode turns on) coincides with the original unshaded I_{MP1} determined in a), like curve c) in Figure 5.~~
- ~~Expose the module to a steady-state radiant source providing a total irradiance of 800 W/m^2 to 1 000 W/m^2 at the module surface. Shade each of the selected test cells in turn at 100 % and measure the cell temperature using the IR camera. Decrease the shading by 10 %. If the temperature decreases by 100 %, shading produces the worst case. If the temperature increases or stays the same continue to decrease the shading by 10 % until the temperature does decrease. Go back and use the previous shading level as worst-case shading.~~

~~g) Select the cell selected in c). Use the IR camera to determine the hottest spot on the cell when it is shaded 100 %. Shadow that cell to the worst-case condition as determined in f). Short-circuit the module. If possible make sure that this hottest spot is within the illuminated area.~~

~~h) Expose the module again to (1 000 ± 100) W/m^2. This test shall be performed at a module temperature in the range (50 ± 10) °C.~~

~~i) Maintain this condition for a total exposure time of 1 h.~~

~~j) At the end of the time period, determine the hottest area on the shaded cell using an IR camera or appropriate temperature detector.~~

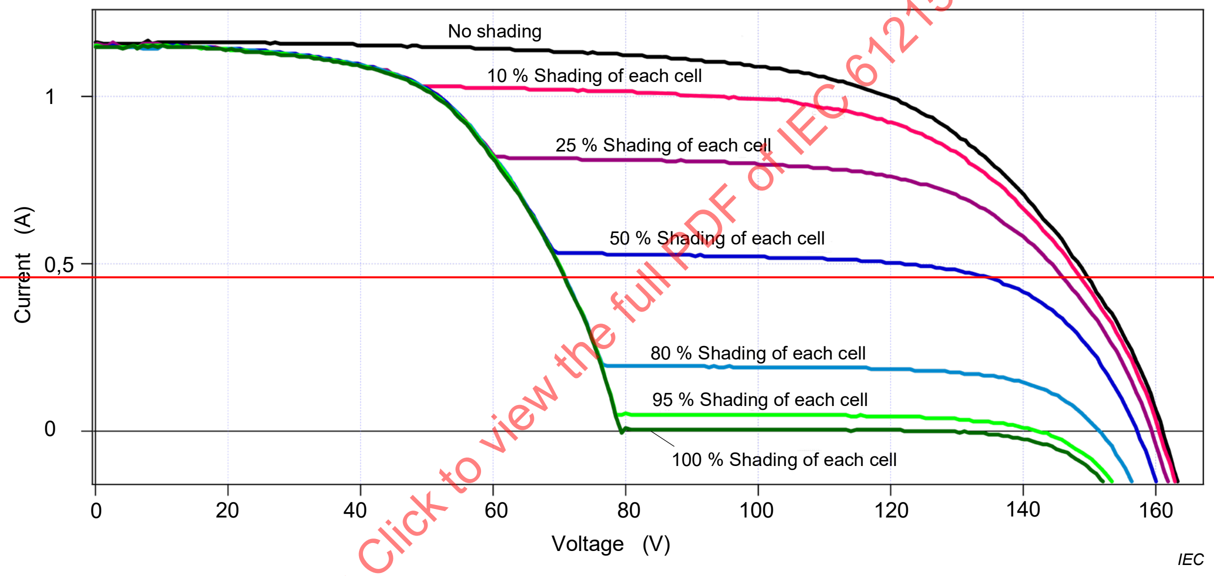
~~k) Repeat steps f) through j) for the other 2 cells selected in step d).~~

~~l) Select the cell selected in step e). Shadow the cell to the worst case condition as determined in f). Short circuit the module.~~

~~m) Expose the module again to (1 000 ± 100) W/m^2. This test shall be performed at a module temperature in the range of (50 ± 10) °C.~~

~~n) Maintain the condition for 1 h and monitor the temperature of the shadowed cell. If the temperature of the shadowed cell is still increasing at the end of 1 h continue for a total exposure time of 5 h.~~

~~o) At the end of the time period, determine the hottest area on the shaded cell using an IR camera or appropriate temperature detector.~~



~~**Figure 8 – Module I-V characteristics with the test cell shadowed at different levels where the module design includes bypass diodes**~~

~~4.9.5.3.5 Case SP with inaccessible cell circuit and no reverse bias protection~~

~~If a module of the series-parallel type (case SP) has an inaccessible internal cell circuit but contains no internal bypass diodes nor equivalent means of reverse bias protection, the following method shall be used to select the cell(s) to be shaded and to determine the worst case shadowing condition.~~

~~Steps a) through i) are best conducted using either a pulsed simulator or non-continuous illumination as opposed to a steady-state simulator or natural sunlight. When determining the size and location of the shaded area, the use of a non-continuous light source minimizes the potential for damage to the module prior to extended exposure in steps j), k), l).~~

~~a) Employing a pulsed or non-continuous simulator where the module temperature will be close to room temperature (25 ± 5) °C expose the un-shaded module to a total irradiance of 800 W/m^2 to 1 000 W/m^2 at the module surface. Optionally, a steady-state simulator or sunlight can be used where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.~~

~~b) When thermal stabilization is attained, measure the module I-V characteristic and determine the maximum power current range ($I_{min} < I < I_{max}$) where $P > 0,99 \cdot P_{max1}$.~~

~~c) Then calculate the maximum power current range to be applied I (*) according to the following formula.~~

~~$I_{min} / P + I_{sc} \cdot (P – 1) / P < I (*) < I_{max} / P + I_{sc} \cdot (P – 1) / P$~~

~~where~~

~~P is the number of parallel strings of the module.~~

~~d) Short-circuit the module and monitor the short-circuit current.~~

~~e) 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.~~

~~f) Cut the opaque cover to the experimentally found size.~~

~~g) 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 %.~~

~~h) Re-measure the module I-V characteristic and determine maximum power P_{max2}.~~

~~i) Place the cover on the candidate module area and short-circuit the module.~~

~~j) Expose the module to the steady-state radiant source providing a total irradiance of (1 000 ± 100) W/m^2 at the module surface. This can be done using:~~

- ~~A steady-state simulator where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.~~
- ~~Sunlight where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.~~

~~This test shall be performed at a module temperature in the range (50 ± 10) °C.~~

~~k) Monitor the value of I_{sc} and keep the module in the condition of maximum power dissipation by ensuring that I_{sc} is in the range I (*) found in step c). If necessary, re-adjust the shadow to maintain I_{sc} within this I (*) range.~~

~~l) Maintain these conditions for a total exposure time of 1 h.~~

~~m) At the end of the endurance test, determine the hottest area on the shaded cells using an IR camera or appropriate temperature detector.~~

4.9.5.3.4 Case PS

If a module of the parallel-series type (case PS) has an inaccessible internal cell circuit but contains no internal bypass diodes nor equivalent means of reverse bias protection, the following method shall be used to select the cell(s) to be shadowed and to determine the worst case shadowing condition.

i) a) Expose the ~~un-shaded~~ un-shadowed module to a total irradiance of 800 W/m^2 to ~~1 000~~ 1 100 W/m^2 at the module surface. This can be done using:

- A pulsed simulator where the module temperature will be close to room temperature (25 ± 5) °C.
- A steady-state simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
- Sunlight where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.

When thermal stabilization is attained, measure the module *I-V* characteristic and determine the maximum power $P_{\max1}$.

j) b) Expose the module to the steady-state radiant source providing a total irradiance (1 000 ± 100) W/m^2 at the module surface. This test shall be performed at a module temperature in the range (55 ± 15) °C.

k) c) Short-circuit the module and ~~shade~~ shadow at random a block in the module. Shadow at least 10 % of ~~the parallel blocks in the module~~ the cells within the block, and shadow an increasing area of the block until the maximum temperature is determined using thermal imaging equipment or other appropriate means.

l) d) Re-measure the ~~un-shaded~~ un-shadowed module *I-V* characteristic and determine maximum power $P_{\max2}$.

m) e) Apply the shadow found in step c) and maintain these conditions for a total exposure time of 1 h.

At the end of the endurance test, determine the hottest area on the ~~shaded~~ shadowed cells using an IR camera or appropriate temperature detector.

4.9.6 Final measurements

Repeat tests MQT 01, MQT 02, MQT 03, and MQT 15.

4.9.7 Requirements

a) No evidence of major visual defects permitted, as defined in IEC 61215-1:2021, particularly looking for signs of melted solder, openings in the enclosure, delaminations and burn spots. If there is evidence of serious damage that does not qualify as a major visual defect, repeat the test on two additional cells within the same module. If there is no visual damage around either of these two cells the module type passes the hot-spot test.

b) Verify that the module shows the electrical characteristics of a functional photovoltaic device. MQT 02 is not a pass/fail requirement (Gate No 2) for power loss.

c) Insulation resistance shall meet the same requirements as for the initial measurements.

d) Wet leakage current shall meet the same requirements as for the initial measurements.

e) Any damage resulting from determining the worst case ~~shading~~ shadowing shall be noted in the test report.

4.10 UV preconditioning test (MQT 10)

4.10.1 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.

NOTE MQT 10 is meant to detect gross susceptibility to UV degradation, as the dose is small compared to typical lifetime expectations for modern modules, and wavelength distribution of the UV source is not tightly specified. Documents applying MQT 10 toward other goals (such as comparative degradation studies) should consider what further requirements are necessary to achieve those goals.

4.10.2 Apparatus

a) A temperature-controlled test chamber with a window or fixtures for a UV light source and the module(s) under test. The chamber shall be capable of maintaining the module temperature at (60 ± 5) °C.

b) A means for monitoring the temperature of the module to an accuracy of ±2,0 °C and repeatability of ±0,5 °C. The temperature sensors shall be attached to the front or back surface of the module near the middle without obstructing any of the UV light incident on the active cells within the module. If more than one module is tested simultaneously, it will suffice to monitor the temperature of one ~~representative sample~~ of the test modules.

c) Instrumentation capable of measuring the irradiance 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 uncertainly of ±15 % or better.

d) A UV light source capable of producing UV radiation with an irradiance uniformity of ±15 % over the test plane of the module(s) with no appreciable irradiance at wavelengths below 280 nm and capable of providing the necessary total irradiance in the different spectral regions of interest as defined in 4.10.3.

~~e) For light sources with a negligible spectral content in the visible range the module shall be short circuited. Alternatively the module can be connected to a load sized such that the module will operate near the maximum power point. The latter is recommended for light sources emitting a significant portion of light in the visible spectrum where the module exhibits a power equal to or larger than 20 % of its STC measured power.~~

e) The module shall either be short-circuited or open-circuited during exposure, as per manufacturer recommendations. The circuitry condition used during this test shall be noted in the test report.

4.10.3 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 W/m^2 (i.e. about five times the natural sunlight level) and that it has a uniformity of ± 15 % over the test plane.~~

~~b) According to the apparatus used as defined in 4.10.2 e) short-circuit or 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 sensors read (60 ± 5) °C.~~

~~c) Subject the module(s) front side to a total UV irradiation of at least 15 kWh/m^2 in the wavelength range between 280 nm and 400 nm with at least 3 %, but not more than 10 % in the wavelength band between 280 nm and 320 nm, while maintaining the module temperature within the prescribed range.~~

a) 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 W/m^2 (i.e. about five times the natural sunlight level) and that it has a uniformity of ±15 % over the test plane.

b) According to the recommendations of 4.10.2e), short-circuit or open-circuit the module. Mount it in the test plane at the location selected in a), normal to the UV irradiance beam. Make sure that the module temperature sensors read (60 ± 5) °C. For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment/mounting means during the test.

c) Subject the module(s) front side to a total UV irradiation of at least 15 kWh/m^2 in the wavelength range between 280 nm and 400 nm with at least 3 %, but not more than 10 % in the wavelength band between 280 nm and 320 nm, while maintaining the module temperature within the prescribed range.

For bifacial modules repeat the procedure of UV irradiation on the rear-side of the modules.

4.10.4 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.10.5 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.11 Thermal cycling test (MQT 11)

4.11.1 Purpose

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

4.11.2 Apparatus

a) A climatic chamber with automatic temperature control with means for circulating the air inside and means to minimize condensation on the module during the test, capable of subjecting one or more modules to the thermal cycle in Figure 7.

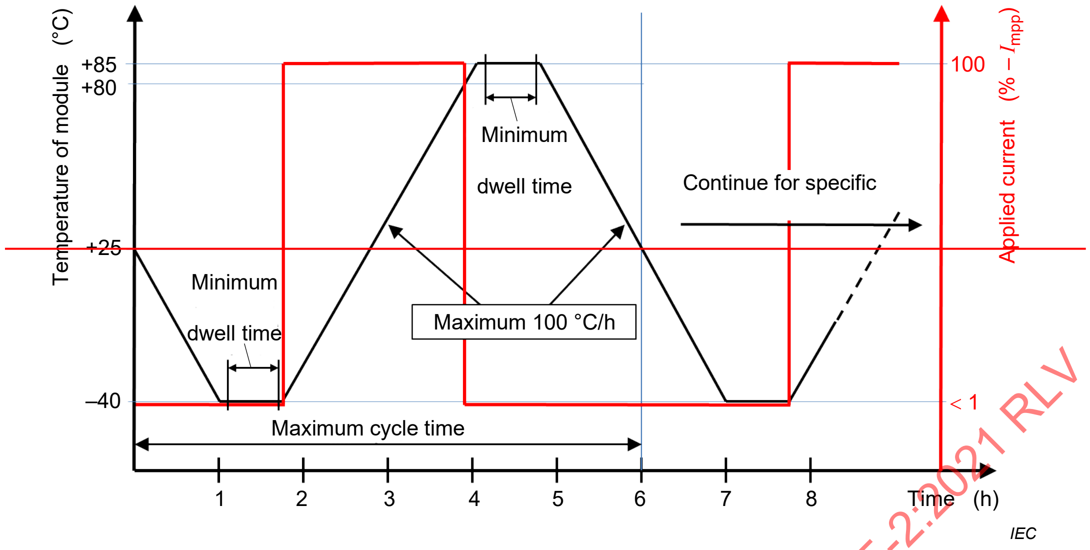
b) Means for mounting or supporting the module(s) in the chamber, so as to allow free circulation of the surrounding air. The thermal conduction of the mount or support shall be low, so that, for practical purposes, the module(s) are thermally isolated.

c) Measurement instrumentation having an accuracy of ±2,0 °C and repeatability of ±0,5 °C for measuring and recording the temperature of the module(s).

d) Means for applying a continuous current. The value of the current is defined in the technology specific parts in this standard.

e) Means for monitoring the flow of current through each module during the test.

f) A 5 N weight capable of being attached to the electrical termination leads of the module.



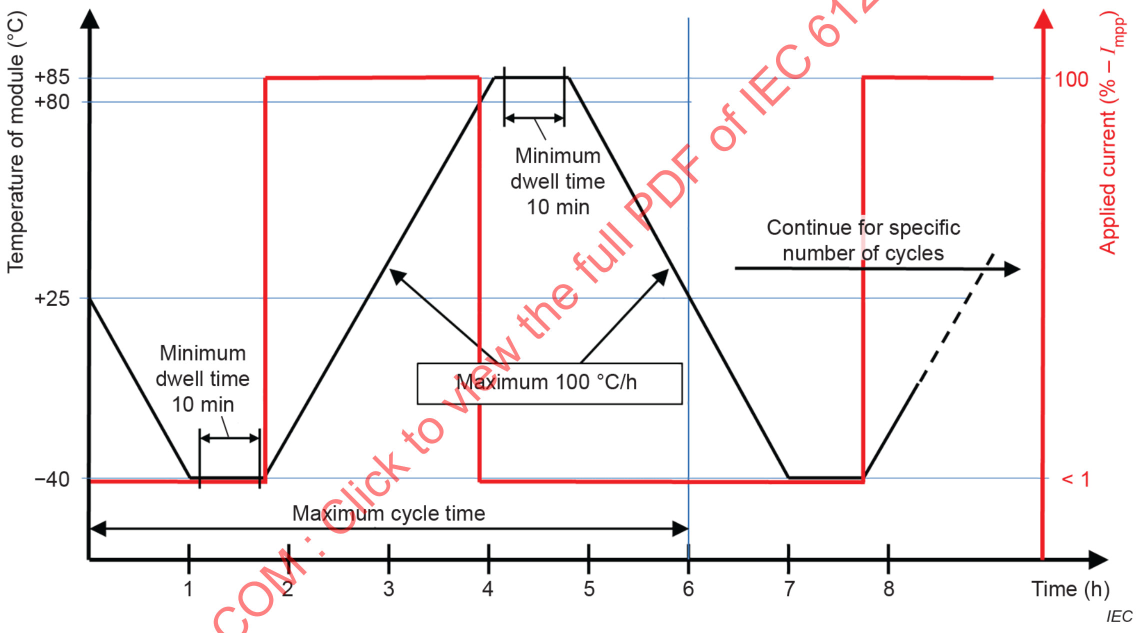


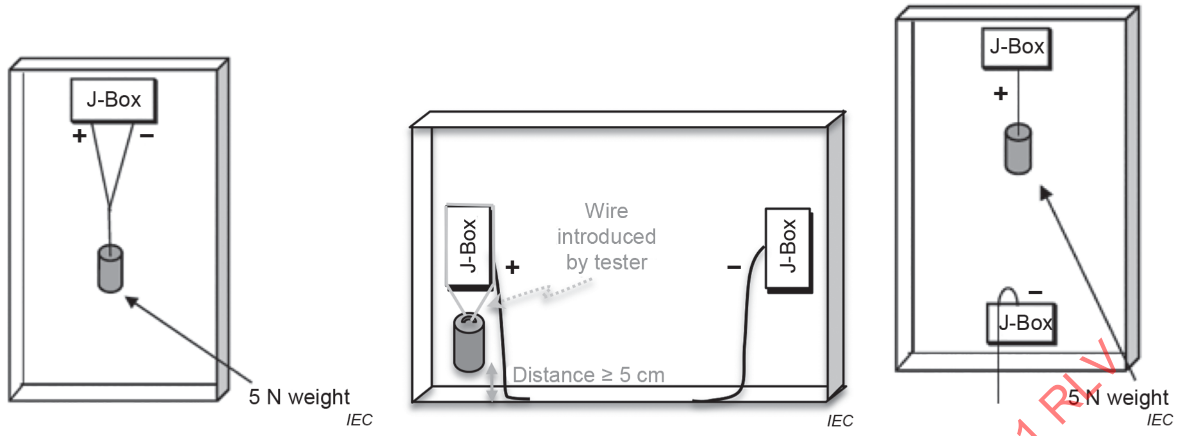
Figure 7 – Thermal cycling test – Temperature and applied current profile

4.11.3 Procedure

a) Attach a suitable temperature sensor to the front or back surface of the module(s) near the middle. If more than one module of the same type are tested simultaneously, it will suffice to monitor the temperature of one ~~representative sample~~ of the test modules.

b) Install the module(s) at room temperature in the chamber. Attach a single 5 N weight to the junction box using one of two options. The weight may be attached utilizing the electrical termination leads of each module so that it hangs down vertically from the junction box, as shown in Figure 8a). The weight may also be attached to the junction box using a wire introduced by the tester, as shown in Figure 8b). A wire introduced by the tester shall not be attached to the junction box lid. In either case, the weight shall not impact or damage the module back surface, and shall be at least 5 cm above the floor or module frame at the start of the test, as indicated in Figure 8b). If there are more than one similar junction boxes per module, only one junction box need be weighted, as shown in Figure 8b) or Figure 8c). However, if the junction boxes differ in design, each should carry weights independently.

For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment/mounting means during the test.



a) b) c)

Figure 8 – Proper attachment of 5 N weight to junction box for module utilizing a) electrical termination leads, b) or wire for attachment, and c) only one junction box

c) Connect the temperature-monitoring equipment to the temperature sensor(s). Connect each module to the appropriate current supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly. During the thermal cycling test set the continuous current flow during the heat up cycle to the technology specific current specified ~~current~~ in 4.11.2d), at temperature from -40 °C to +80 °C. During cool down, the -40 °C dwell phase and temperatures above 80 °C the continuous current shall be reduced to no more than 1,0 % of the measured STC peak power current to measure continuity. If the temperature rises too fast (greater than 100 °C/h) at the lowest temperature, the start of the current flow can be delayed until the temperature has reached -20 °C.

d) Close the chamber and subject the module(s) to cycling between measured module temperatures of (-40 ± 2) °C and (+85 ± 2) °C, in accordance with the profile in Figure 7. 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 unless the module has such a high heat capacity that a longer cycle is required. The number of cycles shall be as shown in the relevant sequences in Figure ~~1~~ 2 of IEC 61215-1:~~2016~~2021. Air circulation around the module(s) has to ensure compliance with each module under test meeting the temperature cycling profile.

e) Throughout the test, record the module temperature and monitor the current flow through the module(s). Document in test report the actual dwell duration at high and low temperatures.

NOTE In a module with parallel circuits, an open circuit in one branch will cause a discontinuity in the voltage, but not cause the current to go to zero.

4.11.4 Final measurements

After a minimum recovery time of 1 h at (23 ± 5) °C and a relative humidity less than 75 % under open-circuit conditions, repeat the tests of MQT 01 and MQT 15.

4.11.5 Requirements

a) No interruption of current flow during the test; in the case of a module with parallel circuits, a discontinuity in current flow indicates an interruption of flow in one of the parallel circuit.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

4.12 Humidity-freeze test (MQT 12)

4.12.1 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.

4.12.2 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 9.

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) is (are) thermally isolated.

c) Measurement instrumentation having an accuracy of ±2,0 °C and repeatability of ±0,5 °C for measuring and recording the temperature of the module(s).

d) Means for monitoring, throughout the test, the continuity of the internal circuit of each module.

4.12.3 Procedure

a) Attach a suitable temperature sensor to the front or back surface of the module(s) near the middle. If more than one module of the same type is tested simultaneously, it will suffice to monitor the temperature of one ~~representative sample~~ of the test modules.

b) Install the module(s) at room temperature in the climatic chamber. For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment/mounting means during the test.

c) Connect the temperature-monitoring equipment to the temperature sensor(s). Connect each module to the appropriate current supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly. During the humidity freeze test set the continuous current flow to no more than 0,5 % of the measured STC peak power current. If 0,5 % of the measured STC current is less than 100 mA, then 100 mA may be applied instead.

d) After closing the chamber, subject the module(s) to ~~the number of cycles defined in sequence C in Figure 1 of IEC 61215-1:2016~~ 10 cycles in accordance with the profile in Figure 9. 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 when the temperature is at the maximum value of 85 °C. Air circulation around the module(s) has to ensure compliance with each module under test meeting the temperature cycling profile.

e) Throughout the test, record the module temperature and monitor the current and voltage through the module.

4.12.4 Final measurements

After a recovery time between 2 h and 4 h at (23 ± 5) °C and a relative humidity less than 75 % under open-circuit conditions, repeat the tests of MQT 01 and MQT 15.

4.12.5 Requirements

a) No interruption of current flow or discontinuity in voltage during the test; in the case of a module with parallel circuits, a discontinuity in current flow indicates an interruption of flow in one of the parallel circuits.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

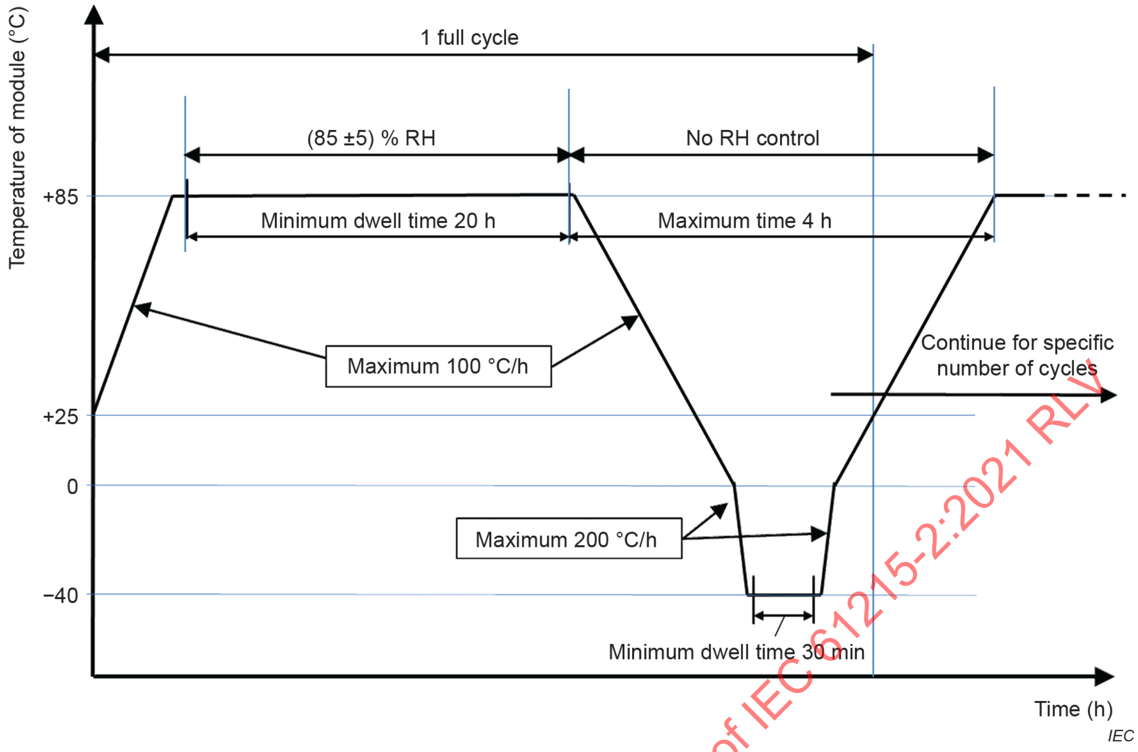


Figure 9 – Humidity-freeze cycle – Temperature and humidity profile

4.13 Damp heat test (MQT 13)

4.13.1 Purpose

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

4.13.2 Apparatus

Requirements for the test chamber are listed in IEC 60068-2-78:2012, 4.1.

4.13.3 Procedure

The procedure for introducing the sample into the chamber and starting the test is described in IEC 60068-2-78:2012, 4.4. The test shall be carried out ~~in accordance with IEC 60068-2-78~~ with the following provisions.

Severities:

~~The following severities are applied.~~

Test temperature: (85 ± 2) °C

Relative humidity: (85 ± 5) %

Test duration: $\left(1000^{+48}_{\ 0}\right)$ h

No preconditioning shall be performed.

Module connectors shall be short-circuited, unless current is being applied according to options provided in some of the technology-specific parts.

For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment/mounting means during the test.

4.13.4 Final measurements

After a recovery time of ~~between~~ 2 h, and no more than 4 h, at (23 ± 5) °C and a relative humidity less than 75 % under open-circuit conditions, repeat the tests of MQT 01 and MQT 15.

4.13.5 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.14 Robustness of terminations (MQT 14)

4.14.1 Purpose

To determine that the terminations, the attachment of the terminations, and the attachment of the cables to the body of the module will withstand stresses that are likely to be applied during normal assembly or handling operations. Test in 4.14.2 (MQT 14.1) and test in 4.14.3 (MQT 14.2) are to be performed in Sequence C after MQT 12 as given by the test flow in IEC 61215-1:2021.

4.14.2 Retention of junction box on mounting surface (MQT 14.1)

4.14.2.1 Apparatus

Means for applying a force of 40 N to the centre of the test object. Prevent torque from being applied to the junction box.

Attaching the means for applying the force to the junction box shall not impair its functions.

4.14.2.2 Procedure

~~The test shall be performed 2 h to 4 h after completion of MQT 12.~~

A force of 40 N shall be gradually applied for (10 ± 1) s (in accordance to IEC 60068-2-21) in each direction parallel to the mounting surface parallel to the module edges, in steps of 90°.

A force of 40 N shall be gradually applied for (10 ± 1) s without jerks, in a direction perpendicular to the mounting surface.

The pull force should be applied at the centre point of the box.

4.14.2.3 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.14.2.4 Requirements

During test, there shall be no displacement of the junction box at the mounting surface impairing isolating characteristics.

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.14.3 Test of cord anchorage (MQT 14.2)

~~4.14.3.1 General~~

~~This test can be omitted if junction box is qualified in accordance to IEC 62790.~~

~~4.14.3.2 Procedure and apparatus~~

~~4.14.3.2.1 Junction boxes intended to be used with cables specified by the manufacturer~~

~~For junction boxes intended to be used with cables specified by the manufacturer, the tests shall be performed with cables provided by the manufacturer.~~

~~a) Pull test~~

~~The unloaded cable shall be marked so that any displacement relative to the gland can be easily detected.~~

~~The cable is pulled for duration of 1 s, 50 times, without jerks in the direction of the axis with the relevant force as specified in Table 1. See Figure 11.~~

~~At the end of the pull test, remove the force from the test mandrel. Then measure the displacement of the cable at the outlet of the junction box.~~

~~b) Torque test~~

~~After the pull test the specimen shall be mounted in the test apparatus for torque test. See Figure 12.~~

~~The unloaded cable shall be marked so that any torsion relative to the gland can be easily detected, and then a torque as specified in Table 2 shall be applied for 1 min.~~

~~During the test, the twist or torsion inside the cable gland or other cord anchorage shall not exceed 45°. The cable shall be held in position by the cord anchorage.~~

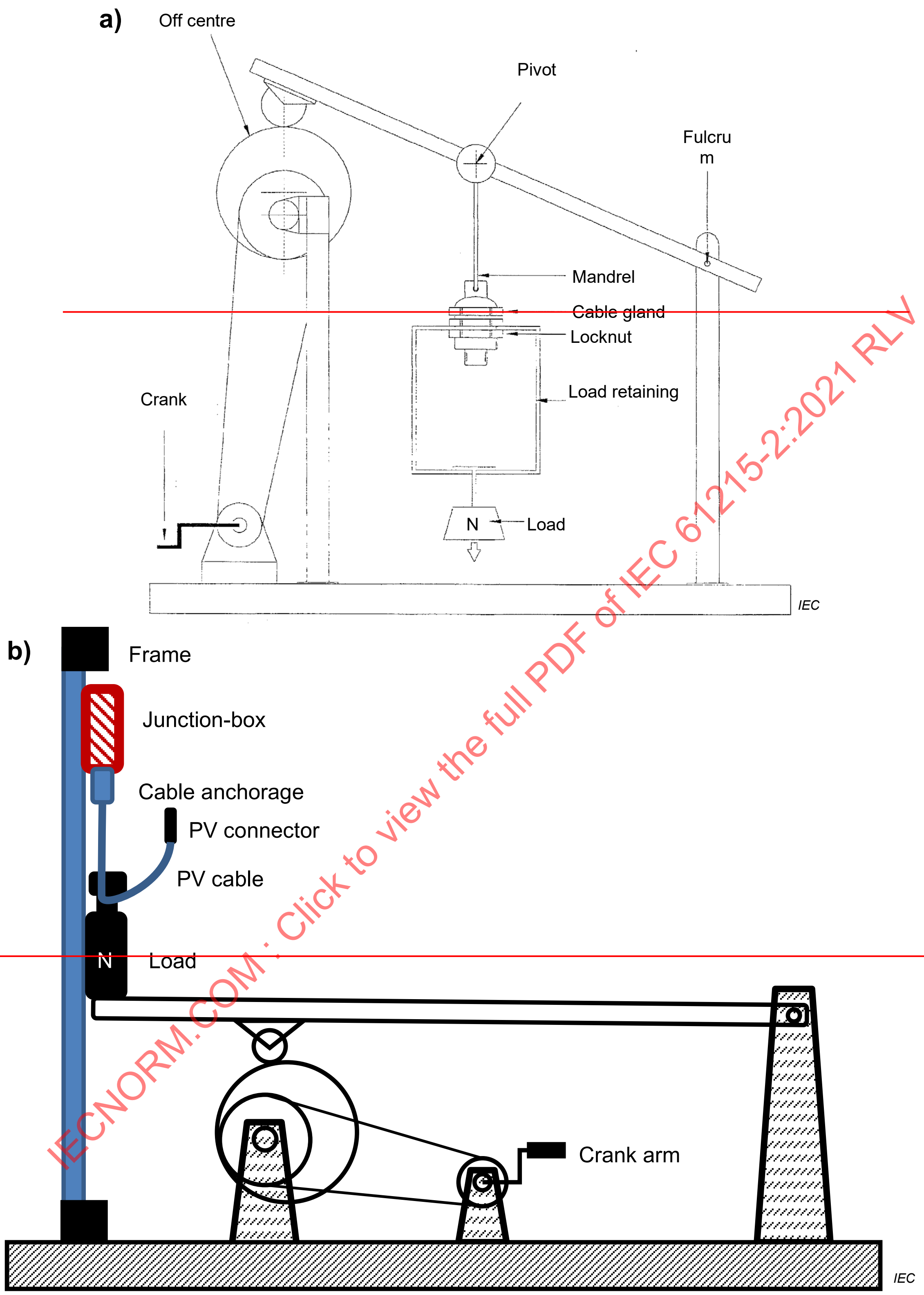
~~Table 1 – Pull forces for cord anchorage test~~

~~Cable diameter~~ ~~With insulation if applicable~~ ~~mm~~	~~Pull force~~ ~~N~~	~~Minimum sheath thickness of test mandrel~~ ~~mm~~
~~< 4~~	~~30~~	~~1~~[a]
~~> 4 to 8~~	~~30~~	~~1~~
~~> 8 to 11~~	~~42~~	~~2~~
~~> 11 to 16~~	~~55~~	~~2~~
~~> 16 to 23~~	~~70~~	~~2~~
~~> 23 to 31~~	~~80~~	~~2~~
~~> 31 to 43~~	~~90~~	~~2~~
~~> 43 to 55~~	~~100~~	~~2~~
~~> 55~~	~~115~~	~~2~~

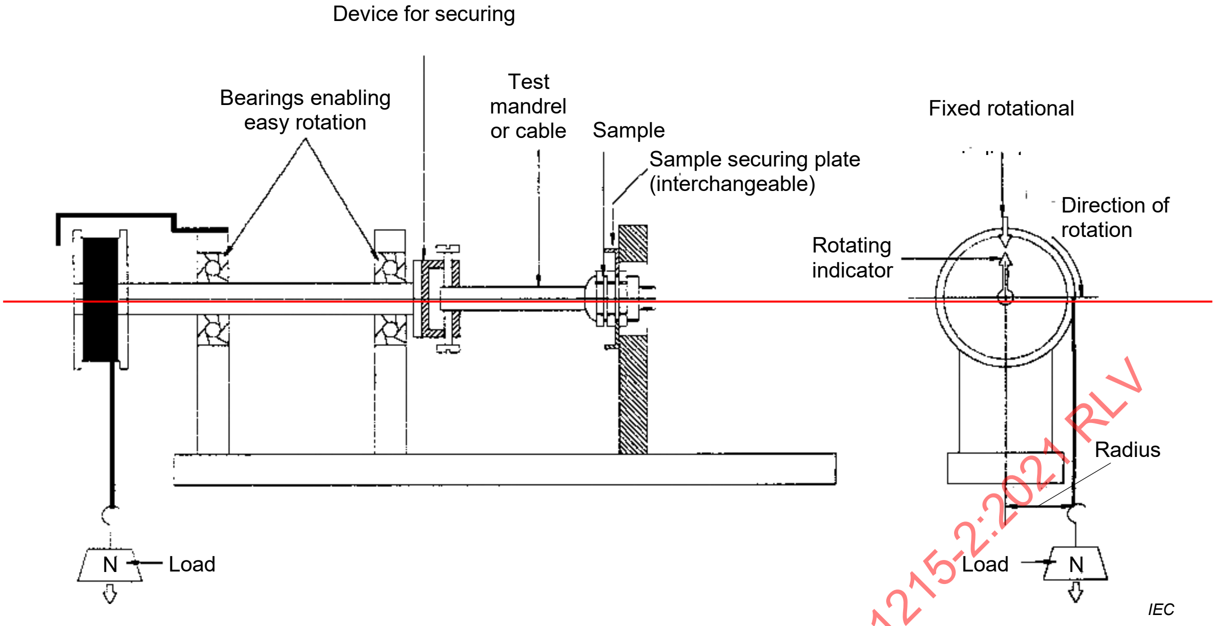
[a] ~~For cable diameters up to 4 mm, a suitable non-metallic mandrel may be used.~~

~~Table 2 – Values for torsion test~~

~~Cable diameter~~ ~~With insulation if applicable~~ ~~mm~~	~~Torque~~ ~~Nm~~	~~Minimum sheath thickness of test mandrel~~ ~~mm~~
~~< 4~~	~~0,10~~	~~1~~
~~> 4 to 8~~	~~0,10~~	~~1~~
~~> 8 to 11~~	~~0,15~~	~~2~~
~~> 11 to 16~~	~~0,35~~	~~2~~
~~> 16 to 23~~	~~0,60~~	~~2~~
~~> 23 to 31~~	~~0,80~~	~~2~~
~~> 31 to 43~~	~~0,90~~	~~2~~
~~> 43 to 55~~	~~1,00~~	~~2~~
~~> 55~~	~~1,20~~	~~2~~



~~Figure 11 – a) Typical arrangement for the cord anchorage pull test for component testing from IEC 62790.~~
~~b) Typical schematic arrangement for cord anchorage pull test on PV module mounted junction box~~



~~If the test is performed with the manufacturer's cable, the fixture for securing the cable shall be as close as possible to the cable securing plate of the junction box.~~

~~Figure 12 – Typical arrangement for torsion test~~

~~4.14.3.2.2 Junction boxes intended to be used with generic cables~~

~~A test mandrel equivalent to the minimum value of the anchorage range of the cable gland as specified by the manufacturer or supplier, with a sheath thickness as specified in Table 1 shall be fixed to the sample.~~

~~The unloaded test mandrel shall be marked so that any displacement relative to the gland can be easily detected.~~

~~The test mandrel shall be pulled for duration of 1 s, 50 times, without jerks in the direction of the axis with the relevant force as specified in Table 1. See Figure 11.~~

~~At the end of the pull test, remove the force from the test mandrel. Then measure the displacement of the cable at the outlet of the junction box.~~

~~Unless otherwise specified, test mandrels shall consist of a metallic rod with an elastomeric sheath having a hardness of 70 Shore D ± 10 points in accordance with ISO 868 and a sheath thickness as specified in Table 1 or Table 2. The complete test mandrel shall have a tolerance of ± 0,2 mm for mandrels up to and including 16 mm diameter and ± 0,3 mm for mandrels larger than 16 mm diameter. The shape shall be circular or a profile simulating the outer dimension of the cable as specified by the manufacturer or supplier.~~

~~After the pull test the specimen shall be mounted in the test apparatus for torque test. See Figure 12.~~

~~The unloaded cable shall be marked so that any torsion relative to the gland can be easily detected, and then a torque as specified in Table 2 shall be applied for 1 min.~~

~~During the test, the twist or torsion inside the cable gland or other cord anchorage shall not exceed 45°. The cable shall be held in position by the cord anchorage.~~

~~The torsion test shall be performed by using a test mandrel equivalent to the maximum value of the anchorage range of the cable gland as specified by the manufacturer or supplier, with a torque for the appropriate maximum cable diameter as specified in Table 2.~~

~~4.14.3.3 Final measurements~~

~~Repeat the tests of MQT 01, MQT 03 and MQT 15.~~

~~4.14.3.4 Requirements~~

~~a) No evidence of major visual defects, as defined in IEC 61215-1.~~

~~b) Insulation test shall meet the same requirements as for the initial measurements.~~

~~c) Wet leakage current shall meet the same requirements as for the initial measurements.~~

~~d) The displacement of the cable at the outlet of the junction box shall not exceed 2 mm.~~

The junction box, separate from the module, shall be tested to IEC 62790 "Test of cord anchorage" and shall meet the requirements therein. If the junction box has been pre-qualified prior to IEC 61215-2:2021 testing, the test report shall note the test lab name and date when the requirement was met. The cord anchorage test cannot be applied to junction boxes with integrated connectors, and thus junction boxes with integrated connectors are exempt from this requirement. Exemption shall be noted in the test report.

4.15 Wet leakage current test (MQT 15)

4.15.1 Purpose

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

4.15.2 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
Solution temperature:	(22 ± 2) °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~~, if the entire junction box is not going to be submerged~~.

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.

4.15.3 Procedure

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~~. ~~If not immersed,~~ The cable entries shall be thoroughly sprayed with solution. If the module is provided with a mating connector, the connector should be sprayed 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.

   Some module technologies may be sensitive to static polarization if the module is maintained at positive voltage to the frame. In this case, the connection of the tester shall be done in the opposite way. If applicable, information with respect to sensitivity to static polarization shall be provided by the manufacturer and documented in the test report.

c) Increase the voltage applied by the test equipment at a rate not exceeding 500 V/s 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.

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.

e) Ensure that the used solution is well rinsed off the module before continuing the testing.

4.15.4 Requirements

- For modules with an area of 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 $M\Omega \cdot m^2$.

4.16 Static mechanical load test (MQT 16)

4.16.1 Purpose

The purpose of this test is to determine the ability of the module to withstand a minimum static load. The minimum required design load for a particular site will depend on construction, applicable standards, building codes, probability of event occurrence, design assumptions and location/climate and might require higher sampling rates and other safety factors γ_m.

~~Additional requirements may apply for certain installations and climates.~~

~~MQT 16 verifies minimum test loads. To determine the minimum possible design load e.g. by test-to-fail of a construction is not part of this standard. The minimum required design load will depend on construction, applicable standards and location/climate and might require higher sampling rates and other safety factors γ_m.~~

~~MQT 16 verifies The manufacturer's defined design load. The test load is defined as:~~

To determine the maximum possible test load, e.g. by test-to-fail of a construction is not part of this document.

MQT 16 verifies minimum test loads. The manufacturer's minimum design load is back calculated from the above minimum test load. The test load is defined as:

$$\text{Test load} = \gamma_m \times \text{design load}$$

where the safety factor γ_m is at least ≥ 1,5.

The minimum required design load per this document is 1 600 Pa, resulting in a minimum test load of 2 400 Pa.

The manufacturer may specify higher design load(s) for positive (downward) and negative (upward) and also a higher γ_m for certain applications. The design load(s) and γ_m are to be specified in the documentation of the manufacturer per each mounting method.

EXAMPLE Manufacturer specifies the following design loads: positive 3 600 Pa and negative 2 400 Pa with γ_m = 1,5. The test sequence will contain 3 cycles each performed at 5 400 Pa positive and 3 600 Pa negative loading.

Each module undergoing MQT 16 test shall be pre-tested according to Sequence E in IEC 61215-1:2021, unless a module is an additional, full-size, very large module tested alongside representative samples, as described in IEC 61215-1:2021 Clause 4.

NOTE Inhomogeneous snow loads are not covered by this test. ~~A standard for such kind of load is under development (IEC 62938).~~ IEC 62938:2020 may be used.

4.16.2 Apparatus

a) 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 within the constraints of the manufacturers prescribed method of mounting.

b) Instrumentation to monitor the electrical continuity of the module during the test.

c) Suitable weights or pressure means that enable the load to be applied in a gradual, uniform manner. The test load may be applied pneumatically or by means of weights. All force shall be applied normal to the module surface. The apparatus shall not contribute to the rigidity of the module (e.g. force applied via a large, flat, plate).

d) The entire payload should be applied to the module surface uniformly and gradually without causing impact spikes. The weight shall only be applied on the frontsheet (e.g. the glass) and not on the module frame or cross support rails in the module. If weights are used to load the module, Annex A provides additional recommendations to ensure quality control and consistency of test results.

NOTE 1 With incremental loading where weights are loaded by hand, impact shocks not representative of field stress have been observed and are undesirable.

e) If an automated system using pistons (or other discrete-point application) is used to load the module, document the coverage ratio in the test report. Coverage ratio is the area under the suction cups (connected to pistons or other contacting points to module) to the surface area of the module. A minimum coverage ratio of 10 % is recommended to assure uniformity of loading on the module.

f) The environmental conditions for performing the tests are (25 ± 5) °C in a relative humidity not exceeding 75 %.

NOTE 2 As most adhesives will perform worse under elevated temperatures, room temperature is considered to be a best case condition for testing.

4.16.3 Procedure

a) Equip the module so that the electrical continuity of the internal circuit can be monitored continuously during the test.

b) Mount the module on a rigid structure using the method prescribed by the manufacturer including the mounting means (clips/clamps and any kind of fastener) and underlying support rails. If there are different possibilities each mounting method needs to be evaluated separately. ~~For all mounting methods, mount the module in a manner where the distance between the fixing points is worst case, which is typically at the maximum distance. Allow the modules to equilibrate for a minimum of 2 h after MQT 13 before applying the load.~~ For all mounting methods, mount the module in a manner where the loading is worst case. If there are different possibilities, each mounting configuration needs to be evaluated separately. Worst case loading is typically associated with largest cantilever (overhang span) or largest deflection. For all mounting configurations, mount the module in a manner where the distance between the fixing points is worst case, which typically results in the worst deflection of the module, while following manufacturer recommendations for the specified mounting means. Allow the modules to equilibrate for a minimum of 2 h after MQT 13 before applying the load. For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment means during the test.

c) On the front surface, gradually and uniformly apply the test load. Load uniformity needs to be better than ±5 % across the module with respect to the test load. Maintain this load for 1 h.

~~NOTE The test load may be applied pneumatically or by means of weights covering the entire surface.~~

d) Apply the same procedure as in step c) to the back surface of the module or as uplift load to the front surface.

e) Repeat steps c) and d) for a total of three cycles.

4.16.4 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.16.5 Requirements

a) No intermittent open-circuit fault detected during the test.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

4.17 Hail test (MQT 17)

4.17.1 Purpose

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

4.17.2 Apparatus

a) Moulds of suitable material for casting spherical ice balls of the required diameter. Minimum requirement is a diameter of 25 mm. For hail prone locations larger ice balls may be required for testing as listed in Table 2. The test report should indicate what ice ball diameter and test velocity was used for the hail test.

b) A freezer controlled at (-10 ± 5) °C.

c) A storage container for storing the ice balls at a temperature of (-4 ± 2) °C.

d) A launcher capable of propelling an ice ball at the specified velocity, within ±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) A 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 ±2 %.

g) An instrument for measuring the velocity of the ice ball to an accuracy of ±2 %. The velocity sensor shall be no more than 1 m from the surface of the test module.

As an example, Figure 10 shows in schematic form a suitable apparatus comprising a horizontal pneumatic launcher, a vertical module mount and a velocity meter which measures electronically the time it takes the ice ball to traverse the distance between two light beams. This is only one example as other types of apparatus including slingshots and spring-driven testers have been successfully utilized.

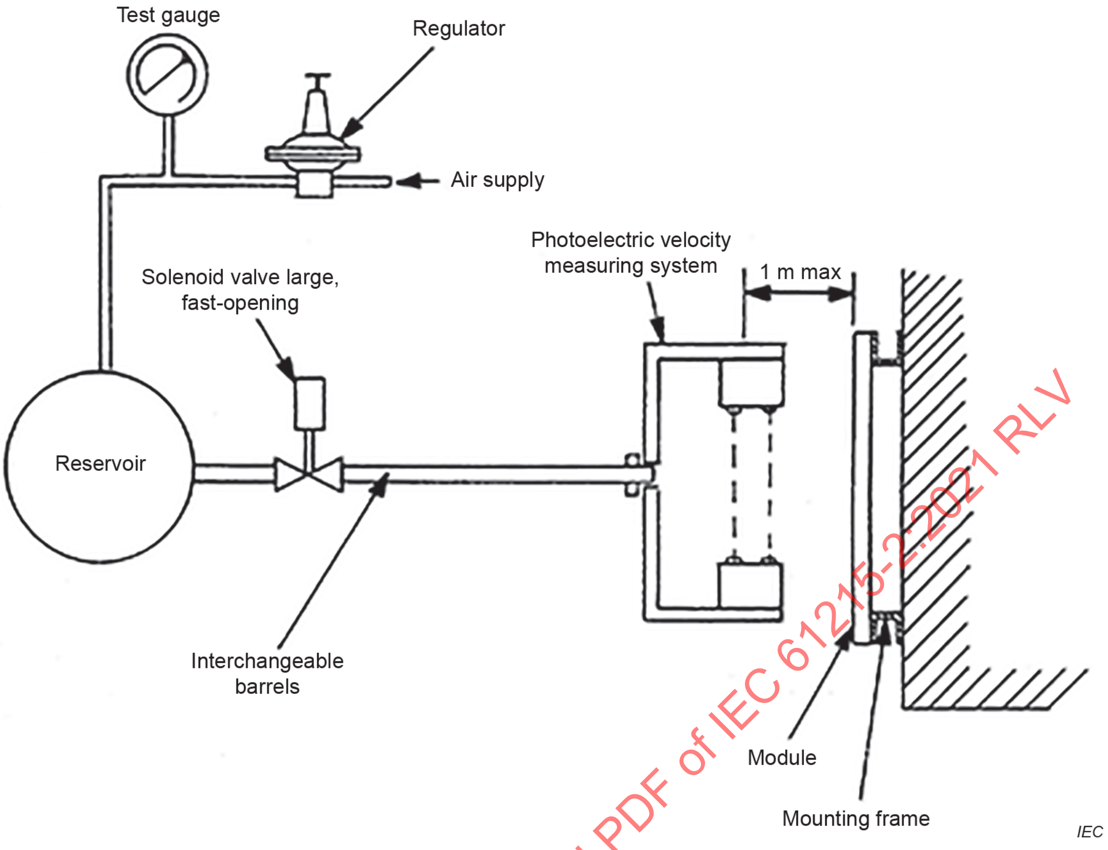


Figure 10 – Hail-test equipment

Table 2 – Ice-ball masses and test velocities

Diameter mm	Mass g	Test velocity m/s	Diameter mm	Mass g	Test velocity m/s
25	7,53	23,0	55	80,2	33,9
35	20,7	27,2	65	132,0	36,7
45	43,9	30,7	75	203,0	39,5

4.17.3 Procedure

a) Using the moulds and the freezer, make a sufficient number of 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 criteria:

- no cracks visible to the unaided eye;
- diameter within ±5 % of that required;
- mass within ±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 ±5 % of the appropriate hailstone test velocity in Table ~~4~~ 2.

f) ~~Install the module at room temperature in the prescribed mount, with the impact surface normal to the path of the ice ball.~~ Mount the module according to manufacturer specifications. The module shall be at room temperature, with the impact surface normal to the path of the ice ball. For flexible modules, the modules shall be mounted per the manufacturer’s documentation with prescribed substrate and adhesive or attachment/mounting means during the test. If the manufacturer’s specified application allows mounting in a rigid or flexible mounting condition, testing shall be done on the worst-case condition. The test configuration(s) shall be documented in the test report.

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 in Table 3 , as illustrated in Figure 11.

Table 3 – Impact locations

Shot No.	Location
1	Any corner of the module window, not more than one radius of ice-ball from the module edge.
2	Any edge of the module, not more than one radius of ice-ball from the module edge.
3, 4	Over the circuit near interconnects (i.e. cell interconnects and bus ribbons).
5, 6	Over edges of the circuit (e.g. individual cells).
7, 8	On the module window, not more than half diameter of ice ball from one of the points at which the module is mounted to the supporting structure.
9, 10	On the module window, at points farthest from the points selected above.
11	Any points which may prove especially vulnerable to hail impact like over the junction box.

4.17.4 Final measurements

Repeat tests MQT 01 and MQT 15.

4.17.5 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

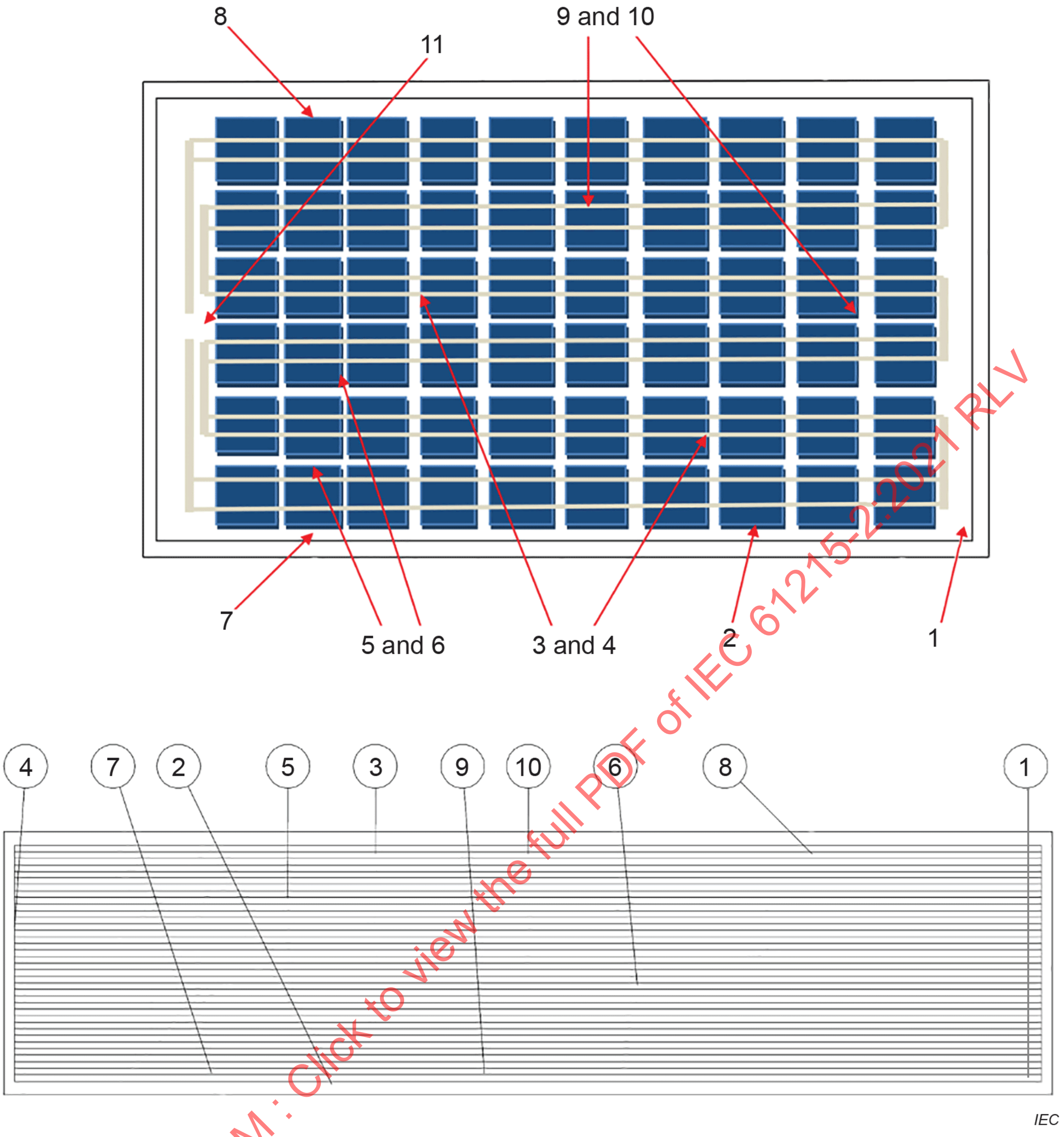


Figure 11 – Hail test impact locations: top for wafer/cell based technologies, bottom for monolithic processed thin film technologies

4.18 Bypass diode testing (MQT 18)

4.18.1 Bypass diode thermal test (MQT 18.1)

4.18.1.1 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.

The test is designed to determine the diode's temperature characteristic and its maximum diode junction temperature T_J under continuous operation.

4.18.1.2 Test sample

If the module contains three or fewer bypass diodes, then all diodes shall be tested for forward voltage as per 4.18.1.4 and for functionality as per 4.18.2. If the module contains more than three diodes, then three bypass diodes are to be selected for testing. These bypass diodes are to be selected by the test laboratory and should be representative bypass diodes which are subject to the most stress in the design. The test lab shall indicate in the test report which three bypass diodes were selected and why they were selected.

a) For more than three diodes embedded in a laminate, select the diodes in these locations:
   1) Closest to the centre of the junction box (may be underneath the junction box).
   2) Closest to the module frame (or module edge, in case of frameless module).
   3) Closest to module centre.
b) For more than three diodes in a junction box, select diodes in these locations:
   1) Closest to the centre of the junction box.
   2) Next closest to the centre of the junction box.
   3) Closest to the edge of the junction box.

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 module and does not have to be an active PV module. The test shall then proceed as normal. This special test sample shall be used only for measuring the bypass diode temperature in 4.18.1.4 c) to ~~m~~ k). Exposure to 1,25 times the STC short-circuit current shall be performed on a fully functional module which is then used for making the final measurements of 4.18.1.5. The special sample shall allow electrical access to the three bypass diodes in locations complying with the above selection criteria.

4.18.1.3 Apparatus

a) Means for heating the module up to a temperature of (90 ± 5) °C.
b) Means for monitoring the temperature of the module to an accuracy of ±2,0 °C and repeatability of ±0,5 °C.
c) Means for measuring the junction voltage V_D of the bypass diodes to an accuracy of 2 %.
d) Means for applying a current equal to 1,25 times the STC short-circuit current of the module under test with a pulse width not exceeding 1 ms and means for monitoring the flow of current through the module, throughout the test. For bifacial modules, the applicable current is 1,25 times short-circuit current at elevated irradiance BSI, as defined in IEC 61215-1:2021. The short-circuit current at irradiance BSI may be determined either by a measurement (MQT 06.1) at irradiance BSI, or by assuming linearity of short-circuit current with irradiance (as defined in IEC 60904-10). Assuming linearity allows one to calculate the short-circuit current at BSI, $I_\text{sc-BSI}$, using I_sc values measured for Gate No. 1 ($I_\text{sc-STC}$ and $I_\text{sc-BNPI}$), and the relevant equivalent irradiances: 1 000 Wm^{-2}, G_BNPI, and G_BSI. To extrapolate $I_\text{sc-BSI}$, these quantities are combined as follows:

$$I_\text{sc–BSI} = I_\text{sc–BNPI} + \frac{\left(I_\text{sc–BNPI} - I_\text{sc–STC}\right)}{G_{BNPI} - 1\,000\ \text{Wm}^{-2}} \cdot \left(G_{BSI} - G_{BNPI}\right)$$

In the above formula, equivalent irradiance are calculated as in IEC TS 60904-1-2, specifically:

$$G_\text{BNPI} = 1\,000\ \text{Wm}^{-2} + \varphi \cdot 135\ \text{Wm}^{-2}$$

$$G_\text{BSI} = 1\,000\ \text{Wm}^{-2} + \varphi \cdot 300\ \text{Wm}^{-2}$$

$$\varphi = Min(\varphi_{\mathrm{Isc}}, \varphi_{\mathrm{Pmax}})$$

4.18.1.4 Procedure

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. For bifacial modules, use the value of the short-circuit current at elevated irradiance BSI, as defined in IEC 61215-1:2021.

c) Connect the lead wire for V_D and I_D on both diode terminals as shown in Figure 12.

If the diodes are potted the connections shall be made by the module manufacturer before delivery of the module.

Care shall be taken that the lead wires do not cause heat dissipation from the terminal box leading to misinterpretation of the test results. Thus, current connections should be made as far as possible away from the terminal box, and voltage probes made as small and thin as possible.

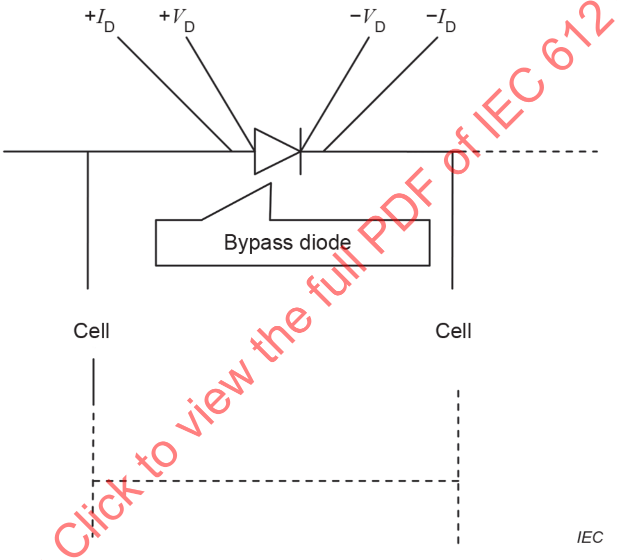


Figure 12 – Bypass diode thermal test

d) Heat the module and junction box up to a temperature of (30 ± 2) °C.

e) 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. For bifacial modules, use the value of the short-circuit current at elevated irradiance BSI.

f) Using the same procedure, measure V_{D2} at (50 ± 2) °C.

g) Using the same procedure, measure V_{D3} at (70 ± 2) °C.

h) Using the same procedure, measure V_{D4} at (90 ± 2) °C.

i) 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}.

T_J is assumed to be the ambient temperature of the junction box for steps d) to i).

j) Heat the module to (75 ± 5) °C. Apply a current to the module equal to the short-circuit current I_{sc} ± 2% ~~of the moduleas measured at STC~~ as determined in step b). After 1 h measure the forward voltage of each of the selected diodes.

   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 W/m^2, (43 ± 3) °C ambient with no wind rather than at 75 °C.

k) Using the V_D versus T_J characteristic obtained in item i), obtain T_J from V_D at T_{amb} = 75 °C, $I_D = I_{sc}$ of the diode during the test in j).

l) Increase the applied current to 1,25 times the short-circuit current of the module as ~~measured at STC~~ determined in step b) while maintaining the module temperature at (75 ± 5) °C.

m) Maintain the current flow for 1 h.

4.18.1.5 Final measurements

Repeat the tests of MQT 01, MQT 15 and MQT 18.2.

4.18.1.6 Requirements

a) The diode junction temperature T_J as determined in 4.18.1.4 k) shall not exceed the diode manufacturer's maximum junction temperature rating for continuous operation.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

d) The diode shall still function as a diode after the conclusion of the test as per MQT 18.2.

4.18.2 Bypass diode functionality test (MQT 18.2)

4.18.2.1 Purpose

The purpose of this test is to verify that the bypass diode(s) of the test samples remain(s) functional following MQT 09 and MQT 18.1. In case of PV modules without bypass diodes this test can be omitted.

4.18.2.2 Apparatus

Means for measuring current-voltage curve within 1 s; e.g. I-V curve tracer, with an accuracy of the voltage and current measurements ~~shall be at least 1 % of reading~~ of ±1 % of the open-circuit voltage and short-circuit current, respectively.

4.18.2.3 Procedure

4.18.2.3.1 General

The test can be conducted according to either of the following two methods.

4.18.2.3.2 Method A

This procedure shall be conducted in any ambient temperature within (25 ± 10) °C. During the test the sample shall not be subjected to illumination.

a) Electrically short any blocking diodes incorporated to the test sample.

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

b) Determine the rated STC short-circuit current of the test sample from its name plate. For bifacial modules, use the value of I_{SC} measured at STC.

c) Connect the DC power source's I-V curve tracer's positive output to the test sample's negative terminal and the DC power source's I-V curve tracer's negative output to the test sample's positive terminal, respectively. With this configuration the current shall pass through the solar cells in the reverse direction and through the bypass diode(s) in the forward direction.

d) Run current sweep from 0 A to 1,25 × I_{sc} and record voltage. Use the value of I_{sc} determined in step b).

4.18.2.3.3 Method B

Successive I-V measurements of the PV module can be performed in conjunction with maximum power determination (MQT 02) with portions of a string in the interconnection circuit completely ~~shaded~~ shadowed in order to "turn on" the diode. This procedure should be repeated for each substring.

4.18.2.4 Requirements

4.18.2.4.1 Method A

~~The measured diode(s) forward voltage (VFM):~~

In the current sweep of 4.18.2.3.2 d), identify the largest current at which the forward voltage is specified on the data sheet. The diode(s) forward voltage measured at the identified current is defined as VFM and shall meet the following requirement:

$$VFM = (N \times V_{\text{FMrated}}) \pm 10\ \%$$

where:

N is the number of bypass diodes;

V_{FMrated} is the diode forward voltage as defined in diode data sheet for 25 °C.

4.18.2.4.2 Method B

The bypass diode belonging to the ~~shaded~~ shadowed string is working properly, if the characteristic bend in the I-V curve is observed.

Example: a crystalline silicon PV module with 60 cells and three strings protected each by one diode will have a power drop to roughly 2/3, if cells in one string are ~~shaded~~ shadowed.

4.19 Stabilization (MQT 19)

4.19.1 General

All PV modules need to be electrically stabilized. For this purpose, all modules shall be exposed to a defined procedure, and the output power shall be measured directly afterwards. This procedure and output power measurement shall be repeated until the module is assessed to have reached an electrically stable power output level. Where light is used for stabilization, simulated solar irradiance is preferred over natural light.

4.19.2 Criterion definition for stabilization

The following formula shall be taken as the criterion to assess whether a module has reached its stabilized electrical power output:

$$(P_{\text{max}} - P_{\text{min}}) / P_{\text{average}} < x$$

where x is defined in the technology specific parts of this standards series.

Here, P_{max}, P_{min} and $P_{average}$ are defined as extreme values of three consecutive output power measurements P_1, P_2 and P_3 taken from a sequence of alternating stabilization and measurement steps using MQT 02. $P_{average}$ is the average of all three, P_1, P_2 and P_3. STC output power is determined using procedure MQT 06.1.

4.19.3 Light induced stabilization procedures

4.19.3.1 Apparatus for indoor stabilization

a) A class CCC solar simulator or better, in accordance with IEC 60904-9.

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) Use the reference device to set the irradiance between 800 W/m^2 and 1 000 W/m^2.

e) During the simulator exposure, module temperatures shall stay in the range of (50 ± 10) °C. All subsequent stabilizations should be done at the same temperature as the initial within ±2 °C.

f) Means for monitoring the temperature of the module to an accuracy of ±2,0 °C and repeatability of ±0,5 °C. The temperature sensor shall be mounted on a representative position for the average module temperature.

g) A resistive load sized such that the module will operate near its maximum power point or an electronic maximum power point tracker (MPPT).

4.19.3.2 Requirements for outdoor exposure for stabilization

a) A suitable reference device, with integrator, for monitoring the irradiation.

b) Means to mount the modules, as recommended by the manufacturer, co-planar with the reference device.

c) Only irradiance levels above 500 W/m^2 will count for total irradiance dose required to check stabilization. Temperature limits are specified in the technology specific parts.

d) Means for monitoring the temperature of the module to an accuracy of ±2,0 °C and repeatability of ±0,5 °C. The temperature sensor shall be mounted on a representative position for the average module temperature.

e) A resistive load sized such that the module will operate near its maximum power point or an electronic maximum power point tracker (MPPT).

A maximum power point tracking device is advisable, e.g. a micro-inverter.

4.19.3.3 Procedure

a) Measure the output power of each module using the maximum power determination (MQT 02) procedure at any convenient module temperature within the allowable range that can be reproduced within ±2 °C for future intermediate measurements.

b) Attach the load to the modules and mount them, as recommended by the manufacturer, with the reference device in the test plane of the simulator.

c) Record the irradiance levels, integrated irradiation, temperature and used resistive load of the module.

d) Subject each module to at least two intervals of the irradiation as defined in the technology specific parts of MQT 19 of this standard until its maximum power value stabilizes. Stabilization is defined in 4.19.2.

e) The output power shall be measured using MQT 02. The time period between light exposure including MQT 02 measurements and the final determination of maximum power in accordance to MQT 06.1 is specified in the technology specific part.

f) Intermediate measurements of MQT 02 shall be performed in approximately equal integrated irradiation dose intervals. Minimum doses are defined in the technology specific parts of this standard. All intermediate maximum power measurements shall be performed at any convenient module temperature reproduced within ±2 °C.

g) Report the integrated irradiation and all parameters at which this stability is reached. For outdoor procedure, where applicable, state the type of load used and show temperature and irradiance profiles.

4.19.4 Other stabilization procedures

Other stabilization techniques can be used after validation. It is known that the application of current or voltage bias can lead to similar effects in solar cells as is the case for light exposure. Such alternate stabilization procedures will be provided by the manufacturer.

This subclause defines the validation process for alternate stabilization procedure.

Alternate procedures can be used instead of light exposure if validated according to this procedure. Validation shall be done with three modules. The validation shall be performed in sequence A as initial stabilization. Perform the following to validate alternate procedures:

a) Perform alternate procedure.

b) Measure MQT 06.1 after the minimum and no more than the maximum time specified in the technology specific parts.

c) Perform indoor light induced stabilization procedure 4.19.3.1 in accordance to technology specific requirements.

d) Measure MQT 06.1 after the minimum and no more than the maximum time specified in the technology specific parts.

An alternate method is considered valid if the two MQT 06.1 measurements from b) and d) above are within 2 % for all three evaluated modules. If one module does not meet the pass criteria the method is not validated.

4.19.5 Initial stabilization (MQT 19.1)

Initial stabilization is performed following procedure and requirements defined in MQT 19. Stabilization is reached if 4.19.2 is fulfilled.

The initial stabilization is performed to verify manufacture label values as defined in the pass criterion in IEC 61215-1:~~2016~~2021, 7.2.2 (Gate No. 1).

The number of modules subjected to MQT 19.1 is defined in the technology specific parts of this standard.

4.19.6 Final stabilization (MQT 19.2)

Final stabilization is performed following procedure and requirements defined in MQT 19. Stabilization is reached if 4.19.2 is fulfilled.

The final stabilization is performed to determine module degradation during the test as defined in the pass criterion in IEC 61215-1:~~2016~~2021, 7.2.3 (Gate No. 2).

If not otherwise stated all modules from sequences A, and C to E have to undergo MQT 19.2 testing.

4.19.7 Stress-specific stabilization – BO LID (MQT 19.3)

4.19.7.1 General

Some stress conditions may change the state of semiconductor defects in a way that is not representative of field behavior and is not related to the degradation mechanisms that are targeted by the stress tests. In this case, a stress-specific stabilization may be required to set the defects into a reproducible state either before or after stress. When to apply a stress-specific stabilization is prescribed in the technology-specific parts.

MQT 19.3 describes a stabilization procedure that puts the defects causing boron-oxygen light induced degradation into the regenerated state. It shall only be used at points in the test flow specifically allowed in IEC 61215-1-1:2021.

4.19.7.2 Apparatus for BO-LID stress-specific stabilization

a) A climatic chamber with automatic temperature control.

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) is (are) thermally isolated.

c) Measurement instrumentation having an accuracy of ±2,0 °C and repeatability of ±0,5 °C for measuring and recording the temperature of the module(s).

d) Means for applying, throughout the test, a current equal to the module short-circuit current I_{sc}.

4.19.7.3 Procedure

a) Install the module(s) at room temperature in the climatic chamber.

b) Connect the temperature-monitoring equipment to the temperature sensor(s). Connect each module to the appropriate current supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly.

c) Close the chamber, and apply a current of I_{sc} ± 5 % to each module. As long as the current applied to each module is within 5 % of its I_{sc}, the currents applied through multiple modules in one chamber need not be the same.

d) Increase the climactic chamber setpoint such that the temperature of each module reaches (80 ± 5) °C, and never exceeds 85 °C.

e) Maintain the current and temperature within the limits prescribed in steps c) and d) for (48 ± 2) h.

4.20 Cyclic (dynamic) mechanical load test (MQT 20)

4.20.1 Purpose

The purpose of this test is to evaluate if components within the module are extremely susceptible to low levels of mechanical stress. The most likely reason for extreme susceptibility to low levels of mechanical stress is a module assembly process that compromises the integrity of module components (for example tabbing that puts too much pressure on the cell and creates microcracks). Components that may be evaluated by the cyclic dynamic mechanical load test (DML) include solar cells, interconnect ribbons, electrical bonds, and edge seals.

4.20.2 Procedure

The test shall be carried out in accordance with IEC TS 62782.

4.20.3 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.20.4 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.21 Potential induced degradation test (MQT 21)

4.21.1 Purpose

The purpose of this test is to measure the module design's ability to withstand degradation from applied system voltage, also known as Potential Induced Degradation (PID).

NOTE The test is not designed to evaluate PID involving polarization mechanisms (PID-p) and therefore PID-p may not be detected.

4.21.2 Samples

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. Four samples (two for each polarity of the system voltage that is specified or allowed in the module documentation) per Clause 4 of IEC 61215-1:2021 shall be procured for each test. Modules not explicitly requiring string connections with one terminal earthed shall be tested in both polarities. If only two modules are tested (i.e. one allowed polarity), the two modules not subjected to stress during MQT 21 shall only progress through the test flow (IEC 61215-1:2021, Figure 2) as far as MQT 21, then shall not be subjected to further testing. Specifically, the two unused modules shall progress through Gate No 1 but not Gate No 2.

If the PV module is provided with or is specified for use with a specific means for earthing, then the earthing 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.

4.21.3 Apparatus

The test shall be carried out using the apparatus described in IEC TS 62804-1:2015, 4.3.1.

4.21.4 Procedure

The test shall be carried out in accordance with the stress method testing in damp heat using an environmental chamber as given in IEC TS 62804-1:2015, 4.3.2 with the following provisions

Severities:

Module temperature: 85 °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.

4.21.5 Final measurements

Repeat the MQT 01 and MQT 15 tests. The MQT 15 test shall be performed within 8 h of the end of the PID stress described in 4.21.4.

As per the test flow shown in IEC 61215-1:2021, Figure 2, modules shall be subjected to MQT 19.2, MQT 06.1 (including gate 2), and MQT 03 following the PID test (MQT 21). Bifaciality coefficients shall be remeasured when performing MQT 06.1 for gate 2. Modules from sequence F do not need to repeat MQT 15 at the end of the test flow. In order to maximize repeatability when partially-reversible PID may be present, the modules that have undergone PID testing shall be stored with controlled conditions between testing steps after PID (i.e. MQT 19.2, MQT 6.1, MQT 03). Between these test steps, the modules shall be maintained indoors, in the dark, and at temperatures 25 °C or below. For the post-PID tests, no more than 48 h shall elapse between the end of MQT 21 and the beginning of MQT 19.2. The time limit between MQT 19.2 and MQT 06.1 shall be either 48 h or the time limit specified in the technology-specific stabilization procedure, whichever is shorter.

4.21.6 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021, Clause 8.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.22 Bending test (MQT 22)

4.22.1 Purpose

The purpose of this test is to verify that a flexible module can be rolled up (without damage) to form a radius of curvature defined by the module manufacturer in at least one direction per the manufacturer's specification. If the manufacturer's installation guide allows bending in more than one direction, the worst-case condition shall be used. The test may be performed on a representative sample, as described in IEC 61215-1:2021, Clause 4.

NOTE Once the radius of curvature is defined, the bending stresses are the same as long as the thickness is the same between "representative sample" and a longer module.

4.22.2 Apparatus

a) A cylinder with a diameter of twice the radius of curvature specified by the module manufacturer. The flexible module will be bent over this cylinder.

b) Instrumentation to monitor the electrical continuity of the module during the test.

c) The environmental conditions for performing the tests are (25 ± 5) °C.

4.22.3 Procedure

a) Equip the module so that the electrical continuity of the internal circuit can be monitored continuously during the test.

b) Roll the flexible module from a flat/planar starting position over the cylinder of the specified radius of curvature. If the module is large enough, it shall roll up on the cylinder in excess of 360°.

c) Unroll the flexible module back to the flat/planar position.

d) Repeat b) and c) 25 times.

4.22.4 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.22.5 Requirements

a) No intermittent open-circuit fault detected during the test when a continuous current is applied and monitored as performed per MQT 11.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

Annex A
(informative)

Recommended setup for managing weights during mechanical loading (MQT 16)

Many factors are known to introduce noise into test that can lead to false module failures during MQT 16. These factors include nonuniformity of loads, periodic spikes of pressure from weight placement, frequency of loading, heavy bags, flowing media in bags, and ergonomics of loading weights. In the absence of an automated system (for example, a pneumatic system) which can place the entire payload in a controlled and uniform fashion on the test module, recommendations to ensure quality control of the test methodology are indicated in this annex.

A gantry crane arrangement such as that illustrated in Figure A.1 is recommended to place the entire payload in a controlled and uniform manner onto the test module. The gantry crane should be equipped with a variable frequency drive controlled motor which can control the rate of load placement on the module. The hoist should be rated adequately to handle the expected loads and should have adequate clearance to accommodate the loading jig to be lifted above the mounting jig and placed on the module mounted into the mounting jig.

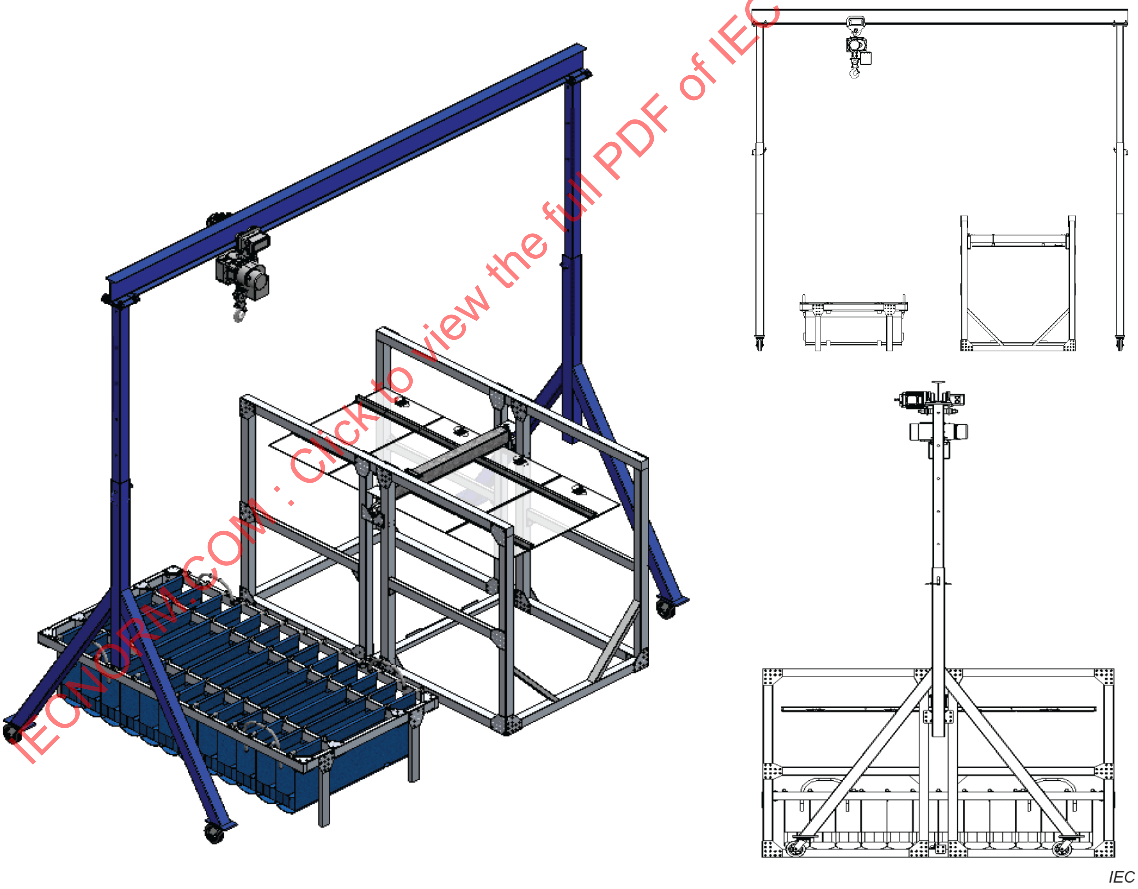


Figure A.1 – 3D view (at left of figure), end view (at top right), and side view (at bottom right) of gantry crane over mounting jig and loading jig

The mounting jig should be designed to mount the module per manufacturer requirements and should provide sufficient clearance for the load to be placed on the module surface. The mounting jig illustrated in Figure A.2 shows a module mounting arrangement on a central torque tube mounted tracker. The example jig in Figure A.2 is fabricated using T-slot aluminium extrusions. Figure A.3 illustrates a profile view of the mounting jig, which illustrates a pivoting mechanism to easily turn the module over for loading the opposite side without removing the fasteners. Alternative arrangements to accommodate a girder based tracker or purlins in fixed tilt structures are possible.

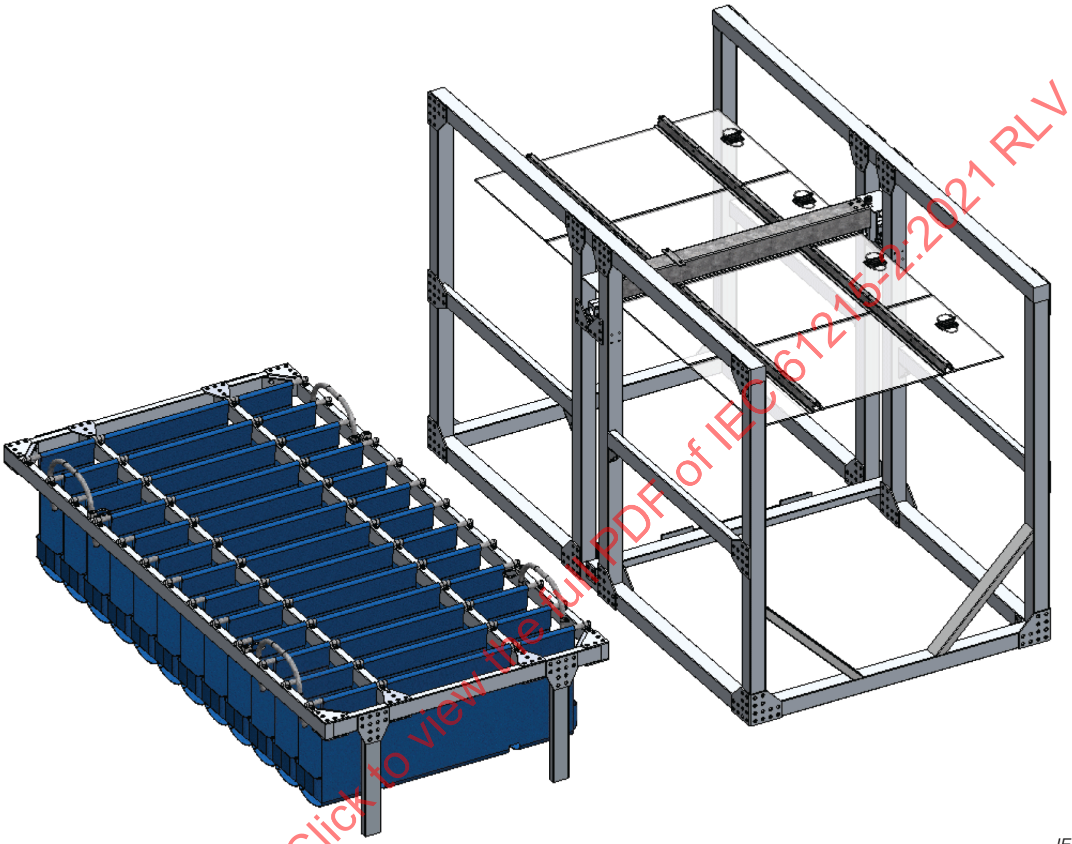


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Figure A.2 – 3D close up views of mounting jig (right) and loading jig (left)

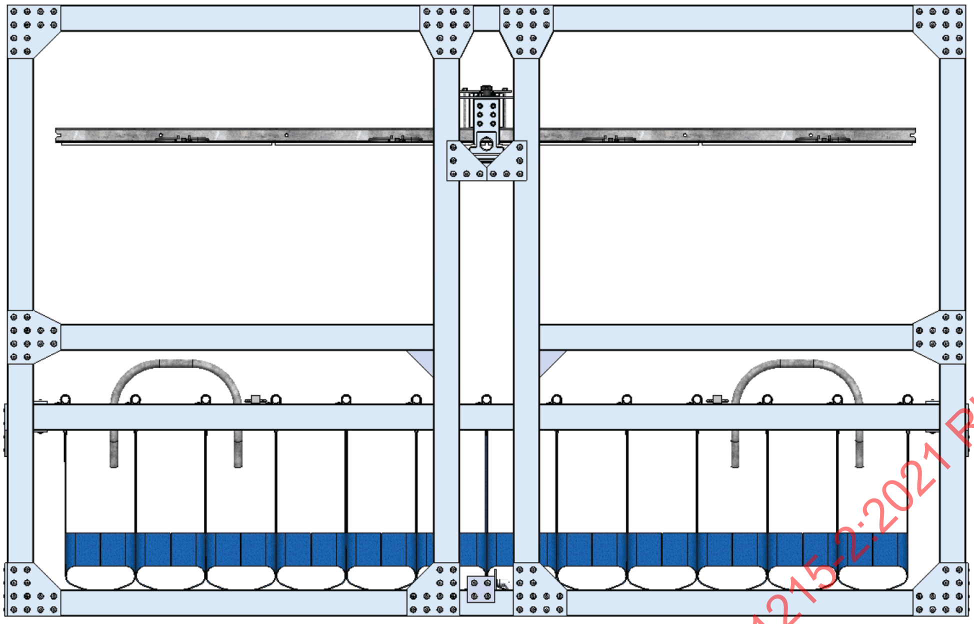

Figure A.3 – 2D view of mounting jig and loading jig

Figure A.4 and Figure A.5 show further detail of the loading jig with configurable channels where weights can be placed. The configurable channels can be fabricated from thick tarpaulin and adhesive tape, and are supported by rods. The rods can be moved on the T-slot rails of the mounting jig and clamped down by U clamps as illustrated to make room for any cross support rails in the module frame, thus avoiding loading such members. It is a critical to ensure load is not placed on frame members. The legs of the mounting jig are shorter than the depth of the channels so the weight can bottom out on the load surface before the legs make contact.

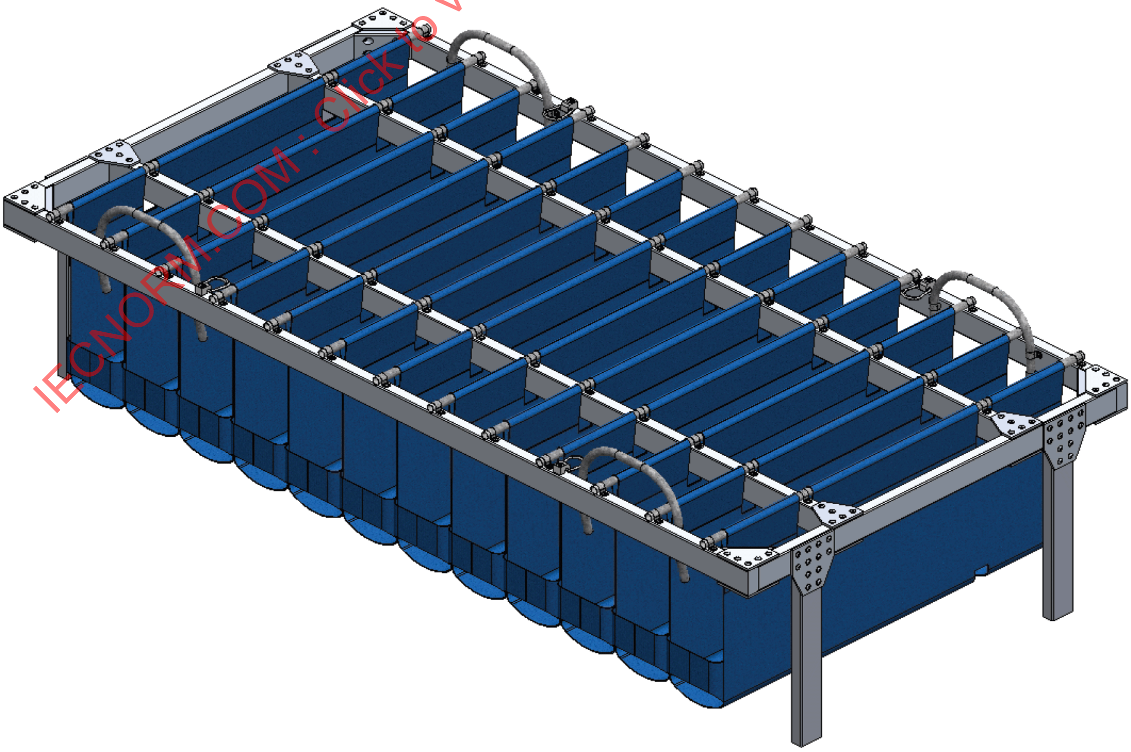

Figure A.4 – 3D view of loading jig

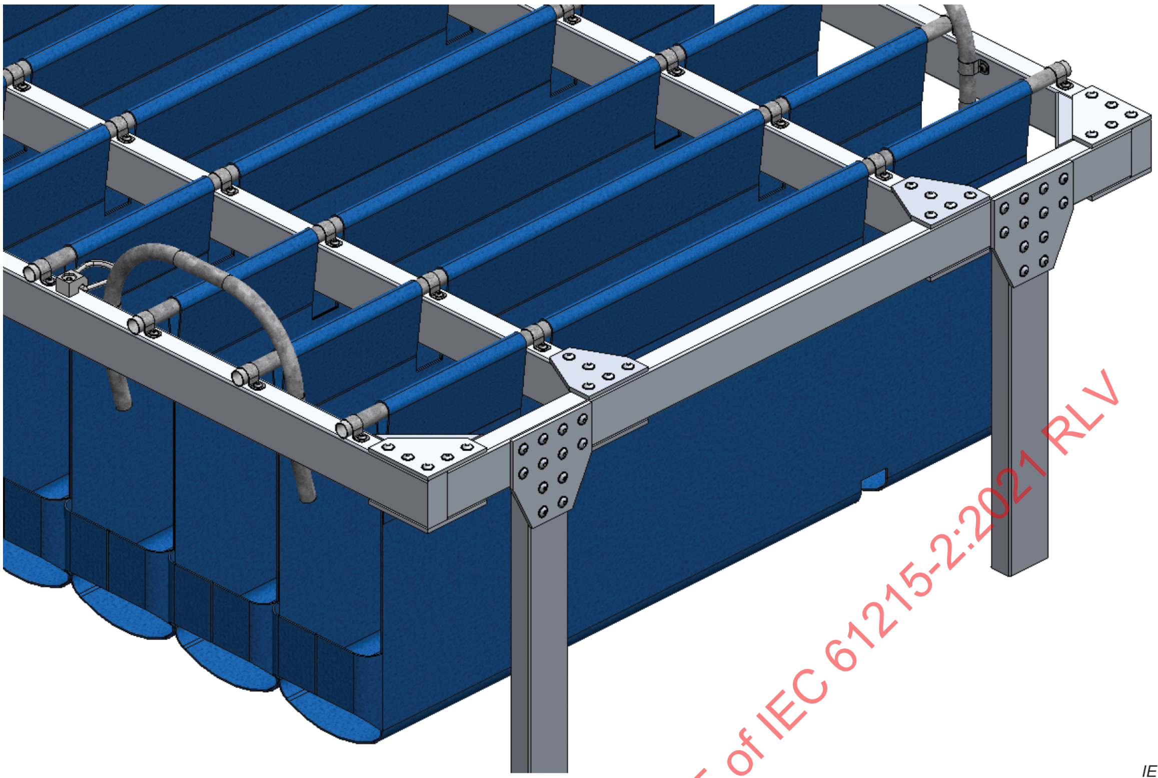

Figure A.5 – Close-up view of loading jig

While the media used for the load can vary (lead shot, sand, metal pellets, bricks etc.), some form of metal pellet is recommended as the load medium. The columnar bags should be constructed of heavy duty material, so that they can retain their shape and surface area. The size and shape of the bag chosen should be ergonomic and hold no more than 10 kg of weight. Each bag should be filled of same medium and measured by a calibrated scale prior to placing in the appropriate channel to assure a uniform load distribution on the module. Each channel should carry equal amount of weight to assure a loading uniformity of <5 % as specified in the test.

Bibliography

IEC 60050-311, *International Electrotechnical Vocabulary (IEV) – Part 300: Electrical and electronic measurements and measuring instruments – Part 311: General terms relating to measurements – Part 312: General terms relating to electrical measurements – Part 313: Types of electrical measuring instruments – Part 314: Specific terms according to the type of instrument*

IEC 62506, *Methods for product accelerated testing*

IEC 62938:2020, *Photovoltaic (pv) modules – Non-uniform snow load testing*

IEC 62941, *Terrestrial photovoltaic (PV) modules – Quality system for PV module manufacturing*

IEC TS 63126, *Guidelines for qualifying PV modules, components and materials for operation at high temperatures*

ISO/IEC Guide 99:2007*, International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

IEC 61215-2

Edition 2.0 2021-02

INTERNATIONAL STANDARD

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inside

Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures

Modules photovoltaïques (PV) pour applications terrestres – Qualification de la conception et homologation – Partie 2: Procédures d'essai

IEC 61215-2:2021-02(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 2: Test procedures

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

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International Standard IEC 61215-2 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This second edition of IEC 61215-2 cancels and replaces the first edition of IEC 61215-2 issued in 2016; it constitutes a technical revision.

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

a) Addition of cyclic (dynamic) mechanical load testing (MQT 20).

b) Addition of a test for detection of potential-induced degradation (MQT 21).

c) Addition of test methods required for bifacial PV modules.

d) Addition of test methods required for flexible modules. This includes the addition of the bending test (MQT 22).

e) Revision of simulator requirements to ensure uncertainty is both well-defined and minimized.

f) Correction to the hot spot endurance test, where the procedure for monolithically integrated (MLI) thin film technologies (MQT 09.2) previously included two sections describing a procedure only appropriate for silicon modules.

g) Selection of three diodes, rather than all, for testing in the bypass diode thermal test (MQT 18).

h) Removal of the nominal module operating test (NMOT), and associated test of performance at NMOT, from the IEC 61215 series.

Informative Annex A of IEC 61215-1:2021 explains the background and reasoning behind some of the more substantial changes that were made in the IEC 61215 series in progressing from edition 1 to edition 2.

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

FDIS	Report on voting
82/1829/FDIS	82/1853/RVD

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

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

A list of all parts in the IEC 61215 series, published under the general title *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*, can be found on the IEC website.

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

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

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

Whereas Part 1 of this standards series describes requirements (both in general and specific with respect to device technology), the sub-parts of Part 1 define technology variations and Part 2 defines a set of test procedures necessary for design qualification and type approval. The test procedures described in Part 2 are valid for all device technologies.

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

Part 2: Test procedures

1 Scope

This document lays down requirements for the design qualification of terrestrial photovoltaic modules suitable for long-term operation in open-air climates. The useful service life of modules so qualified will depend on their design, their environment and the conditions under which they are operated. Test results are not construed as a quantitative prediction of module lifetime.

In climates where 98th percentile operating temperatures exceed 70 °C, users are recommended to consider testing to higher temperature test conditions as described in IEC TS 63126[1]. Users desiring qualification of PV products with lesser lifetime expectations are recommended to consider testing designed for PV in consumer electronics, as described in IEC TS 63163 (under development). Users wishing to gain confidence that the characteristics tested in IEC 61215 appear consistently in a manufactured product may wish to utilize IEC 62941 regarding quality systems in PV manufacturing.

This document is intended to apply to all terrestrial flat plate module materials such as crystalline silicon module types as well as thin-film modules.

This document does not apply to modules used with concentrated sunlight although it may be utilized for low concentrator modules (1 to 3 suns). For low concentration modules, all tests are performed using the irradiance, current, voltage and power levels expected at the design concentration.

The objective of this test sequence is to determine the electrical 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 outdoors. Accelerated test conditions are empirically based on those necessary to reproduce selected observed field failures and are applied equally across module types. Acceleration factors may vary with product design and thus not all degradation mechanisms may manifest. Further general information on accelerated test methods including definitions of terms may be found in IEC 62506.

Some long-term degradation mechanisms can only reasonably be detected via component testing, due to long times required to produce the failure and necessity of stress conditions that are expensive to produce over large areas. Component tests that have reached a sufficient level of maturity to set pass/fail criteria with high confidence are incorporated into the IEC 61215 series via addition to Table 1 in IEC 61215-1:2021. In contrast, the tests procedures described in this series, in IEC 61215-2, are performed on modules.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

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[1] Information on 98th percentile operating temperature as a function of system location and mounting configuration is included in IEC TS 63126.

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

IEC 60891, *Photovoltaic devices – Procedures for temperature and irradiance corrections to measured I-V characteristics*

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

IEC 60904-1-1, *Photovoltaic devices – Part 1-1: Measurement of current-voltage characteristics of multi-junction photovoltaic (PV) devices*

IEC TS 60904-1-2, *Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices*

IEC 60904-2, *Photovoltaic devices – Part 2: Requirements for photovoltaic reference 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 the spectral mismatch correction for measurements of photovoltaic devices*

IEC 60904-8, *Photovoltaic devices – Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device*

IEC 60904-9:2020, *Photovoltaic devices – Part 9: Classification of solar simulator characteristics*

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

IEC TR 60904-14: *Photovoltaic devices – Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions*

IEC 61140, *Protection against electric shock – Common aspects for installation and equipment*

IEC 61215-1:2021, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements*

IEC 61215-1-1, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules*

IEC 61730-1:2016, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*

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

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC TS 62782, *Photovoltaic (PV) modules – Cyclic (dynamic) mechanical load testing*

IEC 62790, *Junction boxes for photovoltaic modules – Safety requirements and tests*

IEC TS 62804-1:2015, *Photovoltaic (PV) modules – Test methods for the detection of potential-induced degradation – Part 1: Crystalline silicon*

IEC TS 63163: –[2] *Terrestrial photovoltaic (PV) modules for consumer products – Design qualification and type approval*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 and IEC 61215-1:2021 apply, as well as the following.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1

accuracy <of a measuring instrument>
quality which characterizes the ability of a measuring instrument to provide an indicated value close to a true value of the measurand [consistent with the International Vocabulary of Metrology (VIM), 5.18]

Note 1 to entry: This term is used in the "true value" approach.

Note 2 to entry: Accuracy is all the better when the indicated value is closer to the corresponding true value.

[SOURCE: IEC 60050-311:2001, 311-06-08]

3.2

control device
irradiance sensor (such as a reference cell or module) that is used to detect drifts and other problems of the solar simulator

3.3

electrically stable power output level
state of the PV module where it will operate under long-term natural sunlight

3.4

repeatability <of results of measurements>
closeness of agreement between the results of successive measurements of the same measurand, carried out under the same conditions of measurement, i.e.:

- by the same measurement procedure,
- by the same observer,
- with the same measuring instruments,
- used under the same conditions,
- in the same laboratory,

at relatively short intervals of time [≈ VIM, 3.6].

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[2] Under preparation. Stage at the time of publication: ADTS.

Note 1 to entry: The concept of "measurement procedure" is defined in VIM, 2.5.

[SOURCE: IEC 60050-311:2001, 311-06-06]

3.5
Gate No. 1
a pass / fail comparison between the performance of a module and its nameplate specifications, as described in IEC 61215-1:2021

3.6
Gate No. 2
a pass / fail comparison between the performance of a module before versus after stress, as described in IEC 61215-1:2021

4 Test procedures

The subclauses below provide detailed instructions for performing each module quality test (MQT). Reporting and test sequence requirements for qualification are described in IEC 61215-1.

4.1 Visual inspection (MQT 01)

4.1.1 Purpose

To detect any visual defects in the module.

4.1.2 Procedure

Carefully inspect each module under an illumination of not less than 1 000 lux for conditions and observations as defined in IEC 61215-1:2021.

Make note of and/or photograph any defects that may be major visual defects as defined in IEC 61215-1. Also make note of and/or photograph the nature and position of any cracks, bubbles or delaminations, etc., which may worsen and adversely affect the module performance in subsequent tests. Record any other relevant information regarding origin of failure and associated test or lab conditions.

4.1.3 Requirements

No evidence of major visual defects permitted, as defined in IEC 61215-1:2021.

4.2 Maximum power determination (MQT 02)

4.2.1 Purpose

To determine the maximum power of the module after stabilization as well as before and after the various environmental stress tests.

4.2.2 Apparatus

a) Apparatus for measuring I-V characteristics in accordance with IEC 60904-1.

b) A PV reference device in accordance with IEC 60904-2.

c) At least one of the following two options to reduce the spectral mismatch component of uncertainty shall be utilized:

  - Perform a spectral mismatch correction. The spectral responsivity of the module shall be measured according to IEC 60904-8. The spectral response data may originate from the same lab that is performing IEC 61215-2:2021, or from a different lab. The sample used to obtain the spectral response data may be the test module or may be a reference cell made with the same bill of materials as the test module. The spectral distribution of the solar simulator shall then be utilized to correct for spectral mismatch according to IEC 60904-7.
  - Use a matched reference cell or module. The reference device shall be of the same cell technology as the test module, to match spectral responsivity. There is no requirement on the cell or module size.

d) A radiant source: natural sunlight or a solar simulator of class CAA or better in accordance with IEC 60904-9. For very large modules, as defined in IEC 61215-1:2021, a class CBA simulator may be used.

NOTE 1 Class CBA is defined according to IEC 60904-9: The AM1.5 spectral match is categorized as C, non-uniformity of irradiance for the module size categorized as B, and temporal stability of irradiance categorized as A.

To achieve a high accuracy of power measurement, the spectral irradiance distribution of the solar simulator should cover the whole wavelength range that is spanned by the spectral responsivity of the PV device under test. See IEC TR 60904-14 and IEC 60904-9:2020.

e) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.

NOTE 2 MQT 02 measurement procedures are intended for minimal uncertainty, for example as performed by an accredited testing laboratory. Lesser requirements, such as use of CAB class simulators, may be appropriate for other applications, such as quality control in the factory. Applications that only require repeatability, such as comparing module performance before and after an extended stress, may wish to relax spectral mismatch correction requirements.

4.2.3 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 20 °C and 50 °C and an irradiance between 700 W/m^2 and 1 100 W/m^2) using the apparatus described in 4.2.2. 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 (as defined in IEC 60904-10) temperature and irradiance corrections can be made in accordance with IEC 60891 in order to compare sets of measurements made on the same module before and after environmental tests. For nonlinear modules (as defined in IEC 60904-10) the measurement shall be performed within ±5 % of the specified irradiance and within ±2 °C of the specified temperature. However, every effort should be made to ensure 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.

For flexible modules, the maximum power determination shall be measured with the flexible module in the flat position.

4.3 Insulation test (MQT 03)

4.3.1 Purpose

To determine whether or not the module is sufficiently well insulated between live parts and accessible parts.

4.3.2 Apparatus

a) DC voltage source, with current limitation, capable of applying the voltage as specified in the third column of Table 1 for the various module classes.

b) An instrument to measure the insulation resistance.

4.3.3 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 %.

The voltage stress levels applied to the module are determined by the module's maximum system voltage (V_{sys}), the module class, and whether or not cemented joints are present. The definitions of module classes are taken from IEC 61140, and are discussed as related to PV modules in IEC 61730-1:2016, Clause 4. The definition of cemented joints is given in IEC 61730-1:2016, 3.4.2, and is further discussed in IEC 61730-1:2016, Clauses B.5 and B.9. The voltage stress levels applied in this test are the same as those applied for IEC 61730-2 MST 16.

4.3.4 Procedure

a) Connect the shorted output terminals of the module to the positive terminal of a DC 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. Connect all foil covered parts to the negative terminal of the tester.

c) Some module technologies may be sensitive to static polarization if the module is maintained at positive voltage to the frame. In this case, the connection of the tester shall be done in the opposite way. If applicable, information with respect to sensitivity to static polarization shall be provided by the manufacturer and documented in the test report.

d) Read the "one-minute preconditioning" voltage, V_{Test1} from the third column of Table 1. Increase the voltage applied by the tester at a rate not exceeding 500 V/s to a maximum equal to V_{Test1}. Maintain the voltage at this level for 1 min.

e) Reduce the applied voltage to zero and short-circuit the terminals of the test equipment to discharge the voltage build-up in the module.

f) Remove the short-circuit.

g) Read the "two-minute stress" voltage, V_{Test2} from the fourth column of Table 1. Increase the voltage applied by the test equipment at a rate not exceeding 500 V/s to V_{Test2}. Maintain the voltage at this level for 2 min. Then determine the insulation resistance.

h) Reduce the applied voltage to zero and short-circuit the terminals of the test equipment to discharge the voltage build-up in the module.

i) Remove the short-circuit and disconnect the test equipment from the module.

Table 1 – Voltage stress levels

Module class	**Are cemented joints present?**	**1 min preconditioning V_{Test1} V**	**2 min stress for measuring insulation resistance, V_{Test2} V**
0	No	1 000 + 2 x V_{sys}	Greater of 500 or V_{sys}
II	No	2 000 + 4 x V_{sys}	Greater of 500 or V_{sys}
III	No	500	500
0	Yes	1,35 x (1 000 + 2 x V_{sys})	Greater of 500 or V_{sys}
II	Yes	1,35 x (2 000 + 4 x V_{sys})	Greater of 500 or V_{sys}
III	Yes	1,35 x (500)	500

4.3.5 Test requirements

a) No dielectric breakdown or surface tracking.

b) For modules with an area of less than 0,1 m^2 the insulation resistance shall not be less than 400 MΩ.

c) 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.

4.4 Measurement of temperature coefficients (MQT 04)

Determine the temperature coefficients of current (α), voltage (β) and peak power (δ) from module measurements as specified in IEC 60891. The coefficients so determined are valid at the irradiance at which the measurements were made. See IEC 60904-10 for evaluation of module temperature coefficients at different irradiance levels. For bifacial modules determine the temperature coefficients utilizing the same procedure, but insuring no backside irradiation. The backside shall be covered such that the contribution from the non-exposed side of the module is limited to or below the levels specified for "non-irradiated background" in IEC TS 60904-1-2. If open-circuit voltage or short-circuit current cannot be measured due to module-integrated electronics, the associated temperature coefficient shall be reported as "not measurable due to module-integrated electronics." Open-circuit voltage or short-circuit current shall not be determined by any method other than direct measurement, such as extrapolation.

NOTE For linear modules in accordance to IEC 60904-10, temperature coefficients are valid over an irradiance range of ±30 % of this level.

4.5 Placeholder section, formerly NMOT

The nominal module operating temperature (NMOT) test, formerly MQT 05, is no longer a part of this document. This subclause is preserved so that, in the following subclauses of the document, the MQT numbers match the subclause numbers.

4.6 Performance at STC (MQT 06.1)

4.6.1 Purpose

To determine how the electrical performance of the module varies with load at STC (1 000 W/m^2, 25 °C cell temperature, with the IEC 60904-3 reference solar spectral irradiance distribution). MQT 06.1 is a case of maximum power determination (MQT 02) performed at STC. MQT 06.1 is used to verify the name plate information of the module, and for determining power loss from the stress tests. Uncertainty, m_1, shall include a component from spectral mismatch, based either on measured spectral response or the worst-case possibility for a given technology type, and the method used to set the simulator intensity. For nameplate verification, the uncertainty m_1 is subject to the limits specified in the technology-specific parts. For determining the power loss from the stress tests, reproducibility of the test, r, is subject to the limits specified in the technology-specific parts.

4.6.2 Apparatus

a) The apparatus shall be as described in 4.2.2 (MQT 02).

b) It shall also be equipped with a means for monitoring the temperature of the test specimen and the reference device to an accuracy of ±1 °C and repeatability of ±0,5 °C.

c) For measurement of bifacial modules the following capability is also necessary: The radiant source utilized as specified in 4.6.2a shall be operable with adjustable irradiance levels and/or rear-side irradiance such that BNPI (as defined in IEC 61215-1:2021) can be applied by at least one method allowed by IEC TS 60904-1-2.

d) For measurement of multi-junction modules, the simulator and reference device shall meet the additional requirements imposed by IEC 60904-1-1.

4.6.3 Procedure for measuring at STC (MQT 06.1)

Maintain the module at (25 ± 2) °C and trace its current-voltage characteristic at an irradiance of (1 000 ± 100) W/m^2 (as measured by a suitable reference device), in accordance with IEC 60904-1, using the apparatus described in 4.6.2.

Module temperature shall be corrected to 25 °C using temperature coefficients and IEC 60904 series and IEC 60891.

For bifacial modules, measurements shall proceed as specified in IEC TS 60904-1-2. MQT 06 shall be performed at STC and at elevated irradiance BNPI for Gate No 1. Each time MQT 06 is performed at STC, the STC bifaciality coefficients of short-circuit current ($\varphi_{I\mathrm{sc}} = I_{\mathrm{scr}} / I_{\mathrm{scf}}$), of open circuit voltage ($\varphi_{V\mathrm{oc}} = V_{\mathrm{ocr}} / V_{\mathrm{ocf}}$), and of power ($\varphi_{P\mathrm{max}} = P_{\mathrm{maxr}} / P_{\mathrm{maxf}}$) shall be measured according to IEC TS 60904-1-2. Full definition of these quantities, the method to measure them, and the symbols used to describe them are specified in IEC TS 60904-1-2. When evaluating Gate No 2 (i.e. post-stress), MQT 06 shall only be performed at BNPI. Post-stress, bifaciality coefficients need not be remeasured. unless specifically noted in the MQT stress test procedure. The bifaciality coefficients measured pre-stress may be utilized to calculate the appropriate equivalent intensity in a single-sided illumination measurement. When performing MQT 06 at BNPI, any method described in IEC 60891 may be used to correct the applied irradiance to desired equivalent front-side irradiance, as long requirements on maximum uncertainty m_1 are met.

NOTE 1 Using methods from IEC 60891 to correct the applied irradiance to desired equivalent front-side irradiance can help the tester avoid using a different simulator calibration for every module with a slightly different bifaciality coefficient.

NOTE 2 Measurement of performance at BSI is not required. Where stress levels are set according to BSI, currents may be extrapolated from lower intensities, as described specifically in the MQTs utilizing BSI for bifacial modules.

For flexible modules, the maximum power determination shall be measured with the flexible module in the flat (i.e. completely unfolded) position. For very large modules (as defined in IEC 61215-1:2021), testing by the testing entity may be performed at the manufacturer’s facility, but shall still meet the requirements stated in 4.6.2.

For multi-junction modules, measurements shall proceed as specified in IEC TS 60904-1-1.

4.7 Performance at low irradiance (MQT 07)

4.7.1 Purpose

To determine how the electrical performance of the module varies with load at 25 °C and an irradiance of 200 W/m^2.

4.7.2 Apparatus

a) The apparatus shall be as described in 4.2.2 (MQT 02).

The apparatus shall also have the following capabilities:

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 means for monitoring the temperature of the test specimen and the reference device to an accuracy of ±1 °C and repeatability of ±0,5 °C.

d) For measurement of bifacial modules the following equipment is also necessary: Baffles that can be arranged around the modules edges, as well as a non-reflective cover allowing for temporarily blocking the irradiance to the opposite module side, to evaluate the front- and back-side performance of bifacial modules individually.

e) For measurement of multi-junction modules, the simulator and reference device shall meet the additional requirements imposed by IEC 60904-1-1.

4.7.3 Procedure

Determine the current-voltage characteristic of the module at (25 ± 2) °C and an irradiance of (200 ± 20) W/m^2 controlled by an appropriate reference device, in accordance with IEC 60904-1 using the apparatus specified in section 4.7.2. The irradiance shall be reduced to the specified level by using neutral density 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.)

Module temperature shall be corrected to 25 °C using temperature coefficients and IEC 60904 series and IEC 60891.

For flexible modules, the maximum power determination shall be measured with the flexible module in the flat (i.e. completely unfolded) position. For very large modules (as defined in IEC 61215-1:2021), testing by the testing entity may be performed at the manufacturer’s facility, but shall still meet the requirements stated in 4.7.2.

For bifacial modules make two single-sided measurements at 200 W/m^2, one on the front-side and one on the rear-side using baffles and back-cover screen. Calculate the bifaciality coefficients at low irradiance according to the procedure specified in IEC TS 60904-1-2, except utilizing an irradiance of 200 W/m^2 instead of 1000 W/m^2.

For multi-junction modules, measurements shall proceed as specified in IEC TS 60904-1-1.

4.8 Outdoor exposure test (MQT 08)

4.8.1 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.

4.8.2 Apparatus

a) An open rack to support the test module(s) and solar irradiation monitor in the specified manner. 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.

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

b) A solar irradiation monitor accurate to ±5 %, mounted in the plane of the module(s) within 0,3 m of the test array.

c) Means to mount the module, as recommended by the manufacturer, co-planar with the irradiation monitor.

d) A resistive load sized such that the module will operate near its maximum power point or an electronic maximum power point tracker (MPPT).

4.8.3 Procedure

a) The test module(s) shall be positioned so that it (they) are normal to the local latitude ±5°. Note the angle of tilt of the test module in the test report.

b) Attach the resistive load or electronic maximum power point tracker 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.

c) Subject the module to an irradiation totalling at least 60 kWh/m^2, as measured by the monitor.

The test modules may be cleaned according to manufacturer instructions during or after the test.

4.8.4 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.8.5 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

d) Wet leakage current shall meet the same requirements as for the initial measurements.

4.9 Hot-spot endurance test (MQT 09)

4.9.1 Purpose

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

4.9.2 Hot-spot effect

Reverse bias 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 group of cells. When such a condition occurs, the affected cell or group of cells is forced into reverse bias and shall dissipate power, which can cause overheating.

If the power dissipation is high enough or localized enough, the reverse biased cell(s) can overheat resulting in – depending on the technology – melting of solder, deterioration of the encapsulant, front and/or backsheet, cracking of the superstrate, substrate and/or cover glass. The correct use of bypass diodes can prevent hot spot damage from occurring.

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

Low shunt resistance cells:

- The worst case shadowing conditions occur when the whole cell (or a large fraction) is shadowed.
- Often low shunt resistance cells are this way because of localized shunts. In this case hot spot heating occurs because a large amount of current flows in a small area. Because this is a localized phenomenon, there is a great deal of scatter in performance of this type of cell. Cells with the lowest shunt resistance have a high likelihood of operating at excessively high temperatures when reverse biased.
- Because the heating is localized, hot spot failures of low shunt resistance cells occur quickly.

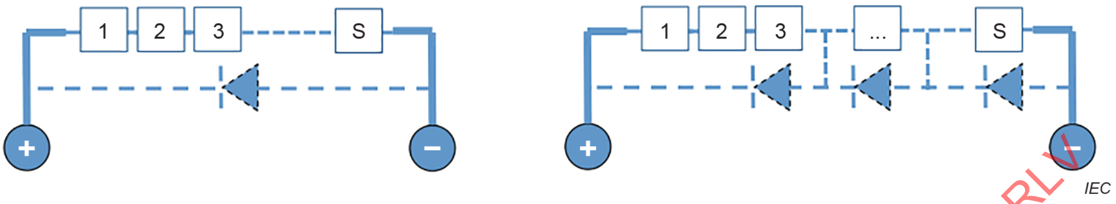
The major technical issue is how to identify the lowest shunt resistance cells and subsequently how to determine the worst case shadowing for those cells. This process is technology dependent and will be addressed in the technology specific parts of this standards series.

High shunt resistance cells:

- The worst case shadowing conditions occur when the cell is partially shadowed.
- Junction breakdown and high temperatures occur more slowly. The shadowing needs to stay in place for some time to create worst case hot-spot heating.

4.9.3 Classification of cell interconnection

Case S: Series connection of all cells in a single string. Refer to Figure 1. Modules with series-connected cells may be protected by a single (Figure 1, left) or multiple (Figure 1, right) bypass diodes.



For the example a module protected by one bypass diode (left) or three bypass diodes (right).

Figure 1 – Case S, series connection with optional bypass diode

Case PS: Parallel-series connection, i.e. a series connection of (S) blocks, where each block consists of a parallel connection of a certain number (P) of cells. Refer to Figure 2.

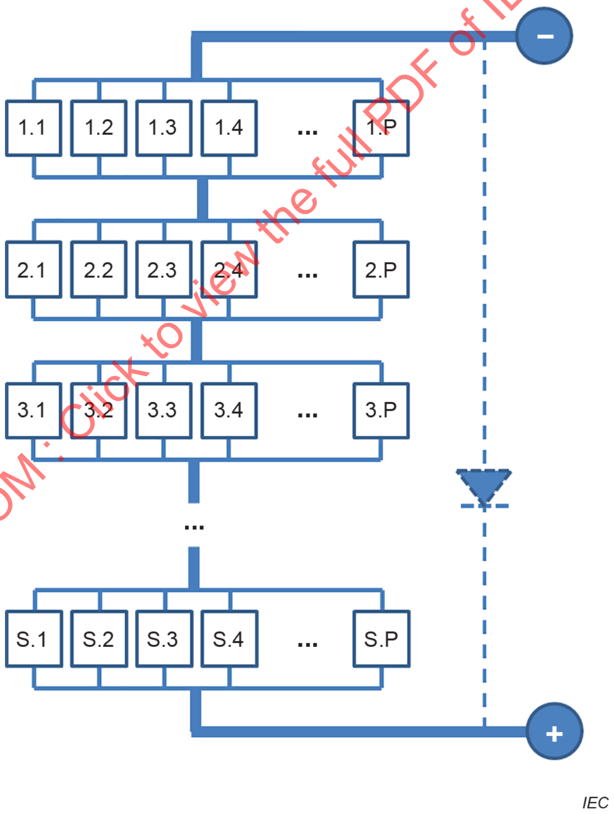


Figure 2 – Case PS, parallel-series connection with optional bypass diode

Case SP: Series-parallel connection, i.e. a parallel connection of (P) blocks, where each block consists of a series connection of a certain number of (S) cells. Refer to Figure 3.

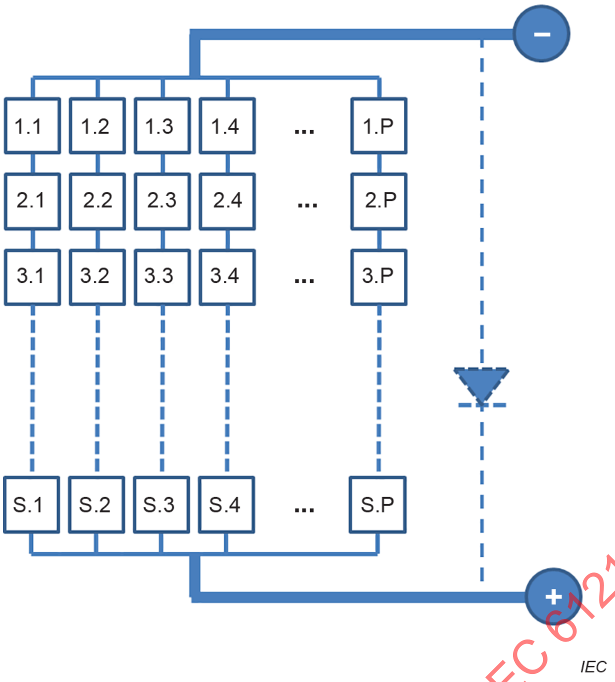


Figure 3 – Case SP, series-parallel connection with optional bypass diode

Each configuration requires a particular hot-spot testing procedure.

4.9.4 Apparatus

a) Radiant source: Natural sunlight, or a class BBB (or better) steady-state solar simulator conforming to IEC 60904-9. Either type of radiant source shall have an irradiance of (1 000 ± 100) W/m^2. This radiant source will be used for applying long-duration stress when worst case shadowing has been applied to the module. This radiant source may be used in the selection of cells for shadowing, or the optional pulsed simulator (described in 4.9.4g) may be used for cell selection.

   For bifacial modules, the radiant source used for prolonged exposure shall be operable with adjustable irradiance levels and/or rear-side irradiance such that BSI (as defined in IEC 61215-1:2021) can be applied by at least one method allowed by IEC TS 60904-1-2. Tolerance in the total irradiance, whether applied in a single-sided or double-sided configuration, shall be no larger than ±50 W/m^2.

b) Module I-V curve tracer.

c) Equipment for current measurement.

d) Completely opaque covers for test cells shadowing.

e) An IR camera to measure and record module temperatures. The camera shall be operable in a manner that allows resolution of features smaller than one cell.

f) Equipment to record irradiance levels, integrated irradiance and ambient temperature.

Optional:

g) For selecting cells most sensitive to hot spot heating, a pulsed simulator of class BBB or better conforming to IEC 60904-9 with an irradiance of 800 W/m^2 to 1 100 W/m^2 for measuring I-V performance may be used.

4.9.5 Procedure

4.9.5.1 General

Depending on the solar cell technology and the manufacturing process two different procedures exist. MQT 09.1 is typically applicable to wafer-based technologies like standard crystalline silicon. For most common, monolithically integrated, thin film technologies (CdTe, CIGS, a-Si) the procedure MQT 09.2 is applicable. Bifacial modules are also to be tested using MQT 09.1.

If MQT 09.1 is performed using a representative sample, the representative sample shall have the same number of cells per bypass diode as the full-size product. Depending on the resulting sample size, this requirement can affect the choice of radiant source needed to perform the test.

For all technologies, selection of the shadowing dimensions and location is performed in the irradiance range of 800 W/m^2 to 1 100 W/m^2. Application of the extended stress is performed with the tighter irradiance specifications described in 4.9.4 a).

4.9.5.2 Procedure for wafer-based technologies (WBT) MQT 09.1

The first step of the procedure is to select cells with the lowest and highest shunt resistances, (as detailed further in steps c), d) and e) below.) If the module circuit is accessible the current flow through the shadowed cell can be monitored directly. If the PV modules to be tested do not have removable diodes or accessible electric circuits, the following non-intrusive method can be utilized.

The selected approach is based on taking a set of I-V curves for a module with each cell shadowed in turn. Figure 4 shows the resultant set of I-V curves for a sample module. The curve with the highest leakage current at the point where the diode turns on was taken when the cell with the lowest shunt resistance was shadowed. The curve with the lowest leakage current at the point where the diode turns on was taken when the cell with the highest shunt resistance was shadowed.

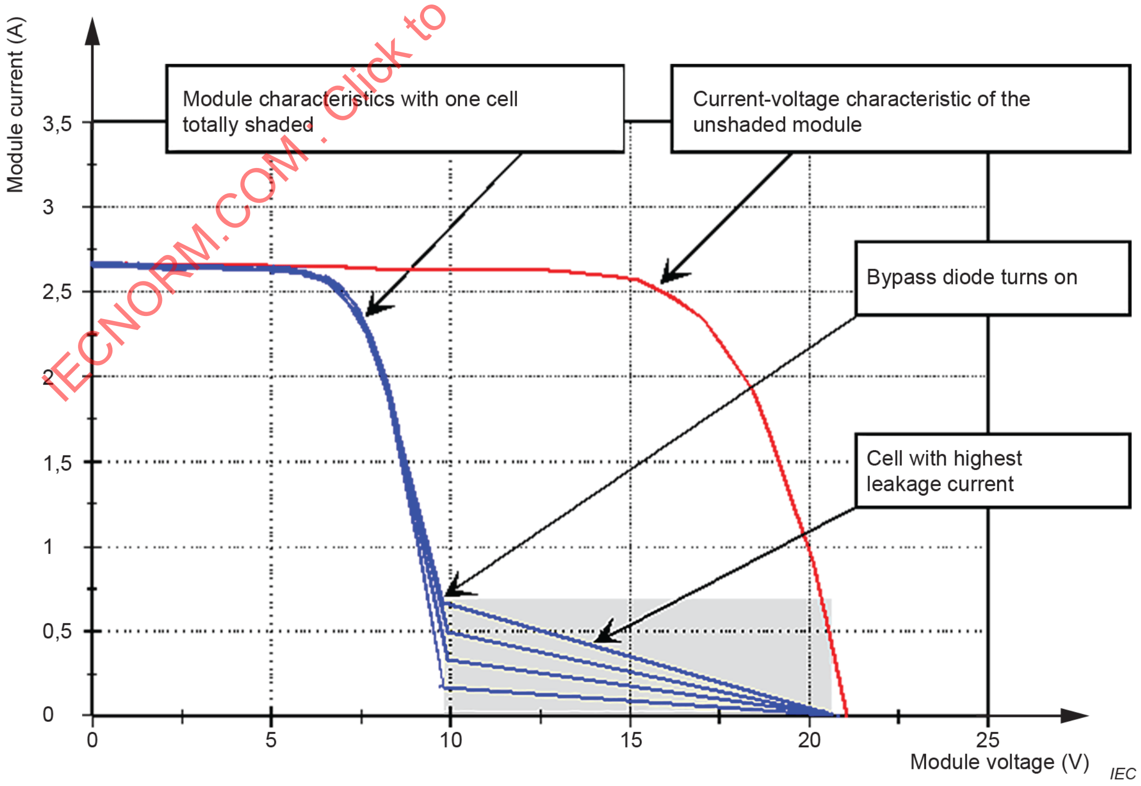


Figure 4 – Module I-V characteristics with different cells totally shadowed

Use the following procedure to identify hot spot sensitive cells:

a) Expose the unshadowed module to the radiant source with irradiance between 800 W/m^2 and 1 100 W/m^2 using one of the following:

- A pulsed solar simulator where the module temperature will be close to room temperature (25 ± 5) °C.
- A steady-state solar simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
- Sunlight where the module temperature shall be stabilised within ±5 °C before beginning the measurements.

For bifacial modules, exposure for cell selection is to the module front, with the module back side covered to sufficiently limit the contribution from the non-exposed side of the module to or below the levels specified for "non-irradiated background" in IEC TS 60904-1-2.

b) Shadow each cell completely in turn, measure the resultant I-V curve and prepare a set of curves like Figure 4. For bifacial modules, if double-side illumination is utilized, both the front and the back of the cell shall be shadowed entirely. If single-side illumination is utilized, the rear shadowing is accomplished by the requirement of non-irradiated background defined in IEC TS 60904-1-2.

NOTE For the SP case the deformation of the module I-V curve is added to the sectional I-V curve of the fully illuminated parallel sub-section and so does not continue to V_{oc}.

c) Select the cell adjacent to the edge of the module that has the lowest shunt resistance, i.e. the one with the highest leakage current.

d) Select the two lowest shunt resistance cells (in addition to the cell in c), those with the highest leakage current.

e) Select the cell with the highest shunt resistance.

f) For bifacial modules, if some cells are permanently shadowed by design (e.g. junction box or back rails), those cells shall also be selected for hot-spot testing.

g) Begin cell testing procedure by determining the worst case shadowing condition for each of the selected cells:

1) Expose the unshadowed module to a single-sided irradiance in the range of 800 W/m^2 to 1 100 W/m^2. The exposure shall meet the requirements described in 4.9.5.2 a).

2) After thermal stabilisation of ±5 °C is attained, measure the module I-V characteristic and determine the maximum power current I_{MP1} (initial performance P_{MP1}).

3) Expose the module to irradiance meeting the requirements of 4.9.5.2 a). Then use one of the methods in step 4) below to determine the worst case shadowing for each selected cell.

4) Determine the worst-case shadowing for each of the selected test cells use one of the methods i) to iii) below.

i) If the cell circuit is accessible, short-circuit the module and attach the current measuring equipment such that it is reading only the current through the cell string under test. For each selected test cell, shadow that cells and determine what shadow level results in the current through the shadowed cell being equal to the unshadowed I_{MP1} determined in step g)2). This is the worst case shadowing for that cell.

ii) If the cell circuit is not accessible, the first option for determining worst case shadowing involves taking I-V curves. Take a set of I-V curves with each of the selected test cells shadowed at different levels as shown in Figure 5. Determine the worst case shadowing condition, which occurs when the current through the shadowed cell (the point where the by-pass diode turns on) coincides with the original unshadowed I_{MP1} determined in a), like curve c) in Figure 5, at the same irradiance level as used in a). If the bypass diode does not turn on when the selected cell is fully shadowed, the worst case hot-spot condition is achieved by completely shadowing the cell.

   iii) If the cell circuit is not accessible, the second option for determining worst case shadowing involves temperature measurements. Short-circuit the module. Shadow each of the selected test cells in turn at 100 % and measure the cell temperature. Decrease the shadowing by 10 %. If the temperature decreases, then 100 % shadowing produces the worst case. If the temperature increases or stays the same, continue to decrease the shadowing by 10 % until the temperature does decrease. Use the previous shadowing level as worst case shadowing.

5) For the cell selected in c), (i.e. the edge cell with the lowest shunt resistance), the positioning of the mask applied during prolonged exposure shall be further specified. Short-circuit the module. Use an IR camera to determine the hottest spot on the cell when it is 100 % shadowed. If possible make sure that this hottest spot is within the illuminated area during the prolonged exposure of step i).

h) Shadow one selected cell that was identified in steps c) through f) to the worst case condition as determined in g). If double-side illumination will be used in step i) for a bifacial module, the cell shall be masked identically on the rear side.

i) Short-circuit the module. Expose the module to steady state irradiance. For monofacial modules, the irradiance shall be (1 000 ± 100) W/m^2. For bifacial modules, the irradiance shall be BSI ± 50 W/m^2. This test shall be performed at a module temperature in the range of (55 ± 15) °C.

j) Maintain the worst case shadowing condition determined in g) for 1 h for the selected cell. If the temperature of the shadowed cell is still increasing at the end of 1 h continue for a total exposure time of 5 h.

k) Repeat steps h) through j) for each cell selected in steps c) through f).

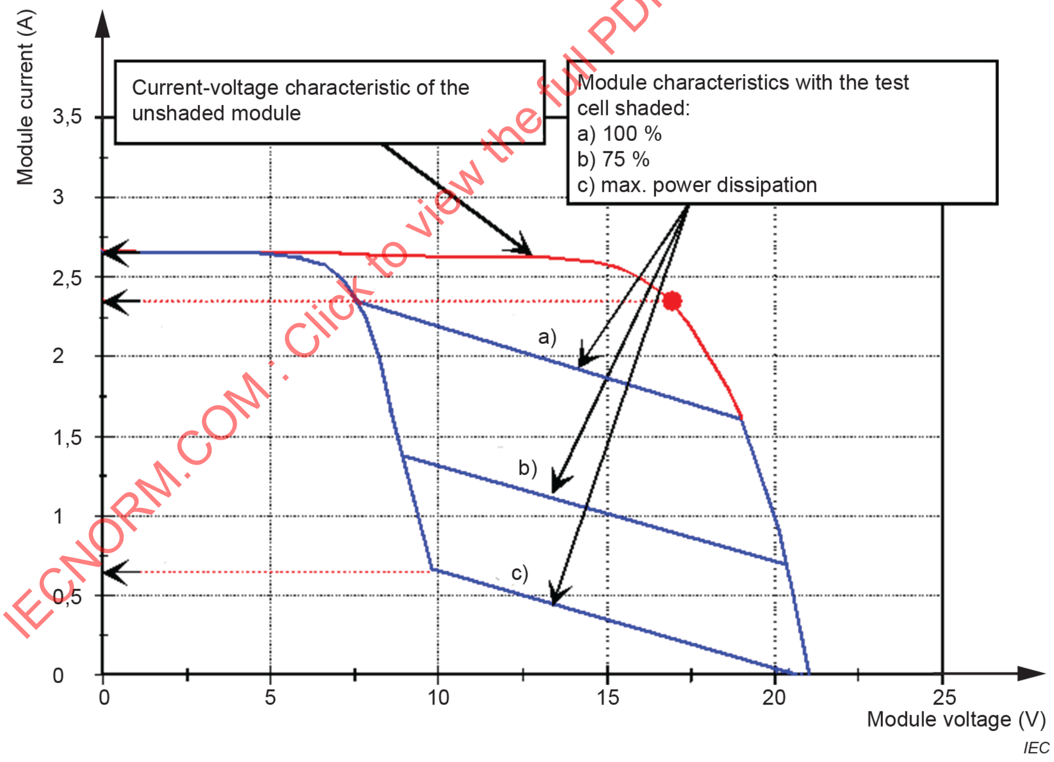


Figure 5 – Module *I-V* characteristics with the test cell shadowed at different levels

4.9.5.3 Procedure for monolithically integrated (MLI) thin film technologies MQT 09.2

4.9.5.3.1 General

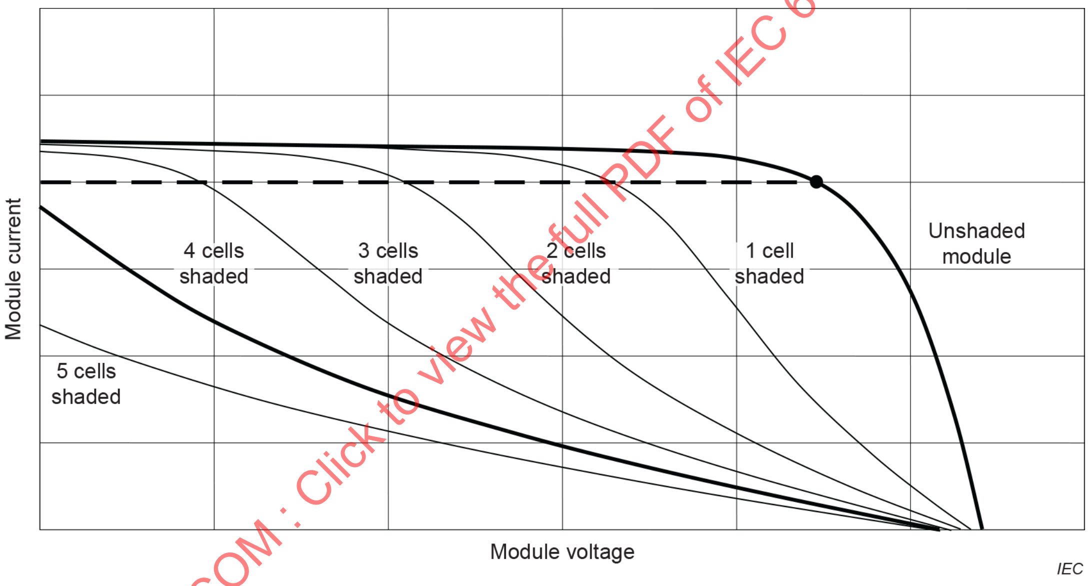
The hot-spot test is performed with the module exposed to (1 000 ± 100) W/m^2 during the extended exposure.

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

The electrical performance of a MLI thin-film module can already be negatively affected by short-term shadowing. Care shall be taken that effects caused by setting worst-case conditions and hot-spot endurance testing are clearly separated. The values of P_{max1} (before any shadowing has been applied), P_{max2} (after worst case conditions have been identified via shadowing) and P_{max3} (after extended stress has been applied) are collected for this purpose.

4.9.5.3.2 Case S

Figure 6 illustrates the hot-spot effect in a MLI thin-film module consisting of a serial connection of cells, when a different number of cells are totally shadowed. The amount of power dissipated in the shadowed cells is equal to the product of the module current and the reverse voltage developed across the group of shadowed cells. For any irradiance level, maximum power is dissipated when the reverse voltage across the shadowed cells is equal to the voltage generated by the remaining illuminated cells in the module (worst case shadowing condition). This is the case when the short-circuit current of the shadowed module equals the maximum power current of the unshadowed module.



NOTE In this example, the worst case shadowing condition is shadowing of 4 cells at the same time.

Figure 6 – Hot-spot effect in a MLI thin-film module with serially connected cells

The following method shall be used to select the cell(s) to be shadowed and to determine the worst case shadowing condition for module connected in series-only (case S).

a) Expose the un-shadowed module to a radiant source providing a total irradiance of 800 W/m^2 to 1 100 W/m^2 at the module surface, using one of the following:
   - A pulsed simulator where the module temperature will be close to room temperature (25 ± 5) °C.
   - A steady-state simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
   - Sunlight where the module temperature shall be stabilised within ±5 °C before beginning the measurements.

b) After thermal stabilisation is attained, measure the module I-V characteristic and determine the maximum power current I_{MP1} and maximum power P_{max1}. Determine the maximum power current range ($I_{\mathrm{min}} < I < I_{\mathrm{max}}$) where I_{max} is the maximum power current of the unshadowed module, and I_{min} is 0,95 I_{max}. This current range is named $I(*)$.

c) Measure the short-circuit current at each position described in the next step.

d) Starting from one edge of the module, use an opaque cover to shadow one cell completely. Move the cover parallel to the cells and increase the shadowed module area (number of shadowed cells) until the short-circuit current falls within the current range of the non-shadowed module. In these conditions, the maximum power is dissipated within the selected group of cells (see Figure 6). The maximum step size between short-circuit current measurements is one cell width. The minimum mask width is two cell widths. If shadowing less than two cells is required to obtain a current within the specified range, then the mask width shall be fixed at the minimum. If shadowing some number of "n" cells results in a current that is too high, and if shadowing n+1 cells causes a current that is too low, then the narrower mask width (n cells) shall be chosen.

e) Move an opaque cover (of the dimensions found in d) above) slowly across the module and measure the short-circuit current at each position. The maximum step size between short-circuit current measurements is the mask width. (Thus, each cell in the module shall be shadowed at some point during this step.) If at a certain position the short-circuit current falls below the specified current range $I(*)$, reduce the size of the cover in increments of one cell width until the current is within the desired range again. If at any point during this process, the mask width is reduced to its minimum value of two cell widths, its size shall not be reduced further, and the process of moving the mask across the module is complete. If shadowing some number of "n" cells results in a current that is too high, and if shadowing n+1 cells causes a current that is too low, then the narrower mask width (n cells) shall be chosen. During this process, the irradiance shall not change by more than ± 2 %. The mask is not to be made larger at any point, i.e. if, during step g), the short-circuit current exceeds the higher limit of $I(*)$, the mask width shall be kept the same.

f) The final width of the cover, together with the position that exhibited the lowest current of each area subjected to the final mask width, determines the minimum area of shadowing that results in the worst case shadowing condition. This is the shadowed area to be used for hot-spot testing.

g) Remove the cover and visually inspect the module.

NOTE Reverse bias operation of the cells in steps d) and e) 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.

h) Re-measure the module I-V characteristic and determine maximum power P_{max2}.

i) Place the cover on the module. Put the cover on the position determined during steps e) and f).

j) Short-circuit the module, including a means to monitor the module current, such as an ammeter.

k) Expose the module to the steady-state radiant source providing a total irradiance of (1 000 ± 100) W/m^2 at the module surface, using one of the following:

- A steady-state simulator where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.
- Sunlight where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.

l) This test shall be performed at a module temperature in the range (55 ± 15) °C. Note the value of I_{sc} and keep the module current above the lower limit for $I(*)$. If I_{sc} falls below the lower limit for $I(*)$, decrease the mask width in increments of one cell width until I_{sc} once again exceeds the lower limit for $I(*)$. If the current falls below the desired range but the mask is already the minimum width, no adjustment shall be made.

m) Maintain these conditions for a total exposure time of 1 h.

n) At the end of the endurance test, determine the hottest area on the shadowed cells using an IR camera or appropriate temperature detector.

4.9.5.3.3 Case SP

Figure 3 illustrates a series-parallel connection, i.e. a parallel connection of P strings each with S cells in series.

If a module is of the series-parallel type (case SP), the following method shall be used to select the cell(s) to be shadowed and to determine the worst case shadowing condition.

a) Expose the un-shadowed module to a radiant source providing a total irradiance of 800 W/m^2 to 1 100 W/m^2 at the module surface, using one of the following:
   - A pulsed simulator where the module temperature will be close to room temperature (25 ± 5) °C.
   - A steady-state simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
   - Sunlight where the module temperature shall be stabilised within ±5 °C before beginning the measurements.

b) After thermal stabilisation is attained, measure the module I-V characteristic and determine the maximum power current I_{MP1} and maximum power P_{max1}. Determine the maximum power current range ($I_{min} < I < I_{max}$) where I_{max} is the maximum power current of the unshadowed module, and I_{min} is 0,95 I_{max}.

c) Then calculate the acceptable maximum power current range to be applied $I(*)$ according to the following formula.

   $I_{min} / N + I_{sc} \cdot (N - 1) / N < I\,(*) < I_{max} / N + I_{sc} \cdot (N - 1) / N$

   where N is the number of parallel strings of the module.

d) Select the substring to be measured. The following criteria are used to select the substring that is likely to experience hotter temperatures during extended stress. If some of the junction box is behind a power-generating area of the module, choose the substring that is in front of the largest fraction of the junction box area. If the junction box area is equally-divided between two substrings, or the module contains two junction boxes on two different sub-strings, choose either substring that is in front of half the junction box area. If the junction box is not located behind a power-generating portion of the module (e.g. the junction box is located in an edge-delete area) select the substring that is in front of the largest fraction of the module label. If no portion of the junction box or label is located behind a power-generating area of the module, choose the substring closest to the geometric centre of the module.

e) Measure the short-circuit current at each position described in the next step.

f) Starting from one edge of the module, use an opaque cover to shadow one cell of a selected substring completely. Move the cover parallel to the cells and increase the shadowed substring module area (number of shadowed cells) until the short-circuit current falls within the current range $I(*)$. In these conditions, the maximum power is dissipated within the selected group of cells (see Figure 6). The maximum step size between short-circuit current measurements is one cell width. The minimum mask width is two cell widths. If shadowing less than two cells is required to obtain a current within the specified range, then the mask width shall be fixed at the minimum. If shadowing some number of "n" cells results in a current that is too high, and if shadowing n+1 cells causes a current that is too low, then the narrower mask width (n cells) shall be chosen.

g) Move an opaque cover (of the dimensions found in f) above) slowly across the module and measure the short-circuit current at each position. The maximum step size between short-circuit current measurements is the mask width. (Thus, each cell in the module shall be shadowed at some point during this step.) If, at a certain position, the short-circuit current falls below the specified current range $I(*)$, reduce the size of the cover in small increments until the current is within the desired range again. If at any point during this process, the mask width is reduced to its minimum value of two cell widths, its size shall not be reduced further, and the process of moving the mask across the module is complete. If shadowing some number of "n" cells results in a current that is too high, and if shadowing n+1 cells causes a current that is too low, then the narrower mask width (n cells) shall be chosen.

During this process, the irradiance shall not change by more than ± 2 %. The mask is not to be made larger at any point, i.e. if, during step g), the short-circuit current exceeds the higher limit of $I(*)$, the mask width shall be kept the same.

h) The final width of the cover, together with the position within the substring that exhibited the lowest current of each area subjected to the final mask width, determine the minimum area of shadowing that results in the worst case shadowing condition. This is the shadowed area to be used for hot-spot testing.

i) Remove the cover and visually inspect the module.

NOTE Reverse bias operation of the cells in step f) and g) 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.

j) Re-measure the module I-V characteristic and determine maximum power P_{max2}.

k) Place the cover on the module. Put the cover on the position determined during steps g) and h).

l) Short-circuit the module, including a means to monitor the module current, such as an ammeter.

m) Expose the module to the steady-state radiant source providing a total irradiance of (1 000 ± 100) W/m^2 at the module surface. This can be done using:

- A steady-state simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
- Sunlight where the module temperature shall be stabilised within ±5 °C before beginning the measurements.

This test shall be performed at a module temperature in the range (55 ± 15) °C. Note the value of I_{sc} and keep the module current above the lower limit for $I(*)$. If I_{sc} falls below the lower limit for $I(*)$, decrease the mask width in increments of one cell width until I_{sc} once again exceeds the lower limit for $I(*)$. If the current falls below the desired range but the mask is already the minimum width, no adjustment shall be made.

n) Maintain these conditions for a total exposure time of 1 h.

o) At the end of the endurance test, determine the hottest area on the shadowed cells using an IR camera or appropriate temperature detector.

4.9.5.3.4 Case PS

If a module of the parallel-series type (case PS) has an inaccessible internal cell circuit but contains no internal bypass diodes nor equivalent means of reverse bias protection, the following method shall be used to select the cell(s) to be shadowed and to determine the worst case shadowing condition.

a) Expose the un-shadowed module to a total irradiance of 800 W/m^2 to 1 100 W/m^2 at the module surface. This can be done using:

- A pulsed simulator where the module temperature will be close to room temperature (25 ± 5) °C.
- A steady-state simulator where the module temperature shall be stabilised within ±5 °C before beginning the measurements.
- Sunlight where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.

When thermal stabilization is attained, measure the module I-V characteristic and determine the maximum power P_{max1}.

b) Expose the module to the steady-state radiant source providing a total irradiance (1 000 ± 100) W/m^2 at the module surface. This test shall be performed at a module temperature in the range (55 ± 15) °C.

c) Short-circuit the module and shadow at random a block in the module. Shadow at least 10 % of the cells within the block, and shadow an increasing area of the block until the maximum temperature is determined using thermal imaging equipment or other appropriate means.

d) Re-measure the un-shadowed module I-V characteristic and determine maximum power P_{max2}.

e) Apply the shadow found in step c) and maintain these conditions for a total exposure time of 1 h.

At the end of the endurance test, determine the hottest area on the shadowed cells using an IR camera or appropriate temperature detector.

4.9.6 Final measurements

Repeat tests MQT 01, MQT 02, MQT 03, and MQT 15.

4.9.7 Requirements

a) No evidence of major visual defects permitted, as defined in IEC 61215-1:2021, particularly looking for signs of melted solder, openings in the enclosure, delaminations and burn spots. If there is evidence of serious damage that does not qualify as a major visual defect, repeat the test on two additional cells within the same module. If there is no visual damage around either of these two cells the module type passes the hot-spot test.

b) Verify that the module shows the electrical characteristics of a functional photovoltaic device. MQT 02 is not a pass/fail requirement (Gate No 2) for power loss.

c) Insulation resistance shall meet the same requirements as for the initial measurements.

d) Wet leakage current shall meet the same requirements as for the initial measurements.

e) Any damage resulting from determining the worst case shadowing shall be noted in the test report.

4.10 UV preconditioning test (MQT 10)

4.10.1 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.

NOTE MQT 10 is meant to detect gross susceptibility to UV degradation, as the dose is small compared to typical lifetime expectations for modern modules, and wavelength distribution of the UV source is not tightly specified. Documents applying MQT 10 toward other goals (such as comparative degradation studies) should consider what further requirements are necessary to achieve those goals.

4.10.2 Apparatus

a) A temperature-controlled test chamber with a window or fixtures for a UV light source and the module(s) under test. The chamber shall be capable of maintaining the module temperature at (60 ± 5) °C.

b) A means for monitoring the temperature of the module to an accuracy of ±2,0 °C and repeatability of ±0,5 °C. The temperature sensors shall be attached to the front or back surface of the module near the middle without obstructing any of the UV light incident on the active cells within the module. If more than one module is tested simultaneously, it will suffice to monitor the temperature of one of the test modules.

c) Instrumentation capable of measuring the irradiance 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 uncertainly of ±15 % or better.

d) A UV light source capable of producing UV radiation with an irradiance uniformity of ±15 % over the test plane of the module(s) with no appreciable irradiance at wavelengths below 280 nm and capable of providing the necessary total irradiance in the different spectral regions of interest as defined in 4.10.3.

e) The module shall either be short-circuited or open-circuited during exposure, as per manufacturer recommendations. The circuitry condition used during this test shall be noted in the test report.

4.10.3 Procedure

a) 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 W/m^2 (i.e. about five times the natural sunlight level) and that it has a uniformity of ±15 % over the test plane.

b) According to the recommendations of 4.10.2e), short-circuit or open-circuit the module. Mount it in the test plane at the location selected in a), normal to the UV irradiance beam. Make sure that the module temperature sensors read (60 ± 5) °C. For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment/mounting means during the test.

c) Subject the module(s) front side to a total UV irradiation of at least 15 kWh/m^2 in the wavelength range between 280 nm and 400 nm with at least 3 %, but not more than 10 % in the wavelength band between 280 nm and 320 nm, while maintaining the module temperature within the prescribed range.

For bifacial modules repeat the procedure of UV irradiation on the rear-side of the modules.

4.10.4 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.10.5 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.11 Thermal cycling test (MQT 11)

4.11.1 Purpose

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

4.11.2 Apparatus

a) A climatic chamber with automatic temperature control with means for circulating the air inside and means to minimize condensation on the module during the test, capable of subjecting one or more modules to the thermal cycle in Figure 7.

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) Measurement instrumentation having an accuracy of ±2,0 °C and repeatability of ±0,5 °C for measuring and recording the temperature of the module(s).

d) Means for applying a continuous current. The value of the current is defined in the technology specific parts in this standard.

e) Means for monitoring the flow of current through each module during the test.

f) A 5 N weight capable of being attached to the electrical termination leads of the module.

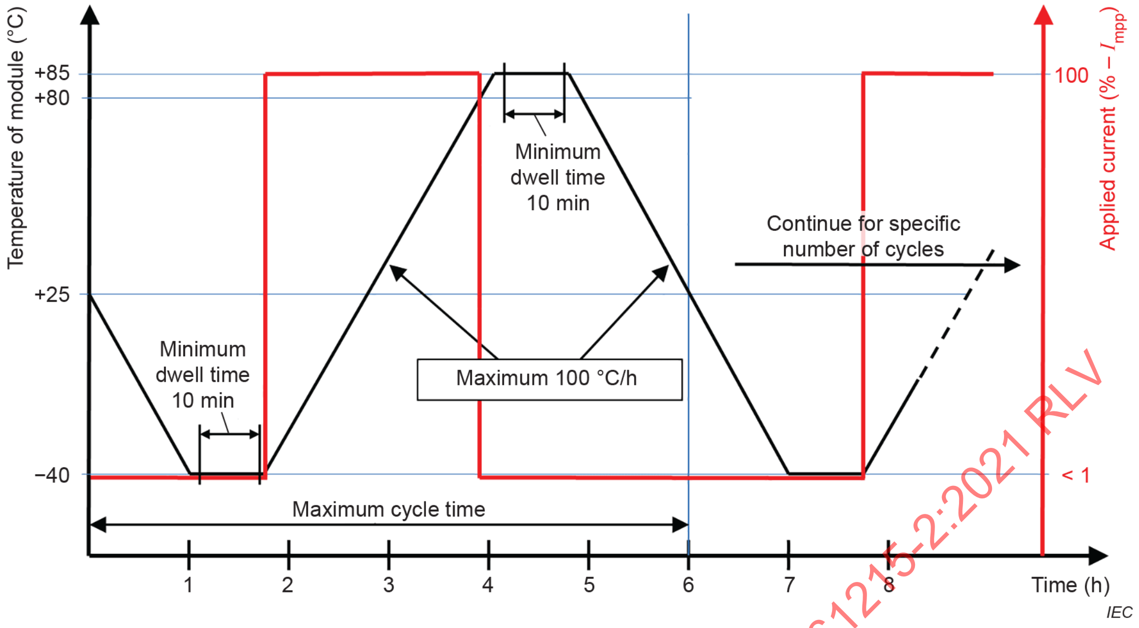


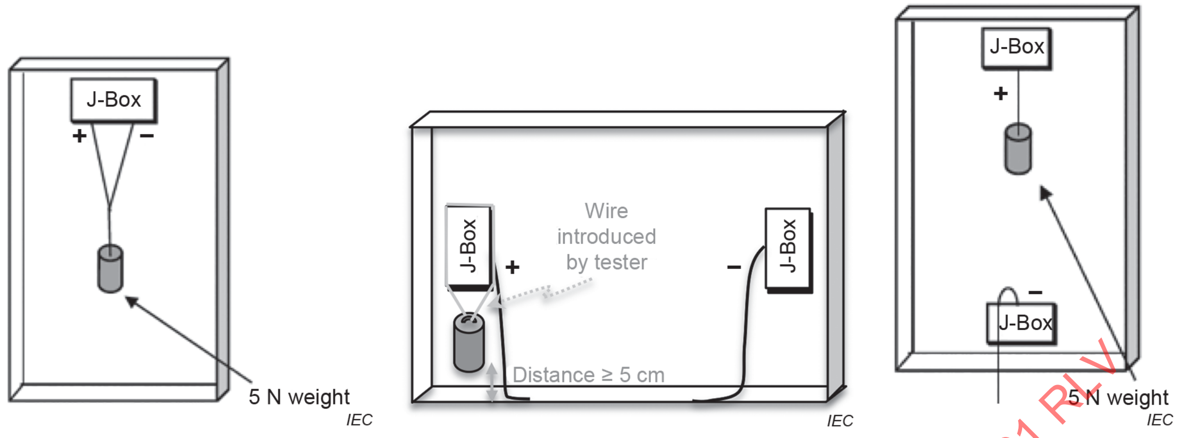
Figure 7 – Thermal cycling test – Temperature and applied current profile

4.11.3 Procedure

a) Attach a suitable temperature sensor to the front or back surface of the module(s) near the middle. If more than one module of the same type are tested simultaneously, it will suffice to monitor the temperature of one of the test modules.

b) Install the module(s) at room temperature in the chamber. Attach a single 5 N weight to the junction box using one of two options. The weight may be attached utilizing the electrical termination leads of each module so that it hangs down vertically from the junction box, as shown in Figure 8a). The weight may also be attached to the junction box using a wire introduced by the tester, as shown in Figure 8b). A wire introduced by the tester shall not be attached to the junction box lid. In either case, the weight shall not impact or damage the module back surface, and shall be at least 5 cm above the floor or module frame at the start of the test, as indicated in Figure 8b). If there are more than one similar junction boxes per module, only one junction box need be weighted, as shown in Figure 8b) or Figure 8c). However, if the junction boxes differ in design, each should carry weights independently.

For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment/mounting means during the test.



a) b) c)

Figure 8 – Proper attachment of 5 N weight to junction box for module utilizing a) electrical termination leads, b) or wire for attachment, and c) only one junction box

c) Connect the temperature-monitoring equipment to the temperature sensor(s). Connect each module to the appropriate current supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly. During the thermal cycling test set the continuous current flow during the heat up cycle to the technology specific current specified in 4.11.2d), at temperature from -40 °C to +80 °C. During cool down, the -40 °C dwell phase and temperatures above 80 °C the continuous current shall be reduced to no more than 1,0 % of the measured STC peak power current to measure continuity. If the temperature rises too fast (greater than 100 °C/h) at the lowest temperature, the start of the current flow can be delayed until the temperature has reached -20 °C.

d) Close the chamber and subject the module(s) to cycling between measured module temperatures of (-40 ± 2) °C and (+85 ± 2) °C, in accordance with the profile in Figure 7. 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 unless the module has such a high heat capacity that a longer cycle is required. The number of cycles shall be as shown in the relevant sequences in Figure 2 of IEC 61215-1:2021. Air circulation around the module(s) has to ensure compliance with each module under test meeting the temperature cycling profile.

e) Throughout the test, record the module temperature and monitor the current flow through the module(s). Document in test report the actual dwell duration at high and low temperatures.

NOTE In a module with parallel circuits, an open circuit in one branch will cause a discontinuity in the voltage, but not cause the current to go to zero.

4.11.4 Final measurements

After a minimum recovery time of 1 h at (23 ± 5) °C and a relative humidity less than 75 % under open-circuit conditions, repeat the tests of MQT 01 and MQT 15.

4.11.5 Requirements

a) No interruption of current flow during the test; in the case of a module with parallel circuits, a discontinuity in current flow indicates an interruption of flow in one of the parallel circuit.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

4.12 Humidity-freeze test (MQT 12)

4.12.1 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.

4.12.2 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 9.

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) is (are) thermally isolated.

c) Measurement instrumentation having an accuracy of ±2,0 °C and repeatability of ±0,5 °C for measuring and recording the temperature of the module(s).

d) Means for monitoring, throughout the test, the continuity of the internal circuit of each module.

4.12.3 Procedure

a) Attach a suitable temperature sensor to the front or back surface of the module(s) near the middle. If more than one module of the same type is tested simultaneously, it will suffice to monitor the temperature of one of the test modules.

b) Install the module(s) at room temperature in the climatic chamber. For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment/mounting means during the test.

c) Connect the temperature-monitoring equipment to the temperature sensor(s). Connect each module to the appropriate current supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly. During the humidity freeze test set the continuous current flow to no more than 0,5 % of the measured STC peak power current. If 0,5 % of the measured STC current is less than 100 mA, then 100 mA may be applied instead.

d) After closing the chamber, subject the module(s) to 10 cycles in accordance with the profile in Figure 9. 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 when the temperature is at the maximum value of 85 °C. Air circulation around the module(s) has to ensure compliance with each module under test meeting the temperature cycling profile.

e) Throughout the test, record the module temperature and monitor the current and voltage through the module.

4.12.4 Final measurements

After a recovery time between 2 h and 4 h at (23 ± 5) °C and a relative humidity less than 75 % under open-circuit conditions, repeat the tests of MQT 01 and MQT 15.

4.12.5 Requirements

a) No interruption of current flow or discontinuity in voltage during the test; in the case of a module with parallel circuits, a discontinuity in current flow indicates an interruption of flow in one of the parallel circuits.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

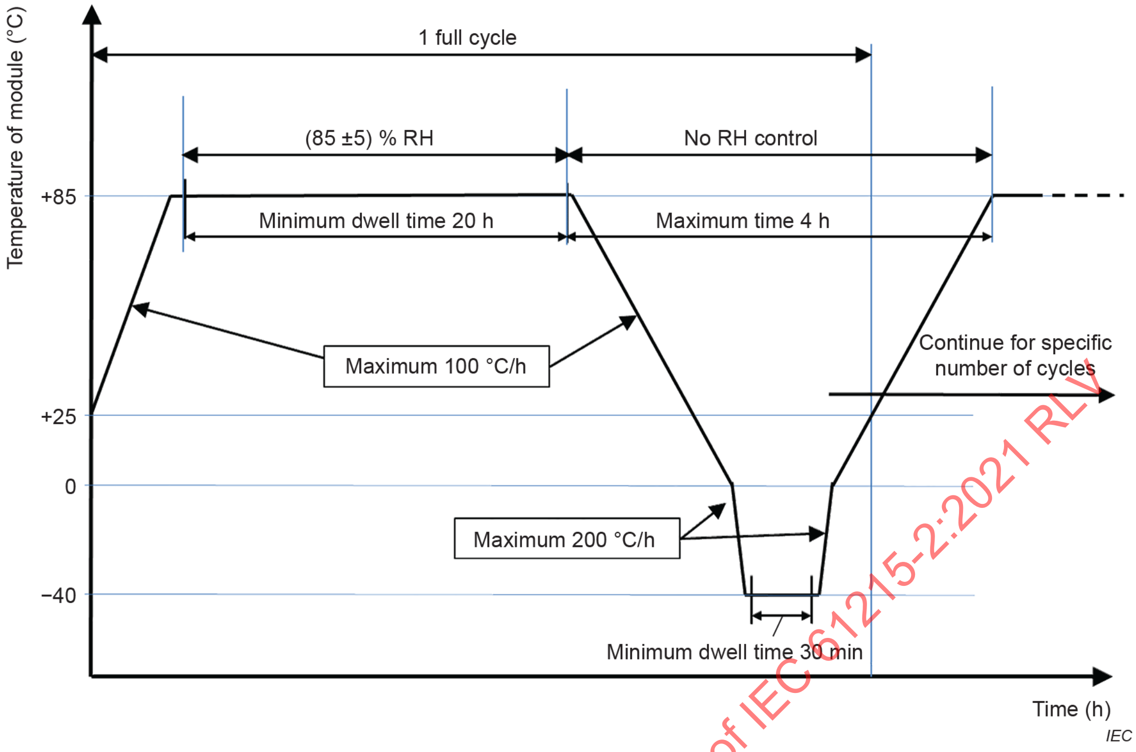


Figure 9 – Humidity-freeze cycle – Temperature and humidity profile

4.13 Damp heat test (MQT 13)

4.13.1 Purpose

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

4.13.2 Apparatus

Requirements for the test chamber are listed in IEC 60068-2-78:2012, 4.1.

4.13.3 Procedure

The procedure for introducing the sample into the chamber and starting the test is described in IEC 60068-2-78:2012, 4.4. The test shall be carried out with the following provisions.

Severities:

Test temperature: (85 ± 2) °C

Relative humidity: (85 ± 5) %

Test duration: $\left(1000^{+48}_{0}\right)$ h

No preconditioning shall be performed.

Module connectors shall be short-circuited, unless current is being applied according to options provided in some of the technology-specific parts.

For flexible modules, the modules shall be mounted per the manufacturer’s documentation with prescribed substrate and adhesive or attachment/mounting means during the test.

4.13.4 Final measurements

After a recovery time of 2 h, and no more than 4 h, at (23 ± 5) °C and a relative humidity less than 75 % under open-circuit conditions, repeat the tests of MQT 01 and MQT 15.

4.13.5 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.14 Robustness of terminations (MQT 14)

4.14.1 Purpose

To determine that the terminations, the attachment of the terminations, and the attachment of the cables to the body of the module will withstand stresses that are likely to be applied during normal assembly or handling operations. Test in 4.14.2 (MQT 14.1) and test in 4.14.3 (MQT 14.2) are to be performed in Sequence C after MQT 12 as given by the test flow in IEC 61215-1:2021.

4.14.2 Retention of junction box on mounting surface (MQT 14.1)

4.14.2.1 Apparatus

Means for applying a force of 40 N to the centre of the test object. Prevent torque from being applied to the junction box.

Attaching the means for applying the force to the junction box shall not impair its functions.

4.14.2.2 Procedure

A force of 40 N shall be gradually applied for (10 ± 1) s (in accordance to IEC 60068-2-21) in each direction parallel to the mounting surface parallel to the module edges, in steps of 90°.

A force of 40 N shall be gradually applied for (10 ± 1) s without jerks, in a direction perpendicular to the mounting surface.

The pull force should be applied at the centre point of the box.

4.14.2.3 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.14.2.4 Requirements

During test, there shall be no displacement of the junction box at the mounting surface impairing isolating characteristics.

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.14.3 Test of cord anchorage (MQT 14.2)

The junction box, separate from the module, shall be tested to IEC 62790 "Test of cord anchorage" and shall meet the requirements therein. If the junction box has been pre-qualified prior to IEC 61215-2:2021 testing, the test report shall note the test lab name and date when the requirement was met. The cord anchorage test cannot be applied to junction boxes with integrated connectors, and thus junction boxes with integrated connectors are exempt from this requirement. Exemption shall be noted in the test report.

4.15 Wet leakage current test (MQT 15)

4.15.1 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, an earth fault or a safety hazard.

4.15.2 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
Solution temperature:	(22 ± 2) °C

The depth of the solution shall be sufficient to cover all surfaces except junction box entries.

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.

4.15.3 Procedure

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. The cable entries shall be thoroughly sprayed with solution. If the module is provided with a mating connector, the connector should be sprayed 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.

   Some module technologies may be sensitive to static polarization if the module is maintained at positive voltage to the frame. In this case, the connection of the tester shall be done in the opposite way. If applicable, information with respect to sensitivity to static polarization shall be provided by the manufacturer and documented in the test report.

c) Increase the voltage applied by the test equipment at a rate not exceeding 500 V/s 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.

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.

e) Ensure that the used solution is well rinsed off the module before continuing the testing.

4.15.4 Requirements

– For modules with an area of 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.

4.16 Static mechanical load test (MQT 16)

4.16.1 Purpose

The purpose of this test is to determine the ability of the module to withstand a minimum static load. The minimum required design load for a particular site will depend on construction, applicable standards, building codes, probability of event occurrence, design assumptions and location/climate and might require higher sampling rates and other safety factors γ_m.

To determine the maximum possible test load, e.g. by test-to-fail of a construction is not part of this document.

MQT 16 verifies minimum test loads. The manufacturer's minimum design load is back calculated from the above minimum test load. The test load is defined as:

$$\text{Test load} = \gamma_m \times \text{design load}$$

where the safety factor γ_m is at least ≥ 1,5.

The minimum required design load per this document is 1 600 Pa, resulting in a minimum test load of 2 400 Pa.

The manufacturer may specify higher design load(s) for positive (downward) and negative (upward) and also a higher γ_m for certain applications. The design load(s) and γ_m are to be specified in the documentation of the manufacturer per each mounting method.

EXAMPLE Manufacturer specifies the following design loads: positive 3 600 Pa and negative 2 400 Pa with γ_m = 1,5. The test sequence will contain 3 cycles each performed at 5 400 Pa positive and 3 600 Pa negative loading.

Each module undergoing MQT 16 test shall be pre-tested according to Sequence E in IEC 61215-1:2021, unless a module is an additional, full-size, very large module tested alongside representative samples, as described in IEC 61215-1:2021 Clause 4.

NOTE Inhomogeneous snow loads are not covered by this test. IEC 62938:2020 may be used.

4.16.2 Apparatus

a) 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 within the constraints of the manufacturers prescribed method of mounting.

b) Instrumentation to monitor the electrical continuity of the module during the test.

c) Suitable weights or pressure means that enable the load to be applied in a gradual, uniform manner. The test load may be applied pneumatically or by means of weights. All force shall be applied normal to the module surface. The apparatus shall not contribute to the rigidity of the module (e.g. force applied via a large, flat, plate).

d) The entire payload should be applied to the module surface uniformly and gradually without causing impact spikes. The weight shall only be applied on the frontsheet (e.g. the glass) and not on the module frame or cross support rails in the module. If weights are used to load the module, Annex A provides additional recommendations to ensure quality control and consistency of test results.

NOTE 1 With incremental loading where weights are loaded by hand, impact shocks not representative of field stress have been observed and are undesirable.

e) If an automated system using pistons (or other discrete-point application) is used to load the module, document the coverage ratio in the test report. Coverage ratio is the area under the suction cups (connected to pistons or other contacting points to module) to the surface area of the module. A minimum coverage ratio of 10 % is recommended to assure uniformity of loading on the module.

f) The environmental conditions for performing the tests are (25 ± 5) °C in a relative humidity not exceeding 75 %.

NOTE 2 As most adhesives will perform worse under elevated temperatures, room temperature is considered to be a best case condition for testing.

4.16.3 Procedure

a) Equip the module so that the electrical continuity of the internal circuit can be monitored continuously during the test.

b) Mount the module on a rigid structure using the method prescribed by the manufacturer including the mounting means (clips/clamps and any kind of fastener) and underlying support rails. If there are different possibilities each mounting method needs to be evaluated separately. For all mounting methods, mount the module in a manner where the loading is worst case. If there are different possibilities, each mounting configuration needs to be evaluated separately. Worst case loading is typically associated with largest cantilever (overhang span) or largest deflection. For all mounting configurations, mount the module in a manner where the distance between the fixing points is worst case, which typically results in the worst deflection of the module, while following manufacturer recommendations for the specified mounting means. Allow the modules to equilibrate for a minimum of 2 h after MQT 13 before applying the load. For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment means during the test.

c) On the front surface, gradually and uniformly apply the test load. Load uniformity needs to be better than ±5 % across the module with respect to the test load. Maintain this load for 1 h.

d) Apply the same procedure as in step c) to the back surface of the module or as uplift load to the front surface.

e) Repeat steps c) and d) for a total of three cycles.

4.16.4 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.16.5 Requirements

a) No intermittent open-circuit fault detected during the test.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

4.17 Hail test (MQT 17)

4.17.1 Purpose

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

4.17.2 Apparatus

a) Moulds of suitable material for casting spherical ice balls of the required diameter. Minimum requirement is a diameter of 25 mm. For hail prone locations larger ice balls may be required for testing as listed in Table 2. The test report should indicate what ice ball diameter and test velocity was used for the hail test.

b) A freezer controlled at (-10 ± 5) °C.

c) A storage container for storing the ice balls at a temperature of (-4 ± 2) °C.

d) A launcher capable of propelling an ice ball at the specified velocity, within ±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) A 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 ±2 %.

g) An instrument for measuring the velocity of the ice ball to an accuracy of ±2 %. The velocity sensor shall be no more than 1 m from the surface of the test module.

As an example, Figure 10 shows in schematic form a suitable apparatus comprising a horizontal pneumatic launcher, a vertical module mount and a velocity meter which measures electronically the time it takes the ice ball to traverse the distance between two light beams. This is only one example as other types of apparatus including slingshots and spring-driven testers have been successfully utilized.

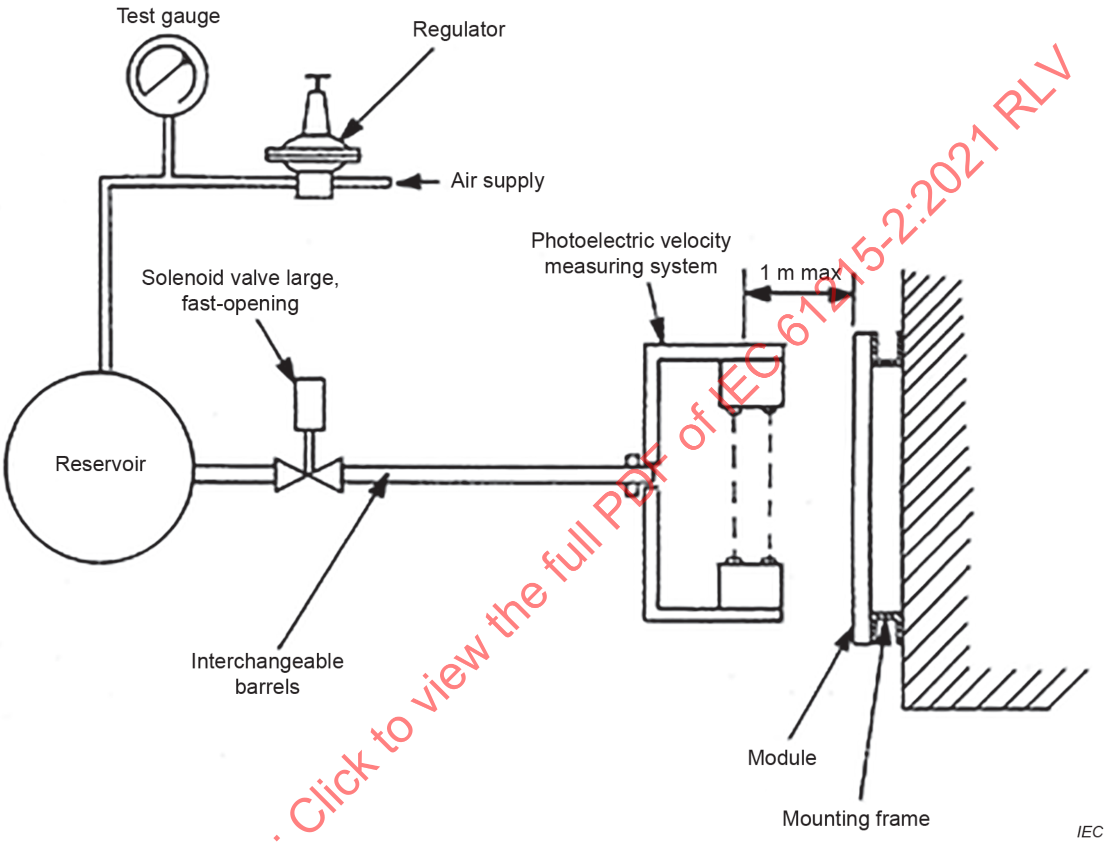


Figure 10 – Hail-test equipment

Table 2 – Ice-ball masses and test velocities

Diameter mm	Mass g	Test velocity m/s	Diameter mm	Mass g	Test velocity m/s
25	7,53	23,0	55	80,2	33,9
35	20,7	27,2	65	132,0	36,7
45	43,9	30,7	75	203,0	39,5

4.17.3 Procedure

a) Using the moulds and the freezer, make a sufficient number of 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 criteria:

  - no cracks visible to the unaided eye;
  - diameter within ±5 % of that required;

  - mass within ±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 ±5 % of the appropriate hailstone test velocity in Table 2.

f) Mount the module according to manufacturer specifications. The module shall be at room temperature, with the impact surface normal to the path of the ice ball. For flexible modules, the modules shall be mounted per the manufacturer's documentation with prescribed substrate and adhesive or attachment/mounting means during the test. If the manufacturer's specified application allows mounting in a rigid or flexible mounting condition, testing shall be done on the worst-case condition. The test configuration(s) shall be documented in the test report.

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 in Table 3 , as illustrated in Figure 11.

Table 3 – Impact locations

Shot No.	Location
1	Any corner of the module window, not more than one radius of ice-ball from the module edge.
2	Any edge of the module, not more than one radius of ice-ball from the module edge.
3, 4	Over the circuit near interconnects (i.e. cell interconnects and bus ribbons).
5, 6	Over edges of the circuit (e.g. individual cells).
7, 8	On the module window, not more than half diameter of ice ball from one of the points at which the module is mounted to the supporting structure.
9, 10	On the module window, at points farthest from the points selected above.
11	Any points which may prove especially vulnerable to hail impact like over the junction box.

4.17.4 Final measurements

Repeat tests MQT 01 and MQT 15.

4.17.5 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

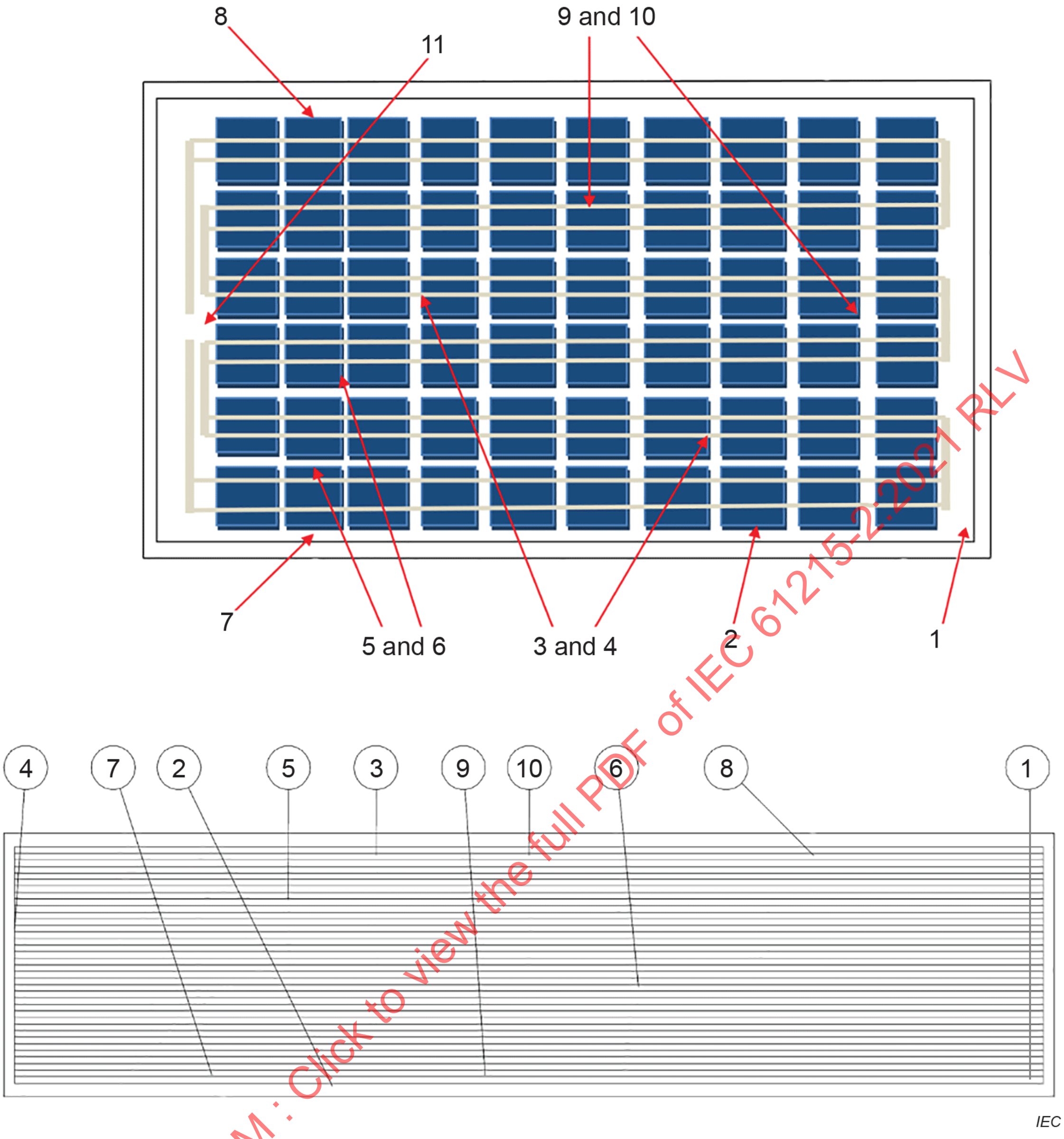


Figure 11 – Hail test impact locations: top for wafer/cell based technologies, bottom for monolithic processed thin film technologies

4.18 Bypass diode testing (MQT 18)

4.18.1 Bypass diode thermal test (MQT 18.1)

4.18.1.1 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.

The test is designed to determine the diode’s temperature characteristic and its maximum diode junction temperature T_J under continuous operation.

4.18.1.2 Test sample

If the module contains three or fewer bypass diodes, then all diodes shall be tested for forward voltage as per 4.18.1.4 and for functionality as per 4.18.2. If the module contains more than three diodes, then three bypass diodes are to be selected for testing. These bypass diodes are to be selected by the test laboratory and should be representative bypass diodes which are subject to the most stress in the design. The test lab shall indicate in the test report which three bypass diodes were selected and why they were selected.

a) For more than three diodes embedded in a laminate, select the diodes in these locations:
   1) Closest to the centre of the junction box (may be underneath the junction box).
   2) Closest to the module frame (or module edge, in case of frameless module).
   3) Closest to module centre.
b) For more than three diodes in a junction box, select diodes in these locations:
   1) Closest to the centre of the junction box.
   2) Next closest to the centre of the junction box.
   3) Closest to the edge of the junction box.

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 module and does not have to be an active PV module. The test shall then proceed as normal. This special test sample shall be used only for measuring the bypass diode temperature in 4.18.1.4 c) to k). Exposure to 1,25 times the STC short-circuit current shall be performed on a fully functional module which is then used for making the final measurements of 4.18.1.5. The special sample shall allow electrical access to the three bypass diodes in locations complying with the above selection criteria.

4.18.1.3 Apparatus

a) Means for heating the module up to a temperature of (90 ± 5) °C.
b) Means for monitoring the temperature of the module to an accuracy of ±2,0 °C and repeatability of ±0,5 °C.
c) Means for measuring the junction voltage V_D of the bypass diodes to an accuracy of 2 %.
d) Means for applying a current equal to 1,25 times the STC short-circuit current of the module under test with a pulse width not exceeding 1 ms and means for monitoring the flow of current through the module, throughout the test. For bifacial modules, the applicable current is 1,25 times short-circuit current at elevated irradiance BSI, as defined in IEC 61215-1:2021. The short-circuit current at irradiance BSI may be determined either by a measurement (MQT 06.1) at irradiance BSI, or by assuming linearity of short-circuit current with irradiance (as defined in IEC 60904-10). Assuming linearity allows one to calculate the short-circuit current at BSI, $I_{\text{sc-BSI}}$, using I_{sc} values measured for Gate No. 1 ($I_{\text{sc-STC}}$ and $I_{\text{sc-BNPI}}$), and the relevant equivalent irradiances: 1 000 Wm^{-2}, G_{BNPI}, and G_{BSI}. To extrapolate $I_{\text{sc-BSI}}$, these quantities are combined as follows:

$$I_{\text{sc–BSI}} = I_{\text{sc–BNPI}} + \frac{(I_{\text{sc–BNPI}} - I_{\text{sc–STC}})}{G_{BNPI} - 1\,000\ \text{Wm}^{-2}} \cdot (G_{BSI} - G_{BNPI})$$

In the above formula, equivalent irradiance are calculated as in IEC TS 60904-1-2, specifically:

$$G_{\text{BNPI}} = 1\,000\ \text{Wm}^{-2} + \varphi \cdot 135\ \text{Wm}^{-2}$$

$$G_{\text{BSI}} = 1\,000\ \text{Wm}^{-2} + \varphi \cdot 300\ \text{Wm}^{-2}$$

$$\varphi = Min\left(\varphi_{\mathrm{Isc}}, \varphi_{\mathrm{Pmax}}\right)$$

4.18.1.4 Procedure

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. For bifacial modules, use the value of the short-circuit current at elevated irradiance BSI, as defined in IEC 61215-1:2021.

c) Connect the lead wire for V_D and I_D on both diode terminals as shown in Figure 12.

If the diodes are potted the connections shall be made by the module manufacturer before delivery of the module.

Care shall be taken that the lead wires do not cause heat dissipation from the terminal box leading to misinterpretation of the test results. Thus, current connections should be made as far as possible away from the terminal box, and voltage probes made as small and thin as possible.

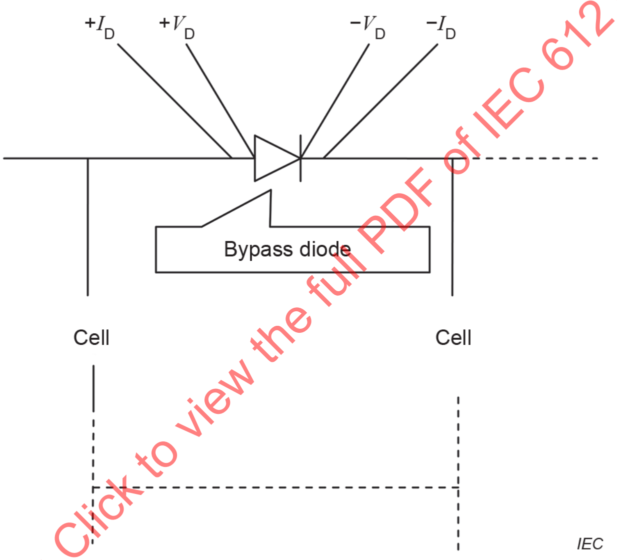


Figure 12 – Bypass diode thermal test

d) Heat the module and junction box up to a temperature of (30 ± 2) °C.

e) 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. For bifacial modules, use the value of the short-circuit current at elevated irradiance BSI.

f) Using the same procedure, measure V_{D2} at (50 ± 2) °C.

g) Using the same procedure, measure V_{D3} at (70 ± 2) °C.

h) Using the same procedure, measure V_{D4} at (90 ± 2) °C.

i) 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}.

T_J is assumed to be the ambient temperature of the junction box for steps d) to i).

j) Heat the module to (75 ± 5) °C. Apply a current to the module equal to the short-circuit current I_{sc} ± 2 % as determined in step b). After 1 h measure the forward voltage of each of the selected diodes.

   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 W/m^2, (43 ± 3) °C ambient with no wind rather than at 75 °C.

k) Using the V_D versus T_J characteristic obtained in item i), obtain T_J from V_D at T_{amb} = 75 °C, $I_D = I_{sc}$ of the diode during the test in j).

l) Increase the applied current to 1,25 times the short-circuit current of the module as determined in step b) while maintaining the module temperature at (75 ± 5) °C.

m) Maintain the current flow for 1 h.

4.18.1.5 Final measurements

Repeat the tests of MQT 01, MQT 15 and MQT 18.2.

4.18.1.6 Requirements

a) The diode junction temperature T_J as determined in 4.18.1.4 k) shall not exceed the diode manufacturer's maximum junction temperature rating for continuous operation.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

d) The diode shall still function as a diode after the conclusion of the test as per MQT 18.2.

4.18.2 Bypass diode functionality test (MQT 18.2)

4.18.2.1 Purpose

The purpose of this test is to verify that the bypass diode(s) of the test samples remain(s) functional following MQT 09 and MQT 18.1. In case of PV modules without bypass diodes this test can be omitted.

4.18.2.2 Apparatus

Means for measuring current-voltage curve within 1 s; e.g. I-V curve tracer, with an accuracy of the voltage and current measurements of ±1 % of the open-circuit voltage and short-circuit current, respectively.

4.18.2.3 Procedure

4.18.2.3.1 General

The test can be conducted according to either of the following two methods.

4.18.2.3.2 Method A

This procedure shall be conducted in any ambient temperature within (25 ± 10) °C. During the test the sample shall not be subjected to illumination.

a) Electrically short any blocking diodes incorporated to the test sample.

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

b) Determine the rated STC short-circuit current of the test sample from its name plate. For bifacial modules, use the value of I_{SC} measured at STC.

c) Connect the DC power source's I-V curve tracer's positive output to the test sample's negative terminal and the DC power source's I-V curve tracer's negative output to the test sample's positive terminal, respectively. With this configuration the current shall pass through the solar cells in the reverse direction and through the bypass diode(s) in the forward direction.

d) Run current sweep from 0 A to 1,25 × I_{sc} and record voltage. Use the value of I_{sc} determined in step b).

4.18.2.3.3 Method B

Successive I-V measurements of the PV module can be performed in conjunction with maximum power determination (MQT 02) with portions of a string in the interconnection circuit completely shadowed in order to "turn on" the diode. This procedure should be repeated for each substring.

4.18.2.4 Requirements

4.18.2.4.1 Method A

In the current sweep of 4.18.2.3.2 d), identify the largest current at which the forward voltage is specified on the data sheet. The diode(s) forward voltage measured at the identified current is defined as VFM and shall meet the following requirement:

$$VFM = (N \times V_{\mathrm{FMrated}}) \pm 10\ \%$$

where:

N	is the number of bypass diodes;
V_{FMrated}	is the diode forward voltage as defined in diode data sheet for 25 °C.

4.18.2.4.2 Method B

The bypass diode belonging to the shadowed string is working properly, if the characteristic bend in the I-V curve is observed.

Example: a crystalline silicon PV module with 60 cells and three strings protected each by one diode will have a power drop to roughly 2/3, if cells in one string are shadowed.

4.19 Stabilization (MQT 19)

4.19.1 General

All PV modules need to be electrically stabilized. For this purpose, all modules shall be exposed to a defined procedure, and the output power shall be measured directly afterwards. This procedure and output power measurement shall be repeated until the module is assessed to have reached an electrically stable power output level. Where light is used for stabilization, simulated solar irradiance is preferred over natural light.

4.19.2 Criterion definition for stabilization

The following formula shall be taken as the criterion to assess whether a module has reached its stabilized electrical power output:

$$(P_{\mathrm{max}} - P_{\mathrm{min}}) / P_{\mathrm{average}} < x$$

where x is defined in the technology specific parts of this standards series.

Here, P_{max}, P_{min} and P_{average} are defined as extreme values of three consecutive output power measurements P_1, P_2 and P_3 taken from a sequence of alternating stabilization and measurement steps using MQT 02. P_{average} is the average of all three, P_1, P_2 and P_3. STC output power is determined using procedure MQT 06.1.

4.19.3 Light induced stabilization procedures

4.19.3.1 Apparatus for indoor stabilization

a) A class CCC solar simulator or better, in accordance with IEC 60904-9.

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) Use the reference device to set the irradiance between 800 W/m^2 and 1 000 W/m^2.

e) During the simulator exposure, module temperatures shall stay in the range of (50 ± 10) °C. All subsequent stabilizations should be done at the same temperature as the initial within ±2 °C.

f) Means for monitoring the temperature of the module to an accuracy of ±2,0 °C and repeatability of ±0,5 °C. The temperature sensor shall be mounted on a representative position for the average module temperature.

g) A resistive load sized such that the module will operate near its maximum power point or an electronic maximum power point tracker (MPPT).

4.19.3.2 Requirements for outdoor exposure for stabilization

a) A suitable reference device, with integrator, for monitoring the irradiation.

b) Means to mount the modules, as recommended by the manufacturer, co-planar with the reference device.

c) Only irradiance levels above 500 W/m^2 will count for total irradiance dose required to check stabilization. Temperature limits are specified in the technology specific parts.

d) Means for monitoring the temperature of the module to an accuracy of ±2,0 °C and repeatability of ±0,5 °C. The temperature sensor shall be mounted on a representative position for the average module temperature.

e) A resistive load sized such that the module will operate near its maximum power point or an electronic maximum power point tracker (MPPT).

A maximum power point tracking device is advisable, e.g. a micro-inverter.

4.19.3.3 Procedure

a) Measure the output power of each module using the maximum power determination (MQT 02) procedure at any convenient module temperature within the allowable range that can be reproduced within ±2 °C for future intermediate measurements.

b) Attach the load to the modules and mount them, as recommended by the manufacturer, with the reference device in the test plane of the simulator.

c) Record the irradiance levels, integrated irradiation, temperature and used resistive load of the module.

d) Subject each module to at least two intervals of the irradiation as defined in the technology specific parts of MQT 19 of this standard until its maximum power value stabilizes. Stabilization is defined in 4.19.2.

e) The output power shall be measured using MQT 02. The time period between light exposure including MQT 02 measurements and the final determination of maximum power in accordance to MQT 06.1 is specified in the technology specific part.

f) Intermediate measurements of MQT 02 shall be performed in approximately equal integrated irradiation dose intervals. Minimum doses are defined in the technology specific parts of this standard. All intermediate maximum power measurements shall be performed at any convenient module temperature reproduced within ±2 °C.

g) Report the integrated irradiation and all parameters at which this stability is reached. For outdoor procedure, where applicable, state the type of load used and show temperature and irradiance profiles.

4.19.4 Other stabilization procedures

Other stabilization techniques can be used after validation. It is known that the application of current or voltage bias can lead to similar effects in solar cells as is the case for light exposure. Such alternate stabilization procedures will be provided by the manufacturer.

This subclause defines the validation process for alternate stabilization procedure.

Alternate procedures can be used instead of light exposure if validated according to this procedure. Validation shall be done with three modules. The validation shall be performed in sequence A as initial stabilization. Perform the following to validate alternate procedures:

a) Perform alternate procedure.
b) Measure MQT 06.1 after the minimum and no more than the maximum time specified in the technology specific parts.
c) Perform indoor light induced stabilization procedure 4.19.3.1 in accordance to technology specific requirements.
d) Measure MQT 06.1 after the minimum and no more than the maximum time specified in the technology specific parts.

An alternate method is considered valid if the two MQT 06.1 measurements from b) and d) above are within 2 % for all three evaluated modules. If one module does not meet the pass criteria the method is not validated.

4.19.5 Initial stabilization (MQT 19.1)

Initial stabilization is performed following procedure and requirements defined in MQT 19. Stabilization is reached if 4.19.2 is fulfilled.

The initial stabilization is performed to verify manufacture label values as defined in the pass criterion in IEC 61215-1:2021, 7.2.2 (Gate No. 1).

The number of modules subjected to MQT 19.1 is defined in the technology specific parts of this standard.

4.19.6 Final stabilization (MQT 19.2)

Final stabilization is performed following procedure and requirements defined in MQT 19. Stabilization is reached if 4.19.2 is fulfilled.

The final stabilization is performed to determine module degradation during the test as defined in the pass criterion in IEC 61215-1:2021, 7.2.3 (Gate No. 2).

If not otherwise stated all modules from sequences A, and C to E have to undergo MQT 19.2 testing.

4.19.7 Stress-specific stabilization – BO LID (MQT 19.3)

4.19.7.1 General

Some stress conditions may change the state of semiconductor defects in a way that is not representative of field behavior and is not related to the degradation mechanisms that are targeted by the stress tests. In this case, a stress-specific stabilization may be required to set the defects into a reproducible state either before or after stress. When to apply a stress-specific stabilization is prescribed in the technology-specific parts.

MQT 19.3 describes a stabilization procedure that puts the defects causing boron-oxygen light induced degradation into the regenerated state. It shall only be used at points in the test flow specifically allowed in IEC 61215-1-1:2021.

4.19.7.2 Apparatus for BO-LID stress-specific stabilization

a) A climatic chamber with automatic temperature control.

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) is (are) thermally isolated.

c) Measurement instrumentation having an accuracy of ±2,0 °C and repeatability of ±0,5 °C for measuring and recording the temperature of the module(s).

d) Means for applying, throughout the test, a current equal to the module short-circuit current I_{sc}.

4.19.7.3 Procedure

a) Install the module(s) at room temperature in the climatic chamber.

b) Connect the temperature-monitoring equipment to the temperature sensor(s). Connect each module to the appropriate current supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly.

c) Close the chamber, and apply a current of I_{sc} ± 5 % to each module. As long as the current applied to each module is within 5 % of its I_{sc}, the currents applied through multiple modules in one chamber need not be the same.

d) Increase the climactic chamber setpoint such that the temperature of each module reaches (80 ± 5) °C, and never exceeds 85 °C.

e) Maintain the current and temperature within the limits prescribed in steps c) and d) for (48 ± 2) h.

4.20 Cyclic (dynamic) mechanical load test (MQT 20)

4.20.1 Purpose

The purpose of this test is to evaluate if components within the module are extremely susceptible to low levels of mechanical stress. The most likely reason for extreme susceptibility to low levels of mechanical stress is a module assembly process that compromises the integrity of module components (for example tabbing that puts too much pressure on the cell and creates microcracks). Components that may be evaluated by the cyclic dynamic mechanical load test (DML) include solar cells, interconnect ribbons, electrical bonds, and edge seals.

4.20.2 Procedure

The test shall be carried out in accordance with IEC TS 62782.

4.20.3 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.20.4 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.21 Potential induced degradation test (MQT 21)

4.21.1 Purpose

The purpose of this test is to measure the module design’s ability to withstand degradation from applied system voltage, also known as Potential Induced Degradation (PID).

NOTE The test is not designed to evaluate PID involving polarization mechanisms (PID-p) and therefore PID-p may not be detected.

4.21.2 Samples

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. Four samples (two for each polarity of the system voltage that is specified or allowed in the module documentation) per Clause 4 of IEC 61215-1:2021 shall be procured for each test. Modules not explicitly requiring string connections with one terminal earthed shall be tested in both polarities. If only two modules are tested (i.e. one allowed polarity), the two modules not subjected to stress during MQT 21 shall only progress through the test flow (IEC 61215-1:2021, Figure 2) as far as MQT 21, then shall not be subjected to further testing. Specifically, the two unused modules shall progress through Gate No 1 but not Gate No 2.

If the PV module is provided with or is specified for use with a specific means for earthing, then the earthing 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.

4.21.3 Apparatus

The test shall be carried out using the apparatus described in IEC TS 62804-1:2015, 4.3.1.

4.21.4 Procedure

The test shall be carried out in accordance with the stress method testing in damp heat using an environmental chamber as given in IEC TS 62804-1:2015, 4.3.2 with the following provisions

Severities:

Module temperature: 85 °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.

4.21.5 Final measurements

Repeat the MQT 01 and MQT 15 tests. The MQT 15 test shall be performed within 8 h of the end of the PID stress described in 4.21.4.

As per the test flow shown in IEC 61215-1:2021, Figure 2, modules shall be subjected to MQT 19.2, MQT 06.1 (including gate 2), and MQT 03 following the PID test (MQT 21). Bifaciality coefficients shall be remeasured when performing MQT 06.1 for gate 2. Modules from sequence F do not need to repeat MQT 15 at the end of the test flow. In order to maximize repeatability when partially-reversible PID may be present, the modules that have undergone PID testing shall be stored with controlled conditions between testing steps after PID (i.e. MQT 19.2, MQT 6.1, MQT 03). Between these test steps, the modules shall be maintained indoors, in the dark, and at temperatures 25 °C or below. For the post-PID tests, no more than 48 h shall elapse between the end of MQT 21 and the beginning of MQT 19.2. The time limit between MQT 19.2 and MQT 06.1 shall be either 48 h or the time limit specified in the technology-specific stabilization procedure, whichever is shorter.

4.21.6 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1:2021, Clause 8.

b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.22 Bending test (MQT 22)

4.22.1 Purpose

The purpose of this test is to verify that a flexible module can be rolled up (without damage) to form a radius of curvature defined by the module manufacturer in at least one direction per the manufacturer's specification. If the manufacturer's installation guide allows bending in more than one direction, the worst-case condition shall be used. The test may be performed on a representative sample, as described in IEC 61215-1:2021, Clause 4.

NOTE Once the radius of curvature is defined, the bending stresses are the same as long as the thickness is the same between "representative sample" and a longer module.

4.22.2 Apparatus

a) A cylinder with a diameter of twice the radius of curvature specified by the module manufacturer. The flexible module will be bent over this cylinder.

b) Instrumentation to monitor the electrical continuity of the module during the test.

c) The environmental conditions for performing the tests are (25 ± 5) °C.

4.22.3 Procedure

a) Equip the module so that the electrical continuity of the internal circuit can be monitored continuously during the test.

b) Roll the flexible module from a flat/planar starting position over the cylinder of the specified radius of curvature. If the module is large enough, it shall roll up on the cylinder in excess of 360°.

c) Unroll the flexible module back to the flat/planar position.

d) Repeat b) and c) 25 times.

4.22.4 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.22.5 Requirements

a) No intermittent open-circuit fault detected during the test when a continuous current is applied and monitored as performed per MQT 11.

b) No evidence of major visual defects, as defined in IEC 61215-1:2021.

c) Wet leakage current shall meet the same requirements as for the initial measurements.

Annex A
(informative)

Recommended setup for managing weights during mechanical loading (MQT 16)

Many factors are known to introduce noise into test that can lead to false module failures during MQT 16. These factors include nonuniformity of loads, periodic spikes of pressure from weight placement, frequency of loading, heavy bags, flowing media in bags, and ergonomics of loading weights. In the absence of an automated system (for example, a pneumatic system) which can place the entire payload in a controlled and uniform fashion on the test module, recommendations to ensure quality control of the test methodology are indicated in this annex.

A gantry crane arrangement such as that illustrated in Figure A.1 is recommended to place the entire payload in a controlled and uniform manner onto the test module. The gantry crane should be equipped with a variable frequency drive controlled motor which can control the rate of load placement on the module. The hoist should be rated adequately to handle the expected loads and should have adequate clearance to accommodate the loading jig to be lifted above the mounting jig and placed on the module mounted into the mounting jig.

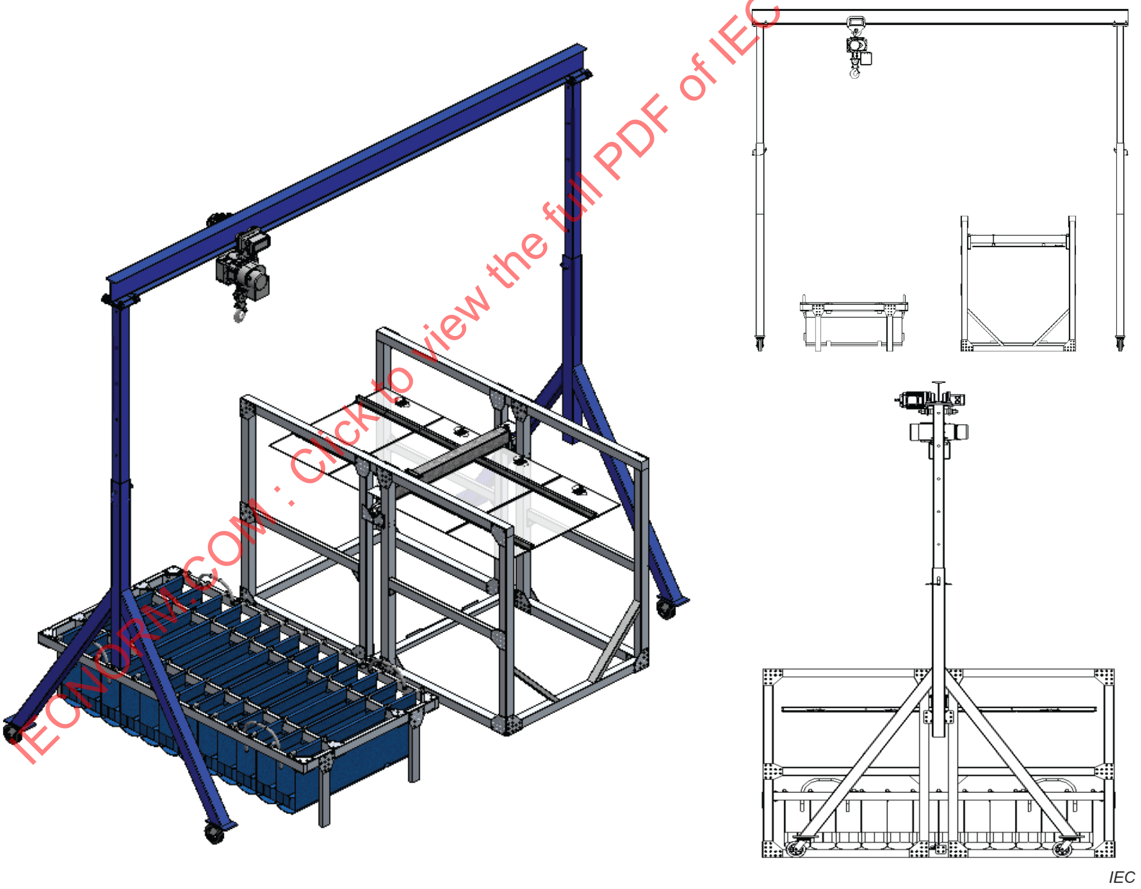


Figure A.1 – 3D view (at left of figure), end view (at top right), and side view (at bottom right) of gantry crane over mounting jig and loading jig

The mounting jig should be designed to mount the module per manufacturer requirements and should provide sufficient clearance for the load to be placed on the module surface. The mounting jig illustrated in Figure A.2 shows a module mounting arrangement on a central torque tube mounted tracker. The example jig in Figure A.2 is fabricated using T-slot aluminium extrusions. Figure A.3 illustrates a profile view of the mounting jig, which illustrates a pivoting mechanism to easily turn the module over for loading the opposite side without removing the fasteners. Alternative arrangements to accommodate a girder based tracker or purlins in fixed tilt structures are possible.

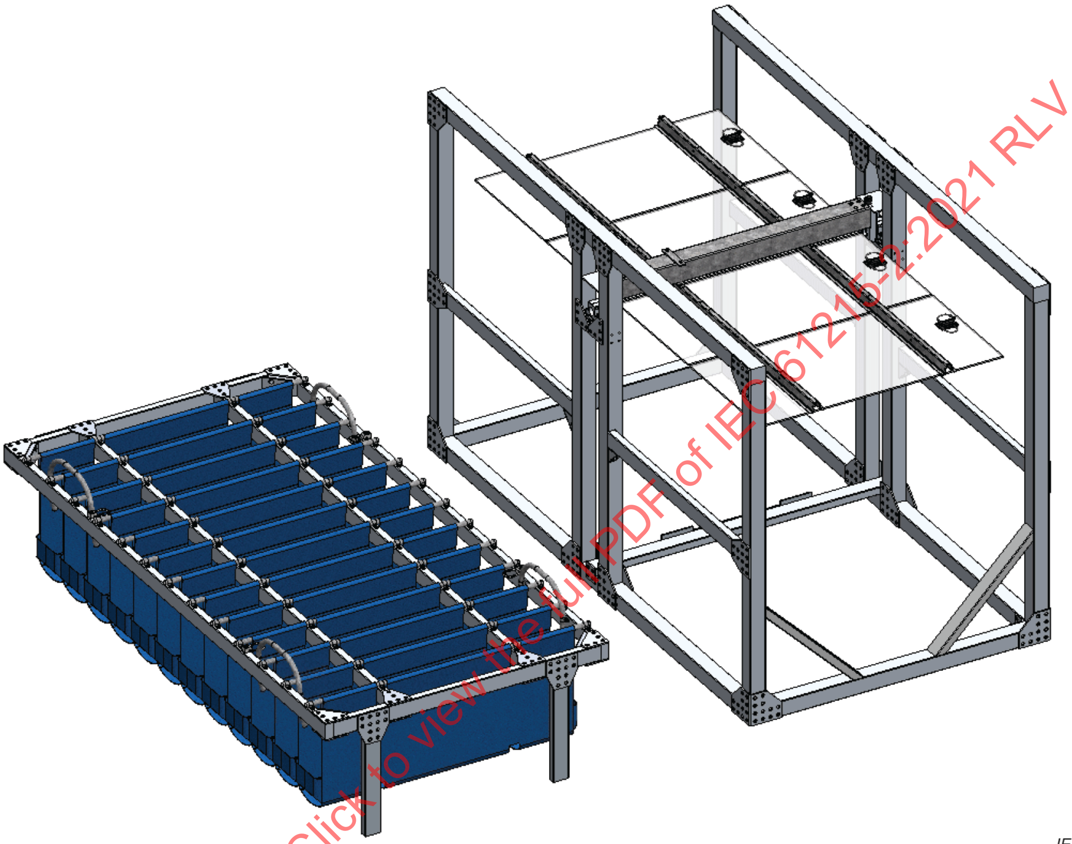


Figure A.2 – 3D close up views of mounting jig (right) and loading jig (left)

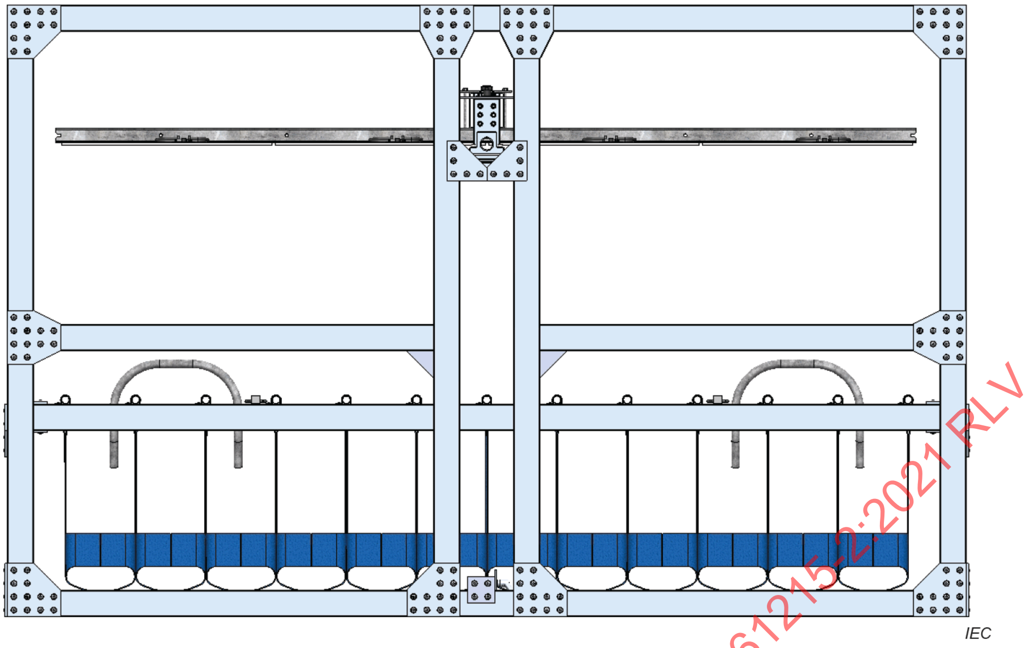


Figure A.3 – 2D view of mounting jig and loading jig

Figure A.4 and Figure A.5 show further detail of the loading jig with configurable channels where weights can be placed. The configurable channels can be fabricated from thick tarpaulin and adhesive tape, and are supported by rods. The rods can be moved on the T-slot rails of the mounting jig and clamped down by U clamps as illustrated to make room for any cross support rails in the module frame, thus avoiding loading such members. It is a critical to ensure load is not placed on frame members. The legs of the mounting jig are shorter than the depth of the channels so the weight can bottom out on the load surface before the legs make contact.

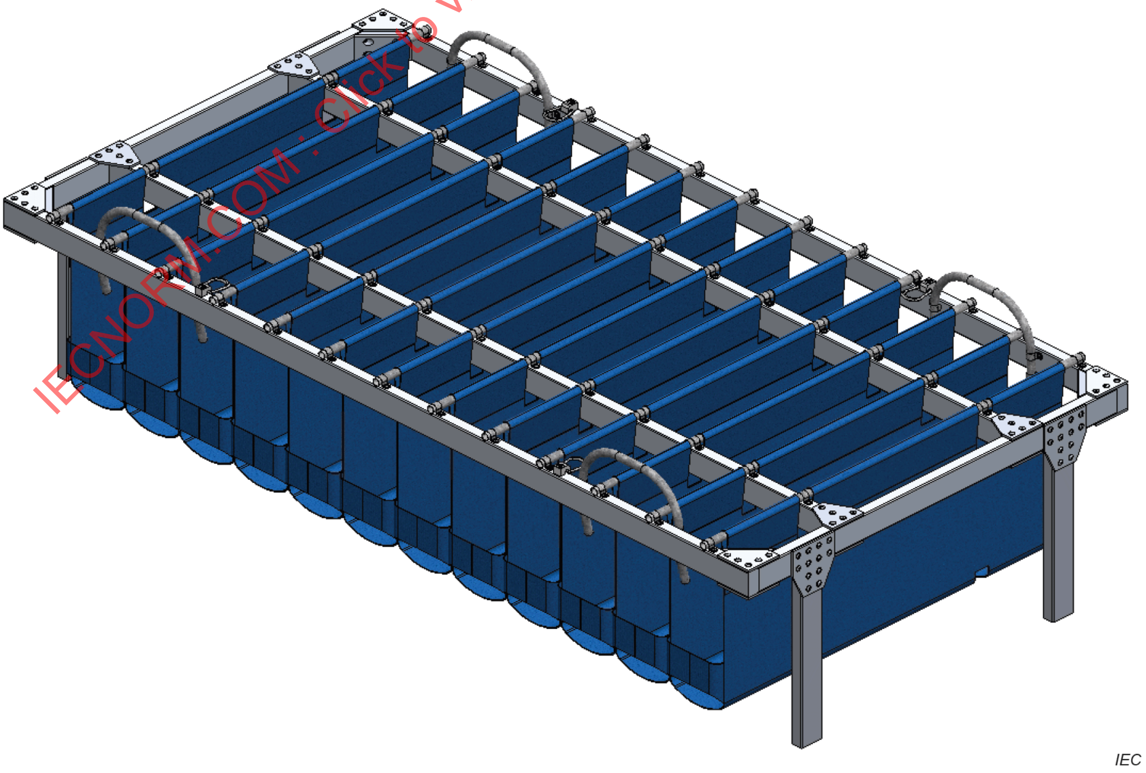


Figure A.4 – 3D view of loading jig

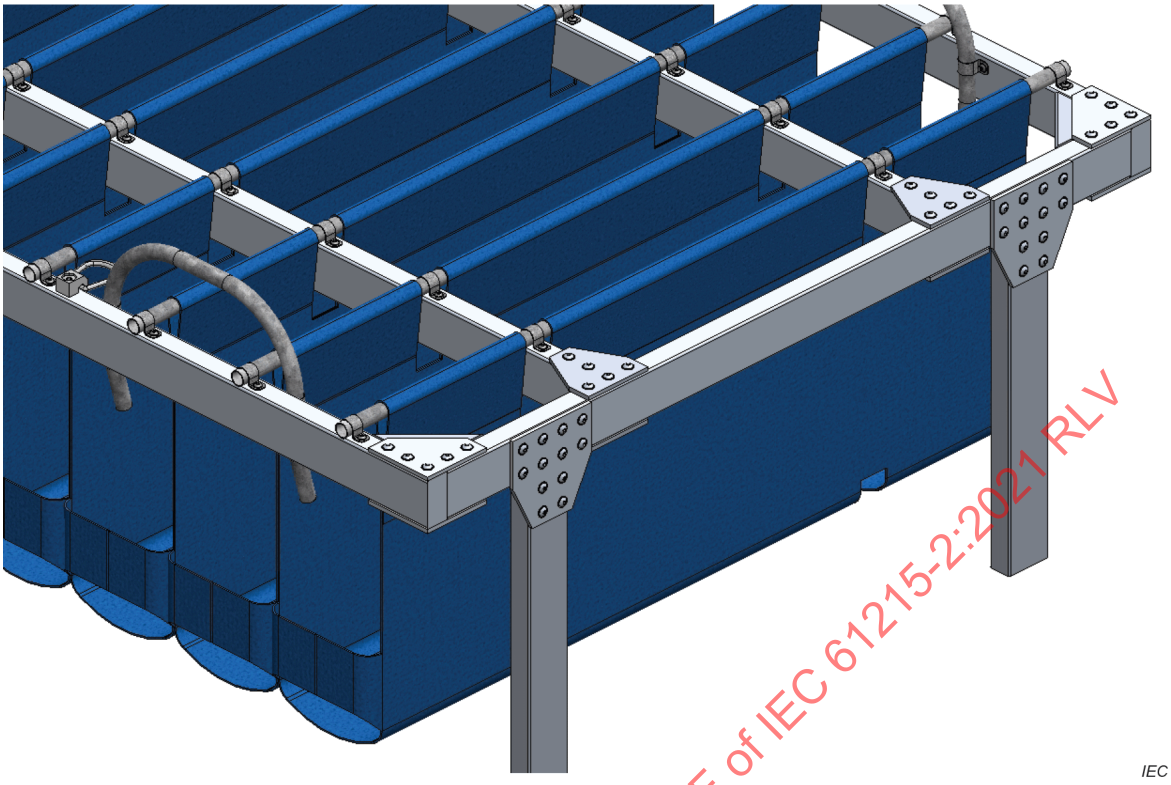


Figure A.5 – Close-up view of loading jig

While the media used for the load can vary (lead shot, sand, metal pellets, bricks etc.), some form of metal pellet is recommended as the load medium. The columnar bags should be constructed of heavy duty material, so that they can retain their shape and surface area. The size and shape of the bag chosen should be ergonomic and hold no more than 10 kg of weight. Each bag should be filled of same medium and measured by a calibrated scale prior to placing in the appropriate channel to assure a uniform load distribution on the module. Each channel should carry equal amount of weight to assure a loading uniformity of <5 % as specified in the test.

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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MODULES PHOTOVOLTAÏQUES (PV) POUR APPLICATIONS TERRESTRES – QUALIFICATION DE LA CONCEPTION ET HOMOLOGATION –

Partie 2: Procédures d'essai

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La Norme internationale IEC 61215-2 a été établie par le comité d'études 82 de l'IEC: Systèmes de conversion photovoltaïque de l'énergie solaire.

Cette deuxième édition de l'IEC 61215-2 annule et remplace la première édition de l'IEC 61215-2 parue en 2016; elle constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente.

a) Ajout de l'essai de charge mécanique cyclique (dynamique) (MQT 20 - Module Quality Test, essai de qualité du module).
b) Ajout d'un essai de détection de la dégradation induite par le potentiel (MQT 21).

c) Ajout de méthodes d'essai exigées pour les modules PV bifaces.
d) Ajout de méthodes d'essai exigées pour les modules flexibles. Cette disposition inclut l'ajout de l'essai de flexion (MQT 22).
e) Révision des exigences du simulateur pour assurer à la fois la définition appropriée et la réduction le plus possible de l'incertitude.
f) Correction de l'essai de tenue à l'échauffement localisé, dont la procédure pour les technologies à couches minces à intégration monolithique (MLI - monolithic integration) (MQT 09.2) comprenait précédemment deux sections décrivant une méthode uniquement adaptée aux modules en silicium.
g) Choix de trois diodes, plutôt que de toutes les diodes d'essai, pour l'essai thermique de la diode de dérivation (MQT 18).
h) Suppression de l'essai nominal de fonctionnement du module (NMOT - nominal module operating test), et de l'essai associé de performances à la température nominale de fonctionnement du module (NMOT - nominal module operating temperature), issus de la série IEC 61215.

L'Annexe A informative de l'IEC 61215-1:2021, explique le contexte et la justification qui sous-tendent certaines des modifications les plus significatives apportées à la série IEC 61215 lors du passage de l'édition 1 à l'édition 2.

Le texte de cette norme est issu des documents suivants:

FDIS	Rapport de vote
82/1829/FDIS	82/1853/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

La version française de la norme n'a pas été soumise au vote.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 61215, publiées sous le titre général *Modules photovoltaïques (PV) pour applications terrestres – Qualification de la conception et homologation*, peut être consultée sur le site web de l'IEC.

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INTRODUCTION

Alors que la Partie 1 de la présente série de normes décrit les exigences (de manière générale et spécifiques par rapport à la technologie du dispositif), les sous-parties de la Partie 1 définissent les variations technologiques, tandis que la Partie 2 définit un ensemble de procédures d'essai nécessaires pour la qualification de la conception et l'homologation. Les procédures d'essai décrites dans la Partie 2 sont valides pour toutes les technologies de dispositifs.

MODULES PHOTOVOLTAÏQUES (PV) POUR APPLICATIONS TERRESTRES – QUALIFICATION DE LA CONCEPTION ET HOMOLOGATION –

Partie 2: Procédures d'essai

1 Domaine d'application

Le présent document établit les exigences concernant la qualification de conception des modules photovoltaïques terrestres appropriés à un fonctionnement de longue durée dans des climats à l'air libre. La durée de vie utile des modules ainsi qualifiés dépend de leur conception, de leur environnement et de leurs conditions de fonctionnement. Les résultats d'essai ne sont pas une prévision quantitative de la durée de vie des modules.

Sous des climats pour lesquels les températures de fonctionnement du 98^{e} centile dépassent 70 °C, il est recommandé que les utilisateurs tiennent compte des essais dans des conditions d'essai à des températures plus élevées telles qu'elles sont décrites dans l'IEC TS 63126[1]. Il est recommandé que les utilisateurs qui recherchent la qualification de produits PV dont la durée de vie prévue est inférieure tiennent compte des essais conçus pour les PV de l'électronique grand public, tels qu'ils sont décrits dans l'IEC TS 63163 (en cours d'élaboration). Les utilisateurs qui souhaitent avoir l'assurance que les caractéristiques soumises à l'essai dans l'IEC 61215 apparaissent de manière constante dans un produit fabriqué peuvent souhaiter utiliser l'IEC 62941 pour ce qui concerne les systèmes de qualité pour la fabrication des modules photovoltaïques.

Le présent document est destiné à s'appliquer à tous les matériaux de modules à plaque plane pour applications terrestres, tels que les types de modules au silicium cristallin et les modules à couches minces.

Le présent document ne s'applique pas aux modules utilisés avec un ensoleillement intense, même s'il peut être utilisé pour les modules à faible concentration (ensoleillement 1 à 3). Pour les modules à faible concentration, tous les essais sont réalisés en utilisant les niveaux d'éclairement, de courant, de tension et de puissance prévus à la concentration théorique.

L'objet de cette séquence d'essais est de déterminer les caractéristiques électriques du module et d'indiquer, dans la mesure du possible avec des contraintes de coût et de temps raisonnables, que le module est capable de supporter une exposition prolongée en site naturel. Les conditions d'essais accélérés sont fondées de manière empirique sur les conditions nécessaires pour reproduire les défaillances sur le terrain observées sélectionnées et sont appliquées de manière égale aux types de modules. Les facteurs d'accélération peuvent varier avec la conception du produit et ainsi les mécanismes de dégradation peuvent ne pas tous se produire. D'autres informations générales concernant les méthodes d'essais accélérés y compris les définitions des termes peuvent être consultées dans l'IEC 62506.

Certains mécanismes de dégradation à long terme ne peuvent raisonnablement être détectés que par l'intermédiaire d'essais des composants, car une longue période est nécessaire à l'apparition des défaillances et car des conditions de contraintes chères à produire sur des zones étendues sont nécessaires. Les essais de composants qui ont atteint un niveau de maturité suffisant pour établir un degré élevé de confiance des critères d'acceptation/de refus sont intégrés dans la série IEC 61215 au sein du Tableau 1 de l'IEC 61215-1:2021. A l'inverse, les procédures d'essai décrites dans cette série sont effectuées sur des modules dans l'IEC 61215-2.

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[1] L'IEC TS 63126 donne des informations relatives aux températures de fonctionnement du 98e centile en fonction de l'emplacement du système et de la configuration du montage.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu’ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l’édition citée s’applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60068-1, *Essais d'environnement – Partie 1: Généralités et lignes directrices*

IEC 60068-2-21, *Essais d'environnement – Partie 2-21: Essais – Essai U: Robustesse des sorties et des dispositifs de montage incorporés*

IEC 60068-2-78:2012, *Essais d'environnement – Partie 2-78: Essais – Essai Cab: Chaleur humide, essai continu*

IEC 60891, *Dispositifs photovoltaïques – Procédures pour les corrections en fonction de la température et de l'éclairement à appliquer aux caractéristiques I-V mesurées*

IEC 60904-1, *Dispositifs photovoltaïques – Partie 1: Mesurage des caractéristiques courant-tension des dispositifs photovoltaïques*

IEC 60904-1-1, *Dispositifs photovoltaïques – Partie 1-1: Mesurage des caractéristiques courant-tension des dispositifs photovoltaïques (PV) multijonctions*

IEC TS 60904-1-2, *Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices* (disponible en anglais seulement)

IEC 60904-2, *Dispositifs photovoltaïques – Partie 2: Exigences applicables aux dispositifs photovoltaïques de référence*

IEC 60904-3, *Dispositifs photovoltaïques – Partie 3: Principes de mesure des dispositifs solaires photovoltaïques (PV) à usage terrestre incluant les données de l'éclairement spectral de référence*

IEC 60904-7, *Dispositifs photovoltaïques – Partie 7: Calcul de la correction de désadaptation des réponses spectrales dans les mesures de dispositifs photovoltaïques*

IEC 60904-8, *Dispositifs photovoltaïques – Partie 8: Mesure de la sensibilité spectrale d'un dispositif photovoltaïque (PV)*

IEC 60904-9:2020, *Dispositifs photovoltaïques – Partie 9: Classification des caractéristiques des simulateurs solaires*

IEC 60904-10, *Dispositifs photovoltaïques – Partie 10: Méthodes de mesure de la linéarité*

IEC TR 60904-14 *Photovoltaic devices – Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions* (disponible en anglais seulement)

IEC 61140, *Protection contre les chocs électriques - Aspects communs aux installations et aux matériels*

IEC 61215-1:2021, *Modules photovoltaïques (PV) pour applications terrestres – Qualification de la conception et homologation – Partie -1: Exigences d'essai*

IEC 61215-1-1, *Modules photovoltaïques (PV) pour applications terrestres – Qualification de la conception et homologation - Partie 1-1: Exigences particulières d'essai des modules photovoltaïques (PV) au silicium cristallin*

IEC 61730-1:2016, *Qualification pour la sûreté de fonctionnement des modules photovoltaïques (PV) – Partie 1: Exigences pour la construction*

IEC 61730-2, *Qualification pour la sûreté de fonctionnement des modules photovoltaïques (PV) – Partie 2: Exigences pour les essais*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols* (disponible en anglais seulement)

IEC TS 62782, *Photovoltaic (PV) modules – Cyclic (dynamic) mechanical load testing* (disponible en anglais seulement)

IEC 62790, *Boîtes de jonction pour modules photovoltaïques – Exigences de sécurité et essais*

IEC TS 62804-1:2015, *Photovoltaic (PV) modules – Test methods for the detection of potential-induced degradation – Part 1: Crystalline silicon* (disponible en anglais seulement)

IEC TS 63163: –[2] *Terrestrial photovoltaic (PV) modules for consumer products – Design qualification and type approval* (disponible en anglais seulement)

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions de l'IEC TS 61836 et de l'IEC 61215-1:2021, ainsi que les suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1

exactitude <d'un appareil de mesure>
qualité qui caractérise l'aptitude d'un appareil de mesure à donner une valeur indiquée proche d'une valeur vraie du mesurande [conforme au Vocabulaire International de Métrologie (VIM) 5.18]

Note 1 à l'article: Ce terme est utilisé dans l'approche "valeur vraie".

Note 2 à l'article: L'exactitude est d'autant meilleure que la valeur indiquée est plus proche de la valeur vraie correspondante.

[SOURCE: IEC 60050-311:2001, 311-06-08]

3.2

dispositif de commande
capteur d'éclairement (cellule ou module de référence, par exemple) utilisé pour détecter les dérives et autres problèmes du simulateur de rayonnement solaire

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[2] En cours d'élaboration. Stade au moment de la publication: ADTS.

3.3

niveau de sortie de puissance électriquement stable

état du module photovoltaïque (PV) dans lequel il fonctionnera sous une exposition prolongée à un éclairement solaire naturel

3.4

répétabilité <des mesures>

étroitesse de l'accord entre les résultats des mesures successives du même mesurande, effectuées dans les mêmes conditions de mesure, c'est-à-dire:

- suivant le même mode opératoire,
- par le même observateur,
- au moyen des mêmes appareils de mesure,
- utilisés dans les mêmes conditions,
- dans le même laboratoire,

à des intervalles de temps assez courts [≈ VIM 3.6].

Note 1 à l'article: La notion de "mode opératoire" est définie en 2.5 dans le VIM.

[SOURCE: IEC 60050-311:2001, 311-06-06]

3.5

point 1

comparaison des critères d'acceptation / de rejet entre les performances d'un module et ses spécifications de plaque signalétique, comme cela est décrit dans l'IEC 61215-1:2021

3.6

point 2

comparaison des critères d'acceptation / de rejet entre les performances d'un module avant et après contrainte, comme cela est décrit dans l'IEC 61215-1:2021

4 Procédures d'essai

Les paragraphes suivants fournissent des instructions détaillées sur la réalisation de chaque essai de qualité du module (MQT). L'IEC 61215-1 décrit les exigences relatives au rapport et à la séquence d'essais de qualification.

4.1 Examen visuel (MQT 01)

4.1.1 Objet

Détecter tout défaut visuel dans le module.

4.1.2 Procédure

Examiner soigneusement chaque module sous un éclairement supérieur ou égal à 1 000 lux selon les conditions et observations définies dans l'IEC 61215-1:2021.

Relever et/ou photographier tous les défauts qui peuvent être des défauts visuels majeurs, tels qu'ils sont définis dans l'IEC 61215-1. Relever et/ou photographier également la nature et l'emplacement des fêlures, bulles ou décollements interlaminaires, etc., qui peuvent se détériorer et compromettre les performances du module lors des essais qui suivent. Enregistrer toutes les autres informations pertinentes concernant l'origine de la défaillance et les conditions d'essai ou de laboratoire associées.

4.1.3 Exigences

Il n'est admis aucun défaut visuel majeur, tel que ceux définis dans l'IEC 61215-1:2021.

4.2 Détermination de la puissance maximale (MQT 02)

4.2.1 Objet

Déterminer la puissance maximale du module après stabilisation, et avant et après les différents essais de contrainte d'environnement.

4.2.2 Appareillage

a) Un appareillage de mesure des caractéristiques I-V conformément à l'IEC 60904-1.

b) Un dispositif PV de référence conforme à l'IEC 60904-2.

c) Au moins une des deux options suivantes qui permettent de réduire la composante de désadaptation des réponses spectrales de l'incertitude doit être utilisée:

- Effectuer une correction de désadaptation des réponses spectrales. La sensibilité spectrale du module doit être mesurée conformément à l'IEC 60904-8. Les données de réponse spectrale peuvent provenir du même laboratoire effectuant l'essai IEC 61215-2:2021 ou d'un autre laboratoire. L'échantillon utilisé pour obtenir les données de réponse spectrale peut être le module d'essai ou une cellule de référence fabriquée avec la même nomenclature que celle du module d'essai. La répartition spectrale du simulateur solaire doit ensuite être utilisée pour corriger la désadaptation des réponses spectrales conformément à l'IEC 60904-7.
- Utiliser une cellule ou un module de référence adapté. Le dispositif de référence doit être de la même technologie de cellule que le module d'essai pour correspondre à la sensibilité spectrale. Il n'existe pas d'exigences applicables à la taille de la cellule ou du module.

d) Une source de rayonnement: éclairement solaire naturel ou simulateur solaire de classe CAA ou meilleur conforme à l'IEC 60904-9. Pour les modules de très grande taille (définis dans l'IEC 61215-1:2021), un simulateur de classe CBA peut être utilisé.

NOTE 1 La classe CBA est définie conformément à l'IEC 60904-9. La correspondance spectrale AM1.5 est classée dans la catégorie C, la non-uniformité de l'éclairement pour la taille du module classée dans la catégorie B, et la stabilité temporelle de l'éclairement dans la catégorie A.

Pour obtenir une exactitude élevée du mesurage de puissance, il convient que la répartition de l'éclairement spectral du simulateur solaire couvre l'ensemble de la plage de longueurs d'onde couverte par la sensibilité spectrale du dispositif PV en essai. Voir l'IEC TR 60904-14 et l'IEC 60904-9:2020.

e) Un support approprié pour maintenir l'éprouvette d'essai et le dispositif de référence dans un plan perpendiculaire au rayon radiant.

NOTE 2 Les procédures de mesure de MQT 02, par exemple celles qui sont effectuées par un laboratoire d'essai certifié, sont conçues pour une incertitude minimale. Des exigences moindres, telles que l'utilisation de simulateurs de classe CAB, peuvent convenir à d'autres applications (par exemple, le contrôle de la qualité en usine). Les applications qui n'exigent que la répétabilité, comme la comparaison des performances du module avant et après une contrainte prolongée, peuvent souhaiter assouplir les exigences de correction de désadaptation des réponses spectrales.

4.2.3 Procédure

Déterminer les caractéristiques courant-tension du module conformément à l'IEC 60904-1 à un ensemble particulier de conditions de température et d'éclairement (une plage recommandée est une température de cellule comprise entre 20 °C et 50 °C et un éclairement compris entre 700 W/m^2 et 1 100 W/m^2), en utilisant l'appareillage décrit en 4.2.2. Dans des circonstances particulières, lorsque les modules sont conçus pour fonctionner dans une plage différente de conditions, les caractéristiques courant-tension peuvent être mesurées en utilisant des niveaux de température et d'éclairement similaires aux conditions de fonctionnement attendues. Pour les modules linéaires (tels que ceux définis dans l'IEC 60904-10), la température et l'éclairement peuvent être corrigés conformément à l'IEC 60891 afin de comparer des ensembles de mesurages réalisés sur le même module avant et après les essais d'environnement. Pour les modules non linéaires (tels que ceux définis dans l'IEC 60904-10), le mesurage doit être réalisé à ±5 % de l'éclairement spécifié et à ±2 °C de la température spécifiée. Cependant, il convient de veiller à réaliser les mesurages de la puissance de crête dans des conditions de fonctionnement similaires, ce qui signifie de réduire le plus possible l'amplitude de la correction en effectuant tous les mesurages de la puissance de crête sur un module particulier approximativement à la même température et au même éclairement.

Concernant les modules flexibles, la puissance maximale doit être déterminée avec le module flexible en position à plat.

4.3 Essai diélectrique (MQT 03)

4.3.1 Objet

Déterminer si oui ou non le module est suffisamment bien isolé entre les parties actives et les parties accessibles.

4.3.2 Appareillage

a) Une source de tension à courant continu disposant d'un limiteur de courant capable d'appliquer la tension spécifiée dans la troisième colonne du Tableau 1 pour les différentes classes du module.

b) Un appareil de mesure de la résistance d'isolement.

4.3.3 Conditions d'essai

L'essai doit être réalisé sur les modules à la température ambiante de l'atmosphère environnante (voir l'IEC 60068-1) et à une humidité relative ne dépassant pas 75 %.

Les niveaux de contrainte de tension appliqués au module sont déterminés par la tension maximale du réseau (V_{sys}) du module, la classe du module et la présence ou non de joints collés. Les définitions des classes de module sont issues de l'IEC 61140, et sont traitées en relation avec les modules PV à l'Article 4 de l'IEC 61730-1:2016. La définition des joints collés est donnée en 3.4.2 de l'IEC 61730-1:2016, et est par ailleurs traitée dans les Articles B.5 et B.9 de l'IEC 61730-1:2016. Les niveaux de contrainte de tension appliqués dans cet essai sont les mêmes que ceux appliqués pour le MST 16 de l'IEC 61730-2.

4.3.4 Procédure

a) Connecter les bornes de sortie court-circuitées du module à la borne positive d'un dispositif d'essai diélectrique à courant continu disposant d'un limiteur de courant.

b) Connecter les parties métalliques exposées du module à la borne négative du dispositif d'essai. Si le module n'a pas de cadre ou que le cadre est un faible conducteur, envelopper les bords d'une feuille conductrice. Connecter les parties recouvertes de feuille à la borne négative du dispositif d'essai.

c) Certaines technologies de modules peuvent être sensibles à la polarisation statique si le module est fixé au cadre à une tension positive. Dans ce cas, la connexion du dispositif d'essai doit être effectuée dans l'autre sens. S'il y a lieu, le fabricant doit fournir les informations relatives à la sensibilité à la polarisation statique, et ces informations doivent être consignées dans le rapport d'essai.

d) Relever la tension de "préconditionnement d'une minute", V_{Test1}, de la troisième colonne du Tableau 1. Augmenter la tension appliquée par le dispositif d'essai à une vitesse qui ne dépasse pas 500 V/s jusqu'à une tension maximale égale à V_{Test1}. Maintenir la tension à ce niveau pendant 1 min.

e) Ramener la tension appliquée à zéro, puis court-circuiter les bornes de l'équipement d'essai afin de décharger la tension produite dans le module.

f) Enlever le court-circuit.

g) Relever la tension de "contrainte de deux minutes", V_{Test2}, de la quatrième colonne du Tableau 1. Augmenter la tension appliquée par l'équipement d'essai à une vitesse qui ne dépasse pas 500 V/s jusqu'à la tension V_{Test2}. Maintenir la tension à ce niveau pendant 2 min, puis mesurer la résistance d'isolement.

h) Ramener la tension appliquée à zéro, puis court-circuiter les bornes de l'équipement d'essai afin de décharger la tension produite dans le module.

i) Enlever le court-circuit et déconnecter l'équipement d'essai du module.

Tableau 1 – Niveaux de contrainte de tension

Classe du module	Les joints collés sont-ils présents?	Préconditionnement d'1 min V_{Test1} V	Contrainte de 2 min pour le mesurage de la résistance d'isolement, V_{Test2} V
0	Non	1 000 + 2 x V_{sys}	Valeur la plus élevée entre 500 et V_{sys}
II	Non	2 000 + 4 x V_{sys}	Valeur la plus élevée entre 500 et V_{sys}
III	Non	500	500
0	Oui	1,35 x (1 000 + 2 x V_{sys})	Valeur la plus élevée entre 500 et V_{sys}
II	Oui	1,35 x (2 000 + 4 x V_{sys})	Valeur la plus élevée entre 500 et V_{sys}
III	Oui	1,35 x (500)	500

4.3.5 Exigences d'essai

a) Il n'existe aucun signe de rupture diélectrique ou de cheminement superficiel.

b) Pour les modules dont la surface est inférieure à 0,1 m^2, la résistance d'isolement ne doit pas être inférieure à 400 MΩ.

c) Pour les modules dont la surface est supérieure à 0,1 m^2, le produit de la résistance d'isolement mesurée et de la surface du module ne doit pas être inférieur à 40 MΩ·m^2.

4.4 Mesurage des coefficients de température (MQT 04)

Déterminer les coefficients de température du courant (α), de la tension (β) et de la puissance de crête (δ) à partir des mesurages de modules spécifiés dans l'IEC 60891. Les coefficients ainsi déterminés sont valables pour l'éclairement sous lequel les mesurages ont été effectués. Voir l'IEC 60904-10 pour l'évaluation des coefficients de température du module à différents niveaux d'éclairement. Pour les modules bifaces, déterminer les coefficients de température en appliquant la même procédure, mais en évitant toute irradiation par la face arrière. La face arrière doit être couverte de sorte que la contribution de la face non exposée du module soit limitée ou inférieure aux niveaux spécifiés dans l'IEC TS 60904-1-2 pour l' "arrière non illuminé". Si la tension en circuit ouvert ou le courant de court-circuit ne peut pas être mesuré en raison de l'électronique intégrée au module, le coefficient de température associé doit être consigné comme "non mesurable en raison de l'électronique intégrée au module". La tension en circuit ouvert ou le courant de court-circuit ne doit pas être déterminé par une méthode autre que le mesurage direct (l'extrapolation, par exemple).

NOTE Pour les modules linéaires conformes à l'IEC 60904-10, les coefficients de température sont valables dans une plage d'éclairement à ±30 % de ce niveau.

4.5 Espace réservé, auparavant NMOT

L'essai de température nominale de fonctionnement du module (NMOT, *nominal module operating temperature*), auparavant MQT 05, ne fait plus partie du présent document. Ce paragraphe est conservé afin que, dans les paragraphes suivants du document, les numéros des MQT soient en accord avec les numéros des paragraphes.

4.6 Performances dans les STC (MQT 06.1)

4.6.1 Objet

Déterminer la variation des performances électriques du module sous charge dans les STC (1 000 W/m^2, température de cellule de 25 °C, avec une répartition de l'éclairement spectral solaire de référence selon l'IEC 60904-3). L'essai MQT 06.1 est un cas de détermination de la puissance maximale (MQT 02) réalisée dans les STC. L'essai MQT 06.1 sert à vérifier les informations de la plaque signalétique du module et à déterminer la perte de puissance résultant des essais de contrainte. L'incertitude, m_1, doit inclure une composante issue de la désadaptation des réponses spectrales, fondée soit sur la réponse spectrale mesurée, soit sur le cas le plus défavorable pour un type de technologie donné, et la méthode utilisée pour régler l'intensité du simulateur. Pour vérifier la plaque signalétique, l'incertitude m_1 est soumise aux limites spécifiées dans les parties de la présente norme spécifiques à la technologie. Pour déterminer la perte de puissance à partir des essais de contrainte, la reproductibilité de l'essai, r, est soumise aux limites spécifiées dans les parties de la présente série de normes spécifiques à la technologie.

4.6.2 Appareillage

a) L'appareillage doit être celui décrit en 4.2.2 (MQT 02).

b) Il doit être aussi équipé d'un dispositif permettant de contrôler la température de l'éprouvette d'essai et du dispositif de référence avec une exactitude de ±1 °C et une répétabilité de ±0,5 °C.

c) Pour le mesurage des modules bifaces, la capacité suivante est également nécessaire: La source de rayonnement utilisée comme cela est spécifié en 4.6.2a doit pouvoir fonctionner avec des niveaux d'éclairement et/ou un éclairement arrière réglables, de sorte que le BNPI (défini dans l'IEC 61215-1:2021) puisse être appliqué selon au moins une méthode admise par l'IEC TS 60904-1-2.

d) Pour le mesurage des modules multijonctions, le simulateur et le dispositif de référence doivent satisfaire aux exigences supplémentaires imposées par l'IEC 60904-1-1.

4.6.3 Procédure de mesure dans les STC (MQT 06.1)

Maintenir le module à (25 ± 2) °C et tracer ses caractéristiques courant-tension sous un éclairement de (1 000 ± 100) W/m^2 (mesuré par un dispositif de référence adapté) selon l'IEC 60904-1, en utilisant l'appareillage décrit en 4.6.2.

Une température de module doit être corrigée à 25 °C en utilisant les coefficients de température, la série IEC 60904 et l'IEC 60891.

Pour les modules bifaces, les mesurages doivent se dérouler comme cela est spécifié dans l'IEC TS 60904-1-2. Le MQT 06 doit être effectué dans les STC et au BNPI à éclairement élevé pour le point 1. Chaque fois que le MQT 06 est effectué dans les STC, les coefficients de bifacialité dans les STC du courant de court-circuit ($\varphi_{I\text{sc}} = I_{\text{scr}} / I_{\text{scf}}$), de la tension en circuit ouvert ($\varphi_{V\text{oc}} = V_{\text{ocr}} / V_{\text{ocf}}$) et de la puissance ($\varphi_{P\text{max}} = P_{\text{maxr}} / P_{\text{maxf}}$) doivent être mesurés conformément à l'IEC TS 60904-1-2. La définition complète de ces grandeurs, la méthode permettant de les mesurer et les symboles utilisés pour les décrire sont spécifiés dans l'IEC TS 60904-1-2. Lors de l'évaluation du point 2, (c'est-à-dire après contrainte), le MQT 06 doit être effectué au BNPI. Après contrainte, il n'est pas nécessaire de mesurer à nouveau les coefficients de bifacialité, sauf si cela est spécifiquement indiqué dans la procédure de l'essai de contrainte MQT. Les coefficients de bifacialité mesurés avant contrainte peuvent être utilisés pour calculer l'intensité équivalente appropriée lors d'un mesurage d'éclairement monoface. Pendant l'application du MQT 06 au BNPI, toute méthode décrite dans l'IEC 60891 peut être utilisée afin de corriger l'éclairement appliqué pour obtenir l'éclairement équivalent désiré de la face avant, tant que les exigences relatives à l'incertitude maximale m_1 sont satisfaites.

NOTE 1 L'utilisation de méthodes de l'IEC 60891 pour corriger l'éclairement appliqué pour obtenir l'éclairement équivalent désiré de la face avant peut aider le dispositif d'essai à éviter l'utilisation d'un étalonnage différent du simulateur pour chaque module dont le coefficient de bifacialité est légèrement différent.

NOTE 2 Le mesurage de la performance au BSI n'est pas exigé. Lorsque les niveaux de contrainte sont fixés conformément au BSI, les courants peuvent être extrapolés à partir des intensités inférieures, comme cela est spécifiquement décrit dans les MQT qui utilisent le BSI pour les modules bifaces.

Concernant les modules flexibles, la puissance maximale doit être déterminée avec le module flexible en position à plat (c'est-à-dire complètement déplié). Pour les modules de très grande taille (définis dans l'IEC 61215-1:2021), des essais certifiés peuvent être effectués par l'organisme d'essai dans les installations du fabricant, mais doivent toujours satisfaire aux exigences énoncées en 4.6.2.

Pour les modules multijonctions, les mesurages doivent se dérouler comme cela est spécifié dans l'IEC TS 60904-1-1.

4.7 Performances sous faible éclairement (MQT 07)

4.7.1 Objet

Déterminer la variation des performances électriques du module sous charge à 25 °C et sous un éclairement de 200 W/m^2.

4.7.2 Appareillage

a) L'appareillage doit être celui décrit en 4.2.2 (MQT 02).

L'appareillage doit également comporter les équipements suivants:

b) Équipement nécessaire pour modifier l'éclairement à 200 W/m^2 sans affecter la répartition relative de l'éclairement spectral et l'uniformité spatiale conformément à l'IEC 60904-10.

c) Un dispositif permettant de contrôler la température de l'éprouvette d'essai et du dispositif de référence avec une exactitude de ±1 °C et une répétabilité de ±0,5 °C.

d) Les équipements suivants sont également nécessaires pour le mesurage des modules bifaces: Il s'agit des déflecteurs pouvant être disposés autour des bords des modules, ainsi qu'un cache non réfléchissant permettant de bloquer temporairement l'éclairement en direction du côté opposé du module, afin d'évaluer les performances avant et arrière des modules bifaces individuellement.

e) Pour le mesurage des modules multijonctions, le simulateur et le dispositif de référence doivent satisfaire aux exigences supplémentaires imposées par l'IEC 60904-1-1.

4.7.3 Procédure

Déterminer les caractéristiques courant-tension du module à (25 ± 2) °C et sous un éclairement de (200 ± 20) W/m^2 (commandé par un dispositif de référence adapté) selon l'IEC 60904-1, en utilisant l'appareillage spécifié en 4.7.2. L'éclairement doit être réduit au niveau spécifié en utilisant des filtres de densité neutres ou une autre technique qui n'affecte pas la répartition de l'éclairement spectral. (Voir l'IEC 60904-10 pour des recommandations relatives à la réduction de l'éclairement sans modifier la répartition de l'éclairement spectral).

Une température de module doit être corrigée à 25 °C en utilisant les coefficients de température, la série IEC 60904 et l'IEC 60891.

Concernant les modules flexibles, la puissance maximale doit être déterminée avec le module flexible en position à plat (c'est-à-dire complètement déplié). Pour les modules de très grande taille (définis dans l'IEC 61215-1:2021), des essais certifiés peuvent être effectués par l'organisme d'essai dans les installations du fabricant, mais doivent toujours satisfaire aux exigences énoncées en 4.7.2.

Pour les modules bifaces, effectuer deux mesurages monofaces à 200 W/m^2, l'un sur la face avant et l'autre sur la face arrière, à l'aide de déflecteurs et d'un écran de couverture arrière. Calculer les coefficients de bifacialité sous faible éclairement conformément à la procédure spécifiée dans l'IEC TS 60904-1-2, à l'exception de l'application d'un éclairement de 200 W/m^2 au lieu de 1 000 W/m^2.

Pour les modules multijonctions, les mesurages doivent se dérouler comme cela est spécifié dans l'IEC TS 60904-1-1.

4.8 Essai d'exposition en site naturel (MQT 08)

4.8.1 Objet

Procéder à une évaluation préliminaire de l'aptitude du module à supporter une exposition dans des conditions de site naturel, et révéler les effets d'une dégradation synergétique qui peuvent ne pas être détectés par des essais en laboratoire.

4.8.2 Appareillage

a) Une structure dégagée pour maintenir le ou les modules d'essai et le moniteur d'irradiation solaire de la manière spécifiée. La structure doit être conçue pour réduire le plus possible la conduction thermique dégagée par les modules et pour interférer aussi peu que possible avec le libre rayonnement de chaleur provenant de leurs faces avant et arrière.

   Si les modules ne sont pas conçus pour être montés sur une structure dégagée, le ou les modules d'essai doivent être montés conformément aux recommandations du fabricant.

b) Un moniteur d'irradiation solaire exact à ±5 %, monté dans le plan du ou des modules à 0,3 m du dispositif d'essai.

c) Des dispositifs pour monter le module, conformément aux recommandations du fabricant, dans le même plan que le moniteur d'irradiation.

d) Une charge résistive aux dimensions telles que le module fonctionne près de son point de puissance maximale ou un dispositif électronique de suivi du point de puissance maximale (MPPT, *maximum power point tracker*).

4.8.3 Procédure

a) Le ou les modules d'essai doivent être placés perpendiculairement à la latitude locale ±5°. Noter l'angle d'inclinaison du module d'essai dans le rapport d'essai.

b) Fixer la charge résistive ou le dispositif électronique de suivi du point de puissance maximale au module, puis installer le module dans des conditions de site naturel conformément aux recommandations du fabricant, dans le même plan que le moniteur d'irradiation. Des dispositifs de protection contre les échauffements localisés recommandés par le fabricant doivent être installés avant de soumettre le module à l'essai.

c) Exposer le module à une irradiation (mesurée par le moniteur) d'au moins 60 kWh/m^2.

Les modules d'essai peuvent être nettoyés conformément aux instructions du fabricant, pendant ou après l'essai.

4.8.4 Mesurages finaux

Répéter les essais MQT 01 et MQT 15.

4.8.5 Exigences

a) Aucun défaut visuel majeur, tel que ceux définis dans l'IEC 61215-1:2021.

b) Le courant de fuite en milieu humide doit satisfaire aux mêmes exigences que pour les mesurages initiaux.

4.9 Essai de tenue à l'échauffement localisé (MQT 09)

4.9.1 Objet

Déterminer l'aptitude du module à supporter les effets d'un échauffement localisé en cas de polarisation inverse dus, par exemple, à la fusion d'une soudure ou à la détérioration de l'encapsulant. Ce défaut peut être provoqué par des cellules défectueuses, incompatibles ou obturées. Bien que la température absolue et la perte de puissance relative ne constituent pas des critères pour cet essai, les conditions d'échauffement localisé les plus défavorables sont utilisées pour garantir la sécurité de la conception.

4.9.2 Effet de l'échauffement localisé

L'échauffement localisé en cas de polarisation inverse d'un module se produit lorsque son courant de fonctionnement excède le courant de court-circuit (I_{sc}) réduit d'une cellule ou d'un groupe de cellules ombré ou défectueux. Lorsqu'une telle condition survient, la cellule ou le groupe de cellules affectées se retrouvent polarisés en inverse et doivent dissiper de la puissance, ce qui peut entraîner un échauffement.

Si la puissance dissipée est suffisamment élevée ou localisée, la ou les cellules polarisées en inverse peuvent s'échauffer, donnant ainsi lieu – selon la technologie utilisée – à une fusion de la soudure, une détérioration de l'encapsulant, une détérioration de la face avant et/ou arrière ou une fissuration du superstrat, du substrat et/ou du verre protecteur. La bonne utilisation des diodes de dérivation peut empêcher les dommages résultant d'un échauffement localisé.

Les caractéristiques inverses des cellules solaires peuvent varier considérablement. Les cellules peuvent faire l'objet soit d'une résistance shunt élevée lorsque les performances inverses sont limitées par la tension, soit d'une résistance shunt faible lorsque les performances inverses sont limitées par le courant. Chacun de ces types de cellules peut, de manière différente, être confronté à des problèmes d'échauffement localisé.

Cellules à faible résistance shunt:

- Les conditions d'ombrage les plus défavorables se produisent lorsque l'intégralité (ou une grande partie) de la cellule est ombrée.
- Souvent, les cellules à faible résistance shunt se présentent ainsi à cause de shunts localisés. Dans ce cas, un échauffement localisé se produit, car une grande quantité de courant traverse une zone réduite. Ce phénomène étant localisé, ce type de cellule présente un risque élevé de dispersion des performances. Les cellules dont la résistance shunt est la plus faible présentent une forte probabilité de fonctionner à des températures excessivement élevées en cas de polarisation inverse.
- L'échauffement étant localisé, les défaillances résultant d'un échauffement localisé des cellules à faible résistance shunt se produisent rapidement.

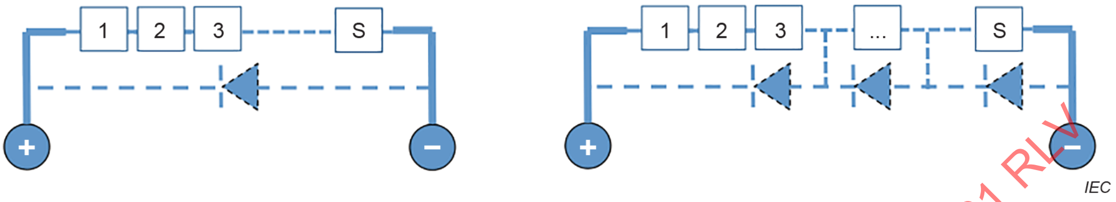
Le principal problème technique consiste à identifier les cellules dont la résistance shunt est la plus faible, puis à déterminer les conditions d'obturation les plus défavorables pour ces cellules. Ce processus dépend de la technologie et est traité dans les parties spécifiques à la technologie de la présente série de normes.

Cellules à résistance shunt élevée:

- Les conditions d'ombrage les plus défavorables se produisent lorsque la cellule est partiellement ombrée.
- Le claquage de la jonction et les températures élevées se produisent plus rarement. Il est nécessaire que l'ombrage demeure en place pendant un certain temps avant de produire un échauffement localisé le plus défavorable.

4.9.3 Classification des interconnexions de cellules

Cas S: Connexion en série de toutes les cellules dans une seule chaîne (ou branche). Voir Figure 1. Les modules à cellules connectées en série peuvent être protégés par une seule diode de dérivation (Figure 1, à gauche) ou plusieurs diodes de dérivation (Figure 1, à droite).



L’exemple présente un module protégé par une diode de dérivation (gauche) ou trois diodes de dérivation (droite).

Figure 1 – Cas S, connexion en série avec diode de dérivation facultative

Cas PS: Connexion en parallèle-série, c'est-à-dire une connexion en série de blocs (S), où chaque bloc est composé d'une connexion en parallèle d'un certain nombre de cellules (P). Voir Figure 2.

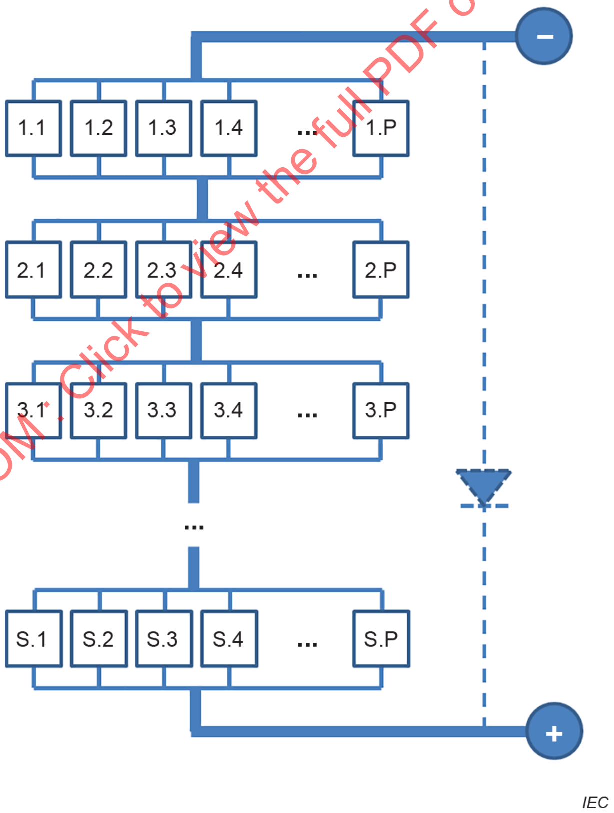


Figure 2 – Cas PS, connexion en parallèle-série avec diode de dérivation facultative

Cas SP: Connexion en série parallèle, c'est-à-dire une connexion en parallèle de blocs (P), où chaque bloc est composé d'une connexion en série d'un certain nombre de cellules (S). Voir Figure 3.

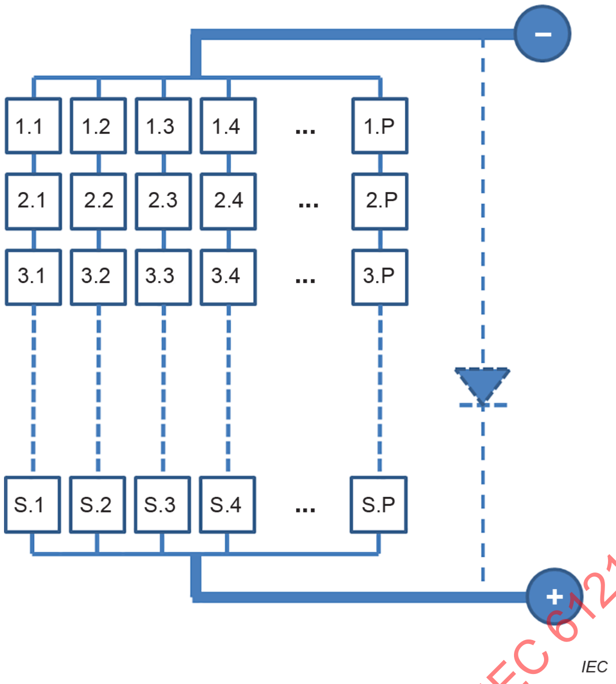


Figure 3 – Cas SP, connexion en série-parallèle avec diode de dérivation facultative

Chaque configuration exige une procédure particulière d'essai de tenue à l'échauffement localisé.

4.9.4 Appareillage

a) Source de rayonnement: Éclairement solaire naturel, ou simulateur solaire à éclairement continu de classe BBB (ou meilleur) conforme à l'IEC 60904-9. L'éclairement de l'une ou l'autre source de rayonnement doit être de (1 000 ± 100) W/m^2. Cette source de rayonnement est utilisée pour appliquer une contrainte de longue durée lorsque les conditions d'ombrage les plus défavorables ont été appliquées au module. Cette source de rayonnement peut être utilisée pour le choix des cellules pour l'ombrage, ou le simulateur pulsé facultatif (décrit en 4.9.4g)) peut être utilisé pour le choix des cellules.

Pour les modules bifaces, la source de rayonnement utilisée pour les expositions prolongées doit pouvoir fonctionner avec des niveaux d'éclairement et/ou un éclairement arrière réglables, de sorte que le BSI (défini dans l'IEC 61215-1:2021) puisse être appliqué selon au moins une méthode admise par l'IEC TS 60904-1-2. La tolérance de l'éclairement total, qu'elle soit appliquée dans une configuration monoface ou double face, ne doit pas dépasser ±50 W/m^2.

b) Un traceur de courbe I-V de module.

c) Un équipement de mesure du courant.

d) Des caches complètement opaques pour ombrer les cellules d'essai.

e) Une caméra infrarouge pour mesurer et enregistrer les températures de module. La caméra doit pouvoir fonctionner de sorte que la résolution des caractéristiques soit inférieure à celle d'une seule cellule.

f) Un équipement pour enregistrer les niveaux d'éclairement, la valeur intégrée de l'éclairement et la température ambiante.

Équipement facultatif:

g) Pour le choix des cellules plus sensibles à l'échauffement localisé, un simulateur pulsé de classe BBB ou meilleurconforme à l'IEC 60904-9 avec un éclairement compris entre 800 W/m^2 et 1 100 W/m^2 pour mesurer les performances I-V peut être utilisé.

4.9.5 Procédure

4.9.5.1 Généralités

Selon la technologie de cellule solaire et le procédé de fabrication utilisés, il existe deux procédures. La procédure MQT 09.1 s'applique habituellement aux technologies fondées sur des plaques (WBT, Wafer-Based Technologies) comme le silicium cristallin normalisé. La procédure MQT 09.2 s'applique aux technologies à couches minces à intégration monolithique (MLI, MonoLithically Integrated) les plus répandues (CdTe, CIGS, a-Si). Les modules bifaces doivent également être soumis à l'essai à l'aide de la procédure MQT 09.1.

Si l'essai MQT 09.1 est effectué à l'aide d'un échantillon représentatif, celui-ci doit comporter le même nombre de cellules par diode de dérivation que le produit en taille réelle. En fonction de l'effectif d'échantillon, cette exigence peut affecter le choix de la source de rayonnement nécessaire pour réaliser l'essai.

Pour toutes les technologies, le choix des dimensions et de l'emplacement de l'ombrage est effectué dans une plage d'éclairement comprise entre 800 W/m^2 et 1 100 W/m^2. L'application de la contrainte prolongée est effectuée avec les spécifications d'éclairement plus strictes décrites en 4.9.4 a).

4.9.5.2 Procédure pour les technologies fondées sur des plaques (WBT) MQT 09.1

La première étape de la procédure consiste à sélectionner les cellules présentant les résistances shunt les plus faibles et les plus élevées (détaillées aux étapes c), d) et e) ci-dessous). Si le circuit du module est accessible, la circulation du courant à travers la cellule ombrée peut être contrôlée directement. Si les modules PV à soumettre à l'essai ne comportent pas de diodes amovibles ou de circuits électriques accessibles, la méthode non intrusive suivante peut être utilisée.

L'approche sélectionnée repose sur la prise en compte d'un ensemble de courbes I-V pour un module dont chaque cellule est tour à tour ombrée. La Figure 4 représente l'ensemble de courbes I-V obtenu pour un échantillon de module. La courbe présentant le courant de fuite le plus élevé au point d'activation de la diode a été prise en compte lors de l'ombrage de la cellule présentant la résistance shunt la plus faible. La courbe présentant le courant de fuite le plus faible au point d'activation de la diode a été prise en compte lors de l'ombrage de la cellule présentant la résistance shunt la plus élevée.