UL 61215-2

STANDARD FOR SAFETY

Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 2: Test Procedures

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UL Standard for Safety for Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 2: Test Procedures, UL 61215-2

Second Edition, Dated July 28, 2021

Summary of Topics

UL 61215-2 is an adoption of IEC 61215-2, Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 2: Test Procedures (Second Edition, issued February 2021). Please note that there are no National Differences.

The requirements are substantially in accordance with Proposal(s) on this subject dated May 21, 2021.

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UL 61215-2

Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 2: Test Procedures

First Edition – February, 2017

Second Edition

July 28, 2021

This ANSI/UL Standard for Safety consists of the Second Edition.

The most recent designation of ANSI/UL 61215-2 as an American National Standard (ANSI) occurred on July 7, 2021. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, or Preface. The IEC Foreword is also excluded from the ANSI approval of IEC-based standards.

Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at https://csds.ul.com.

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PREFACE

This UL Standard is based on IEC Publication IEC 61215-2: Second edition Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 2: Test Procedures. IEC publication IEC 61215-2 is copyrighted by the IEC.

This edition has been issued to satisfy UL Standards policy.

This is the UL Standard for Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 2: Test Procedures. UL 61215-2 is to be used in conjunction with the second edition of UL 61215-1.

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Note – Although the intended primary application of this Standard is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.

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FOREWORD

INTERNATIONAL ELECTROTECHNICAL COMMISSION

TERRESTRIAL PHOTOVOLTAIC (PV) MODULES – DESIGN QUALIFICATION AND TYPE APPROVAL – Part 2: Test procedures

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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 standard can be found in the report on voting indicated in the above table.

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

A list of all parts in the IEC 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 publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

• reconfirmed,

• withdrawn,

• replaced by a revised edition, or

• amended.

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INTRODUCTION

Whereas Part 1 of this standard 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.

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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.

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

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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.

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*

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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*

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

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 sun 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,

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– 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
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.

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.

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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.

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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 VTest1. 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.

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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.

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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 ($\varphi_{Isc} = I_{scr} / I_{scf}$), of open circuit voltage ($\varphi_{Voc} = V_{ocr} / V_{ocf}$), and of power ($\varphi_{Pmax} = P_{maxr} / P_{maxf}$) 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.

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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.

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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.

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

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4.9 Hot-spot endurance test (MQT 09)

4.9.1 Purpose

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

High shunt resistance cells:

• The worst case shadowing conditions occur when the cell is partially shaded.

• Junction breakdown and high temperatures occur more slowly. The shading 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.

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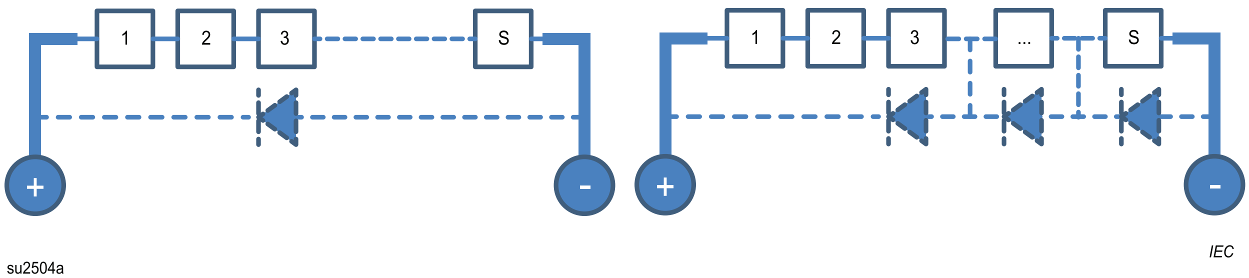

For the example a module protected by one bypass diode (left) or three bypass diodes (right).

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.

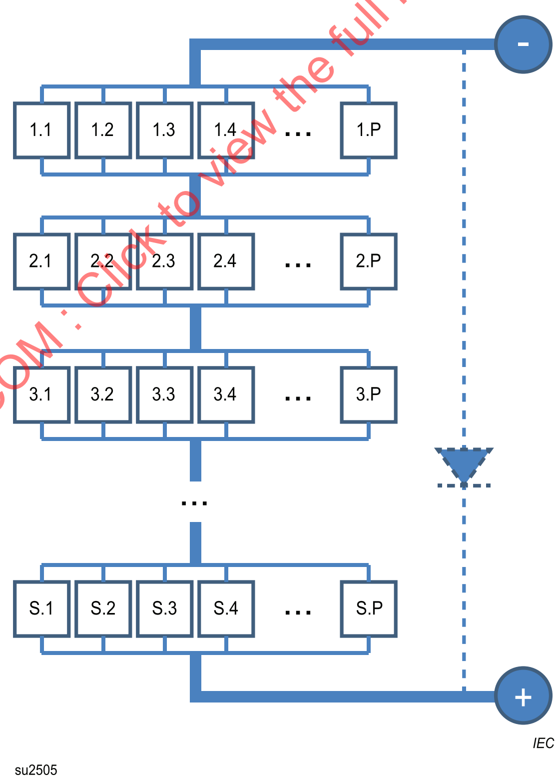

Figure 2

Case PS, parallel-series connection with optional bypass diode

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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.

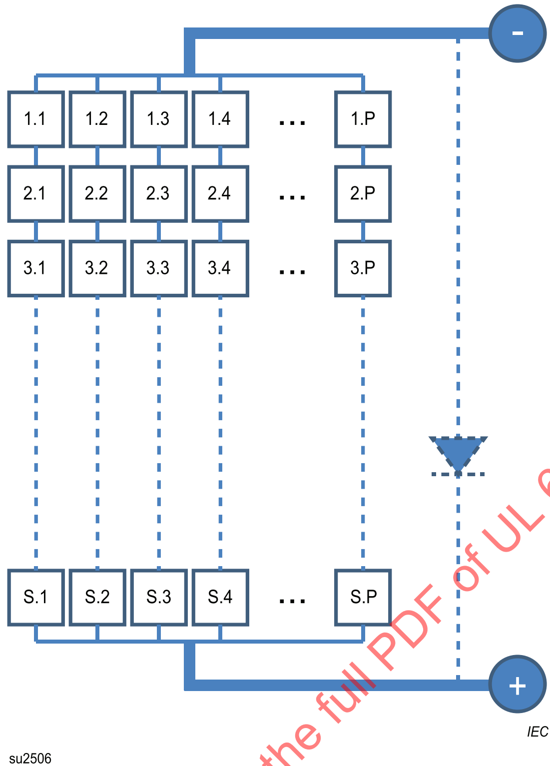

Figure 3

Case SP, series-parallel connection with optional bypass diode

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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.

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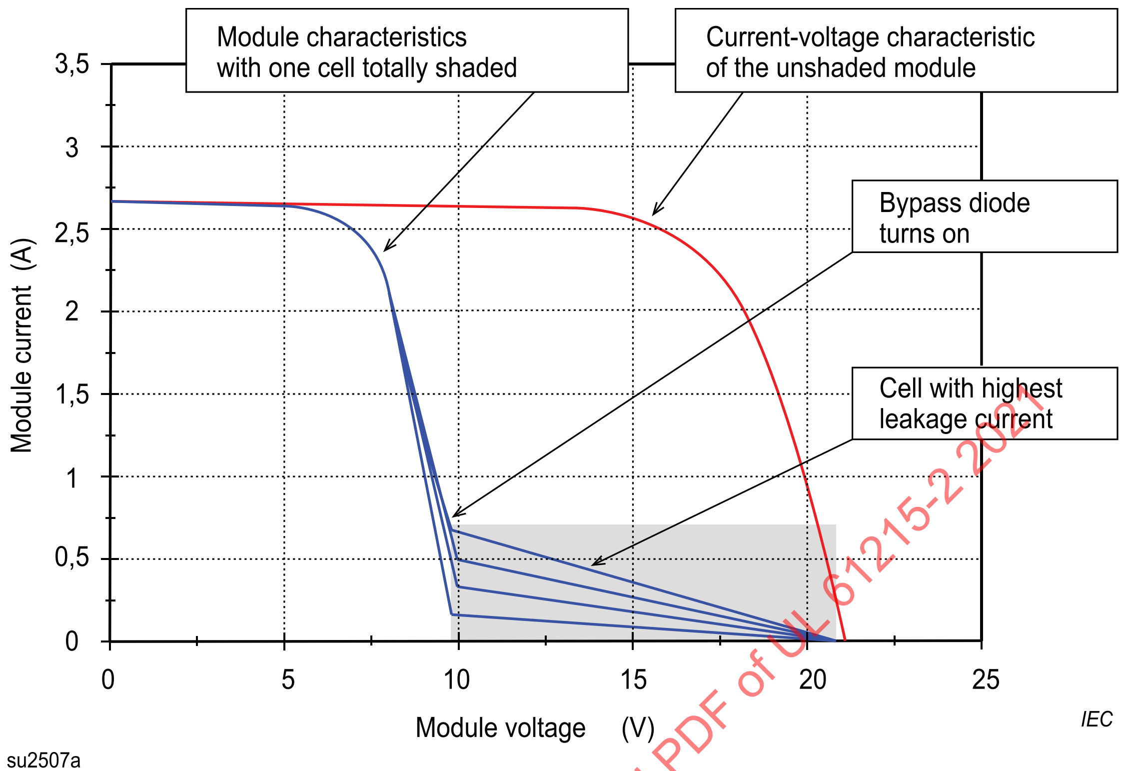

Figure 4

Module I-V characteristics with different cells totally shadowed

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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).

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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).

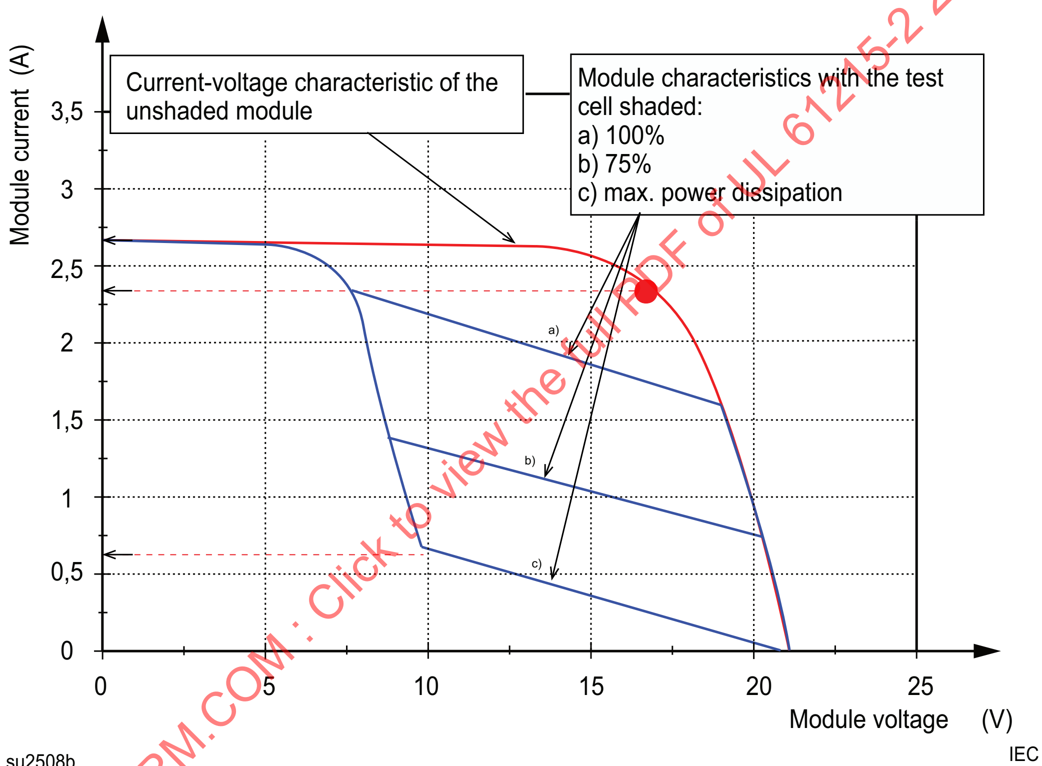

Figure 5

Module *I-V* characteristics with the test cell shadowed at different levels

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

4.9.5.3.1 General

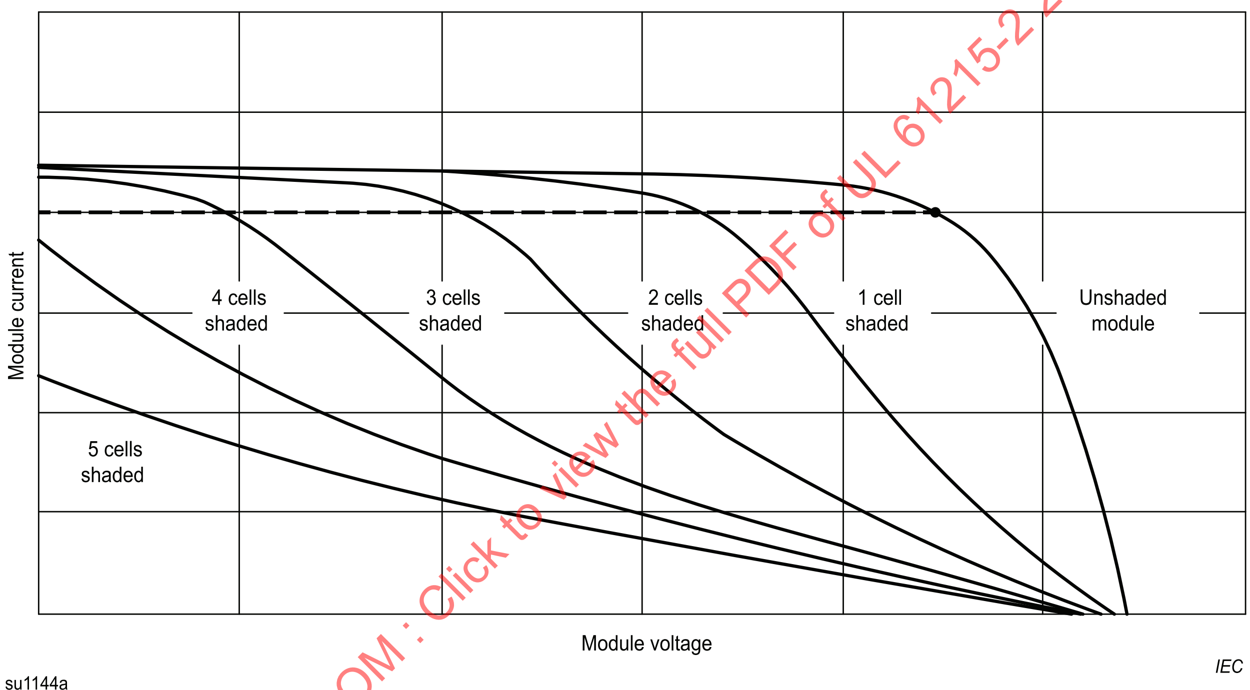
The hot-spot test is performed with the module exposed to (1 000 ± 100) W/m^2 during the extended exposure.

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 shading condition is shading of 4 cells at the same time.

Figure 6

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

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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.

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• 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.

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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.

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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.

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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.

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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.

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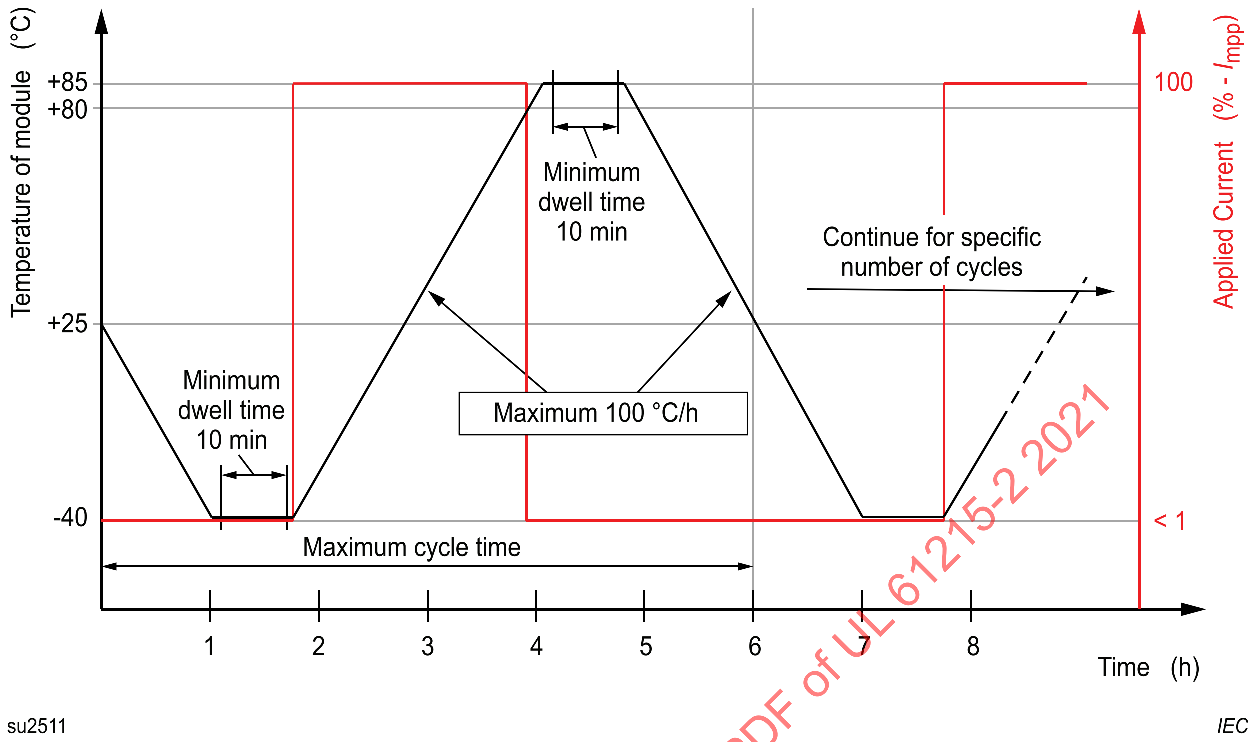

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Figure 7

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.

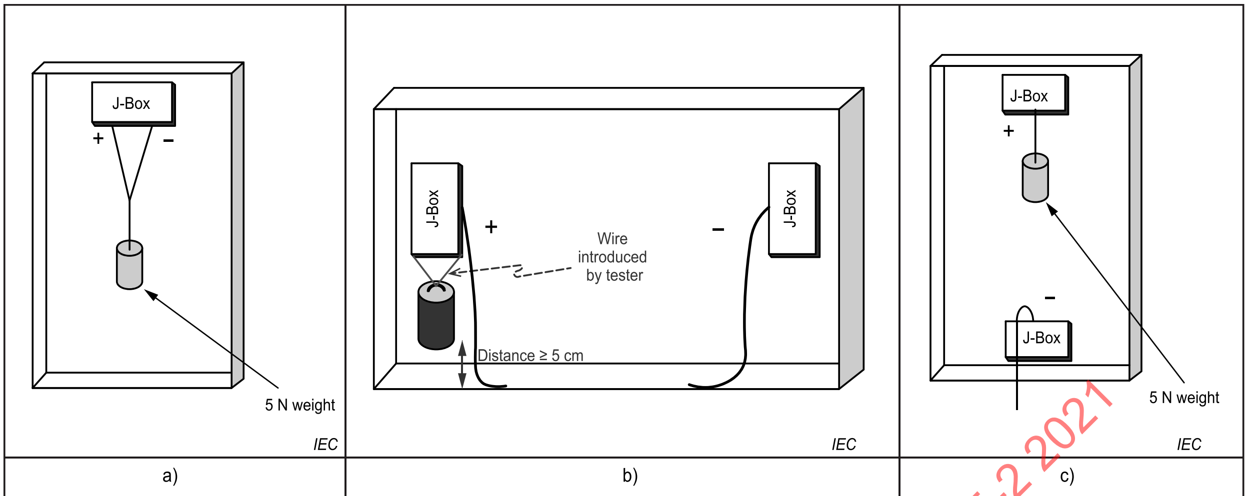

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Figure 8

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.

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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.

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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.

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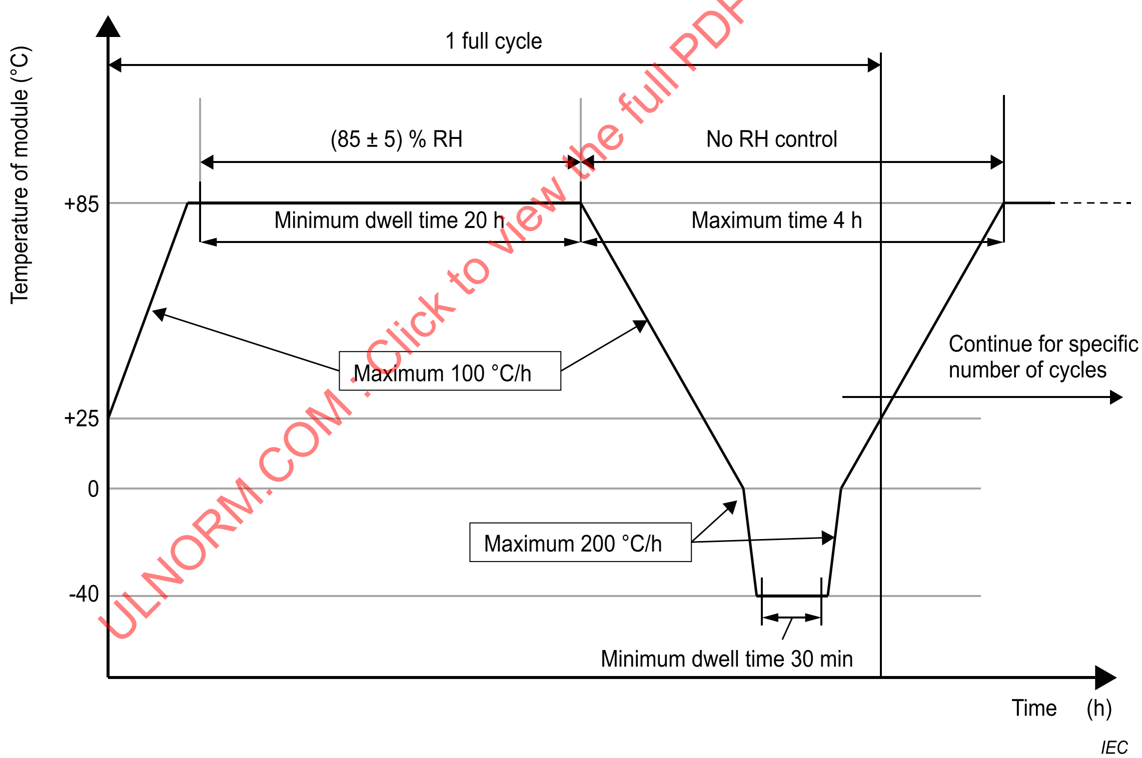

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Figure 9

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 test shall be carried out in accordance with 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: $(1\,000\ ^{+48}_{\ \ 0})$ 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 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.

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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.

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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.

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.

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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 standard is 1 600 Pa that results 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.

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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.

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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.

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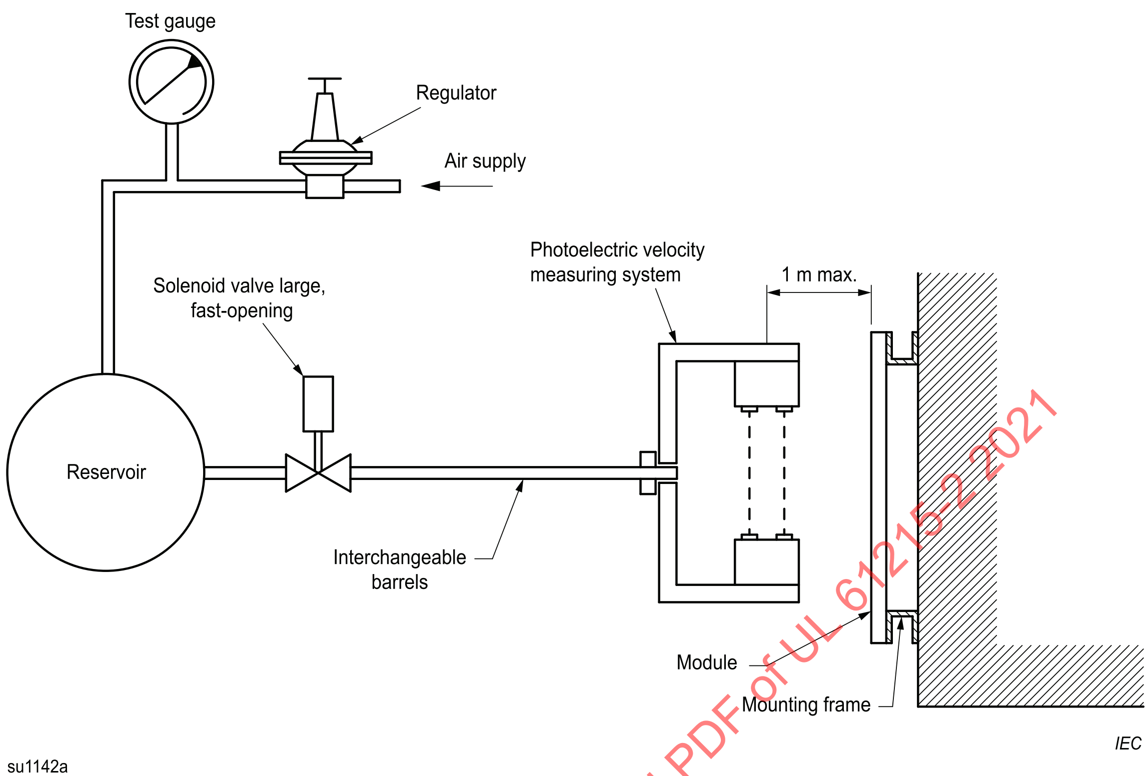

Figure 10

Hail-test equipment

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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.

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Table 3
Impact locations

Shot No.	Location
1	Any corner of the module window, not more than one radius 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.

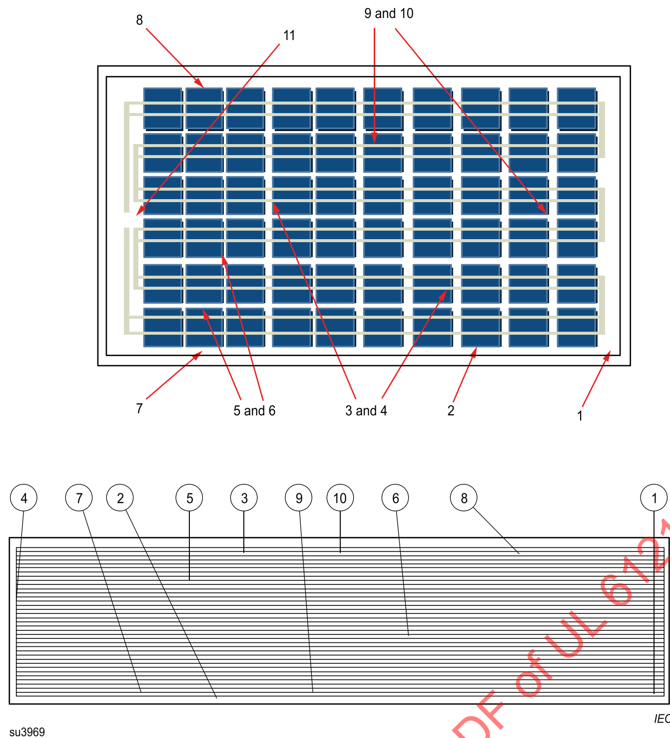

Figure 11

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

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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.

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4.18.1.3 Apparatus

a) Means for heating the module 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, $I_{sc\text{-}BSI}$, using I_{sc} values measured for Gate No. 1 (Isc-STC and Isc-BNPI), and the relevant equivalent irradiances: 1 000 Wm^{-2}, G_{BNPI}, and G_{BSI}. To extrapolate $I_{sc\text{-}BSI}$, these quantities are combined as follows:

$$I_{sc-BSI} = I_{sc-BNPI} + \frac{(I_{sc-BNPI} - I_{sc-STC})}{G_{BNPI} - 1000Wm^{-2}} \cdot (G_{BSI} - G_{BNPI})$$

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

$$G_{BNPI} = 1000Wm^{-2} + \varphi \cdot 135Wm^{-2}$$

$$G_{BSI} = 1000Wm^{-2} + \varphi \cdot 300Wm^{-2}$$

$$\varphi = Min(\varphi_{Isc}, \varphi_{P\max})$$

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.

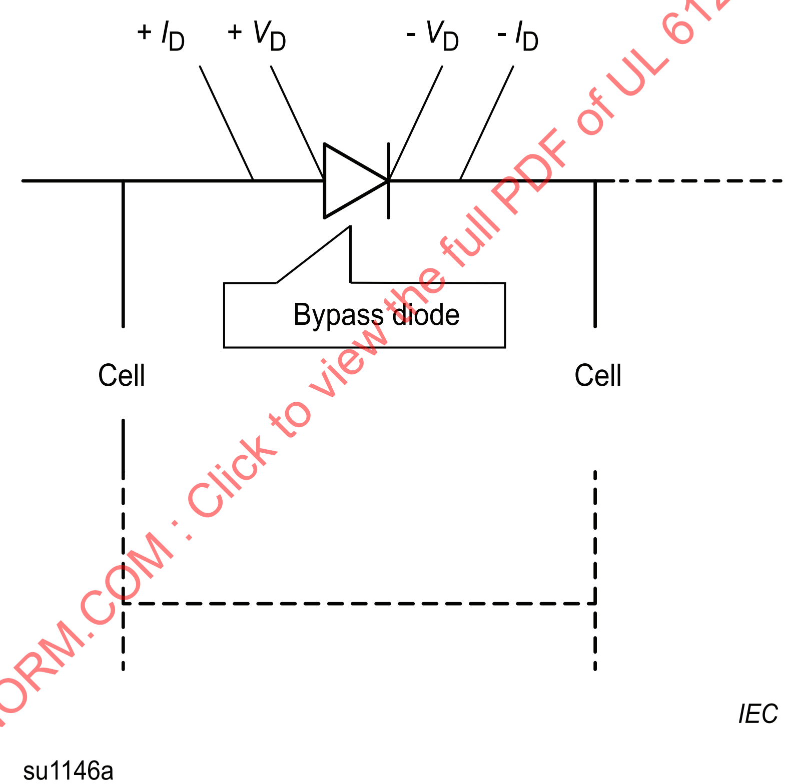

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Figure 12

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 module 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.

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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 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 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

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