BS EN 61215-2:2017

BSI Standards Publication

Terrestrial photovoltaic (PV) modules — Design qualification and type approval

Part 2: Test procedures

bsi.

National foreword

This British Standard is the UK implementation of EN 61215-2:2017. It is identical to IEC 61215-2:2016. Together with BS EN 61215-1:2016, BS EN 61215-1-1:2016, BS EN 61215-1-2, BS EN 61215-1-3 and BS EN 61215-1-4, it supersedes BS EN 61215:2005 which will be withdrawn upon publication of all remaining parts of the BS EN 61215-1 series.

The UK participation in its preparation was entrusted to Technical Committee GEL/82, Photovoltaic Energy Systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2017

ISBN 978 0 580 86070 6

ICS 27.160

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 March 2017.

Amendments/corrigenda issued since publication

Date	Text affected

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 61215-2

February 2017

ICS 27.160

Supersedes EN 61215:2005 (partially)

English Version

Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures (IEC 61215-2:2016)

Modules photovoltaïques (PV) pour applications terrestres - Qualification de la conception et homologation - Partie 2: Procédures d'essai (IEC 61215-2:2016)

Terrestrische Photovoltaik (PV) Module - Bauarteignung und Bauartzulassung - Teil 2: Prüfverfahren (IEC 61215-2:2016)

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Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CENELEC member.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

European foreword

The text of document 82/1048/FDIS, future edition 1 of IEC 61215-2, prepared by IEC/TC 82 “Solar photovoltaic energy systems" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61215-2:2017.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-08-10
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2020-02-10

This document supersedes EN 61215:2005 (partially).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 61215-2:2016 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)
Normative references to international publications with their corresponding European publications

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

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60050	series	International Electrotechnical Vocabulary	-	series
IEC 60068-1	-	Environmental testing -- Part 1: General and guidance	EN 60068-1	-
IEC 60068-2-21	-	Environmental testing -- Part 2-21: Tests - Test U: Robustness of terminations and integral mounting devices	EN 60068-2-21	-
IEC 60068-2-78	-	Environmental testing -- Part 2-78: Tests - Test Cab: Damp heat, steady state	EN 60068-2-78	-
IEC 60721-2-1	-	Classification of environmental conditions - - Part 2-1: Environmental conditions appearing in nature - Temperature and humidity	EN 60721-2-1	-
IEC 60891	-	Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics	EN 60891	-
IEC 60904-1	-	Photovoltaic devices -- Part 1: Measurement of photovoltaic current-voltage characteristics	EN 60904-1	-
IEC 60904-2	-	Photovoltaic devices - Part 2: Requirements for photovoltaic reference devices	EN 60904-2	-
IEC 60904-3	-	Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data	EN 60904-3	-
IEC 60904-7	-	Photovoltaic devices -- Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices	EN 60904-7	-
IEC 60904-8	-	Photovoltaic devices -- Part 8: Measurement of spectral response of a photovoltaic (PV) device	EN 60904-8	-
IEC 60904-9	-	Photovoltaic devices -- Part 9: Solar simulator performance requirements	EN 60904-9	-
IEC 60904-10	-	Photovoltaic devices -- Part 10: Methods of linearity measurement	EN 60904-10	-
IEC 61215-1	-	Terrestrial photovoltaic (PV) modules - Design qualification and type approval -- Part 1: Requirements for testing	EN 61215-1	-
IEC 61853-2	-	Photovoltaic (PV) module performance testing and energy rating -- Part 2: Spectral response, incidence angle and module operating temperature measurements	-	-
IEC 62790	-	Junction boxes for photovoltaic modules - Safety requirements and tests	EN 62790	-
ISO 868	-	Plastics and ebonite - Determination of indentation hardness by means of a durometer (Shore hardness)	EN ISO 868	-

IEC/TS 61836	-	Solar photovoltaic energy systems - Terms, definitions and symbols	CLC/TS 61836	-

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 2: Test procedures

FOREWORD

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

This first edition of IEC 61215-2 cancels and replaces the second edition of IEC 61215 (2005) and parts of the second edition of 61646 (2008) and constitutes a technical revision.

The main technical changes with regard to these previous editions are as follows:

This standard includes the testing procedures – formally Clause 10 – of the previous edition. Revisions were made to subclauses NMOT (replaces NOCT – MQT 05), performance measurements (MQT 06), robustness of terminations (MQT 14) and stabilization (MQT 19).

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

FDIS	Report on voting
82/1048/FDIS	82/1076/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.

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.

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

The committee has decided that the contents of this publication will remain unchanged until the 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.

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

INTRODUCTION

Whereas Part 1 of this 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.

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

Part 2: Test procedures

1 Scope and object

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

This standard 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 current, voltage and power levels expected at the design concentration.

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

2 Normative references

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

IEC 60050, *International Electrotechnical Vocabulary* (available at http://www.electropedia.org)

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

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

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

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

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

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

IEC 60904-2, *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, *Photovoltaic devices – Part 9: Solar simulator performance requirements*

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

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

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

IEC 61853-2, *Photovoltaic (PV) module performance testing and energy rating – Part 2: Spectral response, incidence angle, and module operating temperature measurements*[1]

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

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050 and IEC TS 61836 apply, as well as the following.

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 [≈ 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 exposure in general open-air climates, as defined in IEC 60721-2-1

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1 To be published.

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

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

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

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

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

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

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

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

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

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

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

4 Test procedures

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 the nature and position of any cracks, bubbles or delaminations, etc., which may worsen and adversely affect the module performance in subsequent tests.

4.1.3 Requirements

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

4.2 Maximum power determination (MQT 02)

4.2.1 Purpose

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

4.2.2 Apparatus

a) A radiant source (natural sunlight or a solar simulator class BBA or better in accordance with IEC 60904-9).
b) A PV reference device in accordance with IEC 60904-2. If a class BBA simulator or better is used, the reference device shall be a reference module of the same size with the same cell technology to match spectral responsivity. If such a matched reference device is not available one of the following two options need to be followed:
   1) a Class AAA simulator shall be utilized, or
   2) the spectral responsivity of the module according to IEC 60904-8 and the spectral distribution of the solar simulator need to be measured and the module data corrected according to IEC 60904-7.
c) A suitable mount for supporting the test specimen and the reference device in a plane normal to the radiant beam.
d) Apparatus for measuring an I-V curve in accordance with IEC 60904-1.

4.2.3 Procedure

Determine the current-voltage characteristic of the module in accordance with IEC 60904-1 at a specific set of irradiance and temperature conditions (a recommended range is a cell temperature between 25 °C and 50 °C and an irradiance between 700 W/m^2 and 1 100 W/m^2) using natural sunlight or a class BBA or better simulator conforming to the requirements of IEC 60904-9. 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.

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) d.c. voltage source, with current limitation, capable of applying 500 V or 1 000 V plus twice the maximum system voltage of the module (IEC 61215-1).

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 %.

4.3.4 Procedure

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

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

   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 manufacturer.

c) Increase the voltage applied by the tester at a rate not exceeding 500 V/s to a maximum equal to 1 000 V plus twice the maximum system voltage (IEC 61215-1). If the maximum system voltage does not exceed 50 V, the applied voltage shall be 500 V. Maintain the voltage at this level for 1 min.

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

e) Remove the short circuit.

f) Increase the voltage applied by the test equipment at a rate not 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.

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

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

4.3.5 Test requirements

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

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

c) For modules with an area larger than 0,1 m^2 the measured insulation resistance times the area of the module shall not be less than 40 $M\Omega \cdot m^2$.

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.

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

4.5 Measurement of nominal module operating temperature (NMOT) (MQT 05)

4.5.1 General

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

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

- Tilt angle: (37 ± 5)°
- Total irradiance: 800 W/m^2
- Ambient temperature: 20 °C
- Wind speed: 1 m/s
- Electrical load: A resistive load sized such that the module will operate near its maximum power point at STC or an electronic maximum power point tracker (MPPT).

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

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

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

4.5.2 Principle

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

The temperature of the solar cell junction (T_J) is primarily a function of the ambient temperature (T_{amb}), the average wind speed (v) and the total solar irradiance (G) incident on the active surface of the module. The temperature difference (T_J – T_{amb}) is largely independent of the ambient temperature and is essentially linearly proportional to the irradiance at levels above 400 W/m^2.

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

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

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

4.5.3 Test procedure

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

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

4.6 Performance at STC and NMOT (MQT 06)

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) and at NMOT (an irradiance of 800 W/m^2 and an ambient temperature of 20 °C with the IEC 60904-3 reference solar spectral irradiance distribution). The measurement at STC is used to verify the name plate information of the module.

4.6.2 Apparatus

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

b) A PV reference device in accordance with IEC 60904-2. If a class BBA simulator or better is used, the reference device shall be a reference module of the same size with the same cell technology to match spectral responsivity. If such a matched reference device is not available one of the following two options need to be followed:

   1) a Class AAA simulator shall be utilized, or

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

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

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

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

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

4.6.3 Procedure

4.6.3.1 Measuring at STC (MQT 06.1)

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

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

4.6.3.2 Measuring at NMOT (MQT 06.2)

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

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

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

4.7 Performance at low irradiance (MQT 07)

4.7.1 Purpose

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

4.7.2 Apparatus

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

b) Equipment necessary to change the irradiance to 200 W/m^2 without affecting the relative spectral irradiance distribution and the spatial uniformity in accordance with IEC 60904-10.

c) A PV reference device in accordance with IEC 60904-2. If a class BBA simulator or better is used, the reference device shall be a reference module of the same size with the same cell technology to match spectral responsivity. If such a matched reference device is not available one of the following two options need to be followed:

   1) a Class AAA simulator shall be utilized, or

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

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

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

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

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 natural sunlight or at least a class BBA simulator conforming to the requirements of IEC 60904-9. The irradiance shall be reduced to the specified level by using neutral filters or some other technique which does not affect the spectral irradiance distribution. (See IEC 60904-10 for guidance on reducing the irradiance without changing the spectral irradiance distribution.)

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

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 the test module in the test report.

b) Attach the resistive load or electronic maximum power point tracker to the module and mount it outdoors, as recommended by the manufacturer, co-planar with the irradiation monitor. Any hot-spot protective devices recommended by the manufacturer shall be installed before the module is tested.

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

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

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.

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

4.9 Hot-spot endurance test (MQT 09)

4.9.1 Purpose

To determine the ability of the module to withstand 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

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

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

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

Low shunt resistance cells:

- The worst case shadowing conditions occur when the whole cell (or a large fraction) is shadowed.
- Often low shunt resistant 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.

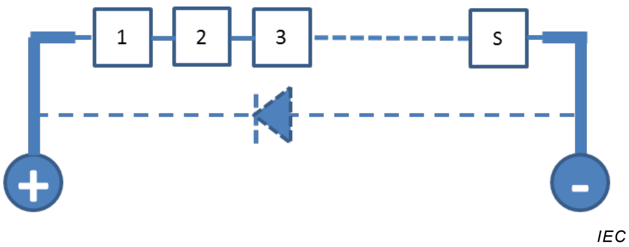


Figure 1 – Case S, series connection with optional bypass diode

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

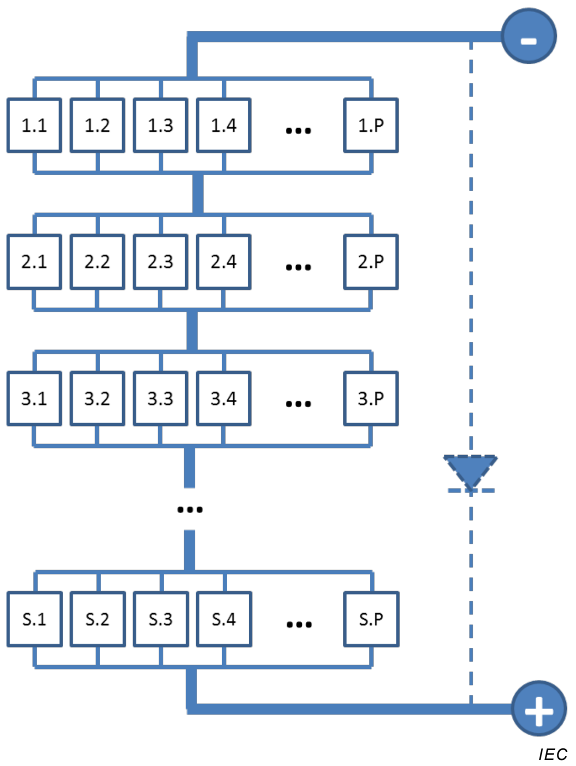


Figure 2 – Case PS, parallel-series connection with optional bypass diode

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

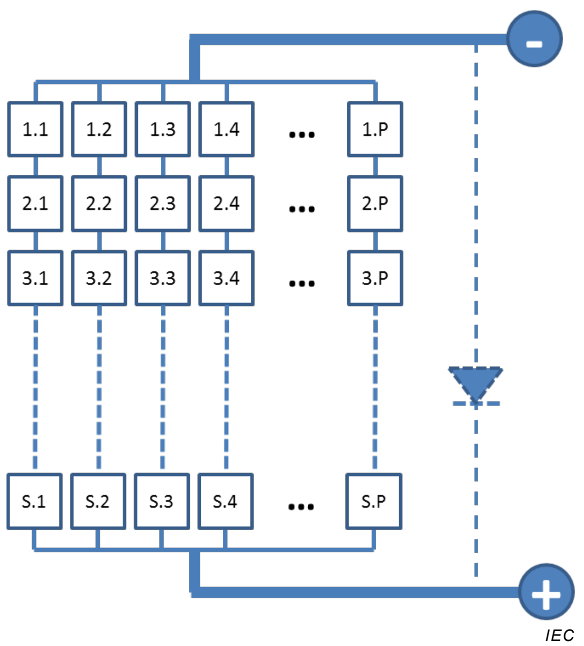


Figure 3 – Case SP, series-parallel connection with optional bypass diode

Each configuration requires a particular hot-spot testing procedure.

4.9.4 Apparatus

a) Radiant source: Natural sunlight, or a class BBB (or better) steady-state solar simulator conforming to IEC 60904-9 with an irradiance of (1 000 ± 100) W/m^2.

b) Module I-V curve tracer.

c) Equipment for current measurement.

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

e) An appropriate temperature detector (preferably an IR camera) to measure and record module temperatures.

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

Optional for selecting cells most sensitive to hot spot heating a pulsed simulator of class BBB or better conforming to IEC 60904-9 with an irradiance of 800 W/m^2 to 1 000 W/m^2 for measuring I-V performance can 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.

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

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

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

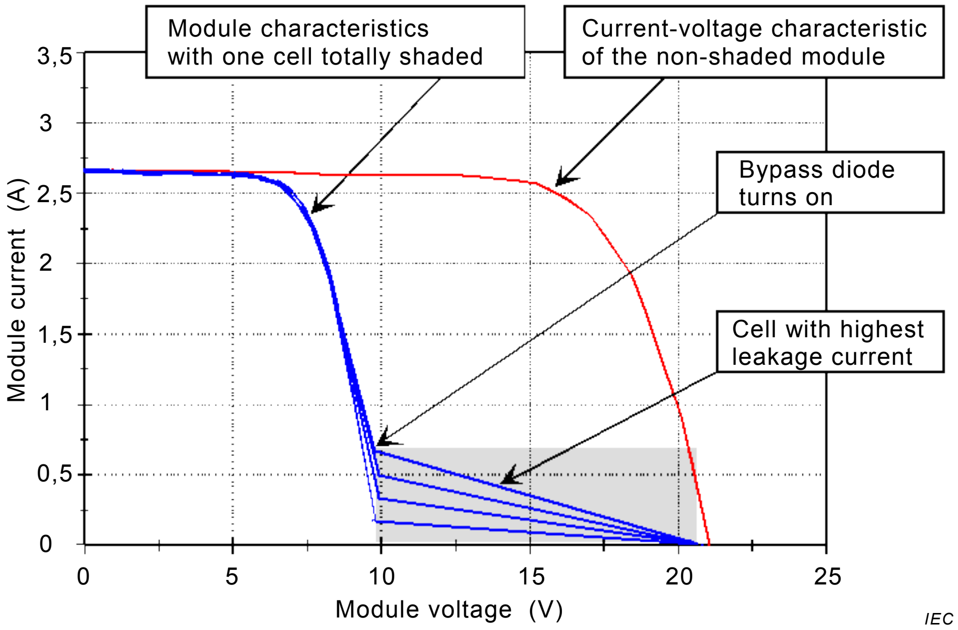


Figure 4 – Module I-V characteristics with different cells totally shadowed

Use the following procedure to identify hot spot sensitive cells:

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

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

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

b) Shadow each cell completely in turn, measure the resultant I-V curve and prepare a set of curves like Figure 4.

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

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

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

e) Select the cell with the highest shunt resistance.

f) Cell testing procedure:

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

1) If the cell circuit is accessible, short circuit the module and attach the current measuring equipment such that it is reading only the current through the cell string under test. Expose the module to steady state irradiance of 800 W/m^2 to 1 000 W/m^2. Shadow each of the test cells and determine what shadow level results in the current through the shadowed cell being equal to the unshaded I_{MP1} determined in a). This is the worst case shadowing for that cell.

2) If the cell circuit is not accessible, take a set of I-V curves with each of the test cells shadowed at different levels as shown in Figure 5. Determine the worst case shadowing condition, which occurs when the current through the shadowed cell (the point where the by-pass diode turns on) coincides with the original unshaded I_{MP1} determined in a), like curve c) in Figure 5.
3) Shade each of the selected test cells in turn at 100 % and measure the cell temperature. Decrease the shading by 10 %. If the temperature decreases 100 % shading produces the worst case. If the temperature increases or stays the same continue to decrease the shading by 10 % until the temperature does decrease. Go back and use the previous shading level as worst case shading.
4) For the SP case if the bypass diode does not turn on when the selected cell is fully shadowed, worst case hot-spot condition is completely shading the cell. If the bypass diode does turn on when the selected cell is fully shadowed, use the procedure given in either f) 2) or f) 3) to determine the worst case shadowing condition.
5) Select the cell selected in c). Use the IR camera to determine the hottest spot on the cell when it is shaded 100 %. Shadow that cell to the worst case condition as determined in f) 1) to f) 4). Short-circuit the module. If possible make sure that this hottest spot is within the illuminated area.

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

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

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

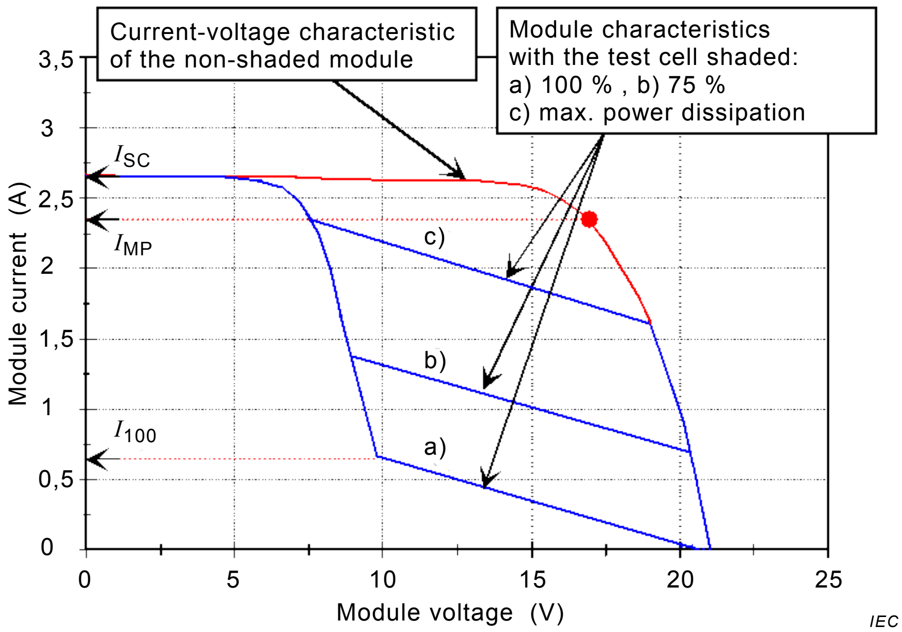


Figure 5 – Module I-V characteristics with the test cell shadowed at different levels

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

4.9.5.3.1 General

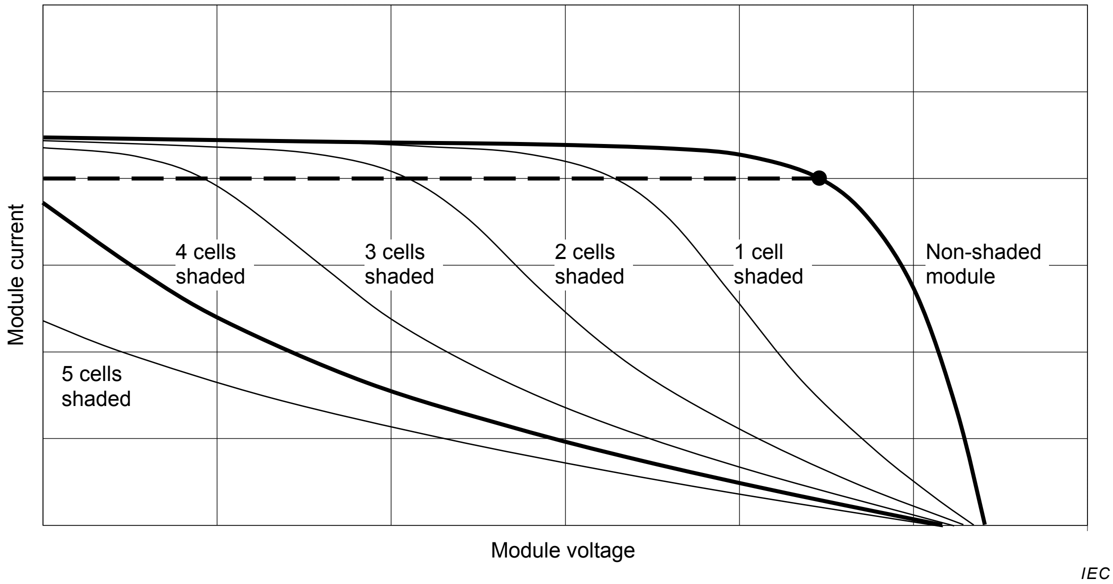
The hot-spot test is performed with the module exposed to 800 W/m^2 to 1 000 W/m^2.

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

The electrical performance of a MLI thin-film module can already be negatively affected by short-term shading. 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}, P_{max2} and P_{max3} are collected for this purpose.

4.9.5.3.2 Case S

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



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

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

a) Employing a pulsed or non-continuous simulator where the module temperature will be close to room temperature (25 ± 5) °C expose the un-shaded module to a total irradiance of 800 W/m^2 to 1 000 W/m^2 at the module surface. Optional a steady-state simulator or sunlight can be used where the module temperature shall be stabilised within ± 5 °C before beginning the measurements. When thermal stabilization is attained, measure the module I-V characteristic and determine the maximum power current range ($I_{min} < I < I_{max}$) where $P > 0{,}99\ P_{max1}$. (The module power measured after preconditioning).
b) Short-circuit the module and monitor the short-circuit current.
c) Starting from one edge of the module, use an opaque cover to shade one cell completely. Move the cover parallel to the cells and increase the shaded module area (number of shaded cells) until the short-circuit current falls within the maximum power current range of the non-shaded module. In these conditions, the maximum power is dissipated within the selected group of cells (see Figure 6).

d) Move an opaque cover (of the dimensions found in c) above) slowly across the module and monitor the module short-circuit current. If at a certain position the short-circuit current falls outside of the maximum power current of the non-shaded module range, reduce the size of the cover in small increments until the maximum power current condition is attained again. During this process, the irradiance shall not change by more than ± 2 %.

e) The final width of the cover determines the minimum area of shading that results in the worst case shading condition. This is the shaded area to be used for hot-spot testing.

f) Remove the cover and visually inspect the module.

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

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

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

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

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

   This test shall be performed at a module temperature in the range (50 ± 10) °C. Note the value of I_{sc} and keep the module in the condition of maximum power dissipation. If necessary, re-adjust the shadow to maintain the I_{sc} within the specified level determined in step a).

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

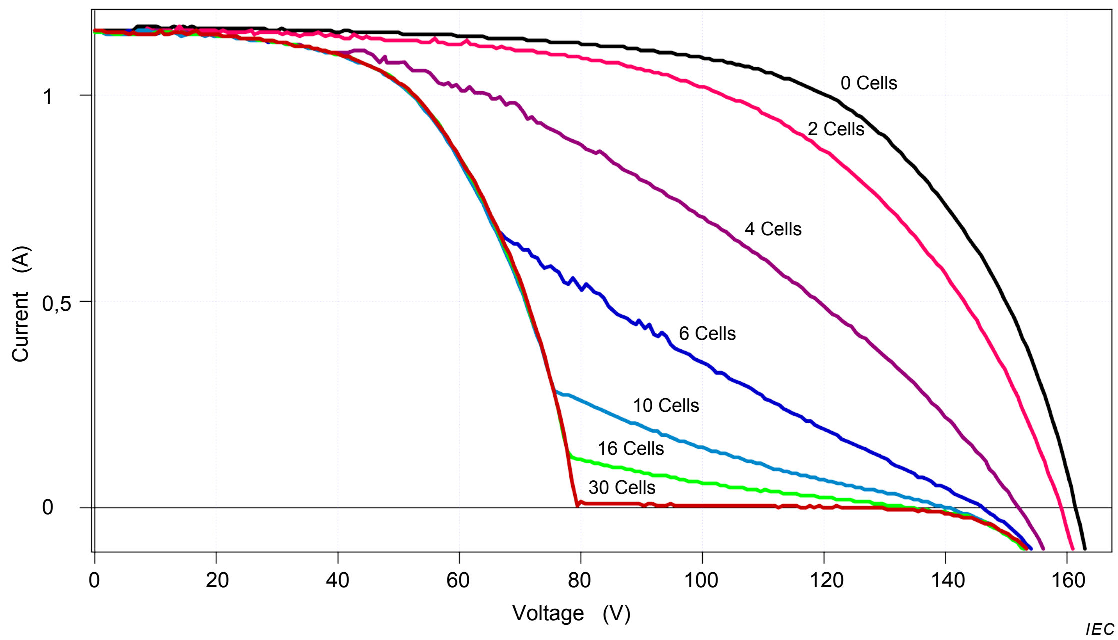
k) At the end of the endurance test, determine the hottest area on the shaded cells using an IR camera or appropriate temperature detector.

4.9.5.3.3 Case SP

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

e) Select the cell with the highest shunt resistance.

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

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

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

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

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

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

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

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

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

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

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

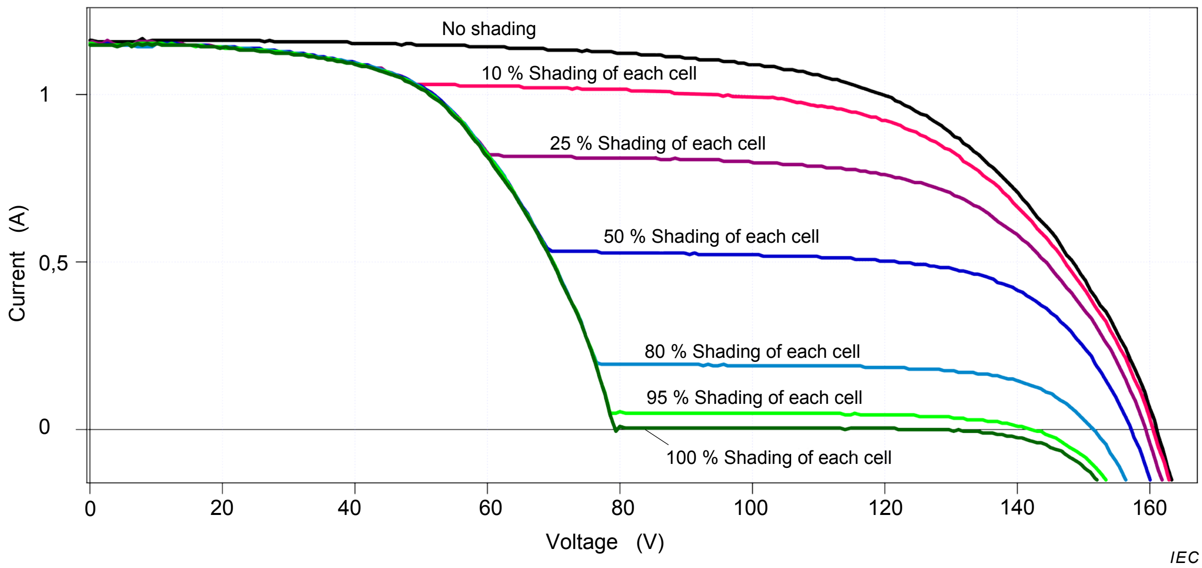


Figure 8 – Module I-V characteristics with the test cell shadowed at different levels where the module design includes bypass diodes

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

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

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

a) Employing a pulsed or non-continuous simulator where the module temperature will be close to room temperature (25 ± 5) °C expose the un-shaded module to a total irradiance of 800 W/m^2 to 1 000 W/m^2 at the module surface. Optionally, a steady-state simulator or sunlight can be used where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.
b) When thermal stabilization is attained, measure the module I-V characteristic and determine the maximum power current range ($I_{min} < I < I_{max}$) where $P > 0{,}99 \cdot P_{max1}$.
c) Then calculate the maximum power current range to be applied I (*) according to the following formula.

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

   where

   P is the number of parallel strings of the module.
d) Short-circuit the module and monitor the short-circuit current.
e) Starting from one edge of one string of the module, use an opaque cover to shade one cell completely. Move the cover parallel to the cells and increase the shaded module area (number of shaded cells) until the short-circuit current falls in the maximum power current range I (*) of the non-shaded module. In these conditions, the maximum power is dissipated within the selected group of cells.
f) Cut the opaque cover to the experimentally found size.
g) Move the cover slowly across the module and monitor the module short-circuit current. If at a certain position, the short-circuit current falls outside of the maximum power current range I (*) of the non-shaded module, cut the cover in increments of one cell until the maximum power current condition is attained again. During this process, the irradiance shall not change by more than ± 2 %.
h) Re-measure the module I-V characteristic and determine maximum power P_{max2}.
i) Place the cover on the candidate module area and short-circuit the module.
j) Expose the module to the steady-state radiant source providing a total irradiance of (1 000 ± 100) W/m^2 at the module surface. This can be done using:
   - A steady-state simulator where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.
   - Sunlight where the module temperature shall be stabilised within ± 5 °C before beginning the measurements.

   This test shall be performed at a module temperature in the range (50 ± 10) °C.
k) Monitor the value of I_{sc} and keep the module in the condition of maximum power dissipation by ensuring that I_{sc} is in the range I (*) found in step c). If necessary, re-adjust the shadow to maintain I_{sc} within this I (*) range.
l) Maintain these conditions for a total exposure time of 1 h.
m) At the end of the endurance test, determine the hottest area on the shaded cells using an IR camera or appropriate temperature detector.

4.9.5.3.6 Case PS

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

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

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.

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

d) Re-measure the un-shaded 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 shaded 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, 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) for power loss.

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

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

e) Any damage resulting from determining the worst case shading 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.

4.10.2 Apparatus

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

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

c) Instrumentation capable of measuring the irradiance of the UV light produced by the UV light source at the test plane of the module(s), within the wavelength ranges of 280 nm to 320 nm and 320 nm to 400 nm with an uncertainly of ± 15 % or better.

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

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

4.10.3 Procedure

a) Using the calibrated radiometer measure the irradiance at the proposed module test plane and ensure that at wavelengths between 280 nm and 400 nm it does not exceed 250 W/m^2 (i.e. about five times the natural sunlight level) and that it has a uniformity of ± 15 % over the test plane.

b) According to the apparatus used as defined in 4.10.2 e) short-circuit or attach the resistive load to the module and mount it in the test plane at the location selected in a), normal to the UV irradiance beam. Make sure that the module temperature sensors read (60 ± 5) °C.

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

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.

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 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) 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.

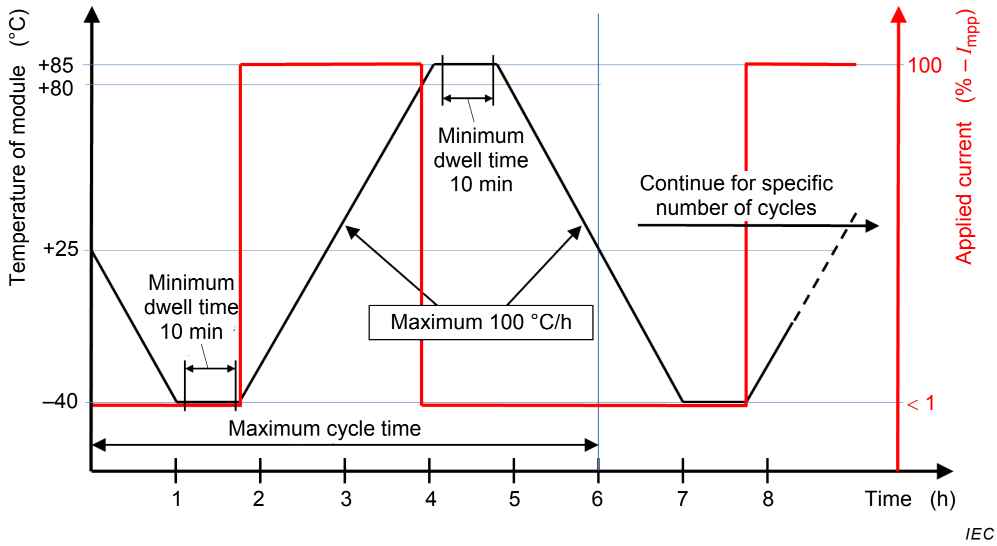


Figure 9 – Thermal cycling test – Temperature and applied current profile

4.11.3 Procedure

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

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

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 specified current in 4.11.2 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 9. The rate of change of temperature between the low and high extremes shall not exceed 100 °C/h and the module temperature shall remain stable at each extreme for a period of at least 10 min. The cycle time shall not exceed 6 h unless the module has such a high heat capacity that a longer cycle is required. The number of cycles shall be as shown in the relevant sequences in Figure 1 of IEC 61215-1:2016. 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).

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

4.11.4 Final measurements

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

4.11.5 Requirements

a) No interruption of current flow during the test; in the case of a module with parallel circuits, a discontinuity in current flow indicates an interruption of flow in one of the parallel circuit.
b) No evidence of major visual defects, as defined in IEC 61215-1.
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 10.
b) Means for mounting or supporting the module(s) in the chamber, so as to allow free circulation of the surrounding air. The thermal conduction of the mount or support shall be low, so that, for practical purposes, the module(s) is (are) thermally isolated.
c) Measurement instrumentation having an accuracy of ± 2,0 °C and repeatability of ± 0,5 °C for measuring and recording the temperature of the module(s).
d) Means for monitoring, throughout the test, the continuity of the internal circuit of each module.

4.12.3 Procedure

a) Attach a suitable temperature sensor to the front or back surface of the module(s) near the middle. If more than one module of the same type is tested simultaneously, it will suffice to monitor the temperature of one representative sample.
b) Install the module(s) at room temperature in the climatic chamber.
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.
d) After closing the chamber, subject the module(s) to the number of cycles defined in sequence C in Figure 1 of IEC 61215-1:2016 in accordance with the profile in Figure 10. 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.
c) Wet leakage current shall meet the same requirements as for the initial measurements.

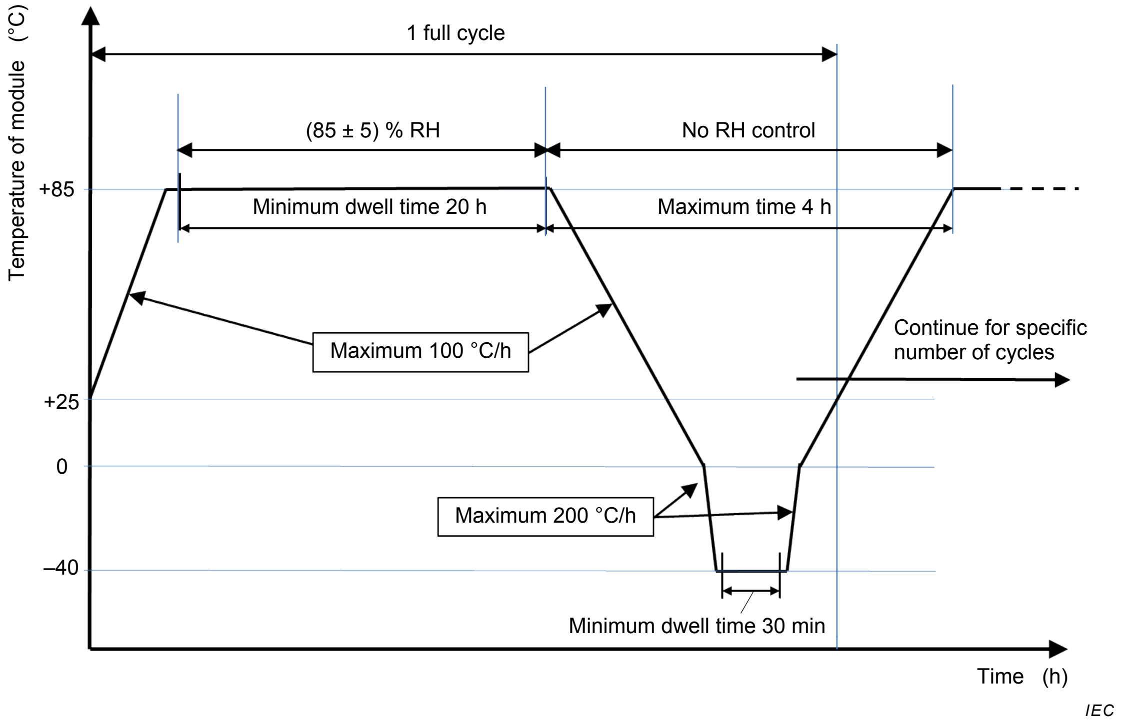


Figure 10 – Humidity-freeze cycle – Temperature and humidity profile

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 Procedure

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

Severities:

The following severities are applied.

Test temperature: (85 ± 2) °C

Relative humidity: (85 ± 5) %

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

4.13.3 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.

4.13.4 Requirements

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

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.

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

4.14.2.1 Apparatus

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

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

4.14.2.2 Procedure

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

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

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

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

4.14.2.3 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.14.2.4 Requirements

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

a) No evidence of major visual defects, as defined in IEC 61215-1.
b) Wet leakage current shall meet the same requirements as for the initial measurements.

4.14.3 Test of cord anchorage (MQT 14.2)

4.14.3.1 General

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

4.14.3.2 Procedure and apparatus

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

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

a) Pull test

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

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

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

b) Torque test

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

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

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

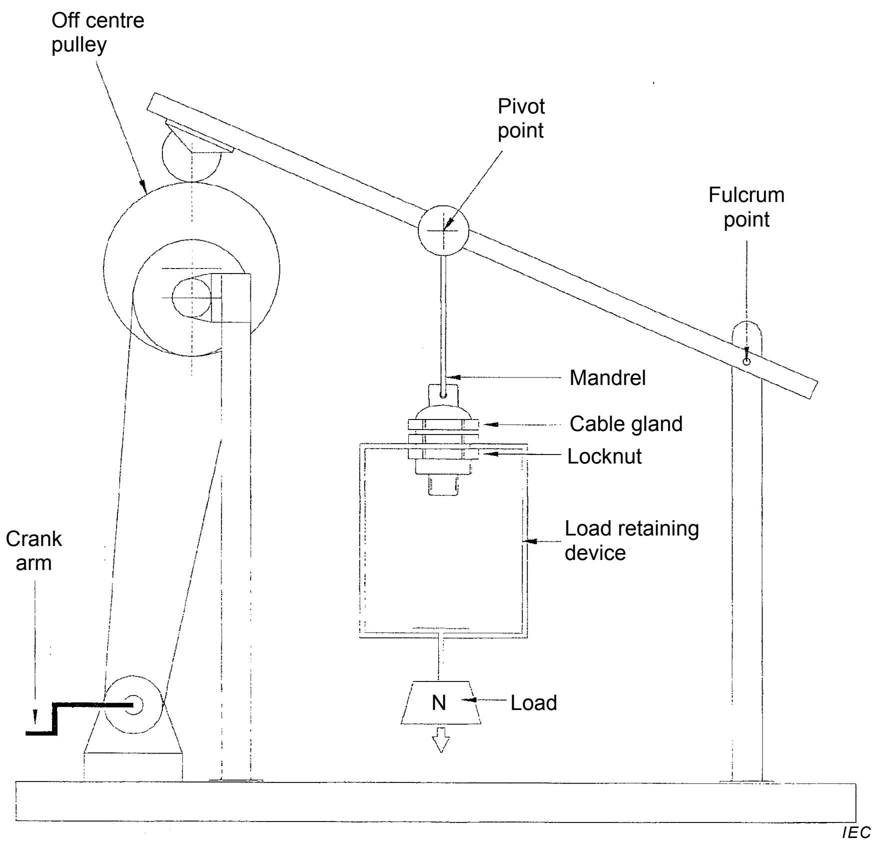
Table 1 – Pull forces for cord anchorage test

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

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

Table 2 – Values for torsion test

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



NOTE For module testing setup depends on the module construction.

Figure 11 – Typical arrangement for the cord anchorage pull test for component testing

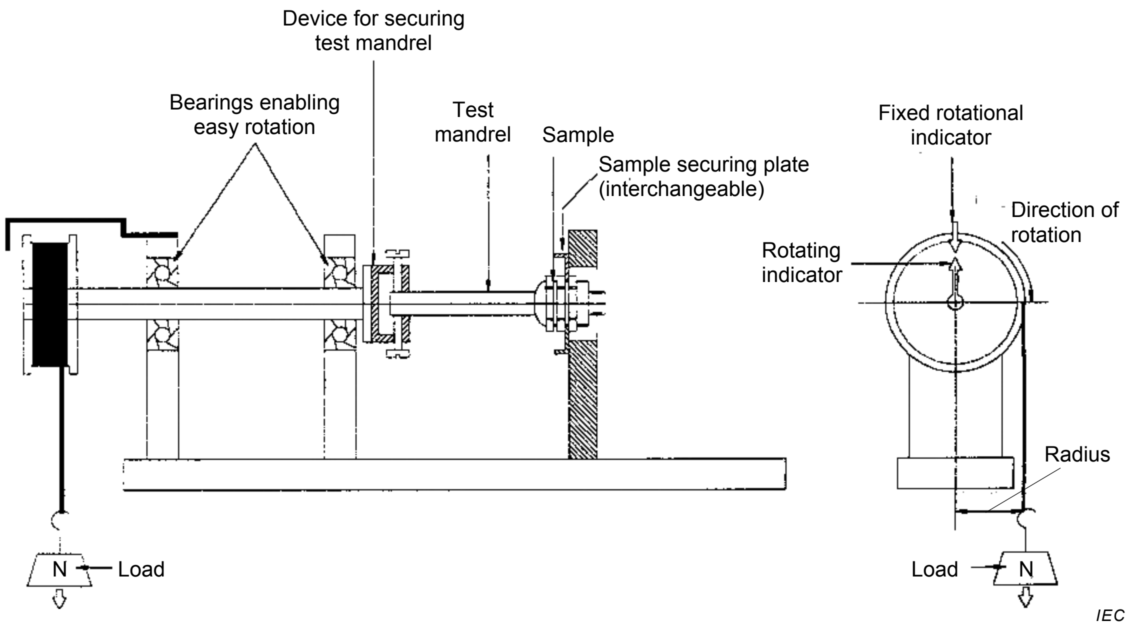


Figure 12 – Typical arrangement for torsion test

4.14.3.2.2 Junction boxes intended to be used with generic cables

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

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

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

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

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

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

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

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

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

4.14.3.3 Final measurements

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

4.14.3.4 Requirements

a) No evidence of major visual defects, as defined in IEC 61215-1.
b) Insulation test shall meet the same requirements as for the initial measurements.
c) Wet leakage current shall meet the same requirements as for the initial measurements.
d) The displacement of the cable at the outlet of the junction box shall not exceed 2 mm.

4.15 Wet leakage current test (MQT 15)

4.15.1 Purpose

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

4.15.2 Apparatus

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

Resistivity:	3 500 Ω/cm or less
Solution temperature:	(22 ± 2) °C

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

b) Spray equipment containing the same solution, if the entire junction box is not going to be submerged.
c) DC voltage source, with current limitation, capable of applying 500 V or the maximum rated system voltage of the module, whichever is more.
d) Instrument to measure insulation resistance.

4.15.3 Procedure

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

a) Immerse the module in the tank of the required solution to a depth sufficient to cover all surfaces except junction box entries not designed for immersion. If not immersed the cable entries shall be thoroughly sprayed with solution. If the module is provided with a mating connector, the connector should be sprayed during the test.
b) Connect the shorted output terminals of the module to the positive terminal of the test equipment. Connect the liquid test solution to the negative terminal of the test equipment using a suitable metallic conductor.

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

c) Increase the voltage applied by the test equipment at a rate not exceeding 500 V/s to 500 V or the maximum system voltage for the module, whichever is greater. Maintain the voltage at this level for 2 min. Then determine the insulation resistance.
d) Reduce the applied voltage to zero and short-circuit the terminals of the test equipment to discharge the voltage build-up on the module.
e) Ensure that the used solution is well rinsed off the module before continuing the testing.

4.15.4 Requirements

– For modules with an area of less than 0,1 m^2 the insulation resistance shall not be less than 400 MΩ.
– For modules with an area larger than 0,1 m^2 the measured insulation resistance times the area of the module shall not be less than 40 $M\Omega \cdot m^2$.

4.16 Static mechanical load test (MQT 16)

4.16.1 Purpose

The purpose of this test is to determine the ability of the module to withstand a minimum static load.

Additional requirements may apply for certain installations and climates.

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

MQT 16 verifies the manufacturer’s defined design load. The test load is defined as:

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

where 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.

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

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.

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

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

4.16.3 Procedure

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

b) Mount the module on a rigid structure using the method prescribed by the manufacturer including the mounting means (clips/clamps and any kind of fastener) and underlying support rails. If there are different possibilities each mounting method needs to be evaluated separately. For all mounting methods, mount the module in a manner where the distance between the fixing points is worst case, which is typically at the maximum distance. Allow the modules to equilibrate for a minimum of 2 h after MQT 13 before applying the load.

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

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

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

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

4.16.4 Final measurements

Repeat the tests of MQT 01 and MQT 15.

4.16.5 Requirements

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

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

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 3. 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 13 shows in schematic form a suitable apparatus comprising a horizontal pneumatic launcher, a vertical module mount and a velocity meter which measures electronically the time it takes the ice ball to traverse the distance between two light beams. This is only one example as other types of apparatus including slingshots and spring-driven testers have been successfully utilized.

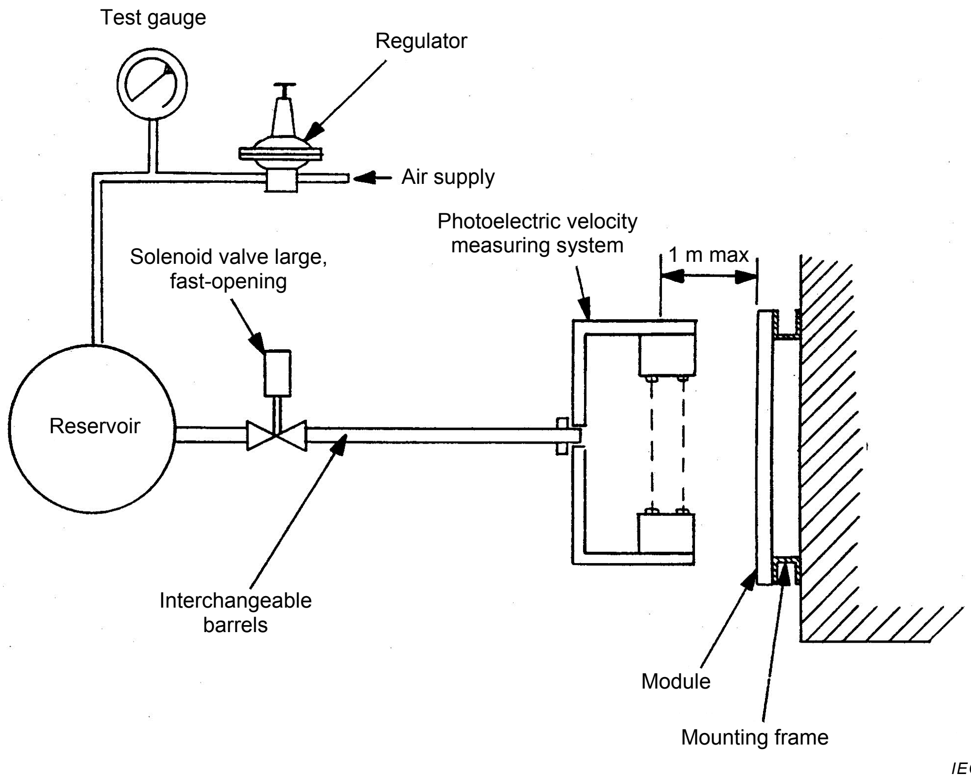


Figure 13 – Hail-test equipment

Table 3 – 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 3.

c) Place the balls in the storage container and leave them there for at least 1 h before use.

d) Ensure that all surfaces of the launcher likely to be in contact with the ice balls are near room temperature.

e) Fire a number of trial shots at a simulated target in accordance with step g) below and adjust the launcher until the velocity of the ice ball, as measured with the velocity sensor in the prescribed position, is within ± 5 % of the appropriate hailstone test velocity in Table 4.

f) Install the module at room temperature in the prescribed mount, with the impact surface normal to the path of the ice ball.

g) Take an ice ball from the storage container and place it in the launcher. Take aim at the first impact location specified in Table 4 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 4, as illustrated in Figure 14.

Table 4 – 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 edges of the circuit (e.g. individual cells).
5, 6	Over the circuit near interconnects (i.e. cell interconnects and bus ribbons).
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.

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

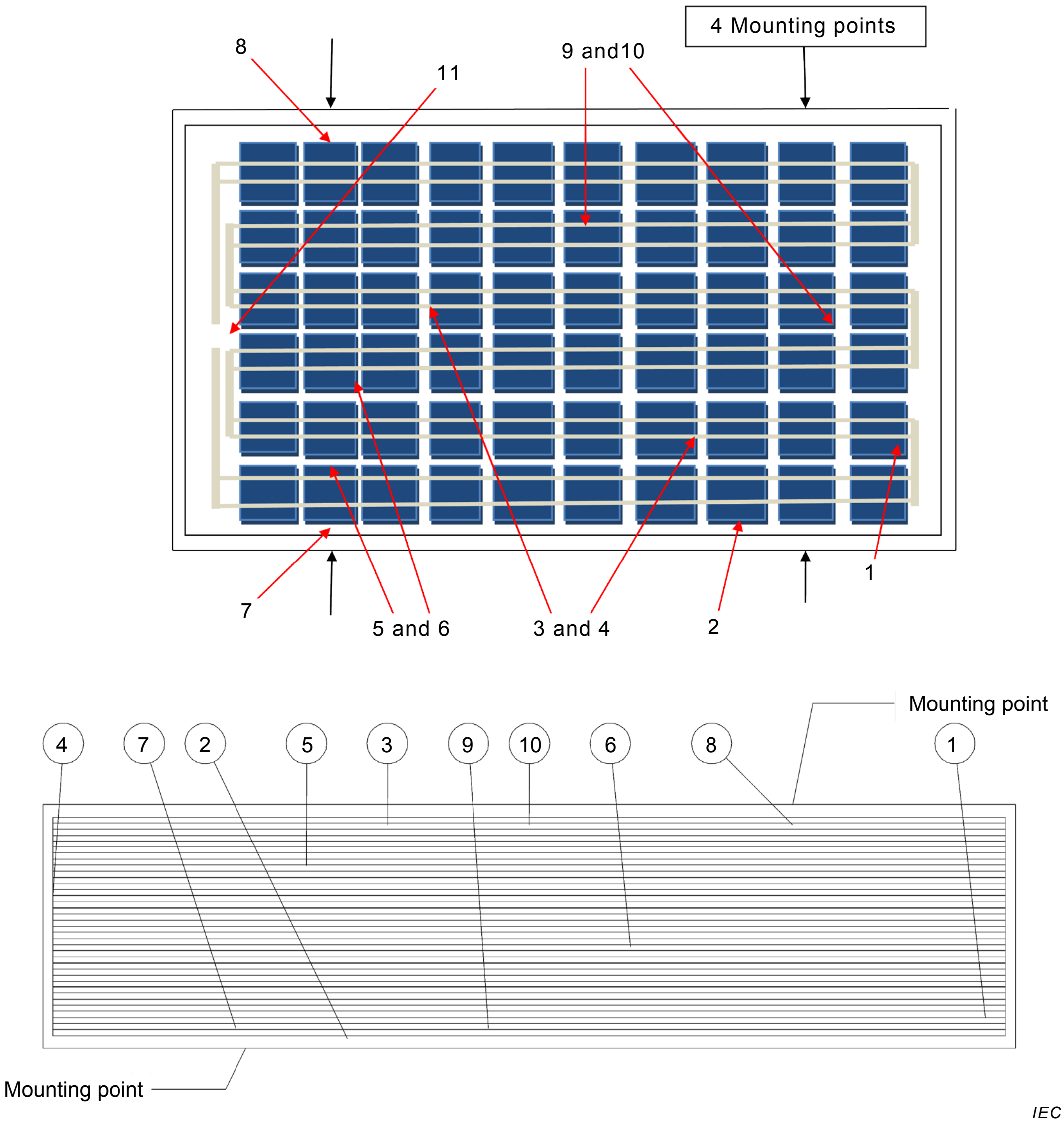


Figure 14 – Hail test impact locations: top for wafer/cell based technologies, bottom for monolithic processed thin film technologies

4.18 Bypass diode testing (MQT 18)

4.18.1 Bypass diode thermal test (MQT 18.1)

4.18.1.1 Purpose

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

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

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 4.18.1.3 c) to m). 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 4.18.1.4.

4.18.1.2 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.

4.18.1.3 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.

c) Connect the lead wire for V_D and I_D on both diode terminals as shown in Figure 15.

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.

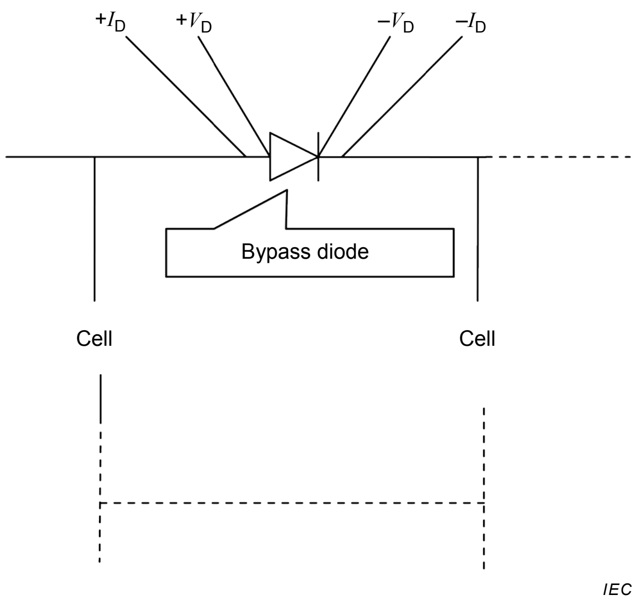


Figure 15 – Bypass diode thermal test

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.

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 measured at STC. After 1 h measure the forward voltage of each of the diodes.

If the module contains a heat sink specifically designed to reduce the operating temperature of the diode, this test may be performed at the temperature the heat sink reaches under conditions of 1 000 W/m^2, (43 ± 3) °C ambient with no wind rather than at 75 °C.

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

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

m) Maintain the current flow for 1 h.

4.18.1.4 Final measurements

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

4.18.1.5 Requirements

a) The diode junction temperature T_J as determined in 4.18.1.3 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.

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 measurement shall be at least 1 % of reading.

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.

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.

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.

4.18.2.4 Requirements

4.18.2.4.1 Method A

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

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

where:

N is the number of bypass diodes;

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

4.18.2.4.2 Method B

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

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

4.19 Stabilization (MQT 19)

4.19.1 General

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

4.19.2 Criterion definition for stabilization

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

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

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

Here, P_{max}, P_{min} and $P_{average}$ are defined as extreme values of three consecutive output power measurements P1, P2 and P3 taken from a sequence of alternating stabilization and measurement steps using MQT 02. STC output power is determined using procedure MQT 06.1.

4.19.3 Light induced stabilization procedures

4.19.3.1 Apparatus for indoor stabilization

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

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

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

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

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

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

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

4.19.3.2 Requirements for outdoor exposure for stabilization

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

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

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

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

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

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

4.19.3.3 Procedure

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

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

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

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

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

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

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

4.19.4 Other stabilization procedures

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

This subclause defines the validation process for alternate stabilization procedure.

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

a) Perform alternate procedure.
b) Measure MQT 06.1 after the minimum and no more than the maximum time specified in the technology specific parts.
c) Perform indoor light induced stabilization procedure (4.19.3.1) in accordance to technology specific requirements.
d) Measure MQT 06.1 after the minimum and no more than the maximum time specified in the technology specific parts.

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

4.19.5 Initial stabilization (MQT 19.1)

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

The initial stabilization is performed to verify manufacture label values as defined in the pass criterion in IEC 61215-1:2016, Clause 7 (Gate No. 1).

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

4.19.6 Final stabilization (MQT 19.2)

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

The final stabilization is performed to determine module degradation during the test as defined in the pass criterion in IEC 61215-1:2016, Clause 7 (Gate No. 2).

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

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