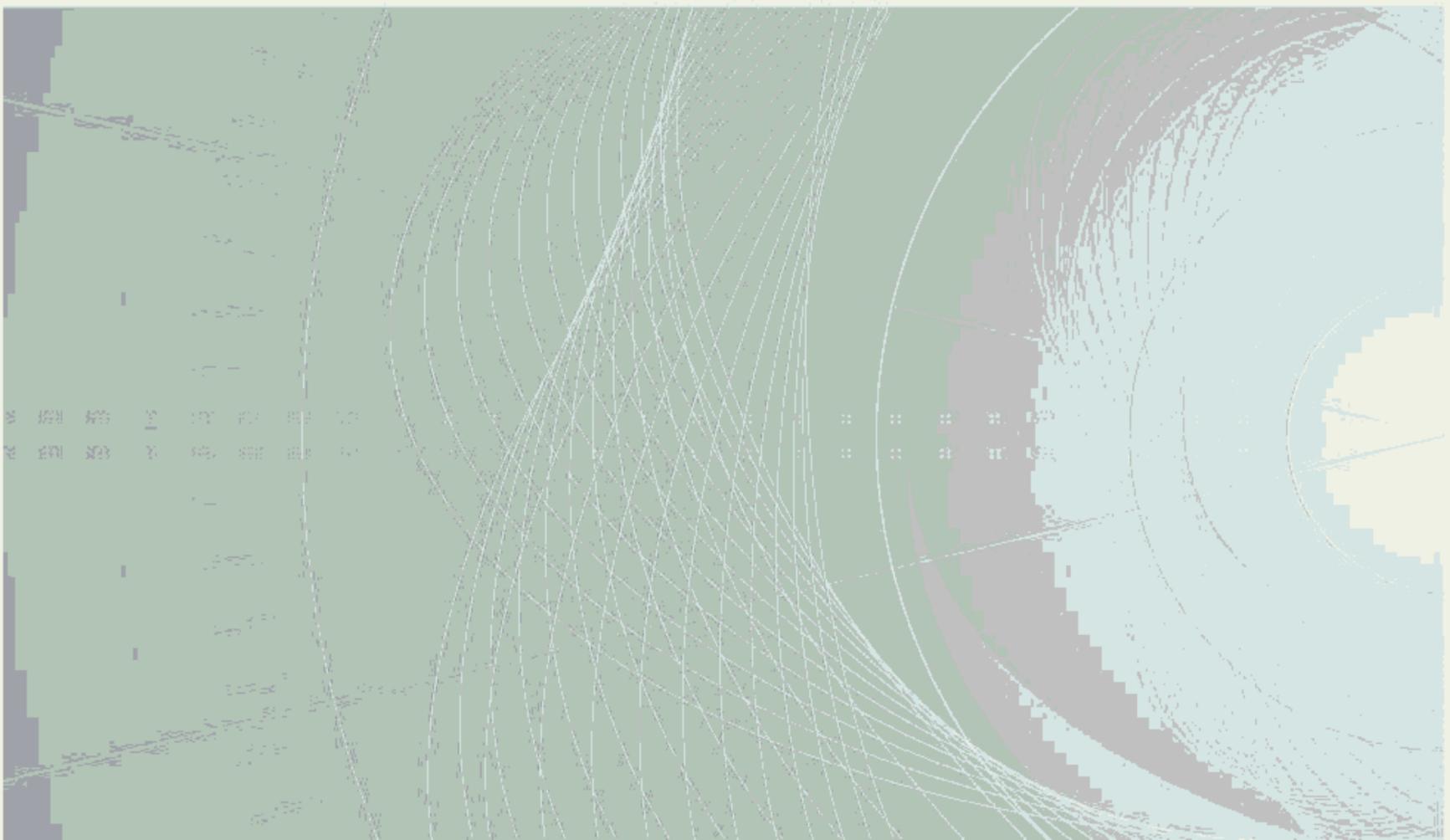


TECHNICAL SPECIFICATION



Photovoltaic (PV) modules – Partial shade endurance testing for monolithically integrated products





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Photovoltaic (PV) modules – Partial shade endurance testing for monolithically integrated products

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC (PV) MODULES – PARTIAL SHADE ENDURANCE TESTING FOR MONOLITHICALLY INTEGRATED PRODUCTS

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IEC TS 63140 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
82/1804/DTS	82/1836/RVDTS

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

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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

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- withdrawn,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

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PHOTOVOLTAIC (PV) MODULES – PARTIAL SHADE ENDURANCE TESTING FOR MONOLITHICALLY INTEGRATED PRODUCTS

1 Scope

This document provides test methods for quantifying the permanent change in a monolithically integrated PV module's power output that may result from some potential partial shade conditions. Three tests are available, representing conditions of use, misuse, and most severe misuse. This document is applicable to monolithically integrated PV modules with one series-connected cell group or with multiple series-connected cell groups that are in turn connected in parallel. This document is not applicable to PV modules formed by the interconnection of separate cells.

With regard to shading, PV module documentation varies significantly by manufacturer. The physical tests prescribed in this document are applied without regard to manufacturer documentation or warranty policy, which may forbid certain shadows. The tests may therefore go beyond intended use, testing a module's response to misuse. The tests are accelerated tests. They are intended to excite similar levels of stress as shadows that are possible during an extended period of outdoor service. The tests represent adverse shadow scenarios, but not necessarily the worst case scenario, which varies by product. The procedures are performed repeatedly and in high-irradiance conditions; shadows occurring only one time or in low-irradiance conditions are likely to cause less damage. This test procedure does not comprehensively evaluate the efficacy or completeness of manufacturer recommendations. This test procedure is not equivalent to, and is not intended to replace, the hot-spot endurance test in IEC 61215-2. The safety aspects of partial shading of PV modules are covered by IEC 61730-2 MST 22 and IEC 61215-2 MQT 09.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

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

IEC TS 60904-13, *Photovoltaic devices – Part 13: Electroluminescence of photovoltaic modules*

IEC 61215-2:2021, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures*

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

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

IEC 61853-1, *Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating*

3 Terms and definitions

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

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

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

3.1

intended use

use of a product, process or product-related service in accordance with the information for use provided by the product manufacturer

3.2

misuse

use of a product, process or product-related service in a way not intended by the product manufacturer as described in the product manufacturer's product-specific manuals and operating instructions

Note 1 to entry: Module warranties are often voided in cases of misuse.

3.3

monolithically integrated

composed of multiple solar cells built on the same substrate or superstrate and integrated through scribing processes during fabrication

3.4

cell pitch

distance between successive repetitions of the monolithic integration pattern

3.5

module height

dimension of the module when measured parallel to the cell integration scribe lines

3.6

module width

dimension of the module when measured perpendicular to the cell integration scribe lines

3.7

string current

current that would pass in a long string of uniformly illuminated modules under the present irradiance conditions and at 25 °C

Note 1 to entry: String current is defined by:

$$I_s = I_{mp,STC} \frac{E_{POA}}{1000 \text{ W m}^{-2}}$$

where

$I_{mp,STC}$ is the current at maximum power listed on the module nameplate, and

E_{POA} is the plane-of-array irradiance.

Note 2 to entry: This formula is strictly valid only for linear devices, as defined in IEC 60904-10. It is acceptable for use in the range of irradiances and temperatures used in this document.

4 Principle

Monolithically integrated PV modules contain multiple PV cells connected in series. When illuminated and non-illuminated cells are connected in series, the non-illuminated cells can operate in reverse bias. In combination with nonuniformities in the device, this reverse bias can lead to highly nonuniform current flow, localized heating, and the formation of permanent shunts. The test procedures excite this nonuniform current flow and quantify the resulting permanent change in PV module power output.

Three test types are available, summarized in Table 1. Any of the tests may be requested by a requestor. The U test verifies the presence of specific warning text in manufacturer documentation. If this text is absent, test M is performed, whether or not it was requested. Test M approximates a person repeatedly walking past the module in sunny conditions. Test SM approximates a narrow tool, such as a cleaning machine, being repeatedly passed across the surface of the module. Selection of tests is summarized in Figure 1.

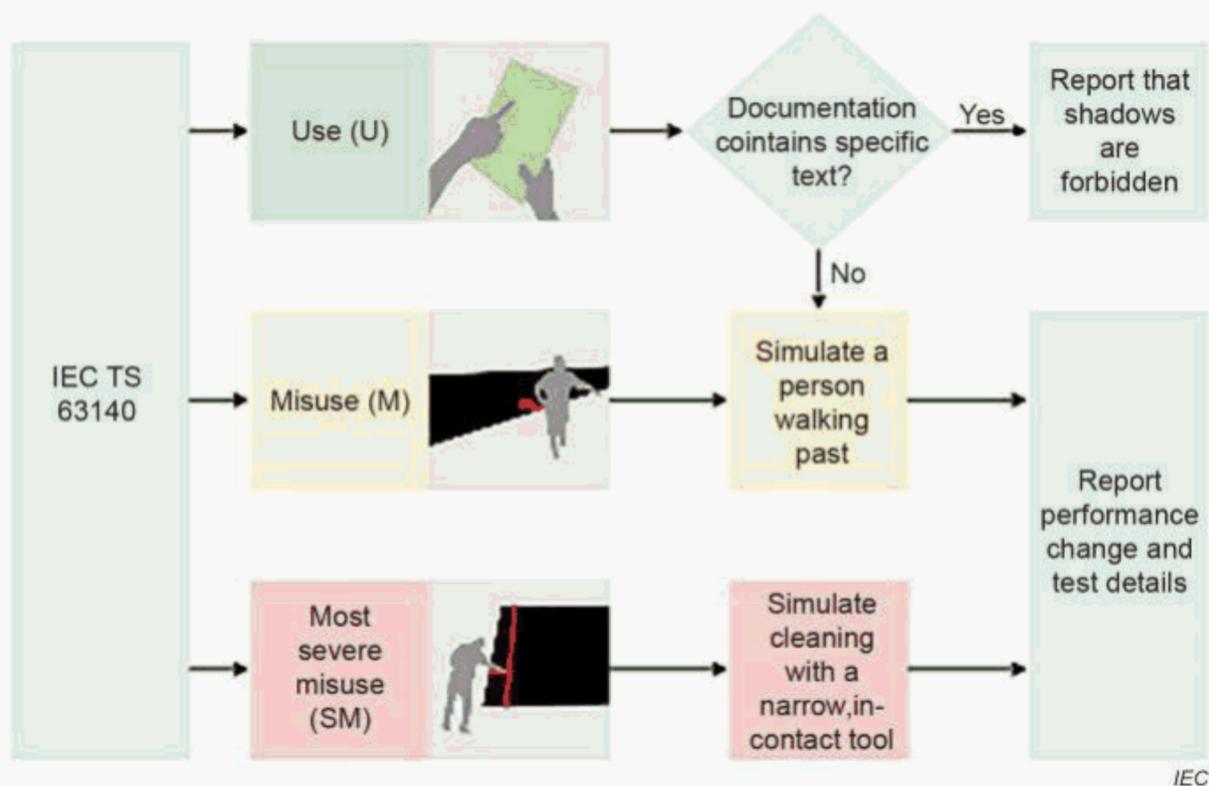


Figure 1 – Selection of the three available tests

Table 1 – Test types available in this document

Test name	Test summary	Explanation
Use (U)	Check documentation for the presence of specific warning text. If present, perform no testing. If absent, perform the misuse (M) test.	Assumes that all users understand the specific warning text and allow no potentially damaging shadows to be cast while current is flowing.
Misuse (M)	In high-irradiance conditions and with current flowing, repeatedly pass the human-sized mask (Figure 2, left) in front of the module.	Represents the following scenario. A person repeatedly walks past the module in clear, sunny conditions while current is flowing. The person casts their shadow in profile, with up to 1 m of their shadow's height overlapping the module. The person's shadow blocks direct irradiance but not diffuse irradiance, so about 90 % of incident light is blocked.
Most severe misuse (SM)	In high-irradiance conditions and with current flowing, repeatedly pass the narrow tool mask (Figure 2, right) in front of the module.	Represents the following scenario. A cleaning device repeatedly passes across the module in sunny conditions while current is flowing. The cleaning device is narrow and is in close contact with the module surface. The shadow extends across the entire height of the module and in parallel to the integration scribe lines. The shadow blocks both direct and diffuse irradiance, so about 100 % of incident light is blocked.

5 Apparatus

If a procedure requiring physical testing is performed, the procedure requires:

NOTE 1 In some cases test U (described below) can be completed without physical testing.

- a) equipment for stabilizing module performance according to IEC 61215-2 MQT 19;
- b) equipment for measuring $I-V$ curves according to IEC 61215-2 MQT 02, per IEC 60904-1;
- c) equipment for operating the PV module in a constant-current mode;
 - if the module under test contains a bypass diode, the electrical load equipment shall be able to sink current up to 1,5 times the module's nameplate I_{mp} ;
 - if the module under test does not contain a bypass diode, the electrical load equipment shall be able to both source and sink current up to 1,5 times the module's nameplate I_{mp} , at whatever voltage (up to the maximum string voltage) is required to do so;

NOTE 2 The voltage required to ensure that I_{mp} is flowing at all times during the test varies by product, and may be negative (reverse bias) when the mask is on the module.

- the current passed by the load equipment shall be updated to accommodate changes in irradiance and these updates shall be frequent enough that changes in irradiance never exceed 5 % between updates;
- d) equipment for mounting the module outdoors in natural sunlight or a class CCC or better continuous solar simulator, in compliance with IEC 60904-9;
 - e) a radiometer (pyranometer or reference cell meeting the requirements of IEC 60904-2) for measuring irradiance incident on the module plane in the continuous solar simulator or in natural sunlight;
 - f) one or more masks conforming to the requirements below for one or more tests selected from Table 1:
 - for test M, a mask roughly approximating the shape of a human body (from thigh to head, approximated by a rectangle for ease of fabrication, conforming to the dimensions in Figure 2) and blocking 88 % to 92 % of incident light;

NOTE 3 Mask M blocks approximately 90 % of incident light, because a shadow cast outdoors by a distant object blocks only direct sunlight, and in clear conditions this is approximately 90 % of incident light.

- for test SM, a mask in the shape of a simple cleaning tool or cleaning device (a rectangle 50 mm wide and the length of the module height, as shown in Figure 2) and blocking 99,9 % to 100 % of incident light;

NOTE 4 Mask SM blocks approximately 100 % of light, because an opaque object in close contact with a surface outdoors blocks nearly all incident sunlight, including both direct and diffuse light.

- the masks shall block the amount of light prescribed above, measured by one of the following methods:
 - Method 1 (recommended): comparing uncovered and completely covered measurements of short-circuit current (from a module, mini-module, or reference cell with the same spectral response as the module under test) under the same illumination conditions as used for the test.
 - Method 2: comparing the integral of the spectral responsivity of the module under test to the integral of the spectral responsivity multiplied by a spectrally resolved measurement of the mask's total hemispherical transmittance.
- if method 2 is used or if natural sunlight is used as the light source, masks using a repeating pattern of apertures in an opaque sheet (as in a textile, a screen, or a printed pattern) shall meet all of the following additional requirements to prevent changes in effective transmission due to differences in the angular distribution of light:
 - the distance between repetitions of the pattern (the pattern pitch) shall be less than 20 % of the cell pitch of the module under test;
 - the shape of each aperture shall be convex (circular or square apertures are acceptable; star-shaped apertures are not);
 - for two-dimensional patterns of apertures, the thickness of the opaque sheet shall be less than 2 % of the pattern pitch;
 - for one-dimensional patterns of apertures, the thickness of the opaque sheet shall be less than 1 % of the pattern pitch;

Dimensions in millimetres

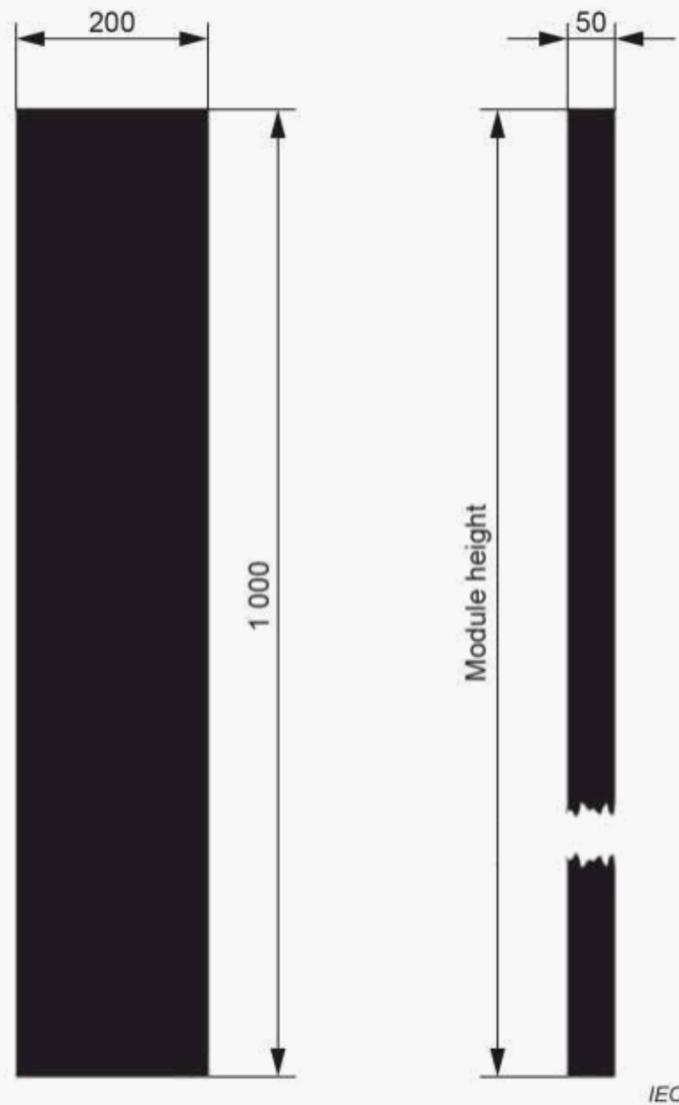


Figure 2 – Dimensions of the mask for test M (left) and the mask for test SM (right)

- g) a temperature sensor for measuring the module surface temperature in the illuminated area;
- h) optionally, infrared (IR) imaging equipment;
- i) optionally, electroluminescence (EL) imaging equipment and a power supply for driving current through the module during EL imaging;
- j) optionally, equipment for illuminating the module with recommended illumination of at least 1 000 lux and optionally photographing the module as a part of visual inspection.

6 Procedure

6.1 General

Perform one or more of the three available tests, as requested by the individual or body requisitioning the test(s).

6.2 Use test (test U)

- a) Determine whether the product documentation (data sheet, user manual, or installation manual) meets all of the following requirements.
 - Documentation shall contain the following text, outlined by a box:

Notice: This product may undergo rapid and permanent loss of efficiency when some particular types of shadows are present while current is flowing. Efficiency loss can continue even after these shadows are removed. This loss of efficiency can be avoided by eliminating shadows or by stopping the flow of current while shadows are present. Other guidelines relating to shadows may not completely eliminate the risk of efficiency loss.

NOTE Outlining the notice text in a box prevents any surrounding text from being misinterpreted as a part of the required notice.

- Documentation shall not bear markings (such as “confidential” or “proprietary”) that may prevent the documentation from being made available to potential users of the product.
- b) If the documentation meets the requirements of item a), the use test is complete and all subsequent steps in this procedure shall be skipped, unless test M or SM is specifically requested. If the documentation does not meet the requirements of item a), perform test M.

6.3 Misuse test (test M) and most severe misuse test (test SM)

6.3.1 General

These tests expose modules to approximations of the two types of shadow shown in the test M and test SM rows of Table 1. Extraordinary care shall be used to prevent even momentary partial shadows from falling on the module while current is flowing through it prior to initial electrical measurements.

Testing shall only be performed as part of a sequence of initial measurements, testing, and final measurements. If a module has been previously subjected to test M or test SM, it shall not be used in further testing.

6.3.2 Initial measurements

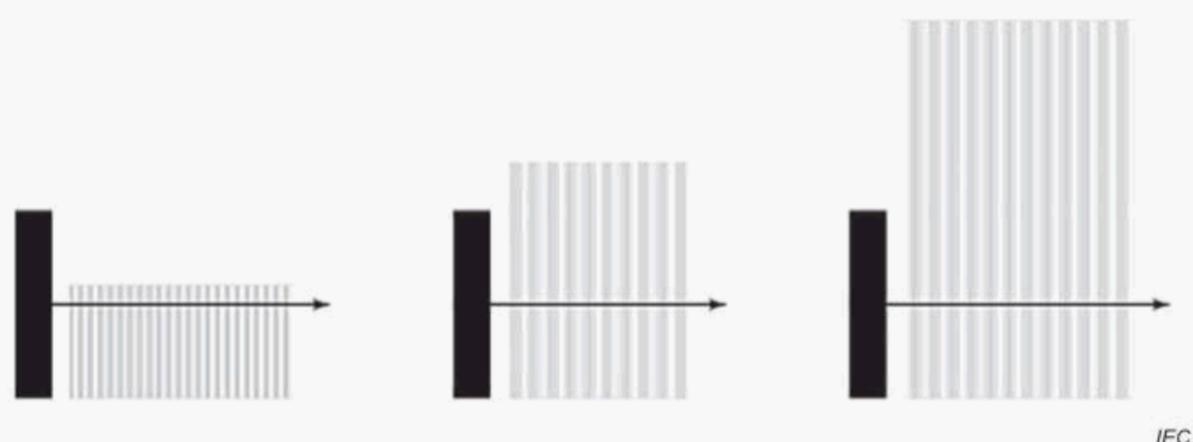
- a) Optionally, perform electroluminescence imaging per the directions in IEC TS 60904-13 at a current not to exceed the module’s nameplate I_{sc} .
- For example, one image at $0,1 I_{sc}$ and a second image at I_{sc} can be useful to illustrate the extent of shunting.
- b) Optionally, carefully inspect the module under an illumination of not less than 1 000 lux and make note of and/or photograph the nature and position of any nonuniformities.

NOTE Shunts resulting from partial shade stress typically appear as thin and serpentine or branched areas that are lighter than their surroundings, 1 mm to 5 mm in length.

- c) Perform MQT 19 according to IEC 61215-2:2021, with the modifications listed below.
- If ‘other stabilization procedures’ are used, the validation process shall be performed both before and after the steps of this technical specification.
 - Report the integrated irradiation at which stability is achieved and the temperature and irradiance conditions used.
- d) Perform MQT 02 at 200 Wm^{-2} and $1\,000 \text{ Wm}^{-2}$ according to IEC 61215-2:2021.
- Report the time between MQT 19 and MQT 02, temperature, irradiance, full I-V curve, V_{oc} , I_{sc} , P_{mp} , I_{mp} , V_{mp} and FF .
 - Optionally, measurements can also be taken at all of irradiance levels in IEC 61853-1 designated for measurement at 25 °C, namely 100 Wm^{-2} , 200 Wm^{-2} , 400 Wm^{-2} , 600 Wm^{-2} , 800 Wm^{-2} , $1\,000 \text{ Wm}^{-2}$, and $1\,100 \text{ Wm}^{-2}$.

6.3.3 Misuse test (test M)

If test M is not being performed, skip the steps in this subclause.



Left: module height <1 000 mm; center and right: module height >1 000 mm.

Figure 3 – Illustration of test M, showing the movement of the fixed-size mask across example modules of three different sizes

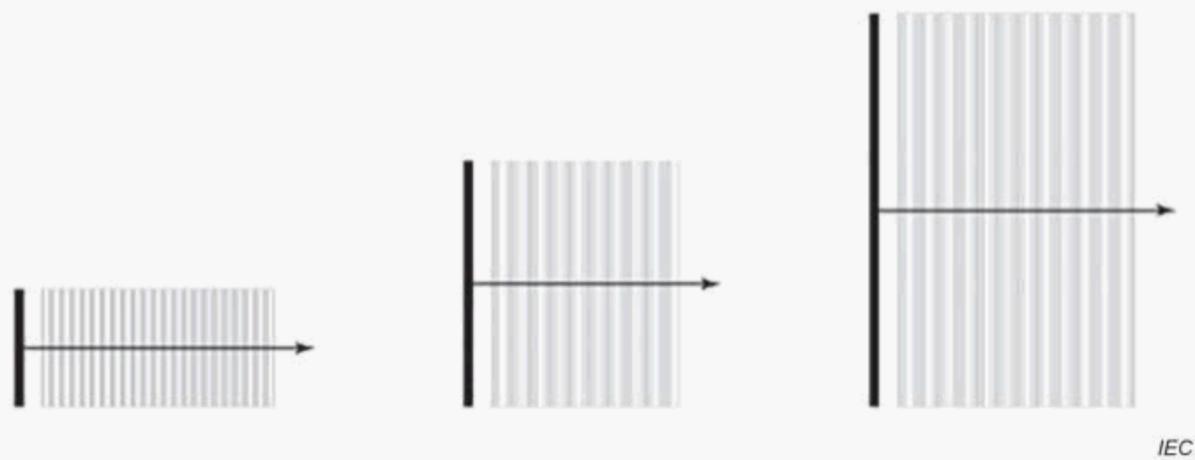
- a) Deploy the module outdoors in natural sunlight or in a continuous solar simulator.
- b) Connect the module to the electrical load equipment configured to pass the string current, updated according to changes in irradiance as described above.
- c) Configure the module to be heated or cooled until its surface temperature is ≥ 20 °C and ≤ 70 °C.

NOTE Under a wide range of ambient conditions and solar simulator configurations, this temperature range can be reached without special heating or cooling equipment.

- d) Position mask M beside the module so that its long dimension is parallel to the module's integration scribe lines and so that, when it is moved across the module surface, the mask will overlap with the module, as shown in Figure 3. The mask shall be parallel with the module's integration scribe lines to within $\pm 0,3^\circ$ (± 5 mm of deviation over 1 000 mm of distance). The height of the overlapping area shall be the lesser of the module height and the mask's 1 000 mm height.
- e) With a minimum irradiance of 900 Wm^{-2} move mask M across the surface of the module, with the direction of motion perpendicular to the module's integration scribe lines. If natural sunlight or a point-source solar simulator is used, the angle between the light source and the module surface normal shall be $\leq 45^\circ$.
 - If the mask is moved continuously, it shall be moved across the module's active area with constant speed ≤ 30 mm/s (approximately 33 s per metre) and ≥ 1 mm/s (1 000 s per metre).
 - If the mask is moved in steps, the steps shall be smaller than 20 mm and the mask shall remain in each position for a minimum of 0,7 s and a maximum of 20 s.
 - The distance between the mask and the module surface shall be ≤ 5 mm.
 - If irradiance falls below the minimum, or if a shadow other than the mask's shadow falls on the module, the mask's motion shall be stopped and the motion resumed when irradiance increases to the minimum again.
- f) Repeat the preceding step 15 times.
 - Optionally, between repetitions, perform some or all of the steps listed in 6.3.2.
 - Optionally, perform IR imaging or otherwise record module surface temperature while the mask is in place.

6.3.4 Most severe misuse test (test SM)

If test SM is not being performed, skip the steps in this subclause.



IEC

Figure 4 – Illustration of test SM, showing the overlap of the mask with the module's full height and the movement of the mask across example modules of three different sizes

- a) Deploy the module outdoors in natural sunlight or in a continuous solar simulator.
- b) Connect the module to the electrical load equipment configured to pass the string current, updated according to changes in irradiance as described above.
- c) Configure the module to be heated or cooled until its surface temperature is ≥ 20 °C and ≤ 70 °C.

NOTE Under a wide range of ambient conditions and solar simulator configurations, this temperature range can be reached without special heating or cooling equipment.

- d) Position mask SM beside the module so that its long dimension is parallel to the module's integration scribe lines and so that, when it is moved across the module surface, the module's entire height will be covered by the mask, as shown in Figure 4. The mask shall be parallel with the module's integration scribe lines to within $\pm 0,3^\circ$ (± 5 mm of deviation per 1 000 mm of distance).
- e) With a minimum irradiance of 900 Wm^{-2} , move the tool mask across the surface of the module, with the direction of motion perpendicular to the module's integration scribe lines. If natural sunlight or a point-source solar simulator is used, the angle between the light source and the module surface normal shall be $\leq 45^\circ$.
 - If the mask is moved continuously, it shall be moved across the module's active area with constant speed ≤ 30 mm/s (approximately 33 s per metre) and ≥ 1 mm/s (1 000 s per metre).
 - If the mask is moved in steps, the steps shall be smaller than 20 mm and the mask shall remain in each position for a minimum of 0,7 s and a maximum of 20 s.
 - The distance between the mask and the module surface shall be ≤ 5 mm.
 - If irradiance falls below the minimum, or if a shadow other than the mask's shadow falls on the module, the mask's motion shall be stopped and the motion resumed when irradiance increases to the minimum again.
- f) Repeat the preceding step 15 times.
 - Optionally, between repetitions, perform some or all of the steps listed in 6.3.2.
 - Optionally, perform IR imaging or otherwise record module surface temperature while the mask is in place.

6.3.5 Final measurements

Perform the same measurements and report the same results as in initial measurements (6.3.2).

7 Test report

A report shall be prepared by the test agency. The report shall contain:

- a) a title;
 - b) the name and address of the test laboratory and location where the tests were carried out;
 - c) unique identification of the report and of each page;
 - d) name and address of client, where appropriate;
 - e) description and unique identification (such as serial number) of the module(s) tested;
 - f) if modules were supplied with documentation making recommendations about practices related to casting shadows on modules, copies of such documentation;
 - g) when an objective assessment is possible, an indication of which tests in this document are forbidden by the documentation provided with the modules;
 - h) date of receipt of test sample(s) and date(s) of test(s), where appropriate;
 - i) description of the equipment used to perform each step;
 - j) indication of which test procedure (U, M, SM) was performed on each test sample;
 - k) any deviations from, additions to, or exclusions from the test method and any other information relevant to a specific test;
 - l) measurements, examination and derived results, including irradiance, current, and temperature measured during the test, and with particular emphasis on the loss of power resulting from partial shade stress, supported by tables, graphs, sketches and photographs as appropriate;
 - m) a statement of the estimated uncertainty of the test results (where relevant);
 - n) a signature and title, or equivalent identification of the person(s) accepting responsibility for the content of the report, and the date of issue;
 - o) where relevant, a statement to the effect that the results relate only to the items tested.
-

