UL 61215-1

STANDARD FOR SAFETY

Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 1: Test Requirements

UL Standard for Safety for Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 1: Test Requirements, UL 61215-1

Second Edition, Dated July 28, 2021

Summary of Topics

UL 61215-1 is an adoption of IEC 61215-1, Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 1: Test Requirements (Second Edition, issued February 2021). Please note that there are no National Differences.

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

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JULY 28, 2021

ANSI/UL 61215-1-2021

UL 61215-1

Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 1: Test Requirements

First Edition – February, 2017

Second Edition

July 28, 2021

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

The most recent designation of ANSI/UL 61215-1 as an American National Standard (ANSI) occurred on July 7, 2021. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, or Preface. The IEC Foreword is also excluded from the ANSI approval of IEC-based standards.

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

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PREFACE

This UL Standard is based on IEC Publication IEC 61215-1: Second edition Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval – Part 1: Test Requirements. IEC publication IEC 61215-1 is copyrighted by the IEC.

This edition has been issued to satisfy UL Standards policy.

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

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

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FOREWORD

INTERNATIONAL ELECTROTECHNICAL COMMISSION

TERRESTRIAL PHOTOVOLTAIC (PV) MODULES – DESIGN QUALIFICATION AND TYPE APPROVAL – Part 1: Test requirements

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8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61215-1 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This second edition of IEC 61215-1 cancels and replaces the first edition of IEC 61215-1, published in 2017; it constitutes a technical revision.

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

a) Addition of a test taken from IEC TS 62782.

b) Addition of a test taken from IEC TS 62804-1.

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

d) Addition of definitions, references and instructions on how to perform the IEC 61215 design qualification and type approval on bifacial PV modules.

e) Clarification of the requirements related to power output measurements.

f) Addition of weights to junction box during 200 thermal cycles.

g) Requirement that retesting be performed according to IEC TS 62915.

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

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

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

FDIS	Report on voting
82/1828A/FDIS	82/1848/RVD

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

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

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

The committee has decided that the contents of this 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.

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TERRESTRIAL PHOTOVOLTAIC (PV) MODULES – DESIGN QUALIFICATION AND TYPE APPROVAL – Part 1: Test requirements

1 Scope

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

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

This document is intended to apply to all terrestrial flat plate module materials such as crystalline silicon module types as well as thin-film modules. It does not apply to systems that are not longterm applications, such as flexible modules installed in awnings or tenting.

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

This document does not address the particularities of PV modules with integrated electronics. It may however be used as a basis for testing such PV modules.

The objective of this test sequence is to determine the electrical characteristics of the module and to show, as far as possible within reasonable constraints of cost and time, that the module is capable of withstanding prolonged exposure outdoors. Accelerated test conditions are empirically based on those necessary to reproduce selected observed field failures and are applied equally across module types. Acceleration factors may vary with product design, and thus not all degradation mechanisms may manifest. Further general information on accelerated test methods including definitions of terms may be found in IEC 62506.

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

2 Normative references

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

IEC 60269-6, *Low-voltage fuses – Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems*

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

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

IEC TS 60904-1-2:2019, *Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices*

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

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

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

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

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

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

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

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

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

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

IEC 62852, *Connectors for DC-application in photovoltaic systems – Safety requirements and tests*

IEC TS 62915, *Photovoltaic (PV) modules – Type approval, design and safety qualification – Retesting*

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

IEC TS 63163: –[1]*Terrestrial photovoltaic (PV) modules for consumer products – Design qualification and type approval*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

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

3 Terms, definitions and abbreviated terms

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

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

• IEC Electropedia: available at http://www.electropedia.org/

• ISO Online browsing platform: available at http://www.iso.org/obp

3.1
bins of power classes
power (typically maximum power) sorting criteria from the PV module manufacturer

3.2
tolerances <on label>
value range of electrical parameters on the label of the PV module as given by the manufacturer

3.3
MQT
Module Quality Test

3.4
type approval
conformity test made on one or more items representative of the production

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

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 [consistent with the International Vocabulary of Metrology (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.

Note 3 to entry: It is recommended that laboratories determine their reproducibility according to the formulas and principles in ISO 5725-2.

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

3.6
flexible module
PV module that exhibits a radius of curvature of 500 mm or less in at least one direction according to the manufacturer's specification and is capable of bending to conform to a flat or curved surface

Note 1 to entry: A curved module with a rigid shape is not considered a flexible module.

Note 2 to entry: Radius of curvature is defined as shown in Figure 1. During testing, the applied radius of curvature is no smaller than that specified by the manufacturer.

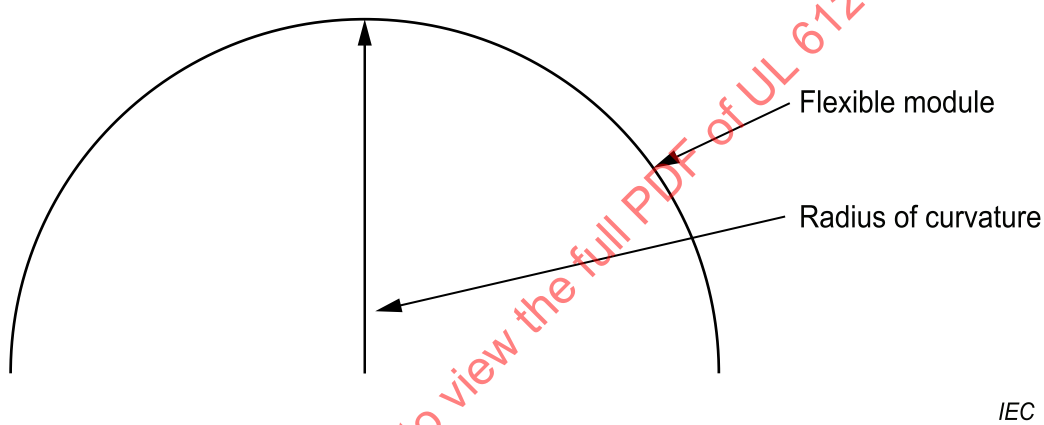

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Figure 1

Geometry that shows radius of curvature of a flexible module

3.7
representative sample
sample that includes all the components of the module, except some repeated parts

Note 1 to entry: The representative samples shall use all key materials and subassemblies, as detailed in Clause 4.

3.8
very large module
module that exceeds the size of standard 2,2 m × 1,5 m commercially-available simulators

Note 1 to entry: A very large module exceeds 2,2 m in length or width, or exceeds 1,5 m in both dimensions. Thus a 3 m × 0,3 m module is considered very large, as is a 2,2 m × 2,2 m module.

Note 2 to entry: Very large modules are exempt from class A simulator spatial irradiance uniformity requirements, as detailed in IEC 61215-2 MQT 02.

Note 3 to entry: During test sequences representative samples may be substituted for very large modules, within the limits described in Clause 4.

Note 4 to entry: In future editions, the size threshold to be considered a very large module will likely increase to larger dimensions.

3.9
bifacial PV
modules modules that can convert irradiation received on both the front-side and rear-side into electric energy by means of the photovoltaic effect

3.10
bifaciality coefficients
ratios between the I-V characteristics of the rear-side and the front-side of a bifacial module each measured under Standard Test Conditions (STC – IEC TS 61836), namely the short-circuit current bifaciality coefficient φ_{Isc}, the open-circuit voltage bifaciality coefficient φ_{Voc} and the maximum power bifaciality coefficient φ_{Pmax}

Note 1 to entry: Bifaciality coefficients are fully defined in IEC TS 60904-1-2:2019, 6.2.

3.11
bifacial nameplate irradiance
BNPI
higher irradiance at which nameplate verification is performed for bifacial modules, corresponding to 1 000 W/m^2 on the module front and 135 W/m^2 on the module rear, applied in any method allowed by IEC TS 60904-1-2

3.12
bifacial stress irradiance
BSI
higher irradiance at which currents for stress are measured on bifacial modules, corresponding to 1 000 W/m^2 on the module front and 300 W/m^2 on the module rear, applied by any method allowed in IEC TS 60904-1-2, *I-V* characteristic at which may be extrapolated from lower irradiances

4 Test samples

The PV module samples shall have been manufactured from specified materials and components in accordance with the relevant drawings and process sheets and have been subjected to the manufacturer's normal inspection, quality control and production acceptance procedures. The PV modules shall be complete in every detail and shall be accompanied by the manufacturer's handling, mounting, and connection instructions. When the PV modules to be tested are prototypes of a new design and not from production, this fact shall be noted in the test report (see Clause 9).

The number of test samples required is derived from the applicable test sequences (see Clause 11).

Special test samples may be required for tests such as the bypass diode test MQT 18 (see IEC 61215-2).

For qualification of multiple bins of power classes within the boundaries given in IEC TS 62915 at least 2 modules each, from the lower end, median and higher end power class shall be used for testing. If median power class does not exist the next higher class shall be used. If qualification of a single power class shall be extended to further bins of power classes within the boundaries given in IEC TS 62915 then at least 2 modules each, from the lower end and higher end power class shall be used for label verification (see Gate No.1 in 7.2.1). If a power class is extended only towards higher (or lower) bins, then modules only from the higher (or lower) bins, respectively, shall be used for verification of rated label values.

Qualification to multiple bins of power classes does not increase the minimum requirement of one control sample used in 7.2.3.

It is advisable to provide additional spare samples meeting the same output power requirements.

If applicable, the test samples shall be used to represent a group or family of products, or variations in the materials, or production processes used to produce the modules. The additional samples required for the test programme are then derived from IEC TS 62915.

For very large modules (as defined in 3.8), representative samples (as defined in 3.7) may be used for all qualification tests given in Clause 11 and IEC 61215-2. During the design and manufacturing of the representative samples, attention should be paid to reach the maximum similarity to the fullsize product in all electrical, mechanical, and thermal characteristics related to quality and reliability. The cell, encapsulation methods, interconnects, terminations, clearance and creepage distances around all edges, and distance through solid insulation (relied upon insulation and cemented joints) shall be the same as on the actual full-size products. Limits are placed on how much one may reduce the dimensions of a very large module in making representative samples for qualification testing. The reduced dimension(s) shall be no less than one half the dimensions that define a very large module. In other words, when reducing the shorter dimension, the representative sample shall be at least 0,75 m wide. In reducing the longer dimension, the representative sample shall be at least 1,1 m long. If representative samples are used for any test, the test report shall include a table listing the dimensions of the product being qualified, and for each MQT, the dimensions of the samples tested. The table shall contain the statement, "Smaller samples were used for some tests as noted above. Use of smaller samples may affect test results." For determination of maximum power degradation during testing (7.2.3) on a representative sample, P_{max}(Lab_GateNo.1) refers to the representative sample's initial stabilized measured power output. However, for verification of rated label values (7.2.2) a standard production product shall be measured, either at the test facility or utilizing a test at the manufacturer monitored by the testing entity.

If representative samples are utilized in Sequence E, then one extra module, full-sized, is required, and shall be subjected only to MQT 16 (static mechanical load test) and the requirements therein.

Any representative sample used for MQT 09 (hot-spot endurance test) shall contain the same number of cells per bypass diode (i.e. the same substring size) as the full-size product.

NOTE It is preferable in any test to measure a full-size sample, rather than a representative sample, when equipment size allows.

Prior to beginning the qualification test, care should be taken not to damage the samples in transit. Such care may include adherence to best practices in packing and shipping,[1][2] as well as electroluminescence imaging according to IEC TS 60904-13 before and after shipping to make sure cracks have not developed in transit.

[2] Numbers in square brackets refer to the Bibliography.

For the requirements in the IEC 61215 series, a module shall be considered "bifacial " if the manufacturer claims bifaciality on the nameplate or datasheet, or if the module exhibits a maximum power bifaciality coefficient ≥ 20 %. If a module is to be tested as a monofacial module, the test laboratory shall verify that the module is monofacial by at least one of the following methods:

a) Information from the manufacturer showing that the rear of the cell is fully metallized;

b) Spectrally-resolved backsheet transmission data from the module manufacturer; or

c) Determination of bifaciality coefficient on one sample according to the procedure in IEC TS 60904-1-2.

5 Marking and documentation

5.1 Name plate

Each module shall include the following clear and indelible markings. Unless otherwise indicated, all the electrical parameters refer to STC:

a) name, registered trade name or registered trade mark of manufacturer;

b) type or model number designation;

c) serial number (unless marked on other part of product);

d) date and place of manufacture; alternatively serial number allowing to trace the date and place of manufacture;

e) maximum system voltage;

f) class of protection against electrical shock (as defined in IEC 61140 and IEC 61730-1);

g) voltage at open-circuit or V_{oc} including tolerances. For bifacial modules, open-circuit voltage shall be reported at two irradiance levels. The first required irradiance level is 1 000 W/m^2. The second required irradiance is BNPI, as defined in 3.11.

h) current at short-circuit or I_{sc} including tolerances. For bifacial modules, short-circuit current shall be reported at two irradiance levels, defined in 5.1g).

i) module maximum power or P_{max} including binning and tolerances as defined in 3.1 and 3.2. For bifacial modules, P_{max} shall be reported at the two irradiance levels, defined in 5.1g).

j) For bifacial modules the following information including tolerances, shall be given on the nameplate: The values for the short-circuit current bifaciality coefficient φ_{Isc}, the open-circuit voltage bifaciality coefficient φ_{Voc}, and the maximum power bifaciality coefficient φ_{Pmax}, measured at STC as defined in IEC TS 60904-1-2.

k) For flexible modules, the minimum radius of curvature.

For items a) through i) all electrical data shall be shown as relative to STC (1 000 W/m^2, 25 °C, AM1.5 according to IEC TS 61836), except for bifacial modules where two irradiance levels are required, as defined in 5.1g).

International symbols shall be used where applicable.

Compliance of marking is checked by inspection and MQT 06.1.

5.2 Documentation

5.2.1 Minimum requirements

Modules shall be supplied with documentation describing the methods of electrical and mechanical installation as well as the electrical ratings of the module. The documentation shall state the class of protection against electrical shock under which the module has been qualified and any specific limitations required for that class. The documentation shall assure that installers and operators receive appropriate and sufficient documentation for safe installation, use, and maintenance of the PV modules.

NOTE It is considered to be sufficient that one set of documentation is supplied with the module shipping unit.

5.2.2 Information to be given in the documentation

a) all information required under 5.1 e) to i), and in addition j) for bifacial modules and k) for flexible modules;

b) reverse current overload rating in accordance with IEC 61730-2 MST 26;

– overcurrent protection device type and rating are e.g. given in IEC 60269-6. Overcurrent protection devices with a 1 h, 1,35 I_n overload rating, where I_n is the rated value of the overcurrent protection device, are recommended;

– recommended maximum series/parallel PV module configurations;

c) manufacturer's stated tolerance for V_{oc}, I_{sc} and maximum power output under standard test conditions;

d) temperature coefficient for voltage at open-circuit;

e) temperature coefficient for maximum power;

f) temperature coefficient for short-circuit current.

All electrical data mentioned above shall be shown as relative to standard test conditions (1 000 W/m^2, 25 °C, AM1.5 according to IEC TS 61836). Moreover the following parameters shall be specified:

g) performance at low irradiance (MQT 07).

International symbols shall be used where applicable.

Compliance is checked by inspection and MQT 04 through MQT 07.

The electrical documentation shall include a detailed description of the electrical installation wiring method to be used. This description shall include:

h) the minimum cable diameters for modules intended for field wiring;

i) any limitations on wiring methods and wire management that apply to the wiring compartment or box;

j) the size, type, material and temperature rating of the conductors to be used;

k) type of terminals for field wiring;

l) specific PV connector model/types and manufacturer to which the module connectors shall be mated. Statement of the connector type only (such as "MC4 compatible ") is not sufficient information to satisfy this requirement. Connector model/types and manufacturers shall be included;

m) the bonding method(s) to be used (if applicable); all provided or specified hardware shall be identified in the documentation;

n) the type and ratings of bypass diode to be used (if applicable);

o) limitations to the mounting situation (e.g., slope, orientation, mounting means, cooling);

p) a statement indicating the fire rating(s) and the applied standard as well as the limitations to that rating (e.g., installation slope, sub structure or other applicable installation information);

q) a statement indicating the design load per each mechanical means for securing the module as evaluated during the static mechanical load test according to MQT 16. At discretion of the manufacturer the test load and/or the safety factor γ_m may be noted, too.

To allow for increased output of a module resulting from certain conditions of use, the installation instructions shall include relevant parameters specified by manufacturer or the following statement or the equivalent:

"Under normal conditions, a photovoltaic module is likely to experience conditions that produce more current and/or voltage than reported at standard test conditions. Accordingly, the values of I_{SC} and V_{OC} marked on this module should be multiplied by a factor of 1,25 when determining component voltage ratings, conductor current ratings, and size of controls connected to the PV output."

5.2.3 Assembly instructions

These shall be provided with a product shipped in subassemblies, and shall be detailed and adequate to the degree required to facilitate complete and safe assembly of the product.

6 Testing

The test laboratory shall use a laboratory simulator control module to be able to detect drifts in their measurement results. The laboratory simulator control module is different than the control module from sequence A, which is taken from the modules under test and is described in 7.2.3 related to the reproducibility *r*. The laboratory simulator control module is a stable module used on a periodic basis to check simulator output after calibration to a specific irradiance.

The modules shall be divided into groups and subjected to the qualification test sequences in Figure 2. Qualification test sequences are to be carried out in the order specified. The MQT designations in the boxes refer to the corresponding test definitions in IEC 61215-2. Technology-specific test details are listed in the respective parts of this standard. Required module component tests are listed in Table 1. For each component qualification, the test report shall note the test laboratory name and date when the requirement was met. Prior certifications may be used to fulfill these requirements, as long as the certifications were performed in accordance with all conditions noted in Table 1.

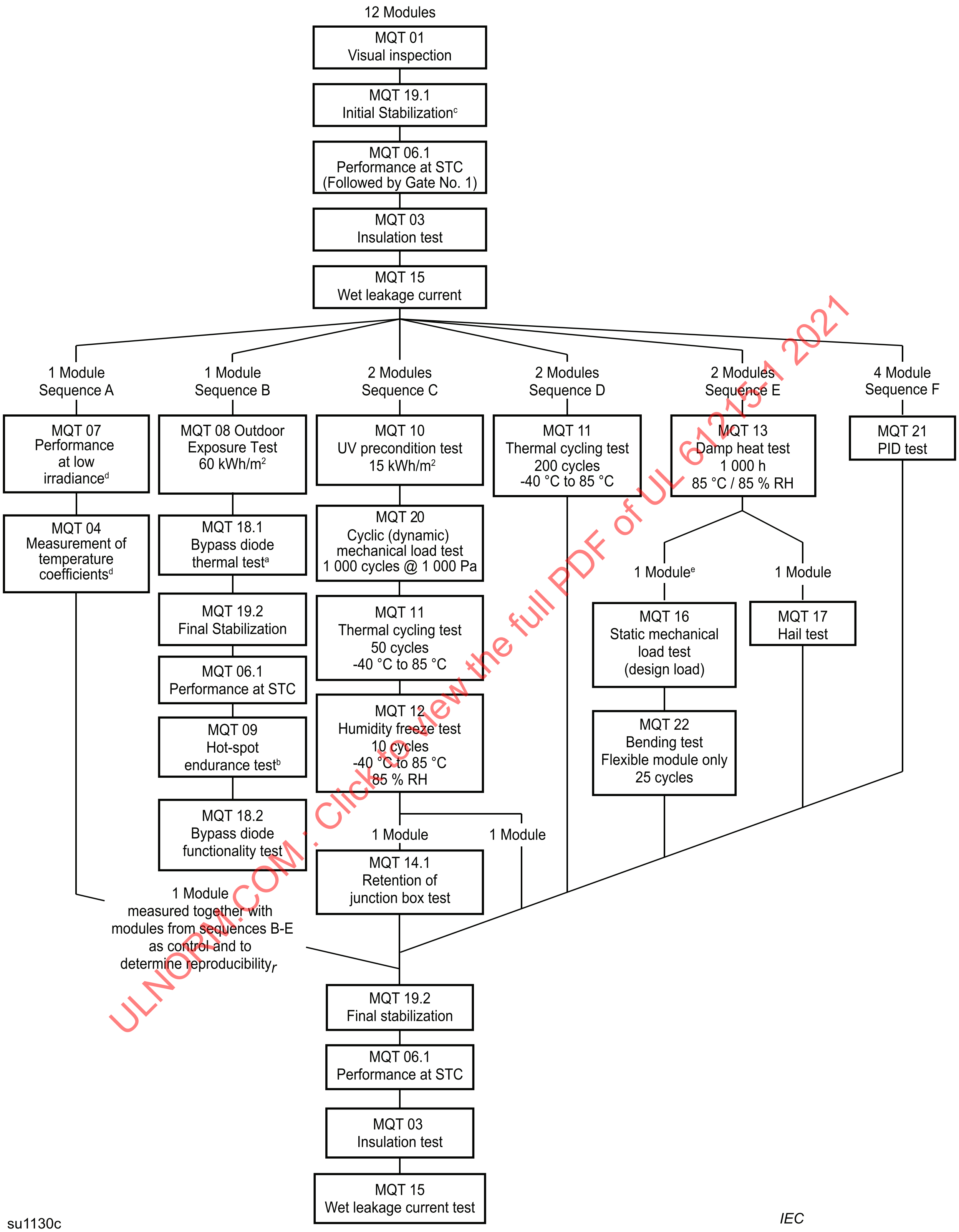
Intermediate measurements of maximum power (MQT 02) and insulation test (MQT 03) are not required, but they may be used to track changes.

Any single test executed independently of a test sequence, e.g., on special test samples for MQT 09 and MQT 18, shall be preceded by the initial tests of MQT 01, MQT 02, MQT 03, and MQT 15 as appropriate.

In carrying out the tests, the tester shall strictly observe the manufacturer's handling, mounting, and connection instructions. Sequence A may be omitted if the module type has been tested according to IEC 61853-1. In this case the relevant test results from IEC 61853-1 shall be stated or referenced in the final report. For bifacial modules Sequence A cannot be omitted until IEC 61853-1 has been amended to take bifacial modules into account.

Test conditions are summarized in Table 3. The test levels in Table 3 are the minimum levels required for qualification. If the laboratory and the module manufacturer agree, the tests may be performed with increased severities. In this case this shall be noted in the test report.

For flexible modules (see 3.6), the mounting substrate and adhesive or attachment means shall also be included in the test. If more than one mounting substrate or adhesive or attachment means is allowed per the manufacturer’s specification, then the tests shall use the combination that is considered to be the worst case. The chosen combination(s) shall be reported, as per Clause 9, j).


12 Modules
MQT 01
Visual inspection
MQT 19.1
Initial Stabilization[c]
MQT 06.1
Performance at STC
(Followed by Gate No. 1)
MQT 03
Insulation test
MQT 15
Wet leakage current
1 Module
Sequence A
1 Module
Sequence B
2 Modules
Sequence C
2 Modules
Sequence D
2 Modules
Sequence E
4 Module
Sequence F
MQT 07
Performance
at low
irradiance[d]
MQT 04
Measurement of
temperature
coefficients[d]
MQT 08 Outdoor
Exposure Test
60 kWh/m²
MQT 18.1
Bypass diode
thermal test[a]
MQT 19.2
Final Stabilization
MQT 06.1
Performance at STC
MQT 09
Hot-spot
endurance test[b]
MQT 18.2
Bypass diode
functionality test
MQT 10
UV precondition test
15 kWh/m²
MQT 20
Cyclic (dynamic)
mechanical load test
1 000 cycles @ 1 000 Pa
MQT 11
Thermal cycling test
50 cycles
-40 °C to 85 °C
MQT 12
Humidity freeze test
10 cycles
-40 °C to 85 °C
85 % RH
1 Module
1 Module
MQT 14.1
Retention of
junction box test
MQT 11
Thermal cycling test
200 cycles
-40 °C to 85 °C
MQT 13
Damp heat test
1 000 h
85 °C / 85 % RH
1 Module[e]
1 Module
MQT 16
Static mechanical
load test
(design load)
MQT 22
Bending test
Flexible module only
25 cycles
MQT 17
Hail test
MQT 21
PID test
1 Module
measured together with
modules from sequences B-E
as control and to
determine reproducibility[f]
MQT 19.2
Final stabilization
MQT 06.1
Performance at STC
MQT 03
Insulation test
MQT 15
Wet leakage current test
su1130c
IEC

[a] If the bypass diodes are not accessible in the standard modules, a special sample can be prepared for the bypass diode thermal test (MQT 18.1). The bypass diode should be mounted physically as it would be in a standard module, with lead wires attached, as required in MQT 18 of IEC 61215-2:2021. This sample does not have to go through the other tests in the sequence.

[b] In sequence B, a different module may be used for the Hot-spot endurance test (MQT 09) than is used for the bypass thermal diode test (MQT 18.1). For this separate module the following test sequence is permissible: MQT 01, MQT 19.1, MQT 06.1 (gate 1), MQT 03, MQT 15, MQT 09, and MQT 18.2.

[c] The initial stabilization MQT 19.1 may include the verification of an alternate stabilization procedure (see IEC 61215- 2:2021).

[d] In Sequence A, tests MQT 07, and MQT 04 may be performed in any order. These tests may also be performed on separate modules (rather than sequential tests on one module), provided that each module used has proceeded through the entire test flow preceding sequence A.

[e] If representative samples are utilized in Sequence E, one extra module, full-sized, is required, and shall be subjected only to MQT 16 and the requirements therein.

Figure 2

Full test flow for design qualification and type approval of photovoltaic modules

Table 1
Required component tests

Component	Shall pass this test
Junction box	IEC 61215-2:201x MQT 14.2, which cites IEC 62790 "Test of cord anchorage."
Connectors	IEC 62852. Compliance shall be obtained with the connector in combination with the same cable size and type as used in the modules under test.

7 Pass criteria

7.1 General

Modules under test are subject to several types of requirements. These include required markings (detailed in Clause 5), comparison of measured electrical quantities with the nameplate ("gate No. 1", detailed in this clause), comparison of measured power before and after stress ("gate No. 2", detailed in this clause), component requirements (detailed in Table 1), and the requirements of each MQT (summarized in Table 3 and Figure 2).

The design is deemed to have met the qualification requirements of 7.2.2 gate No. 1, if they meet the requirements of Table 2:

Table 2
Summary of Gate No. 1 requirements

Sample size (in modules)	Requirement
<10	All modules shall pass. No failure is allowed.
≥10	A single failure is allowable. All other modules shall pass.

NOTE A sample size <10 is only encountered during retesting.

If modules fail to meet the requirements listed in Table 2 then two new samples shall be tested for each of the modules that failed to meet the gate No. 1 criteria. If a new failure occurs, the module supplier has two options. The first option is that the module labels for the existing sample set shall be redefined such that the requirements of Table 2 are met, and testing on that same sample set shall continue to the next step. The second option is that the design is deemed not to have met the qualification requirements, and any further testing constitutes a new attempt at qualification and thus requires a completely new batch of modules. Module labels shall be redefined and samples shall be resubmitted for testing.

In addition, if two or more modules fail to meet the remaining test criteria (7.2.3 Gate No. 2, 7.2.4 electrical circuitry, 7.3 visual defects and 7.4 electrical safety), the design shall be deemed not to have met the qualification requirements. If one module fails any test, two additional modules meeting the requirements of Clause 4 shall be subjected to the entire series of tests of the respective test sequence. The requirement for two additional modules applies for tests where originally only one module was required, as well as for tests where originally two modules were required. For example, a failure in the hot-spot endurance test requires a test repetition with two additional modules. A single failure in the 50 thermal cycles test (one module not meeting the test requirements) requires a test repetition with two additional modules as well.

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

The module design shall meet the requirements of all criteria to be deemed as qualified according to this document. Each test sample shall be subject to the following criteria.

7.2 Power output and electric circuitry

7.2.1 Identification of rated values and tolerances

Gate No. 1 criteria detailed in the following subclauses require use of rated values and tolerances from the nameplate and product datasheet. This clause describes in detail, with examples, how to identify the relevant information. Application of the information in this clause results in consistent requirements when extraneous information is given, or when information appears to be missing or conflicting. Rated values and tolerances shall each be identified for module power, short-circuit current, and open-circuit voltage. Thus, this clause details how to identify these six pieces of information.

NOTE 1 Historically, some products have quoted multiple components of uncertainty, or have used different terminology for uncertainty, such as "tolerance," "production tolerance," "measurement uncertainty," etc. Also, some products have not provided a tolerance, which might be interpreted as 0 % tolerance or as missing information. While a manufacturer is not prohibited from providing additional information, or having 0 % tolerance, application of the rules in this clause provide a consistent manner to interpret such situations.

Information identified in this clause relates to STC current-voltage measurements, obtained in the manner prescribed by following the flow chart of Figure 2. Thus, the obtained values are those measured only after initial stabilization performed according to IEC 61215-2 MQT 19.1. Required stabilization procedures may differ from one product to the next, as specified in the technology-specific parts IEC 61215-1-x. The calculation of tolerances is the responsibility of the module manufacturer. Each tolerance (t_1 , t_2 and t_3) shall be explicitly stated as a single value for each of the performance parameters (P_{max}, V_{OC} and I_{SC} respectively). For bifacial modules, the six pieces of information (values and tolerances for module power, short-circuit current, and open-circuit voltage) shall also be identified at BNPI to evaluate Gate No. 1.

NOTE 2 ISO Guide 98-3 provides further guidance regarding how to combine multiple sources of uncertainty.

Formulas (1) and (2) in 7.2.2 verify that the modules produce at least as much power as the minimum indicated by combining the nameplate rating and tolerance. The minimum nameplate power rating, P_{max}(NP) is the module power output specified on the nameplate. If a single value for module power is stated on the nameplate, P_{max}(NP) is simply that value. If a range of module powers is stated on the nameplate, P_{max}(NP) is the power at the lowest end of that range. Subclause 5.2.2 requires that power binning and tolerance information from the nameplate is reproduced in the datasheet. In the case that P_{max}(NP) derived from the datasheet is different than that on the nameplate, the module shall be judged as not satisfying 5.2.2 and thus does not meet the requirements of IEC 61215-1.

The tolerance, t_1 , is the tolerance in % for P_{max} stated on the nameplate and datasheet, as required by 5.1i) and 5.2.2a). If the tolerance is asymmetric about P_{max}(NP), the tolerance referring to the low power limit shall be utilized as t_1. If the tolerance is not stated on the nameplate or is not stated on the datasheet, then t_1 = 0. If tolerance is not reduced to a single value on the nameplate or data sheet (for example, if multiple tolerances or measurement uncertainty components are specified) the smallest number, not a combination of multiple numbers, shall be utilized.

Formulas (3) and (4) verify, for safety reasons, that the module does not produce more voltage at open circuit, or current at short-circuit, than the maximum indicated by combining the nameplate rating and tolerance. The maximum open circuit voltage V_{oc}(NP) and maximum short-circuit current I_{sc}(NP) are those specified on the nameplate. If a range for open-circuit voltages or short-circuit currents is stated on the nameplate, V_{oc}(NP) or I_{sc}(NP) is to be taken as the highest value in that range. The tolerance (t_2 for open circuit voltage, or t_3 for short-circuit current) is that specified on the nameplate and in the product documentation, as required by 5.1g), 5.1h), and 5.2.2c). If t_2 (or t_3) is asymmetric about V_{oc}(NP) (or I_{sc}(NP)), the tolerance referring to the higher end of the range shall be utilized. If t_2 or t_3 is not stated in the documentation and on the nameplate, that tolerance shall be identified as 0. In the case that V_{oc}(NP), I_{sc}(NP), or the tolerances in these quantities are different when derived from the datasheet than from the nameplate, the module shall be judged as not satisfying 5.2.2 and thus does not meet the requirements of IEC 61215-1. If a tolerance is not reduced to a single value on the nameplate or data sheet (for example, if multiple tolerances or measurement uncertainty components are specified) the smallest number, not a combination of multiple numbers, shall be utilized.

Figure 3 shows partial nameplates, datasheets, and derived values for four hypothetical products. These examples illustrate the rules for identifying rated values and tolerances that were described in the preceding subclauses.

Product Z300W

Maximum power (P_{max})	300 W ±3 %
Maximum power voltage (V_{mp})	37 V
Maximum power current (I_{mp})	8,1 A
Open circuit voltage [a] (V_{oc})	45,9 V
Short circuit current [a] (I_{sc})	8,9 A
Maximum DC system voltage	1 000 V

[a] +5 % / –0 % tolerance

Product Z series
Electrical Data at STC

Peak power watts ±3 % - P_{max} (W)	300	305	310
Maximum power voltage - V_{mp} (V)	37	37,2	37,5
Maximum power current (I_{mp}) (A)	8,1	8,2	8,27
Open circuit voltage [a] - V_{OC} (V)	45,9	45,9	45,9
Short circuit current [a] - I_{SC} (A)	8,9	8,92	8,98
Module efficiency - η_m (%)	14	14,2	14,4

[a] +5 % / –0 % tolerance on I_{SC} and V_{OC}

P_{max} (NP) = 300 W; t_1 = 3 %
V_{OC} (NP) = 45,9 V; t_2 = 5 %
I_{SC} (NP) = 8,9 A; t_3 = 5 %

Product X300W

Maximum power (P_{max})	296 to 300 W
Maximum power voltage (V_{mp})	37 V
Maximum power current (I_{mp})	8,1 A
Open circuit voltage [a] (V_{oc})	45,9 V
Short circuit current [a] (I_{sc})	8,9 A
Maximum DC system voltage	1 000 V

[a] ±4 % / –0 % tolerance

Product X series
Electrical Data at STC

Peak power watts[a] - P_{max} (W)	296 to 300	301 to 305	306 to 310
Maximum power voltage - V_{mp} (V)	37	37,2	37,5
Maximum power current (I_{mp}) (A)	8,1	8,2	8,27
Open circuit voltage [a] - V_{OC} (V)	45,9	45,9	45,9
Short circuit current [a] - I_{SC} (A)	8,9	8,92	8,98
Module efficiency - η_m (%)	14	14,2	14,4

[a] ±4 % / production tolerance

P_{max} (NP) = 296 W; t_1 = 0 %
V_{OC} (NP) = 45,9 V; t_2 = 4 %
I_{SC} (NP) = 8,9 A; t_3 = 4 %

If t_1 is not specified, it is taken to be 0

Product Y300W

Maximum power (P_{max})	300 W ±3 % / -0
Maximum power voltage (V_{mp})	37 V
Maximum power current (I_{mp})	8,1 A
Open circuit voltage [a,b] (V_{oc})	45,9 V
Short circuit current [a,b] (I_{sc})	8,9 A
Maximum DC system voltage	1 000 V

[a] ±2 %measurement uncertainty
[b] ±10 % tolerance I_{SC} and V_{OC}

Product Y series
Electrical Data at STC

Peak power watts - P_{max} (W)	300	305	310
Power output tolerance (%)	–0 / +3	–0 / +3	–0 / +3
Maximum power voltage - V_{mp} (V)	37	37,2	37,5
Maximum power current (I_{mp}) (A)	8,1	8,2	8,27
Open circuit voltage [a, b] - V_{OC} (V)	45,9	45,9	45,9
Short circuit current [a, b] - I_{SC} (A)	8,9	8,92	8,98
Module efficiency - η_m (%)	14	14,2	14,4

[a] ±2 %measurement uncertainty
[b] ±10 % tolerance I_{SC} and V_{OC}

P_{max} (NP) = 300 W; t_1 = 0 %
V_{OC} (NP) = 45,9 V; t_2 = 2 %
I_{SC} (NP) = 8,9 A; t_3 = 2 %

t_2 is not reduced to a single value. Thus, the smaller value is chosen. The same situation exists for t_3.

Product T300W

Maximum power (P_{max}) Power selection (±5 W)	300 W
Maximum power voltage (V_{mp})	37 V
Maximum power current (I_{mp})	8,1 A
Open circuit voltage (V_{oc})	45,9 V
Short circuit current (I_{sc})	8,9 A
Maximum DC system voltage	1 000 V

±3 % tolerance on P_{max}, I_{SC}, V_{OC}

Product T series
Electrical Data at STC

Peak power watts[a] - P_{max} (W)	300	310
Maximum power voltage - V_{mp} (V)	37	37,5
Maximum power current (I_{mp}) (A)	8,1	8,27
Open circuit voltage [a] - V_{OC} (V)	45,9	45,9
Short circuit current [a] - I_{SC} (A)	8,9	8,98
Module efficiency - η_m (%)	14	14,4

[a] ±3 % tolerance on P_{max}, I_{SC}, V_{OC}

Fails to meet requirements of IEC 61215-1 5.2.2. Lower edge of power bin is 295 W on nameplate, but is 300 W on datasheet

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Figure 3

Examples of hypothetical partial nameplates (left column), datasheets (center column), and derived rated values and tolerances (right column)

7.2.2 Verification of rated label values → Gate No. 1

All modules shall be stabilized following method MQT 19.1 from IEC 61215-2:2021 (for technology specific requirements, see sub-parts of IEC 61215-1). After stabilization the modules shall be measured in accordance with MQT 6.1 (P_{max}(Lab)) and shall meet the following criteria:

P_{max} verification:

Each individual module shall meet the following criterion:

(1)

$$P_{max}(Lab) \times \left(1 + \frac{\frac{1,65}{2}|m_1|}{100}\right) \geq P_{max}(NP) \times \left(1 - \frac{|t_1|}{100}\right)$$

where

P_{max} (Lab)	is the measured maximum power at STC of each module in the stabilized state;
P_{max} (NP)	is the minimum rated nameplate power of each module without tolerances;
m_1	is the measurement uncertainty in % of laboratory for P_{max} (expanded combined uncertainty (k=2), ISO/IEC Guide 98-3); the factor 1,65/2 is used to convert the confidence intervals from two-sided to one-sided at 95 % level of confidence; m_1 shall include a component from spectral mismatch, based either on measured spectral response or the worst-case possibility for a given technology type; m_1 shall be less than stated in the technology specific parts of this standards series;
t_1	is the manufacturer's rated lower tolerance in % for P_{max}.

For $\bar{P}_{max}(Lab)$ the following criterion shall apply:

(2)

$$\bar{P}_{max}(Lab) \times \left(1 + \frac{\frac{1,65}{2}|m_1|}{100}\right) \geq P_{max}(NP)$$

where

$\bar{P}_{max}(Lab)$	is the arithmetic average of the measured maximum STC power of the modules in stabilized condition.

For multiple bins of power classes this formula has to be applied to each power class under investigation.

NOTE Formula (2) is not intended for power verification of a batch in mass production as systematic differences between different labs and reference devices are unavoidable. In such cases, formula (1), which includes the relevant uncertainties, better describes the application to average values.

V_{OC} verification:

Each individual module shall meet the following criterion:

(3)

$$V_{OC}(Lab) \times \left(1 + \frac{\frac{1,65}{2}|m_2|}{100}\right) \le V_{OC}(NP) \times \left(1 + \frac{|t_2|}{100}\right)$$

where

V_{OC} (Lab)	is the measured maximum V_{OC} of each module in the stabilized state;
V_{OC} (NP)	is the maximum rated nameplate V_{OC} of each module without tolerances;
m_2	is the measurement uncertainty in % of laboratory for V_{OC}; (expanded uncertainty (k=2), ISO/IEC Guide 98-3); the factor 1,65/2 is used to convert the confidence intervals from two-sided to one-sided at 95 % level of confidence;
t_2	is the manufacturer's rated upper tolerance in % for V_{OC}

If V_{oc} cannot be measured due to module-integrated electronics (such as MOSFETs), the module is exempt from the V_{oc} verification requirement. This exemption shall be noted in the test report. V_{oc} shall not be determined by any means other than direct measurement, such as extrapolation.

I_{SC} verification:

Each individual module shall meet the following criterion:

(4)

$$I_{SC}(Lab) \times \left(1 + \frac{\frac{1,65}{2}|m_3|}{100}\right) \le I_{SC}(NP) \times \left(1 + \frac{|t_3|}{100}\right)$$

where

I_{SC} (Lab)	is the measured maximum I_{SC} of each module in the stabilized state;
I_{SC} (NP)	is the maximum rated nameplate I_{SC} of each module without tolerances;
m_3	is the measurement uncertainty in % of laboratory for I_{SC}; (expanded uncertainty (k=2), ISO/IEC Guide 98-3); the factor 1,65/2 is used to convert the confidence intervals from two-sided to one-sided at 95 % level of confidence;
t_3	is the manufacturer's rated upper tolerance in % for I_{SC}

If I_{sc} cannot be measured due to module-integrated electronics (such as MOSFETs), the module is exempt from the I_{sc} verification requirement. This exemption shall be noted in the test report. I_{sc} shall not be determined by any means other than direct measurement, such as extrapolation.

P_{max} verification of lowest power class:

Each individual module that is used for the qualification of low end power classes shall meet, in addition to the previous stated criteria for P_{max}, V_{OC} and I_{SC}, the following criterion relating to an upper power limit:

(5)

$$P_{max}(Lab) \times \left(1 - \frac{\frac{1,65}{2}|m_1|}{100}\right) \geq P_{max4}(NP) \times \left(1 - \frac{|t_4|}{100}\right)$$

where

P_{max4} (NP) is the maximum rated nameplate power of each lowest power class module, without tolerances;

t_4 is the manufacturer's rated upper tolerance in % for P_{max4}(NP). t_4 is selected subject to the same rules as for t_1 (see Figure 3), except that if the tolerance is asymmetric about P_{max4}(NP), the tolerance referring to the high power limit shall be utilized.

The last criterion ensures that the modules of the lowest power class stay within the upper tolerance of that class. The last criterion is only applicable for the qualification of the lowest power class. It ensures that a module manufacturer can make modules in the lowest power class that are free from major flaws, and thus the lowest power class is not used as a repository for damaged modules after qualification is obtained using severely underrated modules.

For bifacial modules, P_{max}, I_{sc}, and V_{oc} shall each be measured at the two irradiances specified in 5.1. The Gate No. 1 criteria for P_{max}, I_{sc}, and V_{oc} shall be applied at both irradiances.

A systematic variation to either higher or lower output power or bifaciality coefficient will be stated in the final report.

7.2.3 Maximum power degradation during type approval testing → Gate No. 2

At the end of each test sequence or for sequence B after bypass diode test, the maximum power output drop of each module P_{max} (Lab_GateNo. 2) shall be less than 5 %, referenced to the module's initial measured output power P_{max} (Lab_GateNo. 1). Each test sample shall meet the following criterion:

(6)

$$P_{max}(Lab\_GateNo.2) \geq 0,95 \times P_{max}(Lab\_GateNo.1) \cdot \left(1 - \frac{r}{100}\right)$$

The reproducibility r in % shall be determined for P_{max} and shall be used in the formula. The reproducibility shall be less than or equal to that stated in the technology specific parts of this standards series.

The reproducibility r is verified by comparing the control module(s) from sequence A after initial stabilization (beginning of the test) and after final stabilization (end of tests from sequence B to E). The second test shall be performed after completing all tests. The following applies:

a) All modules from sequences B (after MQT 18.1), C, D and E are measured together with one control module from Sequence A.

b) If a) cannot be used due to test flow (different completion time of sequence or customer requests restrictions) the following applies:

For each sequence B (after MQT 18.1), C, D and E one control module from sequence A shall be defined. The control module is stabilized and measured together with the modules from the applicable sequence B (after MQT 18.1), C, D or E. For each determined value *r* the requirement for *r* shall be fulfilled.

The reproducibility parameter *r* is not equal to the total measurement uncertainty of MQT 06.1. It is advisable that the same solar simulator is used for P_{max} (Lab_Gate No. 1) and P_{max} (Lab_Gate No. 2).

If the measured *r* exceeds the technology specific limit for the control module the laboratory needs to check with its own internal reference module(s) whether the test equipment is faulty, or the module under test is responsible for the poor reproducibility, or it is not in a stable state after applied procedure MQT 19.1. If all checks confirm the measurement equipment is performing correctly, this indicates that the control module has drifted by more than the technology specific limit. In this case, proceed by using the technology specific limit for *r*.

For bifacial modules, Gate No. 2 shall each be assessed only at the larger irradiance (BNPI) specified in 5.1g).

7.2.4 Electrical circuitry

Samples are not permitted to exhibit an open-circuit during the tests.

7.3 Visual defects

There is no visual evidence of a major visual defect, as defined in Clause 8.

7.4 Electrical safety

a) The insulation test (MQT 03) requirements are met at the beginning and the end of each sequence.

b) The wet leakage current test (MQT 15) requirements are met at the beginning and the end of each sequence.

c) Specific requirements of the individual tests are met.

8 Major visual defects

The purpose of the visual inspection is to detect any visual defects that may cause a risk of reliability loss, including power output.

In some instances more detailed inspection may be required to finally decide if major visual defects exist or not.

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

a) Broken, cracked, or torn external surfaces.

b) Bent or misaligned external surfaces, including superstrates, substrates, frames and junction boxes to the extent that the operation of the PV module would be impaired.

c) Bubbles or delaminations forming a continuous path between electric circuit and the edge of the module.

d) If the mechanical integrity depends on lamination or other means of adhesion, the sum of the area of all bubbles shall not exceed 1 % of the total module area.

e) Evidence of any molten or burned encapsulant, backsheet, frontsheet, diode or active PV component.

f) Loss of mechanical integrity to the extent that the installation and operation of the module would be impaired.

g) Cracked/broken cells which can remove more than 10 % of the cell's photovoltaic active area from the electrical circuit of the PV module.

h) Voids in, or visible corrosion of any of the layers of the active (live) circuitry of the module extending over more than 10 % of any cell.

i) Broken interconnections, joints or terminals.

j) Any short-circuited live parts or exposed live electrical parts.

k) Module markings (label) are no longer attached or the information is unreadable.

9 Report

Following type approval, a report of the qualification tests, with measured performance characteristics and details of any failures and re-tests, shall be prepared by the test agency. The report shall contain the detail specification for the module. Each test report shall include at least the following information:

a) a title;

b) name and address of the test laboratory and location where the tests were carried out;

c) unique identification of the report and of each page;

d) name and address of client, where appropriate;

e) description and identification of the item tested, including indication if it has been evaluated for bifaciality and/or whether it is has been evaluated as a flexible module;

f) characterization and condition of the test item;

g) date of receipt of test item and date(s) of test, where appropriate;

h) identification of test methods used;

i) reference to sampling procedure, where relevant;

j) any deviations from, additions to, or exclusions from, the test method and any other information relevant to specific tests, such as environmental conditions, or the irradiation dose in kWh/m^2 at which stability is reached;

k) measurements, examinations and derived results supported by tables, graphs, sketches and photographs as appropriate including:

– temperature coefficients of short-circuit current, open-circuit voltage and peak power,

– power at STC and low irradiance,

– bifaciality coefficients at STC and low irradiance (for bifacial modules),

– the maximum shaded cell temperature observed during the hot-spot endurance test,

– spectrum of the lamp used for the UV preconditioning test,

– mounting method(s) utilized in the static mechanical load test,

– the positive/negative test loads and the safety factor γ_m used in the static mechanical load test,

– hail ball diameter and velocity used in the hail test,

– maximum power loss observed after all of the tests,

– for flexible modules, the diameter of the cylinder over which the module was bent during performance of MQT 22, and

– conditions of potential induced degradation (PID) test (MQT 21) including applied rated system voltage, polarities, and mounting configuration;

– choice of test method where procedures allow more than one option (e.g. Method A or B in MQT 18.2; final stabilization method in MQT 19.2, etc.)

– if open-circuit voltage, short-circuit current, or associated temperature coefficients cannot be measured due to module-integrated electronics, these quantities shall be reported as "not measurable due to module-integrated electronics." Any resulting exemptions from Gate 1 requirements on I_{sc} or V_{oc} shall also be noted.

l) any failures observed and any retests performed;

m) a representation of the markings of the module type including manufacturer's power tolerances;

n) the test lab name and date, for each component qualification required in Table 1;

o) a summary of results from all pass criteria defined in Clause 7 in absolute and relative change. If tendencies to either higher or lower values are observed this has to be included in the report. The used stabilization procedure (irradiance, temperature, time) needs to be stated in detail;

p) a statement of the estimated uncertainty of the test results (where relevant); state the reproducibility *r* from the control module that is used for Gate No. 2.

q) a signature and title, or equivalent identification of the person(s) accepting responsibility for the content of the report, and the date of issue;

r) where relevant, a statement to the effect that the results relate only to the items tested;

s) a statement that the report shall not be reproduced except in full, without the written approval of the laboratory.

10 Modifications

Changes in material selection, components and manufacturing process can impact the qualification of the modified product.

Retesting shall be performed according to IEC TS 62915. The recommended test sequences have been selected to identify adverse changes to the modified product.

During retesting, tests that are performed on representative samples do not need to be repeated if the only change to a product is one of size, and the change in product size still allows use of the same representative sample size already tested.

The number of samples to be included in the retesting program and the pass/fail criteria are to be taken from the relevant clauses/subclauses of this document.

11 Test flow and procedures

For design qualification and type approval the following test flow and procedures apply. Table 3 summarizes the different tests. The full test flow is given in Figure 2. A description of the tests and test procedures is given in IEC 61215-2:2021. Technology-relevant differences are described in the respective technology specific part of this standards series.

Table 3
Summary of test levels

Test	Subclause in IEC 61215-2:2021	Title	Test conditions
MQT 01	4.1	Visual inspection	See list of major visual defects in Clause 8
MQT 02	4.2	Maximum power determination	See IEC 60904-1 for monofacial modules and IEC TS 60904-1-2 for bifacial modules
MQT 03	4.3	Insulation test	est levels vary between 500 V minimum and 1,35 × (2000 + 4 × V_{sys}) maximum depending on system voltage, module class, and presence of cemented joints. See MQT 03 procedure for further detail.
MQT 04	4.4	Measurement of temperature coefficients	See IEC 60891 See IEC 60904-10 for guidance
MQT 06.1	4.6	Performance at STC	Cell temperature of 25 °C at STC Irradiance: 1 000 W/m^2 (and BNPI, for bifacial modules) with IEC 60904-3 reference solar spectral irradiance distribution Requirements see Clause 7
MQT 07	4.7	Performance at low irradiance	Cell temperature: 25 °C Irradiance: 200 W/m^2 with IEC 60904-3 reference solar spectral irradiance distribution
MQT 08	4.8	Outdoor exposure test	60 kWh/m^2 total solar irradiation
MQT 09	4.9	Hot-spot endurance test	Exposure to irradiance in worst-case hot-spot condition as per the technology specific part and IEC 61215-2. For monofacial modules, irradiance is 1 000 W/m^2. For bifacial modules the irradiance is BSI.
MQT 10	4.10	UV preconditioning	15 kWh/m^2 total UV irradiation in the wavelength range from 280 nm to 400 nm, with 3 % to 10 % UV irradiance in the wavelength range from 280 nm to 320 nm, at a module temperature of 60 °C. For

Table 3 Continued on Next Page

Table 3 Continued

Test	Subclause in IEC 61215-2:2021	Title	Test conditions
			bifacial modules, exposure is repeated on the rear side.
MQT 11	4.11	Thermal cycling test	50 (Sequence C) or 200 (Sequence D) cycles from −40 °C to +85 °C with current as per technology specific part up to +80 °C, with 5 N weight hanging from the junction box.
MQT 12	4.12	Humidity freeze test	10 cycles from +85 °C, 85 % RH to −40 °C with circuitry continuity monitoring
MQT 13	4.13	Damp heat test	1 000 h at +85 °C, 85 % RH
MQT 14	4.14	Robustness of termination	Test of junction box retention and cord anchorage.
MQT 15	4.15	Wet leakage current test	Test voltage increase 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. Solution temperature is (22 ± 2) °C.
MQT 16	4.16	Static mechanical load test	Three cycles of uniform load specified by the manufacturer, applied for 1 h to front and back surfaces in turn. Minimum test load: 2 400 Pa
MQT 17	4.17	Hail test	Ice ball impact directed at 11 locations. Required minimum ice ball diameter of 25 mm and speed of 23,0 m/s.
MQT 18	4.18	Bypass diode thermal test	MQT 18.1: Bypass diode thermal test: 1 h at I_{sc} and 75 °C 1 h at 1,25 times I_{sc} and 75 °C MQT 18.2: Bypass diode functionality test At 25 °C perform voltage and current measurements For bifacial modules, I_{sc} in the conditions above is that measured at elevated irradiance BSI.
MQT 19	4.19	Stabilization	Three consecutive output power measurements P_1, P_2 and P_3 using MQT 02. STC output power is determined using procedure MQT 06.1.
MQT 20	4.20	Cyclic (Dynamic) Mechanical load test	IEC TS 62782 1 000 cycles at 1 000 Pa
MQT 21	4.21	Potential induced degradation test	IEC TS 62804-1 +85 °C, 85 % RH at maximum system voltage for 96 h
MQT 22	4.22	Bending test – for flexible modules only	25 cycles rolled up (without damage) around a cylinder with a diameter specified by the module manufacturer over which the flexible modules can be bent

Annex A
(informative)

Changes from previous edition

A.1 General

This annex is included with edition 2 of the IEC 61215 series to better explain the project team's reasoning in developing some of the changes made since edition 1. This annex is informative, describing the development history and rationale. This annex does not modify or complete any of the test procedures found in the IEC 61215 series.

The following changes are discussed in this annex:

- Procedures for bifacial modules
- Use of representative samples
- Addition of dynamic mechanical load test
- Addition of test for potential induced degradation
- Simulator requirements
- References to retest guidelines
- Weight on junction boxes
- Correction to monolithically-integrated hot-spot endurance test
- Number of modules in sequence
- Removal of nominal module operating temperature (NMOT)
- Very low currents during thin-film tests
- Limit bypass diode testing to three diodes
- Revert the insulation test to 2005 version
- Bending test
- Stabilization option for boron oxygen LID (MQT 19.3)

To create edition 2, a number of minor corrections and clarifications to the edition 1 wording were also made. These minor changes are not discussed in this annex.

A.2 Procedures for bifacial modules

The IEC 61215 new edition includes text related to bifacial modules, whereas edition 1 did not. The new edition includes several instructions related to bifacial modules:

- Procedures for measuring bifacial modules are included via references to IEC TS 60904-1-2.

• Where test levels need to be adjusted for bifacial modules due to potentially higher currents during operation, these increased values are specified.

• Additional reporting requirements (e.g. bifaciality coefficients) are described.

• Tests that may be omitted because referenced standards have not yet been modified to account for bifaciality are noted.

Qualification of bifacial modules requires measurement of several quantities beyond those required for monofacial modules. The short-circuit current bifaciality coefficient φ_{Isc}, the open-circuit voltage bifaciality coefficient φ_{Voc} and the maximum power bifaciality coefficient φ_{Pmax} shall be listed on the nameplate, as per IEC 61215-1:2021, 5.1j). These coefficients are measured as part of IEC 61215-2:2021. MQT 6.1. Any significant deviation between the measured and listed values shall be noted in the test report, as per IEC 61215-1:2021, 7.2.2. MQT 07, performance at low irradiance, also requires calculation of the bifaciality coefficients at low irradiance.

Qualification of bifacial modules requires performance measurement (MQT 06.1) at three irradiances. These irradiances are

• 1 000 W/m^2 (the irradiance at STC, as defined in IEC TS 61836),

• conditions equivalent to 1 000 W/m^2 on the front side and 135 W/m^2 on the back side (BNPI, as defined in 3.11), and

• conditions equivalent to 1 000 W/m^2 on the front side and 300 W/m^2 on the back side (BSI, as defined in 3.12).

BNPI and BSI may be applied in any method allowed by IEC TS 60904-1-2, such as single-side illumination at equivalent irradiance, or double-side illumination. If single-side illumination is utilized, the simulator setting depends on the module bifaciality through the equivalent irradiance defined in 60904-1-2. Extrapolation of performance parameters at BSI from the values of 1 000 W/m^2 on front and 300 W/m^2 on back is possible if the flasher is unable to achieve high enough irradiance for BSI.

BNPI is used for nameplate verification. 135 W/m^2 rear irradiance is chosen for BNPI based on several published studies that find, with typical module spacing and light-colored soil, the rearside irradiance is in the range of 100-150 W/m^2 when 1 000 W/m^2 is incident on the front side.[2] [3] [4] [5] [6] BNPI thus conveys an approximation of typical power gain due to bifaciality.

BSI is used to measure quantities that determine applied stress conditions. A 300 W/m$_2$ rear irradiance in BSI is used to represent worst case (most stressful) conditions with a reflective (0,5 albedo) ground cover.[7] To ensure safe products, this worst case condition is used to set the stress levels.

For bifacial modules, measurements at both STC and BNPI are used for Gate No. 1, while only measurements at BNPI are utilized for and Gate No. 2 criteria. For final Gate No. 2 measurements (post stress,) STC measurement and re-evaluation of bifaciality coefficients are not required, in order to keep cost of qualifying bifacial modules reasonable. Instead, Gate No. 2 is evaluated only at the more stringent condition, BNPI, where possible series resistance and other fill factor losses induced by stress are expected to be largest. By not requiring STC measurement or re-evaluation of the bifaciality coefficients for the final Gate No. 2 measurement, time-consuming (expensive) steps of re-calibration simulators at multiple intensities, only to obtain a less stringent test, is avoided. Requirements for measurement intensities and evaluation of bifaciality coefficients requirements are stated in IEC 61215-1:2021, 7.2.2 and 7.2.3, and in IEC 61215-2:2021, 4.6.3 "Measuring at STC (MQT 06.1)".

For several tests, stress levels are increased from values based on one-sun front side illumination, in order to account for potentially higher currents during bifacial module operation with backside illumination.

• The test current is increased for the bypass diode thermal test MQT 18.1. For bifacial modules, MQT 18.1 specifies 1,25 times the module short-circuit current at the elevated irradiance BSI. Use of this higher current is required in IEC 61215-2:2021, 4.18.1.4b).

• The test current is also increased in the same manner for the bypass diode functionality test MQT 18.2, as specified in IEC 61215-2:2021,4.18.2.3.2 b).

• In MQT 11 the technology-specific current to be applied during thermal cycling is larger for bifacial modules. IEC 61215-1-1:2021 specifies that the technology specific current which needs to be applied according to test MQT 11 of IEC 61215-2:2021, shall be equal to the peak power current at the elevated irradiance BSI.

• In MQT 09, determination of the cell shading percent and the prolonged exposure are performed at the elevated irradiance BSI. If double-side illumination is used to produce BSI, both the back and the front of the cell are shaded in the same way. During cell selection, any cell that is permanently shaded by a module feature (such as the junction box) is added to the list of selected cells.

A.3 Use of representative samples

At present, there are products intended to be qualified via IEC 61215, that are much larger (e.g. 6 m in one dimension) than typical test equipment. Requiring a test lab to obtain custom test equipment for one product is prohibitively expensive and would create an unfair barrier to qualification. Thus, representative samples may be used for applying stress and evaluating Gate No. 2 on very large modules. A representative sample is one that includes all the components of the module, except some repeated parts, and is therefore smaller than the actual product. A fullsized sample is still required for nameplate verification (Gate No. 1).

A representative sample may be utilized if a module is "very large," as defined in IEC 61215-1:2021. A "very large" module is taken to be anything that will not fit on the largest commercially-available AAA simulator, or in the necessary environmental chambers. The largest commercially-available AAA simulators seldom exceed dimensions of 2,6 m × 2,1 m. A survey of test labs by project team members showed that environmental chamber sizes currently impose a size limit for IEC 61215 qualification in various test labs ranging from 2,2 m to 2,4 m in module length, and 1,2 to 1,9 m in module width. The project team decided that defining a very large module as 2,2 m × 1,5 m is a reasonable compromise between not providing a barrier to certification for large products, but encouraging certification on full-size products when possible. By this definition, a module is considered very large if it exceeds 2,2 m in any dimension, or exceeds 1,5 m in both dimensions.

Limits are placed on how much one may reduce the dimensions of a very large module in making representative modules for qualification testing. The reduced dimension(s) shall be no less than one half the dimensions that define a very large module. In other words, when reducing the shorter dimension, the representative sample shall be at least 0,75 m wide. In reducing the longer dimension, the representative sample shall be at least 1,1 m long. Thus, a manufacturer is not allowed to use, for example, a one-cell mini-module for qualification testing. The use and dimensions of representative samples shall be noted in the test report.

If representative samples are utilized in Sequence E, then one extra module, full-sized, is required, and shall be subjected only to MQT 16 (the static load test) and the requirements therein. The extra module is required because mechanical load on a representative sample is not the same as doing it on a full-size module. (To give an extreme example, a 10 m × 10 m × 5 mm glass pane may collapse under its own weight, whereas a 1 m × 1 m × 5 mm glass pane may resist the 2 400 Pa loading.) However, a general way to convert load requirements from one sample size to the next, for all product designs, does not exist at the time of publication. Also, because of space limitations in the damp heat chamber, the full-size module cannot be required to undergo the entire sequence E. Thus, as a compromise, an extra full-size module in sequence E to supplement the representative sample. The full-size module will be evaluated for structural and safety failures (e.g. broken glass) via the visual inspection (MQT 01) that is embedded in MQT 16. If a design is susceptible to MQT 16 failures that involve DH (for example, a glue that debonds after DH), such effects are best detected using the representative sample.

If there are MLT failures that involve DH (for example, a glue that is not strong after DH), such effects will be captured by the test on the representative sample.

The project team considered whether more thermal cycles should be required when MQT 11 is performed on a representative sample. It was considered that thermomechanical fatigue tends to increase with sample size, and therefore extra thermal cycles might be needed to qualify a fullsize product while stressing a smaller representative sample. However, finite element modelling concluded that the cell size, not the module size, is the critical dimension for thermomechanical fatigue, and thus extra thermal cycles are not warranted.

A.4 Addition of dynamic mechanical load test

A Dynamic Mechanical Load (DML) test has been added in the IEC 61215 new edition and is performed according to IEC TS 62782. The DML test was developed to evaluate the potential for cell breakage within PV modules[8]. The goal was to find a load that would break cells that were already damaged prior to the stress, but would not break intact cells during the stress. During experiments, a load level of 1 000 Pa was selected. Effect on the cells appeared to saturate at 1 000 cycles. These results formed the basis for the stress levels utilized in IEC TS 62782 and the IEC 61215 new edition. DML has subsequently been the subject of other studies.[9], [10], [11] The DML test is intended to detect cell damage that is inherent in processing (such as a tabber that applies too much pressure and cracks cells during module assembly). The DML test is not intended to introduce new cracks into the cells, nor to measure susceptibility of the module to mishandling, abuse, or extreme weather.

Several publications (e.g. [12], [13]) have noted that cracking cells in a module, then applying either DML or thermal cycles, can lead to power loss. However, there are several reasons to be cautious when considering applying DML or thermal cycling after mechanical stress for this qualification standard:

• Not all modules will experience extreme weather or mishandling. Qualification testing that tests for performance retention under these circumstances may lead to costly overdesign.

• There is not yet documented field correlation to determine over what time period power loss from mechanically-cracked cells occurs. Early studies how long it takes cracks to open up, and therefore (even roughly) what time period is relevant for the sequence: hail test + DML or TC. Some published studies are underway, but haven't seen cracks further affect power in the first 1 to 2 years. [14], [15]

• For people who just want to know relative performance without requiring relationship to field performance, static load + DML is in IEC TS 63209-1 for relative comparison.

• It is recommended to first develop and gain experience with a TS related to hail-resistance, module handling, and related performance losses. Such a document should consider that thermal cycles might be more effective than DML.

A.5 Addition of test for potential induced degradation

Potential induced degradation (PID) has been observed to cause power output degradation in some fielded modules. Examples of such reports can be found in the literature.[16], [17], [18], [19], [20] Thus, an accelerated test to screen for PID susceptibility has been added in edition 2 of the IEC 61215 series, as MQT 21.

The PID test, MQT 21, is performed in parallel with other tests, in a new Sequence F. Sequence F requires two modules per installation polarity allowed by the manufacturer. If only one installation polarity is allowed, only two modules receive PID stress. However, all four modules are subjected to Gate No. 1 verification, in order to keep Gate No. 1 statistics independent of the number of allowed installation polarities.

The test procedure for MQT 21 is based on the previously published IEC TS 62804-1. The 85 °C / 85 % RH / 96 h stress ("85/85/96") stress utilized in IEC 61215 edition 2 is one of three stress level options in IEC TS 62804-1. Numerous accelerated test studies preceded the development of IEC TS 62804-1. PID has been studied to the extent that reviews of PID, including experimental dependencies, derived acceleration, and underlying mechanisms, can be found in the literature.[21], [22] Literature reports vary regarding acceleration factors. Equivalent outdoor exposure for the 85/85/96 stress utilized in IEC 61215 edition 2 has been estimated by different groups between 2 to 20 years,[23], [24], [25], [26], [27] for the effect of a humid climate (e.g. Florida, USA) on a crystalline Si module. The differences in the literature reports may reflect a need for utilization of different physical models in some studies, experimental uncertainty, and different behavior among the products tested.

All products (modules based on crystalline Si cells, or thin film cells) are subjected to the same stress conditions when executing MQT 21. The same stress conditions are applied even though it is likely that acceleration factors differ from one product to the next, particularly for thin film modules, where the underlying physical mechanism for PID is different than that in x-Si modules. It is estimated that the acceleration factors for thin film modules are substantially smaller than that of typical c-Si modules.[28], [29], [30] The methodology of defining stress levels that are empirically observed to separate failed versus successful fielded products, then applying these conditions to all modules, is rooted in the JPL block buy study,[31] which formed the basis for several of the IEC 61215 series stress tests. A few sentences explicitly stating the methodology of the IEC 61215 series (constant stress conditions across products) were added to the scope.

The 85 °C / 85 % RH / 96 h level is probably more stressful (in terms of years of equivalent exposure) than some other MQT's, for c-Si in most use environments. However, this relatively harsh condition was selected because:

• Data show thin film modules need a higher accelerated stress level than Si modules to reproduce early-life PID failures.

• Prior to the inclusion of a PID test in IEC 61215, several major module manufacturers had already selected the 85 °C / 85 % RH / 96 h stress level for internal qualification programs.

• Use of a light soak may lead to some power recovery, therefore justifying increasing the stress level.

• Increased use of modules in potentially harsh PID-prone environments, such as very rainy climates, may warrant a harsher test.

The way in which modules are mounted has been observed to affect PID.[32] [33] Thus, during the chamber test in IEC 61215 (and IEC TS 62804-1), on request by the manufacturer, modules might be mounted as described in the installation manual during testing, if the manufacturer states that PID resistance is achieved via mounting method.

PID stress on CIGS may be applied with a modest forward voltage bias applied across the internal circuit. These are the same conditions approved for the damp heat test (MQT 13) in IEC 61215-1-4:2021. The voltage bias prevents effects that do not occur when stress is applied under field-representative illumination.

A wet leakage current test (MQT 15) is part of the final measurements within MQT 21. This wet leakage current test is to be performed within 8 hours of the end of the PID stress, as in IEC TS 62804-1. The inclusion of the test, with a time limit, is motivated by the increase in leakage current seen in some modules during in-situ monitoring, and may have a time scale for reversibility that is similar to the PID.

A final stabilization, MQT 19.2, is performed prior to gate 2 on all modules that have been subjected to PID stress. The conditions for this final stabilization are described in the technology-specific parts (IEC 61215-1-x).

For crystalline Si modules, the final stabilization is a short light soak (2,0 kWh/m^2) meant to reverse the effects of PID-polarization, which results from the movement of charge within the module,[34] as opposed to PID-shunting (PID-s), which results from movement of Na within the module, a slower process. Tests on some modules show that PID-polarization (PID-p) does not occur when PID stress is applied with field-representative illumination,[35] and thus should not be allowed to cause design qualification failure when administering a dark PID stress test. UV has been shown to be important in reversing PID-p.[36] Thus, the class CCC solar listed as required apparatus in MQT 19.2 shall fulfill the class C spectral requirements over at least the short-wavelength portion of the extended wavelength range described in IEC 60904-9, for stabilizations performed after PID testing. For bifacial modules, light is applied to the rear side during this stabilization.[37] Since a small amount of PID-s may reverse during a short light soak,[38] the light soak is applied to the front of monofacial modules, to obtain a consistent comparison of test results across module types.

For thin-film modules, the final stabilization is included to put metastabilities into the light-soaked state and obtain an accurate Gate No. 2 performance measurement. Thus, the thin-film light soak is performed in nearly the same manner as other thin-film final stabilizations (MQT 19.2). One additional requirement exists for final stabilization of thin-film modules after PID stress: Once the stabilization criterion is met, the light soak shall be terminated within two irradiation intervals (as defined in the technology-specific parts of MQT 19). This time limit is included to prevent attempts to reverse Na migration with extremely long light soaks that are many times that needed to account for metastability.

After the completion of MQT 21, module storage conditions between subsequent tests are controlled. Between these test steps, the modules are to be maintained indoors, in the dark, and at temperatures 25 °C or below. No more than 48 h elapse between the end of MQT 21 and the beginning of MQT 19.2. There is also time limit between MQT 19.2 and MQT 06.1: It is either 48 h or the time limit specified in the technology-specific stabilization procedure, whichever is shorter. These controls are intended to prevent attempts to reverse Na migration before Gate No. 2 via anomalous storage time and conditions.

A.6 Simulator requirements

A.6.1 General

Edition 2 revises both the spectral and uniformity requirements for simulators. (Notation for simulator classifications are defined according to IEC 60904-9. The AM1.5 spectral match is denoted by the first letter of the three-letter simulator classification. For example, a CBA simulator is categorized with a type C spectral match, a type B spatial uniformity, and a type A temporal stability.) The revision applies to simulator requirements in MQT 02 (maximum power determination), MQT 6.1 (performance at STC), and MQT 07 (performance at low irradiance).

IEC 61215-2:2016 allowed three options for simulators during the measurement listed above:

a) a class BBA or better simulator plus a reference device of the same size and cell technology as the test sample,

b) a BBA or better simulator, plus the spectral responsivity of the module, plus the spectral distribution of the solar simulator, and a data correction according to IEC 60904-7, or

c) a AAA simulator. Several changes have been made to these requirements:

- Type A spatial uniformity is required.

- A simulator with type C or better spectral class may be utilized.

- There are more possibilities for how one obtains data to use in a spectral mismatch correction (IEC 60904-7). The spectral response data may be taken by any test lab that is accredited for that measurement. The sample used to obtain the spectral response data may be the test module or may be a reference cell made with the same bill of materials as the test module.

- It is specifically stated that the component of uncertainty due to spectral mismatch shall be included m_1, the uncertainty used in evaluating Gate No. 1. Maximum allowable values for m_1 are specified in the technology-specific parts.

- Use of either spectral mismatch correction or a matched reference module (or cell) is required.

The procedures in MQT 02 and MQT 6.1 are based on the most accurate measurement protocols that are practical with current technology. This high level of accuracy is appropriate for the nameplate verification and design qualification of IEC 61215. However, other types of documents refer to IEC 61215 maximum power determination. Such documents include warranties, quality assurance documents, and extended stress tests. A note has been included to remind users that less stringent requirements may be appropriate for non-IEC 61215 applications. The note reads: "MQT 02 measurement procedures are intended for minimal uncertainty, as performed by an accredited testing laboratory. Lesser requirements, such as use of CAB class simulators, may be appropriate for other applications, such as quality control in the factory. Applications that only require repeatability, such as comparing module performance before and after an extended stress, may wish to relax spectral mismatch correction requirements."

A.6.2 Rationale for changes to spectral requirements

Revisions to the spectral requirements were made to limit possible spectral mismatch in a systematic manner, while still allowing test labs several practical choices as to how to achieve an acceptably accurate measurement.

The previous text of IEC 61215 allowed using a solar simulator with Class A spectral match for power rating measurements without spectral correction. This option was originally intended to provide one way to achieve a low spectral mismatch. However, more recent work has shown that requiring a Class A spectrum is neither necessary nor sufficient for low spectral mismatch.[40], [41], [42], [43] In other words, using a Class A spectrum does not guarantee a smaller spectral mismatch error than using a Class B or Class C spectrum. In some cases, spectral mismatch errors can even be larger for a Class A spectrum compared to Class C.[44], [45] The actual spectral mismatch error depends on the procedures, reference samples, and test samples used.

Therefore, the revised text of IEC 61215 has relaxed the spectral requirement to Class C, but includes wording regarding procedures to reduce spectral mismatch errors. The wording is basically the same as IEC 60904-7: either the solar simulator irradiance is calibrated using a reference sample having spectral response that is similar to the device under test, or a full calculation of the spectral mismatch error is made per IEC 60904-7.

Support for this position can be found in several literature studies. Excerpts from some of these studies are reproduced here (with bold type added for emphasis):

• ...**classification** of a solar simulator **does not provide any information about measurement errors**...related to photovoltaic performance measurements...such errors are dependent on the actual measurement devices and procedures used.[40]

• ...**spectral class** of a solar simulator **is not necessarily an indicator for the precision of measurement**. With appropriate reference devices and measurement procedures also class C spectral match yields a good comparability for c-Si PV modules.[41]

• ...the simulator with **the best spectral match (A+) need not yield the best MMF** [spectral mismatch factor].[42]

• **No benchmarking of solar simulators is** therefore **possible based only on the spectral match** information.[42]

...not always the spectrum of higher class would lead to the lower [spectral] mismatch factor. [43]

It is specifically stated that the component of uncertainty due to spectral mismatch shall be included in m_1, and maximum allowable values for m_1 are specified in the technology-specific parts. As stated in IEC 61215-1:2021, m_1 is to be calculated based either on measured spectral response or the worst-case possibility for a given technology type. Worst case possibilities can be evaluated from a combination of published data and the lab's database of measurements.

This approach provides several options for test labs unable to invest in a module spectral response system, while keeping uncertainty within reasonable bounds via limits on m_1. A lab may choose reference modules such that no spectral mismatch correction is needed. Size requirements on the matched reference module have been removed. The lab may also measure cell spectral response, where a reference cell with the same bill of materials as the test module is available. The lab may also obtain spectral response data on such a reference cell, or on the test module, from another accredited test lab.

A.6.3 Rationale for changes to uniformity requirements

The change in simulator uniformity requirements from B to A was made based on an analysis of uncertainty in power rating which includes contributions from several factors including irradiance nonuniformity, current mismatch between cells within a module, spectral mismatch, module temperature, contact resistance, and the procedure(s) used to calibrate simulator irradiance. Uncertainty values listed below (in Table A.1) are from Figure 7 of the referenced work,[46] using a coverage factor $k = 2$.

Table A.1
Published uncertainty values as a function of simulator uniformity class

Irradiance nonuniformity	Approximate power rating uncertainty due to all effects, when simulator irradiance is calibrated using a reference module's...	
	...maximum power	...short-circuit current
2 % (class A limit)	2,6 %	3,2 %
5 % (class B limit)	3,2 %	6,2 %

For modules with higher fill factor, such as new high-efficiency Si modules, effects of irradiance nonuniformity may be greater, since higher fill factor implies that a change in current changes the module power output more sharply. Based on this information, the project team decided the uncertainties for 5 % irradiance nonuniformity would be too large for some measurements, such as the maximum power determination of Gate No. 1.

Polls of working group 2 members representing test labs were performed during a working group 2 meeting and during a IEC 61215 new edition project team meeting. All such members in attendance indicated that they already use simulators with class A uniformity.

The new edition includes one exception to the new uniformity requirement. For evaluation of Gate No. 2, "very large" modules (as defined in IEC 61215-1:2021, 3.8) may be measured with a class B uniformity simulator. It is recognized that class A uniformity simulators larger than 2,2 m × 1,5 m are rarely commercially available at present, and thus imposing use of a class A uniformity simulator on a very large module creates an unfair barrier to qualification. At present, only a small fraction of the market is expected to utilize the exemption for very large modules. In future years, as module sizes and availability of very large simulators evolves, the size definition for a very large module should be adjusted accordingly.

A.7 References to retest guidelines

IEC 61215 Edition 2 requires the use of IEC TS 62915 to determine if a retesting is needed. This requirement is stated as, "Retesting shall be performed according to IEC TS 62915." To avoid any future contradiction between IEC 61215-1 and IEC TS 62915, all further description of conditions that might generate the need for retesting have been removed from IEC 61215-1:2021.

A.8 Weight on junction boxes

Poor adhesion of the junction box to the module has been observed in both fielded modules and accelerated tests.[47], [48], [49], [50] Thus, in edition 2, the thermal cycling test (MQT 11) is modified to include a 5N weight hanging from the junction box.