# IEC TS 63209-1

Edition 1.0 2021-04

# TECHNICAL SPECIFICATION

## Photovoltaic modules – Extended-stress testing –
## Part 1: Modules



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## Part 1: Modules



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# PHOTOVOLTAIC MODULES – EXTENDED-STRESS TESTING –

## Part 1: Modules

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IEC TS 63209-1 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

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

| DTS | Report on voting |
|---|---|
| 82/1820/DTS | 82/1873/RVDTS |

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

A list of all parts in the IEC 63209 series, published under the general title *Photovoltaic modules – Extended-stress testing*, can be found on the IEC website.

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

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

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

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- withdrawn,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

# INTRODUCTION

Existing qualification test standards such as IEC 61215 standard series have been very useful for identifying module designs that avoid most early field failures, but are not intended or able to demonstrate long term performance in all locations within the scope of those documents. In order to assess the risk of product failure it has become industry practice for the different stakeholders to require results of test protocols beyond baseline type approval and safety tests according to the IEC 61215 standard series and IEC 61730 standard series. These extended stress test protocols primarily contain aforementioned baseline tests in different sequences and/or increased test duration or number of cycles. They originate from the various experiences made by third parties such as test institutes/ independent engineering firms/ owners engineers and aim to cause aging that would be seen after long term use of PV modules, or apply a “test to failure” approach, aimed to identify weaknesses rather than to replicate field performance. They do not provide detailed reliability or durability predictions/estimates, but have been useful to reveal deficiencies.

With many variants of extended stress test protocols in use, a standardized approach is desired. The included set of extended stress test sequences is intended to standardize the various approaches used by different industry participants, with a benefit of a common data set for reliability reviews, and a practical benefit to module manufacturers who are faced with the challenge of running (and maintaining after product changes) a number of very similar test protocols in parallel.

This global reference comparative document utilizes a common denominator approach considering all the sequences of the variants, and adds to this subset sequences that are uniquely positioned to capture special failure modes, while excluding sequences where test conditions and durations do not show results that are useful for assessing module field performance. This document is intended to align extended test protocols, in order to make results from different institutes more directly comparable and to reduce test costs and time lines for the industry.

This document is intended to provide a set of data to be used for qualitative reliability risk analysis, highlighting potential failure modes and areas possibly in need of improvement. It is only useful for rank ordering modules and materials for special cases, for very large differences in performance, or with respect to specific understood failure modes and mechanisms. A robust module level rank ordering or service life prediction is beyond the scope of this document. A series of component test suites is in development to complement the module level testing in this specification.

# PHOTOVOLTAIC MODULES – EXTENDED-STRESS TESTING –

## Part 1: Modules

## 1 Scope

This document is intended to provide information to supplement the baseline testing defined in IEC 61215, which is a qualification test with pass-fail criteria. This document provides a standardized method for evaluating longer term reliability of photovoltaic (PV) modules and for different bills of materials (BOMs) that may be used when manufacturing those modules. The included test sequences in this specification are intended to provide information for comparative qualitative analysis using stresses relevant to application exposures to target known failure modes.

A significant constraint imposed was that the test duration was limited, recognizing that customers of the test will proceed with decisions before the test results are available, if the test takes too long. With this business-relevant limitation, some known failure modes cannot be accurately addressed, most notably those related to long-term ultra-violet light (UV) exposures. While failure modes related to UV stress are known to occur on both front and back side of PV modules, the testing time required to achieve a dose of UV stress that causes changes observed in the field during the module's intended lifetime without overstressing is beyond the scope of this document. The included backside UV stress sequence gives increased confidence for some backsheets with regard to backside cracking, and a frontside UV stress sequence is not included at all, leaving gaps for failure modes, such as encapsulant discoloration, frontside backsheet cracking, frontside delamination, etc.

Other limitations of extended stress testing are described in Annex A. This document identifies vulnerabilities without attempting to gather the information needed to make a service-life prediction, which would require identifying failure mechanisms and their dependencies on all of the stresses. Annex B contains a brief background of the origins of the tests.

Out of scope for this document is its use as a pass-fail criterion. The same module deployed in two different locations may fail/degrade in different ways, so a single test protocol cannot be expected to simultaneously exactly match both results, and will depend upon where and how the product is deployed. Additionally, both false positives and false negatives may occur: due to the highly accelerated and extended nature of some of the stress exposures, the tests may cause some changes that do not occur in the field for some module designs, and degradation which is difficult to accelerate will be missed.

This document was developed with primary consideration for c-Si modules, as reflected in the targeted failure modes. However, the applied stresses are based on the service environment, and as such are relevant to generalized PV modules. Interpretation of the data resulting from these tests should always include the possibility that a design change may cause a new failure to occur. In particular, modules with different form factors (e.g. made without the standard glass frontsheet) may be found to differ in the way they fail. In every case, the data collected in this extended-stress test procedure is used as input to an analysis that may then identify the need for additional testing, to more fully assess module performance relative to the intended deployment conditions.

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

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

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

IEC 61215-1-1:2021, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules*

IEC 61215-1-2, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules*

IEC 61215-1-3, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules*

IEC 61215-1-4, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1-4: Special requirements for testing of thin-film* $Cu(In,GA)(S,Se)_2$ *based photovoltaic (PV) modules*

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

IEC 61730 (all parts): *Photovoltaic (PV) module safety qualification*

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

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

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



## 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**
**Module Quality Test**
**MQT**
Module Quality Test in accordance with IEC 61215-2

**3.2**
**Module Safety Test**
**MST**
Module Safety Test in accordance with IEC 61730-2

## 4 Selection of test samples

This document describes data collection methodology. Sample selection, number of samples, and or sample sets are left to the user, based on the purpose of the data collection. The number of samples used in each test may vary between the test sequences and may be selected to emphasize the stresses anticipated in the current application. The confidence in the test results will be greater for a larger number of test samples, and inclusion of multiple samples is encouraged.

## 5 Characterization and stabilization techniques to be applied

### 5.1 General

The characterization methods are as described in published standards, such as the IEC 61215 standard series, including the technology-specific portions of these. Baseline characterization shall be completed before application of stress, and repeated after subsequent applications of stress to establish the trend of response to that stress. Additional intermediate tests may be included between application of stresses at the customer's request. For example, additional characterization may be beneficial after mechanical stress is applied.

### 5.2 Physical measurement

Physical module measurements shall include weight, length, width, and thickness (depth) of frame. Additionally, the cell dimensions shall be recorded. Photographs of module and example cells shall be recorded.

### 5.3 Visual inspection

Observations are completed as defined in IEC 61215-2, MQT 01. All observations shall be recorded and reported as part of the final report. Photographs shall be used to document any changes and included in the final report.

For the visual inspection of the backsheet after UV exposure, magnification of 10X or greater is recommended using an illumination of at least that specified in IEC 61215-2, MQT 01.

### 5.4 Initial stabilization

Initial stabilization shall be completed as defined in IEC 61215-2, MQT 19.1. All measurements (as defined in 5.5) shall be recorded after each stabilization step. These data shall be included in the final report.

### 5.5 Performance

The performance at Standard Test Conditions shall be measured as defined in IEC 61215-2, MQT 06.1. The performance at low-irradiance conditions shall be measured as defined in IEC 61215-2 MQT 07. If the test lab does not have the capability to accurately measure at low irradiance, the low irradiance measurement may be omitted. In both cases, the measurements shall be recorded including $V_{oc}$, $I_{sc}$, $V_{mp}$ and $I_{mp}$ in addition to the maximum power. Performance of bifacial modules shall be characterized using IEC TS 60904-1-2 with Standard Test Conditions applied to both the front side and the back side for initial and final characterizations. Additionally (and for intermediate measurements), bifacial modules shall be characterized under bifacial nameplate irradiance (BNPI) as defined in IEC 61215-1. All measurements shall be included in the final report.

### 5.6 Insulation test

The insulation shall be tested as defined in IEC 61215-2, MQT 03. The insulation resistance measurement shall be recorded and reported as part of the final report.

### 5.7 Wet leakage current

The wet leakage current shall be measured as defined in IEC 61215-2, MQT 15. The measured leakage current shall be recorded and reported in the final report.

### 5.8 Electroluminescent imaging

Electroluminescent imaging shall be completed as defined in IEC TS 60904-13, using both low and high injection levels for the initial characterization for all tests. For the post-stress characterization, the low-injection imaging is optional for test sequences 1-4. The low-injection image is required after the PID stress in test sequence 5. All high-injection images and conditions used for their measurement shall be included in the final report. Low-injection images shall be included in the final report for the PID test sequence 5, but may be omitted for the final report for the other test sequences if they are indistinguishable from the high-injection images.

### 5.9 Insulation thickness test

For modules being stressed according to sequence 3, the final insulation thickness shall be measured on any polymeric insulation sheets using the procedure described in IEC 61730-2, MST 04. The measured thicknesses shall be reported. No pass-fail criteria are applied.

### 5.10 Thermal cycling

Thermal cycling shall be performed according to IEC 61215-2, MQT 11 with applied current defined in the technology specific subclauses of IEC 61215-1-x. For bifacial modules, current applied during MQT 11 shall be that defined in IEC 61215-1-1:2021: the peak power current at bifacial stress irradiance (BSI).

### 5.11 Humidity freeze

Humidity freeze shall be performed according to IEC 61215-2, MQT 12 with any technology specific modifications made consistent with IEC 61215-1-x.

### 5.12 Final stabilization

Final stabilization shall be applied according to MQT 19.2 in IEC 61215-1 and the technology-specific parts of the IEC 61215 series. In sequence 4 (damp heat) of this document, each final stabilization shall include the stress-specific stabilization for B-O LID, as specified in MQT 19.3 of IEC 61215-2:2021.

## 6 Data collection and stress application

### 6.1 General

The individual stress application methods (without pass-fail criteria) are as described in IEC 61215 series and IEC 61730 series, including the technology-specific parts of these. This document describes which characterization tools to apply after each interval of stress application. The sequences are summarized in Clause 8.

### 6.2 Initial characterization

Physical measurements shall be recorded as described in 5.2 to identify variations from sample to sample and to precisely define the properties of the test samples for further comparison. In the final report, these measurements shall be reported and compared with any corresponding values found on the product specifications sheet.

All modules shall be characterized before application of stress using the methods described in 5.2 to 5.8.

Modules are subjected to five types of test sequences.

### 6.3 Test sequence 1: Thermal fatigue

Test sequence 1 is intended to test for thermal fatigue-related failures, such as solder bond failure. It follows sequence D of IEC 61215-1 and is then extended to repeat the sequence two additional times, with characterization at intermediate steps. Initially, the modules shall be characterized as described in 6.2. The stresses and characterizations are completed according to:

- Stress:
  - IEC 61215-2 MQT 11 Thermal cycling (200 cycles, 5.10)
- Post-stress characterization:
  - IEC 61215-2 MQT 01 Visual inspection (5.3)
  - IEC 61215-2 MQT 19.2 Final stabilization (5.12)
  - IEC 61215-2 MQT 06.1 Performance at STC and MQT 07 Performance at low irradiance (5.5)
  - IEC 61215-2 MQT 03 Insulation test (5.6)
  - IEC 61215-2 MQT 15 Wet leakage current test (5.7)
  - Electroluminescent imaging according to IEC TS 60904-13 (5.8).

The stress and post-stress characterization shall be completed three times. A total of 600 thermal cycles shall be applied.

All data shall be reported. No pass-fail criteria shall be applied.

### 6.4 Test sequence 2: Mechanical stress

Test sequence 2 applies mechanical stress in a sequence intended to uncover or reduce concern about reliability problems stemming from cell cracking. For modules designed to be mounted directly on another surface, it may be difficult to define how to do the mechanical load test sequence. In this case, an assessment should be made about whether such a test would provide useful information, and, if not, the test would be omitted.

The sequence includes (after 6.2 initial characterization):

- Stress:
  - IEC 61215-2 MQT 16 Static mechanical load test. For the purpose of this stress sequence, 2 400 Pa will be used regardless of the design load specified for the module.
  - IEC TS 62782 Cyclic (dynamic) mechanical load 1 000 cycles of 1 000 Pa pressure at room temperature
  - IEC 61215-2 MQT 11 Thermal cycling (50 cycles, 5.10)
  - IEC 61215-2 MQT 12 Humidity freeze (10 cycles, 5.11).
- Post-stress characterization:

  As for test sequence 1 in 6.3.

  - All data shall be reported. No pass-fail criteria shall be applied.

### 6.5 Test sequence 3: Sequential testing including UV stress to module back

This sequence is intended to evaluate degradation of polymeric backsheets, but it is also important to consider degradation of all polymeric materials – a test that is designed to duplicate backsheet field results may also identify degradation of other module materials. The samples chosen for the test may be modules from the production line or mini modules. It is recognized by the community that the time required for a high-confidence UV-stress test is longer than the time today's business models typically allow, so the defined test is a compromise.

If a mini module is used, its construction shall be designed to be as similar as possible to the design of the full-size module. As an example, for conventional silicon modules, the mini module will include:

– Use of the same bill of materials (different glass is allowed – if a different glass is used, it is specified in the report).
– Use of the same lamination conditions.
– Use of same spacing between cells and between the cells and the edge of the module.
– Use of same cell-interconnection geometries.
– Use of same junction box and other metal-interconnect (bus wires, etc.) geometries.
– Inclusion of at least two rows of cells and at least two cells per row.
– Length and width both > 20 cm.

In every case, the goal is to design a mini module that will be as similar as possible to the full-size modules with special attention to the stresses that may occur for the backsheet and other polymeric materials.

UV degradation is usually synergistic with other environmental stressors, requiring inclusion of other stresses. So, test sequence 3 combines multiple tests from IEC 61215-2 to test for weathering-related failures (those caused by a combination of UV, moisture, heat, and thermal cycling or other mechanical stress.)

Initially, the modules shall be characterized as described in 6.2. Then, the following shall be applied to the back of the module:

– Stress:
  - IEC 61215-2 MQT 13 Damp heat (200 h only)
  - IEC 61215-2 MQT 10 UV exposure to back side as described in IEC 61730-2 MST 54 with increased dose of 60 kWh/m$^2$. The UV irradiance shall be controlled within the range of 130 W/m$^2$ and 200 W/m$^2$ and the average value and range reported as part of the final report.
  - IEC 61215-2 MQT 11 Thermal cycling (50 cycles, 5.10) plus IEC 61215-2 MQT 12 Humidity freeze (10 cycles, 5.11)
  - IEC 61215-2 MQT 10 UV exposure to back side as described in IEC 61730-2 MST 54 with increased dose of 60 kWh/m$^2$. The UV irradiance shall be controlled within the range of 130 W/m$^2$ and 200 W/m$^2$ and the average value and range reported as part of the final report.
  - IEC 61215-2 MQT 11 Thermal cycling (50 cycles, 5.10) plus IEC 61215-2 MQT 12 Humidity freeze (10 cycles, 5.11)
  - IEC 61215-2 MQT 10 UV exposure to back side as described in IEC 61730-2 MST 54 with increased dose of 60 kWh/m$^2$. The UV irradiance shall be controlled within the range of 130 W/m$^2$ and 200 W/m$^2$ and the average value and range reported as part of the final report.
  - IEC 61215-2 MQT 11 Thermal cycling (50 cycles, 5.10) plus IEC 61215-2 MQT 12 Humidity freeze (10 cycles, 5.11)

  - IEC 61215-2 MQT 10 UV exposure to back side as described in IEC 61730-2 MST 54 with short dose of 6,5 kWh/m$^2$. The UV irradiance shall be controlled within the range of 130 W/m$^2$ and 200 W/m$^2$ and the average value and range reported as part of the final report.
- Post-stress characterization:
  - IEC 61215-2 MQT 01 Visual inspection (5.3) is completed after each stress step, with the addition of the inspection using magnification, as described in 5.3.
  - As an option, the visual inspection (5.3) may be omitted after the first set of stress applications. In this case, the first two 60 kWh/m$^2$ UV exposures may be combined into a single 120 kWh/m$^2$ UV exposure and similarly, the thermal cycling and humidity freeze exposures may be combined to 100 cycles and 20 cycles, respectively.
  - Other characterization may be completed at customer request, especially if visual change is noted. Power measurement and electroluminescence are omitted, as they are unlikely to correlate with field performance of the backsheet.

The following characterization is completed at the end of the entire sequence (in addition to the final visual inspection)

- IEC 61215-2 MQT 03 Insulation test (5.6).
- IEC 61215-2 MQT 15 Wet leakage current test (5.7).
- IEC 61730-2 MST 04 Insulation thickness (5.9).

All data shall be reported. No pass-fail criteria shall be applied.

### 6.6 Test sequence 4: Damp heat

Test sequence 4 applies damp heat stress to uncover problems with the packaging and/or to identify corrosion. The sequence includes (after initial characterization in 6.2).

- Stress:
  - IEC 61215-2 MQT 13 Damp heat test 1 000 h
- Post-stress characterization:

  As for test sequence 1 in 6.3.

The stress and post-stress characterization shall be completed a second time.

All data shall be reported. No pass-fail criteria shall be applied.

Some modules can show transients related to metastable defects. The relevant procedures in IEC 61215-2 should be followed and for interpretation of the data it should be kept in mind that new cell types may show metastabilities that differ from historical behaviour. For example, some modules may change in performance during the time between the two damp heat exposures if not kept in the dark at room temperature.

### 6.7 Test sequence 5: Potential-Induced Degradation (PID) testing

Test sequence 5 applies damp heat stress with voltage bias to uncover problems with degradation associated when the module is placed in a system and operated at a voltage that is quite different from ground, causing small leakage currents within the module. The sequence includes (after initial characterization in 6.2):

– Stress:
  - IEC 61215-2 MQT 21 85 °C / 85 % relative humidity applying the rated maximum system voltage in whatever bias polarities are allowed by the manufacturer's documentation. The stress shall be applied for twice the time requested for MQT 21, which would currently result in 192 h. Details of the stress application and follow up characterization and stabilization procedures designed to increase the value of this test, including any technology-specific procedures, will follow the IEC 61215-series definition of MQT 21.

– Post-stress characterization:

  As for test sequence 1 in 6.3.

All data shall be reported. No pass-fail criteria shall be applied.

## 7 Report

The results shall be reported, normally in a test report, and shall include all the information requested by the client and necessary for the interpretation of the test and all information required by the method used. 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 items tested;

f) characterization and condition of the test items;

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

h) identification of test methods used;

i) reference to sampling procedure, and definition of bill of materials if there is no issue of confidentiality; or definition of bill of materials in a way that respects confidentiality, but would allow future comparisons;

j) if the test items varied in any way (such as use of a minimodule) describe the differences between the test items, including the glass type and the module dimensions and construction differences;

k) any deviations from, additions to or exclusions from the test method, and any other information relevant to specific tests, such as environmental conditions or test methods or procedures and relevant logs, especially if chamber conditions are deviated from planned;

l) measurements, examinations and derived results supported by tables, graphs, sketches and photographs as appropriate, including results of all pre-stress and post-stress characterization;

m) a statement of the estimated uncertainties of the test results (where relevant);

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

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

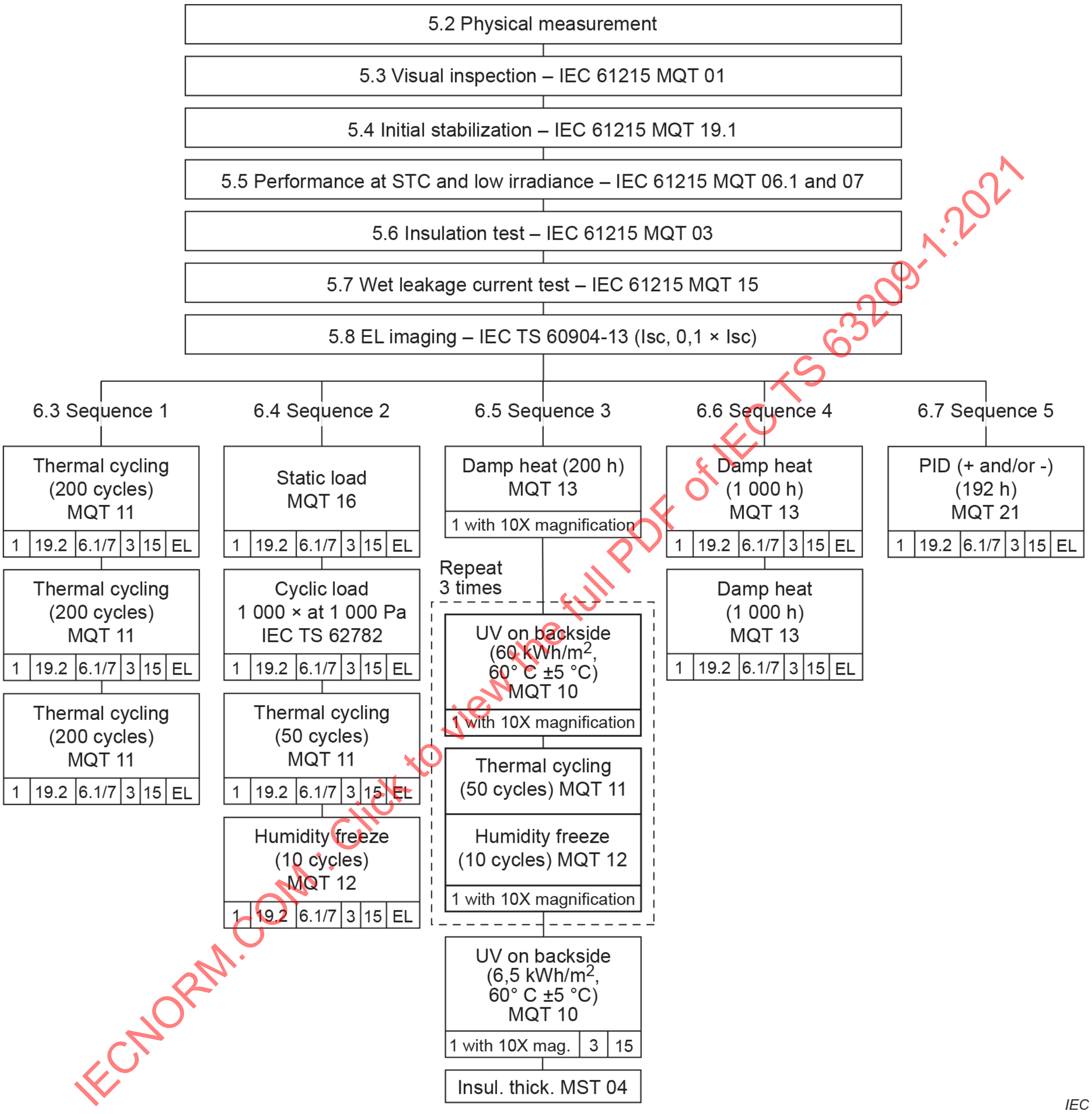
p) where relevant, a statement to note any observations that would have been deemed a failure by IEC 61730. Specifically, such notes would include when application of the stress normally applied in IEC 61730 caused degradation that would not have passed IEC 61730. While this test is not a pass-fail test, it is useful to understand when the result would have been a failure under regular safety testing;

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

A copy of this report shall be kept by the manufacturer for reference purposes.

## 8 Test flow and procedures

The full test flow is given in Figure 1.




NOTE PID bias is selected to match data sheet value(s), but static load is 2 400 Pa regardless of design load.

**Figure 1 – Full test flow – Each box refers to the corresponding MQT in IEC 61215-2**

# Annex A
(informative)

# Appropriate use of IEC TS 63209-1 – Potential weaknesses of the included test sequences

## A.1 General

PV module qualification tests are not intended to establish long-term reliability. There is a gap in the industry as to how to appropriately and consistently evaluate anticipated module long-term performance for various applications. This is not an easy task, and impossible to be 100 % accurate at a reasonable time and cost. It is anticipated that this is an evolutionary process, and that test procedures will improve and adjust as new module designs are used, and field experiences are evaluated. The stress tests laid out in this document are a starting point, intended to provide a standardized method for extended reliability testing of PV modules allowing comparison of designs, and supporting a long-term risk analysis. The tests are best used to find weaknesses in a design, so that one can focus work in those areas as may or may not be needed.

Inherent to any accelerated stress test is the risk of drawing erroneous conclusions. It is commonly understood that designing a test sequence with acceleration factors greater than about 6× to 10× will lead to highly speculative results; the combination of a target of service life of >25 years and target test duration of <6 months results in a 50× acceleration factor. This is a challenging problem, and the analysis of these lab results should include an understanding of potential weaknesses associated with the data.

## A.2 False negatives/false positives

Erroneous interpretations of test results come in the form of false positives and false negatives [1][1].

Some failures will be missed (false positives) by under stressing the material, or by failing to apply the appropriate combination of stresses. Other, non-representative, failures will be seen, (false negatives) arising from greater bias towards the more accelerated degradation modes [1] promoting failure mechanisms that might not be relevant for much longer than the expected lifetime.

In one example of a false negative, extended testing conducted on a module design during manufacturing uncovered a problem with the solder flux for a certain subset of modules [2]. Follow-on experiments were conducted at different stress levels, enabling the determination of approximate acceleration factors. When extrapolated to the use condition, they indicated that the expected amount of degradation was unlikely to be significant to the project. If taken at face value the whole project may have been scrapped at the cost of millions of dollars. While there certainly was a weakness in the subset of modules, it was determined that this was not likely to be discernible on a project level, thus concluding that the initial result was a false negative.

One example of a false positive led to the large-scale deployment of modules containing a new, unique backsheet material that later proved to be faulty [3], [4]. Modules from several manufacturers passed qualification tests and presumably internal acceptance testing. Despite this, it took as little as 4 years in the field for cracks to penetrate completely through the backsheet.

1 Numbers in square brackets refer to the Bibliography.

## A.3 Approximations to service life

It is important to note that the test results are not intended to be used for service life prediction.

With unknown and varied acceleration factors for different materials and designs located in different application environments, there is no unique number delineating the equivalency of test time to service time for the whole module. There is instead an unknown range of likely potential acceleration factors. While the sequences are intended to cause degradation that is most relevant to field experience, it is not expected to capture all failure modes which may be observed in various locations [5] to [8]. The same module deployed in two different locations may fail/degrade in different ways, so a single test protocol cannot be expected to simultaneously exactly match both results. Stresses are chosen to replicate failures in the field, but will sometimes also cause other degradation pathways to occur.

## A.4 Design to test

Ideally, the product design is optimized for the application including the targeted service life. However, new products are often designed to meet the test requirements instead. This can be a problem if some stresses are very accelerated or extended while others are under-utilized causing irrelevant failure modes to be fixed (false negative).

Relevant to field experience, stresses designed to capture degradation related to long term UV exposure are a significant gap in current standardized testing for PV modules; however, a parallel extended component testing document is currently in development [9]. Thus, a module could have superior performance in this set of sequences, but inferior performance in application if UV stresses are not considered.

Similarly, the 85 °C/85 % relative humidity condition for testing potential-induced degradation is a very harsh condition that may cause degradation beyond what will be observed in the field.

# Annex B
(informative)

# Background on IEC TS 63209-1

## B.1 General

The development of IEC TS 63209-1, as well as IEC 61730 and IEC 61215, is complicated and based largely on years of empirical observation of failure modes coupled to the tests found to uncover relevant design weaknesses, horizontal design standards, and an understanding of the use environment [8]. Following review of known extended stress protocols offered by various parties, consensus among the participants drafting this document was to utilize only test chambers and conditions already part of other IEC PV standards, so that testers would not need to invest in new equipment to aid in broader adoption of the methodology [10].

The choice was made to focus on known degradation modes and to create sequences that aim to identify these failure modes but with greater allowance for longer term tests as compared to IEC 61730 and IEC 61215. Extensive research has gone on elsewhere to correlate laboratory stress level to field applied stresses. The experiences of representative industry participants observing failure modes in testing and field deployment informed the discussions and consensus decisions leading to the proposed sequences.

The background on the five sequences of IEC TS 63209-1 are summarized below.

## B.2 Sequence 1: Thermal fatigue – Thermal cycling 600 cycles = 3x IEC 61215 (similar to other extended stress protocols)

This is based on computational models indicating that between 400 and 600 TC is roughly equal to 25 years, depending on the climate, with respect to solder bond fatigue. Other bonds are expected to behave differently, so the meaning of the test should be interpreted in the context of the specific module design.

## B.3 Sequence 2: Mechanical stress (adds static load to sequence similar to other extended stress protocols)

The choice was made to create a new mechanical stress sequence including both static and dynamic loads, as they simulate different sources of stress within the lifecycle of the module and may result in different failure modes or accelerate the same failure mode at different rates. Results using the proposed sequence were produced, demonstrating that cell cracks were formed by the static load test, but that the dynamic mechanical load test was needed to cause them to open up and affect cell performance.

## B.4 Sequence 3: Combines UV, moisture and temperature/mechanical cycling to stress polymeric components

In many industries studying outdoor weathering and accelerated weathering, UV combined with water are known to generate more representative degradation faster than either stress alone. Therefore, the order of sequence 3 seeks to gain the benefit of combining the stresses without building a specialized chamber.

It is difficult to sufficiently accelerate UV exposure stress to mimic expected module lifetimes in a test duration reasonable to apply to PV modules, and the sequence provided is not expected to capture degradation of polymeric components related to long term UV exposure – this is left to a parallel extended component testing document, currently in development.