

This is a preview - click here to buy the full publication



IEC TR 63279

Edition 1.0 2020-08

# TECHNICAL REPORT



---

## Derisking photovoltaic modules – Sequential and combined accelerated stress testing

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

---

ICS 27.160

ISBN 978-2-8322-8737-8

**Warning! Make sure that you obtained this publication from an authorized distributor.**

## CONTENTS

FOREWORD .....	5
1 Scope .....	7
2 Normative references .....	7
3 Terms and definitions .....	8
4 Framework for sequential and combined stress testing .....	8
5 Sequential and cyclic sequential test methods .....	9
5.1 Extended damp heat and addition of ultraviolet light .....	9
5.2 Sequential/combined testing with damp-heat, thermal cycling and ultraviolet light .....	10
5.3 Consideration of interaction of UV radiation and damp heat .....	12
5.4 Test-to-failure—A sequential test protocol.....	13
5.5 Sequential test protocol optimized for differentiating backsheets.....	16
5.6 Mechanical stress testing in combination with damp-heat, humidity-freeze, and thermal-cycling tests for examining cell cracking and its effects .....	20
6 Mechanism-specific multi-factor stress tests .....	22
6.1 General.....	22
6.2 Testing for delamination.....	22
6.2.1 General .....	22
6.2.2 Delamination – UV irradiation with high-temperature stress .....	22
6.2.3 Delamination – UV irradiation with thermal-cycling stress and humidity freeze .....	23
6.2.4 Delamination – UV irradiation with cyclic dynamic mechanical loading, thermal cycling stress, and humidity freeze.....	24
6.2.5 Delamination – Temperature, humidity, and electric field associated with system voltage .....	25
6.3 Testing for potential-induced degradation .....	28
6.3.1 General .....	28
6.3.2 Testing for potential-induced degradation with humidity, voltage, bias, and light .....	28
6.3.3 Factor of salt mist.....	29
6.4 Testing in damp heat with current injection and as a function of temperature .....	30
6.5 Cell cracking and propagation in cyclic loading at various temperatures.....	31
7 Combined-accelerated stress testing .....	33
7.1 Combined-accelerated stress testing for tropical environments .....	33
7.2 Combined-accelerated stress testing for multiple environments .....	36
8 Future directions.....	39
Annex A (informative) Overview of degradation modes and causal stress factors.....	41
Annex B (informative) Failure modes plotted on a failure tree diagram for selected clauses in this document.....	43
Annex C (informative) Summary table of sequential and combined testing: Samples, factors, combination, and stress-test results .....	44
Bibliography.....	49

Figure 1 – Framework for sequential and combined stress testing, showing three axes of comprehensiveness – testing samples, the number of stress factors of the natural environment, and their sequence or combination of application..... 9

Figure 2 – Fraction power loss of modules though stress testing..... 10

Figure 3 – (a) Combined test sequence, and resulting (b) normalized power loss, (c) short-circuit current ( $I_{SC}$ ), and (d) fill factor ( $FF$ ) [1] .....	11
Figure 4 – Power degradation of modules in 85 °C and 85 % relative humidity as a function of extent of preconditioning under Xe light [9] .....	13
Figure 5 – (a) Overview of the test-to-failure sequences, and (b) results showing module power normalized to their post-light-soak values for seven module types.....	14
Figure 6 – Examples of field-relevant degradation modes seen in modules tested in the test-to-failure protocol .....	15
Figure 7 – Module accelerated sequential tests (MAST).....	17
Figure 8 – Degradation modes from MAST and fielded modules .....	19
Figure 9 – (a) Front-side mini-module exposure in a xenon weathering chamber with water spray; (b) fielded module with six years of service in North America with 30 % power loss [21] .....	20
Figure 10 – (a) Test-stage description; (b) relative change in standard test condition (STC) module parameters as a function of stage and maximum power determined at STC [23] .....	21
Figure 11 – (a) Stress testing at 65 °C combined with UV radiation dose of 180 W/m <sup>2</sup> in the range of 300–400 nm, 900 h; (b) 75 °C without UV radiation, 1 000 h [28].....	23
Figure 12 – Delamination in sequential test.....	25
Figure 13 – Delamination associated with system voltage .....	27
Figure 14 – Degradation of three modules with and without UV-A light irradiance in chamber at 60 °C, 85 % RH, and 1 000 V (positive or negative polarity depending on the sample).....	29
Figure 15 – Sheet resistance measured on glass surfaces with various soil types, as a function of relative humidity (RH %), at 60 °C [41] .....	30
Figure 16 – Cyclic unidirectional 4-point bending with loading alternating between 0 N and 500 N at different temperatures as shown, with duration of 4 s at each of the high- and low-pressure dwells, 10 000 to 30 000 cycles with pressure (“Press”) from the front-glass side or backsheets side [49].....	32
Figure 17 – Example of 24 h PV module combined accelerated stress-testing protocol modified from ASTM D7869 .....	34
Figure 18 – Shrinkage of polymer C backsheets leading to delamination and cracking .....	35
Figure 19 – Multiple-environment C-AST sequence.....	37
Figure 20 – Failure of two mini-modules with a polymer B outer-layer backsheets type undergoing different multiple-environment C-AST sequences .....	38
Table 1 – Extended damp heat and ultraviolet light .....	10
Table 2 – Sequential/combined testing with damp-heat thermal cycling and ultraviolet radiation .....	12
Table 3 – Ultraviolet light and damp-heat interaction.....	13
Table 4 – Test-to-failure – Sequential test protocol .....	16
Table 5 – Module accelerated stress test 1 (MAST #1) .....	18
Table 6 – Module accelerated stress test 2 (MAST #2) .....	18
Table 7 – Module accelerated stress test 3 (MAST #3) .....	18
Table 8 – SML-TC-HF sequential test .....	21
Table 9 – UV irradiation under high-temperature conditions .....	23
Table 10 – UV irradiation with TC stress .....	24
Table 11 – UV irradiation with DML-TC-HF sequential test.....	25

Table 12 – DH – Negative system bias stress sequential test.....	28
Table 13 – UV irradiation – negative system bias stress combined test.....	29
Table 14 – Bending load test at various temperatures.....	33
Table 15 – Partial list of observed degradation modes, attributed mechanisms, and stress factors seen in the first application of the combined accelerated stress-testing protocol based on ASTM D7869.....	35
Table 16 – Combined-accelerated stress test (Tropical 24 h ASTM D7869-based sequence).....	36
Table 17 – Multiple-environment combined-accelerated stress test.....	38
Table A.1 – Degradation modes and potential stress factors that can lead to their manifestation .....	42
Table C.1 – Table summarizing sequential and combined stress testing .....	44

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

# DERISKING PHOTOVOLTAIC MODULES – SEQUENTIAL AND COMBINED ACCELERATED STRESS TESTING

## FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 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.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 63279, which is a Technical Report, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

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

Enquiry draft	Report on voting
82/1657/DTR	82/1692B/RVDTR

Full information on the voting for the approval of this technical report 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.

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.

**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.**

## DERISKING PHOTOVOLTAIC MODULES – SEQUENTIAL AND COMBINED ACCELERATED STRESS TESTING

### 1 Scope

This document reviews research into sequential and combined accelerated stress tests that have been devised to determine the potential for degradation modes in PV modules that occur in the field that single-factor and steady-state tests do not show. This document is intended to provide data and theory-based motivation and help visualize the next steps for improved accelerated stress tests that will derisk PV module materials and designs. Any incremental savings as a result of increased reliability and reduced risk translates into lower levelized cost of electricity for PV. Lower costs will result in faster adoption of PV and the associated benefits of renewable energy.

### 2 Normative references

The following documents are referred 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 60721-2-1, *Classification of environmental conditions – Part 2-1: Environmental conditions appearing in nature – Temperature and humidity*

IEC 61215-1:2016, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements*

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

IEC 61730-2:2016, *Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing*

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

IEC TS 62782:2016, *Photovoltaic (PV) modules – Cyclic (dynamic) mechanical load testing*

IEC 62788 (all parts), *Measurement procedures for materials used in photovoltaic modules*

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

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

ASTM D7869-17 *Standard Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings*