

TECHNICAL SPECIFICATION



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



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2020 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org

The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

TECHNICAL SPECIFICATION



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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

ISBN 978-2-8322-7693-8

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

CONTENTS

FOREWORD.....	3
INTRODUCTION.....	5
1 Scope.....	7
2 Normative references	7
3 Terms and definitions	8
4 Samples	8
5 Test procedures	8
5.1 General.....	8
5.2 Initial visual inspection.....	9
5.3 Wet leakage current test	9
5.4 Damp heat test	9
5.5 Voltage stress test.....	9
5.5.1 General	9
5.5.2 Apparatus.....	10
5.5.3 Voltage stress test procedure	10
5.5.4 Severities	11
5.6 Wet leakage current test.....	12
5.7 Final visual inspection.....	12
6 Test report.....	13
Annex A (informative) Examples of delamination	14
Bibliography.....	16
Figure 1 – Test flow	9
Figure 2 – Example test time-temperature-humidity-voltage profile for application of stress in an environmental chamber.....	11
Figure A.1 – Examples of delamination occurring over cell.....	14
Figure A.2 – Examples of delamination occurring over bus ribbon.....	15
Figure A.3 – Examples of precipitation between the glass and the encapsulant	15

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**PHOTOVOLTAIC (PV) MODULES – TEST METHODS FOR THE DETECTION
OF POTENTIAL-INDUCED DEGRADATION –****Part 1-1: Crystalline silicon – Delamination****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. In exceptional circumstances, a technical committee may propose the publication of a Technical Specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specification are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 62804-1-1, which is a Technical Specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

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

Draft TS	Report on voting
82/1566/DTS	82/1596A/RVDTS

Full information on the voting for the approval of this Technical Specification 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 62804 series, published under the general title *Photovoltaic (PV) modules – Test methods for the detection of potential-induced degradation*, can be found on the IEC website.

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.

A bilingual version of this publication may be issued at a later date.

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

Potential-induced degradation (PID) refers to any PV module degradation that is caused by the stress of an electric potential between the active cell circuit and the external surfaces or parts of the PV module. This part of IEC 62804 is for testing and evaluating the durability of crystalline silicon PV modules for PID in the mode of delamination (PID-d), as may be induced by the stress factors of moisture and system voltage.

The applied stresses, with system voltage being the principal factor in IEC 62804-series documents, manifest themselves in different degradation modes that depend in part on the module technology. Therefore, a series of technical specifications is being developed to define PID tests for different PV module technologies and differing PID modes.

IEC TS 62804-1 defines test methods for evaluating power loss by PID in crystalline silicon PV modules.

IEC TS 62804-1-1 defines a test method for evaluating delamination by PID in crystalline silicon PV modules.

IEC TS 62804-2 defines test methods for evaluating power loss by PID in thin-film PV modules and modules with moisture-sensitive components and moisture-barrier packaging.

Additional TSs in the series may be introduced in the future for emerging module technologies, mechanisms, or evaluation methods.

Delamination of PV modules is a failure mode that can lead to electrical shocks, ground faults, rapid moisture ingress or collection of condensed moisture and can be associated with corrosion, some loss in photocurrent and hotspots due to degraded transmission of light to the solar cells, and visual undesirability. Various delamination modes are seen occurring in fielded modules for which standardized methods for accelerated testing do not exist to predict these vulnerabilities.

Delamination in crystalline silicon PV modules has been found to occur associated with electrochemical reactions on the silicon PV cell surface and metallization (Mon and Ross, 1985, Matsuda *et al.* 2012). Moisture has been found to sometimes accelerate the adhesion loss at interfaces in PV modules, along with elevated sodium concentration on the cell surface within the module package, which may result from the electric field of system voltage stress (Dhere *et al.*, 2002, Bosco *et al.*, 2017, Wohlgemuth *et al.*, 2017, Li *et al.*, 2018). Modules with encapsulation materials of low bulk resistivity have been found to have greater susceptibility to PID-d under electric fields due to system voltage stress (Hacke *et al.*, 2016). Modules that do not exhibit significant power loss by PID-shunting (PID-s) or PID polarization (PID-p) modes may still be prone to degradation by the delamination mode examined in this document if, for example, the cells are made durable to power loss by these modes, but the encapsulation is of low bulk resistivity.

Elevated dissolved moisture content in encapsulants has been found to increase the bulk conductivity of many encapsulants (Berghold *et al.*, 2014). An accelerated test is therefore provided in this document to evaluate modules for susceptibility to delamination under the stress factors of moisture and system voltage. While mounting and grounding configuration may be optimized to mitigate PID degradation modes, as a test of the laminate, glass surfaces are grounded in this document independent of consideration of the intended mounting and grounding configuration of the module.

The conductivity of glass and resultant charge transfer through it enable electrochemical reactions within the laminate when subjected to a voltage potential. Therefore, this document is intended primarily for modules with one or two glass faces. To date, module package resistivity has been measured to vary by several orders of magnitude. Accordingly, the testing protocol herein has been found to differentiate susceptible modules from durable modules as a

function of resistivity for this delamination mode (Hacke *et al.*, 2016). The stress test conditions contained herein are highly accelerated and have been determined to differentiate susceptibility of modules to this degradation mode; but their acceleration factor with respect to the rate of occurrence in various natural environments has not been established. Annex A gives examples of the degradation modes manifested by application of the protocol and visually similar examples from the field.

Delamination may additionally occur by other mechanisms, such as from the reaction products of photocatalysis (Matsuda *et al.*, 2012), and may not manifest under this or other presently existing standardized testing protocols.

It is known that variability in manufacturing processes can affect the susceptibility of modules to system voltage stress. Periodic retesting of module samples by the test protocols contained herein, by internal quality assurance programs such as given in IEC TS 62941, and by external audits will aid in verifying not only the durability of the design of the module to system voltage stress, but also, the effects of any variability of the materials and manufacturing processes.

PHOTOVOLTAIC (PV) MODULES – TEST METHODS FOR THE DETECTION OF POTENTIAL-INDUCED DEGRADATION –

Part 1-1: Crystalline silicon – Delamination

1 Scope

This part of IEC 62804 defines procedures to test and evaluate for potential-induced degradation-delamination (PID-d) mode in the laminate of crystalline silicon PV modules—principally those with one or two glass faces. This document evaluates delamination attributable to current transfer between ground and the module cell circuit. Elements driving the delamination that this test is designed to actuate include reduced adhesion associated with damp heat exposure, sodium accumulation at interfaces, and cathodic gas evolution in the cell circuit, metallization, and other components within the PV module activated by the voltage potential. The change in power of crystalline silicon PV modules associated with the stress factors applied (the purview of IEC TS 62804-1) is not considered in the scope.

Modules are tested in a climatic chamber with damp heat and application of module-rated system voltage to the cell circuit in each polarity that is specified or allowed in the module documentation. This document does not differentiate the effects of some construction methods of mitigating PID—for example, the use of rear rail mounts, edge clips, and insulating frames that may serve to electrically isolate the module faces to varying extents. The actual durability of modules to system voltage stress will depend on the mounting design and the environmental conditions under which the modules are operated. These tests are intended to assess the sensitivity of the PV module laminate to PID-d irrespective of actual stresses under operation in different climates and systems.

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 60068-2-78:2012, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state*

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

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

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

IEC TS 62941, *Terrestrial photovoltaic (PV) modules – Guidelines for increased confidence in PV module design qualification and type approval*