IEC TS 62916

Edition 1.0 2017-04

TECHNICAL SPECIFICATION

colour inside

Photovoltaic modules – Bypass diode electrostatic discharge susceptibility testing

IEC TS 62916:2017-04(en)

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

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

ISBN 978-2-8322-4147-9

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC MODULES – BYPASS DIODE ELECTROSTATIC DISCHARGE SUSCEPTIBILITY TESTING

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

IEC TS 62916, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
82/1059/DTS	82/1259/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.

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

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PHOTOVOLTAIC MODULES – BYPASS DIODE ELECTROSTATIC DISCHARGE SUSCEPTIBILITY TESTING

1 Scope

This document describes a discrete component bypass diode electrostatic discharge (ESD) immunity test and data analysis method. The test method described subjects a bypass diode to a progressive ESD stress test and the analysis method provides a means for analyzing and extrapolating the resulting failures using the two-parameter Weibull distribution function.

It is the object of this document to establish a common and reproducible test method for determining diode surge voltage tolerance consistent with an ESD event during the manufacturing, packaging, transportation or installation processes of PV modules.

This document does not purport to address causes of electrostatic discharge or to establish pass or fail levels for bypass diode devices. It is the responsibility of the user to assess the ESD exposure level for their particular circumstances. The data generated by this procedure may support qualification of new design types, quality control for incoming material, and/or identify the need for additional ESD controls in the manufacturing process.

Finally, this document does not apply to large energy surge events such as direct or indirect lightning exposure, utility capacitor bank switching events, or the like.

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 61000-4-2:2008, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity* test

3 Terms, definitions and abbreviated terms

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

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

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

3.1
DUT
device under test

3.2
contact discharge method
method of testing in which the electrode of the test generator is kept in contact with the DUT and the discharge is actuated by the discharge within the generator

Note 1 to entry: In this document, the contact is to the electrical lead of the DUT with no intervening electrical insulation material.

3.3
diode check function

usage of a multimeter with diode function check to verify the diode is functional, short or open

3.4
direct application

application of the test surge directly to the DUT

Note 1 to entry: In this technical specification, the surges are directed to bypass diodes for photovoltaic applications outside of the actual photovoltaic application (e.g., DUT are tested outside of the junction box and are not associated with the photovoltaic module itself when characterized).

3.5
surge relaxation time

amount of time necessary for the DUT to thermally stabilize in the event that surge application creates localized regions of heat generation

4 General

Production line quality excursions due to bypass diode failure have been observed in the PV module manufacturing process due to changes in the electrostatic discharge (ESD) susceptibility of bypass diodes. This document provides a method to evaluate the susceptibility of bypass diodes to fail due to ESD events that may occur in the production, transport or installation of photovoltaic (PV) modules. ESD events occur whenever there is contact, or sufficiently close proximity between objects of different electrostatic charge. The magnitude of the ESD event is a function of the charge difference between the objects and the impedance associated with the charge transfer. Of specific interest in this document are relatively low energy, short-duration surges that may be associated with the manufacturing process, testing, or installation events where the bypass diodes are directly exposed to an ESD event.

Several standard ESD models exist for the evaluation of surge immunity. This document adopts the model provided by IEC 61000-4-2:2008 that provides a method for assessing damage to electrical and electronic equipment subjected to static electricity discharges from operators directly, and from personnel to adjacent objects.

5 Sampling

Ten unconditioned diodes are required for this test. Several factors should be considered when making sample selection:

- Diode types shall be identical. Different diode types will not provide useful surge immunity information.
  - Each diode type that was tested during the development of this procedure yielded a different failure distribution indicating that mixed type testing would not be meaningful.
- Diode date codes and factory location should be identical.
  - The best characterization of a diode's surge immunity will be obtained when the diodes are from one manufacturing location and from a specific manufacturing batch.
  - Comparison of the failure distributions that result from applying this procedure to several different date codes may provide the user with a qualitative understanding of the diode manufacturer's quality control from a surge immunity perspective. Similarity of results from different date codes would indicate a tighter quality control method.
- Diodes are tested independently and outside of a module or junction box. The leads shall be in the form required before assembly into a junction box.

– Lead trimming or lead forming operations should be done before testing as these operations can create stress on the diode die that may have an impact on the diode's surge immunity.

6 Test equipment

Test equipment shall conform to the requirements stated in IEC 61000-4-2:2008, Clause 6 using the discharge electrode for contact discharges. The discharge return connection from the surge generator shall be connected to a grounding block designed to accommodate the DUT samples, taking into account spacing requirements that may be required for formed leads as shown in Figure 1. Multiple DUT samples may be connected to a single grounding block.

The equipment shall be capable of positive polarity surges (with respect to earth ground), conducted in a single-surge mode, and with a voltage that can be incremented in 5 kV steps from 5 kV to a recommended 30 kV or higher capability. Equipment having a surge voltage limitation that is less than 30 kV may be used, but this may limit DUT failure information and subsequent data analysis for a very surge-resistant DUT.

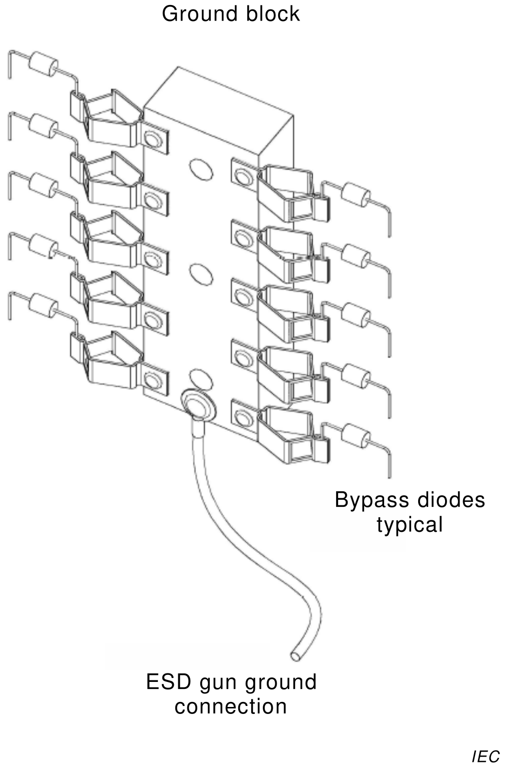

Figure 1 – Example of a test setup for bypass diodes

7 Test method

7.1 Preparation

a) Place 10 unconditioned DUTs into an electrically grounded fixture such that the DUT anode is grounded and the cathode is exposed and accessible (Figure 1).

b) Use a multimeter with diode-check functionality to verify that all DUTs are functional in the forward bias direction and that none are shorted in the reverse bias direction. In the event that a DUT is found to be in a non-operational state before test, replace as necessary so that ten functional units are subjected to the surge testing.

c) Place a contact probe tip (IEC 61000-4-2:2008, Figure 3b) onto a surge generator whose internal impedance conforms to the 330 Ω, 150 pF requirements.

d) Set the initial surge voltage to 5 kV in a positive polarity with respect to earth ground.

e) Ensure equipment is set to provide only a single surge per operation.

f) Record the ambient temperature and relative humidity during the testing period. For comparison purposes, 20 °C ± 5 °C and 50 % ± 10 % RH are recommended.

7.2 Surge testing

a) Conduct one surge on the first DUT. The tip of the contact probe shall be in contact with the electrical leads as close to the DUT protective body as possible. Keep track of time elapsed as each DUT is tested.

b) Repeat step a) on the next DUT until all ten have been tested once.

c) Repeat surge testing, steps a) and b), until each DUT has accumulated a total of ten individual surges. Wait, if necessary, to ensure that 10 s, or more, of surge relaxation time has elapsed before repeating the surge test on any DUT.

d) Use a multimeter with a diode-check function to determine if all DUTs are functional in the forward bias direction and do not exhibit a short-circuit in either forward or reverse bias. Remove any diodes that have failed from the test setup and note the surge voltage at which the failure occurred.

e) Increase the surge equipment potential by 5 kV (positive polarity with respect to earth ground) from its previous setting.

f) Place all remaining diodes back into their starting orientation (if necessary) and repeat steps a) to d).

g) Repeat step f), increasing surge equipment voltage by 5 kV steps until 30 kV or the testing capability of the surge equipment is reached, whichever is smaller.

8 Data analysis

8.1 Two-parameter Weibull distribution for analyzing voltage to failure

The two-parameter Weibull cumulative distribution of the voltage to DUT failure is written as:

$$F(V) = 1 - \exp\left[-\left(\frac{V}{\alpha}\right)^{\beta}\right] \tag{1}$$

where

$F(V)$ is the fraction of all units in the population which fail by V surge voltage;

β is the Weibull distribution shape parameter;

α is the Weibull distribution characteristic life parameter, or the surge voltage corresponding to F = 1 – 1/e = 0,632.

A straight line formula of slope β can be formed by taking the natural logarithm of both sides of formula (1) twice yielding:

$$\ln\left\{\ln\left[\frac{1}{1-F(V)}\right]\right\} = \beta \ln\left(\frac{V}{\alpha}\right) \tag{2}$$

which can be rearranged as:

$$\ln\left\{\ln\left[\frac{1}{1-F(V)}\right]\right\} = \beta \ln(V) - \beta \ln(\alpha) \tag{3}$$

Arrangement of the experimental data into two groups, the independent variable ln(V) on the right hand side and the dependent variable shown on the left hand side of formula (3) allows for a least-squares linear regression technique that results in an estimation of the slope β and the intercept $\beta\ln(\alpha)$ from which, the characteristic life, α, can be estimated.

8.2 Recommended median rank estimation for the cumulative distribution

Several methods are available to estimate the cumulative distribution function. One method that easily lends itself to hand or spreadsheet calculation is median rank estimation.

In order to calculate the left hand side of formula (3), an estimate for the cumulative distribution, $F(V)$ is required. This document uses the median rank estimate defined as:

$$\hat{F}(V) = \frac{O_i - 0{,}3}{n + 0{,}4} \tag{4}$$

where

O_i is the rank order position of the failure for the ith data point, when the data points are ranked in order from earliest failure to latest failure;

n is the total number of data points.

8.3 Recommended form for data analysis by least squares linear regression

Median rank estimation data may be plotted manually or through a simple spreadsheet model. Computer programs are also available and may be used to present data and estimate unknowns in formula (1). In the method provided below, the voltage at failure, V, comes from the test result and cumulative distribution estimate, $\hat{F}(V)$, comes from formula (4). The right most columns are calculated as indicated and the resulting x_i and y_i may be plotted on linear graph paper, or on a spreadsheet program. A linear regression is then fit through these points. See Table 1.

Table 1 – Data organization for least squares regression

Failure order	**Voltage at failure, V in kV**	**$\hat{F}(V)$, formula (4)**	**ln(V) x_i for least squares**	**$\ln\left\{\ln\left[\frac{1}{1-\hat{F}(V)}\right]\right\}$ y_i for least squares**
1				
2				
3				
4				
5				

The best estimate for a linear fit of x_i and y_i is provided by formula (5):

$$\hat{y} = mx + (\bar{y} - m\bar{x}) \tag{5}$$

where

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \qquad \bar{y} = \frac{\sum_{i=1}^{n} y_i}{n} \tag{6}$$

and

$$m = \frac{n\sum_{i=1}^{n} x_i y_i - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \qquad (7)$$

The regression may be used to extrapolate the results to different levels of applied surge voltage other than those used in the experimental program.

9 Report

The report shall contain information necessary to reproduce test results and the details of the samples tested. Specifically, make note of the following:

- Identification of the DUT and date codes associated with the samples tested. For the purpose of interlaboratory comparison, this information may be made generic.
- Test results and graph including method or program used to obtain those results (e.g., 8.3).
- Identification of test equipment by brand, model and serial number.
- Calibration information or method used to validate data.
- Actual environmental conditions of ambient temperature and relative humidity during the testing period.
- Any effects observed with the DUT during the course of testing if other than operational or failure in an electrically short-circuit (e.g., open-circuit, cracked, etc.).
- Picture of any failed DUT, but only in the event the failure can be visually observed from changes in the appearance.
- Rationale for any deviations used in the test method.

Annex A
(informative)

Guidelines for application

Quality excursions have been observed in photovoltaic module manufacturing lines that have been traced to batch failure of bypass diodes. It was observed that the majority of failures occurred during the manufacturing assembly process itself, however, a small percentage of modules that seemingly had functional diodes on shipment were found in the field with failed diodes suggesting that damage had occurred during transport, installation, or as a consequence of cumulative damage suffered from the manufacturing through installation process. This type of diode failure differs significantly from lightning-induced diodes failure damage and is characterized by individual module diode failure versus the failure of most diodes associated with one or more source circuits in the PV array.

This testing specification establishes the diode's surge tolerance voltage consistent with an ESD event and may be useful for one or more of the following elements of a manufacturing quality system:

- Incoming quality control.
- As part of either a control program plan or compliance verification plan as required in IEC 61340-5-1:2016.
- Establishing the minimum required level of diode surge tolerance for a particular facility if this test specification is combined with peak ESD voltage characterization equipment such as the 3M EM Eye.

Annex B
(informative)

Example of application

In the example below, a set of ten diodes are tested according to the test method described in Clause 7. The data, analyses and application are shown in Table B.1 and Figure B.1 below.

Table B.1 – Example of data analysis

Failure order	Voltage at failure, V in kV	F(V), Median rank	ln(V)	ln{ln[1/(1-F(V))]}
1	20	0,067	3,00	–2,66
2	20	0,163	3,00	–1,72
3	20	0,260	3,00	–1,20
4	25	0,356	3,22	–0,82
5	25	0,452	3,22	–0,51
6	30	0,548	3,40	–0,23

$$\frac{\sum x_i}{n} = 3{,}138 \qquad \frac{\sum y_i}{n} = -1{,}192$$

$$m = \frac{n\sum_{i=1}^{n} x_i y_i - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} = 4{,}366$$

$$\hat{y} = mx + \left(\bar{y} - m\bar{x}\right) = 4{,}366x - 14{,}892$$

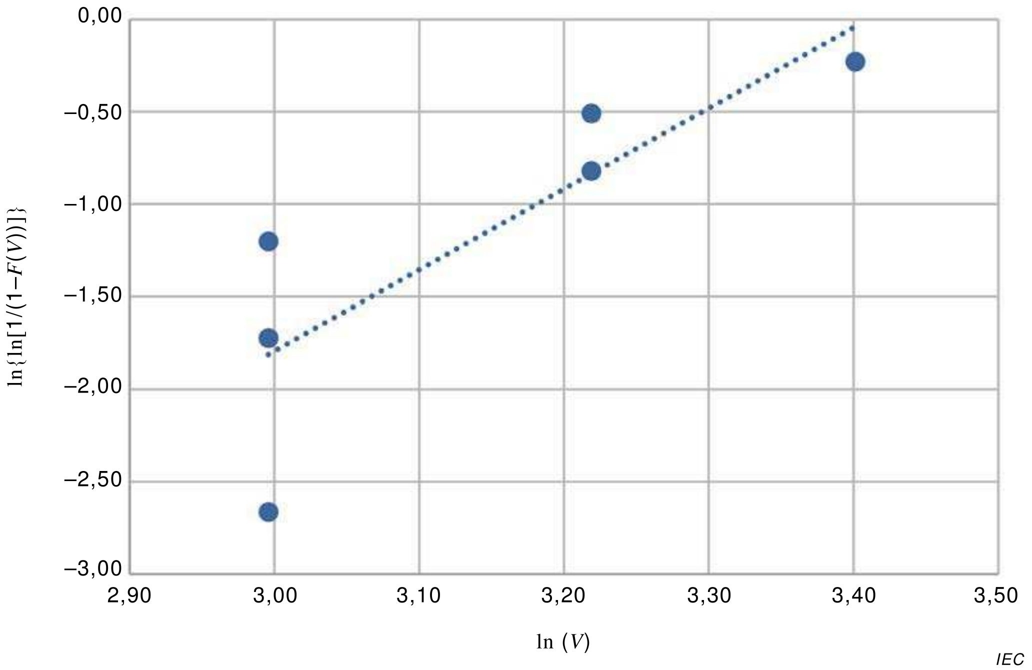

Figure B.1 – Chart of sample data

Based upon the analysis, it is estimated that when placed in an environment where 2 kV ESD events are present, the fraction of units failing, F, in a large population would be approximately 7 parts per million.

INTERNATIONAL
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COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch