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INTERNATIONAL STANDARD

Photovoltaic modules – Bypass diode – Thermal runaway test

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PHOTOVOLTAIC MODULES – BYPASS DIODE – THERMAL RUNAWAY TEST

FOREWORD

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International Standard IEC 62979 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
82/1269/FDIS	82/1311/RVD

Full information on the voting for the approval of this International 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.

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- withdrawn,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.

INTRODUCTION

During the normal operation of PV modules the bypass diodes are reverse biased. When the PV module is partially shaded (for example by utility poles, buildings, or leaves), some of the cells in the PV module may not be able to produce the current being produced by the other cells in the series string. The shaded cells are then driven into reverse bias so the bypass diode of the shaded cell-string becomes forward bias protecting the shaded cells.

Under these circumstances, the temperature of the bypass diode increases due to the forward current flowing through the diode. It is in this condition that the diodes are tested in accordance with IEC 61215-2:2016, 4.18.1: Bypass diode thermal test. When the shade is removed, operating conditions return to normal and the bypass diode is again reversed biased.

Some of the diodes utilized as bypass diodes in PV modules have characteristics where the reverse bias leakage current increases with the diode temperature. So if the diode is already at an elevated temperature when reverse biased, there will be a substantial leakage current and the diode junction temperature can increase considerably. The worst case occurs when this heating exceeds the cooling capability of the junction box in which the diode is installed. As a result of this increasing temperature and leakage current, the diode can break down. These phenomena are called “thermal runaway”. The thermal design of the bypass diode in the junction box shall be verified to ensure that thermal runaway does not occur.

PHOTOVOLTAIC MODULES – BYPASS DIODE – THERMAL RUNAWAY TEST

1 Scope

This document provides a method for evaluating whether a bypass diode as mounted in the module is susceptible to thermal runaway or if there is sufficient cooling for it to survive the transition from forward bias operation to reverse bias operation without overheating.

This test methodology is particularly suited for testing of Schottky barrier diodes, which have the characteristic of increasing leakage current as a function of reverse bias voltage at high temperature, making them more susceptible to thermal runaway.

The test specimens which employ P/N diodes as bypass diodes are exempted from the thermal runaway test required herein, because the capability of P/N diodes to withstand the reverse bias is sufficiently high.

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 as well as 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
reverse current
current flowing in the opposite direction to the polarity of the bypass diode

3.2
reverse bias voltage
voltage applied to the opposite direction to the polarity of the bypass diode

3.3
$T_{\mathbf{lead}}$
temperature of the lead-wire of the bypass diode measured by thermocouple

4 Thermal runaway test

4.1 Diode thermal runaway

Some of the diodes utilized as bypass diodes in PV modules have characteristics where the reverse bias leakage current increases with the diode temperature. So if the diode is already at an elevated temperature when reverse biased, there may be a substantial reverse current and the diode junction temperature can increase considerably. The worst case occurs when this heating exceeds the cooling capability of the junction box in which the diode is installed. As a result of this increasing temperature and leakage current, the diode can break down. These phenomena are called "thermal runaway". The thermal design of the bypass diode in the junction box shall be verified to ensure that thermal runaway does not occur.

How the thermal runaway does or does not occur is illustrated simply in Figure 1.

The curve R indicates the relation of the power injected by the reverse bias voltage versus the junction temperature. As shown, the power injected will rapidly increase at the higher junction temperature. The cooling capability of the junction box is indicated by the curve "Heat dissipation" and the critical temperature T_C is the crossing point of the curve R and the curve "Heat dissipation".

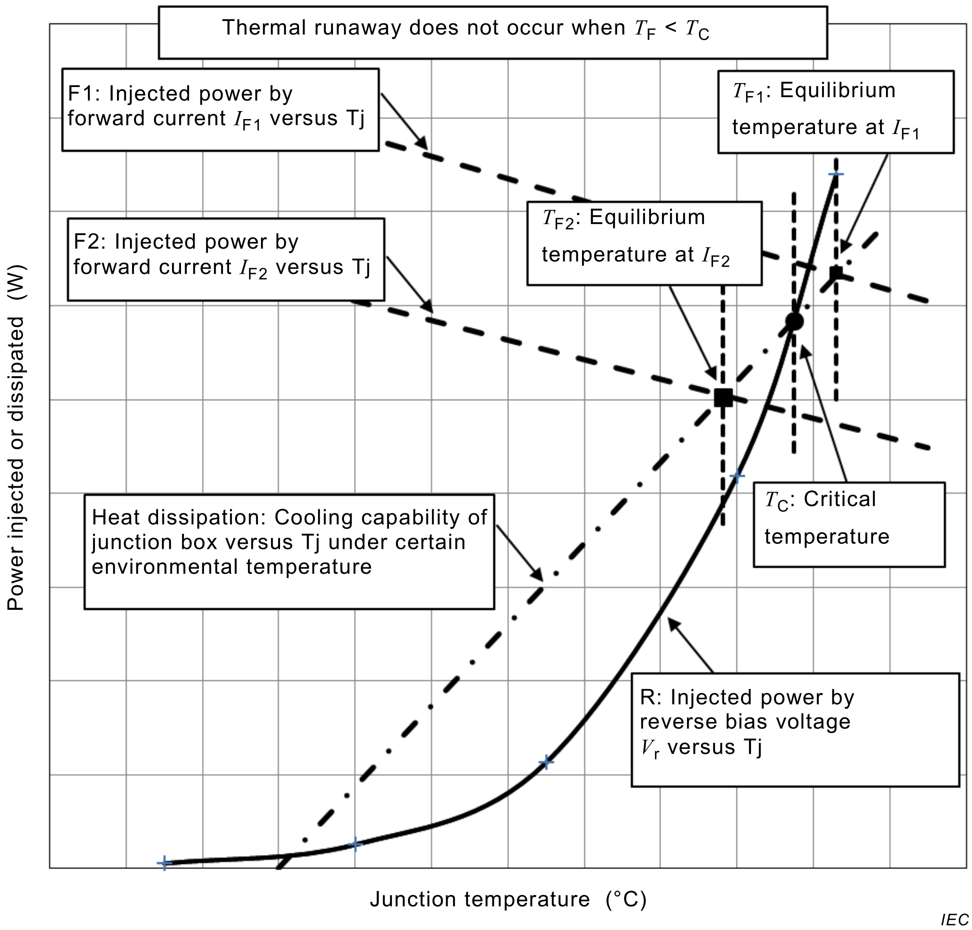

Figure 1 – Illustration of how thermal runaway occurs

If the reverse bias voltage is applied at a junction temperature higher than the critical temperature T_C, the injected power will be more than the cooling capability and the junction temperature will keep increasing until the diode undergoes thermal runaway.

On the other hand, if the reverse bias voltage is applied at a junction temperature lower than the critical temperature T_C, the injected power will be less than the cooling capability and the junction temperature will gradually decrease toward the environmental temperature.

The curves F1 and F2 show the relationship of the power injected by the forward current I_{F1} and I_{F2} versus the junction temperature. The crossing points of these curves and the cooling capability "Heat dissipation" show the equilibrium temperature when the forward current is applied.

The equilibrium temperature T_{F1} corresponding to the curve F1 is higher than T_C and the thermal runaway may occur when the diode is reverse biased. The equilibrium temperature T_{F2} corresponding to the curve F2 is lower than T_C and the thermal runaway will not occur when the diode is reverse biased.

4.2 Test conditions

The test conditions under which the thermal runaway test should be performed are as follows:

a) Initial module temperature: (90 ± 2) °C.

   Modules that carry a label that says "For use in open rack mount only" may be tested at a reduced temperature of (75 ± 2) °C.

   As the occurrence of thermal runaway is related to the temperature at the instance of the reverse bias voltage application, the thermal runaway test is to be performed under the highest environmental temperature the module could encounter during the normal operation.

   The module temperature may be measured by T_{lead}.

b) Specified forward current: 1,25 × "Short circuit current (I_{SC}) at STC" of the PV module for the bypass diode to be tested.

c) Specified reverse bias voltage: Open circuit voltage (V_{OC}) at STC of the cell string of the module protected by the bypass diode to be tested.

4.3 Preparation of test specimen

The test specimen should be the actual module or the special sample having the same construction of the actual module.

In order to perform the test by using a reasonable sized heat chamber, special samples may be used.

The special sample means the junction box including bypass diodes bonded by an adhesive onto a suitable glass-substrate laminated with the back-sheet in order to simulate the actual module.

Because the occurrence of thermal runaway depends upon cooling of the bypass diode, the test shall be performed with the diode mounted in the same way as in the actual module. The special sample may be provided by the module or junction box manufacturer.

In case an actual module is used, the cell strings should be electrically disconnected from the bypass diodes.

The test specimen shall be provided with the connection cables for the test module.

In order to measure T_{lead} and voltage of each bypass diode, connections of the lead-wires and thermocouples are required to be provided with the test specimen as shown in Figure 2.

Thermocouple should be mounted on the cathode lead as close as possible to the diode body.

Care should be taken to minimize any alteration of the properties of the diode or its heat transfer path.

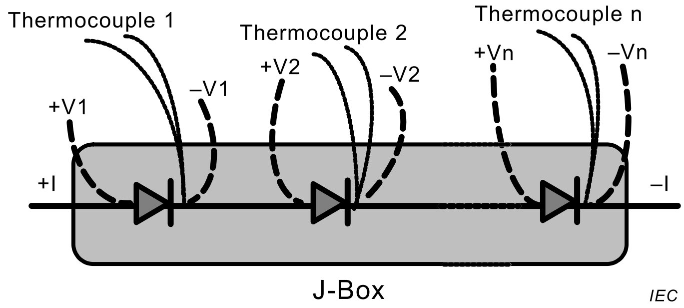

Figure 2 – Circuit for measurement of T_{lead} and forward voltage

4.4 Test equipment

a) Chamber for heating the module to a temperature of (90 ± 2) °C.

b) Means for monitoring the temperature of the chamber to an accuracy of ± 2,0 °C and repeatability of ± 0,5 °C.

c) Thermocouples and means for recording the T_{lead} of the test specimen to an accuracy of ± 1°C.

   Commonly used T-type thermocouple (copper-constantan) with soldering joint is permissible for this test, however it has a limitation since the highest measurable temperature is at 200 °C to 250 °C, which would be above the observed temperature T_C (critical temperature). When a thermal runaway occurs, the temperature will likely go up beyond the thermocouple limitation, but by measuring the reverse current flowing through the diode the thermal runaway phenomena will still be caught.

d) Means for applying the forward current specified in 4.2 b). Means for monitoring the forward current through the module and the forward voltage of the diode selected for the test, throughout the test.

e) Means for applying the reverse bias voltage specified in 4.2 c) to the bypass diode with capability of supplying the current equal to 1,25 x I_{SC} of the test module under the specified reverse voltage. Means for measuring the leakage current and the reverse voltage of the bypass diode.

f) Means for making the swift switching (within 10 ms) from forward current injection to reverse bias voltage application as illustrated in the test circuit of Figure 3 and Figure 4.

   The equipment shall be designed so that harmful voltage peaks are avoided.

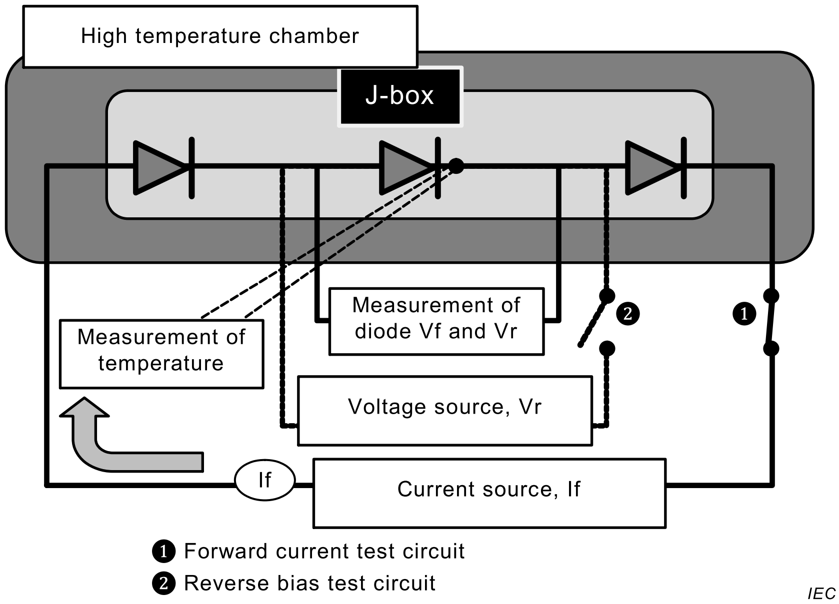

Figure 3 – Circuit for flowing a forward current to the bypass diode

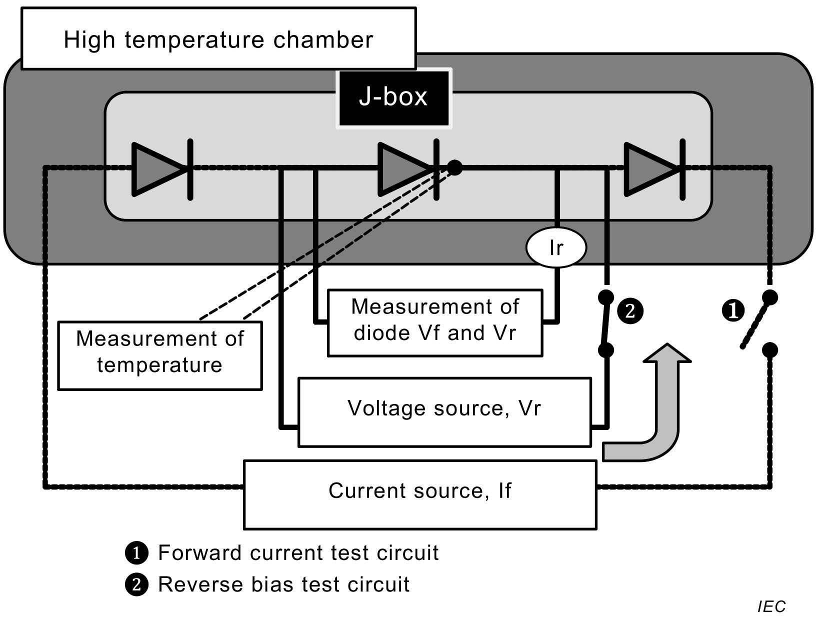

Figure 4 – Circuit for applying a reverse bias voltage to the bypass diode

4.5 Test procedure

a) To obtain initial characteristics of bypass diode and to make sure that bypass diode functions correctly, measure the reverse characteristic including reverse current at specified reverse voltage in 4.2 c) at room temperature (25 ± 5) °C.

b) For the selection of the bypass diode to be tested, apply the specified forward current (4.2 b) to all the bypass diodes in series in the test specimen at (25 ± 5) °C. Select the bypass diode which shows the highest temperature. In case that the diodes are mounted somewhere else – like in the laminate and so on, the bypass diode having the highest temperature should be tested.

c) After putting the test specimen(s) with necessary measuring and monitoring equipment into the test chamber, heat them to the initial module temperature specified in 4.2 a).

The consideration should be taken to minimize the effect of the air flow to the test specimen in the chamber.

d) Apply the specified forward current (4.2 b) to the bypass diodes for at least 40 min and until the range of T_{lead} change during 10 min becomes within 0,3 °C.

Shut-off the forward current. Within 10 ms after that apply the reverse bias voltage specified in 4.2 c) to the bypass diode to be tested. Continue to observe the reverse current and temperature of the reverse biased bypass diode.

In most of the cases the reverse current and the T_{lead} are expected either to rise (as indicated in the Figure 5) or to decrease (as indicated in the Figure 6) soon without staying steady. In borderline cases some time is needed to see the final direction of the change. In such a case, the test should be continued for at least 2 min.

If the reverse current increases up to current limit of the reverse bias power supply, it is regarded as thermal runaway occurred and the reverse bias application may be stopped immediately.

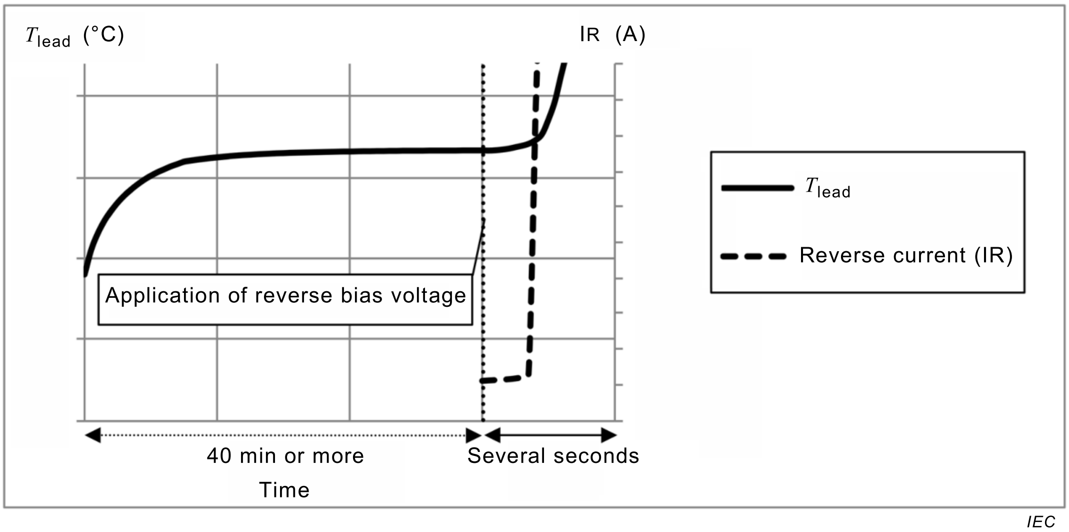

Figure 5 – The typical pattern of thermal runaway

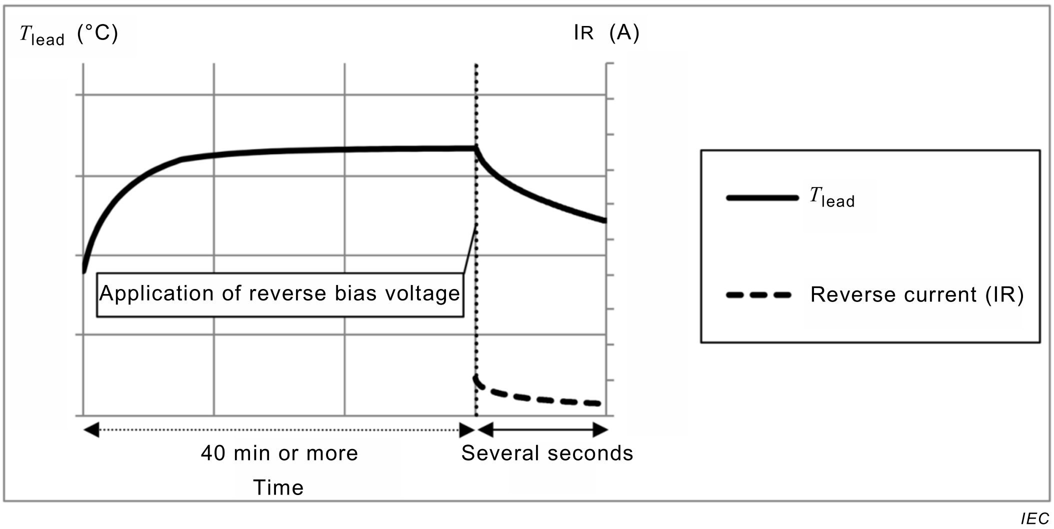

Figure 6 – The pattern of non-thermal runaway

e) Remove the test specimen from the chamber.

f) In order to check the diode performance after test, allow the sample to cool and measure the reverse characteristics of the bypass diode including reverse current at specified reverse voltage (4.2 c)) at room temperature (25 ± 5) °C.

Then compare the reverse current measured after test with the initial measurement taken during step 4.5 a).

5 Pass or fail criteria

a) If T_{lead} and the reverse current decrease during the reverse bias voltage portion of the test (second paragraph of step 4.5 d)), and if the reverse current measured after the test during step 4.5 f) is not more than 5 times of the initial value measured during step 4.5 a), the bypass diode is considered to have passed the test.

b) If T_{lead} and the reverse current increase during the reverse bias voltage portion of the test (second paragraph of step 4.5 d)), or if the reverse current measured after the test during step 4.5 f) is more than 5 times of the initial value measured during step 4.5 a), the bypass diode is considered to have failed the test.

6 Test report

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

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) detail specification, description and identification of the test specimen;

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

g) identification of test method used and test instruments and other equipment used;

h) reference to sampling procedure, where relevant;

i) the values of the specified test conditions with any deviations from, additions to, or exclusions from, the test method and any other information relevant to a specific test, measurements, examinations and derived results supported by tables, graphs, sketches and photographs as appropriate including:

   – The initial module temperature used for the test.
   – Specified forward current (4.2 b)).
   – Specified reverse bias voltage (4.2 c)).
   – Forward current injected for bypass diode.
   – The T_{lead} measured after applying the forward current until T_{lead} stabilises.
   – The duration for which the forward current was applied.
   – The switching time until applying reverse bias voltage from the shut-off of forward current.
   – Reverse bias voltage applied for bypass diode.
   – The application time of specified reverse bias voltage.
   – Records of the T_{lead} after the application of reverse bias voltage.
   – Records of the leakage current of the diode after the application of reverse bias voltage.
   – Photos and a description of the specimens tested.
   – Diode characteristics measured before and after the thermal runaway test;

j) a statement of the estimated uncertainty of the test results (where relevant);

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

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

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