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TECHNICAL SPECIFICATION

colour inside

C-Si photovoltaic (PV) modules – Light and elevated temperature induced degradation (LETID) test – Detection

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C-SI PHOTOVOLTAIC (PV) MODULES – LIGHT AND ELEVATED TEMPERATURE INDUCED DEGRADATION (LETID) TEST – DETECTION

FOREWORD

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IEC TS 63342 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:

Draft	Report on voting
82/2008/DTS	82/2044/RVDTS

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

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 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- withdrawn,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.

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C-SI PHOTOVOLTAIC (PV) MODULES – LIGHT AND ELEVATED TEMPERATURE INDUCED DEGRADATION (LETID) TEST – DETECTION

1 Scope

This document is designed to assess the effect of light induced degradation at elevated temperatures (LETID) by application of electrical current at higher temperatures. LETID is activated by excess carriers caused either through illumination or injection of electrical current at temperatures above 50 °C. In fielded conditions, LETID develops over the course of several months up to years as opposed to days for Boron Oxygen (B-O) degradation. The degradation phase is followed by an even slower recovery phase that develops over a significantly longer time scale. In this document, only the current injection approach for the detection of LETID is addressed.

This document does not address the B-O and Iron Boron (Fe-B) related degradation phenomena, which already occur at room temperatures under the presence of light and on much faster time scales. B-O defects may influence the results, and this document attempts to separate them by application of certain procedures. However, it is noted that the separation may not be perfect. Fe-B effects are excluded by introduction of waiting times before power determination.

The proposed test procedure can reveal sample sensitivity to LETID degradation mechanisms, but it does not provide an exact measure of field observable degradation. The magnitude and time scale of degradation seen in the field depends on climate and the module technology.

In this document LETID testing is done via current injection as this is a simple method in terms of the test equipment required. This allows for better control over conditions compared to application of light and thus ensures comparability between different labs. Application of light with equivalent conditions (i.e. same temperature and excess carrier density/ injection level) will yield comparable results.

The stress conditions in this document differ in injection level from the test method for cells described in IEC TS 63202-4. Whereas IEC TS 63202-4 aims at providing a quick quality check for a known cell that can be used in outgoing or incoming inspection of a specific product, the procedures in this document aim at providing a general product independent test method for LETID detection in a module that can be applied without prior knowledge about the cells inside a module and will yield reproducible results.

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

IEC 61215-1:2021, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements*

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

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

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836, IEC 61215-1, IEC 61215-2 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

3.2 Abbreviated terms

LETID Light and Elevated Temperature Induced Degradation

4 Samples

Three samples are required, one is used as a control and the other two are for testing. The purpose of the control module is to track a possible drift in simulator measurement, or metastabilities of the module type under test itself. The modules should be stored in the dark at room temperature not exceeding 35 °C.

In addition, the PV module samples shall have been manufactured from specified materials and components in accordance with the relevant drawings and process sheets and have been subjected to the manufacturer’s normal inspection, quality control and production acceptance procedures.

5 Apparatus

a) A climatic chamber with automatic temperature control with means for circulating the air inside and means to minimize condensation on the module during the test, capable of subjecting one or more modules up to (75 ± 3,0) °C.

b) Means for mounting or supporting the module(s) in the chamber, so as to allow free circulation of the surrounding air.

c) Measurement instruments having an accuracy of ± 2,0 °C and repeatability of ± 0,5 °C for measuring and recording the temperature of the module(s).

d) Means for applying a continuous current 2 ×·($I_{\text{SC initial n}} - I_{\text{MPP initial n}}$) as determined in 6.4 to the test samples with an accuracy of 1 % of applied current or better.

e) Means for monitoring dark voltage and applied current through each module with minimum resolution of 5 min during test. The accuracy of current and voltage measurement shall be ± 0,2 % or better.

6 Testing

6.1 General

The applicable test sequence is shown in Figure 1.

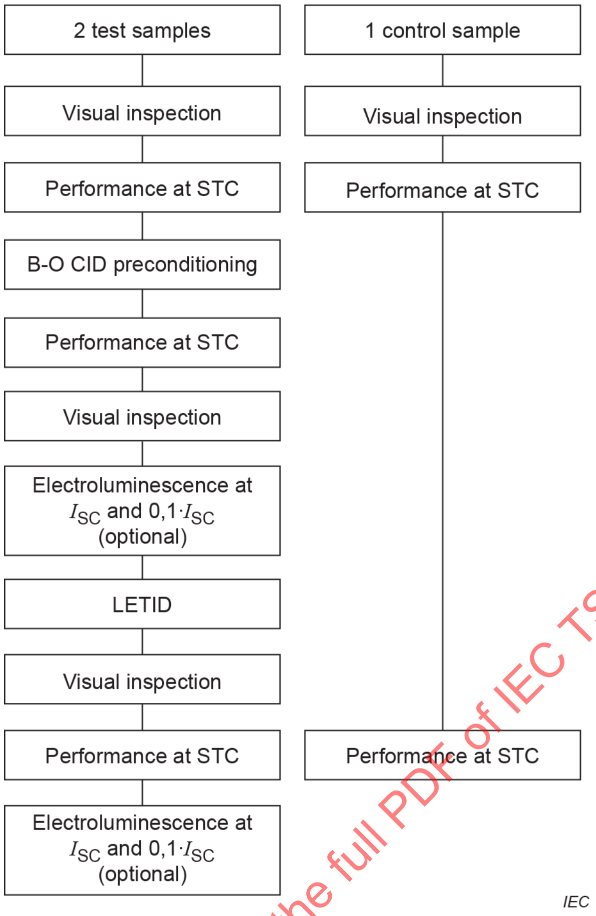

Figure 1 – Test sequence for the detection of LETID in c-Si modules

6.2 Visual inspection

The relevant subclause 4.1 (MQT 01) of IEC 61215-2:2021 is applicable without modifications.

6.3 Electroluminescence images

Measure electroluminescence (EL) at forward bias at a current of I_{SC} and optionally at $0,1 \cdot I_{SC}$. Performing EL measurements at high and low injection can help to identify the relevant root-cause of the observed defects and differentiate lifetime effects from series resistance losses. The user should refer to IEC TS 60904-13 for recommendations on EL settings.

The tester should minimize the amount of time that current is applied during EL measurement, because the application of current is known to advance LID and LETID. However, at room temperature, the amount by which LETID is advanced should be negligible.

6.4 Performance at STC

The relevant subclause 4.6 (MQT 06) of IEC 61215-2:2021 is applicable without modifications. For module n, measure initial electrical characteristics, $P_{\text{initial n}}$, $I_{\text{SC initial n}}$, and $I_{\text{MPP initial n}}$. The performance at STC measurement is repeated after preconditioning according to 6.5 in order to obtain power output $P_{\text{BO n}}$. It is repeated again after 6.6 to determine final power output, $P_{\text{final n}}$.

No stabilization (such as light soaking) shall be performed before performance at STC for $P_{\text{initial n}}$.

6.5 B-O LID preconditioning via current injection (CID)

a) Electrically short any blocking diodes incorporated in the module.

b) Expose the modules at room temperature, in case room temperatures exceed 30 °C then a climatic chamber shall be used.

c) Attach a suitable temperature sensor to the front or back side of the modules near the center to monitor the module temperature.

d) Connect the temperature-monitoring equipment to the temperature sensors. Connect each module to the appropriate current supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly.

e) During the test, set the applied current to $I_{SC\ initial\ n}$ as determined in 6.4.

f) Turn on the power supply and subject the modules to the defined current in step e) for 24 h. During the test, the relative humidity should be less than 60 % and the temperature variation of the same module should be within ± 5 °C.

g) Perform 6.2 and 6.4, the latter should be done no earlier than 4 h after turning off the current to avoid any influence from Fe-B and no later than 24 h to avoid influence from device metastabilities. Modules shall be stored at room temperature not exceeding 35 °C during this time.

NOTE During the 2×(162 +8/-0) h of LETID degradation, BO-LID is expected to recover partly. The amount of BO-LID observed during BO preconditioning gives an indication on the potential masking of LETID by BO recovery during LETID test.

6.6 Light and elevated temperature induced degradation (LETID)

a) Electrically short any blocking diodes incorporated in the module.

b) Install the modules in the climatic chamber.

c) Attach a suitable temperature sensor to the front or back side of the modules near the center.

d) Connect the temperature-monitoring equipment to the temperature sensors. Connect each module to the appropriate current supply by connecting the positive terminal of the module to the positive terminal of the power supply and the second terminal accordingly.

e) Connect the voltage-monitoring equipment to the modules to monitor the dark voltage by connecting the positive terminal of the module to the positive terminal of the equipment and the second terminal accordingly. It is recommended to use four terminal connections to separate series resistance losses by measuring the injected current and applied voltage independently.

f) Close the chamber. Set the chamber temperatures to 75 °C and ensure the module temperatures can be maintained at the required level. When temperatures of the module(s) reach 75 °C, turn on the power supply and subject the modules a current of 2 × ($I_{SC\ initial\ n}$ – $I_{MPP\ initial\ n}$) ± 1 % as determined in 6.4 for (162 +8/-0) h. During the test, the relative humidity should be less than 60 % and the temperature variation of the same module should be within ± 3 °C.

g) For each module, stop current injection if the module has already entered the regeneration phase after this stress period, meaning:

   – the hourly average of temperature corrected measured voltage exceeds the sum of minimum dark voltage (1 + electronic uncertainty);

   – the temperature corrected dark voltage (see 7.3) in the dark voltage diagram (Figure 2) has achieved its minimum value for continuous 10 h.

   If not, then subject the modules to a current of 2 × ($I_{SC\ initial\ n}$ – $I_{MPP\ initial\ n}$) ± 1 % as determined in 6.4 again for another (162 +8/-0) h. See 7.5 for details on evaluating the stop criterion. For modules that exhibit a large degradation of >3 % in power after the 2 × 162 +8/-0) h, a third stress interval of (162 +8/-0) h can be added in order to obtain a better estimate of the maximum LETID degradation.

   NOTE See Clause 7 for definition of electronic uncertainty.

h) If the test needs to be interrupted to stop the test or remove samples from the chamber that have entered regeneration phase, current injection shall be stopped during the cooling phase of the modules and before opening the chamber. It is recommended to turn current injection off when temperatures of the module(s) decrease to below 50 °C. To resume tests, when temperatures of the module(s) reach 75 °C, turn on the power supply and subject the modules to the defined current.

   It is recommended to use an environmental chamber that can reach 75 °C within 2 h after closure. If the time is prolonged, dark annealing may occur, which may influence the reproducibility of final results.

i) Perform 6.2 and 6.4, the latter should be done no earlier than 4 h after cooling down of the modules to room temperature to avoid any influence from Fe-B defects, but no later than 24 h after cooling down of the module(s).

7 Dark voltage analysis

7.1 General

The method is based on the analysis of the time series of dark voltage measurement data. The data obtained are corrected and averaged in a way that allows reproducible and accurate qualitative detection of power degradation, or regeneration. Generally, minority lifetime reduction or increase would also lead to a decrease or increase of the dark voltage V_d under constant current injection. Therefore, dark voltage monitoring can be utilized to identify in-situ early regeneration that may occur under forced current injection at elevated temperatures.

The following methodology is required in order to analyse the measured dark voltage and is only used for this purpose.

7.2 Data filtering

a) Reject all data where the module temperature deviates from (75 ±3) °C.

b) Reject all data where the measured current deviates from the target current 2 × ($I_{SC} - I_{MPP}$) by more than 2 × ($I_{SC} - I_{MPP}$) × U_{el}

where

U_{el} represents the sum of relative electronic uncertainties in current, voltage and temperature at 95 % confidence level, k=2.

Electronic uncertainties are related to the accuracy and repeatability of electronic equipment used for dark voltage monitoring, such as the power supply and data logger. Each laboratory should calculate its own electronic uncertainties. Refer to ISO/IEC Guide 98-3 on how to determine uncertainties.

7.3 Temperature correction

Because the dark voltage, V_d, is affected by module temperature and the temperature in the chamber may vary, a temperature correction to the reference temperature of 75 °C is necessary. A temperature correction can be done based on the formula:

$$V_d' = V_d + \beta \times (75\,°C - T_{mod}) \quad (1)$$

where

V_d is the measured dark voltage;

V_d' is the temperature corrected dark voltage;

T_{mod} is the measured module temperature;

β is the absolute temperature coefficient of open-circuit voltage (expressed in units of Volt per Kelvin) of the module type as stated by the module manufacturer.

Because the module operates in its non-linear region close to V_{MPP}, it is not recommended to apply current corrections, but rather reject all data that deviate to the designated force current condition (7.2b).

During the test it is recommended to display the time-evolution of the temperature corrected dark voltage in a diagram, which is continuously updated.

7.4 Data averaging

Calculate the hourly averages of the time series of data for the temperature corrected dark voltage, $V_{d,avg}'$. Based on the calculated values of $V_{d,avg}'$, calculate the running minimum dark voltage $V_{d,min}'$ of the time series of data from the beginning to the end.

7.5 Stop criterion

The test shall be stopped after (162 +8/-0) h if the temperature corrected dark voltage has achieved its minimum value by then, which indicates that the PV module has entered the regeneration phase. This point can be identified by the following methods:

a) If a diagram of the temperature corrected dark voltage is available and is used to determine whether the minimum has been reached, the test shall be stopped at the earliest 10 h after reaching the minimum. This method is recommended for a low regeneration speed.

b) If the test progress is not visualized in a diagram, the test shall be stopped if the hourly average of temperature corrected measured voltage, $V_{d,avg}'$ exceeds the sum of minimum dark voltage $V_{d,min}' \cdot$ (1 + the electronic uncertainty) as shown in formula (2):

$$V_{d,avg}' > V_{d,min}' \times (1 + U_{el}) \quad (2)$$

U_{el} is an estimation of the relative electronic uncertainty at 95 % confidence level (See explanation in 7.2). Note that due to the often slow regeneration a test might not be stopped after the first 162 h period even though technically the regeneration phase has already started. Due to the slow progression of regeneration the error caused by this is however insignificant.

If the module has not entered the regeneration phase yet after the first (162 +8/-0) h, the test shall be stopped after the second (162 +8/-0) h.

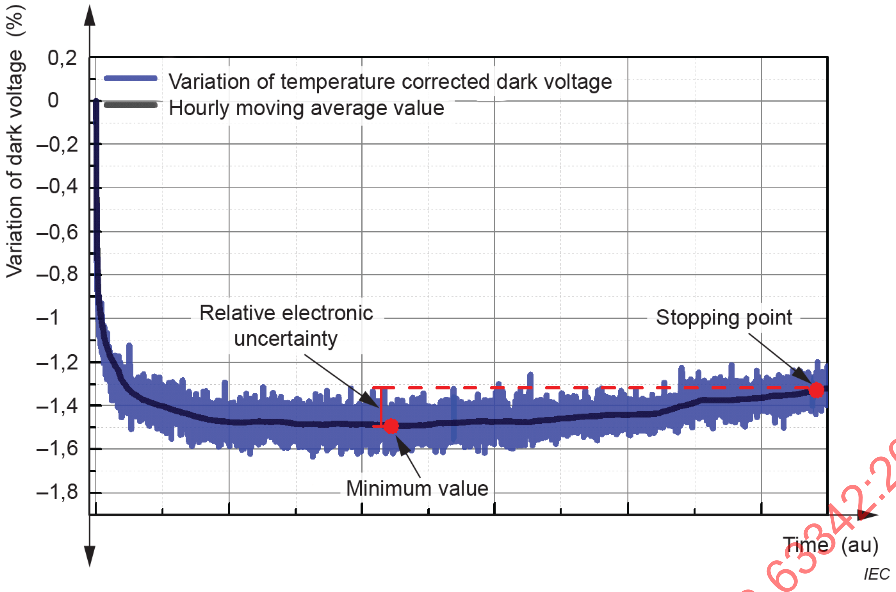

Figure 2 – Dark voltage diagram showing the evolution of the temperature corrected dark voltage over time in arbitrary units during LETID degradation used to identify the time of maximum degradation and the time to stop the LETID degradation sequence

8 Evaluation

$P_{\text{final n}}$ is the result of the final power measurement on module n (n=1,2). For each module, evaluate the following inequity:

$$P_{\text{final n}} \geq 0{,}97 \times P_{\text{BO n}} \times \left(1 - \frac{r[\%]}{100}\right) \tag{3}$$

where

r is the reproducibility, as utilized in IEC 61215-1:2021, Gate No. 2 (7.2.3).

The maximum reproducibility, r, shall not exceed 1 %, k=2.

If the inequity is not satisfied for one or both modules, the module type is deemed “LETID-sensitive” and not to have met the requirements.

9 Report

A test report with measured performance characteristics and test results shall be prepared. The test report shall contain the detail specification for the module tested and at least the following data and 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 item tested;

f) characterization and condition of the test item;

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

h) identification of test method used;

i) reference to sampling procedure, where relevant;

j) injected current during test;

k) the initial power output $P_{\text{initial n}}$, the power after B-O CID preconditioning, the final power $P_{\text{final n}}$, and the duration of current injection;

l) table or diagram showing maximum power variation;

m) table or diagram showing dark voltage variation at fixed current;

n) a statement of the estimated uncertainty of the test results;

o) any abnormalities observed.