SRI LANKA STANDARD 1545 PART 1 : 2016

IEC 61853-1 : 2011

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SPECIFICATION FOR

PHOTOVOLTAIC (PV) MODULE PERFORMANCE TESTING AND ENERGY RATING

PART 1 : IRRADIANCE AND TEMPERATURE PERFORMANCE MEASUREMENTS AND POWER RATING

SRI LANKA STANDARDS INSTITUTION

Sri Lanka Standard Specification for
PHOTOVOLTAIC (PV) MODULE PERFORMANCE TESTING AND ENERGY RATING
PART 1 : IRRADIANCE AND TEMPERATURE PERFORMANCE MEASUREMENTS AND POWER RATING

SLS 1545 Part 1 : 2016
IEC 61853-1 : 2011

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This standard does not purport to include all the necessary provisions of a contract.

Sri Lanka Standard Specification for

PHOTOVOLTAIC (PV) MODULE PERFORMANCE TESTING AND ENERGY RATING PART 1: IRRADIANCE AND TEMPERATURE PERFORMANCE MEASUREMENTS AND POWER RATING

NATIONAL FOREWORD

This standard was approved by the Sectoral Committee on Electronic Engineering and was authorized for adoption and publication as a Sri Lanka Standard by the Council of Sri Lanka Standards Institution on 2016-11-24.

SLS 1545 Sri Lanka Standard Specification for Photovoltaic (PV) module performance testing and energy rating, Part 1: irradiance and temperature performance measurements and power rating. This part of standard is identical with IEC 61853 Photovoltaic (PV) module performance testing and energy rating, Part 1: 2011 Edition 1.0 irradiance and temperature performance measurements and power rating**,** published by the International Electrotechnical Commission (IEC).

All values given in this standard is in SI units.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or an analysis shall be rounded off in accordance with SLS 102, in case if the method of rounding off is not specified in the text of this standard. The number of figures to be retained in the rounded off value, shall be the same as that of the specified value in this standard.

Terminology and conventions

The text of the International Standard has been accepted as suitable for publication, without any deviation as a Sri Lanka Standard. However, certain terminology and conventions are not identical with those used in Sri Lanka Standards; attention is therefore drawn to the following:

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b) Wherever the page numbers are quoted they are the page numbers of IEC standard.

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CROSS REFERENCES

Any corresponding Sri Lanka Standard, for the international standards listed under reference, is not available**.**

SLS 1545-1:2016

IEC 61853-1

Edition 1.0 2011-01

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating

Essais de performance et caractéristiques assignées d'énergie des modules photovoltaïques (PV) – Partie 1: Mesures de performance en fonction de l'éclairement et de la température, et caractéristiques de puissance

IEC 61853-1:2011

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PHOTOVOLTAIC (PV) MODULE PERFORMANCE TESTING AND ENERGY RATING –

Part 1: Irradiance and temperature performance measurements and power rating

FOREWORD

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International Standard IEC 61853-1 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this standard is based on the following documents:

FDIS	Report on voting
82/613/FDIS	82/622/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61853 series can be found, under the general title *Photovoltaic (PV) module performance testing and energy rating*, on the IEC website.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

This International Standard series establishes IEC requirements for evaluating PV module performance based on power (watts), energy (watt-hours) and performance ratio (PR). It is written to be applicable to all PV technologies including non-linear devices, but the methodology does not take into account transient behaviour such as light induced changes and/or thermal annealing.

Included in the IEC 61853 series of standards are: a guide to mapping module performance over a wide range of temperature and irradiance conditions; methods for characterising spectral and angular effects; definition of reference climatic profiles (temperature and irradiance); methods for evaluating instantaneous power and energy results; and a method for stating these results in the form of a numerical rating.

PHOTOVOLTAIC (PV) MODULE PERFORMANCE TESTING AND ENERGY RATING –

Part 1: Irradiance and temperature performance measurements and power rating

1 Scope and object

This part of IEC 61853 describes requirements for evaluating PV module performance in terms of power (watts) rating over a range of irradiances and temperatures. IEC 61853-2 describes test procedures for measuring the performance effect of angle of incidence; the estimation of module temperature from irradiance, ambient temperature and wind speed; and impact of spectral response on energy production. IEC 61853-3 describes the calculations of PV module energy (watt-hours) ratings. IEC 61853-4 describes the standard time periods and weather conditions that can be utilized for calculating standardized energy ratings.

The object of this part of IEC 61853 is to define a testing and rating system, which provides the PV module power (watts) at maximum power operation for a set of defined conditions. A second purpose is to provide a full set of characterization parameters for the module under various values of irradiance and temperature. This set of measurements is required in order to perform the module energy rating described in IEC 61853-3.

2 Normative references

The following referenced documents are indispensable for the application 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 60410, *Sampling plans and procedures for inspection by attributes*

IEC 60891:2009, *Photovoltaic devices – Procedures for temperature and irradiance corrections to measured I-V characteristics*

IEC 60904-1, *Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics*

IEC 60904-2, *Photovoltaic devices – Part 2: Requirements for reference solar devices*

IEC 60904-3, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

IEC 60904-5, *Photovoltaic devices – Part 5: Determination of equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method*

IEC 60904-7, *Photovoltaic devices – Part 7: Computation of spectral mismatch correction for measurements of photovoltaic devices*

IEC 60904-9, *Photovoltaic devices – Part 9: Solar simulator performance requirements*

IEC 60904-10, *Photovoltaic devices – Part 10: Methods of linearity measurement*

IEC 61215:2005, *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61646:2008, *Thin film terrestrial photovoltaic (PV) modules – Design qualification and type approval*

3 Sampling

For performance qualification testing three modules shall be selected at random from a production batch or batches in accordance with the procedure given in IEC 60410. The modules shall be pre-conditioned in accordance with Clause 5 to ensure the stability of the power values.

The modules shall have been manufactured from specified materials and components in accordance with the relevant drawings and process sheets and shall have been subjected to the manufacture's normal inspection, quality control and production acceptance procedures. The modules shall be complete in every detail and shall be accompanied by the manufacturer's handling and final assembly instructions regarding the recommended installation of any diodes, frames, brackets, etc.

When the modules to be tested are prototypes of a new design and not from production, this fact shall be noted in the test report (see Clause 6).

4 Marking

Each module shall carry the following clear and indelible markings:

– name, monogram or symbol of the manufacturer;

– type or model number;

– serial number;

– polarity of terminals or leads (colour coding is permissible);

– nominal and minimum values of maximum output power at STC after preconditioning, as specified by the manufacturer for the product type (see Clause 5).

The date and place of manufacture shall be marked on the module or be traceable from the serial number.

For future production the power ratings for NOCT, LIC, HTC and LTC determined by this standard as defined in Clause 7 and Table 1 and determined via the procedure in 9.2 shall be marked on a label, or be stated in the manufacturer's literature provided with each module of this type.

5 Testing and pass criteria

The modules shall be subjected to the procedure for irradiance and temperature performance measurements defined in Clause 8. In carrying out the tests, the manufacturer's handling, mounting and connection instructions shall be observed.

Special considerations: Preconditioning - Before beginning the measurements, the device under test shall be stabilized by light soaking, as specified in IEC 61215 (Clause 5) or IEC 61646 (10.19).

The values of STC power measured after preconditioning shall fall within the power range specified by the manufacturer of this product.

NOTE The pass/fail criteria must consider the laboratory uncertainty of the measurement. As an example, if the laboratory extended uncertainty of the STC measurement is ±5 %, then a nominal nameplate rated power greater than 95 % of the laboratory measured power would meet the pass criteria.

After generating the matrix of parameters in Section 8 the modules should be remeasured at STC to verify that the performance is stable.

6 Report

Following completion of the procedure, a certified report of the performance tests, with measured power characteristics shall be prepared by the test agency in accordance with the procedures of ISO/IEC 17025. Each certificate or test report shall include at least the following information:

a) a title;

b) name and address of the test laboratory and location where the calibration or tests were carried out;

c) unique identification of the certification or report and of each page;

d) name and address of client, where appropriate;

e) description and identification of the item calibrated or tested;

f) characterization and condition of the calibration or test item;

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

h) identification of calibration or test method used;

i) reference to sampling procedure, where relevant;

j) any deviations from, additions to or exclusions from the calibration or test method, and any other information relevant to a specific calibration or test, such as environmental conditions;

k) a statement as to whether the simplified method in section 8 was used to complete the matrix. If the simplified method was used, the test report should give the values of relative temperature coefficients for maximum power and open circuit voltage for the two different irradiances used to validate the use of the simplified method;

l) measurements, examinations and derived results, including as a minimum table 2 for I_{sc}, P_{max}, V_{oc} and V_{max}, values of the module thermal coefficients $\alpha_{I,}$ β_{I}, the average power and the values for each of the three test modules at all reference power conditions (defined in section 7) and the temperature coefficient of module power (W) at the maximum power point (γ_{I});

m) a statement of the estimated uncertainty of the calibration or test result (where relevant);

n) a statement as to whether the measured STC power agrees with the manufacturer's rated power range within the test laboratories measurement uncertainty;

o) 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;

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

q) a statement that the certificate or report shall not be reproduced except in full, without the written approval of the laboratory.

7 Power rating conditions

7.1 General

The reference power conditions are shown in Table 1 and are described in more detail in the following subclauses. The first three reference power conditions are defined in IEC 61215/IEC 61646. The modules shall be tested and the maximum power determined for the following rating conditions. For each rating condition the Air Mass 1,5 spectral irradiance distribution as given in IEC 60904-3 shall be used as well as normal incidence irradiance.

7.2 STC (Standard Test Conditions)

– Cell temperature: 25 °C.

– Irradiance: 1 000 W·m^{-2}.

7.3 NOCT (Nominal Operating Cell Temperature)

– Cell temperature: NOCT (As determined in accordance with 10.5 of IEC 61215 or IEC 61646).

– Irradiance: 800 W·m^{-2}.

7.4 LIC (Low Irradiance Condition)

– Cell temperature: 25 °C.

– Irradiance: 200 W·m^{-2}.

7.5 HTC (High Temperature Condition)

– Cell temperature: 75 °C.

– Irradiance: 1 000 W·m^{-2}.

7.6 LTC (Low Temperature Condition)

– Cell temperature: 15 °C.

– Irradiance: 500 W·m^{-2}.

Table 1 – Summary of reference power conditions (at AM 1,5)

Condition	**Irradiance** W·m^{-2}	**Temperature** °C
STC Standard Test Conditions	1 000	25 of cell
NOCT Nominal Operating Cell Temperature (Determined according to IEC 61215 or IEC 61646)	800	20 of ambient
LIC Low Irradiance Condition	200	25 of cell
HTC High Temperature Condition	1000	75 of cell
LTC Low Temperature Condition	500	15 of cell
NOTE The conditions provided in this table may be measured directly as part of the performance matrix defined in Clause 8.		

8 Procedure for irradiance and temperature performance measurements

8.1 Purpose

To determine the impact of irradiance and temperature on module performance:

The power delivery of photovoltaic devices is a direct function of module temperature and incident irradiance level. PV device performance is linear with temperature for many crystalline silicon materials, but no general relation can be given for thin film materials. The short circuit current is often linear with respect to irradiance. The logarithmic variation of open circuit voltage and nonlinear variations of fill factor with the irradiance often render the maximum power a nonlinear function of light levels. Rather than using extensive modelling of these processes, the relations will be measured as functions of irradiance and temperature.

NOTE If I_{sc} of the module has been demonstrated to be linear (IEC 60904-10), I_{sc} can be utilized as the measurement of the irradiance level used in the test.

Matrices of module performance with respect to temperature and irradiance shall be measured. Separate tables for I_{sc}, V_{oc}, V_{max} and P_{max} shall be generated using sufficient data to assure statistical validity to the measurements (see 8.3.11 and 8.5.11). The tables for V_{oc} and V_{max} are not utilized for energy ratings, but are useful characteristics of the module type particularly for system design purposes.

Measurements need not be taken at exactly the irradiances and temperatures specified. Translation of I-V curves from the actual irradiance and/or temperature values to the values prescribed by the tables can be performed in accordance with IEC 60891. Such interpolation should be over no more than 100 W·m^{-2}. All such interpolations shall be noted in the test report and their impact on uncertainly shall be included in the uncertainly analysis. Nevertheless, measurements shall be taken at or beyond the extremes of irradiance specified in Table 2 within the measurement accuracy of the instrumentation and the constraints of section 8.3.2.

A table of each of the parameters I_{sc}, P_{max}, V_{oc} and V_{max}, shall be made according to the example in Table 2.

NOTE 1 To assess nonlinearities, measurements at 300 W/m^2 and 50 W/m^2 can be helpful.

NOTE 2 Tables of the parameters I_{max} and Fill Factor (*FF*) can be generated from the four measured parameters.

Table 2 – I_{sc}, P_{max}, V_{oc} and V_{max} versus irradiance and temperature

Irradiance	Spectrum		Module temperature		
W·m^{-2}		15 °C	25 °C	50 °C	75 °C
1 100	AM1,5	NA			
1 000	AM1,5				
800	AM1,5				
600	AM1,5				
400	AM1,5				NA
200	AM1,5			NA	NA
100	AM1,5			NA	NA

AM1,5 is defined in IEC 60904-3.

There are four procedures for performing the test matrix of module performance with respect to temperature and irradiance. The simplified procedure can only be utilized for linear modules per IEC 60904-10. Two of the procedures are performed outdoors in natural sunlight (one requiring a tracker and one that does not require a tracker). The fourth method is performed indoors using a solar simulator.

8.2 Simplified procedure for linear modules

For modules that have been determined to be linear (per IEC 60904-10), the maximum power dependence on irradiance and the maximum power dependence on temperature are independent. In this case it is sufficient to measure:

a) the parameters (I_{sc}, V_{oc}, P_{max} and V_{max}) dependence on irradiance at fixed temperature over the range of 100 W·m^{-2} to 1 100 W·m^{-2}.

b) The parameters (I_{sc}, V_{oc}, P_{max} and V_{max}) dependence on temperature at two fixed irradiances, one of which is between 800 W·m^{-2} and 1 000 W·m^{-2} and the second of which is between 100 W·m^{-2} to 300 W·m^{-2}.

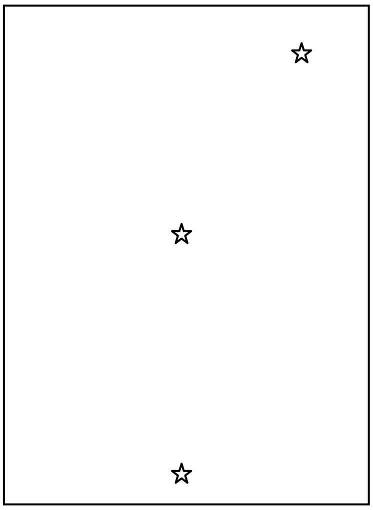
Compare the relative temperature coefficients for maximum power and open circuit voltage determined from the two irradiance sets. If the two values for the relative temperature coefficient of open circuit voltage agree within 10 % and the two values for the relative temperature coefficient of maximum power agree within 15 %, the average of the two temperature coefficients measured in b above can be utilized to fill out the tables. If not the table should be completed by measuring at each set of conditions.

NOTE Because of its small value the relative temperature coefficient of short circuit current is not considered in the above criteria.

8.3 Procedure in natural sunlight with tracker

8.3.1 Equipment required for this procedure is defined in IEC 60904-1.

The temperature of the test module shall be measured at approximately the three positions shown in Figure 1 (assuring that each position is directly behind a cell) and their values shall be averaged. For crystalline silicon modules an alternate approach is to use the Equivalent Cell Temperature measured using the method specified in IEC 60904-5.



IEC 2859/10

Figure 1 – Positions for measuring the temperature of the test module behind the cells

8.3.2 Measurement in natural sunlight shall be performed over the range of irradiance conditions occurring during the day. Short term irradiance variations caused by clouds, haze, or smoke shall be less than ±1 % of the total irradiance as measured by the reference device during the collection of each measurement point as specified in IEC 60904-1. The wind speed should be less than 2 m·s^{-1}. To increase the range and improve the accuracy data should be taken over at least three days.

8.3.3 Mount the reference device (as defined in IEC 60904-2) co-planar with the module on the two-axis tracker such that both are normal to the direct solar beam within ±2°. Connect to the necessary instrumentation.

NOTE The measurements described in the following sub-clauses should be made as expeditiously as possible within a few hours on the same day to minimize the effect of changes in the spectral conditions. If not, spectral corrections may be required.

8.3.4 If the test module and reference device are equipped with temperature controls, set the controls at the desired level. If temperature controls are not used:

a) shade the specimen from the sun and wind until its temperature is uniform within ± 2 °C of the ambient air temperature, or
b) allow the test specimen to equilibrate to its stabilized temperature, or
c) pre-condition the test specimen to a point below the target temperature and then let the module warm up naturally.

NOTE There may be differences between average cell temperature and average back temperature while the module is warming up. IEC 60904-5 can be utilized to determine the temperature change by observing the variance in open circuit voltage during the measurement time period.

8.3.5 Remove the shade (if used) and immediately take simultaneous readings of the test module temperature and I-V performance characteristics (at a minimum I_{sc}, V_{oc}, V_{max} and P_{max}), the temperature and short-circuit current of the reference device and the spectral irradiance using the spectral radiometer (if a matched reference device is not utilized).

8.3.6 The irradiance, G_o, shall be calculated from the measured current (I_{sc}) of the reference device, and its calibration value at STC (I_{rc}). A correction should be applied to account for the temperature of the reference device during the measurement, T_m, using the specified relative short circuit current temperature coefficient of the reference device, α_{rc}.

$$G_o = \frac{G_{rc} \times I_{sc}}{I_{rc}} \times \left[1 - \alpha_{rc}\left(T_m - T_{rc}\right)\right]$$

Where G_{rc} is the irradiance at which the reference device was calibrated, usually 1000 W·m^{-2} and T_{rc} is the temperature at which the reference device was calibrated, usually 25 °C. If the test specimen and reference device are not matched in spectral response, perform the spectral correction on G_o using the method from IEC 60904-7.

8.3.7 If the test parameter being varied is the irradiance, reduce the irradiance on the test specimen to the desired level without affecting the spatial uniformity. There are various methods by which to accomplish this:

a) using calibrated, uniform density mesh filters that do not change the spectral energy distribution of the light. If this method is selected, the reference device should remain uncovered by the filter during the operation to enable the incident irradiance to be measured. In this case, the in plane irradiance is reduced by the filter calibration parameter (fraction of light transmitted). The uniformity of the irradiance from the filters should be verified using the uniformity procedure from IEC 60904-9 using the cell in the test device to size the detector to determine the uniformity class. The results should be provided in the test report.
b) using uncalibrated, uniform density mesh filters. If this method is selected, the reference device should also be covered by the filter during the test. In this case, the reference device must be linear in short circuit current in accordance with IEC 60904-10. In this case in plane irradiance is reduced by the ratio of the reference device output to its calibration value. The uniformity of the irradiance from the filters should be verified using the uniformity procedure from IEC 60904-9 using the smallest device (either the cell in the test device or the reference device) to size the detector to determine the uniformity class. The results should be provided in the test report.
c) by controlling the angle of incidence. If this method is selected, the reference device should have the same reflective properties as the test specimen, and should be mounted co-planar with the test specimen within ±1°. In this case, the reference device must be packaged like the test module (so it has the same angle of incidence behaviour) and be linear in short circuit current in accordance with IEC 60904-10. Then the in plane irradiance is reduced by the ratio of the reference device output to its calibration value.

NOTE 1 The maximum filter mesh opening dimension shall be less than 1 % of the minimum linear dimension of the reference device and the test specimen, or a variable error may occur due to positioning.

NOTE 2 The angle of incidence approach is sensitive to the angular difference between the test specimen and the reference device at high angles. Therefore this method should not be utilized for angles above 60°.

8.3.8 If the test parameter being varied is the temperature, adjust the temperature by means of a controller, or by alternately exposing and shading the module as required to achieve and maintain the desired temperature for the naturally occurring irradiance levels. Alternately, the test specimen may be allowed to warm-up naturally with the data recording procedure of 8.3.5 performed periodically during the warm-up.

8.3.9 Ensure that the test module and reference device temperature are stable and remain constant within ±1 °C and that the irradiance as measured by the reference device remains constant within ±2 % during the data recording period.

8.3.10 Repeat steps 8.3.5 through 8.3.9 until the performance measurements are completed for the matrix of temperature and irradiance combinations as defined in Table 2. This means that full matrices of I_{sc}, V_{oc}, V_{max} and P_{max} have been filled out.

8.3.11 A minimum of three measurements shall be made at each of the test conditions on a minimum of three days. Continue to collect data until the standard deviations for all V_{oc}, I_{sc} and P_{max} values in the matrix are less than 5 %.

NOTE The angular response as well as the spectral response affect the measurements in outdoor conditions. Spectral response can be corrected for by using spectrally matched reference cells or employing a spectroradiometer and carrying out a spectral mismatch calculation. The angular effect can be eliminated by use of a tracker

8.4 Procedure in natural sunlight without tracker

The second approach to collecting the outdoor data is to monitor the test modules outdoors for extended time periods and then to extract the data necessary to populate the matrices. This is a valid approach as long as the conditions specified in 8.3.2 are met. A tracker is not required for this approach, but corrections for angular response may be required (see note in 8.3.11).

8.5 Procedure with a solar simulator

8.5.1 The equipment required for this procedure is defined in IEC 60904-1.

The PV reference device as defined in IEC 60904-2 shall be linear in short-circuit current as defined in IEC 60904-10 over the irradiance range from 100 W·m^{-2} to 1100 W·m^{-2}. If methods a), b), c) and e) from 8.5.7 are used the reference device shall be packaged via the same method as the module under test.

The solar simulator should be a Class BBB or better solar simulator in accordance with IEC 60904-9.

NOTE 1 The encapsulation system does effect the optical performance and spectral response of a PV device to the degree that care must be taken to assure that the reference device used in this procedure is spectrally matched to the module under test.

NOTE 2 Care should be taken if an emission lamp such as xenon is used for direct band gap and multijunciton cells. As the band gap(s) changes due to temperature, it can pass through various emission lines in the lamp spectrum and give rise to large shifts in performance. For multijunction devices, these band gap shifts can alter the subcell current balancing and introduce additional shifts in performance.

NOTE 3 For a multijunction device, both the I_{sc} and the *FF* are nonlinear functions of the simulator spectral irradiance. Measurements made with solar simulators that are not spectrally adjustable can be expected to have large errors because the subcell currents are not balanced with respect to each other. Errors above 15 % in the current and power have been observed in commercial multijunction modules under a class AAA solar simulator.

8.5.2 Mount the test device and the reference device co-planar in the test plane of the simulator so that both are normal to the centre line of the beam within ±2°. Connect to the necessary instrumentation.

8.5.3 If the test device and reference device are equipped with temperature controls, set the controls at the desired level. If temperature controls are not used, allow the test module and reference device to stabilize within ±2 °C of the chamber air temperature.

NOTE If measured in non-equilibrium temperature conditions the temperature sensors shall be placed as in Figure 1.

8.5.4 Set the irradiance at the test plane to the upper limit of the range of interest using the reference device.

8.5.5 Take simultaneous readings of the test device temperature and I-V performance characteristics (at a minimum I_{sc}, V_{oc}, V_{max} and P_{max}), the temperature and short-circuit current of the reference device and the spectral irradiance using the spectral radiometer (if a matched reference device is not utilized).

8.5.6 The irradiance, G_o, shall be calculated from the measured current (I_{sc}) of the PV reference device, and its calibration value at STC (I_{rc}). A correction should be applied to account for the temperature of the reference device, T_m, using the specified relative short circuit current temperature coefficient of the reference device, α_{rc}.

$$G_o = \frac{G_{rc} \times I_{sc}}{I_{rc}} \times \left[1 - \alpha_{rc}\left(T_m - T_{rc}\right)\right]$$

Where G_{rc} is the irradiance at which the reference device was calibrated, usually 1000 W·m^{-2} and T_{rc} is the temperature at which the reference device was calibrated, usually 25 °C. If the test specimen and reference device are not matched in spectral response, perform the spectral correction on G_o using equation 1 in IEC 60904-7 to correct back to the AM1,5 global spectrum for all irradiances.

8.5.7 If the test parameter being varied is the irradiance, reduce the irradiance on the test device to the desired level without affecting the spatial uniformity or the spectral energy distribution. Several methods to accomplish this are:

a) by increasing the distance between the test plane and the lamp. With the reference device maintained in the same plane as the test specimen, in plane irradiance is reduced by the ratio of the reference device output to its calibration value;
b) by the use of an optical lens. Care should be exercised to ensure that the lens does not significantly change either the spectral energy distribution in the wavelength range in which the test and reference specimens are responsive or the spatial uniformity in the test plan. With the reference device maintained in the same plane as the test specimen, in plane irradiance is reduced by the ratio of the reference device output to its calibration value;
c) by controlling the angle of incidence. If this method is selected, the distance between the lamp source and the specimen must be large to limit the irradiance change across the tilted surface to 2 % or less. Also, if this method is selected, the reference device should have the same reflective properties as the test specimen, and should be mounted co-planar with the test specimen. In this case, in plane irradiance is reduced by the ratio of the reference device output to its calibration value;
d) using calibrated, uniform density mesh filters. If this method is selected, the reference device must remain uncovered by the filter during the operation to enable the incident irradiance to be measured. In this case, the in plane irradiance is reduced by the filter calibration parameter (fraction of light transmitted);

e) using uncalibrated, uniform density mesh filters. If this method is selected, the reference device must also be covered by the filter during the test. In this case in plane irradiance is reduced by the ratio of the reference device output to its calibration value;

f) by determining the device characteristics at different irradiance levels during the decaying tail of the flash of a pulsed solar simulator. This requires a spectral radiometer capable of measuring the spectral irradiance of the simulator during the measurement or verification that the reference device identified in a) is well matched to the test device over the range of irradiances, spectral distribution and temperatures of interest.

NOTE 1 The maximum filter mesh opening dimension shall be less than 1 % of the minimum linear dimension of the reference device and the test specimen, or a variable error may occur due to positioning.

NOTE 2 In method f the spectral match of the reference device to the test device should be verified by recording the short circuit current of test and reference device output during a decaying pulse from the solar simulator. The plot of the normalized relative ratio of the short circuit current of the test device to the reference device output versus irradiance should be made and the deviation of the ratio from unity should not exceed 1 % in the irradiance range of interest. Method f should not be used for multijunction devices.

8.5.8 If the test parameter being varied is the temperature, adjust the temperature by appropriate means (see IEC 61215 or IEC 61646).

8.5.9 Ensure that the test module and reference device temperatures remain constant within ±1 °C during the test.

8.5.10 Repeat steps 8.5.5 through 8.5.9 until the performance measurements are completed for the matrix of temperature and irradiance combinations as defined in Table 2.

8.5.11 A minimum of three measurements shall be made at each of the test conditions. Continue to collect data until the standard deviations for all V_{oc}, I_{sc} and P_{max} values in the matrix are less than 5 %.

9 Rating of power

9.1 Interpolation of I_{sc}, V_{oc}, V_{max} and P_{max}

9.1.1 General

To determine I_{sc}, V_{oc}, V_{max} and P_{max} at intermediate values of irradiance and temperature other than those directly measured, the following procedures should be used. The procedures shall provide an estimate of the error (see 9.1.6).

9.1.2 Interpolation of I_{sc}, V_{oc}, V_{max} and P_{max} with respect to temperature

To determine I_{sc}, V_{oc}, V_{max} and P_{max} at intermediate values of temperature, use a linear interpolation (regression) method with respect to the measured temperature dependence.

9.1.3 Interpolation of I_{sc} with respect to irradiance

To determine I_{sc} at intermediate values of irradiance, use a linear interpolation (regression) method with respect to the measured irradiance dependence.

NOTE For non-linear devices the irradiance range used in the interpolation may have to be limited in order to minimize the error.

9.1.4 Interpolation of V_{oc} with respect to irradiance

To determine V_{oc} at intermediate values of irradiance, data should be fitted to find ν_1 and ν_2 in the following equation,

$$V(G) = v_1 \times \ln(G) + v_2$$

NOTE 1 This relation is based on the logarithmic variation of V_{oc} with irradiance. Interpolation of V_{max} can be done using the same functional relationship as used for V_{oc} with a new set of coefficients.

NOTE 2 For non-linear devices the irradiance range used in the interpolation may have to be limited in order to minimize the error.

9.1.5 Interpolation of P_{max} with respect to irradiance

To determine P_{max} at intermediate values of irradiance, data from the region near the irradiance of interest (within ±30 %) should be fitted to a polynomial as this should take into account any non-linearity between data points.

NOTE In some cases it may be impossible to get a good fit to the whole P_{max} versus I_{sc} curve. In that case use several points below and several points above the intermediate I_{sc} value of interest. It may be necessary to take more experimental readings at irradiances closer to the required value.

For linear devices, if the difference between the measured irradiances does not exceed 30 %, linear interpolation may be used to obtain the value of P_{max} at intermediate irradiance levels. (See IEC 60891:2009, correction procedure 3.)

9.1.6 Appropriateness of fitting method

Check that the algorithms for 9.1.2 through 9.1.5 are valid by verifying that the global minimum of the error function has been found (by investigating the error surfaces). If these algorithms are not valid, other appropriate relations may be used.

9.2 Power rating

For each test module utilize Table 2 for P_{max} and if necessary the interpolation procedure given in clause 9.1.5 to determine P_{max} at each of the reference power conditions as defined in Clause 7 and Table 1. For each module type the reported reference power conditions (except for STC) shall be the average of the values determined for the three test modules. This average plus the range of determined values shall be reported and utilized for markings in Clause 4.

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