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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Photovoltaic (PV) module performance testing and energy rating – Part 2: Spectral responsivity, incidence angle and module operating temperature measurements

Essais de performance et caractéristiques assignées d'énergie des modules photovoltaïques (PV) – Partie 2: Mesurages de réponse spectrale, d'angle d'incidence et de température de fonctionnement des modules

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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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PHOTOVOLTAIC (PV) MODULE PERFORMANCE TESTING AND ENERGY RATING –

Part 2: Spectral responsivity, incidence angle and module operating temperature measurements

FOREWORD

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

FDIS	Report on voting
82/1133/FDIS	82/1156/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.

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A list of all parts in the IEC 61853 series, published under the general title *Photovoltaic (PV) module performance testing and energy rating*, can be found 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 website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
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INTRODUCTION

Photovoltaic (PV) modules are typically rated at standard test conditions (STC) of 25 °C cell temperature, 1 000 W·m^{-2} irradiance, and air mass (AM) 1.5 global (G) spectrum. However, the PV modules in the field operate over a range of temperatures, irradiance, and spectra. To accurately predict the energy production of the modules under various field conditions, it is necessary to characterize the modules at a wide range of temperatures, irradiances, angles of incidence, and spectra.

Recognizing this issue, IEC Technical Committee 82 Working Group 2 (TC 82/WG 2) has developed an appropriate power and energy rating standard (IEC 61853). The first part of this four-part standard requires the generation of a 23-element maximum power (P_{max}) matrix at four different temperatures and seven different irradiance levels. The P_{max} matrix can be generated using an indoor solar simulator method or outdoor natural sunlight method. The outdoor test method introduces little/no spectral mismatch error and is much less expensive than the indoor test method because it avoids the use of very expensive solar simulators. However, obtaining an accurate and repeatable P_{max} matrix using the outdoor method over time (several months or years) would be extremely challenging.

This standard consists of four parts:

- IEC 61853-1: *Irradiance and temperature performance measurements and power rating*, which describes requirements for evaluating PV module performance in terms of power (watts) rating over a range of irradiances and temperatures;
- IEC 61853-2: *Spectral responsivity, incidence angle, and module operating temperature measurements*, which describes test procedures for measuring the effect of varying angle of incidence and sunlight spectra as well as the estimation of module temperature from irradiance, ambient temperature, and wind speed;
- IEC 61853-3[1]: *Energy rating of PV modules*, which describes the calculations for PV module energy (watt-hours) ratings; and
- IEC 61853-4[2]: *Standard reference climatic profiles*, which describes the standard time periods and weather conditions that can be used for the energy rating calculations.

Included in the IEC 61853 series of standards are: test methods designed to map module performance over a wide range of temperature and irradiance conditions (IEC 61853-1); test methods to determine spectral responsivity, incidence angle effects and the module operating temperature all as functions of ambient conditions (IEC 61853-2); methods for evaluating instantaneous and integrated power and energy results including a method for stating these results in the form of a numerical rating (IEC 61853-3); and definition of reference irradiance and climatic profiles (IEC 61853-4).

IEC 61853-1 describes requirements for evaluating PV module performance in terms of power (watts) rating over a range of irradiances and temperatures. IEC 61853-2 describes 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 responsivity on module performance. 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 energy ratings.

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[1] Under preparation: Stage at the time of publication: IEC/ACDV 61853-3:2016.

[2] Under preparation: Stage at the time of publication: IEC/ACDV 61853-4:2016.

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IEC published the first part of the standard in January 2011. This standard specifies the performance measurements of PV modules at 23 different sets of temperature and irradiance conditions, using either a solar simulator (indoor) or natural sunlight (outdoor). There are many possible indoor and outdoor techniques, and this standard allows several of them. Validation of these techniques for repeatability over time within the same laboratory and for reproducibility among multiple laboratories is extremely important for the successful implementation of this standard.

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PHOTOVOLTAIC (PV) MODULE PERFORMANCE TESTING AND ENERGY RATING –

Part 2: Spectral responsivity, incidence angle and module operating temperature measurements

1 Scope

The IEC 61853 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, but may not work well for any technology where the module performance changes with time (e.g. modules change their behaviour with light or thermal exposure), or which experience significant non-linearities in any of their characteristics used for the modelling.

The purpose of this part of IEC 61853 is to define measurement procedures for measuring the effects of angle of incidence of the irradiance on the output power of the device, to determine the operating temperature of a module for a given set of ambient and mounting conditions and measure spectral responsivity of the module. A second purpose is to provide a characteristic set of parameters which will be useful for detailed energy predictions. The described measurements are required as inputs into the module energy rating procedure described in IEC 61853-3.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60410[3], *Sampling plans and procedures for inspection by attributes*

IEC 60891, *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 photovoltaic reference devices*

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

IEC 60904-8, *Photovoltaic devices – Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device*

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

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

[3] Withdrawn.

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IEC 61215 (all parts), *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*

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

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

IEC 61853-1:2011, *Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating*

ISO 9059, *Solar energy – Calibration of field pyrheliometers by comparison to a reference pyrheliometer*

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 4 of this standard to assure the stability of the power values. One module (or equivalent reference sample) shall be used for each of the three tests, angle of incidence, spectral responsivity and thermal performance. A single module may be supplied if the test is to be carried out serially or three modules need to be supplied if it is to be carried out in parallel.

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 DUTs (device under test) are prototypes of a new design and not from production, this fact shall be noted in the test report (see Clause 5).

4 Testing

One of the modules, or representative samples, shall be subjected to each of the testing procedures defined in Clauses 6 to 8, i.e. the procedure for spectral responsivity (see Clause 6), angle of incidence (see Clause 7) and module operating temperature measurements (see Clause 8). In carrying out the tests, the manufacturer's handling, cleaning, mounting and connection instructions shall be observed. This can be the same module undergoing all tests sequentially or three distinct modules undergoing the characterisation tests in parallel. It shall be noted in the test report if a single or different modules have been used.

If the module under test is going to be used with a frame that covers the edges of the superstrate, then each of the tests shall be performed with a similar frame in place.

Preconditioning – Before beginning the measurements, the device under test shall be stabilized, as specified in IEC 61215 or IEC 61646.

Figure 1 shows an overview of the testing procedure to be conducted.

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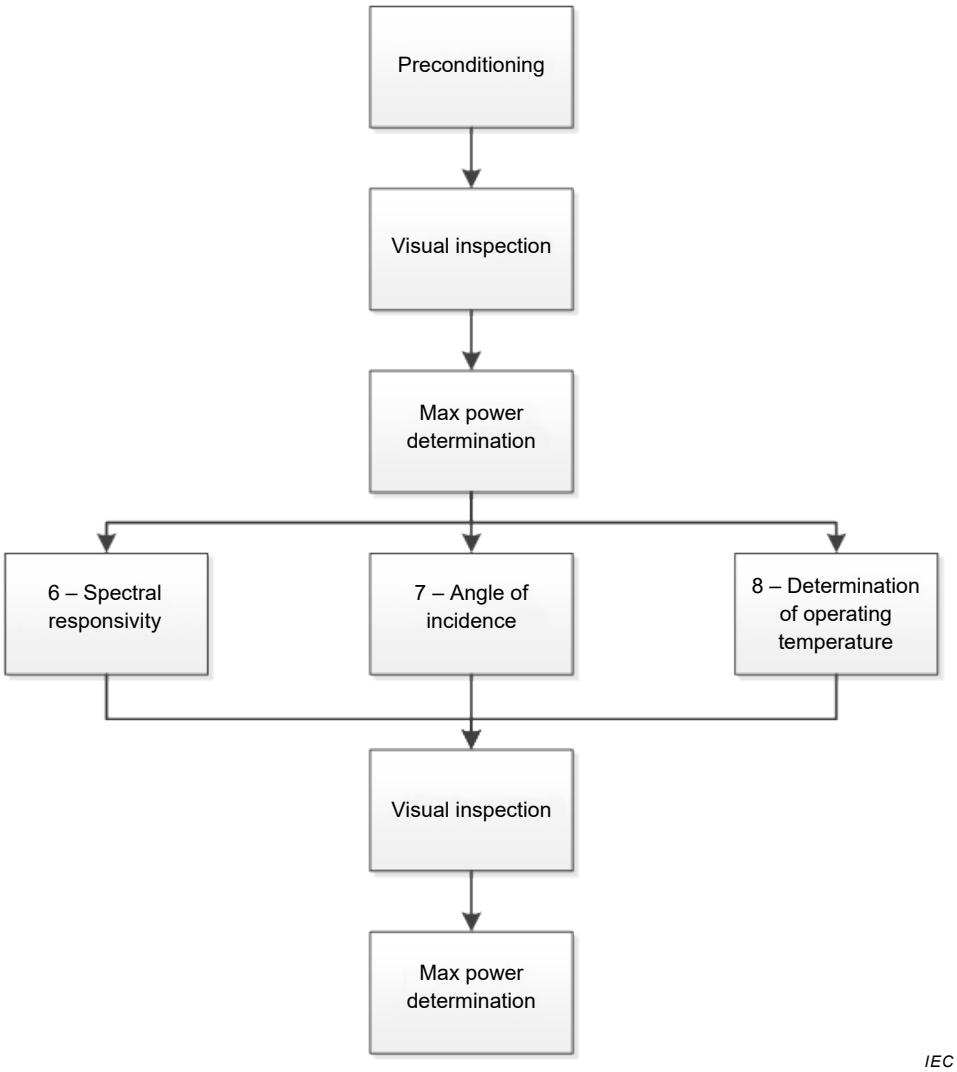

Figure 1 – Overview of the testing cycle to be carried out in IEC 61853-2

5 Report

Following completion of the procedure, a report of the performance tests, with measured module characteristics shall be prepared. 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

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conditions, including the tilt angle of the module used during the temperature test (see 8.4.1) and limits to the field of view;

k) measurements, examinations and derived results of module incidence angle effects, its operating temperature and its spectral responsivity. The report should indicate the method used to deal with the diffuse light component for the measurement of angle of incidence (see 7.3.4);

l) for non-symmetric optical modules, the tilt and azimuth directions have to be specified in a drawing;

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

n) 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;

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

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

6 Procedure for spectral responsivity measurement

The spectral responsivity of a PV module has an impact on the amount of current produced at any given spectral irradiance. Normally it is not necessary to measure the spectral responsivity at all possible values of irradiance and temperature that a module encounters during outdoor operation. A single measurement should be sufficiently accurate for all expected operating conditions. The need for this can be verified by checking the linearity of short circuit conditions measured in IEC 61853-1. Should a non-linearity of I_{sc} with respect to irradiance or temperature larger than 3 % be observed, further investigation might be warranted to identify if the SR changes as a function of irradiance and temperature (If the spectral responsivity of a particular module type is a function of irradiance or temperature, this result fact should appear in the test report).

To measure the spectral responsivity, follow the procedure as laid out in IEC 60904-8 using the short circuit condition, 25 °C device temperature and an appropriate bias light. This procedure should be applied to the full-sized module if possible, i.e. the module should be characterized in its entirety. If this is not possible, a small sample equivalent in construction and materials may be used or a single cell in the module should be characterized according to the measurements described in IEC 60904-8.

The spectral responsivity of a solar cell changes upon encapsulation. Therefore, an encapsulated solar cell shall be used if a full-sized module cannot be tested.

The module power shall be measured after measurement of the spectral responsivity. Any changes shall be noted in the test report.

7 Procedure for the measurement of incidence angle effects

7.1 Purpose

The purpose of the incident angle test is to determine the effect of solar incidence angles on module performance. The incidence angle dictates the fraction of the direct and diffuse irradiance available for conversion into electrical energy inside the module, i.e. the transmitted and reflected fractions of the available light. Both the external (the front surface) reflection and internal reflections are functions of the solar incidence angle and of the module design. Hence, the irradiance absorbed by PV devices at a particular incidence angle may differ between module designs. Also, the orientation of the module installation has a strong influence on the incidence angle effects.

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For modules with a flat uncoated front glass plate, the relative light transmission into the module is primarily influenced by the first glass-air interface. The test can be omitted if the interface is flat and no antireflective coating is applied. The data of a flat glass-air interface can be used. However, normally glasses used for solar modules are somewhat structured and thus it is recommendable to carry out a verification measurement in either case.

Although the relative light transmission into the module is primarily influenced by the glass air interface, the details of other optical interfaces and other measures to enhance optical confinement might be relevant as well. If there is reason to believe that the other optical interfaces have been significantly changed, the test should be conducted.

This document presents two unequal alternatives (indoor and outdoor approach) which might not necessarily yield identical results but results should be equivalent within their uncertainties. It should be noted in the test report, which method has been used.

7.2 Indoor test method

7.2.1 General

The test method for the incident angle test is based on gathering actual measured I_{sc} data for the test modules over a wide range of incidence angles. If no light source with light uniformity in the volume spanned by a full module upon rotation is available (see 7.2.2c), a smaller, optically equivalent test module with one active cell, surrounded by non-active cells, may be tested. In the following, the area of the active cell is referred to as measurement area and all specification shall be met for this area only to allow realistic measurements. The area of influence is the active cell plus one half cell dimension in all directions.

7.2.2 Apparatus

The following apparatus is required to control and measure the test conditions:

a) A PV reference device in conformance with IEC 60904-2 that is linear in output over the range of irradiance variations of the solar simulator according to IEC 60904-10, mounted fixed in the test plane of the simulator to monitor the total irradiance of the solar simulator.

b) Means of measuring the temperature of the ambient, the test module and the reference device to an accuracy of ±1 °C with a repeatability of ±0,5 °C.

c) A solar simulator of class B with respect to the spatial uniformity requirements within the measurement area and class C over the area of influence and with respect to temporal stability according to IEC 60904-9. The solar simulator should have minimal irradiance outside a 30° field of view. It is recommended that the solar simulator should have 95 % of its irradiance within 10° field of view. The spatial uniformity requirement (class B) shall be fulfilled in the volume that is covered by the active element(s) within the module during rotation. The area of influence should maintain class C. The solid angle of the light of the simulator should not vary by more than 1° over the active area of the test device. The spatial uniformity of the active area and the area of influence shall be stated in the report.

NOTE The depth of the volume is determined by the highest inclinations and a detailed assessment of the worst case needs to be carried out in advance of the measurements.

d) Equipment to measure the short circuit current of the test module to an accuracy of ±0,2 % of the value at 1 000 W·m^{-2} (see IEC 60904-1).

e) Equipment for measuring the reference device output to an accuracy of ±0,2 % of the value at 1 000 W·m^{-2}.

f) An adjustable rack capable of accurately positioning the module at the specified angles of incidences to an accuracy of ±1°. Care shall be taken to ensure that rotation of the test apparatus does not change the irradiance on the reference device. The device should be rotated around the rotational axis of the cell centre under investigation. The rotational axis shall not change during the entire angular range of measurements.

g) Module temperature sensors, attached by solder or thermally conducive adhesive to the backs of two solar cells near the middle of each test module, or to the back of the active

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cell if an optically equivalent mini-module is used. Alternatively, use IEC 60904-5 and its associated equipment for determining cell temperature. The total accuracy of the module temperature determination shall be ±1 °C.

h) A data acquisition system capable of recording the following parameters for each angle setting:

- reference device output,
- short circuit current of the module,
- module temperature,
- reference device temperature.

The measurement of module current and reference device output shall be simultaneous.

7.2.3 Set-up procedure

The set-up procedure is as follows.

a) Make sure that the front surface of the module is clean.

It is acceptable to mechanically isolate and contact a single crystalline cell, i.e. cut through the back sheet to access the contacts of a single cell directly. In the case of thin film modules one would need to manufacture a specific test device with a single cell, or an area of interest, being contacted separately and isolated for these measurements.

b) Mount the module in the test plane of the simulator so that it is normal to the centre line of the beam within ±1°. Connect to the necessary instrumentation.

c) If the test system is equipped with temperature controls, set the controls at the desired level. If temperature controls are not used, allow the module to stabilize within ±1 °C of the room air temperature.

d) Set the irradiance at the test plane of the simulator to 1 000 $W \cdot m^{-2}$ at perpendicular incidence using the reference device. Maintain this irradiance throughout the measurements. If this is not possible, a value in the range of 700 $W \cdot m^{-2}$ to 1 000 $W \cdot m^{-2}$ (see IEC 60891) is sufficient.

Care shall be taken to prevent reflection from within the room. There shall be no protrusions to prevent full irradiance of the test module during the measurement. Reflections off the floor, walls or ceiling or objects shall be avoided.

Some black paints are highly reflective in the infrared. It is recommended to test the reflective properties of the paint used to assess the uncertainties of the procedure.

7.2.4 Measurement procedure

Measurements should be taken along two orthogonal angular directions with respect to the module normal. In cases of known symmetrical reflection properties, measurements in one axis are sufficient and the second axis may be omitted. Symmetrical behaviour is expected if samples with similar cells and the same front glass have been shown to be symmetrical.

The following procedure assumes symmetry in the rotational axis.

NOTE There is no knowledge of a device which does not meet this requirement.

a) At 0° rotation angle position the test cell in the test area so that the center of the cell lies in the optical axis and the axis of rotation in the middle of the cell. Rotational symmetry of the test arrangement shall be verified at –80° and 80° rotation angle. The ratios (I_{SC}, 80° / I_{SC}, 0°) / cos 80° for both directions shall not differ by more than 2 %.

b) Vary the angle between the module normal and the optical axis of the light source between –60° and + 60° in steps of a maximum of 10°. Outside that range vary the angle in steps of maximum 5°.

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