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Interested committees:

Title: BS EN IEC 61853-2 Photovoltaic (PV) module performance testing and energy rating

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

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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UK Vote

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Submission of Comments

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



82/2298/CD

COMMITTEE DRAFT (CD)

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SECRETARIAT:

United States of America

SECRETARY:

Mr George Kelly

OF INTEREST TO THE FOLLOWING COMMITTEES:

HORIZONTAL FUNCTION(S):

ASPECTS CONCERNED:

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TITLE:

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

NOTE FROM TC/SC OFFICERS:

This project was discussed and supported by WG2 during their meeting in 2024-04.

The title has been changed to PHOTOVOLTAIC (PV) MODULE PERFORMANCE TESTING AND ENERGY RATING - Part 2: Spectral responsivity, incidence angle and nominal module operating temperature measurements".

"Nominal" was added to the title.

CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
1 Scope.....	9
2 Normative references	9
3 Terms and definitions	10
4 Sampling	12
5 Testing	12
6 Procedure for spectral responsivity measurement.....	13
7 Procedure for the measurement of incidence angle effect.....	13
7.1 Purpose	13
7.2 Indoor test method 1: irradiation on full cell (or module) or on an optically equivalent device	15
7.2.1 General	15
7.2.2 Test sample preparation	15
7.2.3 Apparatus	15
7.2.4 Set-up procedure	17
7.2.5 Measurement procedure	18
7.2.6 Data evaluation	19
7.2.7 Uncertainty contributions	19
7.3 Indoor test method 2: irradiation on a partially shaded cell in a module	20
7.3.1 General	20
7.3.2 Test sample preparation	20
7.3.3 Apparatus	20
7.3.4 Set-up procedure	20
7.3.5 Measurement procedure for c-Si PV modules with series-connected cells.....	20
7.3.6 Measurement procedure for c-Si PV modules with series-parallel connection	21
7.3.7 Measurement procedure for monolithically integrated thin-film PV modules.....	21
7.3.8 Data evaluation	22
7.3.9 Uncertainty contributions	22
7.4 Indoor test method 3: partial irradiation (on cells or modules)	22
7.4.1 General	22
7.4.2 Test sample preparation	22
7.4.3 Apparatus	22
7.4.4 Set-up procedure	24
7.4.5 Measurement procedure for cells (indoor method 3a)	24
7.4.6 Measurement procedure for modules (indoor method 3b)	25
7.4.7 Data evaluation	25
7.4.8 Uncertainty contributions	25
7.5 Indoor test method 4: spectrally resolved method	25
7.5.1 General	25
7.5.2 Test sample preparation	26
7.5.3 Apparatus	26

48	7.5.4	Set-up procedure	27
49	7.5.5	Measurement procedure for cells (indoor method 4a) and module	
50		(indoor method 4b)	27
51	7.5.6	Data evaluation	27
52	7.5.7	Uncertainty contributions	28
53	7.6	Outdoor test method 1: absolute method	28
54	7.6.1	General	28
55	7.6.2	Apparatus	28
56	7.6.3	Set-up procedure	29
57	7.6.4	Measurement procedure	30
58	7.6.5	Tabulation of the relative internal angular transmittance $\tau_{rel\theta}$	31
59	7.6.6	Uncertainty contributions	31
60	7.7	Outdoor test method 2: relative method	32
61	7.7.1	General	32
62	7.7.2	Apparatus	32
63	7.7.3	Set-up procedure	32
64	7.7.4	Measurement procedure	33
65	7.7.5	Uncertainty contributions	33
66	7.8	Interpolation of the relative internal angular transmittance $\tau_{rel\theta}$	33
67	8	Methodology for determining coefficients for calculating the Nominal Module	
68		Operating Temperature (NMOT)	34
69	8.1	General	34
70	8.2	PV module temperature model	34
71	8.3	Apparatus	35
72	8.4	Test module mounting	36
73	8.5	Procedure	36
74	8.5.1	Data recording	36
75	8.5.2	Data filtering	37
76	8.5.3	Determination of u_0	37
77	8.5.4	Determination of u_1	37
78	8.5.5	Calculation of NMOT	38
79	8.6	Uncertainty sources	38
80	9	Report	38
81	9.1	Specific requirements for measurements of SR	39
82	9.2	Specific requirements for measurements of the incidence angle effect	39
83	9.3	Specific requirements for measurements of NMOT	40
84	Annex A (informative)	Specific exceptions for photovoltaic modules installed on	
85		buildings	41
86	A.1	Spectral responsivity of coloured modules	41
87	A.1.1	Size of the incident monochromatic beam: over-irradiation and under-	
88		irradiation modes	41
89	A.1.2	Spectral responsivity measurements of monochromatic samples	42
90	A.1.3	Spectral responsivity measurements of polychromatic samples with	
91		repeated pattern	43
92	A.1.4	Spectral responsivity measurements of polychromatic samples with	
93		non-repeated pattern	43
94	A.1.5	Spectral responsivity of gradient-coloured samples	43
95	A.2	Incidence angle effect of modules with modified surfaces, antiglare	
96		treatments or colouration	43
97	A.3	Specific thermal conditions of modules installed on buildings	43

98	Annex B (normative) Stray light effects in indoor methods for measurements of the	
99	angle of incidence effects and correction procedure	46
100	B.1 Origin of possible stray light effects	46
101	B.2 Correction procedure	47
102	B.2.1 General	47
103	B.2.2 Apparatus	47
104	B.2.3 Set-up procedure	48
105	B.2.4 Measurement procedure	48
106	B.2.5 Correction procedure	48
107	B.2.6 An example for calculation of the size of the shading paddle	
108	(informative)	49
109	Annex C (informative) Diagrams illustrating the evaluation of raw data and the	
110	determination of u_0 and u_1 parameters in NMOT measurements	50
111	Bibliography	54
112		
113	Figure 1 – Overview of the testing cycle to be carried out in IEC 61853-2 (with	
114	reference to IEC 61215)	12
115	Figure 2 – Optical alignment method (clause 7.2.4.3): the red dots indicate the 4	
116	correctly aligned points; the crosses indicate conditions of misalignment	18
117	Figure 3 – Examples of the function $\tau_{rel\theta}$ of a typical PV module: a) With correct zero	
118	alignment; b) with a $\theta_0 = 1,0^\circ$ misalignment at normal incidence.	19
119	Figure 4 – Indoor test method 2. Cell masking with an opaque adhesive tape and axis	
120	of rotation in: a) c-Si module, case S; b) c-Si module, case SP; and c) monolithically	
121	integrated thin-film module	20
122	Figure 5 – Example block diagram of a measuring instrument for the incidence angle	
123	effect using the partial-irradiation method on a module (indoor test method 3b)	23
124	Figure 6 – Recommended positions for measuring the temperature of the test module	
125	behind the cells	28
126	Figure A.1 – Possible sizes of the monochromatic beam in SR measurements of PV	
127	modules (see IEC 60904-8): a) over-irradiation mode; b) under-irradiation mode.	41
128	Figure A.2 – Example of SR measurements on a blue-white coloured module (shown in	
129	the boxes) in under-irradiation mode: a) with spot monochromatic beam in the white	
130	region of the DUT; b) with spot monochromatic beam in the blue region of the DUT.	42
131	Figure A.3 – Examples of different coloured PV modules: a) monochromatic sample; b)	
132	polychromatic sample with repeated pattern; c) polychromatic sample with non-	
133	repeated pattern; d) colour-gradient sample	42
134	Figure A.4 – Example of incidence angle effect and interpolation from clause 7.8 of a	
135	module with antiglare treatment with inadequate best fit.	44
136	Figure B.1 – Example of possible stray light from the surfaces of walls, ceiling or floors	
137	of the darkroom: a) direct irradiance diffused by the darkroom to the front of the DUT;	
138	b) direct irradiance reflected by the front of the DUT to the darkroom and then diffused	
139	back to the DUT; c) direct irradiance diffused by the rear of the darkroom to the front of	
140	the DUT (wide angles); d) direct irradiance diffused by the darkroom to the rear of a	
141	bifacial DUT; e) direct irradiance diffused by rear of the darkroom to the rear of a	
142	bifacial DUT; and f) secondary reflection from any irradiation optics that may be	
143	present between the flash lamp and the DUT	46
144	Figure B.2 – A scheme of the apparatus for stray light correction in indoor test	
145	methods 1 and 2 for the measurement of the incidence angle effect.	47
146	Figure B.3 – Scheme for the calculation of the shading paddle size x , for a solar	
147	simulator with lamp size L larger than the control cell size L'	49

149	Figure C.1 – Frequency distribution of irradiance data in bins of 100 W m^{-2}	50
150	Figure C.2 – Frequency distribution of wind speed data in bins of 1 m s^{-1}	50
151	Figure C.3 – Measured data ($TM - Tamb$) plotted versus the irradiance in the plane-of-	
152	array GPOA	51
153	Figure C.4 – Measured data and filtered data, fulfilling the stability criteria for wind	
154	speed, irradiance and module temperature.	51
155	Figure C.5 – Filtered data with N98 diagonal.	52
156	Figure C.6 – Filtered data and modelled data $TM - Tamb = GPOAu0 + u1 \cdot vw$	52
157	Figure C.7 – Residuals of filtered TM data and modelled TM, modelled data: ($TM -$	
158	TM, modelled).	53
159		
160		

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**PHOTOVOLTAIC (PV) MODULE
PERFORMANCE TESTING AND ENERGY RATING****Part 2: Spectral responsivity, incidence angle and nominal module
operating temperature measurements****FOREWORD**

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IEC 61853 has been prepared by WG2: Modules, non-concentrating, of IEC technical committee 82: Solar photovoltaic energy systems. It is an International Standard.

This second edition cancels and replaces the first edition published in 2016-09. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) New clause 3 "Terms and definitions" was added;
- b) New measurement methods are introduced in clause 7 "Procedure for the measurement of incidence angle effects";

- c) A new procedure for data filtering was added to clause 8 “Methodology for determining coefficients for calculating the Nominal Module Operating Temperature (NMOT)”;
- d) Annex A (informative) Annex B (normative) and Annex C (informative) were added;
- e) The term “calibration” was removed;
- f) The wording in clauses 4 and 5 was aligned to the last edition of IEC 61215;
- g) The tilt angle for NMOT measurement was harmonized to (37 ± 5) °C throughout the text.

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

Draft	Report on voting
XX/XX/FDIS	XX/XX/RVD

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 International Standard 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/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.

240

INTRODUCTION

241 Photovoltaic (PV) modules are typically rated at standard test conditions (STC) of 25 °C cell
242 temperature, 1 000 W m⁻² total irradiance, normal incidence and air mass (AM) 1,5 spectrum.
243 However, PV modules in the field operate over a range of temperatures, total and spectral
244 irradiances, and incidence angles. Hence, PV modules can be rated based on the calculated
245 energy production under a standardized set of environmental and climatic conditions.

246 This series proposes a standard method for energy rating and consists of four parts:

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

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PHOTOVOLTAIC (PV) MODULE PERFORMANCE TESTING AND ENERGY RATING

Part 2: Spectral responsivity, incidence angle and nominal 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, including bifacial PV modules, 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 second part of IEC 61853 is to define 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 specific set of ambient and mounting conditions and measure spectral responsivity of the module.

The described measurements are required as inputs into the module energy rating procedure described in IEC 61853-3. Results of the measurements described in this part, however, may also be used for other purposes, where relevant, e.g. yield prediction with commercially available simulation tools that need spectral responsivity or relative angular transmittance.

PV modules to be installed onto buildings (either in building integrated or in building applied photovoltaics systems, BIPV or BAPV, respectively) may exhibit very peculiar spectral, optical and thermal properties for which the procedures described in this standard may lead to significant inaccuracies: the specificity of PV modules to be installed in buildings is illustrated in informative Annex A.

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.

ISO 2859-1, *Sampling procedures for inspection by attributes - Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection*

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

ISO 9060, *Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

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 TS 60904-1-2, *Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices*

IEC 60904-2, *Photovoltaic devices – Part 2: Requirements for photovoltaic reference 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 60904-8, *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*

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

IEC TS 61724-2, *Photovoltaic system performance - Part 2: Capacity evaluation method*

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

IEC 61853-3, *Photovoltaic (PV) module performance testing and energy rating – Part 3: Energy rating of PV modules*

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

IEC 63092-1, *Photovoltaics in buildings - Part 1: Requirements for building-integrated photovoltaic modules*

IEC TS 63126, *Guidelines for qualifying PV modules, components and materials for operation at high temperatures*

3 Terms and definitions

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

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

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

3.1

angle of incidence (AOI)

θ

angle between the direct irradiant beam and the normal to the active surface

Note: Unit °

3.2**incidence angle**

SEE: “angle of incidence (AOI)”, 3.1

Note: Unit: °

3.3**incidence angle modifier (IAM)**

SEE: “relative angular transmittance”, 3.5

Note: Unit: dimensionless

3.4**nominal module operating temperature****NMOT**

equilibrium mean solar cell junction temperature within a mounted module operating near peak power in the following standard reference environment:

- Tilt angle: $(37 \pm 5)^\circ$
- Total irradiance: 800 W m^{-2}
- Ambient temperature: 20°C
- Wind speed: 1 m s^{-1}
- Electrical load: An electronic Maximum Power Point Tracker (MPPT)

Note: Unit: °C

3.5**relative internal angular transmittance** **$\tau_{\text{rel}}(\theta)$** quotient of the transmittance from air to the PV cell at angle of incidence θ , and the transmittance at normal incidence ($\theta = 0^\circ$)Note 1: Also known as incidence angle modifier, $IAM(\theta)$

Note 2: Unit: dimensionless

3.6**relative internal spectral angular transmittance** **$\tau_{\text{rel}}(\theta, \lambda)$**

relative internal angular transmittance as a function of wavelength

Note: Unit: dimensionless

3.7**spectral responsivity** **$S(\lambda)$**

short-circuit electric current density generated by unit irradiance at a particular wavelength, plotted as a function of wavelength

Note: Unit: A W^{-1} **3.8****target volume**

the volume spanned by the active element (cell, cells or entire module) upon rotation

Note: Unit m^3 or cm^3 **3.9****volume of influence**

the volume spanned by the active cell plus one-half cell dimension in all directions upon rotation

Note: Unit m^3 or cm^3

4 Sampling

For performance qualification testing, three modules shall be selected randomly from a production batch or batches in accordance with the procedure given in ISO 2859-1. The modules shall be initially stabilised in accordance with clause 5 of this standard to assure the stability of the power values. One module (or equivalent representative sample) shall be used for each of the three tests, spectral responsivity, angle of incidence, and thermal performance. A single module may be supplied if the test is to be carried out in sequence. Up to three modules need to be supplied if tests are 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 devices under test (DUTs) are prototypes of a new design and not from production, this fact shall be noted in the test report.

5 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 nominal module operating temperature measurements (see clause 8). In carrying out the tests, the manufacturer's handling, mounting, connection and cleaning 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 test shall be performed with a similar frame in place.

Initial stabilization – Before beginning the measurements, the DUT shall be electrically stabilized, as specified in technologically specific documents of the IEC 61215 series (MQT 19.1) based on the technology of the DUT.

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

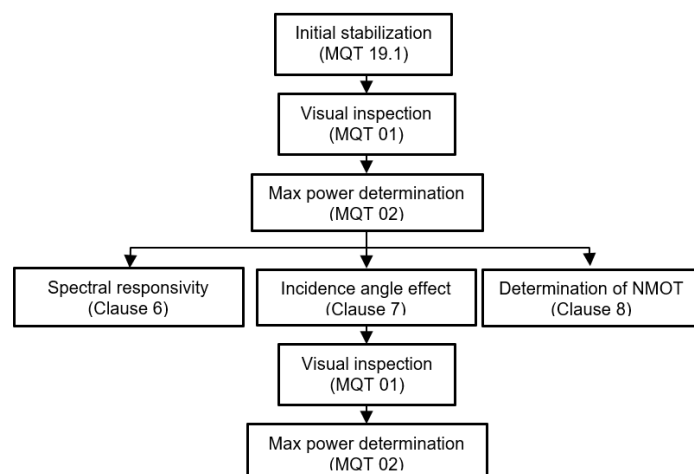


Figure 1 – Overview of the testing cycle to be carried out in IEC 61853-2 (with reference to IEC 61215).

6 Procedure for spectral responsivity measurement

The spectral responsivity (SR) $S(\lambda)$ 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 $S(\lambda)$ 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 the short-circuit current with respect to irradiance or temperature larger than 3 % be observed, further investigation might be warranted to identify if $S(\lambda)$ changes as a function of irradiance and temperature. If $S(\lambda)$ of a particular module type is a function of irradiance or temperature, this result should appear in the test report.

To measure $S(\lambda)$, the procedure described in IEC 60904-8 shall be followed using the short circuit condition, 25 °C cell temperature and an appropriate bias light, where required by IEC 60904-8. 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.

For bifacial modules, $S(\lambda)$ shall be measured on both sides of the testing sample and reported accordingly.

Coloured PV modules present additional challenges: these are addressed in Annex A, clause A.1.

The SR 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 before and after measurement of the SR, according to MQT 02 of IEC 61215. Any variation in the DUT's maximum power shall be noted in the test report.

7 Procedure for the measurement of incidence angle effect

7.1 Purpose

The purpose of this test is to determine the effect of the incidence angle on module performance. In real operation, 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 reflection (front surface) 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.

For modules with a flat front glass plate, the relative internal angular transmittance into the module is primarily influenced by the first glass-air interface.

For bifacial modules, the irradiance contribution to the opposite side of the DUT shall not exceed 3 W m⁻² during the measurement: this can be achieved by blocking the rear side with a non-reflective panel (see IEC TS 60904-1-2).

Modules for use in buildings may have peculiar surface treatment, such as antiglare, coloured glass, textured glass: examples are addressed in Annex A, clause A.2.

For frameless modules (both monofacial and bifacial), the edges of the modules shall be blocked with an opaque tape or similar material, to avoid irradiance entering the module from its edges.

This document presents various methods (either indoors or outdoors) that were proven to be reproducible [1]. Table 7-1 summarises the proposed methods that are described in the indicated clauses, specifying whether the method is applicable to cells, modules or cells in a module; the equipment required in each method; the specific uncertainty contributions (other than usual uncertainty contributions); and an informative indication of the advantages (“pros”) and disadvantages (“cons”) of each method, according to how close it approximates the ideal conditions for measurement of the incidence angle effect (i.e. uniform and collimated total irradiance of 1 000 W m⁻², AM1.5 spectral irradiance, and 25 °C cell temperature). The method used shall be noted in the test report.

Table 7-1 – Measurement methods for the incidence angle effect.

Measurement method	Applicable to (cell/module)	Main equipment requirement	Specific uncertainty contribution(s)	Pros and/or cons (informative)
Indoor method 1: irradiation on full cell (or module) or on an optically equivalent device (clause 7.2)	Cell or module	Minimum Class B uniformity simulator over the active area Minimum Class B spectral match (recommended)	Spatial uniformity of irradiance Stray light (reflections)	Pros: spectral match Cons: uniformity requirement; control of stray light is critical
Indoor method 2: irradiation on a partially shaded cell in a module (clause 7.3)	Single cell in a module	Class B uniformity simulator over the cell area Minimum Class B spectral match (recommended)	Spatial uniformity of irradiance Stray light (reflections)	Pros: can be easily applied with “tunnel” simulators; spectral match Cons: control of stray light is critical; only one axis of rotation can be tested.
Indoor method 3a: partial irradiation (on cells) (clause 7.4)	Cell	Collimated beam and angular probe holder Minimum Class B spectral match (recommended) Lock-in (recommended) Bias light (recommended)	Homogeneity (within and between cell) Divergence of the collimated beam Spectral mismatch (if minimum Class B is not met)	Pros: negligible stray light Cons: care should be taken to address edge effects and reflections by busbars
Indoor method 3b: partial irradiation (on modules) (clause 7.4)	Single cell in a module	Collimated beam and angular probe holder Lock-in technique Bias light Minimum Class B spectral match (recommended)		
Indoor method 4a: spectrally resolved method (on cells) (clause 7.5)	Cell	Monochromator Lock-in (recommended) Bias light (recommended)	Spatial uniformity of irradiance Stray light (reflections) Homogeneity (within cell and between cells)	Cons: when the monochromatic beam is smaller than cell area, care should be taken to address edge effects and reflections by busbars; if filtered simulator is used, same cons as Indoor methods 1 or 2.
Indoor method 4b: spectrally resolved method (on modules) (clause 7.5)	Module or single cell in a module	Filtered simulator Or: Collimated beam and angular probe holder Lock-in technique Bias light		
Outdoor method 1: absolute method (clause 7.6)	Cell or module	1 or 2-axis tracker Pyranometer + pyrhelimeter	Angular positioning	Pros: can be performed in ideal measurement conditions
Outdoor method 2: relative method (clause 7.7)	Cell or module	1 or 2-axis tracker Reference detector	Angular positioning Calibration of the reference detector	Pros: it can be performed in ideal measurement conditions; it may be faster than outdoor method 1 Cons: it requires a reference with calibrated relative angular transmittance

7.2 Indoor test method 1: irradiation on full cell (or module) or on an optically equivalent device

7.2.1 General

Indoor test method 1 for the incidence angle effect is based on measuring the short-circuit current (I_{sc}) data for the test module or test cell over a wide range of incidence angles.

In the following clauses, “target volume” indicates the volume spanned by the active area (the target cell, cells, or the entire module, see clause 7.2.2) upon the entire rotation of the DUT during the test; “volume of influence” is the volume spanned by the active cell plus one-half cell dimension in all directions (the volume of interest equals to the target volume when the full-size module is measured, clause 7.2.2.a).

7.2.2 Test sample preparation

In indoor method 1, the incidence angle effect can be measured on three types of test samples:

- a) A full-size module, if the solar simulator uniformity satisfies the specified requirements of spatial uniformity over the volume of interest (see clause 7.2.3.c).
- b) A small-sized, optically equivalent test module with one active cell surrounded by non-active cells. If a mini-module without surrounding cells is used, the test laboratory should address the effect of missing surrounding cells in the uncertainty budget: in this case, the area around the cell shall be masked to ensure that the exposed backsheet portion is equivalent to the exposed backsheet portion in the full-size module; the edges of the sample shall also be covered to avoid irradiation entering the sample from there.
- c) A full-size module, with a single cell electrically isolated and contacted. This can be achieved, for example, cutting through the back sheet to access the contacts of the target cell; cells near the edges or frame of the module shall be avoided.

NOTE In cases where there is a concern of edge effect due to framed or frameless module design, the testing laboratory may optionally investigate isolated cells from different locations in the module and consider the dispersion of results in the uncertainty budget.

7.2.3 Apparatus

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

- a) A PV reference device in conformance with IEC 60904-2 that is linear in output over the range of irradiances under test according to IEC 60904-10, mounted in the test plane of the simulator to monitor the total irradiance. It is also acceptable to mount the reference device outside the test plane, if the test plane is part of the rotating test rack. In this case, the irradiance setting shall be transferred to the new location of the reference device, to ensure that the sample is measured at the target irradiance.
- b) Means of measuring the ambient temperature, and the temperature of the DUT and of the reference device to a minimum accuracy of ± 1 °C with a minimum repeatability of $\pm 0,5$ °C.
- c) When a solar simulator is used without bias light, the solar simulator shall be minimum class B with respect to the spatial uniformity requirements within the target volume and minimum class A with respect to temporal stability according to IEC 60904-9.

When bias light is used (differential method), bias light should be minimum class B with respect to the spatial uniformity requirements within the target volume and minimum class A with respect to temporal stability according to IEC 60904-9.

The solar simulator should have negligible diffuse irradiance in the target volume. For this purpose, baffles with increasing apertures shall be used in the light path. It is recommended that the view angle of the test sample related to the lamp unit should be within $\pm 15^\circ$. The spatial uniformity in the volume of influence should be minimum class C. The deviation from normal incidence of the direct beam from the simulator should not be more than 1° over the target volume.

An estimation for the spatial non-uniformity in the target volume and volume of influence shall be stated in the report according to the following equation

$$\frac{G_{\max} - G_{\min}}{G_{\max} + G_{\min}} \cdot 100 \%, \quad (1)$$

where:

$G_{\max}$ is the maximum irradiance (in the target volume or volume of influence, whichever is the case) for the widest angle of incidence ($\theta = 90^\circ$), expressed in W m^{-2} ;

$G_{\min}$ is the minimum irradiance (in the target volume or volume of influence, whichever is the case) for the widest angle of incidence ($\theta = 90^\circ$), in W m^{-2} .

If the solar simulator in use can be approximated by a point-like source (i.e. "tunnel" solar simulators), a good approximation of equation (1) is

$$\frac{2 \cdot D \cdot d}{D^2 + d^2} \cdot 100 \% \quad (2)$$

where:

D is the distance between the lamp and the test area measured at the optical axis, expressed in m;

d is half the dimension of the measurement area, expressed in m.

Care shall be taken to prevent reflections from within the room to the rotational test area. There shall be no protrusions to prevent full irradiance over the target volume during the measurement. Diffusion of irradiance from the floor, walls, ceiling or objects shall be avoided. If black paint or black curtains are used to reduce reflections from inner walls of the solar simulator test room, it is required to check the reflective properties of the materials. The material may be highly reflective in the infrared. Annex B illustrates the possible sources of irradiance diffusion and how to correct for them.

- d) For bifacial devices, the contribution from the irradiance incident on the opposite side of the device under test shall be eliminated during the measurement by creating a non-irradiating background, as indicated in IEC TS 60904-1-2.
- e) The spectral match of the solar simulator should be minimum Class B according to IEC 60904-9; however, if a different source is used, the effect of the spectral mismatch shall be quantified and included as an uncertainty component and reported.
- f) Equipment to measure the short circuit current of the test module to an accuracy of $\pm 0,2 \%$ at the target irradiance value (see IEC 60904-1).
- g) Equipment for measuring the reference device output to an accuracy of $\pm 0,2 \%$ at the target irradiance value.
- h) An adjustable rack capable of accurately positioning the module at the specified angles of incidence to a minimum accuracy of $\pm 1^\circ$. Care shall be taken to ensure that rotation of the test apparatus does not change the irradiance on the reference device (see Annex A). When measurement is performed on a single active cell, the device should be rotated around the rotational axis of the cell centre under investigation. The axis of rotation shall not change during the entire angular range of measurements.
- i) The DUT temperature sensor shall be attached by solder or thermally conductive adhesive to the back near the middle of the DUT, or to the back of the active cell, if an optically equivalent mini-module or a module with a single active cell are used. Alternatively, use IEC 60904-5 and its associated equipment for determining cell temperature.
- j) A data acquisition system capable of recording the following parameters for each incidence angle setting:
 - The irradiance recorded by the reference device,
 - The short-circuit current of the module,
 - The DUT temperature,