IEC TS 60904-1-2

Edition 2.0 2024-11

TECHNICAL SPECIFICATION

colour inside

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

IEC TS 60904-1-2:2024-11(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

ISBN 978-2-8322-9832-9

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC DEVICES –

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FOREWORD

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IEC TS 60904-1-2 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

This second edition cancels and replaces the first edition published in 2019. This edition constitutes a technical revision.

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

a) The scope has been updated and refers to IEC TS 63202-3 for the measurement of non-encapsulated solar cells.
b) The requirements for the non-uniformity of irradiance have been updated and now refer to classifications introduced in IEC 60904-9.

c) The requirement for non-irradiated background has been revised.

d) Spectral mismatch corrections are no longer mandatory, unless required by another standard. Spectral mismatch would have to be considered in the measurement uncertainty.

e) The requirement regarding the calculation of bifaciality has been modified: Equivalent irradiance shall not be calculated based on the minimum bifaciality value between I_{SC} and P_{max}, but on the bifaciality of I_{SC}.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
82/2278/DTS	82/2309/RVDTS

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

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 60904 series, published under the general title *Photovoltaic devices*, can be found on the IEC website.

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, or
- revised.

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PHOTOVOLTAIC DEVICES –

Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices

1 Scope

This part of IEC 60904 describes procedures for the measurement of the current-voltage (I-V) characteristics of single junction bifacial photovoltaic devices in natural or simulated sunlight. It is applicable to encapsulated solar cells, sub-assemblies of such cells or entire PV modules. For measurements of I-V characteristics of non-encapsulated solar cells, IEC TS 63202-3 applies.

The requirements for measurement of I-V characteristics of standard (monofacial) PV devices are covered by IEC 60904-1, whereas this document describes the additional requirements for the measurement of I-V characteristics of bifacial PV devices.

This document can be applicable to PV devices designed for use under concentrated irradiation if they are measured without the optics for concentration, and irradiated using direct normal irradiance and a mismatch correction with respect to a direct normal reference spectrum is performed.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC 60904-4, *Photovoltaic devices – Part 4: Photovoltaic reference devices – Procedures for establishing calibration traceability*

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

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

IEC 60904-9, *Photovoltaic devices – Part 9: Classification of solar simulator characteristics*

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

IEC 62788-1-4, *Measurement procedures for materials used in photovoltaic modules – Part 1-4: Encapsulants – Measurement of optical transmittance and calculation of the solar-weighted photon transmittance, yellowness index, and UV cut-off wavelength*

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
bifacial PV device
PV device, both surfaces of which (front and rear sides) are capable of power generation

3.2
front side
side of the PV device declared by the manufacturer as the front side, which is the side designed to be oriented toward the sun

Note 1 to entry: If no declaration is provided, the front side is the side with the higher maximum power measured under standard test conditions (STC).

3.3
rear side
side of the PV device declared by the manufacturer as the rear side, that is the side designed to point away from the sun

Note 1 to entry: If no declaration is provided, the rear side is the side with the lower maximum power measured under STC.

3.4
bifaciality
property expressing the ratio between the main characteristics of the rear side and the front side of a bifacial PV device quantified by specific bifaciality coefficients

Note 1 to entry: Unless otherwise specified, the bifaciality refers to standard test conditions (STC). The bifaciality of the performance parameters is expressed as:

– Short-circuit current bifaciality: $\varphi_{I_{\mathrm{SC}}}$

– Open-circuit voltage bifaciality: $\varphi_{V_{\mathrm{OC}}}$

– Maximum power bifaciality: $\varphi_{P_{\mathrm{max},BiFi}}$.

3.5
equivalent irradiance
G_{E}
irradiance required to illuminate the front of the device under test, so that it produces the same power output as if it were illuminated from the device front with irradiance 1 000 Wm^{-2} and from the rear with irradiance G_{r}

3.6
rear face irradiance
G_{r}
irradiance arriving at the rear face of the DUT

3.7
bifacial nameplate irradiance
BNPI
irradiance at which nameplate characteristics are reported for bifacial modules, specifically 1 000 Wm^{-2} on the module front and 135 Wm^{-2} on the module rear

3.8
maximum power at BNPI
$P_{\text{max,BNPI}}$
maximum power output of the DUT under BNPI

Note 1 to entry: The quantity can be measured or calculated.

3.9
short-circuit current at BNPI
$I_{\text{SC,BNPI}}$
short-circuit current of the DUT under BNPI

Note 1 to entry: The quantity can be measured or calculated.

3.10
open-circuit voltage at BNPI
$V_{\text{OC,BNPI}}$
open-circuit voltage of the DUT under BNPI

Note 1 to entry: The quantity can be measured or calculated.

3.11
rear irradiance power gain
BiFi
quantity which indicates the power gain, in addition to that obtained at STC conditions, per unit of rear irradiance

Note 1 to entry: Rear irradiance power gain is the slope derived from the linear fit of the P_{max} versus rear irradiance, G_{r}.

Note 2 to entry: $BiFi$ is expressed in $W/(Wm^{-2})$ or m^2.

3.12
relative rear irradiance power gain
$\boldsymbol{BiFi}_{\textbf{rel}}$
rear irradiance power gain, $BiFi$ normalized by front-side irradiance and maximum power output at STC

Note 1 to entry: $BiFi_{\text{rel}}$ is unitless.

3.13
$\boldsymbol{BiFi}_{\textbf{ref}}$
rear irradiance power gain of the bifacial device used as a reference

4 General considerations

The final performance of bifacial PV devices in a power plant depends not only on the spatial distribution of the irradiance incident onto the front surface, but additionally on that incident onto the rear surface of the device, which is strongly affected by site-specific conditions, such as albedo, reflective surface size, the racking system, the device's elevation and its tilt angle. Owing to these dependences and in order to obtain comparable measurement results, *I-V* characterisation is extended to quantify the bifaciality of the device and the rear irradiance power gain. Bifaciality is an intrinsic property of the device, unlike the site-specific conditions such as albedo. The measurement conditions for bifacial devices should strive to generate extra photocurrent proportional to their bifaciality. In general, this can be achieved with a test spectrum close to the reference spectrum such as provided by natural sunlight or with a solar simulator whose irradiance level is adjustable, a high albedo and minimal near object shading. However, in practice, measurement conditions differ from the ideal and will deviate from the reference conditions. This document sets limits on the permissible deviations for obtaining valid measurements. In any case, the deviations of the measurement conditions from the reference conditions shall be accounted for in the analysis of measurement uncertainty.

5 Apparatus

5.1 General

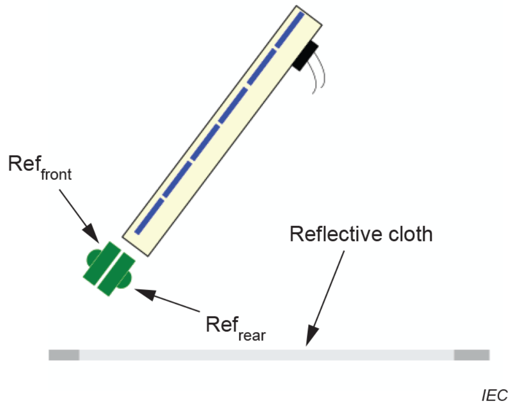
In addition to the apparatus requirements described in IEC 60904-1, one of the equipment sets described in 5.2, 5.3 and 5.4 meeting the requirements for a non-irradiated background as described in 5.5 is necessary for the characterisation of bifacial devices.

5.2 Solar simulator with adjustable irradiance levels for single-side illumination

A solar simulator, as defined in IEC 60904-9, with adjustable irradiance level shall be used for the *I-V* characterisation of bifacial devices. Simulators shall be able to provide irradiance levels above 1 000 Wm^{-2} (typically up to 1 200 Wm^{-2}). The solar simulator's non-uniformity of irradiance shall be Class B or better in accordance with IEC 60904-9 and shall maintain its classification at irradiance levels used for the characterisation of bifacial devices. The non-uniformity of irradiance, the spectral distribution and the temporal instability of irradiance shall be measured at the irradiance levels used for the characterisation of bifacial devices.

5.3 Solar simulator with adjustable irradiance levels for double-side illumination

A solar simulator, as defined in IEC 60904-9, with the additional capability to simultaneously illuminate the bifacial device on both sides shall be used. The non-uniformity, the spectral distribution and the temporal instability of irradiance shall be measured on both sides while the irradiance on the opposite side of the device under test is eliminated by appropriate measures as described in 5.5. In cases where a contribution larger than 5 Wm^{-2} on the opposite side is present, this contribution shall be corrected and incorporated into the evaluation of measurement uncertainty. In cases where a contribution lower than 5 Wm^{-2} from the opposite side is present, it is recommended that the contribution also be corrected (see 5.5) if its magnitude is known. For individual measurements the non-uniformity of irradiance shall be Class B or better in accordance with IEC 60904-9 and shall maintain its classification on both sides, at the irradiance levels used for the characterisation of bifacial devices.



NOTE A reflective cloth can be positioned directly under the device under test to minimise artefacts arising from non-uniformity of irradiance at the rear face.

Figure 1 – Two reference devices (described in IEC 60904-2) to measure irradiance on front and rear sides of device under test during outdoor measurements

5.4 Natural sunlight

In addition to the general measurement requirements described in IEC 60904-1, at least two additional PV reference devices shall be used. The first additional PV reference device shall comply with IEC 60904-2 to measure the irradiance level on the rear side. The second additional PV reference device shall be used to measure the non-uniformity of irradiance of the rear side. Their spectral responsivity should be as close as possible to that of the devices under test, or spectral mismatch corrections shall be applied according to IEC 60904-7. If spectral mismatch corrections are not made, a specific component shall be considered in the evaluation of measurement uncertainty. In addition, the front side non-uniformity of irradiance is practically negligible and can be assumed to be 0 %. The rear side non-uniformity of irradiance shall be 10 % or better in accordance with IEC 60904-9. To minimize the non-uniformity of irradiance at the rear side, a reflective cloth should be optionally positioned directly under the device under test (Figure 1).

5.5 Non-irradiated background

To measure the individual I-V characteristics of both front and rear surfaces of bifacial devices, the contribution from the light incident on the opposite side of the device under test shall be 5 Wm^{-2} or less during the measurement by creating a non-irradiating background. The background is considered to be non-irradiating if the irradiance does not exceed 5 Wm^{-2}, at any point, on the non-exposed side of the device under test. The contribution of remaining background illumination shall be compensated during I-V corrections.

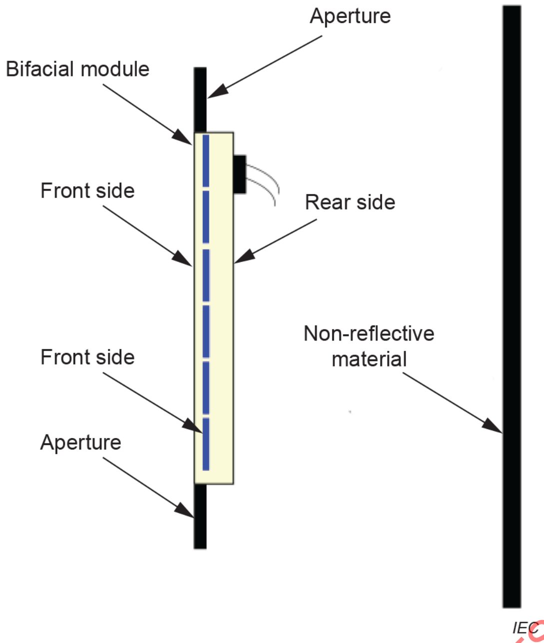


Figure 2 – Scheme of a bifacial PV module and the required non-irradiated background and aperture

In order to fulfil this requirement, in the case of PV modules, it is recommended to limit the size of the test area to that of the device under test using baffles as illustrated in Figure 2. Low reflective materials may be placed against the non-exposed side to reduce the non-irradiated background irradiance.

To measure the irradiance on the non-exposed side, measurements shall be performed at the non-illuminated side. The minimum point density is six points per square meter. The points selected for measurement of non-uniformity of irradiance shall be placed in the middle of a cell at the module's rear face. Furthermore, for c-Si PV modules the distance between neighbouring points horizontally and vertically shall not exceed the area covered by four full-size cells. It is noted that the area covered by two half-cut cells counts as the area of a full-size cell. The area covered by three third-cut cells counts as a full-size cell and so on. For thin film technologies, the maximum distance between the two nearest points shall not exceed 840 mm. For the measurement of non-illuminated background, the PV reference device shall be positioned between the non-reflective surface and the rear side of the module. Figure 3 shows an example of the location of measurement points on a 72-cell PV module. For the measurement of non-illuminated background, the detector shall be positioned against the rear surface of the module. The size of the detector shall be at least half the size of the solar cells used in the module under test.

The criterion for non-irradiated background shall be verified once per optically equivalent module design or when the optical configuration of the measurement system undergoes modifications. Module designs can be considered as optically equivalent if all of the following are the same:

– transparent area fraction,
– total module area, number of cells and cell spacing,
– encapsulation package: this includes the glass (type, thickness, texturing, and spectral transmission), anti-reflective coatings, encapsulant, and backsheet (type, colour, and spectral back-reflection).

The measurement shall be repeated only for devices with higher fraction of transparent areas.

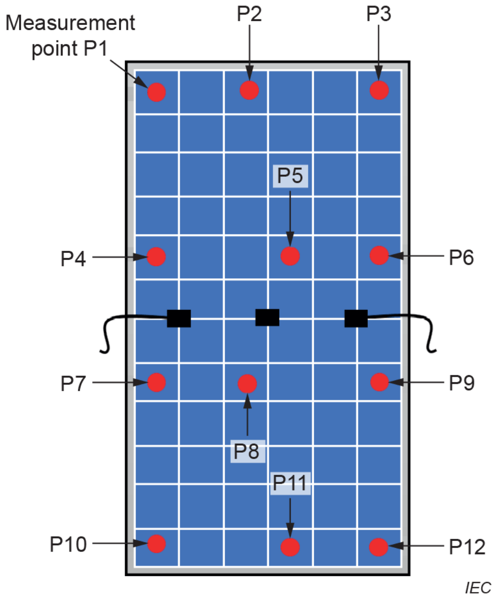


Figure 3 – Suggested points to measure the irradiance at the rear face of a PV module with 72 cells

5.6 Temperature sensors

Care shall be taken to minimize the shadowing if placing sensors to measure the temperature of bifacial devices under natural sunlight or using double-side illumination. When contact sensors are used, sensors should be placed preferably along the solar cell busbars and fixed with transparent thermal tape. Wires shall be placed in such a way that shading on the PV module is minimized (i.e. shortest route to edge). Alternatively, contactless infrared thermometer (IRT) or equivalent cell temperature calculation can be used as described in IEC TS 62446-3 and IEC 60904-5, respectively.

6 Additional I-V characterisations for bifacial devices

6.1 General

The procedure for the measurement of the I-V characteristics of a bifacial PV device is based on the same basic principles as in IEC 60904-1 but requires some additional considerations and also provides supplementary characteristics specific to bifacial devices. For instance, the bifaciality, φ, relative rear irradiance power gain, $BiFi_{\text{rel}}$ and the maximum power output of the device under test at BNPI shall be characterised.

The measurement conditions for I-V characteristics of bifacial devices require more attention than for monofacial devices as the measurement results for bifacial devices are prone to measurements artefacts arising from the deviation of measurement conditions from the reference conditions. For instance, the parasitic reflections towards the rear side of the device under test can significantly increase the measurement uncertainty.

The measured I-V characteristics shall be corrected for spectral mismatch, background irradiance and temperature, wherever possible. As the spectral responsivity of the device may vary between front and rear, it is advisable to measure separately the spectral responsivity from the front and rear side of the device according to IEC 60904-8 and apply separate spectral mismatch corrections for the front and rear. Corrections of measured I-V characteristics are allowed within a range of ±10 % of the target irradiance. The uncertainty of the corrections and furthermore the uncertainty arising from corrections which are not possible or have been omitted shall be considered in the evaluation of measurement uncertainty.

6.2 Determination of bifaciality

In order to determine the bifaciality of the test specimen, the main *I-V* characteristics of the front and the rear sides shall be measured at STC, as schematised in Figure 4 (with G = 1 000 Wm^{-2}). A non-irradiated background, as described in 5.5, shall be used in order to avoid the illumination of the non-exposed side. Ideally a spectrally matched device should be used to determine the irradiance for measurements of front and rear.

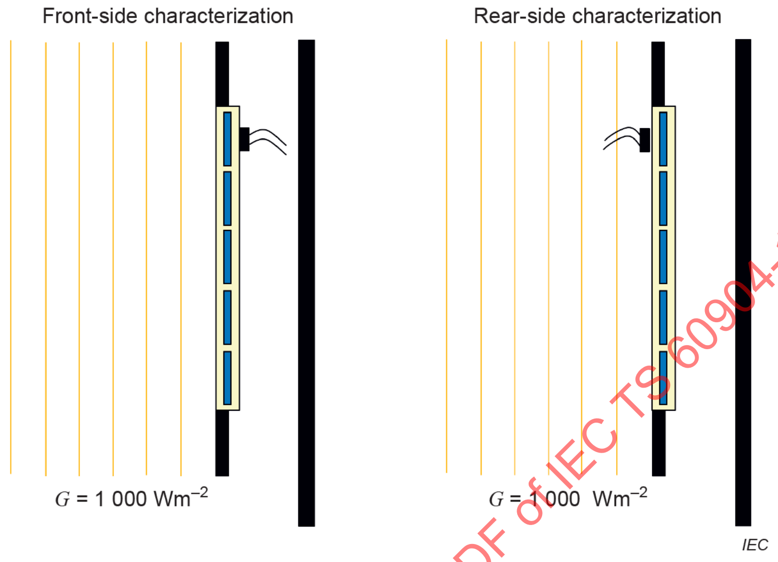


Figure 4 – Front and rear-side characterization of bifaciality

When the rear side of PV modules is measured, care shall be taken to reduce (as practicably as possible) any shading caused from temperature sensors, cables, nameplate, junction box and frame. Manufacturers are responsible for positioning of junction box, frame and nameplate. The measurement setup shall be verified by visual inspection to ensure that no additional shading is introduced, for example by temperature sensors (see also 5.5), cables or other external objects.

When the rear *I-V* curve is measured, the module frame can cause a deviation between the measurement plane and the reference plane. If the reference plane and the measurement plane cannot be brought into alignment, the offset in irradiance intensity shall be determined and corrected. It is noted that the reference plane of irradiance is determined based on the position of solar cells contained in the module, and not its frame.

Short-circuit current bifaciality, $\varphi_{I_{\mathrm{SC}}}$, is the ratio between the short-circuit current generated exclusively by the rear and front side of the bifacial device respectively. Both currents are measured at STC (1 000 Wm^{-2}, 25 °C, with the IEC 60904-3 reference solar spectral irradiance distribution AM1.5):

$$\varphi_{I_{\mathrm{SC}}} = \frac{I_{\mathrm{SCr}}}{I_{\mathrm{SCf}}} \qquad (1)$$

where

$\varphi_{I_{\mathrm{SC}}}$ is the short-circuit current bifaciality. It is usually expressed as a percentage;

I_{SCr} is the short-circuit current when the device is illuminated only on the rear side, at STC;

I_{SCf} is the short-circuit current when the device is illuminated only on the front side, at STC.

The bifaciality, as defined in this document, of the device cannot be determined by double-sided illumination, due to the influence of series resistance that introduces performance losses when the device is exposed to irradiance higher than 1 000 Wm^{-2} and performance gains when the irradiance is lower than 1 000 Wm^{-2}. When double-sided illumination is practiced, it is suggested to report instead the rear irradiance power gain (see 6.3).

For certain technologies and applications, it is advisable to measure the bifaciality at different levels of irradiance. For example, it is typical for c-Si technologies that the bifaciality reduces with reducing irradiance. When the bifaciality is measured at a different irradiance, then the irradiance shall be stated in subscripts omitting SI units. For example, the bifaciality of a device measured at 200 Wm^{-2} of front and rear irradiance shall be expressed as $\varphi_{I_{SC-200}}$.

The bifaciality of open-circuit voltage and maximum power shall be measured at STC and are calculated as described below:

$$\varphi_{V_{OC}} = \frac{V_{OCr}}{V_{OCf}} \tag{2}$$

$$\varphi_{P_{max}} = \frac{P_{maxr}}{P_{maxf}} \tag{3}$$

where

$\varphi_{V_{OC}}$ is the open-circuit voltage bifaciality. It is usually expressed as a percentage;

$\varphi_{P_{max}}$ is the maximum power bifaciality. It is usually expressed as a percentage;

V_{OCr} is the open-circuit voltage when the device is illuminated only on the rear side, at STC;

V_{OCf} is the open-circuit voltage when the device is illuminated only on the front side, at STC;

P_{maxr} is the maximum power when the device is illuminated only on the rear side, at STC;

P_{maxf} is the maximum power when the device is illuminated only on the front side, at STC.

When the bifaciality of open-circuit voltage or maximum power are measured at a different irradiance, the irradiance shall be stated as subscripts omitting SI units. For example, the bifaciality of maximum power for a device measured at 200 Wm^{-2} of front and rear irradiance shall be expressed as $\varphi_{P_{max-200}}$.

It is recommended to measure the bifaciality on multiple samples and to provide its dispersion.

6.3 Determination of the rear irradiance power gain

6.3.1 General

The gain in power generation due to additional rear irradiance on the bifacial device under test shall be determined as a function of the rear side irradiance level. To this end, outdoor or indoor measurement procedures shall be applied as described below.

The bifacial device under test shall be measured at STC, i.e., 1 000 Wm^{-2} (G_r = 0 Wm^{-2}), AM1.5 and 25 °C junction temperature. The front side irradiance shall be within ±10 % of the target irradiance and corrected to this target value (1 000 Wm^{-2}) according to IEC 60891. Note that this irradiance range is more restrictive than that of IEC 60891, which allows for a larger correction range (±30 %).

Additionally, the P_{max} of the device under test shall be measured:

a) In the case of double-sided illumination with G_f = 1 000 Wm^{-2} on the front side plus at least two different rear side irradiance levels G_{r_i};

b) In the case of single sided illumination: with at least two different equivalent irradiance levels G_{E_i} on the front side according to Formula (6) and Formula (7);

with, in both cases (i = 1, 2, …; for instance, $0 \le G_{r_1} < 100\ Wm^{-2}$, $100\ Wm^{-2} \le G_{r_2} < 200\ Wm^{-2}$ and $G_{r_2} - G_{r_1} > 100\ Wm^{-2}$).

The rear irradiance power gain, $BiFi$, is the slope derived from the linear fit of the P_{max} versus G_r data series (see the example in Figure 5 and Table 1). This linear least squares fit shall be forced to cross the P_{max} axis at $P_{max,STC}$ and its non-linearity shall be considered in the uncertainty estimation. The relative rear irradiance power gain $BiFi_{rel}$ is calculated by normalizing $BiFi$ by front irradiance, G = 1 000 Wm^{-2} and front P_{max}, at STC:

$$BiFi = \frac{\Delta P}{\Delta G_r} \tag{4}$$

$$BiFi_{rel} = BiFi \frac{1000\,Wm^{-2}}{P_{max,STC}} \tag{5}$$

NOTE It is planned for next edition of IEC 61215-1 to require either $\varphi_{I_{SC}}$ or $BiFi_{rel}$ to be reported.

Besides $BiFi_{rel}$, the bifacial maximum power, $P_{max,BNPI}$, shall be reported and corresponds to the bifacial nameplate irradiance (BNPI) with front irradiance, G_f = 1 000 Wm^{-2} and rear irradiance, G_r = 135 Wm^{-2}. $P_{max,BNPI}$ shall be obtained according to Formula (6).

$$P_{max,BNPI} = P_{max,STC} + BiFi \cdot G_r \tag{6}$$

Alternative methods, which can predict the bifacial gain and produce a full I-V curve by means of translating known I-V characteristics to target irradiance and temperature, are given in IEC TS 63202-3:2023, Clause A.1 and Clause A.2.

6.3.2 Outdoor rear irradiance power gain measurement

In order to perform outdoor measurement of the rear irradiance power gain, the non-uniformity of irradiance on the rear side shall be below 10 %.

In order to improve the uniformity of irradiance on the rear side, it is recommended to elevate the device under test to higher positions, e.g. to a distance of 0,5 m to 1,0 m between the bottom edge of the device and the ground. A diffusely reflective material may be used to increase the reflection uniformity of the surface behind the device.

6.3.3 Indoor rear irradiance power gain measurement with single-side illumination

In order to perform indoor measurement of the rear irradiance power gain, a solar simulator with adjustable irradiance levels for single-side illumination, as described in 5.2 can be used. To this end, a non-irradiated background is required as described in 5.5.

The equivalent irradiance levels are determined as functions of the bifaciality coefficient $\varphi_{I_{SC}}$ according to Formula (7):

$$G_{\mathrm{E}} = 1\,000\ \mathrm{Wm}^{-2} + \varphi_{I_{\mathrm{SC}}} \cdot G_{\mathrm{r}} \tag{7}$$

Example: A device with bifaciality of $\varphi_{I_{SC}}$ = 80 %, shall be irradiated, on the front side at G_E = 1160 Wm^{-2} to provide the equivalence of G_r = 200 Wm^{-2}.

The same approach may be applied to assess the low-light behaviour of bifacial PV devices, e.g. for a measurement at 200 Wm^{-2} and 40 Wm^{-2} on the front and rear side of a device respectively with 80 % bifaciality, shall be measured at G_f = 200 Wm^{-2} and G_r = 40 Wm^{-2} or G_E = 232 Wm^{-2}.

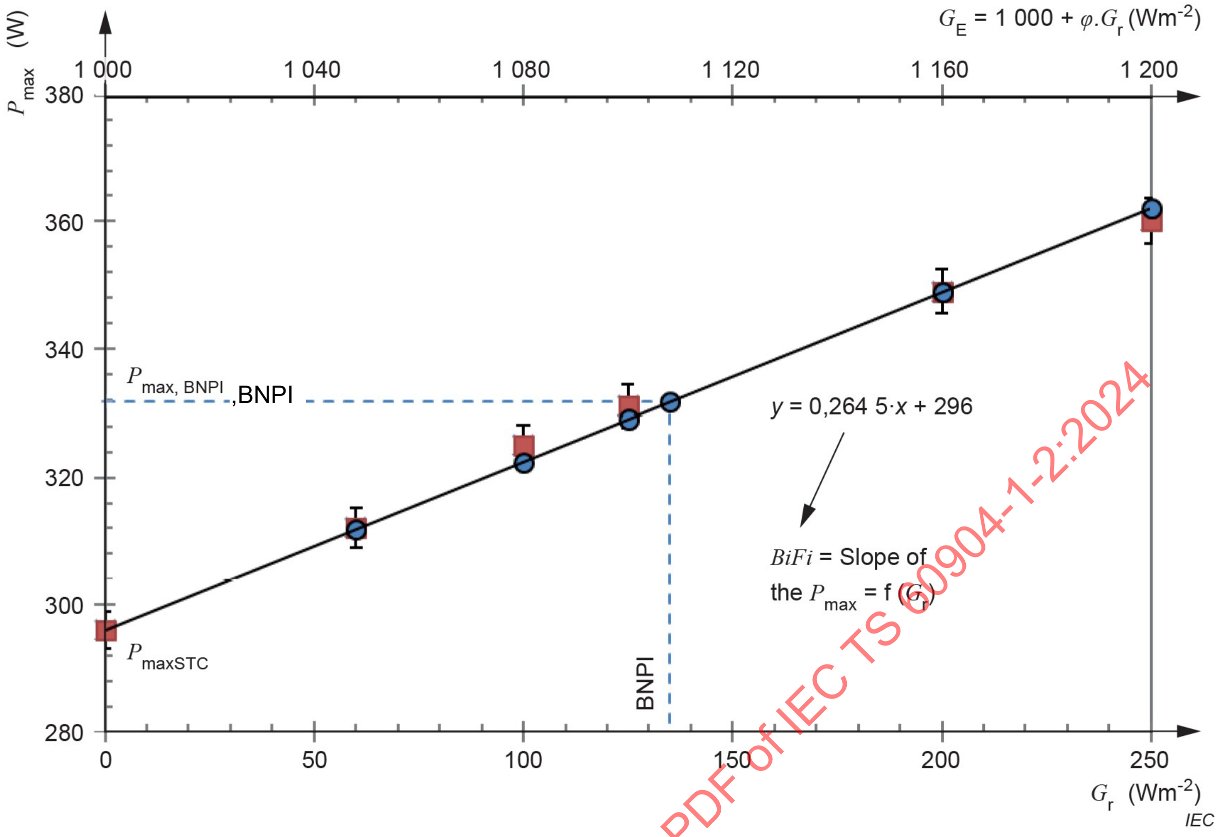


Figure 5 – Examples of P_{max} as a function of irradiance level on the rear side G_r (for outdoor or double-side illumination) or its one-side equivalent irradiance G_e for a device of bifaciality $\varphi_{I_{SC}}$ = 89 %

Table 1 – Maximum power, P_{max}, measured at different rear irradiances, G_r, (double-sided with G_f = 1 000 Wm^{-2}) or alternatively equivalent front irradiances, G_E, and the rear irradiance driven power gain yield, $BiFi$, derived from the slope of the linear fit on $P_{max}(G_r)$

$\varphi_{I_{SC}}$	G_r Wm^{-2}	G_E Wm^{-2}	P_{max} W	$P_{max,BNPI}$ W	$BiFi$ W/(Wm^{-2})	$BiFi_{rel}$ (unitless)
	0	1 000	296			
	60	1 048	312			
	100	1 080	325			
89 %	125	1 100	331		0,264 5	0,8935
	135	1 108	-	331,7		
	200	1 160	349			
	250	1 200	360			

The value of $P_{max,BNPI}$ can be derived from $BiFi$ using Formula (4) as follows:

$$P_{max,BNPI} = P_{max,STC} + BiFi \cdot G_r = 296\ \text{W} + 0{,}264\,5\ \text{m}^2 \cdot 135\ \text{Wm}^{-2} = 331{,}7\ \text{W} \qquad (8)$$

The same value for P_{maxBNPI} may be also derived from $BiFi_{\text{rel}}$ based on Formula (5):

$$P_{\text{max,BNPI}} = P_{\text{max,STC}} + BiFi_{\text{rel}} \cdot \frac{P_{\text{max,STC}}}{1\,000\ \text{Wm}^{-2}} \cdot G_{\text{r}} = 296\ \text{W} + 0{,}893\,5 \cdot \frac{296\ \text{W}}{1\,000\ \text{Wm}^{-2}} \cdot 135\ \text{Wm}^{-2} = 331{,}7\ \text{W} \quad (9)$$

6.3.4 Indoor rear irradiance power gain measurement with double-side illumination

Double-side illumination, as described in 5.3, can alternatively be applied to determine the rear irradiance power gain. In this case, measurements at two different levels at least as described in 6.3.1 are used to assess the power gain yield, $BiFi$.

In order to avoid unwanted reflections between the two light sources, non-reflective masking around the module is recommended. Possible irradiance non-uniformity added by such unwanted reflections shall be assessed in the analysis of measurement uncertainty. The contribution of irradiance on the opposite side determined according to 5.3 can be used to do so.

7 *I-V* characterisation of bifacial PV devices in practice

7.1 General

Two cases are to be considered for the *I-V* characteristics measurement of bifacial devices. In the first case, the bifaciality coefficients of the test specimen are not known. This is usually the case for newly developed or modified devices and PV test and calibration laboratories perform the measurements. The second case corresponds usually to PV production environments, where reference devices of the same technology as the devices to be tested are available.

The determination of the bifaciality coefficients and the measurement of the rear irradiance power gain of the reference devices are to be performed in PV laboratories whereas these characteristics can be used to assess the PV production output. The main differences are described in 7.2.

7.2 *I-V* measurement of bifacial PV devices

In order to assess bifacial devices, in addition to the measurements described in IEC 60904-1 and the requirements of IEC 60904-2 and IEC 60904-4, the bifaciality coefficients and the rear irradiance power gain shall be determined according to the procedures described in this document.

In order to determine the bifaciality coefficients and the rear irradiance power gain the following parameters are required:

- I_{sc}, V_{oc} and P_{max} as functions of at least two irradiance levels larger than zero on the rear side G_{r} or its one-side equivalent irradiance G_{E}.The two rear irradiance levels shall be chosen so that BNPI (corresponding to front irradiance, G_{f} = 1 000 Wm^{-2} and rear irradiance, G_{r} = 135 Wm^{-2}) is within the range, for instance $0 \leq G_{\text{r}_1} < 100$ Wm^{-2}, 100 Wm^{-2} $\leq G_{\text{r}_2} <$ 200 Wm^{-2} and sufficiently distinct from each other, $G_{\text{r}_2} - G_{\text{r}_1} > 100$ Wm^{-2}. For example, G_{r_1} = 50 Wm^{-2} and G_{r_2} = 150 Wm^{-2} is adequate.
- The I_{scBNPI}, V_{ocBNPI} and $P_{\text{max,BNPI}}$ at BNPI shall be either measured at BNPI or calculated from two different rear irradiance levels combined with the STC measurement.

When measuring the spectral responsivity in accordance with IEC 60904-8, care shall be taken to limit the illumination of the non-exposed side.