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

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IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

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This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC TS 60904-1-2 edition 2.1 contains the second edition (2024-11) [documents 82/2278/DTS and 82/2309/RVDTS] and its amendment 1 (2026-03) [documents 82/2552/DTS and 82/2579/RVDTS].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

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 and its amendment 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.

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

$\boldsymbol{BiFi}$

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

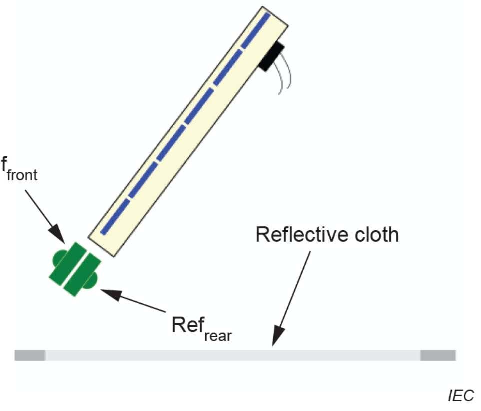
In addition to the apparatus requirements described in IEC 60904-1, one of the equipment sets described in 5.2, 5.3 and 5.4 meeting the requirements for a non-irradiated background as described in 5.5 is necessary for the characterisation of bifacial devices.

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.

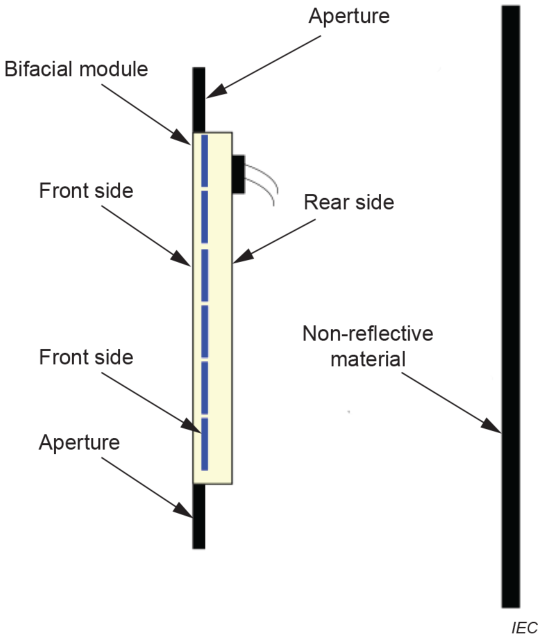


Figure 2 – Scheme of a bifacial PV module and the required non-irradiated background and aperture

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.