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TECHNICAL SPECIFICATION

Photovoltaic cells –
Part 3: Measurement of current-voltage characteristics of bifacial photovoltaic cells

colour inside

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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PHOTOVOLTAIC CELLS –

Part 3: Measurement of current-voltage characteristics of bifacial photovoltaic cells

FOREWORD

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IEC TS 63202-3 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

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

Draft	Report on voting
82/2070/DTS	82/2094/RVDTS 82/2094A/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 https://www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at https://www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 63202 series, published under the general title *Photovoltaic cells*, 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

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- withdrawn,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

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PHOTOVOLTAIC CELLS –

Part 3: Measurement of current-voltage characteristics of bifacial photovoltaic cells

1 Scope

This part of IEC 63202 describes procedures for the measurement of current-voltage (I-V) characteristics of crystalline silicon bifacial photovoltaic (PV) cells for both laboratory and mass production applications.

This document is intended to be used for measurement of individual unencapsulated bifacial PV cells, in addition to the requirements described in IEC 60904-1 and differentiating from IEC TS 60904-1-2 which is more applicable to encapsulated PV device. Specific requirements on bifacial reference cells and calibration of solar simulators are also defined to provide useful guidance for the proposed methods.

The bifacial I-V characteristics contain front standard test condition (STC), rear STC and bifacial STC results for the bifacial PV cells under test. Thus, bifaciality as well as the power generation capability under single-side or bifacial irradiation are evaluated.

NOTE This document does not apply to tandem or multi-junction bifacial PV cells.

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 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 60904-4, *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 60904-9, *Photovoltaic devices – Part 9: Classification of solar simulator characteristics*

IEC 61215-1:2021, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements*

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

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 terminological 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 standard test condition
BSTC
testing conditions that simultaneously meet the following requirements: spectral irradiance distribution according to AM1.5 on both sides, cell temperature of 25 °C, front irradiation intensity of 1 000 $\mathrm{W \cdot m^{-2}}$, and rear irradiation intensity of 135 $\mathrm{W \cdot m^{-2}}$

3.2
low reflection background
testing environment using anti-reflective materials and/or design to reduce the influence of ambient light or light reflected from the testing environment on the intentional irradiance applied to the bifacial PV cells under test

Note 1 to entry: The background is considered to be low reflection, if the difference in short-circuit current is less than 0,3 % when the bifacial PV cell is irradiated single-sided under STC condition, and the non-irradiated side is covered or non-covered.

3.3
bifaciality
ratio between rear and front I-V characteristics of bifacial PV cells

Note 1 to entry: By default, rear STC and front STC I-V characteristics are used to determine bifaciality.

Note 2 to entry: Main bifaciality coefficients include short-circuit current bifaciality φ_{Isc}, open-circuit voltage bifaciality φ_{Voc} and maximum power bifaciality φ_{Pmax}.

Note 3 to entry: The definition of bifaciality is consistent with IEC TS 60904-1-2.

Note 4 to entry: The subscripts "f" and "r" stand for values derived from front- and rear-side measurements, respectively.

3.4
bifacial reference cell
reference cell with bifacial structure similar to the bifacial PV cells under test

Note 1 to entry: The I-V characteristics of the bifacial reference cell, typically calibrated by certified calibration laboratories, are used to calibrate the irradiance of solar simulators. Detailed requirements of bifacial reference cell depend on the method to measure the bifacial PV cells under test.

3.5
bifacial I-V characteristics
I-V characteristics of bifacial PV cells under bifacial standard testing condition (BSTC) with contributions from both front-side and rear-side irradiation

Note 1 to entry: Main bifacial I-V characteristics include bifacial short-circuit current Isc_{BiFi}, bifacial open-circuit voltage Voc_{BiFi} and bifacial maximum power $Pmax_{BiFi}$.

Note 2 to entry: Bifacial I-V characteristics are obtained from direct measurement or equivalent calculation and can be used to evaluate the power generation capability of bifacial PV cells under double-side irradiation.

3.6
bifacial power gain coefficient
$\boldsymbol{BiFi_{rel}}$
gain of $Pmax_{BiFi}$ with respect to $Pmax_f$ as $BiFi_{rel} = \left(\frac{Pmax_{BiFi}}{Pmax_f} - 1\right) \times 100\ \%$

4 Methods

4.1 General

In most cases, bifacial PV modules are operated under double-side irradiance in the outdoor environment. The additional energy yield gain of bifacial PV modules compared to monofacial PV modules comes from the irradiance on the rear-side of the bifacial PV modules.

To evaluate the power generation capability of bifacial PV cells, the I-V characteristics shall be reported at bifacial nameplate irradiance (BNPI), as defined in 3.11 of IEC 61215-1:2021. It corresponds to a front-side irradiance, $G_f = 1\,000\ W \cdot m^{-2}$, and a rear-side irradiance, $G_r = 135\ W \cdot m^{-2}$, on the device under test. Deviation of the measurement test conditions from the reporting standard test conditions are allowed (temperature and irradiance), in which case correction according to IEC 60891 shall be applied and taken into account in the uncertainty calculations.

One out of the following three methods shall be used for measuring bifacial PV cells, depending on the apparatus available. The three methods yield equivalent results following the procedures and requirements described in this document.

a) Double-side simultaneous irradiation.
b) Equivalent irradiation.
c) Sequential irradiation.

The double-side simultaneous irradiation method requires a specific apparatus to provide irradiance to both sides of the bifacial PV cells under test. The monofacial and bifacial I-V characteristics of each cell under test can be measured at the same position and with a single contacting unit and cycle.

Alternatively, the equivalent irradiation method can be used with conventional apparatus for measuring monofacial PV cells. The equivalent irradiation intensity, G_E, is determined in formula (1) using the bifaciality, φ_{Isc}, as follows:

$$G_E = 1\,000 + \varphi_{Isc} \times 135\ W \cdot m^{-2} \tag{1}$$

When measurement time allows (typically for laboratory applications), φ_{Isc} is determined by measuring front STC and rear STC I-V characteristics of each cell under test. When measurement time is limited (typically for mass production applications), φ_{Isc} can be inferred from a bifacial reference cell and reported as representative to all cells under test. The error resulting from such a method is acceptable if the production spread of φ_{Isc} remains within ±3 % relative to that of the bifacial reference cell. Samling of the spread of φ_{Isc} shall be taken into consideration for mass production applications.

The sequential irradiation method can also be used with conventional apparatus. The front-side and rear-side of the bifacial PV cells are characterised in sequence, requiring the cells to be flipped between measurements. The measured front STC, rear STC and optional rear low irradiance I-V characteristics are used to calculate the bifacial I-V characteristics following procedures described in the Annexes to this document based on IEC 60891.

4.2 Double-side simultaneous irradiation

With the bifacial PV cells under test placed in a low reflection background environment, the front STC, rear STC and bifacial I-V characteristics are respectively measured by applying front STC only, rear STC only and simultaneously BSTC irradiation to the bifacial PV cells.

For laboratory application, the front STC, rear STC and BSTC irradiations to the bifacial PV cell under test can be conducted separately and in any sequence.

For mass production application where cycle time matters, the three measurement steps are typically integrated into one sequence. An example schematic procedure of double-side simultaneous irradiation method with integrated flash conditions is shown in Figure 1.

a) step 1 (t1-t2): measure rear STC I-V characteristics under rear STC irradiation;
b) step 2 (t3-t4): measure bifacial I-V characteristics under BSTC irradiation;
c) step 3 (t5-t6): measure front STC I-V characteristics under front STC irradiation.

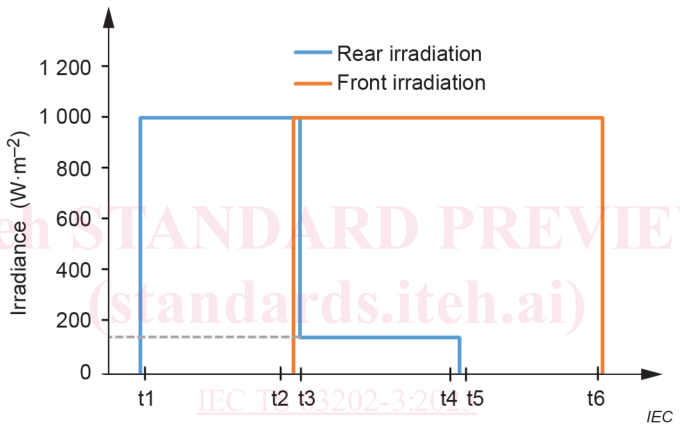

Figure 1 – Schematic procedure of double-side simultaneous irradiation method with integrated flash conditions

In this case, since double-side simultaneous irradiation is used, the irradiance correction described in IEC 60891 cannot be applied without adaptation. The required adaptation is described in formulae (2) and (3) by calculating the equivalent measured, $G_{E,meas}$, and BSTC, $G_{E,BSTC}$, irradiance, such that:

$$G_{E,meas} = G_f + \varphi_{Isc} \times G_r \; W \cdot m^{-2} \tag{2}$$

$$G_{E,BSTC} = 1\,000 + \varphi_{Isc} \times 135 \; W \cdot m^{-2} \tag{3}$$

Then $G_1 = G_{E,meas}$ and $G_2 = G_{E,BSTC}$ can be applied in procedure 1 or 2 of IEC 60891. As in IEC 60904-1, deviation up to 10 % from STC or BSTC conditions are acceptable. For BSTC however, irradiance of the rear-side light source should not be smaller than 100 $W \cdot m^{-2}$ in order to achieve sufficient contribution from the rear side.

4.3 Equivalent irradiation

With the bifacial PV cells under test placed in a low reflection background environment, the front STC, rear STC and equivalent bifacial I-V characteristics are respectively measured by applying front STC, rear STC and front-side equivalent irradiation to the bifacial PV cells. Depending on the set-up and limitation of measurement time, equivalent irradiation method can be conducted in different approaches.

One approach is to sequentially measure front STC, rear STC and equivalent bifacial I-V characteristics of cell under test. For the latter, the φ_{Isc} of each cell under test is used to determine the equivalent irradiation intensity G_E.

The sequential irradiation process can be conducted with one solar simulator, typically for laboratory application, or under the irradiation of two consecutive solar simulators, typically in a production line.

An example schematic procedure of such approach is shown in Figure 2.

a) step 1 (t1-t2): measure front STC I-V characteristics under front STC irradiation;

b) step 2 (t3-t4): measure rear STC I-V characteristics under rear STC irradiation;

c) step 3 (t5-t6): measure equivalent bifacial I-V characteristics under equivalent irradiation.

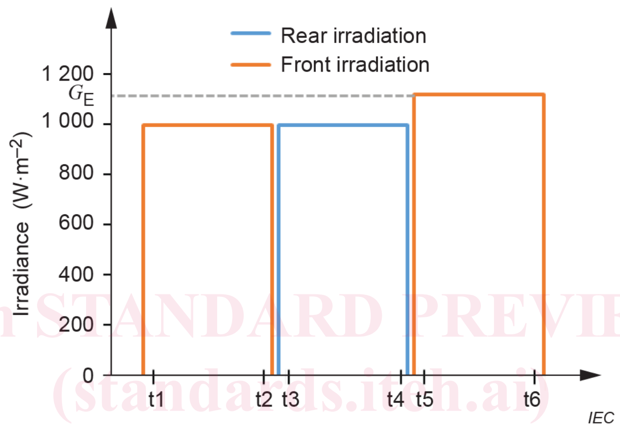

Figure 2 – Schematic procedure of equivalent irradiation method with sequential flash conditions

Another approach is to measure front STC and equivalent bifacial I-V characteristics of cell under test, usually under one contacting and one integrated flash condition. φ_{Isc}, inferred from a bifacial reference cell and assumed to be representative for all cells under test, is used to determine the equivalent irradiation intensity G_E. The error resulting from such approach is acceptable if the spread of φ_{Isc} of cells under test remains within ±3 % relative to that of the bifacial reference cell.

An example schematic procedure of this approach is shown in Figure 3.

a) step 1 (t1-t2): measure equivalent bifacial I-V characteristics under equivalent irradiation;

b) step 2 (t3-t4): measure front STC I-V characteristics under front STC irradiation.