

INTERNATIONAL STANDARD



**Photovoltaic devices –
Part 2: Requirements for photovoltaic reference devices**

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**Photovoltaic devices –
Part 2: Requirements for photovoltaic reference devices**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC DEVICES –

Part 2: Requirements for photovoltaic reference devices

FOREWORD

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This commented version (CMV) of the official standard IEC 60904-2:2023 edition 4.0 allows the user to identify the changes made to the previous IEC 60904-2:2015 edition 3.0. Furthermore, comments from IEC TC 82 experts are provided to explain the reasons of the most relevant changes, or to clarify any part of the content.

A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text. Experts' comments are identified by a blue-background number. Mouse over a number to display a pop-up note with the comment.

This publication contains the CMV and the official standard. The full list of comments is available at the end of the CMV.

IEC 60904-2 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is an International Standard.

This fourth edition cancels and replaces the third edition published in 2015. This edition constitutes a technical revision.

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

- a) added calibration procedures for calibrating PV devices at maximum power by extending the respective Clauses 12 and 13;
- b) revised requirements for mandatory measurement of spectral responsivity, temperature coefficients and linearity, depending on usage and allowing some measurements on equivalent devices;
- c) revised requirements for built-in shunt resistor;
- d) added requirements for traceability of calibration explicitly.

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

Draft	Report on voting
82/2127/FDIS	82/2151/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.

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

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PHOTOVOLTAIC DEVICES –

Part 2: Requirements for photovoltaic reference devices

1 Scope

This part of IEC 60904 gives requirements for the classification, selection, packaging, marking, calibration and care of photovoltaic reference devices.

This document ~~covers~~ applies to photovoltaic (PV) reference devices that are used to ~~determine~~ measure the irradiance of natural or simulated sunlight for the purpose of quantifying the electrical performance of photovoltaic devices (cells, modules and arrays ~~under natural and simulated sunlight~~). It does not cover photovoltaic reference devices for use under concentrated sunlight.

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

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

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

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~~ ~~performance requirements~~ characteristics*

IEC 60904-10, *Photovoltaic devices – Part 10: Methods of ~~linear dependence and linearity~~ measurements*

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 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

calibration traceability

~~traceability as defined in IEC 60904-4~~

<of a PV reference device> requirement for any PV reference device, to tie its calibration value to SI units in an unbroken and documented chain of calibration transfers including stated uncertainties **1**

Note 1 to entry: Photovoltaic reference devices are distinguished by their position in a chain of calibration traceability.

[SOURCE IEC 60904-4:2019, 3.6, modified – The term "traceability" has been replaced with "calibration traceability" and Note 1 to entry has been replaced.]

3.2

reference device

~~specialty calibrated photovoltaic devices which are used to measure natural or simulated irradiance or to set simulator irradiance levels for measuring the performance of other photovoltaic devices~~

traceably calibrated photovoltaic device

Note 1 to entry: Normally used to measure natural or simulated solar irradiance or to set solar simulator irradiance levels for measuring the performance of other photovoltaic devices. **2**

3.3

primary reference device

photovoltaic reference device ~~whose calibration is based on a radiometer or standard detector or standard light source~~ with calibration based on a secondary standard for irradiance **3** traceable to SI units as defined in IEC 60904-4

Note 1 to entry: Typically, a PV cell is used as a reference device for the measurement of natural or simulated solar irradiance.

Note 2 to entry: Primary references are normally used by calibration and testing laboratories to calibrate secondary references.

Note 3 to entry: Normally calibrated at periodic intervals. **4**

3.4

secondary reference device

photovoltaic reference device calibrated in natural or simulated sunlight against a primary reference device

Note 1 to entry: Secondary references are normally used by calibration and testing laboratories to calibrate working references, but also for daily routine measurements, in industrial production and in monitoring.

Note 2 to entry: Normally calibrated at periodic intervals. **5**

3.5

working reference device

photovoltaic reference device calibrated in natural or simulated sunlight against a secondary reference device

Note 1 to entry: Working references are normally used for daily routine measurements, in industrial production and in monitoring.

Note 2 to entry: Normally calibrated at periodic intervals. **6**

3.6

reference cell

~~single photovoltaic cell used primarily for transfer of calibration values~~

reference device consisting of a single photovoltaic cell **7**

Note 1 to entry: For practical reasons, such cells are small in surface area, and are usually mounted on a fixture which ensures reproducibility in mounting, thermal control, electrical connections and protects the device. A typical sample is sketched in Figure 1.

Note 2 to entry: Normally the reference cells are also provided with a protective window and embedded in an encapsulant.

Note 3 to entry: Recommended use: as a laboratory primary, secondary and working reference.

Note 4 to entry: If the encapsulation system has been demonstrated to withstand long-term outdoor exposure, applying test levels according to the IEC 61215 series [1], such reference cells can also be suitable to be used as a monitoring device for long-term assessment of operational PV arrays.

Note 5 to entry: If the reference cell is provided with a protective window but without encapsulant, then it should only be used when measuring the performance of other PV devices using direct beam natural or simulated sunlight. **8**

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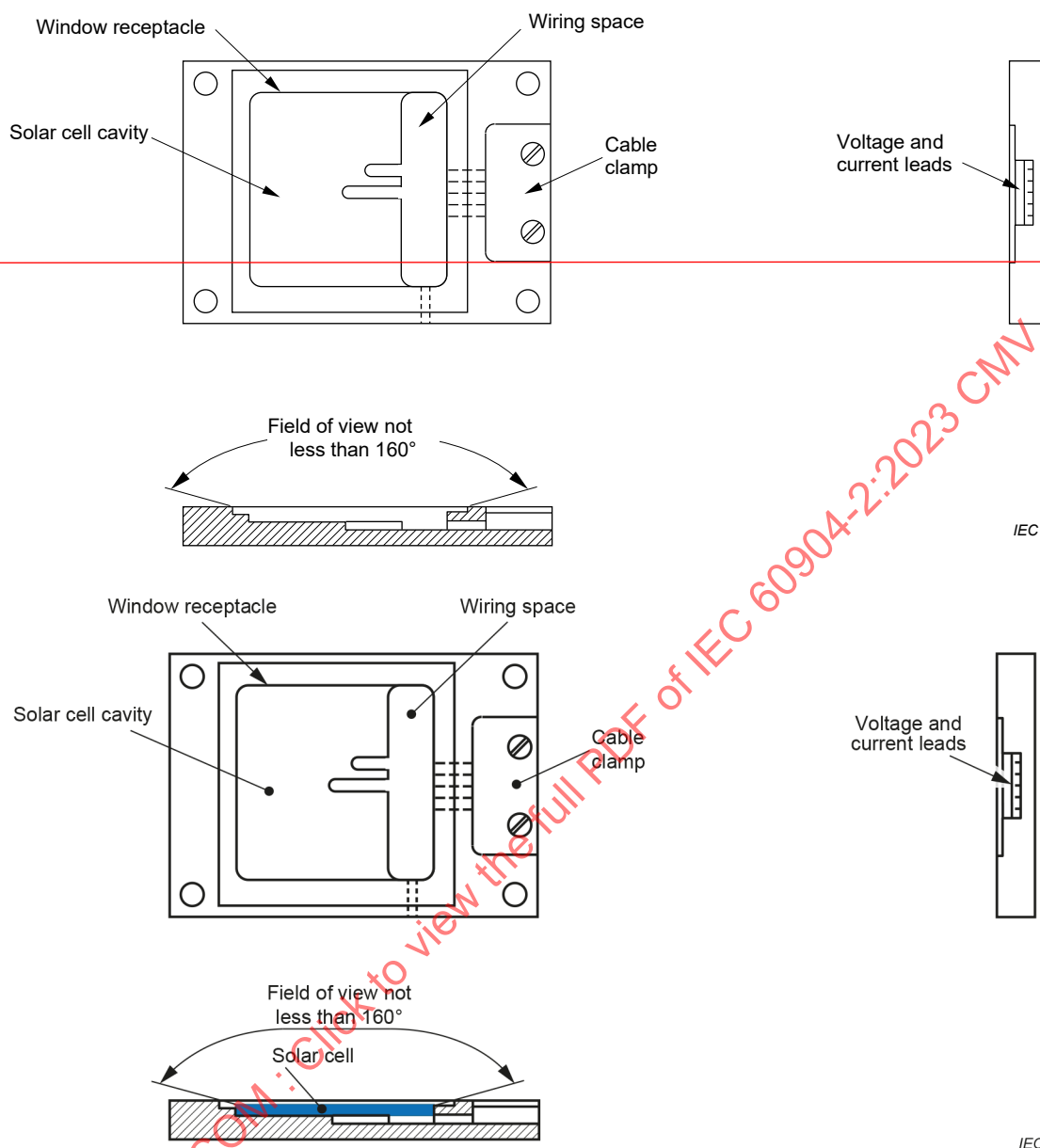


Figure 1 – Single cell package

3.6.1

~~reference cell with protective cover but without encapsulant~~

~~photovoltaic reference cell similar to 3.6, but provided with a protective cover~~

~~Note 1 to entry: Recommended use: as a laboratory primary, secondary and working reference, in particular when measuring the performance of other photovoltaic devices using solar simulators or natural sunlight with direct beam only.~~ **9**

~~3.6.2~~

~~encapsulated reference cell~~~~photovoltaic reference cell similar to 3.6, but encapsulated in a protective assembly so as to withstand short term outdoor exposure~~

~~Note 1 to entry: Recommended use: as a laboratory primary, secondary and working reference, in particular when measurements of the performance of other photovoltaic devices under natural sunlight are performed.~~

~~Note 2 to entry: If the encapsulation system has been demonstrated to withstand long-term outdoor exposure, applying test levels according to IEC 61215, such reference cells may also be suitable to be used as a monitoring device for long-term assessment of operational photovoltaic arrays.~~ **10**

3.7

~~multi-cell reference devices~~

~~photovoltaic device consisting of several photovoltaic cells~~

~~Note 1 to entry: Recommended use: as the diffuse component of natural sunlight and non-normal incidence of simulated sunlight interact with encapsulants and back sheets of a module and influence the amount of irradiance which a particular cell receives, it is recommended that reference devices used for measuring sub-assemblies of modules and arrays be encapsulated in a multi-cell package, matching the mechanical and optical features of the test specimen (module, sub-assemblies of modules, arrays) so as to respond to variations in the geometrical distribution of the incident radiation in the same way as the test specimen.~~ **11**

3.7

single reference cell in a multi-cell package

reference device consisting of a single photovoltaic cell mounted in a package such that frame, encapsulation system, shape, size and spacing of the cells surrounding it are the same as in the PV module to be tested

Note 1 to entry: The surrounding cells may be real or dummies that have the same optical properties.

3.8

reference module

~~photovoltaic module consisting of the encapsulation of a series and/or parallel connection of photovoltaic cells~~

reference device consisting of a photovoltaic module **12**

Note 1 to entry: Recommended use: for measuring other modules in order to achieve correspondence of dimensions, mechanical construction, optical properties and electrical circuitry of the reference module and test module, so as to minimize discrepancies due to solar simulator spatial non-uniformity, internal reflections ~~or~~, temperature distribution and spectral mismatch.

Note 2 to entry: As the diffuse component of natural sunlight and non-normal incidence of simulated sunlight interact with encapsulants and back sheets of a PV module and influence the amount of irradiance which a particular cell receives, it is recommended that reference devices used for measuring PV modules, sub-assemblies of PV modules and PV arrays be encapsulated matching the mechanical and optical features of the device under test. **13**

3.9

built-in shunt resistor

resistor connected across the output terminals of photovoltaic devices including connection wiring

Note 1 to entry: The resistor shunts the output of the photovoltaic device providing an output voltage to be measured and avoiding user-provided means of establishing short-circuit condition.

Note 2 to entry: For details consult 4.4.

4 Selection of reference device

4.1 General requirements

Depending on their intended use, reference devices need to meet different requirements in terms of their spectral responsivity, mechanical construction, optical properties, dimensions and electrical circuit. The spectral responsivity of the reference device, for example, is determined by the transmission of any protective ~~cover~~ window in front of the device and the spectral responsivity of the device itself. Therefore, the overall spectral responsivity can be adapted by using suitable filters as or in addition to the protective ~~cover~~ window.

~~A reference device shall meet the following requirements:~~

~~a) photovoltaic characteristics shall be stable according to the requirements in Clause 11;~~

~~b) the output signal of the reference device shall vary linearly with irradiance, as defined in IEC 60904-10, over the range of interest.~~ **14**

Reference devices should be made using a PV technology that is known to be stable with time. In particular, the calibration value should not change after the reference device has been exposed to solar irradiation, device temperatures different from its calibration temperature and/or extended storage in the dark. The photovoltaic characteristics of a reference device shall be stable according to the requirements in Clause 11. **15**

The reference device shall be constructed such that the photovoltaic performance parameters, in particular short-circuit current and maximum power, can be measured. The only exception are devices with a built-in shunt resistor, see 4.4.

4.2 Additional requirements for single reference cell in a multi-cell package

The dotted line in Figure 2 indicates the minimum acceptable size of a multi-cell package. For other cell arrangements, such as half-cut cells, an analogous configuration applies.

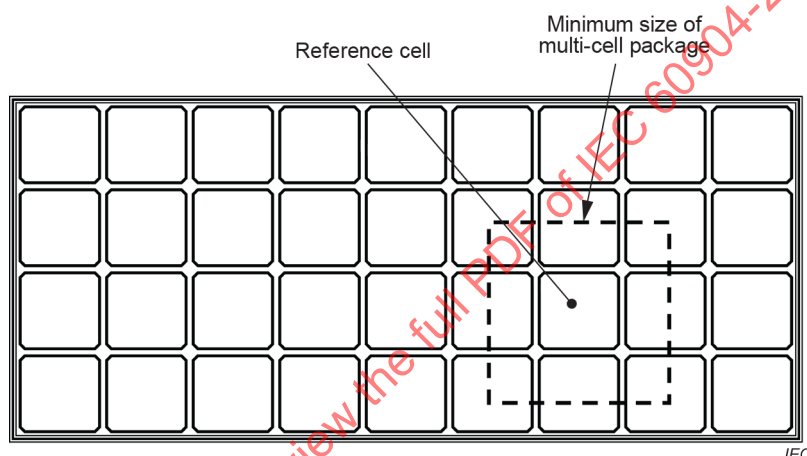


Figure 2 – Single reference cell in a multi-cell package

4.3 Additional requirements for reference modules

Additional requirements apply to reference modules.

a) Bypass diodes:

- general reference modules, which are used to measure a range of module types and geometries, should not contain bypass diodes. The presence or absence of bypass diodes shall be noted and considered in conjunction with the measurement conditions, in particular spatial non-uniformity of the irradiance on the module during measurement;
- for reference modules, which are intended to be matched to the module under test, the number, type and connection of bypass diodes (if present) shall match those in the module under test.

b) If they are made from discrete cells, these ~~shall~~ should **16** be matched as follows depending on the intended use of the reference module:

- if only the short-circuit current of the reference module will be used, the short-circuit current of the individual cells ~~shall~~ should **17** be matched to within ± 1 %;
- if other parameters (such as maximum power) are used additionally or exclusively, both the short-circuit current and the fill factor of the individual cells ~~shall~~ should **18** be matched to within ± 1 %.

The matching of the individual cells is the responsibility of the manufacturer of the reference module, bearing in mind that matching ~~may~~ can also be influenced by encapsulation or lamination. The cell matching need not be checked by the calibration laboratory. However, if I - V curves of the reference module indicate inconsistent response (i.e. obvious steps are noted in the I - V curve), ~~the I - V curve should be measured under light that is known to be uniform (e.g. natural sunlight) to determine whether there is evidence that the cells within the module are matched within 1 %~~ this should be discussed between calibration laboratory and the client supplying the module before proceeding with calibration. ~~If the module exhibits evidence of > 1 % mismatch between cells, the module shall not be used as reference module.~~ 19

4.4 Requirements for built-in shunt resistors

The built-in shunt resistor (see 3.9) ~~shall~~ should 20 be chosen such as to ensure that the reference device operates sufficiently near to short-circuit condition, meeting the requirement in Formula (1):

$$I_{SC} \times R_{CAL} < 0,03 \times V_{OC}$$

$$R_{CAL} < \frac{0,2 \times V_{OC}}{I_{SC}} \quad (1)$$

where

R_{CAL} is the built-in shunt resistor;

I_{SC} is the short-circuit current of the reference device at desired reference conditions;

V_{OC} is the open circuit voltage of the reference device at desired reference conditions.

~~If a shunted reference cell does not meet the requirement of formula (1), it shall only be used at irradiances (± 5 %) and temperatures (± 2 °C) at which it was calibrated.~~ 21

The long-term stability of ~~such resistors~~ the built-in shunt resistor shall also meet the stability requirements of the reference device. Calibration values of such reference devices shall be measured as the voltage drop across the built-in shunt resistor and stated with the dimension [V] ~~at standard test conditions (see Clause 7)~~. The temperature coefficient of the built-in shunt resistor is part of the temperature coefficient of the calibration value of the reference device. As the uncertainty in the calibration ~~may~~ can be strongly dependent on the built-in shunt resistor stability and temperature coefficient, respective values should be provided with the reference cell data sheet.

~~If a shunted reference cell is to be used for low irradiance measurements, either a dedicated cell can be constructed with the restriction of formula (1), where the short circuit current is considered at the desired low irradiance rather than at STC. Alternatively a shunted cell can have a larger shunt resistor, but requires a separate calibration for each irradiance and temperature it is to be used at.~~ 22

It is recommended that the shunt resistor be a removable 4-wire resistor, to allow for standard (current-based) measurements of spectral responsivity and periodic checking of the reference device stability by ~~taking~~ measuring an I - V curve ~~per~~ in accordance with IEC 60904-1. However, the reproducibility of the electrical connection shall be maintained.

Formula (1) means that the measured output voltage of a shunted reference cell ~~shall~~ should be less than ~~3~~ 20 % 23 of its open circuit voltage. For typical crystalline silicon this equates to about ~~20~~ 120 mV output.

5 Temperature measurement

Means shall be provided for determining the reference cell temperature or, for reference modules, the equivalent cell temperature (ECT), according to IEC 60904-5. Temperature sensors and instrumentation shall have instrumental measurement uncertainty of 1 °C or less **24**. The required uncertainty for temperature measurements for the cell junction shall be less than $\pm 2,0$ °C for all reference devices. ~~A minimum accuracy of $\pm 1,0$ °C for the temperature sensor is suggested to achieve this uncertainty in the temperature measurement.~~

6 Electrical connections

The electrical connections to reference cells without built-in shunt resistor shall consist of a four-wire contact system (Kelvin probe). ~~Care shall be taken to avoid~~ Measurement errors due to voltage drops along the cell's contact bars and the package wiring shall be avoided.

The electrical connections to the reference module shall be designed to meet the requirements of IEC 60904-1.

7 Calibration

7.1 General requirements

Each calibration of a reference device shall be made with a calibration procedure that is traceable according to IEC 60904-4. Any measurement instrument used in the calibration procedure shall be an instrument with an unbroken traceability chain. **25**

The laboratory performing the calibration of the reference device shall maintain a documented uncertainty analysis as well as documented repeatability and results from interlaboratory comparisons.

7.2 Calibration value(s)

Each reference device shall be calibrated in terms of its calibration value(s) at the desired reference conditions. ~~normally standard test conditions (STC) ($1\,000\text{ W m}^{-2}$, 25 °C device temperature with the reference spectral irradiance distribution as defined in IEC 60904-3).~~ Calibration values shall be reported together with the three main parameters of total irradiance, device junction temperature and spectral irradiance. The most common calibration conditions are standard test conditions (STC). A calibration at STC shall refer to a total irradiance of $1\,000\text{ W m}^{-2}$, a device junction temperature of 25 °C and the reference spectral irradiance distribution as defined in IEC 60904-3. Sometimes calibration is required at other conditions. A reference device can have multiple calibration values for different desired reference conditions. In particular, IEC 61853-1 [2]¹ requires the use of a reference device at a range of irradiances and temperatures and therefore the calibration at the respective conditions. **26**

Methods for calibrating primary reference devices are included in IEC 60904-4. ~~A method~~ procedure of calibrating secondary reference devices is described in Clause 13. The calibration of working reference devices is treated in Clause 14.

7.3 Spectral responsivity

In general, the spectral responsivity at short-circuit current conditions of each reference device shall be measured in accordance with IEC 60904-8. ~~If for reference modules this cannot be measured directly, it shall be deduced from measurements made on representative encapsulated photovoltaic cells.~~ For exceptions related to working references, see Clause 14. **27**

¹ Numbers in square brackets refer to the Bibliography.

7.4 Temperature coefficients

The determination of the temperature coefficient(s) of each reference device ~~shall be measured~~ in accordance with IEC 60891 is in general optional but depending on usage might be mandatory, and in any case is strongly recommended. If the temperature coefficient(s) are determined, also their linear dependence in accordance with IEC 60904-10 shall be reported. For exceptions related to working references, see Clause 14. **28**

7.5 Linearity

The determination of linearity in accordance with IEC 60904-10 is in general optional but depending on usage might be mandatory, and in any case is strongly recommended. For exceptions related to working references, see Clause 14. **29**

8 Documentation and report **30**

~~Each time a reference device is calibrated, the following information shall be recorded on a data sheet:~~

- ~~— Identification number~~
- ~~— Type (primary reference cell; secondary reference device; working reference device)~~
- ~~— Cell manufacturer~~
- ~~— Material type~~
- ~~— Type of package~~
- ~~— Type and dimension of cell(s)~~
- ~~— Circuit diagram, in particular of any connectors~~
- ~~— Calibration organization~~
- ~~— Site and date of calibration~~
- ~~— Method of calibration (refer to standard)~~
- ~~— Radiometer or standard lamp characteristics (where applicable)~~
- ~~— Primary reference cell identification (where applicable)~~
- ~~— Simulator characteristics (where applicable)~~
- ~~— Type of temperature sensor (where applicable)~~
- ~~— Spectral responsivity~~
- ~~— Temperature coefficient of calibration value~~
- ~~— Calibration value at reference conditions~~
- ~~— Reference conditions~~
- ~~— Estimated uncertainty~~
- ~~— Shunt resistor nominal resistance and temperature coefficient (where applicable)~~
- ~~— Either the mismatch correction value used in the measurement or an estimate of the uncertainty introduced by using the mismatched reference device.~~

~~For reference cells without fixed electrical connection to the cell, the following information shall be recorded on the data sheet:~~

- ~~— Illustration of type, shape and location of electrical contacts during calibration.~~

~~For reference modules, the following information shall be recorded in addition on the data sheet:~~

- ~~— manufacturer~~
- ~~— model designation~~
- ~~— serial number~~

- ~~— cell technology~~
- ~~— construction and dimensions of module~~
- ~~— electrical circuit layout~~
- ~~— presence or absence of bypass diodes and if present their number and type.~~

8.1 General

The information given in 8.2 and 8.3 shall be recorded for each reference device.

8.2 Device documentation

The data sheet shall be compiled by the manufacturer of the reference device and contain the following information:

- a) unique identification of the device;
- b) cell manufacturer and device manufacturer;
- c) material type;
- d) type of package;
- e) type and dimension of cell(s);
- f) circuit diagram, in particular of any connectors;
- g) type of temperature sensor (where applicable) and its uncertainty;
- h) shunt resistor type, nominal resistance and temperature coefficient (where applicable).

For reference modules, the following information shall be recorded in addition:

- a) manufacturer of module;
- b) model designation;
- c) serial number;
- d) cell technology;
- e) construction and dimensions of module;
- f) electrical circuit layout;
- g) presence or absence of bypass diodes and if present their number and type.

8.3 Calibration report

Each time a reference device is calibrated, the calibration report shall contain the following information:

- a) unique identification of the device;
- b) indication that the device has a built-in shunt resistor (where applicable);
- c) type (primary reference cell; secondary reference device, working reference device);
- d) calibration organization;
- e) site and date of calibration;
- f) method of calibration (refer to standard);
- g) identification of the reference device used for the calibration and its traceability according to IEC 60904-4;
- h) simulator type and classification (where applicable);
- i) calibration value(s) and corresponding reference conditions (total irradiance, device junction temperature, spectral irradiance); in case of calibration via current-voltage characteristics both short-circuit current and maximum power shall be reported; the open-circuit voltage should also be reported;
- j) spectral responsivity (where applicable);

- k) temperature coefficient of calibration value(s) as well as linear dependence (where applicable);
- l) linearity (where applicable);
- m) uncertainties for items i), j), k) and l);
- n) either the spectral mismatch correction value used in the measurement or an estimate of the uncertainty introduced by using an equivalent device;
- o) statement that measurements originate from an equivalent device and an identification of which measurements these are (where applicable);
- p) unique identification of the equivalent device(s) (where applicable).

For reference cells without fixed electrical connection to the cell, the following information shall be provided:

- q) illustration of type, shape and location of electrical contacts during calibration.

9 Marking

The reference device shall carry a clear, indelible serial or identification number for cross-reference to its data sheet.

10 Packaging

10.1 Recommended packaging for use in natural sunlight

The reference device used for measurement in natural sunlight should respond to variations in the geometrical distribution of the incident radiation in the same way as the **device under test specimens** (cells, sub-assemblies of cells, modules). As encapsulants and back sheets respond to the diffuse component of natural sunlight, it is recommended that reference cells used for measuring modules be enclosed in a multi-cell package (see Figure 2), simulating the neighbouring optical parameters of a module.

In this case, the frame, the encapsulation system, the shape, and the size and spacing of the cells surrounding the reference cell shall be the same as in the module to be tested. The surrounding cells may be real or dummies that have the same optical properties. The dotted line in Figure 2 indicates the minimum acceptable size of the multi-cell package for outdoor testing.

10.2 Recommended packaging for use under solar simulators

In some **solar** simulators which allow multiple reflections of light to and from the **device under test-specimen**, the irradiance in the test plane ~~may~~ can change depending on whether or not the **device under test-specimen** is present. Therefore, in order to measure accurately the irradiance that will be present when the **device under test-specimen** is in place, the reference devices used in such **solar** simulators ~~shall~~ should be packaged in the same way as the **device under test-specimen**, so that the change in irradiance due to multiple reflections is the same for both the reference device and the **device under test-specimen**.

Reference cells used for measurements in **solar** simulators designed to minimize any error from multi-reflected light may be packaged singly or, if not intended for day-to-day use, mounted in the unpackaged state on a temperature-controlled block.

Alternatively, the requirements given for reference cells for use in natural sunlight may be followed.

10.3 Single cell package

If a single cell package is used, the following recommendations are made.

- a) The field of view should be at least 160°. In case of a protective window the optical properties of the latter have to be considered in determining the effective field of view of the photovoltaic cell. The field of view is particularly important for measurements under natural sunlight, whereas for usage on solar simulators with a limited range of angles of incidence, it is less critical. **31**
- b) All surfaces in the package within the cell's field of view should be non-reflective, with ~~an absorption~~ a spectral absorptance of at least 0,95 in the cell's wavelength responsivity band.
- c) The material used for bonding the cell to the holder should be resistant to degradation, either electrically or optically. Its physical characteristics should remain stable over the entire period of intended use.
- d) The use of a protective window is recommended. If encapsulated, the space between the window and the cell should be filled with a stable encapsulant. Both the protective window and the encapsulant should be transparent over the wavelength range in which the PV reference device has a non-zero spectral responsivity. The refractive index of the encapsulant should be similar (within 10 %) to that of the window to minimize errors due to the internal reflection of light. The transparency, homogeneity and adhesion of the encapsulant should not be adversely affected by ultra-violet light and operational temperatures.
- e) The protective window may embody a filter to match the spectral responsivity of the reference cell to that of the ~~device under test~~ **specimen**, provided that the other ~~requirements~~ **recommendations** of d) are met.

Figure 1 shows an example of a suitable single cell package. Other suitable single cell packages can be found in JIS C8910 [3] or the World Photovoltaic Scale [4].

11 Care of reference devices

It is recommended that reference devices be recalibrated on an annual basis.

The window of a packaged reference device shall be kept clean and scratch-free.

Uncovered reference cells shall be preserved against damage, contamination and degradation.

A reference device exhibiting any defect which might impair its function shall not be used.

The calibration value of a reference device might change systematically as a function of time for successive calibrations. If the calibration value of a reference device has changed by more than 1 % with respect to its previous calibration or by more than 5 % of its initial calibration, it shall not be used as a reference device.

12 Usage of reference devices **32**

Reference devices shall only be used at irradiances (± 10 %) and temperatures (± 5 °C) at which they were calibrated. For the ranges given, use of a simple correction according to established procedures provided in IEC 60891 with generic correction coefficients is acceptable, as long as the additional uncertainties introduced are taken into account.

The usage of reference devices outside the ranges given above requires the following in addition to the single calibration at one reference condition (normally STC):

- a) a separate calibration for each desired reference condition it is to be used at; or
- b) if to be used over a wider temperature range: a determination of the relevant temperature coefficient(s) according to IEC 60891 (and their linear dependence according to IEC 60904-10) and appropriate corrections for differences between the temperatures during usage and the calibration temperature; and/or

- c) if to be used over a wider irradiance range: a determination of the linearity (output versus irradiance) over the relevant irradiance range according to IEC 60904-10 and appropriate corrections for differences between the irradiance during usage and the calibration irradiance.

The reference device can be used in the ranges of conditions mentioned above around the additional reference conditions with a). Alternatively, it can be used with the calibration value of the original reference condition over a wider temperature range with b) or a wider irradiance range with c). If a usage over wider temperature and irradiance ranges is desired, b) and c) are both required.

13 Calibration of secondary reference devices against a primary reference cell

13.1 General

This Clause 13 describes a procedure for calibrating a secondary reference device in natural or simulated sunlight against a primary reference cell whose calibration is traceable to SI units according to IEC 60904-4. The procedure described is an example and other calibration procedures are acceptable as long as they meet the requirements of 7.1. In any case, the spectral ~~responsivity~~ mismatch between the primary reference cell and that of the secondary reference device under the ~~illumination~~ irradiance used for the calibration shall be determined according to IEC 60904-7. ~~If the spectral mismatch correction is less than 1 %, the mismatch correction may be omitted.~~ **33**

The primary reference cell is calibrated such that its output (short-circuit current or voltage across a built-in shunt resistor in case of shunted cell) can be used to determine the irradiance of the natural or simulated sunlight. The calibration value(s) of the secondary reference device can be determined by measuring:

- a) its output (short-circuit current or voltage across a built-in shunt resistor in case of a shunted device). This is the most common calibration if the secondary reference device is a cell;
- b) its current-voltage characteristics according to IEC 60904-1. This permits the calibration of the maximum power and of the short-circuit current. This is the most common calibration if the secondary reference device is a module.

For secondary reference devices with built-in shunt resistor only a) is applicable, as b) is not possible. For secondary reference devices without built-in shunt resistor, the choice of calibration depends on the intended use. For guidance on the use of short-circuit current or maximum power of a reference device refer to IEC TR 60904-14 [5]. **34**

The procedure can be applied using both natural and simulated sunlight according to the requirements in IEC 60904-1 with the restrictions given in 13.2 and 13.3.

13.2 Natural sunlight

Calibration in natural sunlight shall be carried out under the following conditions:

- a) clear, sunny weather, with the diffuse irradiance not greater than 20 % of the global irradiance. For determining the contribution of diffuse irradiance, see IEC 60904-4;
- b) no observable cloud formations within 30° of the sun;
- c) total irradiance (sun + sky + ground reflection) not less than 800 W m⁻², as measured by the primary reference cell;
- d) geometric air mass between AM1 and AM2;
- e) radiation sufficiently stable so that the variation in reference cell output signal is less than ±0,5 % over the time taken for a measurement.

13.3 Simulated sunlight

The simulated sunlight for calibration can either be continuous or pulsed. Normally the primary reference cell and the secondary reference device are positioned side by side and measured simultaneously. In this case the solar simulator shall be of Class AAA or better in accordance with IEC 60904-9 with the additional requirement that the non-uniformity of irradiance is less than ± 1 % within the surface that includes the device to be calibrated and the primary reference device. For 13.1 a) the requirement of Class A with respect to temporal instability as defined in IEC 60904-9 need only be met for the short-term instability (STI) as the long-term instability (LTI) is not relevant in this case. In case that the primary and secondary reference device are of the same or similar size (ratio of active areas between 0,5 and 2,0), an additional measurement shall be taken exchanging their positions. A valid result is only obtained if both measurements agree within the measurement uncertainty.

If the requirement of spatial non-uniformity of less than ± 1 % cannot be met for calibrating reference modules made from a series connection of cells, the solar simulator shall be class A for spatial non-uniformity and a detailed uncertainty analysis shall be provided ~~taking into account mismatch in short-circuit current of the individual cells.~~

In the special case that the primary reference cell and the secondary reference device are of the same or similar size (ratio of active areas between 0,5 and 2,0) and that the continuous simulated sunlight is stable, the two devices can be placed in the same position one after the other and measured consecutively. In this case the solar simulator shall be of Class AAA in accordance with IEC 60904-9 with the additional requirement that the LTI of irradiance is less than ± 1 %, where the LTI is with respect to the total time period needed for the measurements. A pulsed solar simulator ~~may~~ can also be suitable if the repeatability of each pulse is better than 1 %. ~~This shall be recorded using a suitable monitor cell.~~

In any case, a detailed measurement uncertainty analysis considering both spatial ~~and temporal~~ non-uniformity and temporal instability of the simulated sunlight needs to be provided, considering the specifics of the chosen measurement strategy.

13.4 Test procedure

~~12.4.1 Before the initial calibration, measure the spectral responsivity and temperature coefficient of short circuit current of the secondary reference device, using the procedures specified in IEC 60904-8 and IEC 60891, respectively. Whenever a change in the calibration value at the reference conditions of more than 2 % with respect to this initial calibration is detected, the measurements of spectral responsivity and temperature coefficient shall be repeated.~~ 35

13.4.1 Adjust the mount so that the devices are normal to the light source within $\pm 5^\circ$:

- a) mount the primary reference cell and the secondary reference device co-planar within ~~$\pm 4^\circ$~~ $\pm 2^\circ$ 36 and in close proximity on the same mount (for simultaneous measurement), or
- b) mount the primary reference cell in the designated position (for consecutive measurement).

13.4.2 Control the cell temperature of both the primary reference cell to the temperature at which it was calibrated (normally $(25 \pm 2)^\circ\text{C}$) and the secondary reference device ~~at~~ to the desired temperature for calibration (also normally $(25 \pm 2)^\circ\text{C}$). Where this is not practical, readings of output signal shall be subsequently corrected to ~~25°C~~ the respective temperatures in accordance with IEC 60891. 37

13.4.3 The spectral mismatch shall be corrected according to IEC 60904-7. Appropriate measurements of the spectral irradiance shall be recorded.

13.4.4 Record simultaneous readings of:

- a) the output signal and temperature of the primary reference cell (for consecutive measurement) (only for measurements under simulated sunlight), or

- b) the output signal and temperature of both primary reference cell and secondary reference device (for simultaneous measurement and calibration according to 13.1 a)), or
- c) the output signal and temperature of primary reference cell as well as temperature and current-voltage characteristics of secondary reference device (for simultaneous measurement and calibration according to 13.1 b)). **38**

13.4.5 Repeat step 13.4.4 a) or b) until at least five, or 13.4.4 c) until at least three successive sets of readings are obtained in which:

- ~~— the ratio of the output signals (corrected to 25 °C and for spectral mismatch as required) does not vary by more than $\pm 0,5$ % (for simultaneous measurement),~~
- ~~— the output signals for the primary reference cell (corrected to 25 °C and for spectral mismatch as required) do not vary by more than $\pm 0,5$ %; then remove primary reference cell and mount the secondary reference device in the same position and repeat step 12.4.5 with the same constraints as for the primary reference cell (for consecutive measurement).~~
- for consecutive measurement: the output signals for the primary reference cell (corrected to the temperature at which it was calibrated (normally (25 ± 2) °C)) do not vary by more than $\pm 0,5$ %; then remove the primary reference cell and mount the secondary reference device in the same position and
 - a) repeat step 13.4.4 a) with the same constraints as for the primary reference cell (for calibration according to 13.1 a)), or
 - b) record temperature and current-voltage characteristics of secondary reference device (calibration according to 13.1 b)); **39**
- for simultaneous measurement: the ratio of the output signals (corrected for temperature and for spectral mismatch as required) does not vary by more than $\pm 0,5$ %. **40**

13.4.6 If the primary reference cell and the secondary reference device are of the same or similar size (ratio of active areas between 0,5 and 2,0) and are measured simultaneously, exchange the position between the primary reference cell and the secondary reference device and repeat steps 13.4.4 and 13.4.5.

~~**12.4.8** When calibrating in natural sunlight, steps 12.4.2 to 12.4.6, inclusive, shall be performed at least twice a day on at least three separate days. **41**~~

13.4.7 From the acceptable data, calculate the ratio of the output of the secondary reference device to the output of the primary reference cell.

$$\frac{\text{Output signal of secondary reference device at } 25\text{ °C}}{\text{Output signal of primary reference cell at } 25\text{ °C}}$$

13.4.8 To obtain the calibration value of the secondary reference device:

For calibration according to 13.1 a): multiply the calibration value of the primary reference cell by the calculated:

- a) ratio of the means of the output signals from secondary reference device to primary reference cell (for consecutive measurement), or
- b) mean of the ratios of output signals from secondary reference device to primary reference cell (for simultaneous measurement).

The output signals shall be corrected for amplification factors of measurement electronics.

For calibration according to 13.1 b): determine the current-voltage characteristics at the desired reference conditions according to IEC 60891 based on the irradiance measured with the primary reference cell; then determine the maximum power and the short-circuit current as well as the open-circuit voltage from each measured current-voltage characteristic according to

IEC 60904-1 (for consecutive and simultaneous measurement). The calibration values are determined as the average of the respective parameters from all measured current-voltage characteristics. **42**

If measurements have been taken with the positions of the primary reference cell and the secondary reference device exchanged, calculate the calibration value for both cases. The results are only valid if both agree within the measurement uncertainty. Both values ~~are to~~ shall be reported and their geometric average ~~is to~~ shall be used as the calibration value.

13.5 Additional measurements **43**

13.5.1 Spectral responsivity

Measure the spectral responsivity of the secondary reference device, using the procedures specified in IEC 60904-8.

13.5.2 Temperature coefficient(s)

If required, measure the temperature coefficient(s) of short-circuit current and/or maximum power of the secondary reference device, using the procedures specified in IEC 60891.

13.5.3 Linearity

If required, measure the linearity of the secondary reference device output, using the procedures specified in IEC 60904-10.

14 Calibration of working reference device against a secondary reference device **44**

For calibration of a working reference device against secondary reference device the above procedure (Clause 13) or other calibration procedures that meet the requirements in this document and in particular those of 7.1 may be applied, ~~omitting the spectral mismatch correction if the secondary and working reference are of the same material and construction, otherwise the same procedure as described in Clause 12 should be applied.~~ If the secondary reference has been calibrated according to 13.1 b) then its maximum power can be used as reference value. For guidance on the use of short-circuit current or maximum power of a reference device, refer to IEC TR 60904-14 [5]. **45**

Sometimes it is not required or possible (technically or economically) to perform all measurements on every single working reference device. Therefore, in some cases measurements can be made on equivalent devices as detailed below. For two devices to be equivalent, they shall be constructed using the same cell technology and encapsulation package. This includes the glass (type, thickness, texturing, and spectral transmission), anti-reflective coatings, encapsulant, and back sheet (type, colour, and spectral back-reflection).

The measurement of the calibration value(s) at all desired reference conditions shall be performed on every single working reference device.

The measurement of the spectral responsivity of the working reference device and the spectral mismatch correction can be omitted when the secondary reference and working reference are equivalent devices. The measurement of the spectral responsivity of the working reference device can also be omitted if the spectral responsivity of a device equivalent to the working reference device is used for spectral mismatch correction. In both cases additional contributions to uncertainty shall be considered explicitly.

The measurement of the temperature coefficient(s) of the working reference device can be omitted when the respective temperature coefficient(s) of an equivalent device is/are available.

The measurement of the linearity of the working reference device can be omitted when the respective linearity of an equivalent device is available and the calibration values of the two equivalent devices do not differ by more than 5 %.

When parameters (spectral responsivity, temperature coefficient(s) and linearity) determined on an equivalent device are used, specific additional contributions to measurement uncertainty shall be considered explicitly. An example is the usage of the spectral responsivity of the working reference device for spectral mismatch correction of a measurement of another PV device against the working reference device.

The report shall state clearly which measurements were made on the working reference device and which originate from an equivalent device. The equivalent devices shall be identified.

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Bibliography

- [1] IEC 61215 (all parts), *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*
- [2] IEC 61853-1, *Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating*
- [3] JIS C8910, *Primary reference solar cells*
- [4] C.R. Osterwald et al., "The World Photovoltaic Scale: an international reference cell calibration program", *Progress in Photovoltaics Research and Applications*, vol. 7, pp. 287-297, 1999
- [5] IEC TR 60904-14, *Photovoltaic devices – Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions*

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List of comments

- 1 Wording is taken from IEC 60904-4 (slightly modified) rather than making reference to IEC 60904-4.
- 2 Modification is made to distinguish between definition and use.
- 3 This clarifies that the traceability hierarchy is decisive, not the type of instrument.
- 4 Notes are added for user guidance.
- 5 Notes are added for user guidance.
- 6 Notes are added for user guidance.
- 7 Modification is made to distinguish between definition and use.
- 8 Notes are added for user guidance, maintaining information previously contained in 3.6.1 and 3.6.2.
- 9 This is incorporated into 3.6.
- 10 This is incorporated into 3.6.
- 11 This is incorporated into 3.8.
- 12 Modification is made to clarify that being a reference device is important, not construction.
- 13 This is moved here from previous 3.7.
- 14 The requirement for linearity is moved to Subclause 7.5.
- 15 This text expands on the previous a) for clarification.
- 16 This is made a recommendation rather than a requirement because it cannot be verified after construction.
- 17 This is made a recommendation rather than a requirement because it cannot be verified after construction.
- 18 This is made a recommendation rather than a requirement because it cannot be verified after construction.
- 19 This modification is made for better user guidance.
- 20 This is made a recommendation rather than a requirement because the stipulations about usage in Clause 12 are sufficient to result in proper utilisation of reference devices with built-in shunt resistors.
- 21 These requirements are now included in Clause 12.
- 22 This is now stipulated in Clause 12.
- 23 The larger deviation is chosen because the stipulations about usage in Clause 12 are sufficient to result in proper utilisation of reference devices with built-in shunt resistors.
- 24 Modification is made to be consistent with IEC 60904-1.
- 25 This addition is made to clarify the requirement for traceability which was previously more implicit.
- 26 This is reworded to be generic rather than only at standard test conditions (STC).
- 27 Modification is made as there are now exceptions for working references.

- 28 This was previously mandatory for all references devices, but is now optional as it depends on usage.
- 29 This was previously mandatory for all references devices, but is now optional as it depends on usage.
- 30 This clause is completely revised. It is divided into two sections, one referring to the actual device and one to its calibration.

The items included are revised to be consistent with the rest of the document.

- 31 This addition is made to clarify the intention of this recommendation.
- 32 This clause is added to clarify under which conditions a reference device with a given calibration can be used, or which calibrations are required for the reference device for a certain usage.
- 33 This is removed as the measurement of spectral responsivity (SR) is now mandatory for secondary references.
- 34 The calibration of reference devices with current-voltage characteristics is added as it is commonly used in PV industry.
- 35 This is removed here, as the test procedure is concerned with the measurement of short-circuit current or current-voltage characteristics. Additional measurements (such as spectral responsivity (SR) and temperature coefficients) are detailed in Clause 7.
- 36 Modification is made to be consistent with IEC 60904-1.
- 37 This is reworded to be generic rather than only referring to the temperature of standard test conditions (STC).
- 38 The calibration of reference devices with current-voltage characteristics is added as it is commonly used in PV industry.
- 39 The calibration of reference devices with current-voltage characteristics is added as it is commonly used in PV industry.
- 40 This is reworded to clarify distinction between simultaneous and consecutive measurements.
- 41 This requirement is removed since it is excessive given that spectral mismatch correction is mandatory.
- 42 The calibration of reference devices with current-voltage characteristics is added as it is commonly used in PV industry.
- 43 This is added to clarify which measurement procedures to use.
- 44 This clause is extended to relax the requirements for working references. Previously they were identical to those for secondary references, which is not practical.
- 45 The calibration of reference devices with current-voltage characteristics is added as it is commonly used in PV industry.

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Photovoltaic devices –
Part 2: Requirements for photovoltaic reference devices**

**Dispositifs photovoltaïques –
Partie 2: Exigences applicables aux dispositifs photovoltaïques de référence**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC DEVICES –

Part 2: Requirements for photovoltaic reference devices

FOREWORD

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IEC 60904-2 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is an International Standard.

This fourth edition cancels and replaces the third edition published in 2015. This edition constitutes a technical revision.

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

- a) added calibration procedures for calibrating PV devices at maximum power by extending the respective Clauses 12 and 13;
- b) revised requirements for mandatory measurement of spectral responsivity, temperature coefficients and linearity, depending on usage and allowing some measurements on equivalent devices;
- c) revised requirements for built-in shunt resistor;
- d) added requirements for traceability of calibration explicitly.

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

Draft	Report on voting
82/2127/FDIS	82/2151/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.

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

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

PHOTOVOLTAIC DEVICES –

Part 2: Requirements for photovoltaic reference devices

1 Scope

This part of IEC 60904 gives requirements for the classification, selection, packaging, marking, calibration and care of photovoltaic reference devices.

This document applies to photovoltaic (PV) reference devices that are used to measure the irradiance of natural or simulated sunlight for the purpose of quantifying the electrical performance of photovoltaic devices (cells, modules and arrays). It does not cover photovoltaic reference devices for use under concentrated sunlight.

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 60904-3, *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 60904-5, *Photovoltaic devices – Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method*

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 60904-10, *Photovoltaic devices – Part 10: Methods of linear dependence and linearity measurements*

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 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

calibration traceability

<of a PV reference device> requirement for any PV reference device, to tie its calibration value to SI units in an unbroken and documented chain of calibration transfers including stated uncertainties

Note 1 to entry: Photovoltaic reference devices are distinguished by their position in a chain of calibration traceability.

[SOURCE IEC 60904-4:2019, 3.6, modified – The term "traceability" has been replaced with "calibration traceability" and Note 1 to entry has been replaced.]

3.2

reference device

traceably calibrated photovoltaic device

Note 1 to entry: Normally used to measure natural or simulated solar irradiance or to set solar simulator irradiance levels for measuring the performance of other photovoltaic devices.

3.3

primary reference device

photovoltaic reference device with calibration based on a secondary standard for irradiance traceable to SI units as defined in IEC 60904-4

Note 1 to entry: Typically, a PV cell is used as a reference device for the measurement of natural or simulated solar irradiance.

Note 2 to entry: Primary references are normally used by calibration and testing laboratories to calibrate secondary references.

Note 3 to entry: Normally calibrated at periodic intervals.

3.4

secondary reference device

photovoltaic reference device calibrated in natural or simulated sunlight against a primary reference device

Note 1 to entry: Secondary references are normally used by calibration and testing laboratories to calibrate working references, but also for daily routine measurements, in industrial production and in monitoring.

Note 2 to entry: Normally calibrated at periodic intervals.

3.5

working reference device

photovoltaic reference device calibrated in natural or simulated sunlight against a secondary reference device

Note 1 to entry: Working references are normally used for daily routine measurements, in industrial production and in monitoring.

Note 2 to entry: Normally calibrated at periodic intervals.

3.6

reference cell

reference device consisting of a single photovoltaic cell

Note 1 to entry: For practical reasons, such cells are small in surface area, and are usually mounted on a fixture which ensures reproducibility in mounting, thermal control, electrical connections and protects the device. A typical sample is sketched in Figure 1.

Note 2 to entry: Normally the reference cells are also provided with a protective window and embedded in an encapsulant.

Note 3 to entry: Recommended use: as a laboratory primary, secondary and working reference.

Note 4 to entry: If the encapsulation system has been demonstrated to withstand long-term outdoor exposure, applying test levels according to the IEC 61215 series [1], such reference cells can also be suitable to be used as a monitoring device for long-term assessment of operational PV arrays.

Note 5 to entry: If the reference cell is provided with a protective window but without encapsulant, then it should only be used when measuring the performance of other PV devices using direct beam natural or simulated sunlight.

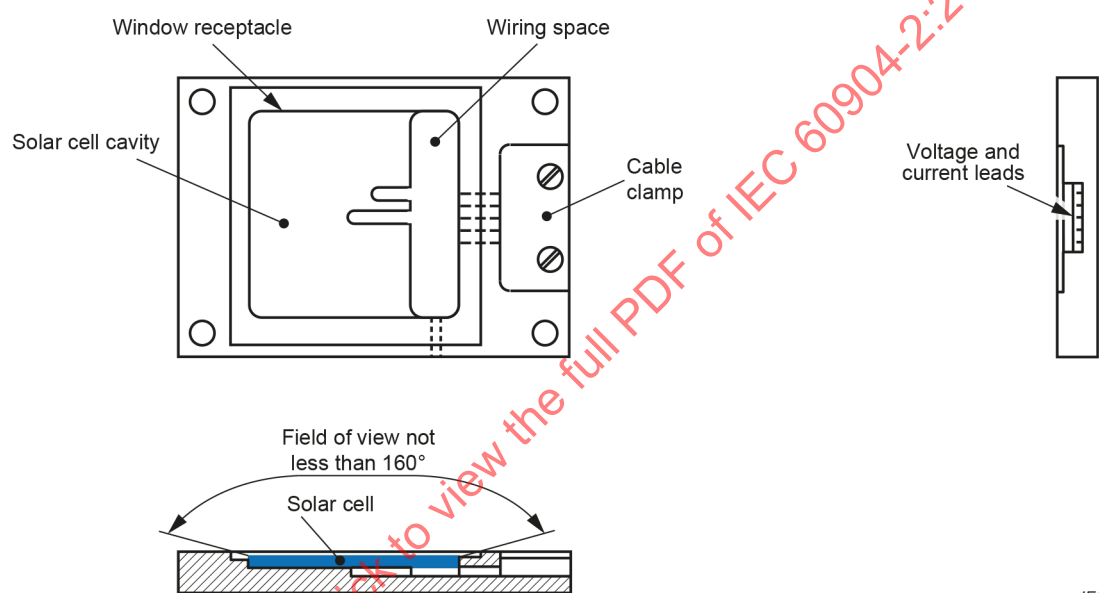


Figure 1 – Single cell package

3.7

single reference cell in a multi-cell package

reference device consisting of a single photovoltaic cell mounted in a package such that frame, encapsulation system, shape, size and spacing of the cells surrounding it are the same as in the PV module to be tested

Note 1 to entry: The surrounding cells may be real or dummies that have the same optical properties.

3.8

reference module

reference device consisting of a photovoltaic module

Note 1 to entry: Recommended use: for measuring other modules in order to achieve correspondence of dimensions, mechanical construction, optical properties and electrical circuitry of the reference module and test module, so as to minimize discrepancies due to solar simulator spatial non-uniformity, internal reflections, temperature distribution and spectral mismatch.

Note 2 to entry: As the diffuse component of natural sunlight and non-normal incidence of simulated sunlight interact with encapsulants and back sheets of a PV module and influence the amount of irradiance which a particular cell receives, it is recommended that reference devices used for measuring PV modules, sub-assemblies of PV modules and PV arrays be encapsulated matching the mechanical and optical features of the device under test.

3.9

built-in shunt resistor

resistor connected across the output terminals of photovoltaic devices including connection wiring

Note 1 to entry: The resistor shunts the output of the photovoltaic device providing an output voltage to be measured and avoiding user-provided means of establishing short-circuit condition.

Note 2 to entry: For details consult 4.4.

4 Selection of reference device

4.1 General requirements

Depending on their intended use, reference devices need to meet different requirements in terms of their spectral responsivity, mechanical construction, optical properties, dimensions and electrical circuit. The spectral responsivity of the reference device, for example, is determined by the transmission of any protective window in front of the device and the spectral responsivity of the device itself. Therefore, the overall spectral responsivity can be adapted by using suitable filters as or in addition to the protective window.

Reference devices should be made using a PV technology that is known to be stable with time. In particular, the calibration value should not change after the reference device has been exposed to solar irradiation, device temperatures different from its calibration temperature and/or extended storage in the dark. The photovoltaic characteristics of a reference device shall be stable according to the requirements in Clause 11.

The reference device shall be constructed such that the photovoltaic performance parameters, in particular short-circuit current and maximum power, can be measured. The only exception are devices with a built-in shunt resistor, see 4.4.

4.2 Additional requirements for single reference cell in a multi-cell package

The dotted line in Figure 2 indicates the minimum acceptable size of a multi-cell package. For other cell arrangements, such as half-cut cells, an analogous configuration applies.

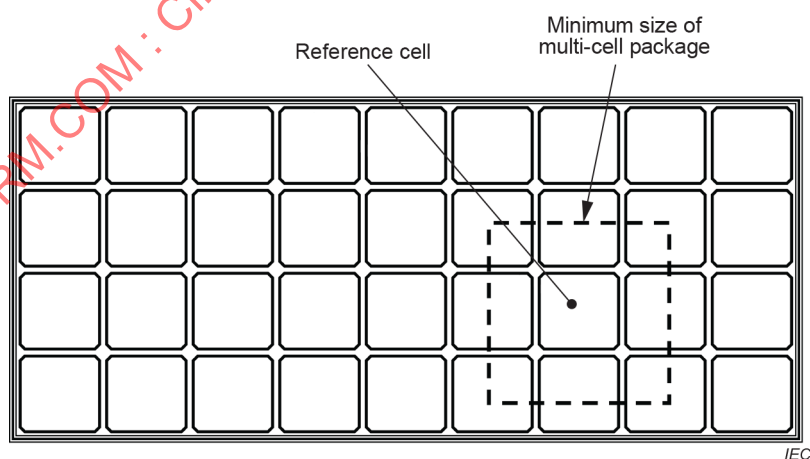


Figure 2 – Single reference cell in a multi-cell package

4.3 Additional requirements for reference modules

Additional requirements apply to reference modules.

a) Bypass diodes:

- general reference modules, which are used to measure a range of module types and geometries, should not contain bypass diodes. The presence or absence of bypass diodes shall be noted and considered in conjunction with the measurement conditions, in particular spatial non-uniformity of the irradiance on the module during measurement;
- for reference modules, which are intended to be matched to the module under test, the number, type and connection of bypass diodes (if present) shall match those in the module under test.

b) If they are made from discrete cells, these should be matched as follows depending on the intended use of the reference module:

- if only the short-circuit current of the reference module will be used, the short-circuit current of the individual cells should be matched to within ± 1 %;
- if other parameters (such as maximum power) are used additionally or exclusively, both the short-circuit current and the fill factor of the individual cells should be matched to within ± 1 %.

The matching of the individual cells is the responsibility of the manufacturer of the reference module, bearing in mind that matching can also be influenced by encapsulation or lamination. The cell matching need not be checked by the calibration laboratory. However, if I - V curves of the reference module indicate inconsistent response (i.e. obvious steps are noted in the I - V curve), this should be discussed between calibration laboratory and the client supplying the module before proceeding with calibration.

4.4 Requirements for built-in shunt resistors

The built-in shunt resistor (see 3.9) should be chosen such as to ensure that the reference device operates sufficiently near to short-circuit condition, meeting the requirement in Formula (1):

$$R_{\text{CAL}} < \frac{0,2 \times V_{\text{OC}}}{I_{\text{SC}}} \quad (1)$$

where

R_{CAL} is the built-in shunt resistor;

I_{SC} is the short-circuit current of the reference device at desired reference condition;

V_{OC} is the open circuit voltage of the reference device at desired reference condition.

The long-term stability of the built-in shunt resistor shall also meet the stability requirements of the reference device. Calibration values of such reference devices shall be measured as the voltage drop across the built-in shunt resistor and stated with the dimension [V]. The temperature coefficient of the built-in shunt resistor is part of the temperature coefficient of the calibration value of the reference device. As the uncertainty in the calibration can be strongly dependent on the built-in shunt resistor stability and temperature coefficient, respective values should be provided with the reference cell data sheet.

It is recommended that the shunt resistor be a removable 4-wire resistor, to allow for standard (current-based) measurements of spectral responsivity and periodic checking of the reference device stability by measuring an I - V curve in accordance with IEC 60904-1. However, the reproducibility of the electrical connection shall be maintained.

Formula (1) means that the measured output voltage of a shunted reference cell should be less than 20 % of its open circuit voltage. For typical crystalline silicon this equates to about 120 mV output.

5 Temperature measurement

Means shall be provided for determining the reference cell temperature or, for reference modules, the equivalent cell temperature (ECT), according to IEC 60904-5. Temperature sensors and instrumentation shall have instrumental measurement uncertainty of 1 °C or less. The required uncertainty for temperature measurements for the cell junction shall be less than 2,0 °C for all reference devices.

6 Electrical connections

The electrical connections to reference cells without built-in shunt resistor shall consist of a four-wire contact system (Kelvin probe). Measurement errors due to voltage drops along the cell's contact bars and the package wiring shall be avoided.

The electrical connections to the reference module shall be designed to meet the requirements of IEC 60904-1.

7 Calibration

7.1 General requirements

Each calibration of a reference device shall be made with a calibration procedure that is traceable according to IEC 60904-4. Any measurement instrument used in the calibration procedure shall be an instrument with an unbroken traceability chain.

The laboratory performing the calibration of the reference device shall maintain a documented uncertainty analysis as well as documented repeatability and results from interlaboratory comparisons.

7.2 Calibration value(s)

Each reference device shall be calibrated in terms of its calibration value(s) at the desired reference conditions. Calibration values shall be reported together with the three main parameters of total irradiance, device junction temperature and spectral irradiance. The most common calibration conditions are standard test conditions (STC). A calibration at STC shall refer to a total irradiance of 1 000 W m⁻², a device junction temperature of 25 °C and the reference spectral irradiance distribution as defined in IEC 60904-3. Sometimes calibration is required at other conditions. A reference device can have multiple calibration values for different desired reference conditions. In particular, IEC 61853-1 [2]¹ requires the use of a reference device at a range of irradiances and temperatures and therefore the calibration at the respective conditions.

Methods for calibrating primary reference devices are included in IEC 60904-4. A procedure of calibrating secondary reference devices is described in Clause 13. The calibration of working reference devices is treated in Clause 14.

¹ Numbers in square brackets refer to the Bibliography.

7.3 Spectral responsivity

In general, the spectral responsivity at short-circuit current conditions of each reference device shall be measured in accordance with IEC 60904-8. For exceptions related to working references, see Clause 14.

7.4 Temperature coefficients

The determination of the temperature coefficient(s) of each reference device in accordance with IEC 60891 is in general optional but depending on usage might be mandatory, and in any case is strongly recommended. If the temperature coefficient(s) are determined, also their linear dependence in accordance with IEC 60904-10 shall be reported. For exceptions related to working references, see Clause 14.

7.5 Linearity

The determination of linearity in accordance with IEC 60904-10 is in general optional but depending on usage might be mandatory, and in any case is strongly recommended. For exceptions related to working references, see Clause 14.

8 Documentation and report

8.1 General

The information given in 8.2 and 8.3 shall be recorded for each reference device.

8.2 Device documentation

The data sheet shall be compiled by the manufacturer of the reference device and contain the following information:

- a) unique identification of the device;
- b) cell manufacturer and device manufacturer;
- c) material type;
- d) type of package;
- e) type and dimension of cell(s);
- f) circuit diagram, in particular of any connectors;
- g) type of temperature sensor (where applicable) and its uncertainty;
- h) shunt resistor type, nominal resistance and temperature coefficient (where applicable).

For reference modules, the following information shall be recorded in addition:

- i) manufacturer of module;
- j) model designation;
- k) serial number;
- l) cell technology;
- m) construction and dimensions of module;
- n) electrical circuit layout;
- o) presence or absence of bypass diodes and if present their number and type.

8.3 Calibration report

Each time a reference device is calibrated, the calibration report shall contain the following information:

- a) unique identification of the device;
- b) indication that the device has a built-in shunt resistor (where applicable);
- c) type (primary reference cell; secondary reference device, working reference device);
- d) calibration organization;
- e) site and date of calibration;
- f) method of calibration (refer to standard);
- g) identification of the reference device used for the calibration and its traceability according to IEC 60904-4;
- h) simulator type and classification (where applicable);
- i) calibration value(s) and corresponding reference conditions (total irradiance, device junction temperature, spectral irradiance); in case of calibration via current-voltage characteristics both short-circuit current and maximum power shall be reported; the open-circuit voltage should also be reported;
- j) spectral responsivity (where applicable);
- k) temperature coefficient of calibration value(s) as well as linear dependence (where applicable);
- l) linearity (where applicable);
- m) uncertainties for items i), j), k) and l);
- n) either the spectral mismatch correction value used in the measurement or an estimate of the uncertainty introduced by using an equivalent device;
- o) statement that measurements originate from an equivalent device and an identification of which measurements these are (where applicable);
- p) unique identification of the equivalent device(s) (where applicable).

For reference cells without fixed electrical connection to the cell, the following information shall be provided:

- q) illustration of type, shape and location of electrical contacts during calibration.

9 Marking

The reference device shall carry a clear, indelible serial or identification number for cross-reference to its data sheet.

10 Packaging

10.1 Recommended packaging for use in natural sunlight

The reference device used for measurement in natural sunlight should respond to variations in the geometrical distribution of the incident radiation in the same way as the device under test (cells, sub-assemblies of cells, modules). As encapsulants and back sheets respond to the diffuse component of natural sunlight, it is recommended that reference cells used for measuring modules be enclosed in a multi-cell package (see Figure 2), simulating the neighbouring optical parameters of a module.

In this case, the frame, the encapsulation system, the shape, and the size and spacing of the cells surrounding the reference cell shall be the same as in the module to be tested. The surrounding cells may be real or dummies that have the same optical properties. The dotted

line in Figure 2 indicates the minimum acceptable size of the multi-cell package for outdoor testing.

10.2 Recommended packaging for use under solar simulators

In some solar simulators which allow multiple reflections of light to and from the device under test, the irradiance in the test plane can change depending on whether or not the device under test is present. Therefore, in order to measure accurately the irradiance that will be present when the device under test is in place, the reference devices used in such solar simulators should be packaged in the same way as the device under test, so that the change in irradiance due to multiple reflections is the same for both the reference device and the device under test.

Reference cells used for measurements in solar simulators designed to minimize any error from multi-reflected light may be packaged singly or, if not intended for day-to-day use, mounted in the unpackaged state on a temperature-controlled block.

Alternatively, the requirements given for reference cells for use in natural sunlight may be followed.

10.3 Single cell package

If a single cell package is used, the following recommendations are made.

- a) The field of view should be at least 160° . In case of a protective window the optical properties of the latter have to be considered in determining the effective field of view of the photovoltaic cell. The field of view is particularly important for measurements under natural sunlight, whereas for usage on solar simulators with a limited range of angles of incidence, it is less critical.
- b) All surfaces in the package within the cell's field of view should be non-reflective, with a spectral absorptance of at least 0,95 in the cell's wavelength responsivity band.
- c) The material used for bonding the cell to the holder should be resistant to degradation, either electrically or optically. Its physical characteristics should remain stable over the entire period of intended use.
- d) The use of a protective window is recommended. If encapsulated, the space between the window and the cell should be filled with a stable encapsulant. Both the protective window and the encapsulant should be transparent over the wavelength range in which the PV reference device has a non-zero spectral responsivity. The refractive index of the encapsulant should be similar (within 10 %) to that of the window to minimize errors due to the internal reflection of light. The transparency, homogeneity and adhesion of the encapsulant should not be adversely affected by ultra-violet light and operational temperatures.
- e) The protective window may embody a filter to match the spectral responsivity of the reference cell to that of the device under test, provided that the other recommendations of d) are met.

Figure 1 shows an example of a suitable single cell package. Other suitable single cell packages can be found in JIS C8910 [3] or the World Photovoltaic Scale [4].

11 Care of reference devices

It is recommended that reference devices be recalibrated on an annual basis.

The window of a packaged reference device shall be kept clean and scratch-free.

Uncovered reference cells shall be preserved against damage, contamination and degradation.

A reference device exhibiting any defect which might impair its function shall not be used.

The calibration value of a reference device might change systematically as a function of time for successive calibrations. If the calibration value of a reference device has changed by more than 1 % with respect to its previous calibration or by more than 5 % of its initial calibration, it shall not be used as a reference device.

12 Usage of reference devices

Reference devices shall only be used at irradiances (± 10 %) and temperatures (± 5 °C) at which they were calibrated. For the ranges given, use of a simple correction according to established procedures provided in IEC 60891 with generic correction coefficients is acceptable, as long as the additional uncertainties introduced are taken into account.

The usage of reference devices outside the ranges given above requires the following in addition to the single calibration at one reference condition (normally STC):

- a) a separate calibration for each desired reference condition it is to be used at; or
- b) if to be used over a wider temperature range: a determination of the relevant temperature coefficient(s) according to IEC 60891 (and their linear dependence according to IEC 60904-10) and appropriate corrections for differences between the temperatures during usage and the calibration temperature; and/or
- c) if to be used over a wider irradiance range: a determination of the linearity (output versus irradiance) over the relevant irradiance range according to IEC 60904-10 and appropriate corrections for differences between the irradiance during usage and the calibration irradiance.

The reference device can be used in the ranges of conditions mentioned above around the additional reference conditions with a). Alternatively, it can be used with the calibration value of the original reference condition over a wider temperature range with b) or a wider irradiance range with c). If a usage over wider temperature and irradiance ranges is desired, b) and c) are both required.

13 Calibration of secondary reference devices against a primary reference cell

13.1 General

This Clause 13 describes a procedure for calibrating a secondary reference device in natural or simulated sunlight against a primary reference cell whose calibration is traceable to SI units according to IEC 60904-4. The procedure described is an example and other calibration procedures are acceptable as long as they meet the requirements of 7.1. In any case, the spectral mismatch between the primary reference cell and that of the secondary reference device under the irradiance used for the calibration shall be determined according to IEC 60904-7.

The primary reference cell is calibrated such that its output (short-circuit current or voltage across a built-in shunt resistor in case of shunted cell) can be used to determine the irradiance of the natural or simulated sunlight. The calibration value(s) of the secondary reference device can be determined by measuring:

- a) its output (short-circuit current or voltage across a built-in shunt resistor in case of a shunted device). This is the most common calibration if the secondary reference device is a cell;
- b) its current-voltage characteristics according to IEC 60904-1. This permits the calibration of the maximum power and of the short-circuit current. This is the most common calibration if the secondary reference device is a module.

For secondary reference devices with built-in shunt resistor only a) is applicable, as b) is not possible. For secondary reference devices without built-in shunt resistor, the choice of calibration depends on the intended use. For guidance on the use of short-circuit current or maximum power of a reference device refer to IEC TR 60904-14 [5].

The procedure can be applied using both natural and simulated sunlight according to the requirements in IEC 60904-1 with the restrictions given in 13.2 and 13.3.

13.2 Natural sunlight

Calibration in natural sunlight shall be carried out under the following conditions:

- a) clear, sunny weather, with the diffuse irradiance not greater than 20 % of the global irradiance. For determining the contribution of diffuse irradiance, see IEC 60904-4;
- b) no observable cloud formations within 30° of the sun;
- c) total irradiance (sun + sky + ground reflection) not less than 800 W m^{-2} , as measured by the primary reference cell;
- d) geometric air mass between AM1 and AM2;
- e) radiation sufficiently stable so that the variation in reference cell output signal is less than $\pm 0,5 \%$ over the time taken for a measurement.

13.3 Simulated sunlight

The simulated sunlight for calibration can either be continuous or pulsed. Normally the primary reference cell and the secondary reference device are positioned side by side and measured simultaneously. In this case the solar simulator shall be of Class AAA or better in accordance with IEC 60904-9 with the additional requirement that the non-uniformity of irradiance is less than $\pm 1 \%$ within the surface that includes the device to be calibrated and the primary reference device. For 13.1 a) the requirement of Class A with respect to temporal instability as defined in IEC 60904-9 need only be met for the short-term instability (STI) as the long-term instability (LTI) is not relevant in this case. In case that the primary and secondary reference device are of the same or similar size (ratio of active areas between 0,5 and 2,0), an additional measurement shall be taken exchanging their positions. A valid result is only obtained if both measurements agree within the measurement uncertainty.

If the requirement of spatial non-uniformity of less than $\pm 1 \%$ cannot be met for calibrating reference modules made from a series connection of cells, the solar simulator shall be class A for spatial non-uniformity and a detailed uncertainty analysis shall be provided.

In the special case that the primary reference cell and the secondary reference device are of the same or similar size (ratio of active areas between 0,5 and 2,0) and that the continuous simulated sunlight is stable, the two devices can be placed in the same position one after the other and measured consecutively. In this case the solar simulator shall be of Class AAA in accordance with IEC 60904-9 with the additional requirement that the LTI of irradiance is less than $\pm 1 \%$, where the LTI is with respect to the total time period needed for the measurements. A pulsed solar simulator can also be suitable if the repeatability of each pulse is better than 1 %.

In any case, a detailed measurement uncertainty analysis considering both spatial non-uniformity and temporal instability of the simulated sunlight needs to be provided, considering the specifics of the chosen measurement strategy.

13.4 Test procedure

13.4.1 Adjust the mount so that the devices are normal to the light source within $\pm 5^\circ$:

- a) mount the primary reference cell and the secondary reference device co-planar within $\pm 2^\circ$ and in close proximity on the same mount (for simultaneous measurement), or
- b) mount the primary reference cell in the designated position (for consecutive measurement).

13.4.2 Control the cell temperature of both the primary reference cell to the temperature at which it was calibrated (normally $(25 \pm 2)^\circ\text{C}$) and the secondary reference device to the desired temperature for calibration (also normally $(25 \pm 2)^\circ\text{C}$). Where this is not practical, readings of output signal shall be subsequently corrected to the respective temperatures in accordance with IEC 60891.

13.4.3 The spectral mismatch shall be corrected according to IEC 60904-7. Appropriate measurements of the spectral irradiance shall be recorded.

13.4.4 Record simultaneous readings of:

- a) the output signal and temperature of the primary reference cell (for consecutive measurement) (only for measurements under simulated sunlight), or
- b) the output signal and temperature of both primary reference cell and secondary reference device (for simultaneous measurement and calibration according to 13.1 a)), or
- c) the output signal and temperature of primary reference cell as well as temperature and current-voltage characteristics of secondary reference device (for simultaneous measurement and calibration according to 13.1 b)).

13.4.5 Repeat step 13.4.4 a) or b) until at least five, or 13.4.4 c) until at least three successive sets of readings are obtained in which:

- for consecutive measurement: the output signals for the primary reference cell (corrected to the temperature at which it was calibrated (normally 25 ± 2 °C)) do not vary by more than $\pm 0,5$ %; then remove the primary reference cell and mount the secondary reference device in the same position and
 - a) repeat step 13.4.4 a) with the same constraints as for the primary reference cell (for calibration according to 13.1 a)), or
 - b) record temperature and current-voltage characteristics of secondary reference device (calibration according to 13.1 b));
- for simultaneous measurement: the ratio of the output signals (corrected for temperature and for spectral mismatch as required) does not vary by more than $\pm 0,5$ %.

13.4.6 If the primary reference cell and the secondary reference device are of the same or similar size (ratio of active areas between 0,5 and 2,0) and are measured simultaneously, exchange the position between the primary reference cell and the secondary reference device and repeat steps 13.4.4 and 13.4.5.

13.4.7 From the acceptable data, calculate the ratio of the output of the secondary reference device to the output of the primary reference cell.

13.4.8 To obtain the calibration value of the secondary reference device:

For calibration according to 13.1 a): multiply the calibration value of the primary reference cell by the calculated:

- a) ratio of the means of the output signals from secondary reference device to primary reference cell (for consecutive measurement), or
- b) mean of the ratios of output signals from secondary reference device to primary reference cell (for simultaneous measurement).

The output signals shall be corrected for amplification factors of measurement electronics.

For calibration according to 13.1 b): determine the current-voltage characteristics at the desired reference conditions according to IEC 60891 based on the irradiance measured with the primary reference cell; then determine the maximum power and the short-circuit current as well as the open-circuit voltage from each measured current-voltage characteristic according to IEC 60904-1 (for consecutive and simultaneous measurement). The calibration values are determined as the average of the respective parameters from all measured current-voltage characteristics.

If measurements have been taken with the positions of the primary reference cell and the secondary reference device exchanged, calculate the calibration value for both cases. The results are only valid if both agree within the measurement uncertainty. Both values shall be reported and their geometric average shall be used as the calibration value.

13.5 Additional measurements

13.5.1 Spectral responsivity

Measure the spectral responsivity of the secondary reference device, using the procedures specified in IEC 60904-8.

13.5.2 Temperature coefficient(s)

If required, measure the temperature coefficient(s) of short-circuit current and/or maximum power of the secondary reference device, using the procedures specified in IEC 60891.

13.5.3 Linearity

If required, measure the linearity of the secondary reference device output, using the procedures specified in IEC 60904-10.

14 Calibration of working reference device against a secondary reference device

For calibration of a working reference device against secondary reference device the above procedure (Clause 13) or other calibration procedures that meet the requirements in this document and in particular those of 7.1 may be applied. If the secondary reference has been calibrated according to 13.1 b) then its maximum power can be used as reference value. For guidance on the use of short-circuit current or maximum power of a reference device, refer to IEC TR 60904-14 [5].

Sometimes it is not required or possible (technically or economically) to perform all measurements on every single working reference device. Therefore, in some cases measurements can be made on equivalent devices as detailed below. For two devices to be equivalent, they shall be constructed using the same cell technology and encapsulation package. This includes the glass (type, thickness, texturing, and spectral transmission), anti-reflective coatings, encapsulant, and back sheet (type, colour, and spectral back-reflection).

The measurement of the calibration value(s) at all desired reference conditions shall be performed on every single working reference device.

The measurement of the spectral responsivity of the working reference device and the spectral mismatch correction can be omitted when the secondary reference and working reference are equivalent devices. The measurement of the spectral responsivity of the working reference device can also be omitted if the spectral responsivity of a device equivalent to the working reference device is used for spectral mismatch correction. In both cases additional contributions to uncertainty shall be considered explicitly.

The measurement of the temperature coefficient(s) of the working reference device can be omitted when the respective temperature coefficient(s) of an equivalent device is/are available.

The measurement of the linearity of the working reference device can be omitted when the respective linearity of an equivalent device is available and the calibration values of the two equivalent devices do not differ by more than 5 %.

When parameters (spectral responsivity, temperature coefficient(s) and linearity) determined on an equivalent device are used, specific additional contributions to measurement uncertainty shall be considered explicitly. An example is the usage of the spectral responsivity of the working reference device for spectral mismatch correction of a measurement of another PV device against the working reference device.

The report shall state clearly which measurements were made on the working reference device and which originate from an equivalent device. The equivalent devices shall be identified.

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COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

DISPOSITIFS PHOTOVOLTAÏQUES –

Partie 2: Exigences applicables aux dispositifs photovoltaïques de référence

AVANT-PROPOS

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L'IEC 60904-2 a été établie par le comité d'études 82 de l'IEC: Systèmes de conversion photovoltaïque de l'énergie solaire. Il s'agit d'une Norme internationale.

Cette quatrième édition annule et remplace la troisième édition parue en 2015. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

- a) ajout de procédures d'étalonnage des dispositifs PV à la puissance maximale en développant les Articles 12 et 13) correspondants;

- b) révision des exigences applicables au mesurage obligatoire de la sensibilité spectrale, des coefficients de température et de la linéarité, en fonction de l'usage et en permettant certains mesurages sur des dispositifs équivalents;
- c) révision des exigences applicables aux résistances de shunt intégrées;
- d) ajout d'exigences pour la traçabilité de l'étalonnage de manière explicite.

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
82/2127/FDIS	82/2151/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Ce document a été rédigé selon les directives ISO/IEC, Partie 2, il a été développé selon les directives ISO/IEC, Partie 1 et les directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/publications.

Une liste de toutes les parties de la série IEC 60904, publiées sous le titre général *Dispositifs photovoltaïques*, peut être consultée sur le site web de l'IEC.

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DISPOSITIFS PHOTOVOLTAÏQUES –

Partie 2: Exigences applicables aux dispositifs photovoltaïques de référence

1 Domaine d'application

La présente partie de l'IEC 60904 donne les exigences relatives à la classification, à la sélection, au conditionnement, au marquage, à l'étalonnage et aux précautions d'utilisation des dispositifs photovoltaïques de référence.

Le présent document s'applique aux dispositifs photovoltaïques (PV) de référence utilisés pour mesurer l'irradiance de la lumière solaire naturelle ou simulée afin de quantifier les performances électriques des dispositifs PV (cellules, modules et panneaux). Il ne couvre pas les dispositifs photovoltaïques de référence pour une utilisation sous éclairage solaire concentré.

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60891, *Dispositifs photovoltaïques – Procédures pour les corrections en fonction de la température et de l'éclairement à appliquer aux caractéristiques I-V mesurées*

IEC 60904-1, *Dispositifs photovoltaïques – Partie 1: Mesurage des caractéristiques courant-tension des dispositifs photovoltaïques*

IEC 60904-3, *Dispositifs photovoltaïques – Partie 3: Principes de mesure des dispositifs solaires photovoltaïques (PV) à usage terrestre incluant les données de l'éclairement énergétique spectral de référence*

IEC 60904-4, *Dispositifs photovoltaïques – Partie 4: Dispositifs photovoltaïques de référence – Procédures pour établir la traçabilité de l'étalonnage*

IEC 60904-5, *Dispositifs photovoltaïques – Partie 5: Détermination de la température de cellule équivalente (ECT) des dispositifs photovoltaïques (PV) par la méthode de la tension en circuit ouvert*

IEC 60904-7, *Dispositifs photovoltaïques – Partie 7: Calcul de la correction de désadaptation des réponses spectrales dans les mesures de dispositifs photovoltaïques*

IEC 60904-8, *Dispositifs photovoltaïques – Partie 8: Mesure de la sensibilité spectrale d'un dispositif photovoltaïque (PV)*

IEC 60904-9, *Dispositifs photovoltaïques – Partie 9: Classification des caractéristiques des simulateurs solaires*

IEC 60904-10, *Dispositifs photovoltaïques – Partie 10: Méthodes de mesure de la dépendance linéaire et de la linéarité*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols* (disponible en anglais seulement)

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions de l'IEC TS 61836, ainsi que les suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse <http://www.electropedia.org/>
- ISO Online browsing platform: disponible à l'adresse <https://www.iso.org/obp>

3.1

traçabilité de l'étalonnage

<d'un dispositif PV de référence> exigence, pour tout dispositif PV de référence, de lier sa valeur d'étalonnage en unités SI dans une chaîne ininterrompue et documentée de transferts d'étalonnage comprenant les incertitudes établies

Note 1 à l'article: Les dispositifs photovoltaïques de référence se distinguent par leur position dans une chaîne de traçabilité de l'étalonnage.

[SOURCE IEC 60904-4:2019, 3.6, modifié – Le terme "traçabilité" a été remplacé par "traçabilité de l'étalonnage" et la Note 1 à l'article a été remplacée.]

3.2

dispositif de référence

dispositif photovoltaïque étalonné de manière traçable

Note 1 à l'article: Il est généralement utilisé pour mesurer l'irradiance solaire naturelle ou simulée ou pour régler les niveaux d'irradiance du simulateur solaire pour mesurer les performances d'autres dispositifs photovoltaïques.

3.3

dispositif primaire de référence

dispositif photovoltaïque de référence dont l'étalonnage est fondé sur un étalon secondaire pour l'irradiance traçable en unités SI, tel qu'il est défini dans l'IEC 60904-4

Note 1 à l'article: Généralement, une cellule PV est utilisée comme dispositif de référence pour le mesurage de l'irradiance solaire naturelle ou simulée.

Note 2 à l'article: Les références primaires sont généralement utilisées par les laboratoires d'étalonnage et d'essai pour étalonner des références secondaires.

Note 3 à l'article: Le dispositif de travail de référence est en principe étalonné périodiquement.

3.4

dispositif secondaire de référence

dispositif photovoltaïque de référence étalonné en éclairement solaire naturel ou simulé par rapport à un dispositif primaire de référence

Note 1 à l'article: Les références secondaires sont généralement utilisées par les laboratoires d'étalonnage et d'essai pour étalonner des références de travail ainsi que pour effectuer des mesurages de routine quotidiens, dans la production industrielle et pendant les travaux de surveillance.

Note 2 à l'article: Le dispositif de travail de référence est en principe étalonné périodiquement.

3.5

dispositif de travail de référence

dispositif photovoltaïque de référence étalonné en éclairement solaire naturel ou simulé par rapport à un dispositif secondaire de référence

Note 1 à l'article: Les références de travail sont généralement utilisées pour les mesurages de routine quotidiens, dans la production industrielle et pendant les travaux de surveillance.

Note 2 à l'article: Le dispositif de travail de référence est en principe étalonné périodiquement.

3.6

cellule de référence

dispositif de référence constitué d'une seule cellule photovoltaïque

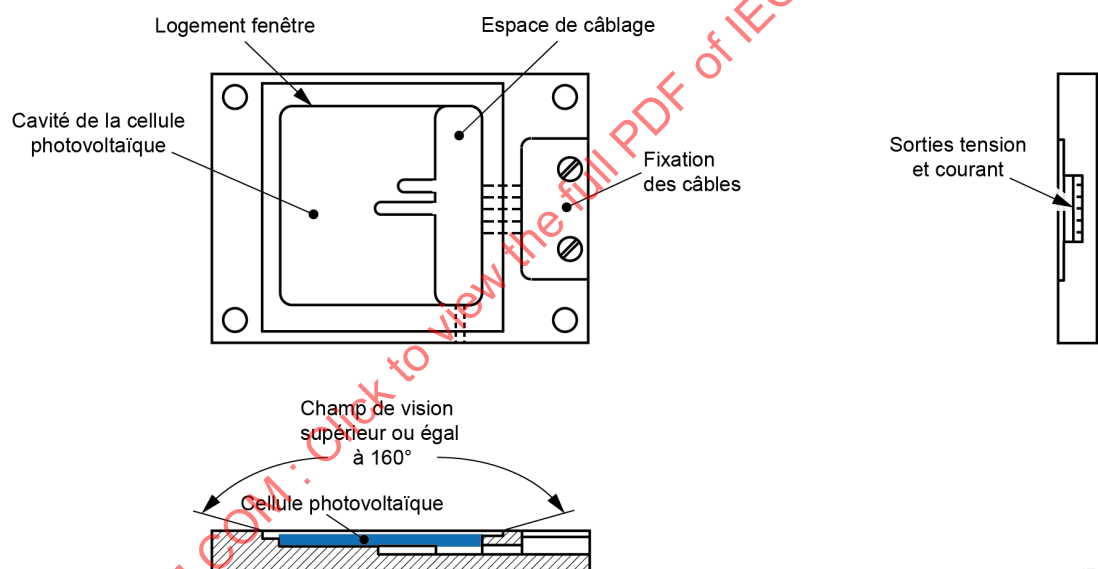
Note 1 à l'article: Pour des raisons pratiques, de telles cellules ont de petites surfaces, et sont généralement montées sur un support qui assure la reproductibilité du montage, de la commande thermique des connexions électriques, ainsi que la protection du dispositif. Un exemple type est esquissé à la Figure 1.

Note 2 à l'article: En règle générale, les cellules de référence sont également équipées d'une fenêtre de protection et sont intégrées dans un encapsulant.

Note 3 à l'article: Utilisation recommandée: comme référence primaire, secondaire ou de travail en laboratoire.

Note 4 à l'article: S'il a été démontré que le système d'encapsulation résiste à une exposition extérieure de longue durée, en appliquant les niveaux d'essai de la série IEC 61215 [1], de telles cellules de référence peuvent aussi convenir pour être utilisées comme dispositifs de surveillance pour une évaluation à long terme du fonctionnement de groupes photovoltaïques.

Note 5 à l'article: Lorsque la cellule de référence est équipée d'une fenêtre de protection, mais sans encapsulant, il convient de ne l'utiliser que pour mesurer les performances d'autres dispositifs PV en utilisant un faisceau direct de l'éclairement solaire naturel ou simulé.



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Figure 1 – Boîtier d'une cellule individuelle

3.7

cellule de référence unique dans un boîtier multicellule

dispositif de référence constitué d'une cellule photovoltaïque unique montée dans un boîtier de sorte que le châssis, le système d'encapsulation, la forme, les dimensions et l'espacement des cellules l'entourant soient les mêmes que dans le module PV à soumettre à l'essai

Note 1 à l'article: Les cellules environnantes peuvent être des cellules réelles ou factices ayant les mêmes propriétés optiques.

3.8

module de référence

dispositif de référence constitué d'un module photovoltaïque

Note 1 à l'article: Utilisation recommandée: pour mesurer d'autres modules afin d'obtenir une correspondance des dimensions, de la construction mécanique, des propriétés optiques et des circuits électriques du module de référence et du module d'essai, de façon à réduire le plus possible les divergences dues à la non-uniformité spatiale du

simulateur solaire, aux réflexions internes, à la distribution de la température et à la désadaptation des réponses spectrales.

Note 2 à l'article: Étant donné que la composante diffuse de l'éclairement solaire naturel et le rayon incident non perpendiculaire de l'éclairement solaire simulé entrent en interaction avec les encapsulants et les feuilles arrière d'un module PV et influencent la quantité d'irradiance que reçoit une cellule particulière, il est recommandé que les dispositifs de référence utilisés pour mesurer les modules PV, les sous-ensembles de modules PV et les groupes PV soient encapsulés de manière à avoir les caractéristiques mécaniques et optiques du dispositif en essai.

3.9

résistance de shunt intégrée

résistance connectée aux bornes de sortie de dispositifs photovoltaïques y compris le câblage de connexion

Note 1 à l'article: La résistance shunte la sortie du dispositif photovoltaïque pour délivrer une tension de sortie à mesurer et éviter que des moyens fournis par l'utilisateur établissent une condition de court-circuit.

Note 2 à l'article: Pour des informations détaillées, se référer au 4.4.

4 Sélection des dispositifs de référence

4.1 Exigences générales

Suivant leur utilisation prévue, il est nécessaire que les dispositifs de référence satisfassent à des exigences différentes en matière de sensibilité spectrale, de construction mécanique, de propriétés optiques, de dimensions et de circuit électrique. La sensibilité spectrale du dispositif de référence, par exemple, est déterminée par la transmission d'une fenêtre de protection quelconque située devant le dispositif et par la sensibilité spectrale du dispositif lui-même. La sensibilité spectrale globale peut donc être adaptée en utilisant des filtres appropriés en tant que fenêtre de protection ou s'ajoutant à celle-ci.

Il convient de fabriquer les dispositifs de référence en utilisant une technologie PV dont la stabilité dans le temps est connue. En particulier, il convient que la valeur de l'étalonnage ne change pas après l'exposition du dispositif de référence à l'irradiation solaire, à des températures du dispositif différentes de sa température d'étalonnage et/ou à un stockage prolongé dans l'obscurité. Les caractéristiques photovoltaïques d'un dispositif de référence doivent être stables conformément aux exigences de l'Article 11.

Le dispositif de référence doit être construit de façon à pouvoir mesurer les paramètres photovoltaïques de performance, en particulier le courant de court-circuit et la puissance maximale. Les dispositifs équipés de résistances de shunt intégrées constituent la seule exception (voir 4.4).

4.2 Exigences supplémentaires pour une cellule de référence unique dans un boîtier multicellule

La ligne en pointillés de la Figure 2 indique les dimensions minimales acceptables d'un boîtier multicellule. Pour d'autres montages de cellules, tels que les demi cellules, une configuration analogue s'applique.