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Photovoltaic devices –
Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PHOTOVOLTAIC DEVICES –

Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 60904-7 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This fourth edition cancels and replaces the third edition published in 2008. It constitutes a technical revision.

The main technical changes with respect to the previous edition are as follows:

- For better compatibility and less redundancy, the clause “Determination of test spectrum” refers to IEC 60904-9.
- The spectral mismatch factor is called SMM instead of MM to enable differentiation to the angular mismatch factor AMM and spectral angular mismatch factor $SAMM$.
- Formulae for the derivation and application of the spectral mismatch factor SMM are added.
- Links to new standards are given, e.g. concerning multi-junction devices.
- Corrected wording (responsivity instead of response and irradiance instead of intensity).

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

FDIS	Report on voting
82/1590/FDIS	82/1605/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of 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 "http://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 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices

1 Scope ~~and object~~

This part of IEC 60904 describes the procedure for correcting the ~~bias~~ spectral mismatch error introduced in the testing of a photovoltaic device, caused by the mismatch between the test spectrum and the reference spectrum (e.g. AM1.5 spectrum) and by the mismatch between the spectral ~~responses~~ responsivities (SR) of the reference ~~cell~~ device and of the device under test ~~specimen~~ and therewith reduce the systematic uncertainty. ~~The procedure applies only to photovoltaic devices linear in SR as defined in IEC 60904-10.~~ This procedure is valid for single-junction devices but the principle may be extended to cover multi-junction devices.

The purpose of this document is to give guidelines for the correction of ~~measurement bias~~ the spectral mismatch error, should there be a spectral mismatch betweenthe test spectrum and the reference spectrum as well as between the reference device SR and the device under test ~~specimen~~ SR. The calculated spectral mismatch correction is only valid for the specific combination of test and reference devices measured with a particular test spectrum.

Since a PV device has a wavelength-dependent ~~response~~ spectral responsivity, its performance is significantly affected by the spectral distribution of the incident radiation, which in natural sunlight varies with several factors such as location, weather, time of year, time of day, orientation of the receiving surface, etc., and with a solar simulator varies with its type and conditions. If the irradiance is measured with a thermopile-type radiometer (that is not spectrally selective) or with a PV reference ~~solar cell~~ device (IEC 60904-2), the spectral irradiance distribution of the incoming light must be known to make the necessary corrections to obtain the performance of the PV device under the reference ~~solar~~ spectral irradiance distribution defined in IEC 60904-3.

If a reference PV device or a thermopile type detector is used to measure the irradiance, then, following the procedure given in this document, it is possible to calculate the spectral mismatch correction necessary to obtain the short-circuit current of the ~~test PV~~ device under test under the reference ~~solar~~ spectral irradiance distribution in IEC 60904-3 or any other reference spectrum. If the reference PV device has the same relative spectral ~~response~~ responsivity as the ~~test PV~~ device under test then the reference device automatically takes into account deviations of the ~~real light~~ measured spectral irradiance distribution from the ~~standard~~ reference spectral irradiance distribution, and no further correction of spectral ~~bias~~ mismatch errors is necessary. In this case, location and weather conditions are not critical when the reference device method is used for ~~outdoor~~ performance measurements ~~provided both reference cell and test PV device have the same relative spectral response~~ under natural sunlight. Also, for identical relative SRs, the spectral classification of the simulator is not critical for ~~indoor~~ measurements with solar simulators.

If the performance of a PV device is measured using a known spectral irradiance distribution, its short-circuit current at any other spectral irradiance distribution can be computed using the spectral ~~response~~ responsivity of the PV ~~test~~ device under test.

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* ~~*of crystalline silicon photovoltaic devices*~~

IEC 60904-1, *Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics*

IEC 60904-1-1, *Photovoltaic devices – Part 1-1: Measurement of current-voltage characteristics of multi-junction photovoltaic (PV) devices*

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

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

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

IEC 60904-8-1, *Photovoltaic devices – Part 8-1: Measurement of spectral responsivity of multi-junction photovoltaic (PV) devices*

IEC 60904-9, *Photovoltaic devices – Part 9: Solar simulator performance requirements*

~~IEC 60904-10, *Photovoltaic devices – Part 10 Methods of linearity measurement*~~

~~IEC 61215, *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval*~~

~~IEC 61646, *Thin film terrestrial photovoltaic (PV) modules – Design qualification and type approval*~~

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

ISO 9288:1989, *Thermal insulation – Heat transfer by radiation – Physical quantities and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 and ISO 9288 apply.

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

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

NOTE The index e for the energetic quantities is omitted, as in this document the quantities need not be distinguished from photometric quantities. Thus, for the quantity irradiance the quantity symbol E instead of the quantity symbol E_{e} is used.

The index λ that denotes that the irradiance is differentiated with respect to the wavelength λ and not to the frequency ν to obtain the spectral irradiance $E_{\lambda}(\lambda)$ is mostly omitted for clarity. Therefore, the spectral irradiance is referred to herein as $E(\lambda)$.

4 Description of method

For many PV devices, the shape of the I-V characteristic depends on the short-circuit current and the device temperature, but not on the spectrum used to generate the short-circuit current. For these devices, the correction of spectrum mismatch or spectral ~~response~~ responsivity mismatch is possible using the following procedure. For other devices, a measurement of the I-V characteristic shall be done using a light source with the appropriate spectrum.

A correction is not necessary if either the test spectrum is identical to the reference spectrum (see IEC 60904-3) or if the ~~test specimen's~~ device under test's relative spectral ~~response~~ responsivity is identical to the reference ~~cell~~ device relative spectral ~~response~~ responsivity. In this case, the reading as obtained from the reference ~~cell~~ device specifies which ~~intensity~~ irradiance at the reference spectrum will generate the same short-circuit current in the ~~test~~ device under test as the test spectrum.

If there is a mismatch between spectra (spectrum mismatch) as well as spectral ~~responses~~ responsivities (spectral responsivity mismatch) then a mismatch correction should be calculated. As the test spectrum and the spectral responsivities always have an assigned measurement uncertainty, for the calculation of the total uncertainty the uncertainty of spectral mismatch shall be always taken into account.

~~Due to the mismatch in spectra and spectral responses, the reading of the reference cell (see IEC 60904-2) does not give the intensity of the reference spectrum that generates the short-circuit current as measured for the test device. One must determine the effective irradiance of the reference spectrum that generates the same short-circuit current in the test device as generated by the test spectrum at the measured irradiance G_{meas}.~~

~~$$G_{eff\ at\ ref\ spectrum} = MM \times G_{meas} \quad (1)$$~~

~~where G_{meas} is the irradiance as measured by the reference device with its specific spectral response $S_{ref}(\lambda)$ and MM is the spectral mismatch factor as determined in Clause 7.~~

~~For a measurement to be referred to the reference spectral irradiance, two correction methods are possible:~~

~~a) If possible, adjust the simulator intensity so that the effective irradiance as determined by equation (1) equals the reference irradiance G_{ref} (e.g. 1 000 W/m^2 for STC, as defined in IEC 61215 and IEC 61646). That is to say that the simulator intensity as measured by the reference cell using its calibration value given for the reference spectrum has to be set to~~

~~$$G_{meas} = G_{ref} / MM \quad (2)$$~~

~~Thus, the inverse mismatch factor $1/MM$ gives the degree by which the simulator intensity has to be adjusted, if the device is linear (see IEC 60904-10). Now, the simulator spectrum +++at this irradiance with its actual simulator spectrum generates the same short-circuit current as the reference spectrum at the reference intensity. Proceed to measure the I-V characteristic per IEC 60904-1.~~

~~b) Otherwise, measure the I-V characteristic using the given simulator intensity. Determine the effective irradiance at the reference spectrum using equation (1). Then transfer the I-V characteristic to the reference irradiance using IEC 60891 with the effective irradiance determined from equation (1).~~

~~Method a) is preferred for simulated sunlight (see IEC 60904-9), as the actual measurement is performed at the correct short-circuit current, minimising non-linearity errors. Method b) is usually chosen for outdoor measurements, if the light intensity cannot be easily controlled.~~

When a mismatch in spectra and/or spectral responsivities exists, the reading of the reference device (see IEC 60904-2) does not give the irradiance of the test spectrum that would generate the same short-circuit current for the device under test as the reference spectrum. Therefore, one shall determine the effective irradiance of the test spectrum, E_{eff} that generates the same short-circuit current in the device under test as generated by the reference spectrum.

$$E_{eff} = SMM \times E_{meas} \tag{1}$$

where E_{meas} is the irradiance as measured by the reference device with its specific spectral responsivity $s_{ref}(\lambda)$ before applying spectral mismatch corrections and SMM is the spectral mismatch factor as determined in Clause 7.

For a measurement to be referred to the reference spectral irradiance, two correction methods are possible:

a) If possible, adjust the measured test spectrum irradiance so that the effective irradiance as determined by formula (1) equals the reference irradiance E_{ref} (e.g. 1 000 W/m2 for STC, as defined in IEC TS 61836). That is to say that the solar simulator's irradiance as measured by the reference device using its calibration value before applying spectral mismatch correction given for the reference spectrum has to be set to

$$E_{meas} = E_{ref} / SMM \tag{2}$$

Thus, the inverse mismatch factor 1/SMM gives the degree by which the solar simulator's irradiance has to be adjusted. Now, the solar simulator spectrum at this irradiance with its actual measured test spectrum generates the same short-circuit current for the device under test as would be obtained under the reference spectrum. If the adjustment is done without using the feedback of the reference device (e.g. using a control dial), the adjusted value should be checked using a reference device. Thereafter, proceed to measure the I-V characteristic as per IEC 60904-1.

b) Otherwise, measure the I-V characteristic using the measured spectral irradiance. Determine the effective irradiance at the reference spectrum using formula (1). Then translate the I-V characteristic to the reference irradiance using IEC 60891 with the effective irradiance determined from formula (1).

Method a) is preferred for simulated sunlight, as the actual measurement is performed at the correct reference irradiance, minimising non-linearity errors of the device under test and errors arising from the I-V curve translation. Method b) is usually chosen for measurements under natural sunlight, as the spectral irradiance of sunlight cannot be easily adjusted.

~~4 Apparatus~~

~~**4.1** Spectral response measurement set up according to IEC 60904-8.~~

~~**4.2** Apparatus for measurement of PV current voltage characteristics according to IEC 60904-1.~~

~~**4.3** Spectroradiometer capable of measuring the spectral irradiance in the test plane in a spectral range exceeding that of the spectral responses of the reference and test devices.~~

~~NOTE 1 For example spectroradiometer measurements are described in CIE 63 (1984).~~

~~NOTE 2 The input head of the spectroradiometer and the test device should have a similar field of view with a similar dependency of the solid angle.~~

5 Determination of spectral ~~response~~ responsivity

5.1 ~~The relative spectral response of the test specimen shall be measured according to IEC 60904-8.~~ If not available, the relative spectral responsivity of the device under test and the reference device shall be measured according to IEC 60904-8 for single-junction devices and IEC 60904-8-1 for multi-junction devices under test.

5.2 ~~If not available from the calibration documents, the relative spectral response of the reference device shall be measured according to IEC 60904-8.~~ Take care not to use the differential spectral responsivity, but the spectral responsivity, that can be calculated using differential spectral responsivities at different bias level (see IEC 60904-8).

6 Determination of test spectrum

~~**6.1** Mount the input head of the spectroradiometer in the position where the test device will subsequently be mounted, or as close as possible to that location. It shall be mounted coplanar to the test specimen within ± 2°.~~

~~**6.2** Record the spectrum of the light source. For simulator measurements, steps of 2 nm or less with 2-5 nm bandwidths are recommended. For outdoor spectra, steps and bandwidth of up to 10 nm are allowable. Verify that the total irradiance does not vary by more than ± 2 % during this measurement. If necessary, apply a linear intensity correction to all measurement points with respect to the actual total irradiance. Alternatively, several scans can be taken, they shall agree within ± 2 %. Then determine the average relative spectrum.~~

~~**6.3** If the acquisition time for a full spectrum is larger than the acquisition time for the I-V characteristic, or if the light source is not spectrally stable over time (e.g. flash simulators or natural sunlight), special care must be given to determine the correct test spectrum.~~

~~NOTE 1 A pulsed simulator may not be spectrally stable during the I-V measurement period. Also, at the rising and falling edge of the pulse, the spectrum may be different from the spectrum during the designated measurement time. Therefore, it may not be correct to measure the spectrum with an integration time including the rise and tail of the pulse.~~

~~NOTE 2 Outdoor spectra may not be stable due to changes in the atmospheric conditions.~~

The relative spectral irradiance distribution of the radiation source shall be measured according to IEC 60904-9. This shall be done for simulated as well as natural sunlight.

7 Determination of the spectral mismatch factor

~~Determine the spectral mismatch factor from~~

$$MM = \frac{\int E_{\text{ref}}(\lambda) S_{\text{ref}}(\lambda)\, d\lambda \int E_{\text{meas}}(\lambda)\, S_{\text{sample}}(\lambda)\, d\lambda}{\int E_{\text{meas}}(\lambda) S_{\text{ref}}(\lambda)\, d\lambda \int E_{\text{ref}}(\lambda)\, S_{\text{sample}}(\lambda)\, d\lambda} \qquad (3)$$

~~where~~

~~$E_{\text{ref}}(\lambda)$ is the irradiance per unit bandwidth at a particular wavelength λ, of the reference spectral irradiance distribution, for example as given in IEC 60904-3;~~

~~$E_{\text{meas}}(\lambda)$ is the irradiance per unit bandwidth at a particular wavelength λ, of the spectral irradiance distribution of the incoming light at the time of measurement;~~

~~$S_{\text{ref}}(\lambda)$ is the spectral response of the reference PV device;~~

~~$S_{\text{sample}}(\lambda)$ is the spectral response of the test PV device.~~

All integrals must be performed in the full spectral range where the reference device and the sample are spectrally sensitive.

NOTE 1 The spectral irradiance distributions and the spectral responses can be given on an absolute or relative scale.

NOTE 2 Due to the irregular shape of the solar and simulator spectra, spectral responses should be interpolated to the wavelength points of the spectral irradiance measurements, not vice versa.

NOTE 3 Equation 3 is valid for single junction devices, but may be used for multi-junction devices. For multi-junction devices, the calculation must be performed for each junction in the device, using its spectral response including the spectral filtering caused by the junctions above the junction under consideration. The test report should specify the mismatch factors and the relative current generation of the individual junctions.

NOTE 4 The integral boundaries should be the boundary wavelengths of the SR.

In the case, that absolute spectra and absolute spectral responses are used for the analysis, Equation 3 can be interpreted as

$$MM = \frac{I_{\mathrm{sc,ref,E_{ref}}} \; I_{\mathrm{sc,sample,E_{meas}}}}{I_{\mathrm{sc,ref,E_{meas}}} \; I_{\mathrm{sc,sample,E_{ref}}}} \qquad (4)$$

where

$I_{\mathrm{sc,\ sample,\ E_{ref}}}$ is the short-circuit current of the test sample under the reference spectrum;

$I_{\mathrm{sc,\ ref,\ E_{ref}}}$ is the short-circuit current of the reference device under the reference spectrum;

$I_{\mathrm{sc,\ sample,\ E_{meas}}}$ is the short-circuit current of the test sample under the measured spectrum;

$I_{\mathrm{sc,\ ref,\ E_{meas}}}$ is the short-circuit current of the reference device under the measured spectrum

because $I_{\mathrm{sc}} = \int E(\lambda) S(\lambda) d\lambda$

7.1 General

Determine the spectral mismatch factor from :

$$SMM = \frac{\int E_{\mathrm{ref}}(\lambda) s_{\mathrm{ref}}(\lambda)\, d\lambda \int E_{\mathrm{meas}}(\lambda)\, s_{\mathrm{DUT}}(\lambda)\, d\lambda}{\int E_{\mathrm{meas}}(\lambda) s_{\mathrm{ref}}(\lambda)\, d\lambda \int E_{\mathrm{ref}}(\lambda)\, s_{\mathrm{DUT}}(\lambda)\, d\lambda} \qquad (3)$$

where

$E_{\mathrm{ref}}(\lambda)$ is the irradiance per unit bandwidth at a particular wavelength λ, of the reference spectral irradiance distribution (reference spectrum), for example as given in IEC 60904-3;

$E_{\mathrm{meas}}(\lambda)$ is the irradiance per unit bandwidth at a particular wavelength λ, of the spectral irradiance distribution of the incoming light at the time of measurement (test spectrum);

$s_{\mathrm{ref}}(\lambda)$ is the spectral responsivity of the reference PV device at reference conditions;

$s_{\mathrm{DUT}}(\lambda)$ is the spectral responsivity of the device under test at reference conditions.

All integrals shall be performed in the entire spectral range where the respective quantities are not zero. The irradiance distribution shall be known over the entire combined spectral range of sensitivity of the device under test and the reference PV device.

The spectral irradiance distributions and the spectral responsivities can be given on an absolute or relative scale.

If the relative test spectrum would be identical to relative reference spectrum, then the *SMM* is 1 and spectral mismatch corrections can be neglected, even if the spectral responsivities of the devices differ. However, considering that the test spectrum as a physical quantity has a measurement uncertainty assigned to it that is not zero, the *SMM* will still have a measurement uncertainty contribution different to zero. Thus, the *SMM* factor cannot be neglected when considering its measurement uncertainty contribution, though the value of the factor is 1.

If the relative spectral responsivity of the device under test would be identical to the relative spectral responsivity of the reference device, then the *SMM* is 1, even if the relative spectral irradiance distributions differ (perfectly matched reference device). Considering that both spectral responsivities have a measurement uncertainty that is not zero, the *SMM* will still have a measurement uncertainty contribution different to zero. Thus, the *SMM* factor cannot be neglected when considering its measurement uncertainty contribution, though the value of the factor is 1.

Due to the irregular shape of the reference and measured spectra, spectral responsivities should be interpolated to the wavelength points of the spectral irradiance measurements, not vice versa.

Formula (3) is valid for single-junction devices, but may be used for multi-junction devices. For multi-junction devices, the calculation shall be performed for each junction in the device, using its spectral responsivity including the spectral filtering caused by the junctions above the junction under consideration. The test report should specify the spectral mismatch factors and the relative current generation of the individual junctions. For multi-junction devices, refer to IEC 60904-1-1 (I-V) and IEC 60904-8-1 (SR).

The spectral responsivities used shall be valid at the level of target irradiance for which the SMM factor applies because for non-linear devices they may vary with the level of irradiance.

Derivation of SMM

In the case that absolute spectral irradiances and absolute spectral responsivities are used for the analysis, Formula (3) can be interpreted as:

$$SMM = \frac{I_{\mathrm{ref},E_{\mathrm{ref}}}\ I_{\mathrm{DUT},E_{\mathrm{meas}}}}{I_{\mathrm{ref},E_{\mathrm{meas}}}\ I_{\mathrm{DUT},E_{\mathrm{ref}}}} \tag{4}$$

where

$I_{\mathrm{DUT},\,E_{\mathrm{ref}}}$ is the short-circuit current of the device under test that would be obtained under the reference spectrum $E_{\mathrm{ref}}(\lambda)$;

$I_{\mathrm{ref},\,E_{\mathrm{ref}}}$ is the short-circuit current of the reference device that would be obtained under the reference spectrum $E_{\mathrm{ref}}(\lambda)$;

$I_{\mathrm{DUT},\,E_{\mathrm{meas}}}$ is the short-circuit current of the device under test under the measured test spectrum $E_{\mathrm{meas}}(\lambda)$;

$I_{\mathrm{ref},\,E_{\mathrm{meas}}}$ is the short-circuit current of the reference device under the measured test spectrum $E_{\mathrm{meas}}(\lambda)$

because $I_{sc} \propto \int E_\lambda(\lambda)\, s(\lambda)\, d\lambda$.

Using these quantities, one can write according to the definition of the responsivity:

$$s_{DUT} = \underbrace{\frac{I_{DUT,\,E_{ref}}}{E_{ref}}}_{\text{What you want to know}} = s_{ref} \cdot \frac{I_{DUT,\,E_{ref}}}{I_{ref,\,E_{ref}}} = s_{ref} \cdot \frac{I_{DUT,\,E_{ref}}}{I_{ref,\,E_{ref}}} \cdot \underbrace{\frac{I_{ref,\,E_{meas}}}{I_{DUT,\,E_{meas}}} \cdot \frac{I_{DUT,\,E_{meas}}}{I_{ref,\,E_{meas}}}}_{1} = s_{ref} \cdot \frac{1}{SMM} \cdot \underbrace{\frac{I_{DUT,\,E_{meas}}}{I_{ref,\,E_{meas}}}}_{\text{What you measure}} \qquad (5)$$

where

s_{DUT} is the (integral) responsivity of the device under test under reference spectrum:

$$s_{DUT} = \frac{I_{DUT,\,E_{ref}}}{E_{ref}}$$

s_{ref} is the (integral) responsivity of the reference device under reference spectrum: $s_{ref} = \frac{I_{ref,\,E_{ref}}}{E_{ref}}$

E_{ref} is the reference irradiance, typically 1 000 W/m^2.

7.2 Simplified formula for a thermopile detector (pyranometer)

IEC 60904-1 also allows the use of a thermopile detector (pyranometer) as reference device for the measurement of the test irradiance (under steady-state simulated or natural sunlight). As their spectral responsivity is nearly spectrally independent, one can assume $s_{ref}(\lambda) = 1$. In this case the formulae are modified as follows:

$$SMM = \frac{\int E_{ref}(\lambda)\, d\lambda \int E_{meas}(\lambda)\, s_{DUT}(\lambda)\, d\lambda}{\int E_{meas}(\lambda) d\lambda \int E_{ref}(\lambda)\, s_{DUT}(\lambda)\, d\lambda} \qquad (6)$$

$$SMM = \frac{E_{ref} \int E_{meas}(\lambda)\, s_{DUT}(\lambda)\, d\lambda}{E_{meas} \int E_{ref}(\lambda)\, s_{DUT}(\lambda)\, d\lambda} \qquad (7)$$

$$SMM = \frac{E_{ref}\; I_{DUT,E_{meas}}}{E_{meas}\; I_{DUT,E_{ref}}} \qquad (8)$$

where

E_{ref} is the reference irradiance, typically 1 000 W/m^2;

E_{meas} is the irradiance measured by the thermopile detector.

In Formula (6) the two integrals in the first fraction have to be taken over the entire wavelength range of sensitivity of the thermopile detector. This in general poses a problem, as the sensitivity range of such detectors is larger than the range readily measurable with spectroradiometers.

Formula (7) offers a solution by just using the measured irradiance. However, in this case the spectral irradiance of the test spectrum $E_{meas}(\lambda)$ has to be on an absolute scale.

8 Report

The following information should be given in the test report according to IEC 60904-1.

a) If the spectral mismatch is used for the irradiance correction of a measurement based on IEC 60904-1 or another relevant standard, the calculated spectral mismatch factor, the identification of the ~~test~~ device under test and the reference device as well as their spectral ~~responses~~ responsivities according to their test report (IEC 60904-8 or IEC 60904-8-1), the test spectrum and the reference spectrum or a reference to it should all be included in the test report, along with the method used to calculate the integrals.

   If the reference device and the device under test are of different dimensions (active area), the dimensions should be specified in the test report.

b) If a perfectly matched reference device is used and no mismatch correction is applied, the identification of the ~~test~~ device under test and the reference device, as well as the spectral ~~responses~~ responsivities of reference and ~~test devices~~ device under tests according to their test report (IEC 60904-8 or IEC 60904-8-1) should be included in the test report.

   If the reference device and the device under test are of different dimensions (active area), the dimensions should be specified in the test report.

   If the spectral ~~response~~ responsivity of the device under test cannot be measured, the test report should include the criteria used to define the equivalency of the spectral ~~responses~~ responsivities.

c) Note that the spectral mismatch factor determined by applying this procedure is only valid for correcting a measurement of the specific device under test considered with the particular reference device and test spectrum used to calculate the SMM. When measuring this device under test under different spectral irradiance (being it simulated or natural sunlight) and/or with a different reference device, the spectral mismatch factor shall be recalculated.

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CIE 63:1984, *The Spectroradiometric Measurement of Light Sources*

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NORME INTERNATIONALE

Photovoltaic devices –
Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices

Dispositifs photovoltaïques –
Partie 7: Calcul de la correction de désadaptation des réponses spectrales dans les mesures de dispositifs photovoltaïques

IEC 60904-7:2019-08(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PHOTOVOLTAIC DEVICES –

Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices

FOREWORD

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International Standard IEC 60904-7 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This fourth edition cancels and replaces the third edition published in 2008. It constitutes a technical revision.

The main technical changes with respect to the previous edition are as follows:

- For better compatibility and less redundancy, the clause "Determination of test spectrum" refers to IEC 60904-9.
- The spectral mismatch factor is called SMM instead of MM to enable differentiation to the angular mismatch factor AMM and spectral angular mismatch factor $SAMM$.
- Formulae for the derivation and application of the spectral mismatch factor SMM are added.
- Links to new standards are given, e.g. concerning multi-junction devices.

- Corrected wording (responsivity instead of response and irradiance instead of intensity).

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

FDIS	Report on voting
82/1590/FDIS	82/1605/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of 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 "http://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.

PHOTOVOLTAIC DEVICES –

Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices

1 Scope

This part of IEC 60904 describes the procedure for correcting the spectral mismatch error introduced in the testing of a photovoltaic device, caused by the mismatch between the test spectrum and the reference spectrum (e.g. AM1.5 spectrum) and by the mismatch between the spectral responsivities (SR) of the reference device and of the device under test and therewith reduce the systematic uncertainty. This procedure is valid for single-junction devices but the principle may be extended to cover multi-junction devices.

The purpose of this document is to give guidelines for the correction of the spectral mismatch error, should there be a spectral mismatch between the test spectrum and the reference spectrum as well as between the reference device SR and the device under test SR. The calculated spectral mismatch correction is only valid for the specific combination of test and reference devices measured with a particular test spectrum.

Since a PV device has a wavelength-dependent spectral responsivity, its performance is significantly affected by the spectral distribution of the incident radiation, which in natural sunlight varies with several factors such as location, weather, time of year, time of day, orientation of the receiving surface, etc., and with a solar simulator varies with its type and conditions. If the irradiance is measured with a thermopile-type radiometer (that is not spectrally selective) or with a PV reference device (IEC 60904-2), the spectral irradiance distribution of the incoming light must be known to make the necessary corrections to obtain the performance of the PV device under the reference spectral irradiance distribution defined in IEC 60904-3.

If a reference PV device or a thermopile type detector is used to measure the irradiance, then, following the procedure given in this document, it is possible to calculate the spectral mismatch correction necessary to obtain the short-circuit current of the device under test under the reference spectral irradiance distribution in IEC 60904-3 or any other reference spectrum. If the reference PV device has the same relative spectral responsivity as the device under test then the reference device automatically takes into account deviations of the measured spectral irradiance distribution from the reference spectral irradiance distribution, and no further correction of spectral mismatch errors is necessary. In this case, location and weather conditions are not critical when the reference device method is used for performance measurements under natural sunlight. Also, for identical relative SRs, the spectral classification of the simulator is not critical for measurements with solar simulators.

If the performance of a PV device is measured using a known spectral irradiance distribution, its short-circuit current at any other spectral irradiance distribution can be computed using the spectral responsivity of the PV device under test.

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 60904-1-1, *Photovoltaic devices – Part 1-1: Measurement of current-voltage characteristics of multi-junction photovoltaic (PV) devices*

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

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

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

IEC 60904-8-1, *Photovoltaic devices – Part 8-1: Measurement of spectral responsivity of multi-junction photovoltaic (PV) devices*

IEC 60904-9, *Photovoltaic devices – Part 9: Solar simulator performance requirements*

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

ISO 9288:1989, *Thermal insulation – Heat transfer by radiation – Physical quantities and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 and ISO 9288 apply.

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

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

NOTE The index e for the energetic quantities is omitted, as in this document the quantities need not be distinguished from photometric quantities. Thus, for the quantity irradiance the quantity symbol E instead of the quantity symbol E_e is used.

The index λ that denotes that the irradiance is differentiated with respect to the wavelength λ and not to the frequency ν to obtain the spectral irradiance $E_\lambda(\lambda)$ is mostly omitted for clarity. Therefore, the spectral irradiance is referred to herein as $E(\lambda)$.

4 Description of method

For many PV devices, the shape of the I-V characteristic depends on the short-circuit current and the device temperature, but not on the spectrum used to generate the short-circuit current. For these devices, the correction of spectrum mismatch or spectral responsivity mismatch is possible using the following procedure. For other devices, a measurement of the I-V characteristic shall be done using a light source with the appropriate spectrum.

A correction is not necessary if either the test spectrum is identical to the reference spectrum (see IEC 60904-3) or if the device under test's relative spectral responsivity is identical to the reference device relative spectral responsivity. In this case, the reading as obtained from the reference device specifies which irradiance at the reference spectrum will generate the same short-circuit current in the device under test as the test spectrum.

If there is a mismatch between spectra (spectrum mismatch) as well as spectral responsivities (spectral responsivity mismatch) then a mismatch correction should be calculated. As the test spectrum and the spectral responsivities always have an assigned measurement uncertainty, for the calculation of the total uncertainty the uncertainty of spectral mismatch shall be always taken into account.

When a mismatch in spectra and/or spectral responsivities exists, the reading of the reference device (see IEC 60904-2) does not give the irradiance of the test spectrum that would generate the same short-circuit current for the device under test as the reference spectrum. Therefore, one shall determine the effective irradiance of the test spectrum, E_{eff} that generates the same short-circuit current in the device under test as generated by the reference spectrum.

$$E_{\text{eff}} = SMM \times E_{\text{meas}} \quad (1)$$

where E_{meas} is the irradiance as measured by the reference device with its specific spectral responsivity $s_{\text{ref}}(\lambda)$ before applying spectral mismatch corrections and SMM is the spectral mismatch factor as determined in Clause 7.

For a measurement to be referred to the reference spectral irradiance, two correction methods are possible:

a) If possible, adjust the measured test spectrum irradiance so that the effective irradiance as determined by formula (1) equals the reference irradiance E_{ref} (e.g. 1 000 W/m2 for STC, as defined in IEC TS 61836). That is to say that the solar simulator's irradiance as measured by the reference device using its calibration value before applying spectral mismatch correction given for the reference spectrum has to be set to

$$E_{\text{meas}} = E_{\text{ref}} / SMM \quad (2)$$

Thus, the inverse mismatch factor 1/SMM gives the degree by which the solar simulator's irradiance has to be adjusted. Now, the solar simulator spectrum at this irradiance with its actual measured test spectrum generates the same short-circuit current for the device under test as would be obtained under the reference spectrum. If the adjustment is done without using the feedback of the reference device (e.g. using a control dial), the adjusted value should be checked using a reference device. Thereafter, proceed to measure the I-V characteristic as per IEC 60904-1.

b) Otherwise, measure the I-V characteristic using the measured spectral irradiance. Determine the effective irradiance at the reference spectrum using formula (1). Then translate the I-V characteristic to the reference irradiance using IEC 60891 with the effective irradiance determined from formula (1).

Method a) is preferred for simulated sunlight, as the actual measurement is performed at the correct reference irradiance, minimising non-linearity errors of the device under test and errors arising from the I-V curve translation. Method b) is usually chosen for measurements under natural sunlight, as the spectral irradiance of sunlight cannot be easily adjusted.

5 Determination of spectral responsivity

5.1 If not available, the relative spectral responsivity of the device under test and the reference device shall be measured according to IEC 60904-8 for single-junction devices and IEC 60904-8-1 for multi-junction devices under test.

5.2 Take care not to use the differential spectral responsivity, but the spectral responsivity, that can be calculated using differential spectral responsivities at different bias level (see IEC 60904-8).

6 Determination of test spectrum

The relative spectral irradiance distribution of the radiation source shall be measured according to IEC 60904-9. This shall be done for simulated as well as natural sunlight.

7 Determination of the spectral mismatch factor

7.1 General

Determine the spectral mismatch factor from :

$$SMM = \frac{\int E_{\text{ref}}(\lambda) s_{\text{ref}}(\lambda)\, d\lambda \int E_{\text{meas}}(\lambda)\, s_{\text{DUT}}(\lambda)\, d\lambda}{\int E_{\text{meas}}(\lambda) s_{\text{ref}}(\lambda)\, d\lambda \int E_{\text{ref}}(\lambda)\, s_{\text{DUT}}(\lambda)\, d\lambda} \quad (3)$$

where

$E_{\text{ref}}(\lambda)$ is the irradiance per unit bandwidth at a particular wavelength λ, of the reference spectral irradiance distribution (reference spectrum), for example as given in IEC 60904-3;

$E_{\text{meas}}(\lambda)$ is the irradiance per unit bandwidth at a particular wavelength λ, of the spectral irradiance distribution of the incoming light at the time of measurement (test spectrum);

$s_{\text{ref}}(\lambda)$ is the spectral responsivity of the reference PV device at reference conditions;

$s_{\text{DUT}}(\lambda)$ is the spectral responsivity of the device under test at reference conditions.

All integrals shall be performed in the entire spectral range where the respective quantities are not zero. The irradiance distribution shall be known over the entire combined spectral range of sensitivity of the device under test and the reference PV device.

The spectral irradiance distributions and the spectral responsivities can be given on an absolute or relative scale.

If the relative test spectrum would be identical to relative reference spectrum, then the SMM is 1 and spectral mismatch corrections can be neglected, even if the spectral responsivities of the devices differ. However, considering that the test spectrum as a physical quantity has a measurement uncertainty assigned to it that is not zero, the SMM will still have a measurement uncertainty contribution different to zero. Thus, the SMM factor cannot be neglected when considering its measurement uncertainty contribution, though the value of the factor is 1.

If the relative spectral responsivity of the device under test would be identical to the relative spectral responsivity of the reference device, then the SMM is 1, even if the relative spectral irradiance distributions differ (perfectly matched reference device). Considering that both spectral responsivities have a measurement uncertainty that is not zero, the SMM will still have a measurement uncertainty contribution different to zero. Thus, the SMM factor cannot be neglected when considering its measurement uncertainty contribution, though the value of the factor is 1.

Due to the irregular shape of the reference and measured spectra, spectral responsivities should be interpolated to the wavelength points of the spectral irradiance measurements, not vice versa.

Formula (3) is valid for single-junction devices, but may be used for multi-junction devices. For multi-junction devices, the calculation shall be performed for each junction in the device, using its spectral responsivity including the spectral filtering caused by the junctions above the junction under consideration. The test report should specify the spectral mismatch factors and the relative current generation of the individual junctions. For multi-junction devices, refer to IEC 60904-1-1 (I-V) and IEC 60904-8-1 (SR).

The spectral responsivities used shall be valid at the level of target irradiance for which the SMM factor applies because for non-linear devices they may vary with the level of irradiance.

Derivation of SMM

In the case that absolute spectral irradiances and absolute spectral responsivities are used for the analysis, Formula (3) can be interpreted as:

$$SMM = \frac{I_{\mathrm{ref},E_{\mathrm{ref}}} \; I_{\mathrm{DUT},E_{\mathrm{meas}}}}{I_{\mathrm{ref},E_{\mathrm{meas}}} \; I_{\mathrm{DUT},E_{\mathrm{ref}}}} \qquad (4)$$

where

$I_{\mathrm{DUT},\,E_{\mathrm{ref}}}$ is the short-circuit current of the device under test that would be obtained under the reference spectrum $E_{\mathrm{ref}}(\lambda)$;

$I_{\mathrm{ref},\,E_{\mathrm{ref}}}$ is the short-circuit current of the reference device that would be obtained under the reference spectrum $E_{\mathrm{ref}}(\lambda)$;

$I_{\mathrm{DUT},\,E_{\mathrm{meas}}}$ is the short-circuit current of the device under test under the measured test spectrum $E_{\mathrm{meas}}(\lambda)$;

$I_{\mathrm{ref},\,E_{\mathrm{meas}}}$ is the short-circuit current of the reference device under the measured test spectrum $E_{\mathrm{meas}}(\lambda)$

because $I_{\mathrm{sc}} \propto \int E_{\lambda}(\lambda)\, s(\lambda)\, d\lambda$.

Using these quantities, one can write according to the definition of the responsivity:

$$s_{\mathrm{DUT}} = \underbrace{\frac{I_{\mathrm{DUT},\,E_{\mathrm{ref}}}}{E_{\mathrm{ref}}}}_{\text{What you want to know}} = s_{\mathrm{ref}} \cdot \frac{I_{\mathrm{DUT},\,E_{\mathrm{ref}}}}{I_{\mathrm{ref},\,E_{\mathrm{ref}}}} = s_{\mathrm{ref}} \cdot \frac{I_{\mathrm{DUT},\,E_{\mathrm{ref}}}}{I_{\mathrm{ref},\,E_{\mathrm{ref}}}} \cdot \underbrace{\frac{I_{\mathrm{ref},\,E_{\mathrm{meas}}}}{I_{\mathrm{DUT},\,E_{\mathrm{meas}}}} \frac{I_{\mathrm{DUT},\,E_{\mathrm{meas}}}}{I_{\mathrm{ref},\,E_{\mathrm{meas}}}}}_{1} = s_{\mathrm{ref}} \cdot \frac{1}{SMM} \cdot \underbrace{\frac{I_{\mathrm{DUT},\,E_{\mathrm{meas}}}}{I_{\mathrm{ref},\,E_{\mathrm{meas}}}}}_{\text{What you measure}} \qquad (5)$$

where

s_{DUT} is the (integral) responsivity of the device under test under reference spectrum:

$$s_{DUT} = \frac{I_{DUT,\,E_{ref}}}{E_{ref}}$$

s_{ref} is the (integral) responsivity of the reference device under reference spectrum: $s_{ref} = \frac{I_{ref,\,E_{ref}}}{E_{ref}}$

E_{ref} is the reference irradiance, typically 1 000 W/m^2.

7.2 Simplified formula for a thermopile detector (pyranometer)

IEC 60904-1 also allows the use of a thermopile detector (pyranometer) as reference device for the measurement of the test irradiance (under steady-state simulated or natural sunlight). As their spectral responsivity is nearly spectrally independent, one can assume $s_{ref}(\lambda) = 1$. In this case the formulae are modified as follows:

$$SMM = \frac{\int E_{ref}(\lambda)\, d\lambda \int E_{meas}(\lambda)\, s_{DUT}(\lambda)\, d\lambda}{\int E_{meas}(\lambda) d\lambda \int E_{ref}(\lambda)\, s_{DUT}(\lambda)\, d\lambda} \quad (6)$$

$$SMM = \frac{E_{ref} \int E_{meas}(\lambda)\, s_{DUT}(\lambda)\, d\lambda}{E_{meas} \int E_{ref}(\lambda)\, s_{DUT}(\lambda)\, d\lambda} \quad (7)$$

$$SMM = \frac{E_{ref}\ I_{DUT,E_{meas}}}{E_{meas}\ I_{DUT,E_{ref}}} \quad (8)$$

where

E_{ref} is the reference irradiance, typically 1 000 W/m^2;

E_{meas} is the irradiance measured by the thermopile detector.

In Formula (6) the two integrals in the first fraction have to be taken over the entire wavelength range of sensitivity of the thermopile detector. This in general poses a problem, as the sensitivity range of such detectors is larger than the range readily measurable with spectroradiometers.

Formula (7) offers a solution by just using the measured irradiance. However, in this case the spectral irradiance of the test spectrum $E_{meas}(\lambda)$ has to be on an absolute scale.

8 Report

The following information should be given in the test report according to IEC 60904-1.

a) If the spectral mismatch is used for the irradiance correction of a measurement based on IEC 60904-1 or another relevant standard, the calculated spectral mismatch factor, the identification of the device under test and the reference device as well as their spectral responsivities according to their test report (IEC 60904-8 or IEC 60904-8-1), the test spectrum and the reference spectrum or a reference to it should all be included in the test report, along with the method used to calculate the integrals.

If the reference device and the device under test are of different dimensions (active area), the dimensions should be specified in the test report.

b) If a perfectly matched reference device is used and no mismatch correction is applied, the identification of the device under test and the reference device, as well as the spectral responsivities of reference and device under tests according to their test report (IEC 60904-8 or IEC 60904-8-1) should be included in the test report.

   If the reference device and the device under test are of different dimensions (active area), the dimensions should be specified in the test report.

   If the spectral responsivity of the device under test cannot be measured, the test report should include the criteria used to define the equivalency of the spectral responsivities.

c) Note that the spectral mismatch factor determined by applying this procedure is only valid for correcting a measurement of the specific device under test considered with the particular reference device and test spectrum used to calculate the SMM. When measuring this device under test under different spectral irradiance (being it simulated or natural sunlight) and/or with a different reference device, the spectral mismatch factor shall be recalculated.

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

DISPOSITIFS PHOTOVOLTAÏQUES –

Partie 7: Calcul de la correction de désadaptation des réponses spectrales dans les mesures de dispositifs photovoltaïques

AVANT-PROPOS

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La Norme internationale IEC 60904-7 a été établie par le comité d'études 82 de l'IEC: Systèmes de conversion photovoltaïque de l'énergie solaire.

Cette quatrième édition annule et remplace la troisième édition parue en 2008. Cette édition constitue une révision technique.

Les modifications techniques principales par rapport à l'édition précédente sont les suivantes:

- pour davantage de compatibilité et moins de redondance, l'article "Détermination du spectre pour l'essai" fait référence à l'IEC 60904-9;
- le facteur de désadaptation des réponses spectrales est appelé *SMM* plutôt que *MM* afin de permettre la différenciation avec le facteur de désadaptation angulaire *AMM* et le facteur de désadaptation angulaire spectral *SAMM;*

- les formules correspondant à la dérivée et à l'application du facteur de désadaptation spectral SMM sont ajoutées;
- des références à de nouvelles normes sont données, par exemple concernant les dispositifs multijonctions;
- des formulations ont été corrigées ("sensibilité" remplace "réponse" et "éclairement" remplace "intensité").

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

FDIS	Rapport de vote
82/1590/FDIS	82/1605/RVD

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

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2.

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.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives au document recherché. A cette date, le document sera

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- amendé.

DISPOSITIFS PHOTOVOLTAÏQUES –

Partie 7: Calcul de la correction de désadaptation des réponses spectrales dans les mesures de dispositifs photovoltaïques

1 Domaine d'application

Cette partie de l'IEC 60904 décrit la procédure pour corriger l'erreur de mesure spectrale introduite dans l'essai d'un dispositif photovoltaïque, due d'une part à la désadaptation du spectre pour l'essai et du spectre de référence (par exemple, spectre AM1.5), et d'autre part à la désadaptation entre les sensibilités spectrales (SS) du dispositif de référence et du dispositif soumis à essai, et ainsi réduire l'incertitude systématique. Cette procédure est valable pour les dispositifs à jonction unique, mais le principe peut être étendu aux dispositifs multijonctions.

Le but du présent document est de donner des lignes directrices pour la correction de l'erreur de mesure spectrale se traduisant par une désadaptation à la fois du spectre pour l'essai et du spectre de référence, ainsi que des sensibilités spectrales (SS) du dispositif de référence et celles du dispositif soumis à essai. La correction calculée de désadaptation des réponses spectrales n'est valable que pour la combinaison spécifique des dispositifs d'essai et de référence mesurés à l'aide d'un spectre d'essai particulier.

Comme la sensibilité spectrale d'un dispositif PV est liée à la longueur d'onde, ses performances sont influencées de manière significative par la distribution spectrale du rayonnement incident, qui, dans le cas d'un éclairement solaire naturel, varie selon plusieurs facteurs tels que l'emplacement, les conditions météorologiques , le moment de l'année ou de la journée, l'orientation de la surface de réception, etc., et qui, avec un simulateur solaire, varie selon son type et les conditions correspondantes. Si l'éclairement est mesuré avec un radiomètre à thermopile (qui n'est pas spectralement sélectif) ou avec un dispositif PV de référence (IEC 60904-2), la distribution spectrale de l'éclairement de la lumière entrante doit être connue de façon à appliquer les corrections nécessaires pour obtenir les performances du dispositif PV avec la distribution spectrale de l'éclairement de référence définie dans l'IEC 60904-3.

Si un dispositif PV de référence ou un détecteur de type thermopile est utilisé pour mesurer l'éclairement, alors, en suivant la procédure donnée dans le présent document, il est possible de calculer la correction de désadaptation des sensibilités spectrales nécessaire à la détermination du courant de court-circuit du dispositif soumis à essai avec une distribution spectrale de l'éclairement de référence donnée dans l'IEC 60904-3 ou avec tout autre spectre de référence. Si le dispositif PV de référence a la même sensibilité spectrale relative que le dispositif soumis à essai alors le dispositif de référence prend automatiquement en compte les écarts de la distribution spectrale de l'éclairement mesurée par rapport à la distribution spectrale de l'éclairement de référence, et aucune correction supplémentaire des erreurs de mesure spectrales n'est nécessaire. Dans ce cas, l'emplacement et les conditions atmosphériques ne sont pas critiques lorsque la méthode employant un dispositif de référence est utilisée pour des mesures de performance sous éclairement solaire naturel. De plus, pour des sensibilités spectrales relatives identiques, la classification spectrale du simulateur n'est pas critique pour des mesures avec des simulateurs solaires.

Si la performance d'un dispositif PV est mesurée en utilisant une distribution spectrale de l'éclairement connue, son courant de court-circuit avec toute autre distribution spectrale de l'éclairement peut être calculé en utilisant la sensibilité spectrale du dispositif PV soumis à essai.

2 Références normatives

Les documents suivants cités dans le texte 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: Mesure des caractéristiques courant-tension des dispositifs photovoltaïques*

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

IEC 60904-2, *Dispositifs photovoltaïques – Partie 2: Exigences applicables aux dispositifs photovoltaïques de référence*

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

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

IEC 60904-8-1, *Dispositifs photovoltaïques – Partie 8-1: Mesurage de la sensibilité spectrale des dispositifs photovoltaïques (PV) multijonctions*

IEC 60904-9, *Dispositifs photovoltaïques – Partie 9: Exigences pour le fonctionnement des simulateurs solaires*

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

ISO 9288:1989, *Isolation thermique – Transfert de chaleur par rayonnement – Grandeurs physiques et définitions*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions données dans l'IEC TS 61836 et l'ISO 9288 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 http://www.iso.org/obp

NOTE L'indice e des grandeurs énergétiques est omis, étant donné que dans le présent document les grandeurs peuvent ne pas être distinguées des grandeurs photométriques. Le symbole de grandeur E est donc utilisé pour l'éclairement quantitatif plutôt que le symbole de grandeur E_e.

L'indice λ indiquant que l'éclairement est différencié par rapport à la longueur d'onde λ et non par rapport à la fréquence ν pour obtenir l'éclairement spectral $E_\lambda(\lambda)$ est omis pour plus de clarté. Par conséquent, l'éclairement spectral est désigné ici par $E(\lambda)$.