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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

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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland
Email: inmail@iec.ch
Web: www.iec.ch

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Email: csc@iec.ch
Tél.: +41 22 919 02 11
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC DEVICES –

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

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

The text of this standard is based on the following documents:

FDIS	Report on voting
82/540/FDIS	82/547/RVD

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

This third edition cancels and replaces the second edition published in 1998. It constitutes a technical revision. The main changes with respect to the previous edition are listed below:

- the title has been modified in order to better reflect the purpose of the standard (changed from "mismatch error" to "mismatch correction");

- formulae are now accompanied by explanatory text;
- Clause 3 “Description of method” now describes when it is necessary to use the method and when it may not be needed. It describes what data must be collected before the mismatch correction can be calculated;
- Clauses 4, 5 and 6 have added;
- the formula for the mismatch correction has been corrected.

This publication 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 publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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- withdrawn,
- replaced by a revised edition, or
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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 error introduced in the testing of a photovoltaic device, caused by the mismatch between the test spectrum and the reference spectrum and by the mismatch between the spectral responses (SR) of the reference cell and of the test specimen. 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 multijunction devices.

The purpose of this standard is to give guidelines for the correction of measurement bias, should there be a mismatch between both the test spectrum and the reference spectrum and between the reference device SR and the test specimen SR.

Since a PV device has a wavelength-dependent response, 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 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 reference solar cell, 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 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 standard, it is possible to calculate the spectral mismatch correction necessary to obtain the short-circuit current of the test PV device under the reference solar spectral irradiance distribution included in Table 1 of IEC 60904-3 or any other reference spectrum. If the reference PV device has the same relative spectral response as the test PV device then the reference device automatically takes into account deviations of the real light spectral distribution from the standard spectral distribution, and no further correction of spectral bias 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. Also, for identical relative SR's, the spectral classification of the simulator is not critical for indoor measurements.

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 of the PV test device.

2 Normative references

The following referenced documents are indispensable for the application 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, *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 60904-2, *Photovoltaic devices – Part 2: Requirements for 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 of a photovoltaic (PV) device*

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*

3 Description of method

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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 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 relative spectral response is identical to the reference cell relative spectral response. In this case, the reading as obtained from the reference cell specifies which intensity at the reference spectrum will generate the same short-circuit current in the test device as the test spectrum.

If there is a mismatch between both spectra and spectral responses then a mismatch correction should be calculated.

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}.

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

where G_{meas} is the irradiance as measured by the reference device with its specific spectral response $S_{\text{ref}}(\lambda)$ 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

$$G_{\text{meas}} = G_{\text{ref}} / MM \tag{2}$$

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.

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.

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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.

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5 Determination of spectral response

5.1 The relative spectral response of the test specimen shall be measured according to IEC 60904-8.

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.

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.

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.

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

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

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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

$$MM = \frac{I_{\text{sc,ref,E}_{\text{ref}}}\; I_{\text{sc,sample,E}_{\text{meas}}}}{I_{\text{sc,ref,E}_{\text{meas}}}\; I_{\text{sc,sample,E}_{\text{ref}}}} \qquad (4)$$

where

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

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

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

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

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

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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 and the reference device, as well their spectral responses according to their test report (IEC 60904-8), the test spectrum and the reference spectrum 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 (area), the dimensions should be specified in the test report.

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

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

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

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