IEC 60904-5

Edition 2.0 2022-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

AMENDMENT 1

AMENDEMENT 1

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

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 60904-5:2011-02/AMD1:2022-11(en-fr)

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ICS 27.160 ISBN 978-2-8322-5728-9

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PHOTOVOLTAIC DEVICES –

Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method

AMENDMENT 1

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Amendment 1 to IEC 60904-5:2011 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

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

Draft	Report on voting
82/2069/FDIS	82/2082/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 Amendment 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/standardsdev/publications/.

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- replaced by a revised edition, or
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INTRODUCTION

Add the following new text:

For modules with large thermal inertia such as glass-glass construction for BIPV applications, measurements become even more challenging with increased temperature difference between the cell and module external temperatures during transient conditions. In addition, for bifacial PV modules the temperature sensors may shade an active cell, potentially even creating local hotspots where sensors are located on effective cell areas.

NOTE 1 NMOT is defined as the equilibrium mean solar cell junction temperature within an open-rack mounted module operating near peak power, in the following standard reference environment:

– Tilt angle: (37 ± 5)°.
– Total irradiance: 800 W/m^2.
– Ambient temperature: 20 °C.
– Wind speed: 1 m/s.
– Electrical load: A resistive load sized such that the module will operate near its maximum power point at STC or an electronic maximum power point tracker (MPPT).

NOTE 2 NMOT is similar to the former NOCT except that it is measured with the module under maximum power rather than in open circuit. Under maximum power conditions (electric) energy is withdrawn from the module, therefore less thermal energy is dissipated throughout the module than under open-circuit conditions. Therefore NMOT is typically a few degrees lower than the former NOCT.

1 Scope and object

Replace the first paragraph with the following text:

This part of IEC 60904 describes the preferred method for determining the equivalent cell temperature (ECT) of PV devices (cells, modules and arrays of one type of module), for the purposes of comparing their thermal characteristics, determining NOCT (nominal operating cell temperature) or alternatively NMOT (nominal module operating temperature), and translating measured I-V characteristics to other temperatures.

2 Normative references

Add the following standards to the list of normative references:

IEC TS 60904-1-2:2019, *Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices*

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

Delete the following standard from the list of normative references:

ISO/IEC 17025, *General requirements for competence of testing and calibration laboratories*

3.1 Principle

Replace the text of this subclause with the following new text:

Experience shows that the equivalent cell temperature can be determined more precisely by the method described herein than by any alternative technique [1][1]. However, increased variability and errors have been observed at irradiances below 400 W/m^2, so this method should only be used at irradiances above this threshold.

3.2 General measurement requirements

Add the following new text:

a) Use of the ECT method requires calibration of the device to be measured.

NOTE It is not sufficient to use calibration of another device of the same type, because even small differences in parameters between a calibrated device and a similar one can lead to significant errors (e.g. 0,3 % variation in module V_{OC} leads to 1 °C impact on ECT temperature).

Renumber existing item a)1) as item b)1) as follows:

1) The variation of V_{OC} needs to be linear as defined in IEC 60904-10 with respect to temperature.

Replace item a)2) as item b)2) with the following new text:

2) The variation of V_{OC} with respect to irradiance needs to have a quadratic dependence on the logarithm of irradiance.

Delete items a)3) and a)4).

1 Numbers in square brackets refer to the Bibliography.

Replace the first two paragraphs of item b) with the following new text:

c) The irradiance measurements shall be made using a PV reference device packaged and calibrated in conformance with IEC 60904-2 or a pyranometer. Either use a PV reference device that is spectrally matched to the device under test (DUT), or perform a spectral mismatch correction and report in conformance with IEC 60904-7. The reference device shall be linear in short-circuit current as defined in IEC 60904-10 over the irradiance range of interest.

In accordance with IEC 60904-2, to be considered spectrally matched, a reference device shall be constructed using the same cell technology and encapsulation package as the device under test.

Add the following new item d):

d) Some devices, in particular multi-junction, might have a spectral dependency of the open-circuit voltage [2]. For these devices, the spectral irradiance shall be determined with a spectroradiometer.

Replace existing item c) as item e) with the following new text:

e) The active surface of the device under test shall be coplanar within ±2° of the active surface of the reference device.

Replace existing item d) as item f) with the following new text:

f) For appropriate connection method and measurement of voltages refer to IEC 60904-1.

4 Apparatus

Replace items a), b) and c) as follows:

a) A PV reference device that meets the conditions stated in 3 c).

b) Equipment to measure the open-circuit voltage to an instrumental measurement uncertainty better than ±0,2 %.

c) Equipment to measure temperature to an instrumental measurement uncertainty of ±1 K.

5 Determination of required input parameters

Replace the bulleted list, given after the introductory text "The procedure requires a number of input parameters. These are:" *with the following:*

- Relative temperature coefficient of open circuit voltage, β_{rel}. This shall be determined from cell or module measurements of representative samples in accordance with IEC 60891.

  For bifacial modules, the temperature coefficient only needs to be determined from front side measurements.

- Open-circuit voltage (V_{OC1}) at a reference condition (G_1, T_1) in accordance with IEC 60904-1 or IEC TS 60904-1-2 for a cell or module or in accordance with IEC 61829 for a PV array. The reference condition is often chosen to be the standard test conditions, i.e. G_{STC} = 1 000 W/m^2 and T_{STC} = 25 °C with a reference spectral irradiance distribution as defined in IEC 60904-3.

- When outdoor measurement (G_1, T_1) is carried out, it is recommended to apply insulating thermal tape, e.g. polyethylene foam, 1 mm thickness, with mass density less than 0,03 g/cm^3, to cover the temperature sensor which is fixed by either aluminium or polyimide tape. If the temperature around the module is subjected to spatial and temporal variability, use of insulating thermal tape shields the temperature sensor from influence of environmental factors such as wind, allowing more accurate measurements.

NOTE A method to determine the mass density can be found in ISO 7214[4].

- The procedure requires the irradiance correction factors, B_1 and B_2. B_1 is linked to the thermal diode voltage and B_2 accounts for non-linearity of V_{OC} with irradiance scaling. The determination of these constants requires the measurement of the module I-V characteristic in accordance with IEC 60891 under at least five different irradiance levels.

6.2 Operating in a controlled environment

Add the following as new item c):

c) For bifacial modules, a non-irradiated background is required as described in IEC TS 60904-1-2.

Replace existing item c) as item d) with the following:

d) Take simultaneous readings of the open-circuit voltage of the device under test V_{OC2} and the incident irradiance (G_2). Should there be any variation in the irradiance, treat as a measurement in arbitrary irradiance conditions as given in 6.3 and carry out the appropriate correction. An irradiance correction should be carried out if the scatter in the determined ECT is more than 1 K.

Renumber existing item d) as item e):

e) Calculate the ECT as described in Clause 7.

6.3 Taking measurements under arbitrary irradiance conditions

Replace existing item a) with the following:

a) Mount the radiation sensor coplanar with the device under test to an agreement better than ±2 °.

Replace existing items b) and c) as follows:

b) For bifacial modules, two different setups are recommended for the measurement:

   Method 1: use a low reflectivity black cover material to reduce back-to-front irradiance ratio to < 1 %, in order to minimize the rear irradiance contribution. The cover should be mounted behind the module in a way to limit interference with the module natural convective heat dissipation as much as possible.

   Method 2: measure the plane-of-array irradiance on front side G_{f_i} and the average irradiance on the rear side G_{r_i} using PV reference devices compliant to IEC 60904-2. G_{r_i} is the average of at least 5 measurement points located per the requirements of IEC TS 60904-1-2:2019, 6.3.2. The equivalent irradiance GE on the bifacial module is then determined by:

$$G_{E_i} = G_{f_i} + \varphi \times G_{r_i} \quad (1)$$

   where φ is the module bifaciality coefficient as determined in accordance with IEC TS 60904-1-2.

NOTE 1 Decision on which method to use is left to the user, on consideration of the targeted measurement uncertainty budget. Method 1 is expected to enable lower uncertainty when applied to NOCT or NMOT measurements, and for translating field measured I-V characteristics to standard test conditions.

NOTE 2 When applying method 2, particularly for bifacial systems, proper selection of the modules to be tested has to consider thermal and irradiance non-uniformities at the system level. IEC 61829 provides some guidance on the selection of typical modules within a PV array, recommending in particular to avoid selecting modules at ends of rows.

c) Take simultaneous readings of the open-circuit voltage of the device under test V_{OC2} and the incident plane-of-array irradiance G_2 (method 1), or alternatively of the irradiance on front side G_{f_2} and average irradiance on the rear side G_{r_2} (method 2).

7 Calculation of equivalent cell temperature

Replace the existing text with the following new text:

The equivalent cell temperature ECT is derived from the single diode equations describing the current voltage characteristic.

Solving the equation for $V_2 = V_{OC2}$, with $V_1 = V_{OC1}$ and $I_2 = I_1 = 0$ results in the following dependence of the open circuit voltage:

$$f\left(G_1,G_2\right) = 1 + B_1 \times \ln\frac{G_1}{G_2} + B_2 \times \ln^2\left(\frac{G_1}{G_2}\right) \tag{2}$$

$$V_{oc2} = \frac{V_{oc1} \times \left[1 + \beta_{rel} \times \left(T_2 - T_1\right) \times f^2\left(G_1,G_2\right)\right]}{f\left(G_1,G_2\right)} \tag{3}$$

where

V_{OC1} is the open-circuit voltage measured in Clause 5 at the chosen reference conditions, irradiance G_1 and module temperature T_1;

V_{OC2} is the open-circuit voltage measured in Clause 6 at irradiance G_2 and module temperature T_2;

the relative temperature coefficient of the open-circuit voltage β_{rel} and the irradiance correction factors B_1 and B_2 are determined in Clause 5.

NOTE These formulae are derived from the IEC 60891 correction procedure 2 [3].

For measurement of bifacial modules using method 2, the irradiance G_2 has to be replaced by the equivalent irradiance G_{E_2}.

$$f\left(G_1,G_{E_2}\right) = 1 + B_1 \times \ln\frac{G_1}{G_{E_2}} + B_2 \times \ln^2\left(\frac{G_1}{G_{E_2}}\right) \tag{4}$$

$$V_{oc2} = \frac{V_{oc1} \times \left[1 + \beta_{rel} \times (T_2 - T_1) \times f^2\left(G_1, G_{E_2}\right)\right]}{f\left(G_1, G_{E_2}\right)} \tag{5}$$

The relation between the different values of V_{OC} can then be rewritten to calculate the equivalent ECT per the formulas given below, for monofacial (6) and bifacial (7) devices:

$$\text{ECT} = T_2 = T_1 + \frac{1}{\beta_{rel} \times f^2(G_1, G_2)} \times \left[\frac{V_{OC2}}{V_{OC1}} \times f(G_1, G_2) - 1\right] \tag{6}$$

$$\text{ECT} = T_2 = T_1 + \frac{1}{\beta_{rel} \times f^2\left(G_1, G_{E_2}\right)} \times \left[\frac{V_{OC2}}{V_{OC1}} \times f\left(G_1, G_{E_2}\right) - 1\right] \tag{7}$$

In the case of base measurements described in Clause 5 being taken at standard test conditions, the ECT for monofacial devices can be determined as:

$$\text{ECT} = T_2 = 25 + \frac{1}{\beta_{rel} \times f^2(1000, G_2)} \times \left[\frac{V_{OC2}}{V_{OC,\,STC}} \times f(1000, G_2) - 1\right] \tag{8}$$

8 Test report

Delete the following sentence in the first paragraph:

A test report with measured performance characteristics and test results shall be prepared by the test agency in accordance with ISO/IEC 17025.

Replace existing item e) as follows:

e) A description and identification of the device under test (solar cell, sub-assembly of solar cells or PV module).

Replace existing item n) as follows:

n) A statement to the effect that the results relate only to the device tested.

Add the following new Bibliography:

Bibliography

[1] S. Krauter, A. Preiss, "Comparison of module temperature measurement methods", *Conference record of the IEEE Photovoltaic Specialists Conference, 10.1109/PVSC.2009.5411669*

[2] M. Pravettoni, A. Virtuani, K. Keller, M. Apolloni, H. Mullejans, "Spectral Mismatch Effect to the Open-circuit Voltage in the Indoor Characterization of Multi-junction Thin-film Photovoltaic Modules", *2013 IEEE 39th Photovoltaic Specialists Conference, 10.1109/PVSC.2013.6744249*

[3] C. Monokroussos, H. Mullejans, Q. Gao, W. Herrmann, "I-V translation procedure for higher accuracy and compliance with PERC cell technology requirements", *35th European Photovoltaic Solar Energy Conference (EUPVSEC), online, 2020, 10.4229/EUPVSEC20202020-4AV.2.19*

[4] ISO 7214: *Cellular plastics – Polyethylene – Methods of test*

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