IEC 60904-5

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INTERNATIONAL STANDARD

NORME INTERNATIONALE

**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

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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

FOREWORD

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International Standard IEC 60904-5 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This second edition cancels and replaces the first edition, issued in 1993, and constitutes a technical revision.

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

- added and updated normative references;
- added reporting section;
- added method on how to extract the input parameters;
- rewritten method on how to calculate ECT;
- reworked formulae to be in line with IEC 60891.

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

CDV	Report on voting
82/595/CDV	82/626/RVC

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

A list of all parts of IEC 60904 series, under the general title *Photovoltaic devices*, can be found on the IEC website.

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

The committee has decided that the contents of this publication will remain unchanged until the stability 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

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- withdrawn,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

INTRODUCTION

When temperature sensors, such as thermocouples, are used to determine the cell temperature of PV devices under natural or simulated steady-state irradiance, two main problems arise. First, a considerable spread of temperature can be observed over the area of the module. Second, as the solar cells are usually not accessible, sensors are attached to the back of the module and the measured temperature thus is influenced by the thermal conductivity of the encapsulant and back materials. These problems are aggravated when determining the equivalent cell temperature for on-site measurements of array performance where all cells have slightly different temperatures and one cannot easily determine the average cell temperature.

The equivalent cell temperature (ECT) is the average temperature at the electronic junctions of the device (cells, modules, arrays of one type of module) which equates to the current operating temperature if the entire device were operating uniformly at this junction temperature.

PHOTOVOLTAIC DEVICES –

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

1 Scope and object

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) and translating measured I-V characteristics to other temperatures.

This standard applies to linear devices with logarithmic V_{OC} dependence on irradiance and in stable conditions. It may be used for all technologies but one has to verify that there is no preconditioning effect influencing the measurement.

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

IEC 60904-7, *Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices*

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 61829, *Crystalline silicon photovoltaic (PV) array – On-site measurement of I-V characteristics*

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

3 Measurement principle and requirements

3.1 Principle

The method described below is based on the fact that the open-circuit voltage (V_{OC}) of a solar cell changes with temperature in a predictable fashion. If the open-circuit voltage of the device at standard test conditions is known, together with its temperature coefficient, the equivalent temperature of all the cells in the device can be determined. The open-circuit voltage is also slightly affected by the irradiance, so an additional correction may be required as outlined in IEC 60891. Experience shows that the equivalent cell temperature can be determined more precisely by the method described here than by any alternative technique. However, as the temperature coefficient β drops rapidly at irradiances below 200 W/m^2, this method should only be used at irradiances above this threshold.

3.2 General measurement requirements

a) The device under test needs to match the following criteria:

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

   2) The variation of V_{OC} needs to follow a logarithmic dependence with irradiance.

   3) It needs to have an ohmic series resistance as otherwise there will be different ECT-coefficients for different temperature regions.

   4) The shunt resistances of the device need to be reasonably high, as for the majority of commercially available devices, as otherwise there will be different ECT-coefficients for different temperature regions.

b) The irradiance measurements shall be made using a PV reference device packaged and calibrated in conformance with IEC 60904-2 or a pyranometer. The PV reference device shall either be spectrally matched to the test specimen, or a spectral mismatch correction shall be performed 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 test device. Otherwise the spectral mismatch will have to be reported.

   NOTE Some devices might have a significant spectral dependency in the open-circuit voltage. In such a case, a spectroradiometer would be needed to ensure stable incident spectrum.

c) The active surface of the specimen shall be coplanar within ± 2° of the active surface of the reference device.

d) Voltages shall be measured to an accuracy of ± 0,2 % of the open-circuit voltage using independent leads from the terminals of the specimen and keeping them as short as possible. The measurement ranges of the data acquisition should be carefully chosen. If the test specimen is a module, the 4-wire connection should start at the terminals or connectors. If the test specimen is a cell, the 4-wire connection should start at the bus bars.

4 Apparatus

In addition to the general measurement requirements of Clause 3 the following equipment is required to perform I-V characteristic measurements:

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

b) Equipment to measure the open-circuit voltage to a precision better than ± 0,2 %.

c) Equipment to measure temperature to a precision ±1 K.

5 Determination of required input parameters

The procedure requires a number of input parameters. These are:

- Temperature coefficient of the open circuit voltage, β. This shall be determined from cell or module measurements of representative samples in accordance with IEC 60891.
- Open-circuit voltage (V_{OC1}) at a reference condition (G_1, T_1) in accordance with IEC 60904-1 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 as defined in IEC 61215, i.e. G_{STC} = 1 000 W/m^2 and T_{STC} = 25 °C.

- The procedure requires a constant, a, which is also interpreted as the thermal diode voltage. The determination of this requires the measurement of the open-circuit voltage at two different irradiance levels G_3 and G_4, one of which may be the point G_1,T_1.

6 Procedure

6.1 General

The procedure can be carried out either in a controlled environment or by taking measurements at arbitrary irradiances and correcting to the reference irradiance G_1.

6.2 Operating in a controlled environment

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

b) Set the irradiance to be equal to that of the reference condition G_1 using the reference device.

c) Take simultaneous readings of the open-circuit voltage of the test device 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.

d) Calculate the ECT as described in Clause 7.

6.3 Taking measurements under arbitrary irradiance conditions

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

b) Take simultaneous readings of the open-circuit voltage of the test device V_{OC2} and the incident irradiance G_2.

c) Carry out a correction of V_{OC2} to an irradiance equal to G_1.

d) Calculate the ECT as described in Clause 7.

7 Calculation of equivalent cell temperature

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:

$$V_{OC2} = V_{OC1} + V_{OC1}\left[\beta(T_2 - T_1) + a \ln \frac{G_2}{G_1}\right] \tag{1}$$

where

V_{OC1} is the open-circuit voltage measured in Clause 5 at the 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 temperature coefficient of the open-circuit voltage β has also been measured as part of Clause 5 in accordance with IEC 60891;

the parameter, a, is the thermal diode voltage, which can be determined from measurements at different light intensities but identical temperatures as:

$$a = \frac{V_{OC4} - V_{OC3}}{V_{OC3} \ln \left(G_4 / G_3 \right)} \tag{2}$$

where V_{OC3} and V_{OC4} are the voltages measured in Clause 5 at the same module temperatures but at different irradiances G_3 and G_4, respectively.

Instead of the irradiances G_1 and G_2, one can also use the ratio of short-circuit currents, which then is called self-reference. This requires short circuit current to be linear according to IEC 60904-10. This simplifies the measurements to be taken significantly as one essentially eliminates the requirement for measuring the irradiance and the dependence on the spectrally matched devices.

The relation between the different values of V_{OC} can then be rewritten to calculate the equivalent ECT as:

$$\text{ECT} = T_2 = T_1 + \frac{1}{\beta}\left[\frac{V_{OC2}}{V_{OC1}} - 1 - a \ln\left(\frac{G_2}{G_1}\right)\right] \tag{3}$$

NOTE This assumes that the spatial and thermal non-uniformity between the two V_{OC} is identical. For non-uniform temperature or illumination there will be a small error in ECT because the equivalent circuit model assumes uniform temperature and illumination.

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

$$\text{ECT} = 25\,°\text{C} + \frac{1}{\beta}\left[\frac{V_{OC2}}{V_{OC,STC}} - 1 - a \ln\left(\frac{G_2}{1\,000}\right)\right] \tag{4}$$

This equation is closely related to the formulation of method 1 in the standard for temperature and irradiance corrections (IEC 60891). The factor a is linked to the number of cells (junctions) in series in the module (n_s) as well as the thermal voltage D as defined in IEC 60891. Thus one can write the ECT in terms of this standard as:

$$\text{ECT} = T_2 = T_1 + \beta^{-1}\left[\frac{V_{OC2}}{V_{OC1}} - 1 + D \times n_s \times \ln\left(\frac{G_2}{G_1}\right)\right] \tag{5}$$

8 Test report

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

a) A title.

b) Name and address of the test laboratory and location where the tests were carried out.

c) Unique identification of the report and of each page.

d) Name and address of client.

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

f) Description of the test environment (natural or simulated sunlight and, in the latter case, brief description and class of simulator).

g) Date of receipt of test item and date(s) of calibration or test, where appropriate.

h) Reference to sampling procedure, where relevant.