IEC 60904-5

Edition 2.1 2022-11
CONSOLIDATED VERSION

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

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 CSV(en-fr)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC
The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications
The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform
The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee, …). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished
Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc
If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org
The world's leading online dictionary on electrotechnology, containing more than 22 300 terminological entries in English and French, with equivalent terms in 19 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

A propos de l'IEC
La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC
Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC - webstore.iec.ch/advsearchform
La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études, …). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished
Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc
Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

IEC Products & Services Portal - products.iec.ch
Découvrez notre puissant moteur de recherche et consultez gratuitement tous les aperçus des publications. Avec un abonnement, vous aurez toujours accès à un contenu à jour adapté à vos besoins.

Electropedia - www.electropedia.org
Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 300 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 19 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

IEC 60904-5

Edition 2.1 2022-11
CONSOLIDATED VERSION

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

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

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 27.160

ISBN 978-2-8322-6144-6

IEC 60904-5

Edition 2.1 2022-11
CONSOLIDATED VERSION

REDLINE VERSION

VERSION REDLINE

colour inside

**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 CSV(en-fr)

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC DEVICES –

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

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.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 60904-5 edition 2.1 contains the second edition (2011-02) [documents 82/595/CDV and 82/626/RVC] and its amendment 1 (2022-11) [documents 82/2069/FDIS and 82/2082/RVD].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

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

This second edition 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.

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 the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under 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.

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

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.

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.

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) or alternatively NMOT (nominal module operating 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 TS 60904-1-2:2019, *Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices*

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 60904-7, *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 herein than by any alternative technique [1][1]. However, ~~as the temperature coefficient β drops rapidly~~ increased variability and errors have been observed at irradiances below ~~200~~ 400 W/m^2, so this method should only be used at irradiances above this threshold.

3.2 General measurement requirements

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).

~~a~~b) 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} with respect to irradiance needs to ~~follow a logarithmic dependence with irradiance~~ have a quadratic dependence on the logarithm of 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~~c) 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~~ 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 ~~test~~ device under test. ~~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.

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.

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

~~d~~f) ~~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~~

1 Numbers in square brackets refer to the Bibliography.

~~bars.~~ For appropriate connection method and measurement of voltages refer to IEC 60904-1.

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~~c).

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

c) Equipment to measure temperature to an ~~precision~~ instrumental measurement uncertainty of ±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/m² 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.~~
- 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/m² 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/cm³, 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 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) For bifacial modules, a non-irradiated background is required as described in IEC TS 60904-1-2.

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

~~d)~~e) 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 under test to an agreement better than ±2 °.

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.

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

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

~~d)~~e) 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:

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

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:

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

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

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}.

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

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

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:

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

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

In the case of base measurements described in Clause 5 being taken at standard