IEC 60904-10

Edition 3.0 2020-09

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Photovoltaic devices –
Part 10: Methods of linear dependence and linearity measurements

Dispositifs photovoltaïques –
Partie 10: Méthodes de mesure de la dépendance linéaire et de la linéarité

IEC 60904-10:2020-09(en-fr)

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

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

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PHOTOVOLTAIC DEVICES –

Part 10: Methods of linear dependence and linearity measurements

FOREWORD

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International Standard IEC 60904-10 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This third edition cancels and replaces the second edition published in 2009. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) Modification of title.
b) Inclusion of an Introduction explanatory of the changes and the reasoning behind them.
c) Inclusion of a new Clause Terms and Definitions (Clause 3), with distinction between generic linear dependence and linear dependence of short-circuit current versus irradiance (linearity).
d) Explicit definition of equivalent sample (Clause 4).

e) Technical revision of the apparatus (Clause 5), of the measurement procedures (Clause 6 to Clause 8) and of the data analysis (Clause 9), with separation of the data analysis for a generic linear dependence from the data analysis specific to linearity (i.e. short-circuit current dependence on irradiance) assessment. Additionally, inclusion of impact of spectral effects on both linearity and linear dependence assessment.

f) Introduction of specific data analysis for two-lamp method, making it fully quantitative. Addition of extended version called N-lamp method.

g) Modification of the linearity assessment criterion with inclusion of a formula that can be used to correct the irradiance reading of a PV reference device for non-linearity of its short-circuit current versus irradiance. A linearity factor is specifically newly defined for this purpose.

h) Revision of the requirements for the report (Clause 10) in order to improve clearness about what information is always necessary and what is dependent on the procedure actually followed to measure the linear dependence, including the type of dependence measured (generic or linearity).

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

FDIS	Report on voting
82/1759/FDIS	82/1784/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 the IEC 60904 series, 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.

INTRODUCTION

IEC 60904-10 is the reference document for several IEC standards when the linear dependence of one or more electrical parameters of a photovoltaic (PV) device has to be assessed in relation to a test parameter. Test parameters are usually either the device temperature or the irradiance. In order to better reflect the different cases to be handled and the peculiarities of the linear dependence of the short-circuit current of a PV device on the irradiance, IEC 60904-10 has been extensively revised.

To avoid confusion, in this document the word "linearity" will be used only for the dependence of the short-circuit current (I_{SC}) on the irradiance (G), while all the other dependences will be referred to as generic linear dependence (when not explicitly described).

Three major technical changes have been included in this third edition compared to the second edition.

The first main change is the split of the data analysis for the linearity from the one to be used for a generic linear dependence (like for example $V_{OC}(T)$, which gives the open-circuit voltage as function of temperature). The latter keeps the same approach already included in the previous edition, i.e. the least squares fit method, with addition of the recommended use of the measurement uncertainties within the data analysis. The former applies the proportionality function that describes the dependence between I_{SC} and G for an ideal linear PV device. It also makes use of the calibration value of the I_{SC} to establish a reference point towards which the non-linearity is explicitly referred. Also, the impact of test spectra and spectral mismatch on both linearity and generic linear dependence is now considered.

Following this new approach for the linearity assessment, the second major change involves a modification of the definition of non-linearity (referred now explicitly to the calibration value) and the inclusion of a formula to correct the measured irradiance for the non-linearity of the PV device used to measure it. Such a PV device is usually a reference device. However, IEC 61853-1 explicitly considers the case of using the short-circuit current of the PV device itself to measure the irradiance when its linearity has been proved (Note in IEC 61853-1:2011: 8.1). A correction of the actual irradiance measurement to account for deviations of I_{SC} from linearity is therefore relevant when the irradiance is measured by a reference device as well as by the device under test itself. In principle, this can be extended to non-linear devices as well, provided that the non-linearity information is stated in addition to the calibration value of the PV device itself. The irradiance correction for non-linearity is made in this document by means of a multiplication factor, resembling the same approach used in the IEC 60904-7 for the spectral mismatch correction. This formula has been introduced in order to address the explicit reference of the other standards to IEC 60904-10 in terms of handling non-linear devices. However, this formula can be useful to correct deviations from linearity within the acceptance limits even in the case of reference devices classified as linear according to the previous edition of this standard.

The third main change is the revision of the two-lamp method approach. This is achieved first by the introduction of a specific data analysis for the two-lamp method, which was a simple pass/fail test in the second edition and gains now the status of a quantitative method. This change is crucial in order to have results, obtained by any procedure for linearity measurements allowed by this standard, to be fully comparable to each other within their stated measurement uncertainties. Thereby, the irradiance correction formula is also applicable to the results from the two-lamp method. With these additions, the two-lamp method becomes the simplest quantitative method to assess the linearity (i.e. dependence of short-circuit current I_{SC} on irradiance) of PV devices, not even requiring a reference device when devices under test are single PV cells. An extended version called N-lamp method has been included, which overcomes some limitations of the two-lamp method.

A secondary change, which was introduced to improve locating the necessary procedure within the document, is the distinction between the cases of irradiance and of temperature as test parameter, i.e. the parameter being varied and on which the dependence is checked.

Furthermore, when the linear dependence of a device parameter (e.g. I_{SC}) has to be assessed towards more than a single test parameter, intermediate steps applying the procedures described by this standard can be followed if the device under test is stable according to the criterion given in IEC 61215-1 and its relevant part. For example, the measurement of a power matrix as defined by IEC 61853-1 requires the measurement of the maximum power as a function of both irradiance and temperature. In this case, the most convenient way of performing the power matrix measurement is usually to vary one parameter (e.g. the temperature) while keeping the other (e.g. the irradiance) steady, and then to repeat this procedure at different levels of the second parameter until the full matrix is completed. In this view, the second parameter would be considered as the fixed one, and the first one would be the test parameter towards which the linear dependence is evaluated according to this standard. However, once the full power matrix has been measured, the subsequent data analysis of the maximum power (as well as of any other relevant electrical parameter) of the device under test can be done by considering either parameter as the test parameter as long as the other one is kept constant. Therefore, a linear dependence can be assessed with respect to one or the other parameter, independent of the measurement procedure used to obtain the data.

PHOTOVOLTAIC DEVICES –

Part 10: Methods of linear dependence and linearity measurements

1 Scope

This part of IEC 60904 describes the procedures used to measure the dependence of any electrical parameter (Y) of a photovoltaic (PV) device with respect to a test parameter (X) and to determine the degree at which this dependence is close to an ideal linear (straight-line) function. It also gives guidance on how to consider deviations from the ideal linear dependence and in general on how to deal with non-linearities of PV device electrical parameters. Typical device parameters are the short-circuit current I_{SC}, the open-circuit voltage V_{OC} and the maximum power P_{max}. Typical test parameters are the temperature T and the irradiance G. However, the same principles described in this document can be applied to any other test parameter with proper adjustment of the procedure used to vary the parameter itself.

Performance evaluations of PV modules and systems, as well as performance translations from one set of temperature and irradiance to another, frequently rely on the use of linear equations (see for example IEC 60891, IEC 61853-1, IEC 61829 and IEC 61724-1). This document lays down the requirements for linear dependence test methods, data analysis and acceptance limits of results to ensure that these linear equations will give satisfactory results. Such requirements prescribe also the range of the temperature and irradiance over which the linear equations may be used. This document gives also a procedure on how to correct for deviations of the short-circuit current I_{SC} from the ideal linear dependence on irradiance (linearity) for PV devices, regardless of whether they are classified linear or non-linear according to the limits set in 9.7. The impact of spectral irradiance distribution and spectral mismatch is considered for measurements using solar simulators as well as under natural sunlight.

The measurement methods described herein apply to all PV devices, with some caution to be used for multi-junction PV devices, and are intended to be carried out on a device, or in some cases on an equivalent device of identical technology, that is stable according to the criteria set in the relevant part of IEC 61215. These measurements are meant to be performed prior to all measurements and correction procedures that require a linear device or that prescribe restrictions for non-linear devices.

The main methodology used in this document is based on a fitting procedure in which a linear (straight-line) function is fitted to a set of measured data points $\{X_i, Y_i\}$. The linear function uses a least-squares fit calculation routine, which in the most advanced analysis also accounts for the expanded combined uncertainty (k=2) of the measurements. The linear function crosses the origin in the case of short-circuit current data versus irradiance. The deviation of the measured data from the ideal linear function is also calculated and limits are prescribed for the permissible percentage deviation.

Procedures to determine the deviation of the $Y(X)$ dependence from the linear (straight-line) function are described in Clause 6 (measurements under natural sunlight and with solar simulator), Clause 7 (differential spectral responsivity measurements) and Clause 8 (measurements via two-lamp and N-lamp method). Data analyses to determine the deviations from the linear function are given in Clause 9.

A device is considered linear for the specific measured dependence $Y(X)$, when it meets the requirements of 9.7.

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 multijunction photovoltaic (PV) devices*

IEC TS 60904-1-2, *Photovoltaic devices – Part 1-2: Measurement of current-voltage characteristics of bifacial 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 60904-7, *Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices*

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 multijunction photovoltaic (PV) devices*

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

IEC 61215 (all parts), *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61724-1, *Photovoltaic system performance – Part 1: Monitoring*

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

ISO TS 28037, *Determination and use of straight-line calibration functions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 and the following 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

3.1
linear dependence
any generic linear (straight-line) dependence of a PV device parameter on a test parameter

EXAMPLE A common linear dependence for PV devices is the one between the open-circuit voltage and the temperature of the PV device.

Note 1 to entry: This term embraces all possible linear dependences based on a straight line. The linearity defined in the following item is only one special case of them.

3.2
linearity
linear dependence that describes the pure proportionality of the short-circuit current of the PV device to the irradiance that illuminates it

Note 1 to entry: The concept of linearity in physics, which is applicable also to PV devices, implies pure proportionality between the two variables involved in it.

Note 2 to entry: One of the major sources of observed non-linearity of solar PV cells is due to series resistance, which can cause the short-circuit current measured as output of the solar cell to be non-linear even when the photocurrent is linear. All methods included in this document address non-linearity of the short-circuit current, not of the photocurrent.

3.3
limiting junction
junction in a multi-junction photovoltaic device in which under given illumination conditions the lowest photocurrent is generated

[SOURCE: IEC 60904-1-1:2017, 3.1, modified – "photovoltaic current" has been replaced by "photocurrent".]

4 Device selection

The measurement procedure shall be applied to a full-size device, if possible. If this is not possible, a small sample equivalent in construction and materials to the full-size device to be tested for linearity shall be used. The full-size device and the equivalent device should be stable according to the relevant part of IEC 61215. However, an equivalent sample shall not be used to measure the linearity of a reference device (as defined by IEC 60904-2).

A small sample is deemed to be equivalent to the full-size PV device under test (DUT) when its physical properties relevant to the linear dependence to be measured are the same as for the full-size PV device. This requirement applies to dependence versus irradiance as well as to dependence versus temperature. Also, the configuration of the electrical connections should be well represented.

In particular, when irradiance is the test parameter the relevant optical properties of the small device (including the packaging) shall be the same as for the represented device. This requirement includes for example the use of the same type of front glass (including texture and refraction index) and the same aperture angle that are used in the full-size device.

In the case of PV devices active on both sides (bifacial PV devices, which shall conform to IEC TS 60904-1-2), the above requirement applies to both front and rear sides of the device.

When the equivalence to the full-size device cannot be achieved with a small sample, the report of the measurement results shall state the limits of their validity.

5 Apparatus

5.1 General requirements common to all procedures

The following requirements and recommendations are valid for all linear dependences and for all measurement procedures, unless explicitly specified differently. Requirements and recommendations that are specific to the apparatuses used for each type of measurement are given in the following subclauses.

Light sources characterised by intense peaks over a broad continuum, like for example Xenon sources or some lamps based on light emitting diodes (LEDs), should be carefully evaluated before use. Indeed, for some PV devices and/or technologies the spectral responsivity can vary with temperature as well as with irradiance level. Therefore, it can pass through various emission lines in the lamp spectrum as temperature or irradiance varies. When this occurs, it can cause shifts in performance that are related mainly to a change in the interaction between the band gap region of the spectral responsivity and the actual spectral irradiance in the same wavelength range. If this possibility is not properly assessed in each specific case, such shifts could be misinterpreted as deviations from the linear dependence while they are not. However, based on the measured DUT spectral responsivity as a function of temperature or of irradiance (depending on what applies) and on the measured spectral irradiance, the magnitude of this effect can be calculated by performing a SMM calculation according to IEC 60904-7 as a function of temperature or of irradiance (depending on what applies). Some guidance on how to do this is reported in the Bibliography. The SMM calculation can then be applied as SMM correction to every single measurement at all temperatures different from 25 °C or irradiance levels other than 1 000 W/m^2 (depending on what applies). If the change in SMM is not larger than 1 % over the entire range of temperatures or than ±0,5 % for irradiances, it may alternatively be included as component of the SMM uncertainty in the measurement uncertainty calculation.

EXAMPLE Crystalline silicon’s band gap is known to shift due to temperature changes.

When the test parameter is the irradiance, the equipment and procedure used to change irradiance are to be verified with a spectroradiometer. This applies to all measurement procedures other than the two-lamp and N-lamp methods both applied to single cells and other than the linearity measurement by means of differential spectral responsivity. A radiometer is allowed as alternative to the spectroradiometer only if the following conditions are both met:

a) the reference device is spectrally-matched to the DUT, and
b) the setup to measure the linearity is a solar simulator used only with filtering elements neutral with respect to the spectrum of the light.

To reduce the change in the heat load in all measurements where the irradiance is the test parameter, and therefore to improve the temperature stabilization of the DUT over the whole measurement sequence, it can be useful to reduce the infrared portion of the light whose energy is below the DUT’s energy band gap by interposing suitable filters between the light beam and the test plane.

NOTE Meshes or light source’s filters are believed to be the most suitable methods for changing irradiance on large surfaces.

In the case of linearity measurements of single PV cells by means of the two-lamp or N-lamp methods, the variation in spectral irradiance and the spatial non-uniformity of the light sources are not crucial and as such no restriction is given for them. Instead, when the PV devices are made of series-connected cells, the light sources in the two-lamp or N-lamp methods should conform to class BBA or better according to IEC 60904-9 over the area covered by the DUT. For both single-cells and series-connected PV devices, the short-term instability of the light (STI, defined in IEC 60904-9) shall be less than 0,5 % during the period necessary to measure each of the required triplets of signals (see 8.1). If this is not achievable, one photoactive monitoring device (e.g. a photodiode) shall be used to monitor individually each light source; its reading shall then be used to correct the short-circuit current signal of the DUT for the light's temporal instability. In any case, the variation of the irradiance not corrected for shall be included in the measurement uncertainty calculation.

Under specific conditions and for all affected measurement procedures, the change in the relative spectral irradiance distribution may be considered as an uncertainty contribution to the overall measurement uncertainty instead of being systematically corrected for. The condition to be met is that the change in the relative spectral irradiance distribution shall not result in more than ±0,5 % change in the spectral mismatch (SMM) of the DUT short-circuit current (refer to IEC 60904-7 for SMM calculation). With regard to spatial uniformity of the irradiance on the test plane (IEC 60904-9), any change to it due to the variation in the irradiance level should not result in more than ±0,5 % change in the DUT short-circuit current.

If the DUT is a multi-junction device, the spatial variation of the spectral irradiance on the test plane should be carefully considered while changing the irradiance level. In particular, it shall not cause a change of the limiting junction with respect to the one that is limiting under the relevant reference spectrum defined by IEC 60904-3. Also, accounting for the proper SMM at each irradiance level as required by Clause 7 of IEC 60904-1-1:2017 shall be done before calculating the linearity of the multi-junction device.

When the test parameter is the temperature, uniformity of the DUT temperature shall be considered in the uncertainty calculation of the measurement.

In general, an uncertainty calculation shall always be done by explicitly considering the specific setup under use and the measurement performed (see 9.2 for additional details).

5.2 Apparatus for measurement of all linear dependences under natural sunlight or with a solar simulator

The following equipment shall be used for any linear dependence. Where no specification is explicitly given, the listed item shall be considered as required for any test parameter.

a) Equipment necessary to measure I-V curves of the DUT under natural or simulated sunlight, as listed in IEC 60904-1 or its relevant Part. The equipment may be limited to that necessary for the measurement of the short-circuit current (I_{SC}) in case the linear dependence measurements (versus irradiance or temperature) are of reference cells.

b) Means for actively controlling the temperature of the DUT and of the reference device. Alternatively, means of limiting light exposure with a long-pulsed light source or a removable shade in the case of measurements under natural sunlight or with a steady-state solar simulator.

c) If the test parameter is the irradiance (see 6.4), equipment necessary to change it over the range of interest without affecting the relative spectral irradiance distribution and the spatial uniformity.

d) If the test parameter is the temperature (see 6.5), equipment or means necessary to change the DUT temperature over the range of interest.

5.3 Apparatus for measurement of all linear dependences of short-circuit current by differential spectral responsivity measurements

a) Equipment to measure the differential spectral responsivity of the DUT in accordance with IEC 60904-8 (for single-junction devices) or IEC 60904-8-1 (for multi-junction devices) to a repeatability equal or less than ±0,5 % of the reading.

b) If the test parameter is the temperature, equipment necessary to change the DUT temperature over the range of interest.

5.4 Apparatus for linearity measurement of short-circuit current by two-lamp method

No reference device is required. The following equipment is required:

a) Two light sources A and B that can be controlled individually, with total in-plane irradiance achievable by the combined source A+B at least as high as the upper limit of the range of interest. The light sources A and B may be two individual lamps, two groups of lamps or a single lamp with suitable masking in front of it to simulate a double-lamp setup (see the Bibliography for examples). To facilitate the achievement of the starting irradiance level, it is recommended that the spectral distribution of the light sources extends over a wavelength range wide enough to cover at least two thirds of the wavelength range where the spectral responsivity of the DUT is more intense. Also, the influence of the infrared portion of the spectral distribution should be assessed in terms of its influence on the device temperature to be maintained according to 5.4 c).

NOTE 1 To reduce the change in the heat load, and therefore to improve the temperature stabilization of the DUT over the whole measurement sequence, it can be useful to reduce the infrared portion of the light whose energy is below the DUT's energy band gap by interposing suitable filters between the light beam and the test plane.

b) Equipment necessary to measure the short-circuit current of the DUT with a repeatability of ±0,1 % or better of the reading.

c) Equipment to control the temperature of the DUT, if necessary to keep it within ±1 °C of the target temperature.

NOTE 2 The use of a reference device during the linearity measurement is not necessary for the two-lamp method, although it can be useful in order to immediately verify that the irradiance range of interest is fully covered. If a reference device is not used, an iterative approach can be followed to extend the irradiance range to the one of interest.

5.5 Apparatus for linearity measurement of short-circuit current by N-lamp method

The apparatus is the same as for the two-lamp method, with the difference that more than two light sources (1, … , N) are required. The individual light sources shall produce about the same short-circuit current in the device under test.

6 Procedures to measure linearity and other linear dependences under natural sunlight or with a solar simulator

6.1 Additional general requirements for natural sunlight

Measurements under natural sunlight shall only be made when the following conditions are met, in addition to the general ones set in 5.1:

– The total in-plane irradiance is at least as high as the upper limit G_0 of the range of interest.

– The irradiance variation caused by short-term oscillations (e.g. due to clouds, haze, or smoke) is less than ±2 % of the total in-plane irradiance as measured by the reference device. These variations shall be corrected for by using the reading of the reference device.

– The wind speed is less than 2 m/s.

6.2 Mounting under natural sunlight

6.2.1 Mount the reference device co-planar with the DUT within 2° so that both are normal to the direct solar beam within ±5°. Connect to the necessary instrumentation. The measurements described in the following subclauses should be made as expeditiously as possible within a few hours on the same day to minimize the effect of changes in the spectral conditions. SMM calculation according to IEC 60904-7 is required if the reference device is not spectrally matched to the DUT or when the test parameter is the temperature.

6.2.2 If the DUT and the reference device are equipped with temperature controls, set the controls at the desired level. If temperature controls are not used and shading of the DUT from the sun is applied, allow the DUT to stabilize within ±1 °C of the target temperature before starting the measurements. In order to bring the DUT temperature close to the target value, pre-cooling or pre-heating of the device is permitted as long as the shading/unshading operation allows to stabilize it within the limits. The reference device should also be stable within ±1 °C of its equilibrium temperature before proceeding. For both DUT and reference device, temperature stabilization is considered achieved when for each device at least three consecutive temperature measurements are taken in at least 90 s and all the measured values remain inside the required temperature range.

6.3 Mounting with a solar simulator

6.3.1 Mount the DUT and the reference device co-planar to each other within 2° in the test plane of the solar simulator so that both are normal to the center line of the beam within ±5°. Connect to the necessary instrumentation.

6.3.2 If the DUT and the reference device are equipped with temperature controls, set the controls at the desired level. If temperature controls are not used, allow the DUT and the reference device to stabilize in temperature within ±1 °C of their equilibrium temperature, even if this means changing the room temperature if that is necessary and feasible. In the case of steady-state solar simulators, a removable shade may be used as under natural sunlight to control the temperature of the DUT and of the reference device. For both DUT and reference device, temperature stabilization is considered achieved when for each device at least three consecutive temperature measurements are taken in at least 90 s and all the measured values remain inside the required temperature range.

6.3.3 Set the irradiance at the test plane to the upper limit G_0 of the range of interest using the measured short-circuit current (I_{RC}) of the reference device and its calibration value ($I_{\mathrm{RC,STC}}$) at Standard Test Conditions (STC) (see Formula (1)).

6.4 Linear dependence measurements versus irradiance

6.4.1 The initial irradiance G_0 shall be calculated from the measured short-circuit current (I_{RC}) of the reference device and its calibration value ($I_{\mathrm{RC,STC}}$) at STC. A correction should be applied according to Formula (1) in order to account for the measured temperature of the reference device ($T_{\mathrm{m,RC}}$) by using the relative temperature coefficient (α_{RC}) of the reference device short-circuit current.

$$G_0 = \frac{1\,000}{I_{\mathrm{RC,STC}}} \times \frac{I_{\mathrm{RC}}}{\left[1+\alpha_{\mathrm{RC}}\left(T_{\mathrm{m,RC}}-25\right)\right]} \times \frac{1}{R_{0,\mathrm{norm}}} \tag{1}$$

where

$R_{0,\mathrm{norm}}$ is the linearity factor determined according to this document and accounts for the non-linearity of the reference device at the irradiance G_0;

1 000 is the STC value of the total irradiance, given in W/m^2;

25 is the STC value of the junction temperature, given in °C.

NOTE By definition, $R_{0,\mathrm{norm}}$ equals 1 at the irradiance at which the PV device is calibrated.