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Edition 1.0 2020-11

TECHNICAL REPORT

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Photovoltaic devices –
Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions

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PHOTOVOLTAIC DEVICES –

Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions

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IEC TR 60904-14, which is a Technical Report, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
82/1748/DTR	82/1785A/RVDTR

Full information on the voting for the approval of this Technical Report 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 in the 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 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- withdrawn,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.

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PHOTOVOLTAIC DEVICES –

Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions

1 Scope

This document provides guidelines for measurements of the maximum power (P_{max}) output of single-junction photovoltaic (PV) modules and for reporting at standard test conditions (STC) in industrial production line settings. Such measurements typically:

- Record current-voltage (I-V) data while illuminating the module with a solar simulator;
- Are performed on 100 % of manufactured modules, in order to determine whether they meet nameplate requirements for various bins spanning different power output levels.

This type of measurement is widespread and performed in high volume by PV module manufacturers worldwide. As it is desirable to have consistent measurement practices across the industry, this document describes the following features of such measurements:

- Essential elements, in order to provide common understanding;
- Common issues or complications;
- Sources of error and uncertainty, including recommendations to minimize them.

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Understanding of P_{max} measurement uncertainties is expected to be useful in application of other IEC documents, such as IEC 61215-1 and IEC 62941, where P_{max} tolerances and uncertainties must be determined. Whenever possible, this document references specific IEC documents covering topics in more detail. Where no such documents exist, this document provides guidance and recommendations based on other publications relevant to the PV industry.

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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 60512-2-1, *Connectors for electronic equipment – Tests and measurements – Part 2-1: Electrical continuity and contact resistance tests – Test 2a: Contact resistance – Millivolt level method*

IEC 60891, *Photovoltaic devices – Procedures for temperature and irradiance corrections to measured I-V characteristics*

IEC 60904-1:2020, *Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics*

IEC 60904-2:2015, *Photovoltaic devices – Part 2: Requirements for photovoltaic reference devices*

IEC 60904-3:2019, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

IEC 60904-4, *Photovoltaic devices – Part 4: Reference solar devices – Procedures for establishing calibration traceability*

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

IEC 60904-9:2020, *Photovoltaic devices – Part 9: Classification of solar simulator characteristics*

IEC 60904-10, *Photovoltaic devices – Part 10: Methods of linear dependence and linearity measurements*

IEC 61215-1, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval - Part 1: Test requirements*

IEC 61215-2:2016, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures*

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

IEC 61853-2:2016, *Photovoltaic (PV) module performance testing and energy rating – Part 2: Spectral responsivity, incidence angle and module operating temperature measurements*

IEC 62941:2019, *Terrestrial photovoltaic (PV) modules – Quality system for PV module manufacturing*

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ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the uncertainty of measurement (GUM:1995)*

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JCGM 200, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836, IEC 60904-1, IEC 60904-9, ISO/IEC Guide 98-3, and JCGM 200 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

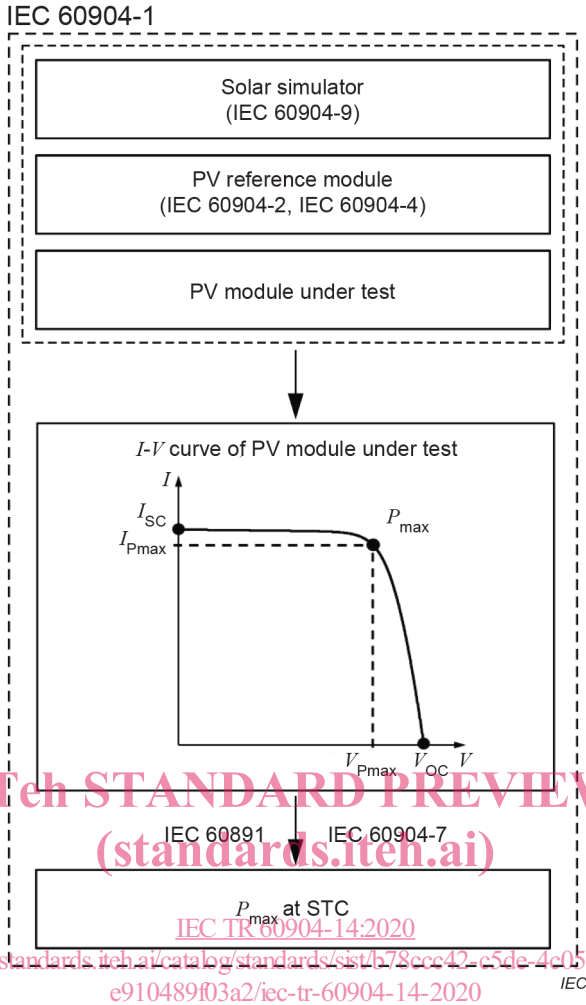
- IEC Electropedia: available at http://www.electropedia.org/
- ISO online browsing platform: available at http://www.iso.org/obp

4 Measurement principles

4.1 Measurement of *I-V* curves

Figure 1 summarizes the application of IEC documents in order to measure PV module I-V curves and report STC P_{max} values in production line settings. The following symbols refer to common parameters measured directly from a module I-V curve:

- Short-circuit current and open-circuit voltage: I_{SC} and V_{OC}, respectively
- Current and voltage at the maximum power point: I_{Pmax} and V_{Pmax}, respectively
- Maximum power: P_{max}, which is equal to the product $I_{Pmax} \times V_{Pmax}$



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Documents referenced by the correction procedures of IEC 60891 and IEC 60904-7 are omitted for simplicity.

Figure 1 – Application of IEC documents to report STC P_{max} values, adapted from published work [1][1]

4.2 Standard test conditions

4.2.1 General

STC give the essential properties of the light to which the PV module is exposed and the thermal state at which the PV module is kept during measurement of its *I-V* characteristic. STC are intended to give a common and standardized reference point for a practical assessment of PV module performance in both laboratory and industrial settings; they are not necessarily intended to describe all conditions under which a PV module operates when installed outdoors. STC are defined in IEC TS 61836 as follows:

a) A spectral irradiance equal to the global spectral irradiance defined in IEC 60904-3 (essential light property);

b) Total irradiance equal to 1 000 W m^{-2} (essential light property);

c) Cell junction temperature within the module equal to 25 °C (thermal state of the PV module).

IEC 60904-3:2019, Clause 5 further specifies that the angular distribution of irradiance is defined such that "the complete radiation hits the solar device perpendicularly under normal incidence." STC are summarized graphically in Figure 2.

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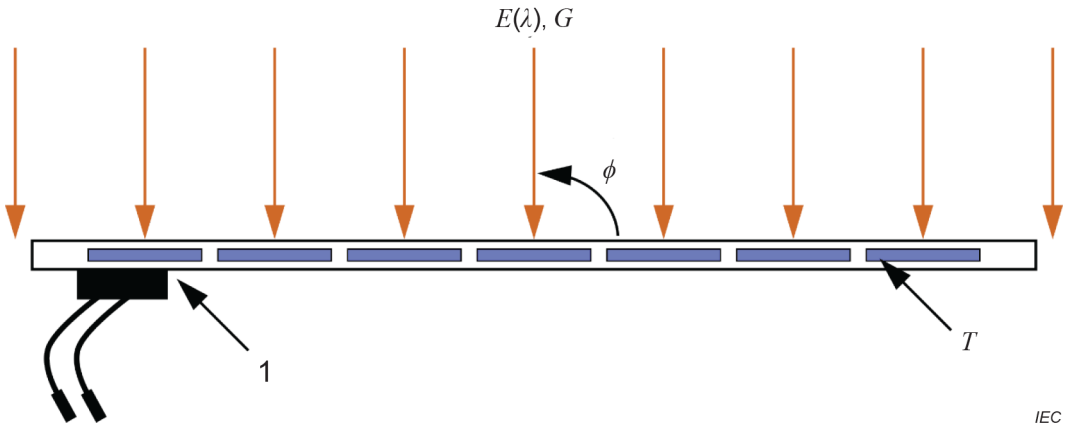
1 Numbers in square brackets refer to the Bibliography.



Key

1 PV module under test

$E(\lambda)$ global spectral irradiance as defined in IEC 60904-3:2019

G total irradiance equal to 1 000 W m^{-2}

T cell junction temperature within the module equal to 25 °C

ϕ normal (perpendicular) incidence angle of irradiance as defined in IEC 60904-3:2019

Figure 2 – Graphical summary of STC (cross-sectional view of module)

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It is commonly understood that STC describe spatially uniform conditions across the module area, and temporally uniform conditions during measurement of the module I-V curve. For example:

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- Spectral irradiance and total irradiance should be uniform across the module area, and for the duration required to measure the module I-V curve;
- Cell junction temperature should be uniform for all cells in the module, and for the duration required to measure the module I-V curve.

4.2.2 Additional practical considerations

The measured electrical characteristics of a PV module can vary depending on additional factors not included in STC, such as:

- The prior illumination history of the module (light soaking or metastability effects);
- The instantaneous rate of change of voltage or current versus time during measurement of the I-V curve (capacitive or hysteresis effects);
- The electrical connection to the module (contact resistance and cable resistance).

Stabilization techniques for metastabilities specific to different PV technologies are described in the IEC 61215 series (e.g. IEC 61215-2:2016, MQT 19). Methods for minimizing capacitive effects are described in IEC 60904-1:2020, Annex B. Effects of contact resistance and cable resistance are described in 4.5.4.3.

4.2.3 Deviations from STC, errors, and uncertainties

In practice, actual measurement conditions always deviate from STC. This can cause errors in measured I-V curve parameters relative to their STC values, as summarized in Table 2. Errors in various I-V curve parameters related to total irradiance and temperature can be corrected by the methods of IEC 60891 if they fall within the relevant ranges allowed by that standard. Errors in I_{SC} due to spectral irradiance can be corrected by the methods of IEC 60904-7.

Even after all significant errors have been identified and corrected for, reported I-V curve parameters, including P_{max}, will still have some (non-zero) uncertainty. For guidance on evaluating and reporting all measurement aspects contributing to the overall uncertainty, refer to ISO/IEC Guide 98-3. If the uncertainty of a correction is comparable in magnitude to the error that it is intended to correct, such correction may be omitted, provided the error is still considered in the uncertainty evaluation. Unless otherwise specified, uncertainty values stated in this document are standard uncertainties (coverage factor $k = 1$), consistent with ISO/IEC Guide 98-3:2008, 6.1. In addition to the corrections described above, reduction of P_{max} uncertainty is generally accomplished by one or more of the following strategies:

- Minimizing deviations from STC as in 4.3;
- Setting solar simulator total irradiance using a reference module that is matched to the production module under test. “Matched” refers to similarity in spectral responsivity, as well as several other factors described in 4.4.4.

Often, several interacting factors contribute to P_{max} uncertainty, as described in the remainder of this subclause. In general, a single factor (for example, the solar simulator’s characteristics) cannot be used in isolation to reliably evaluate P_{max} uncertainties. However, these factors can still be grouped together for convenience:

- Characteristics of the irradiance produced by the solar simulator as described in 4.3;
- Dimensional, optical, and electrical characteristics of the reference device used to set irradiance described in 4.4, and in particular, the device’s matching (or lack of matching) to the production module under test as described in 4.4.4;
- Dimensional, optical, and electrical characteristics of the production module under test;
- Operation procedures of the solar simulator and other measurement equipment as described in 4.5.

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Table 1 (adapted from a previous publication [1]) lists these factors approximately according to their expected contribution to P_{max} uncertainty reported from various publications [3][5][7][10], with largest uncertainty contributions listed first. Table 1 can be considered a checklist for PV module manufacturers to be used in developing a P_{max} uncertainty evaluation according to ISO/IEC Guide 98-3.

Not all factors in Table 1 will affect all PV module manufacturers equally; therefore, each PV manufacturer should implement a detailed evaluation of the elements that can contribute to the P_{max} uncertainty within their specific production processes and production lines. Factors having significant uncertainty contributions should be systematically monitored to keep P_{max} uncertainties within acceptable limits. The procedures described in Clause 0 can be used as a starting point for quantifying some uncertainty factors using gauge study methods.

Table 2 lists these factors according to their effect on the module I-V curve parameters. Each factor affects P_{max} indirectly, since $P_{max} = I_{Pmax} \times V_{Pmax}$.