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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Photovoltaic (PV) array – On-site measurement of current-voltage characteristics

Champ de modules photovoltaïques (PV) – Mesurage sur site des caractéristiques courant-tension

IEC 61829:2015-10(en-fr)

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PHOTOVOLTAIC (PV) ARRAY – ON-SITE MEASUREMENT OF CURRENT-VOLTAGE CHARACTERISTICS

FOREWORD

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International Standard IEC 61829 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This second edition cancels and replaces the first edition published in 1995. This edition constitutes a technical revision.

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

a) it addresses many outdated procedures;
b) it accommodates commonly used commercial I-V curve tracers;
c) it provides a more practical approach for addressing field uncertainties;
d) it removes and replaces procedures with references to other updated and pertinent standards, including the IEC 60904 series, and IEC 60891.

The result is a much more practical and useful standard.

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

FDIS	Report on voting
82/1008/FDIS	82/1041/RVD

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

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 website 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- withdrawn,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

The performance of photovoltaic (PV) systems over their decades-long life time is determined by comparing measured power production with the expected production as estimated from recorded weather conditions. Continuous measurements of system- or subsystem-level operating output can detect underperforming arrays but are not well suited for tracking degradation with any accuracy, or for identifying the weaknesses or failure modes that may exist within the array. Field I-V curve measurements offer a practical method of *in situ* benchmarking or troubleshooting for modules, strings and arrays. This International Standard specifies methods and approaches for field I-V curve measurements and calculations, and includes guidance for addressing the uncertainties associated with measurement devices and array configurations. Consistent and proper application of I-V curve measurement procedures helps to ensure that a PV system's performance is adequately characterized over time.

PHOTOVOLTAIC (PV) ARRAY – ON-SITE MEASUREMENT OF CURRENT-VOLTAGE CHARACTERISTICS

1 Scope

This International Standard specifies procedures for on-site measurement of flat-plate photovoltaic (PV) array characteristics, the accompanying meteorological conditions, and use of these for translating to standard test conditions (STC) or other selected conditions.

Measurements of PV array current-voltage (I-V) characteristics under actual on-site conditions and their translation to reference test conditions (RTC) can provide:

- data for power rating or capacity testing;
- verification of installed array power performance relative to design specifications;
- detection of possible differences between on-site module characteristics and laboratory or factory measurements;
- detection of possible performance degradation of modules and arrays with respect to on-site initial data;
- detection of possible module or array failures or poor performance.

For a particular module, on-site measurements translated to STC can be directly compared with results previously obtained in a laboratory or factory for that module. Corrections for differences in the spectral or spatial response of the reference devices may need to be assessed as specified in IEC 60904.

On-site array measurements are affected by diode, cable, and mismatch losses, soiling and shading, degradation due to aging, and other uncontrolled effects. Therefore, they are not expected to be equal to the product of the number of modules and the respective module data.

If a PV array is formed with sub-arrays of different tilt, orientation, technology, or electrical configuration, the procedure specified in this International Standard is applied to each unique PV sub-array of interest.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 photovoltaic reference devices*

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

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

IEC60904-7, *Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices*

IEC 60904-10, *Photovoltaic devices – Part 10: Methods for linearity measurements*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
pyranometer
radiometer normally used to measure global irradiance on a horizontal plane

Note 1 to entry: A pyranometer can also be used to measure diffuse irradiance when used with a shade ring or disc.

Note 2 to entry: A pyranometer can also be used to measure total irradiance on an inclined plane, which would include radiation reflected from the foreground.

[SOURCE: IEC TS 61836:2007, 3.5.7 b)]

3.2
radiometer
instrument for measuring the intensity of solar irradiance

Note 1 to entry: See also IEC 60050-845:1987, 845-05-06.

Note 2 to entry: Commonly, a radiometer is a thermal instrument using thermocouples or thermopiles and is independent of wavelength.

[SOURCE: IEC TS 61836:2007, 3.5.7]

3.3
spectroradiometer
instrument used to measure spectral irradiance distribution of an incident radiation as a function of wavelength

[SOURCE: IEC TS 61836:2007, 3.5.7 d)]

4 Apparatus

4.1 Irradiance measurements in natural sunlight

The irradiance measurements shall be made using a PV reference device packaged and calibrated in conformance with IEC 60904-2 or with a pyranometer. PV reference devices shall have spectral matching addressed by one of the following methods.

a) The reference device is spectrally matched to the modules in the array under test.

b) A spectral mismatch correction should 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.

c) If spectral measurements are not practical, uncertainties associated with the irradiance measurement and specific sensors used should be reported as part of the analysis. Measurements should be completed under clear-sky conditions with the nearest clouds at least 15° from the sun and the sensor mounted in the plane of the items under test as discussed elsewhere.

To be considered spectrally matched, a reference device shall be constructed using the same cell technology and encapsulation package as the modules in the array under test. If this is not the case, the spectral mismatch shall be reported or an estimate of the uncertainty shall be made as part of the analysis. Spectral mismatch is of particular concern with thin film modules.

For modules that concentrate sunlight with an optical concentration ratio of greater than 3:1, at least one radiometer shall provide a collimated measure of direct normal irradiance (IEC 60904-4).

The temperature of the reference device shall be measured using instrumentation with an accuracy of ±1 °C with repeatability of ±0,5 °C. If the reference device has internal correction for temperature or if the reference device is a pyranometer with a temperature coefficient $< 0,02$ %/°C, temperature measurement is not required. However, the mounting of a thermopile shall be consistent with the conditions used for calibrating it.

A suitable means is required to check that the reference device and the modules are coplanar within ±2° accuracy.

NOTE A digital level or other calibrated device can be used to confirm coplanar modules.

An additional pyranometer is required for checking the uniformity of the in-plane radiance. This radiometer shall provide a stable output, but need not be calibrated since it is only used for relative measurements.

If spectral corrections will be made, a spectroradiometer is required that is capable of measuring the spectral irradiance of the sunlight in the range of the spectral response of the test specimen and the reference device.

4.2 Module temperature measurements

The temperature of the module backsheets of the array under test shall be measured using instrumentation with an accuracy of ±1 °C with repeatability of ±0,5 °C. It is recommended to mechanically attach a flat thermal sensor with fine leads directly to the backsheet in the middle of a module and at least 10 cm from any junction box, but opposite an active part of the module. The attachment method should not change the temperature of the module, as may be identified by infrared imaging from the front of the module. An optical thermometer may be used only if the backsheet emissivity has been calibrated well enough that the optical thermometer accuracy is within 1 °C. A handheld contact thermometer may be used only if it has been verified that the accuracy is within 1 °C.

NOTE Most handheld thermometers conduct heat into the handle of the thermometer causing a temperature reading that is less than the actual backsheet temperature.

4.3 Electrical measurements

A self-contained I-V curve tracing unit shall be able to accommodate the anticipated array voltage, current, and power levels. The rate at which the unit sweeps the curve should be fast enough to avoid changes in irradiance during the curve but slow enough to ensure that the PV modules are achieving steady state conditions. Other equipment suitable for sweeping the array through a significant portion of its I-V curve may be used though any limitations with respect to the above requirements shall be clearly stated in the measurement report.

The I-V curve tracing unit shall be able to measure voltages and currents with an accuracy of ±1 % of the open-circuit voltage and short-circuit current using independent leads from the terminals of the array under test and keeping all wires that would add series resistance as short as possible. If only two leads are used, the error introduced shall be included in the uncertainty analysis. The measurement ranges of the data acquisition should be carefully chosen to match the array being measured.

The instrumentation should be capable of measuring current at zero voltage, using a variable bias (preferably electronic) to offset the voltage drop across the external series resistance. If the instrumentation is not capable of reaching zero voltage bias, extrapolation may be used, but the instrumentation shall be able to reach a voltage bias of 3 % of the device open-circuit voltage.

5 Measurement procedure

5.1 Choose and record appropriate conditions for measurement

The ideal conditions for an outdoor I-V curve test are clear skies (no clouds and no fog) and little wind. Variable irradiance and wind both introduce temperature transients in the array that confound the accuracy of the measurements. In practice, time and contractual constraints limit the periods in which it is possible to perform a test. Therefore, it is the responsibility of the person(s) conducting the test to ensure that all tests are performed under the most stable conditions possible, and that special attention is given to noting variable irradiance, wind, and array temperatures. For example, even though irradiance during the course of the I-V measurement does not vary more than 2 %, it may be that the irradiance increased by 30 % in the 5 min leading up to the test, and that the array temperature may not have equilibrated before the test was run.

Record the weather conditions, qualitatively, and periodically note when and how conditions change over the period during which I-V curves are being taken. It is recommended to take a picture of the sky and record the time periodically.

NOTE This information is for identifying potentially erroneous data, and is not directly used in the analysis.

5.2 Clean the modules

The cleanliness of the module surfaces shall be consistent with the intent of the test. The state of cleanliness, whether or not cleaning has been attempted, shall be reported.

If the intent of the test is to detect any possible differences between fielded modules and laboratory or factory measurements, either

a) the array shall be cleaned thoroughly immediately prior to the measurement, or
b) a representative string shall be tested immediately prior to and immediately after a thorough cleaning. The level of soil on the array is determined by comparing the results of the string I-V test before and after the cleaning. Such an assessment of soiling should be conducted under very stable irradiance conditions, and care should be taken to allow the string’s temperature to fully stabilize after the washing.

If the intent of the test is to document the performance of the array in a soiled state, then no cleaning is expected, but the soiled state shall be documented through such things as photographs and weather records defining the most recent rain.

5.3 Check for shading

Verify that there is no shading of the direct beam component of irradiance on the array under test and that the environmental conditions meet the requirements of IEC 60904-1, with the following exception: For measurements to be extrapolated to STC (Standard Test Conditions, see Annex A), the total in-plane irradiance shall be at least 700 W/m^2 and the incident sun beam shall be within a cone of 45° full-aperture angle around the module normal.

There may be times when it is desirable to measure an I-V curve when the array is partially shaded either by nearby objects or self-shading. This procedure may be used for the measurement procedure, but the correction of the shaded I-V curve to standard test conditions is outside of the scope of this International Standard, since the meaning of the standard conditions is unclear in this case.

5.4 Confirm uniformity of irradiance over the test array

Using a suitable pyranometer, check the uniformity of the in-plane irradiance over the area to be tested as needed and select a module on which the irradiance is typical. This step is useful if row-based array orientations, for example, create some non-uniformity in diffuse irradiance. Pyranomter measurements may be used to reveal variations and select the modules with irradiance that is most representative of the irradiance on the total array. The choice of these selected modules is based on the principle and example indicated in Figure 1. If the purpose of the I-V measurements is to document stability of the array over time, then the uniformity need not be checked, but the geometry of the test should remain consistent to facilitate consistent results.

Selecting a typical module may be straightforward when measuring a single string if the modules are all located in one row. Combiner box level measurements include modules that span several rows, so uniformity should be checked over the applicable rows. Selection of a typical irradiance model may be limited by the length of the pyranometer conductors, therefore any variation from what is considered typical should be noted in the report.

In the event that a particular module or string is not accessible, such as in a complicated roof-mounted system, and the measurement is conducted from a combiner box, it is acceptable to place and orient the reference device in a practical location that best approximates the condition of the module or string. The uncertainty associated with these measurement approaches shall be evaluated and included in the report.

5.5 Mount the reference device

Mount the reference device as near as possible to and co-planar with the module identified in 4.4. The reference device should be placed such that no shade of the direct beam component of irradiance is present on the device and any reflection or diffuse shading is consistent with the reflection and diffuse shading apparent to the array under test. Connect to the necessary instrumentation.

The reference device shall be mounted such that it is coplanar within ±2° of the average orientation of the active surfaces of the modules under test.

If the modules are not coplanar, the choice of irradiance plane of measurement shall be described in the report. If the array under test has inconsistent alignment, separate measurements should be done for each subsection of the array, and/or the variability of alignment of the array should be noted in the report.

5.6 Prepare to measure the array temperature

Select one or more modules whose operating temperatures are representative of the array under test. The choice of these selected modules is based on the principle and example indicated in Figure 1 and should be determined by making sample measurements as follows:

a) at minimally one centrally located module;

b) at minimally one module that has been identified as one of the coolest because of being upstream in the wind or because of being near the ground with the best cooling caused by convection;

c) at minimally one module that has been identified as one of the hottest because of being downstream in the wind, because of being at the top of the array when cooling is caused by convection, or because of being in a location that has little circulation.