BRITISH STANDARD

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60904-1:2006

Photovoltaic devices —

Part 1: Measurement of photovoltaic current-voltage characteristics

The European Standard EN 60904-1:2006 has the status of a British Standard

ICS 27.160

BSi
British Standards

National foreword

This British Standard was published by BSI. It is the UK implementation of EN 60904-1:2006. It is identical with IEC 60904-1:2006. It supersedes BS EN 60904-1:1993 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/82, Solar photovoltaic energy systems.

A list of organizations represented on GEL/82 can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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Foreword

The text of document 82/433/FDIS, future edition 2 of IEC 60904-1, prepared by IEC TC 82, Solar photovoltaic energy systems, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60904-1 on 2006-10-01.

This European Standard supersedes EN 60904-1:1993.

The main changes with respect to EN 60904-1:1993 are as follows:

- Added object.
- Added normative references.
- Updated original Clause 2 (General Measurement Requirements), removing Figure 1 as it is obsolete.
- Provided more detail and guidance on how to measure in sunlight or simulated sunlight.
- Expanded original Clause 6 (Test Report) with requirements based on ISO 17025.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2007-07-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2009-10-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60904-1:2006 was approved by CENELEC as a European Standard without any modification.

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PHOTOVOLTAIC DEVICES –

Part 1: Measurement of photovoltaic current-voltage characteristics

1 Scope and object

This part of IEC 60904 describes procedures for the measurement of current-voltage characteristics of photovoltaic devices in natural or simulated sunlight. These procedures are applicable to a single photovoltaic solar cell, a sub-assembly of photovoltaic solar cells, or a PV module.

NOTE 1 This standard may be applicable to multi-junction test specimens, if each sub-junction generates the same amount of current as it would under the reference AM1,5 spectrum in IEC 60904-3.

NOTE 2 This standard may be applicable to PV devices designed for use under concentrated irradiation if they are irradiated using direct normal irradiance and a mismatch correction with respect to a direct normal reference spectrum is performed.

The purpose of this standard is to lay down basic requirements for the measurement of current-voltage characteristics of photovoltaic devices, to define procedures for different measuring techniques in use and to show practices for minimising measurement uncertainty.

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: *Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic (PV) devices*

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

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

IEC 60904-5: *Photovoltaic devices – Part 5: Determination of equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method*

IEC 60904-6: *Photovoltaic devices – Part 6: Requirements for reference solar modules*

IEC 60904-7: *Photovoltaic devices – Part 7: Computation of spectral mismatch error introduced in the testing of a photovoltaic device*

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

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

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

3 General measurement requirements

a) The irradiance measurements shall be made using a PV reference device packaged and calibrated in conformance with IEC 60904-2 or IEC 60904-6 or a pyranometer. The PV reference device shall either be spectrally matched to the test specimen, or a spectral mismatch correction shall be performed in conformance with IEC 60904-7. The reference device shall be linear in short-circuit current as defined in IEC 60904-10 over the irradiance range of interest.

NOTE To be considered spectrally matched, a reference device must be constructed using the same cell technology and encapsulation package as the test device. If this is not the case, the spectral mismatch must be reported.

b) The temperature of the reference device and the specimen shall be measured using instrumentation with an accuracy of ±1 °C with repeatability of ±0,5 °C. If the temperature of the reference device differs by more than 2 °C from the temperature at which it was calibrated, the calibration value shall be adjusted to the measured temperature. If the reference device is a pyranometer, temperature measurement and temperature correction of its output signal are not required.

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

d) Voltages and currents shall be measured using instrumentation with an accuracy of ±0,2 % of the open-circuit voltage and short-circuit current 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 cell bus bars.

NOTE The connection method for cells should be carefully evaluated. Differences may occur if soldered tabs are used as probe or non-soldered methods are implemented such as bars having contact springs or conductive plates having a large-area contact with the cell back contact. Non-soldered methods can result in higher fill factors than are observed in the module. The contacting method should be appropriate to the intended use of the cell or of the measurement.

e) The short-circuit current shall be measured at zero voltage, using a variable bias (preferably electronic) to offset the voltage drop across the external series resistance. Alternatively, short circuit current may be extrapolated from the current-voltage characteristic. The curve is extrapolated to zero voltage provided that voltage drop is not higher than 3 % of the device open-circuit voltage and that there is a linear relationship between current and voltage.

f) The accuracy of the procedure for irradiance and temperature correction in conformance with IEC 60891 shall be verified periodically by measuring the performance of a specimen at selected irradiance and temperature levels and comparing the results with corresponding extrapolated data as in IEC 60904-10.

NOTE If temperature and irradiance correction is performed across wide ranges module correction parameters can considerably affect the test result. Care should be taken regarding the relevance of the module parameters used. In particular series resistance cannot be generalized to a batch of specimens of the same type.

In measuring PV devices which are non stable, care must be taken in selecting a representative spectral response.

4 Apparatus

4.1 For measurements in natural sunlight

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

a) A PV reference device or pyranometer that meets the conditions stated in item a) of Clause 3.

b) Means for measuring temperature of the reference device that meets the conditions stated in item b) of Clause 3, if necessary.

c) Equipment to determine the temperature of the test device using the Equivalent Cell Temperature (ECT) method specified in IEC 60904-5 or other means to measure the temperature of the test device as stated in item b) of Clause 3.

d) A two-axis tracking system capable of tracking the sun to an accuracy of ±5°.

e) A spectroradiometer capable of measuring the spectral irradiance of the sunlight in the range of the spectral response of the test specimen and the reference device, if spectral corrections are needed as defined in item a) of Clause 3.

4.2 For measurements in simulated sunlight

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

a) A PV reference device that is well matched to the test device over the ranges of irradiances, spectral distributions and temperatures of interest and meets the conditions stated in item a) of Clause 3.

b) Means for measuring the temperature of the reference device and the test specimen that meets the conditions stated in item b) of Clause 3.

c) A Class BBB or better solar simulator in accordance with IEC 60904-9. The designated test area shall be equal to or greater than the area that is spanned by the test specimen.

d) An irradiance sensor that tracks the instantaneous irradiance in the test plane. This irradiance sensor should be linear in the range of irradiances over which the measurements are taken (see IEC 60904-10).

e) A spectroradiometer capable of measuring the spectral irradiance of the simulator in the range of the spectral response of the test specimen and the reference device, if spectral corrections are needed as defined in item a) of Clause 3.

NOTE Care should be taken in the use of an emission lamp such as Xenon for testing direct band gap cells. As the band gap changes due to temperature, it can pass through various emission lines in the lamp spectrum and give rise to large shifts in performance.

5 Measurements in natural sunlight

Measurements in natural sunlight shall be made only when global solar irradiance is not fluctuating by more than ±1 % during a measurement. When the measurements are intended for reference to STC the irradiance shall be at least 800 $W \cdot m^{-2}$.

The test procedure is as follows:

5.1 Mount the reference device as near as possible to and co-planar with the specimen on the two-axis tracker. Both shall be normal to the direct solar beam within ±5°. Connect to the necessary instrumentation.

5.2 If the specimen and reference device are equipped with temperature controls, set the controls at the desired level.

If temperature controls are not used:

5.2.1 shade the specimen and the reference device from the sun and wind until their temperature is uniform within ±2 °C of the ambient air temperature, or

5.2.2 allow the test specimen to equilibrate to its stabilized temperature, or

5.2.3 pre-condition the test specimen to a point below the target temperature and then let the module warm up naturally.

NOTE There may be differences between average cell temperature and average back temperature during warming up.

5.3 Record the current-voltage characteristic and temperature of the specimen concurrently with recording the output and temperature (if required) of the reference device at the desired temperatures. If necessary, make the measurements immediately after removing the shade.

NOTE In most cases the thermal inertia of the specimen and the reference device will limit the temperature rise during the first few seconds to less than 2 °C. Their temperatures will remain reasonably uniform.

5.4 Ensure that the specimen and reference device temperature are stable and remain constant within ±1 °C and that the irradiance as measured by the reference device remains constant within ±1 % (fluctuations caused by clouds, haze, or smoke) during the recording period for each data set.

5.5 If a pyranometer or an unmatched reference device is used as reference device, perform a simultaneous measurement of spectral irradiance using the spectroradiometer. Calculate the effective irradiance for the specimen under the AM1,5 spectrum (see IEC 60904-3) using its spectral response data (apply IEC 60904-7).

NOTE When no spectral irradiance data are available the match of the reference device to the specimen and the air mass conditions should be checked carefully. Measurement should be performed on a clear sunny day (no observable clouds around the sun, diffuse contents of solar irradiance not higher than 30 %).

5.6 Correct the measured current-voltage characteristic to the desired irradiance and temperature conditions in accordance with IEC 60891 (for linear devices). For non-linear devices refer to IEC 60904-10 for guidance in determining over what range the device can be considered to be linear.

6 Measurement in steady-state simulated sunlight

Steady-state sunlight simulation for photovoltaic performance measurements shall meet the requirements of IEC 60904-9. The uniformity of light distribution in the test area shall be known and periodically checked. The accuracy of the measurement shall be verified periodically by successive measurements at the same test condition. Three methods for calibration can be applied. If the device under test is the same size as the reference device, use method A. If the device under test is larger than the reference device, use method B. If the device under test is smaller than the reference device, use method C.

NOTE Method A is the preferred method as it minimises the effects of non-uniformity of irradiance and scale factors in the electronics.

Method A: The design of the device under test shall be identical with the reference device with respect to dimensions and electrical properties. For modules, this requirement concerns the cell type and cell interconnection circuit. The reference device and the device under test shall be placed at the same position in the test area.

Method B: The distribution of irradiance in the test plane may not be completely uniform. The effective irradiance is the averaged irradiance across a device's active area. For a reference device smaller than the test device, the reference device should be measured at different locations within the envelope of the test device. A position that yields the average value of the reference device measurements should be used for positioning the reference device for setting the irradiance in 6.2.

Method C: The distribution of irradiance in the test plane may not be completely uniform. The effective irradiance is the averaged irradiance across a device's active area. For a reference device larger than the test device, the test device should be measured at different locations within the envelope of the reference device. A position that yields the average value of the test device measurements should be used for positioning the test device during subsequent tests.

The test procedure is as follows:

6.1 Place the reference device in the test plane with its active surface within ±5° normal to the centre line of the beam.

NOTE Care should be taken that the test plane of the solar simulator is qualified according to IEC 60904-9.

6.2 Set the irradiance of the solar simulator so that the reference device produces its calibrated short-circuit current or maximum power at the desired level using Method A, B or C.

6.3 Remove the reference device and place the specimen in the test plane as described in 6.1.

6.4 Connect the specimen to the necessary instrumentation.

NOTE If the beam is sufficiently wide and uniform the specimen can be placed beside the reference device.

6.5 If the test arrangement is equipped with temperature control, set the control at the desired level. If temperature controls are not used, allow the test module and reference device to stabilize within ±1 °C of the ambient air temperature. Shade the specimen and/or the device from the simulator beam until the device temperature is uniform within ±2 °C at ambient air temperature.

6.6 Without changing the simulator setting, take simultaneously readings of the current-voltage characteristic and temperature of the specimen. If equipped the irradiance sensor should be used to assure that the irradiance in the test plane is the same for the test device as it was for the reference device. Where it is not practical to control the temperature of the specimen make the measurement immediately after removing the shade (see applicable note in 5.3).

6.7 If the temperature of the specimen is not the desired temperature, correct the measured current-voltage characteristic to this temperature using the procedure in accordance with IEC 60891 (for linear devices). For non-linear devices refer to IEC 60904-10 for guidance in determining over what range the device can be considered to be linear.

NOTE 1 Any non-uniformity of the irradiance incident on a module can affect the resultant I-V characteristics. This effect is influenced by: bypass diodes in the interconnection circuit of the module, the reverse I-V characteristics of the cell type and the irradiance distribution in the test area. Non-uniformity effects should be carefully analysed and considered in the uncertainty analyses.

NOTE 2 If a module is used as reference device, carefully evaluate whether short-circuit current or maximum power is the appropriate parameter for setting the irradiance level of the solar simulator. The short circuit current method is nearly independent of module temperature and the module connection technique but may introduce errors due to non-uniform illumination. The maximum power method can compensate non-uniform illumination but may introduce errors due to module temperature and the module connection technique. The most accurate results will be achieved if the irradiance level is set to yield both the short circuit current and peak power of the reference module.

NOTE 3 If the spatial distribution in the test area is unknown and a reference cell is used as reference device, the measurement result of the device under test may change if the reference cell is repositioned within the test area. Therefore the optimal position for placement of the reference cell should be determined by selecting a position of average irradiance within the module test area. This effect can be reduced by using a calibrated reference module of similar size to the device under test.

NOTE 4 Open circuit voltage or fill factor may be influenced by the spectral irradiance distribution of the light source. If necessary this effect should be analysed by comparison with measurement results recorded in natural sunlight.

7 Measurement in pulsed simulated sunlight

Pulsed sunlight simulation for photovoltaic performance measurements shall meet the requirements of IEC 60904-9. The uniformity of light distribution in the test area shall be known and periodically checked. The accuracy of the measurement shall be verified periodically by successive measurements at the same test conditions.

NOTE Two types of pulsed solar simulators are commonly used: Long pulse systems with a pulse length up to 1 s and acquisition of the I-V characteristic during one flash and short pulse systems using stroboscope type lamps of <1 ms pulse length, acquiring one I-V data point per flash. The use of solar simulators with short pulse may not be suitable for accurate I-V measurement of solar cells and modules with high-capacitance.

Three methods for calibration can be applied. If the device under test is the same size as the reference device, use method A. If the device under test is larger than the reference device, use method B. If the device under test is smaller than the reference device, use method C.

Method A: The design of the device under test shall be identical with the reference device with respect to dimensions and electrical properties. For modules, this requirement concerns the cell type and cell interconnection circuit. The reference device and the device under test shall be placed at the same position in the test area.

Method B: The distribution of irradiance in the test plane may not be completely uniform. The effective irradiance is the averaged irradiance across a device's active area. For a reference device smaller than the test device, the reference device should be measured at different locations within the envelope of the test device. A position that yields the average value of the reference device measurements should be used for positioning the reference device for setting the irradiance in 7.2.

Method C: The distribution of irradiance in the test plane may not be completely uniform. The effective irradiance is the averaged irradiance across a device's active area. For a reference device larger than the test device, the test device should be measured at different locations within the envelope of the reference device. A position that yields the average value of the test device measurements should be used for positioning the test device during subsequent tests.

The test procedure is as follows:

7.1 Place the reference device in the test plane with its active surface within ±5° normal to the centre line of the beam.

NOTE Care should be taken that the test plane of the solar simulator is qualified according to IEC 60904-9.

7.2 Set the irradiance at the test plane so that the reference device produces its calibrated short-circuit current or maximum power at the desired irradiance level using method A, B or C.

NOTE In most pulsed solar simulators the I-V measurement is triggered by an irradiance sensor (monitor cell) when the irradiance during the pulse reaches a level which has been previously set with a reference device.

7.3 If necessary remove the reference device and place the specimen as described in 7.1.

NOTE Care should be taken to ensure that the position of the monitor cell is the same during calibration and test.

7.4 Connect the specimen to the necessary instrumentation.

NOTE If the beam is sufficiently wide and uniform, the specimen can be placed beside the reference device.

7.5 If necessary, allow the test module and reference device to stabilize within ±1 °C of the ambient air temperature.

7.6 Record the current-voltage characteristic and temperature of the specimen (or ambient temperature, if it is the same). The time interval between the data points shall be sufficiently long to ensure that the response time of the test specimen and the rate of data collection will not introduce errors.

7.7 If the temperature of the specimen is not the desired temperature, correct the measured current-voltage characteristics to both the desired temperature and irradiance in accordance with IEC 60891 (for linear devices). For non-linear devices refer to IEC 60904-10 for guidance in determining over what range the device can be considered to be linear.

NOTE 1 In the case of long pulse systems I-V data possibly are recorded across a wide range of irradiance. Care should be taken regarding the use of module parameters for irradiance correction. The trigger should be adjusted so as to yield positive and negative irradiance corrections centred on the target irradiance.

NOTE 2 Any non-uniformity of the irradiance incident on a module can affect the resultant I-V characteristics. This effect is influenced by: bypass diodes in the interconnection circuit of the module, the reverse I-V characteristics of the cell type and the irradiance distribution in the test area. Non-uniformity effects should be carefully analysed and considered in the uncertainty analyses.

NOTE 3 If a module is used as reference device, it must be carefully evaluated whether short-circuit current or maximum power is the appropriate parameter for setting the irradiance level of the solar simulator. The short circuit current method is nearly independent from module temperature and the module connection technique but may introduce errors due to non-uniform illumination. The maximum power method can compensate non-uniform illumination but may introduce errors due to module temperature and the module connection technique.

NOTE 4 If the spatial distribution in the test area is unknown and a reference cell is used as reference device, the measurement result of the device under test may change if the reference cell is repositioned within the test area. Therefore the optimal position for placement of the reference cell should be determined by selecting a position of average irradiance within the module test area. This effect can be reduced by using a calibrated reference module of similar size to the device under test.

NOTE 5 Open circuit voltage or fill factor may be influenced by the spectral irradiance distribution of the light source. If necessary this effect should be analysed by comparison with measurement results recorded in natural sunlight.

NOTE 6 Depending on the cell technology, I-V measurement may be influenced by the voltage sweep rate and the sweep direction. Cells with high capacitance are more problematic. These effects should be carefully analysed in a test programme. Negative effects can be excluded when measurements in the positive voltage direction starting at the short-circuit current and in the negative direction starting at the open-circuit voltage overlap optimally.

8 Test report

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

a) a title;

b) name and address of the test laboratory and location where the tests were carried out;

c) unique identification of the report and of each page;

d) name and address of client;

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

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

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

h) reference to sampling procedure, where relevant;

i) identification of calibration or test method used;

j) any deviations from, additions to or exclusions from the calibration or test method, and any other information relevant to a specific calibration or test, such as environmental conditions;

k) description and identification of primary and/or secondary reference device (cell or PV module);

l) identification of the method for temperature and irradiance correction of the measured characteristic;

m) test results supported by tables and graphs, including irradiance level, temperatures of the specimen and reference device, module parameters used for correction of the current-voltage characteristic;

n) either the mismatch correction value used in the measurement or an estimate of the error introduced by using the mismatched reference device;

o) a statement of the estimated uncertainty of test results;

p) a signature and title, or equivalent identification of the person(s) accepting responsibility for the content of the test report, and the date of issue;

q) a statement to the effect that the results relate only to the specimen tested;

r) a statement that the test report shall not be reproduced except in full, without the written approval of the laboratory.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60891	-[1)]	Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic devices	EN 60891	1994[2)]
IEC 60904-2	-[1)]	Photovoltaic devices Part 2: Requirements for reference solar cells	EN 60904-2	1993[2)]
IEC 60904-3	-[1)]	Photovoltaic devices Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data	EN 60904-3	1993[2)]
IEC 60904-5	-[1)]	Photovoltaic devices Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method	EN 60904-5	1995[2)]
IEC 60904-6	-[1)]	Photovoltaic devices Part 6: Requirements for reference solar modules	EN 60904-6	1994[2)]
IEC 60904-7	-[1)]	Photovoltaic devices Part 7: Computation of spectral mismatch error introduced in the testing of a photovoltaic device	EN 60904-7	1998[2)]
IEC 60904-9	-[1)]	Photovoltaic devices Part 9: Solar simulator performance requirements	-	-
IEC 60904-10	-[1)]	Photovoltaic devices Part 10: Methods of linearity measurement	EN 60904-10	1998[2)]
ISO/IEC 17025	-[1)]	General requirements for the competence of testing and calibration laboratories	EN ISO/IEC 17025	2005[2)]

[1)] Undated reference.

[2)] Valid edition at date of issue.

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