BRITISH STANDARD

BS EN 60904-9:2007

Photovoltaic devices —

Part 9: Solar simulator performance requirements

The European Standard EN 60904-9:2007 has the status of a British Standard

ICS 27.160

British Standards

National foreword

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A list of organizations represented on this committee can be obtained on request to its secretary.

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Foreword

The text of document 82/488/FDIS, future edition 2 of IEC 60904-9, prepared by IEC TC 82, Solar photovoltaic energy systems, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60904-9 on 2007-11-01.

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)	2008-08-01
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Annex ZA has been added by CENELEC.

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Endorsement notice

The text of the International Standard IEC 60904-9:2007 was approved by CENELEC as a European Standard without any modification.

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PHOTOVOLTAIC DEVICES –

Part 9: Solar simulator performance requirements

1 Scope and object

IEC standards for photovoltaic devices require the use of specific classes of solar simulators deemed appropriate for specific tests. Solar simulators can be either used for performance measurements of PV devices or endurance irradiation tests. This part of IEC 60904 provides the definitions of and means for determining simulator classifications. In the case of PV performance measurements, using a solar simulator of high class does not eliminate the need to quantify the influence of the simulator on the measurement by making spectral mismatch corrections and analyzing the influences of uniformity of irradiance of the test plane and temporal stability on that measurement. Test reports for devices tested with the simulator shall list the class of simulator used for the measurement and the method used to quantify the simulator’s effect on the results.

The purpose of this standard is to define classifications of solar simulators for use in indoor measurements of terrestrial photovoltaic devices, solar simulators are classified as A, B or C for each of the three categories based on criteria of spectral distribution match, irradiance non-uniformity on the test plane and temporal instability. This standard provides the required methodologies for determining the rating achieved by a solar simulator in each of the categories.

This standard is referred to by other IEC standards in which class requirements are laid down for the use of solar simulators. Solar simulators for irradiance exposure should at least fulfil class CCC requirements where the third letter is related to long term instability. In the case of use for PV performance measurements, classification CBA is demanded where the third letter is related to the short term instability.

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

3 Terms and definitions

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

3.1 solar simulator

A solar simulator can be used for two different applications:

a) I-V measurement.

b) Irradiance exposure.

The equipment is used to simulate the solar irradiance and spectrum. Simulators usually consist of three main components: (1) light source(s) and associated power supply; (2) any optics and filters required to modify the output beam to meet the classification requirements;

and (3) the necessary controls to operate the simulator. Solar simulators shall be labelled by their mode of operation during a test cycle. These are steady state, single pulse, and multi-pulse.

NOTE 1 Two types of solar simulators are commonly used to determine I-V characteristics: Steady-state and pulsed. The pulsed solar simulators can be further subdivided into long pulse systems acquiring the total I-V characteristic during one flash and short pulse systems acquiring one I-V data point per flash.

NOTE 2 Beside the light source, the lamp power supply and the optics, also the I-V data acquisition, the electronic load and the operating software may be an integral part of the solar simulator. Requirements for the related measurement technique are included in other parts of the IEC 60904 series.

3.2 test plane

the plane intended to contain the device under test at the reference irradiance level

3.3 designated test area

region of the test plane that is assessed for uniformity

NOTE If required, typical geometries can be specified. A specification related to a circular geometry is also permitted.

3.4 data sampling time

the time to take a single data set (irradiance, voltage, current). In the case of simultaneous measurement, this is given by the characteristic of the A/D converter. In the case of multiplexed systems the data sampling rate is the multiplexing rate.

EXAMPLE

A multiplexing time of 1 µs would give a sampling rate of 1 MegaSamples per second.

NOTE Due to a possible delay time for transient oscillation at each data point the data sampling rate must be related to the data acquisition system only.

The data sampling time is used for evaluation of temporal stability.

3.5 data acquisition time

the time to take the entire or a part of the current-voltage curve

NOTE 1 The time of data acquisition depends on the number of I-V data points and a delay time that might be adjustable.

NOTE 2 In the case of pulsed solar simulators the time of data acquisition is related to the measurements recorded during a single flash.

3.6 time for acquiring the I-V characteristic

if the I-V curve of a PV device is measured through sectoring in different parts and successive flashes, the full time for acquiring the entire I-V characteristic is the sum of times of data acquisition

3.7 effective irradiance

irradiance may change during data acquisition of a I-V performance measurement. The effective irradiance is then the average irradiance of all data points.

NOTE Care should be taken that possible irradiance correction meets the requirements of IEC 60891.

3.8 spectral range

the reference spectral distribution of sunlight at Air Mass 1,5 Global is defined in IEC 60904-3. For simulator evaluation purposes this standard restricts the wavelength range from 400 nm to 1 100 nm. In accordance with Table 1 this wavelength range of interest is divided in 6 wavelength bands, each contributing a certain percentage to the integrated irradiance.

3.9 spectral match

spectral match of a solar simulator is defined by the deviation from AM 1,5 reference spectral irradiance as laid down in IEC 60904-3. For 6 wavelength intervals of interest, the percentage of total irradiance is specified in Table 1.

Table 1 – Global reference solar spectral irradiance distribution given in IEC 60904-3

	Wavelength range nm	Percentage of total irradiance in the wavelength range 400 nm − 1 100 nm
1	400 − 500	18,4 %
2	500 − 600	19,9 %
3	600 − 700	18,4 %
4	700 − 800	14,9 %
5	800 − 900	12,5 %
6	900 − 1 100	15,9 %

3.10 non-uniformity of irradiance in the test plane

$$Non-uniformity \quad (\%) = \left[\frac{\max irradiance - \min irradiance}{\max irradiance + \min irradiance} \right] \times 100\,\% \tag{1}$$

where the maximum and minimum irradiance are those measured with the detector(s) over the designated test area.

3.11 temporal instability of irradiance

temporal instability is defined by two parameters:

a) Short term instability (STI)

This relates to the data sampling time of a data set (irradiance, current, voltage) during an I-V measurement. This value of temporal instability may be different between data sets on the I-V curve. In that case the short term instability is determined by the worst case.

For batch testing of cells or modules with no irradiance monitoring during I-V measurement the STI is related to the time period between irradiance determination.

b) Long term instability (LTI)

This is related to the time period of interest:

– For I-V measurements it is the time for taking the entire I-V curve.

– For irradiation exposure tests it is related to the time period of exposure.

$$Temporal \quad instability \quad (\%) = \left[\frac{\max irradiance - \min irradiance}{\max irradiance + \min irradiance} \right] \times 100\,\% \tag{2}$$

where the maximum and minimum irradiance depend on the application of the solar simulator.

If the solar simulator is used for endurance irradiation tests, temporal instability is defined by the maximum and minimum irradiance measured with a detector at any particular point on the test plane during the time of exposure.

3.12 solar simulator classification

a solar simulator may be one of three classes (A, B, or C) for each of the three categories – Spectral match, spatial non-uniformity and temporal instability. Each simulator is rated with three letters in order of spectral match, non-uniformity of irradiance in the test plane and temporal instability (for example: CBA).

NOTE The solar simulator classification should be periodically checked in order to prove that classification is maintained. For example spectral irradiance may change with operation time of the used lamp or uniformity of irradiance is influenced by the reflection conditions in the test chamber.

4 Simulator requirements

Table 1 gives the performance requirements for spectral match, non-uniformity of irradiance and temporal instability of irradiance. For the spectral match, all six intervals shown in Table 1 shall agree with the ratios in Table 2 to obtain the respective classes. Refer to Clause 5 for procedures to measure and calculate the three parameters (spectral match, non-uniformity of irradiance and temporal instability) of the simulator.

If the simulator is intended to be used for STC measurement, it should be capable of producing an effective irradiance of 1 000 W/m^2 at the test plane. Higher or lower irradiance levels may also be required.

NOTE If higher or lower irradiance is required, this may change the simulator classification.

These requirements apply to both steady state and pulsed solar simulators.

Table 2 – Definition of solar simulator classifications

Classifications	Spectral match to all intervals specified in Table 1	Non-uniformity of irradiance	Temporal instability	
			Short term instability of irradiance STI	Long term instability of irradiance LTI
A	0,75 – 1,25	2 %	0,5%	2 %
B	0,6 – 1,4	5 %	2 %	5 %
C	0,4 – 2,0	10 %	10 %	10 %

NOTE An example of solar simulator classification for I-V measurement is shown in Table 3. The classification of spectral match is given for a non-filtered Xenon lamp. The classification for non-uniformity of irradiance depends on the module size of interest.

Table 3 – Example of solar simulator rating measurements

Classification as specified in table 2	Spectral match to all intervals specified in Table 1	Non-uniformity of irradiance for a specific module size	Temporal instability of irradiance
CBB	0,81 in 400 – 500 nm (A) 0,71 in 500 – 600 nm (B) 0.69 in 600 – 700 nm (B) 0,74 in 700 – 800 nm (B) 1,56 in 800 – 900 nm (C) 1,74 in 900 – 1 100 nm (C)	2,8 % for module size 100 cm x 170 cm	STI evaluation: Simultaneous measurement of module current, module voltage and irradiance. Trigger delay between channels less than 10 nanoseconds. Within that time less than 0,5 % change of irradiance (A) LTI for taking the entire I-V curve in a 10 ms interval = 3,5 % (B)
	Worst case classification = C	Classification = B	Classification = B

5 Measurement procedures

5.1 Introductory remarks

It is the intent of this standard to provide guidance on the required solar simulator performance data to be taken, and the required locations in the test area for these data to be taken. It is not the intent of this standard to define the possible methods to determine the simulator spectrum or the irradiance at any location on the test plane. It is the responsibility of the simulator manufacturer to provide information upon request for test methods used in the determination of the performance in each classification. These methods should be scientifically and commercially acceptable procedures. The classification of a solar simulator does not provide any information about measurement errors that are related to photovoltaic performance measurements obtained with a classified solar simulator. Such errors are dependent on the actual measurement devices and procedures used.

5.2 Spectral match

5.2.1 Available methods are the use of:

a) spectroradiometer comprising a grating monochomator and a discrete detector,

b) a CCD or photodiode array spectrometer (CCD = charge coupled device),

c) a multiple detector assembly with band pass filters, and

d) a single detector with multiple band pass filters.

NOTE Care should be taken to avoid response from stray light or second order wavelength effects. Care should be taken that the sensitivity of the sensor is suitable in the wavelength range of interest. Care should be taken to ensure that the time constant of the detector is suitable for the pulse length of the simulator.

5.2.2 The spectral irradiance data taken should be integrated in the range 400 nm to 1 100 nm and the percentage contribution of the 6 wavelength intervals defined in Table 1 to the integrated irradiance determined.

5.2.3 Calculate the spectral match for each wavelength interval, which is the ratio of calculated percentage for the simulator spectrum and the solar spectrum.

5.2.4 The data comparison with the solar spectrum shall indicate the spectral match classification as per the following:

– Class A: Spectral match within 0,75-1,25 for each wavelength interval, as specified in Table 2.

– Class B: Spectral match within 0,6-1,4 for each wavelength interval, as specified in Table 2.

– Class C: Spectral match within 0,4-2,0 for each wavelength interval, as specified in Table 2.

5.2.5 All intervals shown in Table 1 shall agree with the spectral match ratios in Table 2 to obtain the respective classes.

NOTE 1 Spectral match may change during the pulse of a pulsed solar simulator. Therefore, integration time for spectral irradiance measurement should be adjusted to the time of data acquisition and spectral match should be calculated for that time period.

NOTE 2 Spectral match may change during the operation time of the solar simulator. If necessary, the spectral match should be checked periodically.

5.3 Non-uniformity of irradiance on the test plane

The irradiance non-uniformity in the test area of a large-area solar simulator for measuring PV modules depends on reflection conditions inside the test chamber or test apparatus. Therefore no generalization can be made and non-uniformity is to be evaluated for each system.

5.3.1 An encapsulated crystalline silicon cell or a mini-module is recommended to be used as uniformity detector for determining the non-uniformity of irradiance in the test area of the simulator by measuring its short-circuit current. The uniformity detector shall have a spectral response appropriate for the simulator. The linearity and time response of the uniformity detector shall conform to the characteristics of the simulator being measured.

NOTE When a mini-module is used as uniformity detector, care should be taken concerning possible measuring effects caused by the interconnection of cells.

5.3.2 Divide the designated test area into at least 64 equally sized (by area) test positions (blocks). The maximum uniformity detector size shall be the minimum of

a) the designated test area divided by 64, or

b) 400 cm².

The area covered by the detector measurements should be 100 % of the designated test area. The measurement positions should be distributed uniformly over the designated test area.

NOTE 1 A mini-module can be used as uniformity detector as long as the dimensions of its active surface fall within the dimensions of the test positions. It should have at least 80 % packing density of cells.

NOTE 2 For multiple-lamp solar simulators a higher resolution of data points using a smaller detector may become necessary in order to detect irradiance non-uniformity.

NOTE 3 Module manufacturers should consider the use of a detector of the same dimensions as the cells in the module.

Example: Large-area solar simulator

A designated test area of 240 cm x 160 cm gives a maximum area of uniformity detector size of 600 cm² if divided by 64. As this value is greater than 400 cm² the maximum uniformity detector size is 400 cm² leading to 76 test positions.

5.3.3 Using the uniformity device, determine the irradiance in each of the test positions applying the following methods:

a) Steady-state solar simulators: At least one measurement of the irradiance shall be made in each location.
b) Pulsed solar simulator: The total irradiance of the solar simulator may not be constant during the monitoring process. Therefore, a second PV device should be used for monitoring the irradiance during the pulse. This is to be placed at a fixed position outside the designated test area (monitoring device). Readings of both devices should be taken simultaneously. If the IV-curve is recorded during a single pulse, at least 10 readings should be taken during the part of the pulse in which the I-V measurement is performed. If necessary, irradiance correction is to be performed. The effective irradiance is the average of all irradiance corrected readings.

5.3.4 While the uniformity device may be centred in the test positions inside the perimeter of the test area, it shall be placed to the outer edge of the test area for those test positions on the test area perimeter.

5.3.5 Spatial non-uniformity is determined using equation (1) in 3.10.

5.3.6 A table of the measured simulator irradiance pattern should be supplied with the solar simulator to assist the user in testing and to clearly define different areas with different classifications and find the optimum test positions for different module/cell sizes.

5.3.7 The class of the simulator for non-uniformity is given by the following:

Class A: Non-uniformity of spatial irradiance 2 %, as specified in Table 2.

Class B: Non-uniformity of spatial irradiance 5 %, as specified in Table 2.

Class C: Non-uniformity of spatial irradiance 10 %, as specified in Table 2.

NOTE The irradiance pattern in the test area of solar simulators may change with operating hours or when lamps are changed. The check of non-uniformity should be included into service and maintenance work.

5.4 Temporal instability of irradiance

5.4.1 Solar simulators for I-V measurement

Both short term instability (STI) and long term instability (LTI) need to be evaluated.

For the evaluation of STI, the I-V data acquisition system may be considered an integral part of the solar simulator. If a solar simulator does not include the data acquisition system, then the simulator manufacturer shall specify the corresponding data sampling time as related to the reported STI classification.

There are two different cases for pulsed solar simulators and three cases for steady-state solar simulators that are considered.

5.4.1.1 Pulsed solar simulator determination of STI

For a pulsed solar simulator where the data acquisition system is an integral part of the solar simulator evaluation of STI can be related to two measurement concepts:

a) When there are three separate data input lines that simultaneously store values of irradiance, current and voltage, the temporal instability is Class A for STI.

   NOTE The uncertainty in simultaneous triggering of the three multiple channels is typically less than 10 nanoseconds.

b) When each data set is taken sequentially (irradiance, current, voltage), determine the temporal instability as defined below (Figures 1 and 2)
   1) Determine the time for taking two successive data sets (irradiance, current, voltage) considering a possible delay time between measurements.

2) STI is related to the worst case irradiance change between successive data sets.
3) Determine the STI using the data from step 2), equation (2) and Table 2.

NOTE For pulsed solar simulators used for I-V measurements but not including an I-V data acquisition system, the sections of the pulse to be utilized and the number of evenly spaced data points for achieving class A, B, C of STI must be stated by the solar simulator manufacturer.

5.4.1.2 Pulse solar simulator determination of LTI

a) For long pulse solar simulators the LTI is related to the irradiance change of measured data sets during the time of data acquisition (Figure 1).
b) For multi-flash systems the LTI is related to the maximum irradiance change measured between all the data sets used to determine the entire I-V curve.

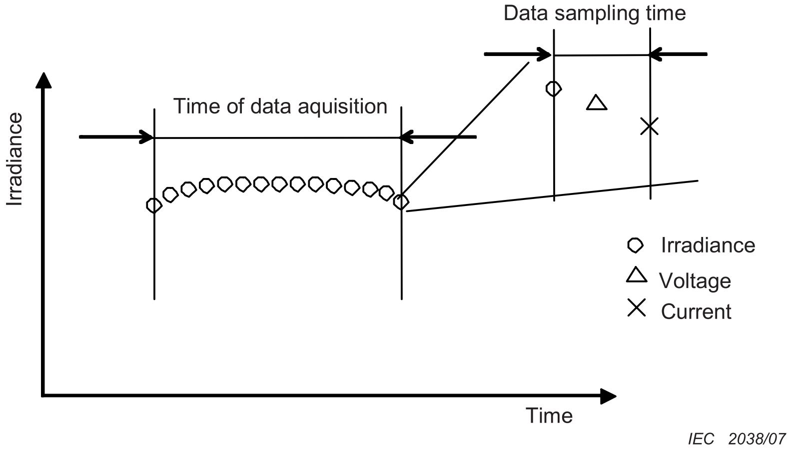

Figure 1 – Evaluation of STI for a long pulse solar simulator

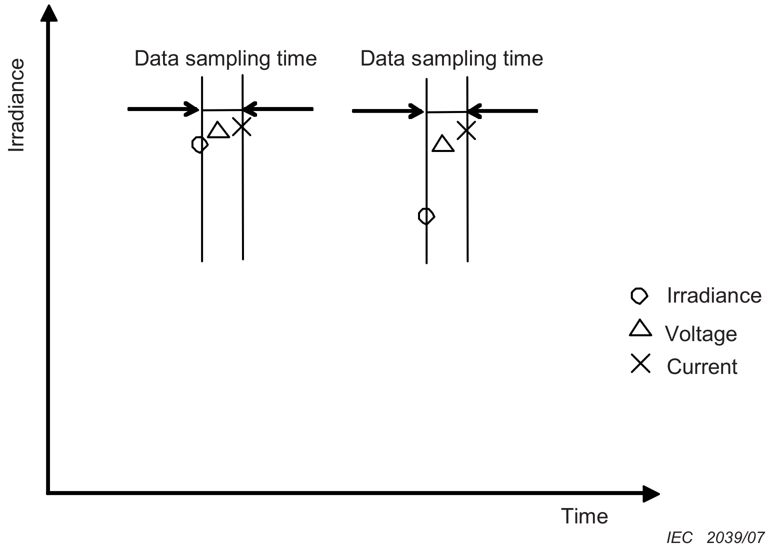

Figure 2 – Evaluation of STI for a short pulse solar simulator

5.4.1.3 Steady state solar simulator for I-V measurement

a) When there are three separate data input lines that simultaneously store values of irradiance, current and voltage, the STI is Class A.

NOTE The uncertainty in simultaneous triggering of the three multiple channels is typically less than 10 nanoseconds.

b) For steady state solar simulators without simultaneous measurement of irradiance, current and voltage the following procedure is used to determine STI:

   1) Determine the time for taking two successive data sets (irradiance, current and voltage) considering a possible delay time between measurements.
   2) STI is related to worst case irradiance change between successive data sets.
   3) Calculate the STI using the data from step 2), equation (2) and Table 2.

NOTE For steady state solar simulators used for PV performance measurements but not including an I-V data acquisition system, the maximum time of data acquisition should be stated by the solar simulator manufacturer for a achieving class A, B, C of STI.

c) For steady state solar simulators not including irradiance measurement for a data set the value of STI shall be determined from prior measurement of the irradiance instability over the time period of interest for the I-V measurement (time between measurement of irradiance). The continuous measurement of irradiance at stabilised operating conditions is evaluated from the maximum and minimum in that time period. For this case there is no LTI.

5.4.2 Solar simulators for irradiance exposure

For steady state solar simulators used for endurance irradiation tests the value of LTI is of primary interest and used for classification. The following procedure is used to determine the LTI:

a) Record the irradiance variations in the time period of interest by using a suitable irradiance sensor and an appropriate averaging time. If multi-lamp systems are used a representative number of locations in the designated test area shall be specified.
b) Determine maximum irradiance and minimum irradiance from data measured in step a).
c) Determine the LTI using the data from step b),equation (2).
d) Apply the calculated value of LTI to determine the classification of STI in Table 2.

5.4.3 The STI class of the solar simulator is given by the following:

Class A: Temporal instability 0,5 %, as specified in Table 2.

Class B: Temporal instability 2 %, as specified in Table 2.

Class C: Temporal instability 10 %, as specified in Table 2.

6 Name plate and data sheet

The following information shall be provided by the solar simulator manufacturer on the name plate that accompanies each simulator:

– manufacturer;
– model;
– type of solar simulator (pulsed or steady-state);
– serial number;
– date of manufacture or traceable from serial number.

In addition the following information shall be provided by the solar simulator manufacturer on a data sheet that accompanies each simulator:

– Date of issue of data sheet.
– Intended use of the solar simulator (I-V measurement or irradiance exposure).
– Classification of “Spectral match”.
– Classification of “Non-uniformity of irradiance”.
– Classification of STI.
– Methods of measurements used to determine classification categories.
– Irradiance range over which these classes are determined.
– Maximum time of data acquisition if used for I-V measurements.
– Operating environment for which the classification is valid (ambient conditions, power requirements).
– Location and nominal area of test plane at which the classification was determined.
– Nominal lamp setting and irradiance levels at which the classes were measured.
– Table of measured spectral irradiance distribution.
– Warm up time for stabilisation of irradiance.
– Warm up time for stabilisation of I-V measurements.
– Table of non-uniformity of irradiance measured over the specified test area.
– Measured temporal instability of irradiance (LTI).
– Maximum angle subtended by the light source (including reflected light) in the test plane.
– Irradiance profile vs. time of the pulse (for pulsed simulator).
– Data sampling rate.
– Changes that may require verification of the classification.

Bibliography

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

NOTE Harmonized as EN 60904-1:2006 (not modified).

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

NOTE Harmonized as EN 60904-2:2007 (not modified).

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

NOTE Harmonized as EN 60904-7:1998 (not modified).

IEC 60904-8: *Photovoltaic devices – Part 8: Measurement of spectral response of a photovoltaic (PV) device*

NOTE Harmonized as EN 60904-8:1998 (not modified).

IEC 60904-10: *Photovoltaic devices – Part 10: Methods of linearity measurement*

NOTE Harmonized as EN 60904-10:1998 (not modified).

IEC 61215: *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval*

NOTE Harmonized as EN 61215:2005 (not modified).

IEC 61646: *Thin-film terrestrial photovoltaic (PV) modules – Design qualification and type approval*

NOTE Harmonized as EN 61646:1997 (not modified).

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 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)]

[1)] Undated reference.

[2)] Valid edition at date of issue.

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W4 4AL