

Photovoltaic devices —

Part 3: Measurement principles for
terrestrial photovoltaic (PV) solar devices with
reference spectral irradiance data

National foreword

This British Standard is the UK implementation of EN 60904-3:2008. It is identical to IEC 60904-3:2008. It supersedes BS EN 60904-3:1993 which is withdrawn.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 this committee 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.

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EN 60904-3

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Supersedes EN 60904-3:1993

English version

Photovoltaic devices -
Part 3: Measurement principles for terrestrial photovoltaic (PV)
solar devices with reference spectral irradiance data
(IEC 60904-3:2008)

Dispositifs photovoltaïques -
Partie 3: Principes de mesure
des dispositifs solaires photovoltaïques
(PV) à usage terrestre incluant
les données de l'éclairement spectral
de référence
(CEI 60904-3:2008)

Photovoltaische Einrichtungen –
Teil 3: Messgrundsätze
für terrestrische photovoltaische (PV)
Einrichtungen mit Angaben über
die spektrale Strahlungsverteilung
(IEC 60904-3:2008)

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

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Foreword

The text of document 82/511/FDIS, future edition 2 of IEC 60904-3, prepared by IEC TC 82, Solar photovoltaic energy systems, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60904-3 on 2008-05-01.

This European Standard supersedes EN 60904-3:1993.

The main changes with respect to EN 60904-3:1993 are as follows:

- wavelength range extended deeper into the ultraviolet (280 nm instead of 305 nm);
- sunfacing surface considered;
- uniform wavelength intervals used (0,5 nm up to 400 nm, 1 nm up to 1 700 nm, 5 nm up to 4 000 nm); better resolution than in EN 60904-3:1993;
- more representative atmospheric conditions are considered;
- the model used to generate the spectrum has changed from BRITE to SMARTS (version 2.9), which is publicly available.

In addition, the terminology annex has been removed from EN 60904-3:2008 because this part is now included in IEC/TS 61836:2007. The titles of some clauses have been changed (others have been added) to accord with the usual structure of IEC standards.

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) | 2009-02-01 |
| – latest date by which the national standards conflicting with the EN have to be withdrawn | (dow) | 2011-05-01 |

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60904-3:2008 was approved by CENELEC as a European Standard without any modification.

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.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60891 + A1	1987 1992	Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic devices	EN 60891	1994
IEC 60904-1	- ¹⁾	Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics	EN 60904-1	2006 ²⁾
IEC 60904-2	- ¹⁾	Photovoltaic devices - Part 2: Requirements for reference solar devices	EN 60904-2	2007 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	EN 60904-9	2007 ²⁾

¹⁾ Undated reference.

²⁾ Valid edition at date of issue.

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PHOTOVOLTAIC DEVICES –

Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data

1 Scope and object

This part of IEC 60904 applies to the following photovoltaic devices for terrestrial applications:

- solar cells with or without a protective cover;
- sub-assemblies of solar cells;
- modules;
- systems.

NOTE The term “test specimen” is used to denote any of these devices.

The principles contained in this standard cover testing in both natural and simulated sunlight.

This standard is not applicable to solar cells designed for operation in concentrated sunlight or to modules embodying concentrators.

Photovoltaic conversion is spectrally selective due to the nature of the semiconductor materials used in PV solar cells and modules. To compare the relative performance of different PV devices and materials a reference standard solar spectral distribution is necessary. This standard includes such a reference solar spectral irradiance distribution.

This standard also describes basic measurement principles for determining the electrical output of PV devices. The principles given in this standard are designed to relate the performance rating of PV devices to a common reference terrestrial solar spectral irradiance distribution.

The reference terrestrial solar spectral irradiance distribution given in this standard is required in order to classify solar simulators according to the spectral performance requirements contained in IEC 60904-9.

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 60891:1987, *Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic devices*
Amendment 1 (1992)

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

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

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*

3 Measurement principles

In current practice the photovoltaic performance of a solar cell or module is determined by exposing it at a known temperature to stable sunlight, natural or simulated, and measuring its current-voltage (I-V) characteristic curve while measuring the magnitude of both the incident irradiance and the PV device temperature. Detailed I-V curve measurement procedures are included in IEC 60904-1. The measured performances can then be corrected to Standard Test Conditions (STC) or other desired conditions of irradiance and temperature according to IEC 60891. The corrected power output at the rated voltage and STC is commonly referred to as the rated power.

Incident irradiance can be measured by means of a PV reference device (whose spectral response must be known) or, if measuring under natural sunlight, by means of a thermopile-type irradiance detector (pyranometer). If a PV reference device is used, it shall satisfy the requirements specified in IEC 60904-2. Temperature determination of the PV device under test shall be made according to IEC 60904-1.

Since a solar cell has a wavelength-dependent response, its performance is significantly affected by the spectral distribution of the incident radiation, which in natural sunlight varies with several factors such as location, weather, time of year, time of day, orientation of the receiving surface, etc., and with a simulator varies with its type and conditions of use. If the irradiance is measured either with a thermopile-type radiometer (that is not spectrally selective) or with a reference solar cell, the spectral irradiance distribution of the incoming light must be known in order to make the necessary corrections to obtain the performance of the PV device under the reference solar spectral distribution defined in this standard as specified in IEC 60904-7. It is also possible for a user or array designer, using the spectral response of the cells, to compute within a reasonable tolerance the performance of a PV device when exposed to light of any other known spectral irradiance distribution. The methodology for this calculation can be found in IEC 60904-7.

4 Reference solar spectral irradiance distribution

The reference solar spectral distribution AM1.5 is given in Table 1 and Figure 1. This is a total distribution (direct + diffuse) of sunlight, corresponding to an integrated irradiance of 1 000 W·m⁻² incident on a sun-facing plane surface tilted at 37° to the horizontal considering the wavelength-dependent albedo of a light bare soil, under the following atmospheric conditions:

- U.S. Standard Atmosphere with CO₂ concentration increased to current level (370 ppm), a rural aerosol model, and no pollution;
- precipitable water: 1,4164 cm;
- ozone content: 0,3438 atm-cm (or 343,8 DU);
- turbidity (aerosol optical depth): 0,084 at 500 nm;
- pressure: 1013,25 hPa (i.e., sea level).

Data contained in Table 1 have been generated using the solar spectral model SMARTS, Version 2.9.2. A general description of this model and its suitability to reproduce actual solar spectral irradiance distributions can be found in “Proposed Reference Irradiance Spectra for Solar Energy Systems Testing” by C. A. Gueymard, C. Myers and K. Emery¹⁾, and in the references therein. Table 1 can be obtained using the data contained in Annex A as an input to the model SMARTS Version 2.9.2. The resulting output spectral irradiance values have to

¹⁾ C. A. Gueymard, C. Myers and K. Emery. “Proposed Reference Irradiance Spectra for Solar Energy Systems Testing”. *Energie solaire*, Vol 73, No. 6, pp. 443-467, 2002.

be multiplied by a normalization factor (0,9971) in order to get an integrated irradiance of $1000 \text{ W} \cdot \text{m}^{-2}$ in the wavelength range 0 to infinity.

At the time of publication of this standard the SMARTS Version 2.9.2 spectral model code is available, free of charge, subject to the author's license agreement, at <http://www.nrel.gov/rredc/smarts>. A copy of the model, not for distribution purposes, is kept under IEC TC 82 WG 2 control.

Table 1 – Reference solar spectral irradiance distribution

Wave-length (nm)	Spectral irradiance ($\text{W}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$)	Spectral photon irradiance ($\text{m}^{-2}\cdot\text{s}^{-1}\cdot\text{nm}^{-1}$)	Cumulative integrated irradiance ($\text{W}\cdot\text{m}^{-2}$)
280,0	4,72E-23	6,649E-05	0,00E+00
280,5	1,23E-21	1,733E-03	3,19E-22
281,0	5,67E-21	8,025E-03	2,04E-21
281,5	1,56E-19	2,213E-01	4,25E-20
282,0	1,19E-18	1,691E+00	3,79E-19
282,5	4,53E-18	6,443E+00	1,81E-18
283,0	1,84E-17	2,621E+01	7,54E-18
283,5	3,53E-17	5,032E+01	2,10E-17
284,0	7,25E-16	1,036E+03	2,11E-16
284,5	2,48E-15	3,550E+03	1,01E-15
285,0	7,99E-15	1,146E+04	3,63E-15
285,5	4,25E-14	6,107E+04	1,62E-14
286,0	1,36E-13	1,964E+05	6,10E-14
286,5	8,36E-13	1,205E+06	3,04E-13
287,0	2,73E-12	3,942E+06	1,20E-12
287,5	1,09E-11	1,573E+07	4,60E-12
288,0	6,22E-11	9,011E+07	2,29E-11
288,5	1,71E-10	2,485E+08	8,12E-11
289,0	5,61E-10	8,162E+08	2,64E-10
289,5	2,07E-09	3,015E+09	9,22E-10
290,0	6,00E-09	8,758E+09	2,94E-09
290,5	1,37E-08	2,010E+10	7,87E-09
291,0	3,50E-08	5,120E+10	2,00E-08
291,5	1,09E-07	1,597E+11	5,60E-08
292,0	2,68E-07	3,932E+11	1,50E-07
292,5	4,26E-07	6,267E+11	3,23E-07
293,0	8,62E-07	1,272E+12	6,45E-07
293,5	2,26E-06	3,345E+12	1,43E-06
294,0	4,16E-06	6,160E+12	3,03E-06
294,5	6,57E-06	9,743E+12	5,72E-06
295,0	1,23E-05	1,820E+13	1,04E-05
295,5	2,77E-05	4,127E+13	2,04E-05
296,0	4,78E-05	7,117E+13	3,93E-05
296,5	7,11E-05	1,062E+14	6,90E-05
297,0	9,65E-05	1,443E+14	1,11E-04
297,5	1,86E-04	2,779E+14	1,81E-04
298,0	2,89E-04	4,336E+14	3,00E-04
298,5	3,57E-04	5,362E+14	4,62E-04
299,0	4,91E-04	7,386E+14	6,73E-04
299,5	8,58E-04	1,294E+15	1,01E-03
300,0	0,0010	1,537E+15	0,00
300,5	0,0012	1,878E+15	0,00
301,0	0,0019	2,916E+15	0,00
301,5	0,0027	4,073E+15	0,00

Wave-length (nm)	Spectral irradiance ($\text{W}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$)	Spectral photon irradiance ($\text{m}^{-2}\cdot\text{s}^{-1}\cdot\text{nm}^{-1}$)	Cumulative integrated irradiance ($\text{W}\cdot\text{m}^{-2}$)
302,0	0,0029	4,428E+15	0,01
302,5	0,0043	6,505E+15	0,01
303,0	0,0071	1,079E+16	0,01
303,5	0,0090	1,368E+16	0,01
304,0	0,0094	1,445E+16	0,02
304,5	0,0119	1,827E+16	0,02
305,0	0,0164	2,520E+16	0,03
305,5	0,0187	2,870E+16	0,04
306,0	0,0185	2,853E+16	0,05
306,5	0,0210	3,247E+16	0,06
307,0	0,0278	4,291E+16	0,07
307,5	0,0355	5,500E+16	0,09
308,0	0,0377	5,850E+16	0,11
308,5	0,0413	6,415E+16	0,13
309,0	0,0404	6,287E+16	0,15
309,5	0,0432	6,728E+16	0,17
310,0	0,0508	7,926E+16	0,19
310,5	0,0653	1,021E+17	0,22
311,0	0,0827	1,294E+17	0,26
311,5	0,0838	1,315E+17	0,30
312,0	0,0931	1,462E+17	0,34
312,5	0,0987	1,553E+17	0,39
313,0	0,1070	1,686E+17	0,44
313,5	0,1073	1,693E+17	0,49
314,0	0,1193	1,886E+17	0,55
314,5	0,1302	2,062E+17	0,61
315,0	0,1359	2,154E+17	0,68
315,5	0,1180	1,875E+17	0,74
316,0	0,1231	1,959E+17	0,80
316,5	0,1499	2,389E+17	0,87
317,0	0,1711	2,730E+17	0,95
317,5	0,1819	2,908E+17	1,04
318,0	0,1754	2,808E+17	1,13
318,5	0,1854	2,972E+17	1,22
319,0	0,2041	3,278E+17	1,32
319,5	0,1953	3,142E+17	1,42
320,0	0,2047	3,297E+17	1,52
320,5	0,2445	3,945E+17	1,63
321,0	0,2495	4,032E+17	1,75
321,5	0,2377	3,848E+17	1,88
322,0	0,2214	3,589E+17	1,99
322,5	0,2165	3,514E+17	2,10
323,0	0,2116	3,441E+17	2,21
323,5	0,2479	4,037E+17	2,43

Wave-length (nm)	Spectral irradiance ($\text{W}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$)	Spectral photon irradiance ($\text{m}^{-2}\cdot\text{s}^{-1}\cdot\text{nm}^{-1}$)	Cumulative integrated irradiance ($\text{W}\cdot\text{m}^{-2}$)
324,0	0,2746	4,478E+17	2,45
324,5	0,2824	4,613E+17	2,59
325,0	0,2781	4,550E+17	2,73
325,5	0,3234	5,299E+17	2,88
326,0	0,3801	6,238E+17	3,06
326,5	0,4060	6,674E+17	3,25
327,0	0,3969	6,534E+17	3,45
327,5	0,3835	6,323E+17	3,65
328,0	0,3501	5,781E+17	3,83
328,5	0,3706	6,128E+17	4,01
329,0	0,4211	6,975E+17	4,21
329,5	0,4674	7,753E+17	4,43
330,0	0,4700	7,808E+17	4,67
330,5	0,4268	7,100E+17	4,89
331,0	0,4015	6,689E+17	5,10
331,5	0,4168	6,956E+17	5,30
332,0	0,4350	7,270E+17	5,52
332,5	0,4379	7,330E+17	5,74
333,0	0,4282	7,178E+17	5,95
333,5	0,4061	6,817E+17	6,16
334,0	0,4138	6,957E+17	6,37
334,5	0,4438	7,473E+17	6,58
335,0	0,4625	7,800E+17	6,81
335,5	0,4518	7,631E+17	7,03
336,0	0,4140	7,002E+17	7,25
336,5	0,3810	6,455E+17	7,45
337,0	0,3727	6,323E+17	7,64
337,5	0,3993	6,785E+17	7,83
338,0	0,4329	7,365E+17	8,04
338,5	0,4539	7,735E+17	8,26
339,0	0,4622	7,888E+17	8,49
339,5	0,4731	8,085E+17	8,72
340,0	0,5003	8,564E+17	8,97
340,5	0,4993	8,558E+17	9,22
341,0	0,4700	8,068E+17	9,46
341,5	0,4680	8,045E+17	9,69
342,0	0,4879	8,400E+17	9,93
342,5	0,5062	8,728E+17	10,18
343,0	0,5134	8,865E+17	10,44
343,5	0,4847	8,381E+17	10,69
344,0	0,4172	7,225E+17	10,91
344,5	0,4019	6,970E+17	11,12
345,0	0,4576	7,948E+17	11,33
345,5	0,4879	8,486E+17	11,57
346,0	0,4764	8,298E+17	11,81
346,5	0,4852	8,463E+17	12,05
347,0	0,4926	8,605E+17	12,29

Wave-length (nm)	Spectral irradiance ($\text{W}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$)	Spectral photon irradiance ($\text{m}^{-2}\cdot\text{s}^{-1}\cdot\text{nm}^{-1}$)	Cumulative integrated irradiance ($\text{W}\cdot\text{m}^{-2}$)
347,5	0,4754	8,316E+17	12,54
348,0	0,4737	8,299E+17	12,77
348,5	0,4820	8,455E+17	13,01
349,0	0,4643	8,157E+17	13,25
349,5	0,4767	8,386E+17	13,48
350,0	0,5264	9,276E+17	13,73
350,5	0,5658	9,983E+17	14,01
351,0	0,5501	9,720E+17	14,29
351,5	0,5287	9,355E+17	14,56
352,0	0,5164	9,151E+17	14,82
352,5	0,4882	8,663E+17	15,07
353,0	0,5189	9,221E+17	15,32
353,5	0,5706	1,015E+18	15,59
354,0	0,6032	1,075E+18	15,89
354,5	0,6098	1,088E+18	16,19
355,0	0,6096	1,089E+18	16,49
355,5	0,5886	1,053E+18	16,79
356,0	0,5523	9,897E+17	17,08
356,5	0,5179	9,295E+17	17,35
357,0	0,4554	8,184E+17	17,59
357,5	0,4608	8,293E+17	17,82
358,0	0,4288	7,728E+17	18,04
358,5	0,3981	7,185E+17	18,25
359,0	0,4682	8,461E+17	18,46
359,5	0,5639	1,020E+18	18,72
360,0	0,5964	1,081E+18	19,01
360,5	0,5637	1,023E+18	19,30
361,0	0,5187	9,427E+17	19,57
361,5	0,5081	9,246E+17	19,83
362,0	0,5327	9,707E+17	20,09
362,5	0,5834	1,065E+18	20,37
363,0	0,6002	1,097E+18	20,66
363,5	0,5837	1,068E+18	20,96
364,0	0,6045	1,108E+18	21,26
364,5	0,5988	1,099E+18	21,56
365,0	0,6218	1,142E+18	21,86
365,5	0,6843	1,259E+18	22,19
366,0	0,7332	1,351E+18	22,54
366,5	0,7344	1,355E+18	22,91
367,0	0,7208	1,332E+18	23,28
367,5	0,7071	1,308E+18	23,63
368,0	0,6657	1,233E+18	23,98
368,5	0,6612	1,227E+18	24,31
369,0	0,6911	1,284E+18	24,65
369,5	0,7425	1,381E+18	25,00
370,0	0,7529	1,402E+18	25,38
370,5	0,6806	1,269E+18	25,74