BRITISH STANDARD

BS EN 61724:1998
IEC 61724: 1998

Photovoltaic system performance monitoring — Guidelines for measurement, data exchange and analysis

The European Standard EN 61724:1998 has the status of a British Standard

ICS 27.160

National foreword

This British Standard is the English language version of EN 61724:1998. It is identical with IEC 61724:1998.

The UK participation in its preparation was entrusted to Technical Committee GEL/82, Solar voltaic energy systems, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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

From 1 January 1997, all IEC publications have the number 60000 added to the old number. For instance, IEC 27-1 has been renumbered as IEC 60027-1. For a period of time during the change over from one numbering system to the other, publications may contain identifiers from both systems.

Cross-references

Attention is drawn to the fact that CEN and CENELEC standards normally include an annex which lists normative references to international publications with their corresponding European publications. The British Standards which implement these international or European publications may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 14 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

This British Standard, having been prepared under the direction of the Electrotechnical Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 December 1998

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Contents

	Page
National foreword	Inside front cover
Foreword	2
Text of EN 61724	3

EUROPEAN STANDARD

NORME EUROPÉENNE

EUROPÄISCHE NORM

EN 61724

August 1998

ICS 27.180

English version

Photovoltaic system performance monitoring Guidelines for measurement, data exchange and analysis

(IEC 61724:1998)

Suivi des performances des systèmes photovoltaïques — Recommandations pour les mesures, et le transfert et l'analyse des données (CEI 61724:1998)

Überwachung des Betriebsverhaltens photovoltaischer Systeme — Leitfaden für Messen, Datenaustausch und Analyse (IEC 61724:1998)

This European Standard was approved by CENELEC on 1998-08-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

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

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

Ref. No. EN 61724:1998 E

Foreword

The text of document 82/189/FDIS, future edition 1 of IEC 61724, prepared by IEC TC 82, Solar photovoltaic energy systems, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61724 on 1998-08-01.

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)	1999-05-01
— latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2001-05-01

Annexes designated "normative" are part of the body of the standard.

Annexes designated "informative" are given for information only.

In this standard, Annex ZA is normative and Annex A is informative.

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61724:1998 was approved by CENELEC as a European Standard without any modification.

Contents

		Page
Foreword		2
Introduction		3
1	Scope	3
2	Normative references	3
3	Measured parameters	3
4	Monitoring method	5
4.1	Measurement of irradiance	5
4.2	Measurement of ambient air temperature	5
4.3	Measurement of wind speed	5
4.4	Measurement of module temperature	5
4.5	Measurement of voltage and current	5
4.6	Measurement of electrical power	6
4.7	Data acquisition system	6
4.8	Sampling interval	6
4.9	Data processing operation	6
4.10	Recording interval, τ_r (expressed in hours)	6
4.11	Monitoring period	6
5	Documentation	6
6	Data format	7
6.1	Separate header with multiple data records	7
6.2	Single record format	8
7	Check of data quality	8
8	Derived parameters	8
8.1	Global irradiation	9
8.2	Electrical energy quantities	10
8.3	BOS component performance	10
8.4	System performance indices	11
Annex A (informative) A suggested method of checking the data acquisition system		13
Annex ZA (normative) Normative references to international publications with their corresponding European publications		14
Figure 1 — Parameters to be measured in real time		5
Table 1 — Parameters to be measured in real time		4
Table 2 — Derived parameters		9

Introduction

This standard describes general guidelines for the monitoring and analysis of the electrical performance of photovoltaic (PV) systems. It does not describe the performance of discrete components, but concentrates on evaluating the performance of an array as part of a PV system.

The intent of the data analysis is to provide a performance summary suitable for comparing PV installations of different sizes, operating in different climates, and providing energy for different uses, in such a way that the relative merits of different designs or operating procedures become evident. Simpler methods might be more cost effective for small, solar home or domestic stand-alone systems.

Guidelines are also included which describe a file format to be used for the exchange of monitoring data between organizations.

The use of a microprocessor-based data acquisition system for monitoring is required.

1 Scope

This International Standard recommends procedures for the monitoring of energy-related PV system characteristics such as in-plane irradiance, array output, storage input and output and power conditioner input and output; and for the exchange and analysis of monitored data. The purpose of these procedures is to assess the overall performance of PV systems configured as stand-alone or utility grid-connected, or as hybridised with non-PV power sources such as engine generators and wind turbines.

This standard may not be applicable to small stand-alone systems due to the relatively high cost of the measurement equipment.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60904-2:1989, *Photovoltaic devices — Part 2: Requirements for reference solar cells*
Amendment 1 (1998).

IEC 60904-6:1994, *Photovoltaic devices — Part 6: Requirements for reference solar modules*
Amendment 1 (1998).

IEC 61194:1992, *Characteristic parameters of stand-alone photovoltaic (PV) systems.*

IEC 61829:1995, *Crystalline silicon photovoltaic (PV) array — On-site measurement of I-V characteristics.*

3 Measured parameters

Parameters to be measured are shown in Table 1 and Figure 1. Other parameters can be calculated from the measured data in real time by the data acquisition system's software. Note that all blocks in Figure 1 can represent multiple components. The measured parameters and array characteristics are defined in IEC 61194.

The parasitic power drawn by all ancillary systems shall be considered a power loss of the PV plant and shall not be considered a load. All monitoring systems not essential for the operation of the PV plant shall be considered part of the load. The monitoring equipment may present a major part of the overall power consumption, and the end user should be made aware that supplemental power may be required to satisfy the total load requirement.

Table 1 — Parameters to be measured in real time

Parameter	Symbol	Unit
Meteorology		
Total irradiance, in the plane of the array[a]	G_I	W·m^{-2}
Ambient air temperature in a radiation shield	T_{am}	°C
Wind speed[b]	S_W	m·s^{-1}
Photovoltaic array		
Output voltage	V_A	V
Output current	I_A	A
Output power	P_A	kW
Module temperature	T_m	°C
Tracker tilt angle[e]	ϕ_T	degrees
Tracker azimuth angle[e]	ϕ_A	degrees
Energy storage[c]		
Operating voltage	V_S	V
Current to storage[d]	I_{TS}	A
Current from storage[d]	I_{FS}	A
Power to storage[d]	P_{TS}	kW
Power from storage[d]	P_{FS}	kW
Load[c]		
Load voltage	V_L	V
Load current	I_L	A
Load power[f]	P_L	kW
Utility grid[c]		
Utility voltage	V_U	V
Current to utility grid[d]	I_{TU}	A
Current from utility grid[d]	I_{FU}	A
Power to utility grid[d, f]	P_{TU}	kW
Power from utility grid[d, f]	P_{FU}	kW
Back-up sources[c]		
Output voltage	V_{BU}	V
Output current	I_{BU}	A
Output power	P_{BU}	kW

[a] Total irradiance, also known as the plane-of-array irradiance, defined as the radiant power, direct plus diffuse, incident upon unit area of an inclined surface.
[b] Parameters such as wind speed are optional, but may be required by special contract or if the PV array is subject to extreme operating conditions.
[c] AC and d.c. quantities may be distinguished by the addition of subscripts. In the case of multi-phase systems, parameters V_L, I_L and P_L shall be specified for each phase.
[d] A single current or power sensor can normally be used for the measurement of current or power for directions of both input and output. A positive sign in the sensor's output signal represents input to the energy storage device or utility grid and a negative sign represents output from the storage device or utility grid. Input and output from a single sensor must be accumulated separately in software.
[e] Tracker angles are optional for systems with tracking arrays. For single axis trackers ϕ_T is used to describe the position of the array about its tracking axis. For example, for a horizontal single axis tracker this parameter would give the angle from horizontal, east is negative and west is positive.
[f] A direct measurement of the power output of the inverter portion of the power conditioner may be made if it improves accuracy.

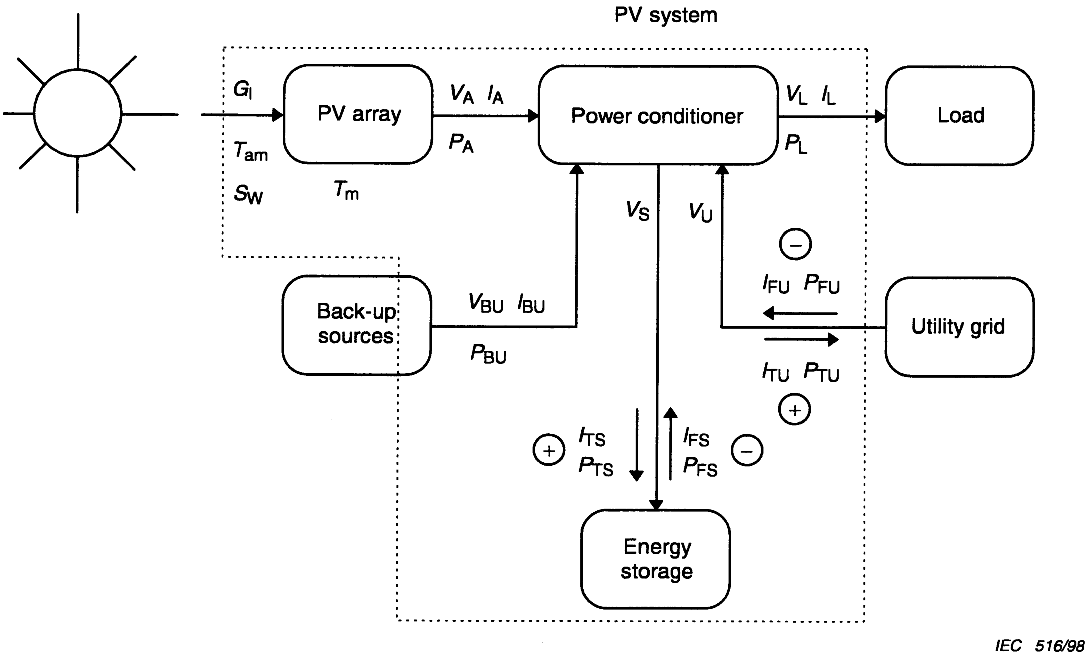

Figure 1 — Parameters to be measured in real time

4 Monitoring method

4.1 Measurement of irradiance

Irradiance data are recorded in the plane of the array for use in the performance analysis of the PV system. Horizontal data may also be recorded to permit comparisons with standard meteorological data from other locations.

In-plane irradiance shall be measured in the same plane as the photovoltaic array by means of calibrated reference devices or pyranometers. If used, reference cells or modules shall be calibrated and maintained in accordance with IEC 60904-2 or IEC 60904-6. The location of these sensors shall be representative of the irradiance conditions of the array. The accuracy of irradiance sensors, including signal conditioning, shall be better than 5 % of the reading.

4.2 Measurement of ambient air temperature

Ambient air temperature shall be measured at a location which is representative of the array conditions, by means of temperature sensors located in solar radiation shields. The accuracy of air temperature sensors, including signal conditioning, shall be better than 1 K.

4.3 Measurement of wind speed

Where applicable, wind speed shall be measured at a height and location which are representative of the array conditions. The accuracy of the wind speed sensors shall be better than 0,5 m s^{-1} for wind speeds ≤ 5 m s^{-1}, and better than 10 % of the reading for wind speeds greater than 5 m s^{-1}.

4.4 Measurement of module temperature

PV module temperature shall be measured at locations which are representative of the array conditions by means of temperature sensors located on the back surface of one or more modules. The selection of module locations is specified under method A in IEC 61829. Care must be taken to ensure that the temperature of the cell in front of the sensor is not substantially altered due to the presence of the sensor. The accuracy of these sensors, including signal conditioning, shall be better than 1 K.

4.5 Measurement of voltage and current

The voltage and current parameters may be either d.c. or a.c. The accuracy of voltage and current sensors, including signal conditioning, shall be better than 1 % of the reading. AC voltage and current may not need to be monitored in every situation.

4.6 Measurement of electrical power

The electrical power parameters may be d.c. or a.c. or both. DC power can either be calculated in real time as the product of sampled voltage and current quantities or measured directly using a power sensor. If d.c. power is calculated, the calculations shall use sampled voltage and current quantities and not averaged voltage and current quantities[1]. The d.c. input power and voltage on stand-alone inverters may have large amounts of a.c. ripple impressed. It may be necessary to use a d.c. wattmeter to accurately measure d.c. power. AC power shall be measured using a power sensor which properly accounts for the power factor and harmonic distortion. The accuracy of power sensors, including signal conditioning, shall be better than 2 % of the reading.

An integrating power sensor with high-speed response (for example, a kWh meter) may be used to avoid sampling errors.

4.7 Data acquisition system

An automatic data acquisition system is required for monitoring. The total accuracy of the monitoring system shall be determined by a calibration method such as given in Annex A. The monitoring system should be based on commercially available hardware and software which is properly documented with user's manuals. Technical support should be available.

4.8 Sampling interval

The sampling interval for parameters which vary directly with irradiance shall be 1 min or less.
For parameters which have larger time constants, an arbitrary interval may be specified between 1 min and 10 min. Special consideration for increasing the sampling frequency shall be given to any parameters which may change quickly as a function of system load. All parameters shall be continuously measured during the specified monitoring period.

NOTE The rates of change for many of the parameters of interest can be relatively high. Irradiance, for example, can change at a rate exceeding 200 $W \cdot m^{-2} \cdot s^{-1}$ under partly cloudy conditions. While the intent within this international standard is not to capture electrical transient-level detail, a sufficient sampling rate is necessary to characterize average performance over the averaging interval. Generally, the parameters in Table 1 should be sampled every minute. Module and ambient temperature may be sampled at slower rates, but it is preferable as well as more convenient to sample all parameters at a common rate. All parameters should be continuously measured during the specified monitoring period.

4.9 Data processing operation

The sampled data from each measured parameter shall be processed into time-weighted averages. Maximum or minimum quantities and transients of special interest may be determined where required. For integrating power sensors, the sampled data is summed and divided by the recording interval τ_r.

4.10 Recording interval, τ_r (expressed in hours)

The processed data values for each parameter shall be recorded hourly. More frequent recordings may be implemented where required, as long as one hour is an integer multiple of the recording interval τ_r.

At each recording interval, the time and date at the end of the period in which measurements were taken shall be recorded. The time shall always refer to local standard time, not to daylight-saving time. Universal time may be useful to avoid winter/summer time changes.

4.11 Monitoring period

The monitoring period shall be sufficient to provide operational data representative of load and ambient conditions. Therefore, the minimum period of continuous monitoring shall be chosen in accordance with the end use of the collected data.

5 Documentation

A monitoring log shall be kept on all unusual events, component changes, failures, faults or accidents. Other comments which would be useful in interpreting and evaluating the data shall also be noted, such as the weather, sensor recalibration, changes to the data acquisition system, load, or system operation, or problems with sensors or the data acquisition system. All system maintenance (such as changing modules, changing the array tilt angle or cleaning soiled array surfaces) shall be explicitly documented.

[1] The error between d.c. power as calculated from the averaged product of sampled voltage and sampled current and d.c. power as calculated from the product of averaged voltage and averaged current depends on the sample rate and the variation in current. Errors can be significant for large current variations.

6 Data format

It is not mandatory that the data be stored nor exchanged in either of the following two illustrative formats. However, the first method based on separate header record and data records is in use in several countries, and may facilitate the exchange of data between organizations. For actual data transfer the line protocol terms, communication protocol and the check-sum terms must also be specified.

6.1 Separate header with multiple data records

This format gives a header record of the site, date, time and comments followed by one or more data records. A record is comparable to a printed line.

a) Each record shall consist of one or more fields with each field separated by a field separation character (FS) which may be preferably a comma (ASCII 44), or optionally a tab (ASCII 9). The records should be separated by an "end-of-line" (EOL) marker consisting of a "carriage-return" character (ASCII 13), a "linefeed" character (ASCII 10), or a "carriage return" followed by a "linefeed".

b) The header record shall be of the following form:

"Station" FS Date FS Time FS Comments

where

"Station" is the name of the site enclosed in double quotation marks (ASCII 34), of which only the first eight letters are mandatory;

Date is the day of the measurement in the format of yy-mm-dd (leading zeros should be included);

Time is the time of the recording in the format of hh:mm. Midnight should be referenced as 24 h in the previous day, not 0 h in the next day;

NOTE Different formats of date and time may be necessary due to the unique software of the data acquisition system.

Comments may be used to describe additional system characteristics, or may be used to record unusual events, switching conditions or other messages at the discretion of the PV plant manager, using ASCII or Extended ASCII characters (or equivalent), corresponding to local character code standards.

c) A data record shall consist of its record number as the first field, followed by one or more numerical data fields. The data fields are defined for the specific record as follows, using the symbols listed in Table 1:

DATA RECORD 1:	1	FS	G_I	FS	T_A	FS	T_m	FS	V_A	FS	I_A	FS	P_A	
DATA RECORD 2:	2	FS	V_S	FS	I_{TS}	FS	I_{FS}	FS	P_{TS}	FS	P_{FS}			
DATA RECORD 3:	3	FS	V_L	FS	I_L	FS	P_L	FS	V_{BU}	FS	I_{BU}	FS	P_{BU}	
DATA RECORD 4:	4	FS	V_U	FS	I_{TU}	FS	I_{FU}	FS	P_{TU}	FS	P_{FU}			

Any number of additional data records may be optionally included in the recording interval.
The content of these data records may be defined by the monitoring organization, with the exception of the first field which should indicate the record number.

d) All numerical data shall be written in single-byte ASCII code. Data can be recorded, either in free-field or fixed-field format, as signed integers or decimal fractions with the period (ASCII 46) used as the radix (decimal point). If any numerical data field is not applicable to a PV installation or if a data value is not available for a record, an empty field should be indicated by an absence of characters. Thus, the FS character at the end of the empty data field would immediately follow the FS character from the preceding data field. However, all FS characters directly preceding the EOL marker should be suppressed. For example, in data record 2 if only I_{TS} and P_{TS} are available, then that record should be written as follows:

2 FS FS I_{TS} FS FS P_{TS} EOL

6.2 Single record format

Another format which can be used is the single record format in which all of the data for a given recording interval is listed on one line. This single record format aids visual inspection, particularly if used in conjunction with fixed field width since all of the data is given in a single vertical column for each parameter.

Data FS Time FS G_I FS T_A FS T_m FS V_A FS I_A FS P_A FS V_S FS I_{TS} FS I_{FS} etc.

Each field should be separated by a field separation character (FS) which may be preferably a comma (ASCII 44), or optionally a tab (ASCII 9).

7 Check of data quality

All recorded data should be checked for consistency and gaps to identify obvious anomalies before any detailed analysis is conducted.

A reasonable set of limits shall be defined for each recorded parameter, based on the known characteristics of the parameter, the PV plant, and the environment. The limits should define the maximum and minimum allowable values for the parameter, and the maximum change between successive data points. Data which fall outside these limits or are otherwise inconsistent with other data shall not be included in the subsequent analyses. If possible (such as with a computer-based data acquisition system), such checks shall be performed with the sampled data in real-time before the data processing operation is executed.

The results of these data quality checks should normally include the following information:

a) a list of any data points falling outside the pre-set ranges;

NOTE With automated systems collecting a large amount of data (megabytes), it is not practical to list the out-of-range data points. However, some monitoring of the quantity of the out-of-range data points should be made and reported. The out-of-range data points should not be used in the analyses.

b) the duration of monitoring activity τ_{MA} (expressed in hours), in the reporting period τ, (commonly one month, but expressed in hours), for which monitoring data have been recorded and checked;

c) the total number of hours of data passing through the quality check should also be stated if different than the duration of the actual quality check period selected;

d) the availability of monitored data A_{MD} (expressed as a fraction of the reporting period), as given by:

$$A_{MD} = \tau_{MA} / \tau \qquad (1)$$

8 Derived parameters

Various derived parameters related to the system's energy balance and performance may be calculated from the recorded monitoring data using sums, averages, maxima, minima, and ratios over reporting periods τ, which are longer than the recording interval τ_r, (such as hours, days, weeks, months or years, but expressed in units of hours). Derived parameters are shown in Table 2.

To calculate any energy quantities from their corresponding measured power parameters over the reporting period τ, the following equation is used:

$$E_{i,\tau} = \tau_r \times \Sigma_\tau P_i \qquad (2)$$

where

E_i is expressed in kWh;

P_i is measured in kW.

The symbol Σ_τ denotes the summation of each power parameter over the reporting period τ.

For example, to calculate $E_{TS,\tau}$ [as referenced in equation (4)] replace index "i" in equation (2) by "TS" so that it becomes $E_{TS,\tau} = \tau_r \times \Sigma_\tau P_{TS}$. Also replace index τ by the actual reporting interval.

8.1 Global irradiation

Mean daily irradiation quantities $H_{I,d}$ (in kWh m^{-2} d^{-1}) are calculated from the recorded irradiance by

$$H_{I,d} = 24 \times \tau_r \times (\Sigma_\tau G_I) / (\Sigma_\tau \tau_{MA} \ 1\,000) \tag{3}$$

The symbol $\Sigma\tau$ denotes the summation over the reporting period τ.

Table 2 — Derived parameters

Parameter	Symbol	Unit
Meteorology		
Daily global or direct irradiation, in the plane of the array	$H_{I,d}$	kWh m^{-2} d^{-1}
Electrical energy quantities		
Net energy from array	$E_{A,\tau}$	kWh
Net energy to load	$E_{L,\tau}$	kWh
Net energy to storage	$E_{TSN,\tau}$	kWh
Net energy from storage	$E_{FSN,\tau}$	kWh
Net energy from back-up	$E_{BU,\tau}$	kWh
Net energy to utility grid	$E_{TUN,\tau}$	kWh
Net energy from utility grid	$E_{FUN,\tau}$	kWh
Total system input energy	$E_{in,\tau}$	kWh
Total system output energy	$E_{use,\tau}$	kWh
Fraction of total system input energy contributed by PV array	$F_{A,\tau}$	Dimensionless
Load efficiency	η_{LOAD}	Dimensionless
BOS component performance		
BOS efficiency	η_{BOS}	Dimensionless
System performance indices		
Array yield[a]	Y_A	h d^{-1}
Final PV system yield[a]	Y_f	h d^{-1}
Reference yield[a]	Y_r	h d^{-1}
Array capture losses[a]	L_c	h d^{-1}
BOS losses[a]	L_{BOS}	h d^{-1}
Performance ratio	R_P	Dimensionless
Mean array efficiency	$\eta_{Amean,\tau}$	Dimensionless
Overall PV plant efficiency	$\eta_{tot,\tau}$	Dimensionless

[a] The units h d^{-1} can be more descriptively given by (kWh d^{-1})$_{ACTUAL}$/(kW)$_{RATED}$

8.2 Electrical energy quantities

Electrical energy quantities can be calculated for the whole system and its components including energy delivered to or from a storage device or utility grid connection, or delivered from an auxiliary generator. The key parameters of interest are those which indicate the contribution of the PV array to the overall operation of the system.

a) The net energy delivered to the storage device in the reporting period τ:

$$E_{TSN,\tau} = E_{TS,\tau} - E_{FS,\tau} \tag{4}$$

where $E_{TSN,\tau}$ has a minimum value of 0.

b) The net energy delivered from the storage device in the reporting period τ:

$$E_{FSN,\tau} = E_{FS,\tau} - E_{TS,\tau} \tag{5}$$

where $E_{FSN,\tau}$ has a minimum value of 0.

NOTE Either $E_{TSN,\tau}$ or $E_{FSN,\tau}$ will always be 0. By using net energy quantities rather than gross energy, the storage device is considered as either a net load or a net energy source during the reporting period.

c) The net energy delivered to the utility grid in the reporting period τ:

$$E_{TUN,\tau} = E_{TU,\tau} - E_{FU,\tau} \tag{6}$$

where $E_{TUN,\tau}$ has a minimum value of 0.

d) The net energy delivered from the utility grid in the reporting period τ:

$$E_{FUN,\tau} = E_{FU,\tau} - E_{TU,\tau} \tag{7}$$

where $E_{FUN,\tau}$ has a minimum value of 0.

NOTE Either $E_{TUN,\tau}$ or $E_{FUN,\tau}$ will always be 0. By using net energy quantities rather than gross energy, the utility grid is considered as either a net load or a net energy source during the reporting period.

e) The total system input energy:

$$E_{in,\tau} = E_{A,\tau} + E_{BU,\tau} + E_{FUN,\tau} + E_{FSN,\tau} \tag{8}$$

f) The total system output energy:

$$E_{use,\tau} = E_{L,\tau} + E_{TUN,\tau} + E_{TSN,\tau} \tag{9}$$

g) The fraction of the energy from all sources which was contributed by the PV array:

$$F_{A,\tau} = E_{A,\tau} / E_{in,\tau} \tag{10}$$

h) The efficiency with which the energy from all sources is transmitted to the loads:

$$\eta_{LOAD} = E_{use,\tau} / E_{in,\tau} \tag{11}$$

8.3 BOS component performance

The BOS efficiency only includes energy conversion efficiency; such things as array tracking error and PCU maximum power point tracking error are excluded.

For each component in the system, the energy balance over the reporting period can be determined by summing the energy quantities into and out of the component. The component energy efficiency is the quotient of energy output over energy input.

The overall efficiency of the BOS components is given by

$$\eta_{BOS} = (E_{L,\tau} + E_{TSN,\tau} - E_{FSN,\tau} + E_{TUN,\tau} - E_{FUN,\tau}) / (E_{A,\tau} + E_{BU,\tau}) \tag{12}$$

For PV hybrid systems and utility grid-connected systems where $E_{L,\tau}$ is less than $E_{A,\tau} \times \eta_{BOS}$, and for all PV stand-alone systems, η_{LOAD} equals η_{BOS}. For utility, grid-connected systems where $E_{L,\tau}$ is greater than $E_{A,\tau} \times \eta_{BOS}$, η_{LOAD} will be greater than η_{BOS} because the utility appears as a loss-less energy source to the PV system.

Both the efficiency of the energy storage device and the change in the amount of energy stored in the device over the reporting period will affect $E_{FS,\tau}$ and $E_{TS,\tau}$.

a) For long reporting periods in which $E_{TS,\tau}$ and $E_{FS,\tau}$ are much greater than the device's energy storage capacity (by more than a factor of 10), the net energy added to or removed from the device can be assumed to have a negligible effect on the system performance calculations. Any difference between $E_{TS,\tau}$ and $E_{FS,\tau}$ is then primarily due to the efficiency of the device. As a result, $E_{TS,\tau}$ and $E_{FS,\tau}$ should be deleted from all equations to include the device's efficiency with the η_{LOAD} and η_{BOS} values. This condition is typical when reporting periods are of several months. The maximum possible effect on the accumulated $E_{TS,\tau}$ or $E_{FS,\tau}$ due to the actual change in the energy stored in the device can be calculated from the quotient of the device's storage capacity over $E_{TS,\tau}$ or $E_{FS,\tau}$.

b) For short reporting periods in which the energy storage capacity of the device is much greater than $E_{TS,\tau}$ and $E_{FS,\tau}$ (by more than a factor of 10), the efficiency of the device can be assumed to have a negligible effect on the system performance calculations. Any difference between $E_{TS,\tau}$ and $E_{FS,\tau}$ is then primarily due to the change in the amount of energy stored in the device. As a result, $E_{TS,\tau}$ and $E_{FS,\tau}$ become important terms in the system performance calculations. This condition is typical when reporting periods are of only a few days. The typical effect on $E_{TS,\tau}$ and $E_{FS,\tau}$ due to the efficiency of the device can be calculated from known measurements of the device's efficiency.

8.4 System performance indices

PV systems of different configurations and at different locations can be readily compared by evaluating their normalised system performance indices such as yields, losses and efficiencies. Yields are energy quantities normalised to rated array power. System efficiencies are normalised to array area. Losses are the differences between yields.

NOTE The performance indices of grid-connected, stand-alone and hybrid systems can differ significantly due to load matching and other unique operating characteristics.

8.4.1 *Daily mean yields*

Daily mean yields are the quotient of energy quantities over the installed array's rated output power P_0 (kW). The yields have units of kWh·d^{-1}·kW^{-1} (or h·d^{-1}) and indicate the amount of time during which the array would be required to operate at P_0 to provide a particular monitored energy quantity. Yields indicate actual array operation relative to its rated capacity.

a) The array yield Y_A is the daily array energy output per kW of installed PV array:

$$Y_A = E_{A,d} / P_0 = \tau_r \times (\Sigma_{day} P_A) / P_0 \tag{13}$$

The symbol Σ_{day} denotes the summation for the day. This yield represents the number of hours per day that the array would need to operate at its rated output power P_0 to contribute the same daily array energy to the system as was monitored [which equals $\tau_r \times (\Sigma_{day} P_A)$].

b) The final PV system yield Y_f is the portion of the daily net energy output of the entire PV plant which was supplied by the array per kW of installed PV array:

$$Y_f = Y_A \times \eta_{LOAD} \tag{14}$$

This yield represents the number of hours per day that the array would need to operate at its rated output power P_0 to equal its monitored contribution to the net daily load.

c) The reference yield Y_r can be calculated by dividing the total daily in-plane irradiation by the module's reference in-plane irradiance $G_{I,ref}$ (kW m^{-2}):

$$Y_r = \tau_r \times (\Sigma_{day} G_I) / G_{I,\,ref} \tag{15}$$

This yield represents the number of hours per day during which the solar radiation would need to be at reference irradiance levels in order to contribute the same incident energy as was monitored.

If $G_{I,ref} = 1$ kW m^{-2}, then the in-plane irradiation in units of kWh m^{-2} d^{-1} is numerically equal to a corresponding nominal array energy output in units of kWh d^{-1} kW^{-1}. Thus Y_r would be, in effect, the number of peak sun-hours per day (h d^{-1}).

8.4.2 ***Normalized losses***

Normalized losses are calculated by subtracting yields. Losses also have units of kWh d^{-1} kW^{-1} (or h d^{-1}) and indicate the amount of time during which the array would be required to operate at its rated power P_0 to provide for the losses.

a) The "array capture" losses L_c represents the losses due to array operation:

$$L_c = Y_r - Y_A \tag{16}$$

b) The BOS losses L_{BOS} represents the losses in the BOS components:

$$L_{BOS} = Y_A \times (1 - \eta_{BOS}) \tag{17}$$

c) The performance ratio R_p indicates the overall effect of losses on the array's rated output due to array temperature, incomplete utilisation of the irradiation, and system component inefficiencies or failures:

$$R_P = Y_f / Y_r \tag{18}$$

8.4.3 ***System efficiencies***

a) The mean array efficiency over the reporting period τ is defined by:

$$\eta_{Amean,\,\tau} = E_{A,\,\tau} / (A_a \times \tau_r \times \Sigma_\tau G_I) \tag{19}$$

where A_a is the overall array area.

This efficiency represents the mean energy conversion efficiency of the PV array, which is useful for comparison with the array efficiency η_{A0} at its rated power, P_0. The difference in efficiency values represents diode, wiring, and mismatch losses as well as energy wasted during plant operation.

b) The overall PV plant efficiency over the reporting period τ is defined by:

$$\eta_{tot,\tau} = \eta_{Amean,\,\tau} \times \eta_{LOAD} \tag{20}$$

8.4.4 ***Monthly or annual yields, losses and efficiencies***

The monthly or annual mean yields can be determined by using the appropriate array energy in equation (13) ($E_{A,m}$ for monthly or $E_{A,y}$ for annual), and the appropriate summation period (Σ_m for monthly or Σ_y for annual summations). The array yield would have units of h m^{-1} for monthly yield or h y^{-1} for annual yield.

Similar monthly or annual yields Y_f, reference yields Y_r, losses and efficiencies can be determined by using the proper array yield and summation periods in equation (14) through (20). Other monthly or annual performance factors may be included to satisfy the user requirements.

Annex A (informative) A suggested method of checking the data acquisition system

A data acquisition system excluding sensors can be checked by applying the simulated input signals specified below, or by other means agreed upon between the manufacturer and the customer. A check should be made every two years. Sensors should be calibrated individually in an appropriate manner.

The channels of the data acquisition equipment can be checked separately or at the same time.

A.1 Types of input signals to be checked

— irradiance;

— ambient temperature;

— voltage, current and power for each component of the PV plant.

A.2 Check of linear response

This check is to be performed on analogue input channels on which a linear scaling operation is applied. A constant d.c. signal shall be applied to the input terminals. The difference between the result measured by the data acquisition system and the products of the input signal value and scaling factor shall be less than ± 1 % of the full scale of the data acquisition system. This procedure should be performed at input signals of 0 %, 20 %, 40 %, 60 %, 80 %, and 100 % of full scale. If the inputs are specified for bipolar signals, negative signals shall also be applied in the same way.

If errors greater than 1 % of full scale are detected, then the scale factor should be corrected by software or hardware and re-verified.

A.3 Check of stability

This check is to be performed on all analogue input channels. A constant d.c. signal of 100 % of full scale shall be applied to the input terminals for 6 h. The fluctuation of the measured value of this signal shall be kept within ± 1 % of full scale. Should the fluctuation of the input signal exceed ± 0,2 %, the results shall be compensated by using a voltmeter with an accuracy better than ± 0,2 %.

A.4 Check of integration

This check is to be performed on input channels from which measurements are to be processed using an averaging or integrating operation. An input signal of a rectangular wave having an amplitude Z_m shall be applied to the channel and its measured values integrated over time period τ_d (recommended to be at least 6 h). The amplitude Z_m for each channel is recommended to be the maximum input level expected from the sensor. The results obtained shall be equal to $Z_m \times \tau_d \pm 1$ %. The amplitude and time period shall be monitored by measuring instruments with a ± 0,5 % precision.

A.5 Check of zero value integrals

This check is to be performed on input channels from which measurements are to be processed using an averaging or integrating operation. The channel shall be short-circuited, and its measured values integrated over time period τ_d of at least 6 h. The result shall be less than ± 1 % of $Z_m \times \tau_d$ where Z_m is defined in **A.4**.

A.6 Check of integrating interval

Under consideration.

Annex ZA (normative)
Normative references to international publications with their corresponding European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

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 60904-2 A1	1989 1998	Photovoltaic devices Part 2: Requirements for reference solar cells	EN 60904-2 A1	1993 1998
IEC 60904-6 A1	1994 1998	Part 6: Requirements for reference solar modules	EN 60904-6 A1	1994 1998
IEC 61194 (mod)	1992	Characteristic parameters of stand-alone photovoltaic (PV) systems	EN 61194	1995
IEC 61829	1995	Crystalline silicon photovoltaic (PV) array On-site measurement of I-V characteristics	EN 61829	1998

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