BS EN 62670-2:2015

BSI Standards Publication

Photovoltaic concentrators (CPV) — Performance testing

Part 2: Energy measurement

National foreword

This British Standard is the UK implementation of EN 62670-2:2015. It is identical to IEC 62670-2:2015.

The UK participation in its preparation was entrusted to Technical Committee GEL/82, 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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Photovoltaic concentrators (CPV) - Performance testing - Part 2: Energy measurement (IEC 62670-2:2015)

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

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Foreword

The text of document 82/940/FDIS, future edition 1 of IEC 62670-2, prepared by IEC/TC 82 "Solar photovoltaic energy systems" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62670-2:2015

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2016-03-11
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2018-06-11

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The text of the International Standard IEC 62670-2:2015 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 documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

Publication	Year	Title	EN/HD	Year
IEC 62670-1	-	Photovoltaic concentrators (CPV) - Performance testing - Part 1: Standard conditions	EN 62670-1	-
ISO/IEC 17025	-	General requirements for the competence of testing and calibration laboratories	-	-
ISO 8601	2004	Data elements and interchange formats - Information interchange - Representation of dates and times	-	-
ISO 9060	-	Solar energy; specification and classification of instruments for measuring hemispherical solar and direct solar radiation	-	-
ISO 9847	-	Solar energy - Calibration of field pyranometers by comparison to a reference pyranometer	-	-
JCGM 100	2008	Evaluation of measurement data - Guide to the expression of uncertainty in measurement	-	-

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PHOTOVOLTAIC CONCENTRATORS (CPV) – PERFORMANCE TESTING –

Part 2: Energy measurement

FOREWORD

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International Standard IEC 62670-2 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

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

FDIS	Report on voting
82/940/FDIS	82/969/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62670 series, published under the general title *Photovoltaic Concentrators (CPV) – Performance testing*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

IEC 62670 series establishes requirements for evaluating concentrator PV performance. It is written to be applicable to all concentrator PV technologies that have a geometric concentration ratio greater than 3× and require tracking.

Included in the IEC 62670 series of standards are definitions of the standard conditions and methods to be used for assessing CPV performance.

IEC 62670-1 defines a standard set of conditions so that power ratings noted on data sheets and nameplates have a standard basis.

IEC 62670-2 describes an on-sun, measurement based method for determining the energy output and performance ratio for CPV arrays, assemblies and power plants.

IEC 62670-3 (under consideration) describes methods for providing a CPV power assessment under a set of standard conditions, enabling assessments both indoors and outdoors.

IEC 62670-4 (under consideration) describes methods for calculating the prospective electrical energy output of CPV modules, arrays, assemblies and power plants based on the measurements carried out in IEC 62670-2.

PHOTOVOLTAIC CONCENTRATORS (CPV) – PERFORMANCE TESTING –

Part 2: Energy measurement

1 Scope

This part of IEC 62670 specifies the minimum requirements for determining the energy output and performance ratio for CPV modules, arrays, assemblies and power plants using an on-sun, measurement based method.

The purpose of this International Standard is to define testing methods, to establish a standard energy measurement for CPV modules, arrays, assemblies and power plants, and to specify the minimum reporting information.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62670-1, *Photovoltaic concentrators (CPV) – Performance testing – Part 1: Standard* conditions

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

ISO 8601:2004, *Data elements and interchange formats – Information interchange – Representation of dates and times*

ISO 9060, *Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

ISO 9847, *Solar energy – Calibration of field pyranometers by comparison to a reference pyranometer*

JCGM 100:2008, *Evaluation of measurement data – Guide to the expression of uncertainty in measurement*

3 Terms and definitions

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

3.1
active AC energy
real AC energy (excluding reactive energy)

3.2
actively cooled
CPV system that requires some type of media (fluid, gas, etc.) to facilitate the transfer of thermal energy from one body to another. This could be by means of force air, pumps, thermo-electric cooler, gas transfer or any other means not covered by passive cooling.

3.3
concentrator
qualifies photovoltaic devices or systems that use concentrated sunlight

Note 1 to entry: Concentrator photovoltaic technology is usually designated as CPV.

3.4
concentrator optics
optical component that performs one or more of the following functions from its input to output: increasing the light intensity, filtering the spectrum, modifying light intensity distribution, or changing light direction

Note 1 to entry: Typically, it is a (refractive) lens or a (reflective) mirror. A primary optic receives un-concentrated sunlight directly from the sun. A secondary optic receives concentrated or modified sunlight from a primary optic and directs it to a cell or a tertiary optic.

3.5
coolant
fluid, gas or other media that is circulated through or around a CPV device and transfers the thermal energy out of the device

3.6
CPV receiver
group of one or more solar cells and secondary optics (if present) that accepts concentrated sunlight and incorporates the means for thermal and electric energy transfer

Note 1 to entry: A receiver can be made of several sub-receivers.

3.7
CPV module
group of receivers, optics, and other related components, such as interconnection and mounting, that accepts un-concentrated sunlight

Note 1 to entry: All above components are usually prefabricated as one unit, and the focus point is not field-adjustable.

3.8
CPV array
group of modules mounted on a tracking device and electrically interconnected

Note 1 to entry: Examples are illustrated in IEC 62108.

3.9
CPV assembly
group of receivers, optics, and other related components, such as interconnects and mounts, that accepts un-concentrated sunlight

Note 1 to entry: All above components would usually be shipped separately and need some field installation, and the focus point is field-adjustable.

3.10
CPV power plant
group of CPV assemblies or CPV arrays electrically interconnected to provide output power to a load

3.11
data acquisition system
DAS
system that typically measures analog values, converts them to digital values and stores them

3.12
device under test
DUT
CPV module(s), array(s), assembly/assemblies or power plant(s) the procedure described in this International Standard is applied to

3.13
direct normal irradiance
DNI
irradiance received from a small solid angle centered on the sun's disc on a plane perpendicular to the sun's rays

3.14
direct plane of array irradiance
DPOAI
irradiance received from a small solid angle centered on the sun's disc in the plane of the CPV array

3.15
global plane of array irradiance
GPOAI
total irradiance received from the sun as a combination of direct normal irradiance and all forms of diffuse light in the plane of the PV array

3.16
gross power/energy
is equal to the net power/energy plus the parasitic power/energy

3.17
net power/energy
is equal to the gross power/energy minus the parasitic power/energy

3.18
normal incidence pyrheliometer
NIP
radiometer designed for measuring the direct irradiance as described in ISO 9060

3.19
parasitic power/energy
power/energy used by the CPV power plant to operate including, but not restricted to, the power and energy used for tracking, control, cooling, drying, measurement, and data acquisition

3.20
passively cooled
cooling with a device that does not require an active energy supply

4 Description of the method

The method of energy measurement of a CPV system is shown in Table 1.

Table 1 – Steps of the energy measurement procedure

Step	Action
1	Select and describe DUT
2	Describe site, location, surroundings
3	Check calibration of DAS, install DAS
4	Start measurements Mandatory: Time, DNI, GPOAI[a], gross power/energy[b], parasitic power/energy[b], net power/energy[b], ambient temperature, wind speed Optionally: Module/receiver temperature, voltage(s), current(s), coolant temperature, wind direction, air humidity
5	Conduct and document operation and maintenance program, e.g. cleaning of modules and NIPs, greasing, tightening of chains Update logbook, e.g. on rainfall events or unscheduled maintenance events
6	Stop measurements
7	Recheck DAS
8	Inspect recorded measurements in order to identify incorrect data, determine DNI time series used to calculate the DNI energy
9	Calculate the DNI energy, gross energy, net energy, uncertainty values, performance ratio, optionally derived parameters
10	Create report

[a] Mandatory for systems that have a geometric concentration ratio of less than 10×.

[b] At least two of the three quantities need to be measured in order to calculate the third quantity.

5 Selection of subset under test

For the energy measurement of a CPV power plant, all components of the system that will be installed with the modules shall be incorporated, so that all parasitic loads of the system are present for the measurement. At times, it may be useful to apply the procedure to a subset of a power plant. In this case, the report shall document the subset that was chosen and the rationale for the choice.

6 Operation, maintenance and cleaning

The CPV modules, arrays, assemblies or power plant shall be operated as suggested by the manufacturer. If the DUT is actively cooled, the flow rate of the coolant and the coolant composition shall be set as suggested by the manufacturer. The flow rate and coolant composition shall be recorded in the testing report.

The scheduled maintenance program as suggested by the manufacturer for all components of the power plant shall be observed, including but not limited to cleaning, greasing, tightening of chains and scheduled change of parts. In particular, cleaning of modules/concentrator optics shall be done at the same frequency as suggested by the manufacturer. In the absence of a suggested frequency, the cleaning of concentrator optics will be performed at a reasonable frequency according to the site conditions.

All scheduled and unscheduled maintenance and cleaning activities shall be noted in the report in detail including time and duration of each event. For each cleaning event it shall be noted whether all of the modules/concentrator optics or only a part thereof were cleaned. In case of a partial cleaning the cleaned part shall be specified unambiguously, e.g. by providing the module or tracker identifiers of the cleaned part.

The NIPs should be cleaned ideally daily, but shall be cleaned at least once per week and each cleaning event shall be noted including time and duration in the report.

7 Downtimes and unavailability

All periods of non-functionality of either the CPV modules, arrays, assemblies or power plant or the sensors or the DAS shall be noted including time and duration and if possible the cause in the report.

8 Parasitic energy

The measurement shall accurately include the parasitic energy consumed by the DUT. Parasitic energy includes, but is not restricted to:

– Energy consumed by the tracking system, including the energy consumed for coming on track, going to stow, and parking the CPV system at night.
– Energy consumed by the control system.
– Energy consumed by the drying system where relevant.
– Energy consumed by the cooling pumps and cooling fans, including the cooling of the inverters, where relevant.
– Energy consumed by the electrical equipment such as inverters, transformers and switch gear.
– Energy consumed by the air conditioning or cooling system in the control room and in the inverter room of the power plant where relevant.

All energy consumed by monitoring and data acquisition equipment not essential for the operation of the power plant shall be considered part of the load and shall not be considered as parasitic energy. If only one or a few modules, arrays or assemblies within a power plant are tested following this International Standard, the parasitic energy drawn by the complete power plant will be divided by the total number of modules, arrays or assemblies in the power plant and multiplied by the number of modules, arrays or assemblies under test.

In cases where parasitic energy is consumed intermittently, e.g. the energy used by the tracking system, particular attention shall be paid to ensuring accurate measurement. When in doubt, the maximum possible parasitic energy shall be used. Details of the calculation will be included in the testing report.

9 Data acquisition

9.1 General requirements

9.1.1 Data acquisition system (DAS)

9.1.1.1 General

An automatic, microprocessor-based, DAS is required for this standard. The total uncertainty of the DAS shall be determined using JCGM 100:2008 as guidance and by checks as laid out below and detailed in the test report.

The DAS 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. The calibrations shall be checked at the beginning and the end of the test. If the check identifies that the calibration has drifted outside of the specification, an assessment of the associated uncertainty/error shall be completed and included in the report.

The channels of the DAS can be checked separately or at the same time.

9.1.1.2 Types of input signals to be checked

- Direct Normal Irradiance power density
- Ambient air temperature
- Wind speed
- Gross power/energy
- Parasitic power/energy
- Net power/energy
- Coolant temperature; only mandatory for actively cooled systems. If optional measurements are taken, the corresponding input signals shall be checked accordingly.

9.1.1.3 Check of linear response

This check is to be performed on analog input channels on which a linear scaling operation is applied. A constant DC or AC (as appropriate) signal shall be applied to the input terminals. The difference between the result measured by the DAS and the products of the input signal value and scaling factor shall be less than ±1 % of the full scale of the DAS. 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.

9.1.1.4 Check of stability

This check is to be performed on all analog input channels. A constant DC 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 uncertainty of less than ±0,2 %.

9.1.1.5 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.

9.1.1.6 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 ±1 % of $Z_m \times \tau_d$ where Z_m is defined in 9.1.1.5.

9.1.2 Sampling interval

The sampling interval for measurands that vary directly with DNI power density shall be 60 s or less. For measurands which have larger time constants, a larger sampling may be selected if necessary, but shall be 5 min or less. For each measured value the time and date shall be recorded in the format defined in the ISO 8601 standard: *YYYY-MM-DDThh:mm:ss.sTZD* (e.g. 1997-07-16T19:20:30.45+01:00)

Where:

YYYY = four-digit year

MM = two-digit month (01=January, etc.)

DD = two-digit day of month (01 through 31, UTC)

hh = two digits of hour (00 through 23, UTC) (am/pm NOT allowed)

mm = two digits of minute (00 through 59, UTC)

ss = two digits of second (00 through 59)

s = one or more digits representing a decimal fraction of a second

TZD = time zone designator (+hh:mm or -hh:mm offset from UTC for local winter time)

9.2 Mandatory measurements

9.2.1 General

The measurements to be taken with the DAS are given in Table 2.

Table 2 – Mandatory measurements.

Quantity	Unit or format	Comment
Date and time	*YYYY-MM-DDThh:mm:ss.sTZD*	As defined in ISO 8601
Direct Normal Irradiance power density	$W·m^{-2}$	
Global plane of array (GPOAI) power density	$W·m^{-2}$	Only mandatory for systems that have a geometric concentration ratio of less than 10×
Ambient air temperature	°C	
Wind speed	$m·s^{-1}$	
Gross power/energy	W (power) or Wh (energy)	At least two of these three quantities need to be measured in order to calculate the third quantity
Parasitic power/energy	W (power) or Wh (energy)	
Net power/energy	W (power) or Wh (energy)	

Additional measurements may be taken for diagnostic purposes.

9.2.2 Direct normal irradiance

The direct normal irradiance power density shall be measured with at least two calibrated NIPs fulfilling at least the first class requirements according to ISO 9060. The total uncertainty of the Direct Normal Irradiance power density measurements shall be determined. It shall be below 3 %.

The two, or, preferably, more, NIPs shall be mounted in a way to reduce periods of shading to a minimum, for example by mounting one NIP on the east side and the other on the west side. The raw values of all NIPs shall be recorded for determination of the DNI time series in 10.3.

The angular range of the tracker(s) carrying the NIPs should allow for tracking the sun under any elevation and azimuth angle occurring at the site. Any DNI energy not measured due to a possibly limited angular range of the tracker(s) shall be assessed in the report.

9.2.3 Global plane of array irradiance

The global plane of array irradiance power density shall be measured with at least two calibrated pyranometers fulfilling at least the first class requirements according to ISO 9847. The total uncertainty of the global plane of array irradiance power density measurements shall be determined. It shall be below 3 %. It is not necessary to obtain global plane of array irradiance measurements if the geometric concentration ratio of the CPV system being considered is more than 10×.

The two, or, preferably, more, pyranometers shall be mounted directly into the plane of the CPV array so that it shall not cause shading onto any CPV module.

If the global plane of array irradiance is measured on a 1-axis tracker that is not always aligned with the sun, it shall be assessed whether it is acceptable to use the irradiance data from the stopped tracker. The assessment shall be included in the report.

9.2.4 Ambient air temperature

The ambient air temperature shall be measured at 2 m height above ground with a sensor in the shade or protected from radiation by a reflective shield. The uncertainty of the ambient temperature shall be determined. It shall be ±1 °C or smaller.

9.2.5 Wind speed

Wind speed shall be measured at a height and location that is representative of the conditions of the DUT. The total uncertainty of the wind speed measurements shall be determined. It shall be 0,5 $m \cdot s^{-1}$ or smaller for wind speed $<5\ m \cdot s^{-1}$ and 10 % of the reading or smaller for wind speeds greater than 5 $m \cdot s^{-1}$.

9.2.6 Electrical power or energy

At least two quantities of gross, net and parasitic power or energy need to be measured in order to calculate the third quantity.

For the energy measurement the electrical DC energy or active AC energy produced by the DUT needs to be determined. It shall either be measured directly using an energy meter or indirectly by measuring the electrical power and conducting an integration to calculate the electrical energy as described in 10.4. The total uncertainty of the power or energy measurements shall be determined. It shall be below 2 %.

9.2.7 Cold source temperature (actively cooled systems only)

The cold source temperature shall be measured by means of one or more temperature sensor(s) at a location that is representative of the array conditions. The uncertainty of the cold source temperature shall be determined. It shall be ±1 °C or smaller. The cold source temperature shall be recorded during the entire testing period. The cold source temperature to be considered is either:

– the air ambient temperature in the shade if active cooling is used and if the final heat exchange is with air, or
– the water temperature in the reservoir if active cooling is used with a large reservoir (e.g. pond, tank, pool) of water.

If the temperature of the cold source is not accessible, the temperature of the coolant at its coolest point shall be recorded.

10 Data post-processing

10.1 Calculation of energy from integrated power values

In the case that the DAS offers a built in integration routine, the energy E for the period from t_0 to t_n shall be calculated as shown in Formula (1).

$$E = E(t_n) - E(t_0) \tag{1}$$

If power was generated and recorded by the built in integration routine during a time when irradiance data is unavailable, this shall be documented in the report along with the method that was used to either reduce the output energy or increase the estimated solar resource to most accurately account for this time period.

10.2 Calculation of energy from discrete power values

In case that the DAS does not offer a built in integration routine, the energy E for the period from t_0 to t_n shall be calculated from the discrete power values using a numerical integration algorithm that ensures a small integration error.

Special attention shall be paid to gaps in the power time series. A time interval larger than 150 % of the regular time interval between two data points has been proven as a reasonable criterion for identifying the beginning and the end of a gap. The integration algorithm shall recognize gaps and shall exclude them from the calculation. Gaps shall not be filled with unreasonable values, which could potentially result, e.g. from a linear interpolation between the boundaries of the gap.

For the calculation of the performance ratio as described in Clause 11 it is of high importance to exclude all periods during a gap that occurred either in the DNI time series, or in the AC/DC power time series, or in both, in order to avoid misleading results.

10.3 Calculation of the DNI time series

Before the DNI time series is calculated, all periods during which active AC or DC energy measurements are not available (e.g. due to unavailability of the energy measurement system, outage of the grid, or other event that does not represent failure of the system itself) shall be removed in order to avoid an underestimation of the performance ratio. The effect of the unavailability of the data shall be summarized in the report.

Afterwards, the DNI time series shall be calculated from the two, or, preferably, more, NIPs mounted in a way to reduce periods of shading to a minimum as described in 9.2.2. Every data set is different and the method of identifying problematic data may need to be adjusted. Some strategies are suggested in Annex A. The exact algorithms used for screening/analyzing the data shall be adjusted to attempt to address the following:

- All sensors shall be maintained in calibration. Inaccurate data shall be discarded. Nighttime data shall also be reviewed for evidence of appropriate function of each sensor.
- Similarly, remove any sensor data that was impacted by events such as cleaning of the sensor, tracker failure (if a tracker malfunctions, the loss of electricity production shall be recorded, but the irradiance measurement shall not be reduced; instead, irradiance data shall be taken from a tracker that was functioning correctly), shading, or other maintenance events.
- To define the final irradiance data, either use data from a single sensor, or average all data that has been determined to be uncompromised.
- In general, there will always be some data points that are difficult to identify as reflecting cloud transients or other anomalies. As long as the fraction of data affected in this way is $<$0,1 % of the total data, these do not need to be fully documented in the report. However, the fraction of the data identified as suspicious shall be identified, and, if the fraction exceeds 0,1 %, then the report shall describe the data that was flagged and possible causes identified.
- Similarly, if 100 % of the irradiance sensors are shaded or not aligned correctly with the sun for more than 15 min within sunrise and sunset, an estimate shall be made of the uncertainty associated with this omission of data.
- Data discrepancies are handled in one of three ways:
  - If the cause of incorrect data can be identified to be sensor malfunction (examples include: loss of electrical connection, evidence of condensation or snow in or on

sensor, or daytime shading) or daytime shading, such data is flagged for omission from further calculations.

- Irradiance data that is a) flagged as a discrepancy, b) of unknown cause, and c) deviates from the average by being lower than the average is also omitted from further calculations.
- Irradiance data that is a) flagged as a discrepancy, b) of unknown cause, and c) deviates from the average by being higher than the average is retained and included in further calculations.

– If there are time steps for which all irradiance data has been flagged as shaded or as incorrect, these time periods are omitted from the final calculations of both irradiance and energy generated and are documented as such in the report.

The DNI energy density E_{DNI} shall be calculated according to 10.2 from the time series of (as just described) DNI values.

For CPV products where the manufacturer specifies use of 1-axis trackers, the available irradiance energy density E_{DPOAI} shall be calculated according to 10.2 from the time series of the Direct Plane of Array Irradiance (P_{DPOAI}). The time series of P_{DPOAI} is calculated from the measured DNI time series according to Formula (2)[1] with (see Figure 1):

θ_z = solar zenith angle

β = tilt angle of the array

γ_s = solar azimuth angle

γ = array azimuth angle

$$P_{DPOAI} = P_{DNI} \cdot \cos(AOI)$$
$$\cos(AOI) = \cos(\theta_z)\cos(\beta) + \sin(\theta_z)\sin(\beta)\cos(\gamma_s - \gamma) \quad (2)$$

1 See C.W. Hansen, J.S. Stein and A. Ellis, "Simulation of One-Minute Power Output from Utility-Scale Photovoltaic Generation Systems", *Sandia Report*, SAND2011-5529.

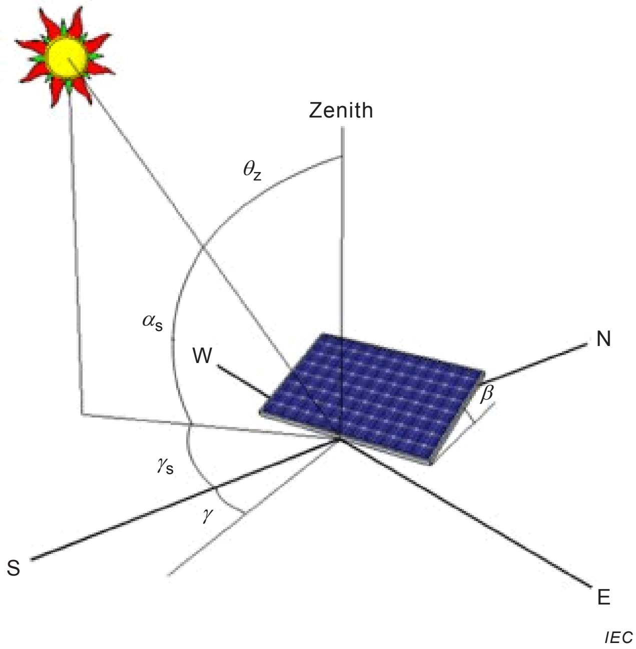

Figure 1 – Nomenclature of angles used in Formula (2)[2]

For systems that have a geometric concentration ratio of less than 10×, the total power density for the available solar resource shall also include the amount of diffuse capture of the CPV system as described in Formula (3), where f_D is the percentage of diffuse capture which is to be determined by a method external to this standard. A future IEC standard or technical specification will address how the diffuse capture percentage is to be determined experimentally. For such systems the total available irradiance energy E_{TOTAL} shall be calculated according to 10.2 from the time series of the P_{TOTAL} time series.

$$P_{TOTAL} = P_{DPOAI} + f_D \cdot \left(P_{GPOAI} - P_{DNI}\right) \quad \left[kWh/m^2\right] \tag{3}$$

10.4 Calculation of the active AC or DC energy

Before the active AC or DC energy is calculated, all periods during which DNI measurements are not available e.g. due to unavailability of the DNI measurement system shall be removed in order to avoid an overestimation of the performance ratio.

Downtimes caused by grid outages or events that were beyond the control of the CPV system shall also be removed. Outages related to calibration, cleaning, or events related specifically to the monitoring equipment and not necessary as part of the normal operation of the plant shall also be removed. However, system outages related to system failure, maintenance events (e.g. array cleaning), or other events that would also impact the delivered power from the plant shall be included in the calculations.

If the DAS offers a built in integration routine, the active AC or DC energy shall be calculated from the integrated power values as described in 10.1.

If the DAS does not offer a built in integration routine, the active AC or DC energy shall be calculated from the discrete power values as described in 10.2.

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2 Copyright © William Surles, ITL Program, College of Engineering, University of Colorado at Boulder.

The relative standard error of the energy RSE_E is the standard error of the energy divided by the mean according to Formula (4).

$$RSE_E = \frac{\sigma_E}{E} \quad [\%] \tag{4}$$

11 Calculation of the performance ratio

11.1 General

Performance ratio may be calculated for a truncated time period. However, when the annual performance ratio is calculated, this is expected to include all irradiance from sunrise to sunset, or to at least within 15 min of sunrise / sunset.

The reference yield Y_r is calculated according to Formula (5). It represents the number of hours during which the DNI power density would need to be 1 000 W/m^2 as defined in the International Standard IEC 62670-1 for Concentrator Standard Test Conditions in order to contribute the same DNI energy density as was monitored. For CPV products where the manufacturer specifies use of 1-axis trackers, the DNI energy density E_{DNI} in Formula (5) shall be replaced with the available irradiance energy density E_{DPOAI} calculated as described in 10.3. For systems that have a geometric concentration ratio of less than 10× the DNI energy density E_{DNI} in Formula (5) shall be replaced with the total energy density for the available solar resource E_{TOTAL} calculated as described in 10.3.

$$Y_r = \frac{E_{DNI}}{1 kW/m^2} \quad \left[\frac{kWh/m^2}{kW/m^2} = h\right] \tag{5}$$

The relative standard error of the reference yield RSE_{Yr} is the standard error of the DNI energy divided by the mean according to Formula (6).

$$RSE_{Y_r} = \frac{\sigma_{Y_r}}{Y_r} = \frac{\sigma_{E_{DNI}}}{E_{DNI}} \quad [\%] \tag{6}$$

11.2 AC performance ratio

The final AC yield $Y_{f,AC}$ represents the number of hours that the array would need to operate at the output power P_{CSTC} at CSTC conditions to equal its monitored net active AC energy. It is calculated according to Formula (7).

$$Y_{f,AC} = \frac{E_{net,AC}}{P_{CSTC}} \quad \left[\frac{kWh}{kW} = h\right] \tag{7}$$

The relative standard error of the final AC yield $RSE_{Y,f,AC}$ is calculated from the standard error of the net active AC energy $\sigma_{E,net,AC}$ and from the standard error of the output power at CSTC conditions $\sigma_{P,CSTC}$ according to Formula (8).

$$RSE_{Y_{f,AC}} = \frac{\sigma_{Y_{f,AC}}}{Y_{f,AC}} = \sqrt{\left(\frac{\sigma_{E_{net,AC}}^{\;2}}{E_{net,AC}^{\;2}}\right) + \left(\frac{\sigma_{P_{CSTC}}^{\;2}}{P_{CSTC}^{\;2}}\right)} \quad [\%] \tag{8}$$

The AC performance ratio PR_{AC} is calculated according to Formula (9) by dividing the final AC yield $Y_{f,AC}$ by the reference yield Y_r.

$$PR_{AC} = \frac{Y_{f,AC}}{Y_r} \tag{9}$$

The relative standard error of the AC performance ratio $RSE_{PR,AC}$ is calculated according to Formula (10).

$$RSE_{PR_{AC}} = \frac{\sigma_{PR_{AC}}}{PR_{AC}} = \sqrt{RSE_{Y_{f,AC}}{}^2 + RSE_{Y_r}{}^2} \quad [\%] \tag{10}$$

11.3 DC performance ratio

The final DC yield $Y_{f,DC}$ represents the number of hours that the array would need to operate at the output power P_{CSTC} at CSTC conditions to equal its monitored net DC energy. It is calculated according to Formula (11). In presence of an AC parasitic load it may be difficult to convert the AC parasitic energy to a DC parasitic energy in order to calculate the net DC energy. In this case the AC parasitic load may be omitted from the calculation of the DC performance ratio if this is clearly stated in the report and an assessment of the impact is included in the report.

$$Y_{f,DC} = \frac{E_{net,DC}}{P_{CSTC}} \quad \left[\frac{kWh}{kW} = h\right] \tag{11}$$

The relative standard error of the final DC yield $RSE_{Y,f,AC}$ is calculated from the standard error of the net DC energy $\sigma_{E,net,DC}$ and from the standard error of the output power at CSTC conditions $\sigma_{P,CSTC}$ according to Formula (12).

$$RSE_{Y_{f,DC}} = \frac{\sigma_{Y_{f,DC}}}{Y_{f,DC}} = \sqrt{\left(\frac{\sigma_{E_{net,DC}}{}^2}{E_{net,DC}{}^2}\right) + \left(\frac{\sigma_{P_{STC}}{}^2}{P_{CSTC}{}^2}\right)} \quad [\%] \tag{12}$$

The DC performance ratio PR_{DC} is calculated according to Formula (13) by dividing the final DC yield $Y_{f,DC}$ by the reference yield Y_r.

$$PR_{DC} = \frac{Y_{f,DC}}{Y_r} \tag{13}$$

The relative standard error of the DC performance ratio $RSE_{PR,DC}$ is calculated according to Formula (14).

$$RSE_{PR_{DC}} = \frac{\sigma_{PR_{DC}}}{PR_{DC}} = \sqrt{RSE_{Y_{f,DC}}{}^2 + RSE_{Y_r}{}^2} \quad [\%] \tag{14}$$

12 Derived parameters

For the complete period of the test as well as for each day of the test period, the following parameters shall be calculated and included in the test report:

- Gross active AC or DC energy
- Net active AC or DC energy
- Parasitic active AC or DC energy
- Reference Yield Y_r
- Final AC yield ($Y_{f,AC}$) and/or final DC yield ($Y_{f,DC}$)
- AC performance ratio (PR_{AC}) and/or DC performance ratio (PR_{DC})

For each value also the corresponding relative standard error shall be given.

13 Report

Following completion of the procedure, a report shall be prepared in accordance with the procedures of ISO/IEC 17025. Each test report shall include, at a minimum, the following information:

a) Title
b) Name and address of the test laboratory and location (including latitude, longitude, and altitude) where the calibration or tests were carried out
c) Unique identification of the certification or report and of each page
d) Name and address of client
e) Description and unambiguous identification of the device under test
f) Characterization and condition of the DUT including, if applicable, power conditioning systems, inverters, tracking systems, cooling systems, and other parasitic power consumers
g) Date of receipt of DUT and date(s) and times of test
h) Reference to sampling procedure, for example location of the array or assembly within the power plant, where relevant
i) Exact location where the testing procedure took place, including name of location, latitude, longitude, elevation of site, description of site, particular aspects such as shading objects
j) Plan view of the CPV power plant
k) Photo(s) of the CPV power plant
l) Short description of the type of climate and weather pattern
m) Description of the cooling system if active cooling is used, including flow rate and coolant composition
n) Documentation of temperature measurements including the locations of temperature sensors
o) Any deviations from, additions to or exclusions from the test method or from manufacturer-suggested operating parameters, and any other information relevant to a specific test, such as environmental conditions, shading effects
p) Derived parameters as set forth in Clause 12
q) Details of the test procedure including the measurement sampling frequency and the integration technique for energy measurement
r) Description of measuring equipment, including how DNI power density is measured and where the NIPs are located compared to the DUT (indicated in plan view of CPV power plant)

s) Acceptance angle of the NIPs

t) Assessment of not measured DNI energy due to a possibly limited angular range of the tracker(s) on which the NIPs are mounted

u) Confirmation that the manufacturer supplied the tracker as part of the plant. If a component test used a tracker supplied by the test lab or the tracker is not a standard part of the PV plant design, provide the following information: manufacturer and model of the tracker (for the hardware that supports the modules, the hardware that moves the tracker, the controller of the movement, etc.), description of the tracker and tracker controlling algorithm, documentation of the tracking accuracy, an assessment of the impact that the tracking accuracy might have on the test results, and any other information about the tracker and/or method of mounting the CPV components that may be relevant to the test results.

v) Description of the scheduled operation and maintenance program and any departure from the maintenance plan during the testing period

w) Documentation of downtime including cause, duration, the fraction of the plant that was affected, and any other relevant details.

x) Major events during the testing period, including but not restricted to storms, unscheduled maintenance, damage to any item, replacement of any item

y) Frequency and dates of any cleaning and rain during the testing period

z) Frequency and dates of cleaning of the NIPs

aa) Measurements, examinations and derived results, including, as a minimum, a graph showing the daily active AC or DC energy production and the daily performance ratio

bb) Description of how the parasitic power was calculated

cc) Description of time periods for which data was unavailable and/or was not included in the calculations. Include an assessment of the impact of omissions on the calculations. Document rejection of irradiance data from individual sensors, reasons for rejections, and whether these rejections may have affected the final calculations.

dd) Tabulation of the uncertainties of all calculated numbers, including the uncertainties associated with drifts in calibration identified during the calibration checks, and data omissions, as described in the previous item. Principles from JCGM 100:2008 shall be used to determine the uncertainties of the measurements.

ee) Raw data

ff) A signature and title, or equivalent identification of the person(s) accepting responsibility for the content of the certificate or report, and the date of issue

gg) A statement to the effect that the results relate only to the DUT and only to the reported cooling parameters

hh) A statement that the certificate or report shall not be reproduced except in full, without the written approval of the test laboratory.

Additional information may be included in the report. Any information not specified in this Standard shall be separated from the body of the report in an annex.

Annex A
(informative)

Some suggested ways to filter data in order to identify incorrect data

The simplest algorithm for eliminating the effects of shading and other irregularities from the irradiance data while still accounting for real transients in irradiance data may depend on the plant design, the exact locations of the irradiance sensors, and the locations of nearby obstructions. It is the intent of the test method to accurately reflect the total DNI resource from sunrise to sunset. The following may be useful:

a) Check for error codes, data out of bounds, or data flagged because of maintenance events. If there is a tracking error monitor, use this to flag bad data.

b) Identify times when DNI sensors are shaded in the morning and the evening and flag these times as such. This may be accomplished by computing the times when a sensor will be shaded based on the known geometry. Alternatively, flag all values in the morning as "shaded" until 3 min after a value above the total uncertainty of the DNI measurement determined in 9.2.2 is encountered. Similarly, in the evening, all values are flagged as "shaded" starting 3 min before the values are below the total uncertainty of the DNI measurement. The 3 min width for rejecting data may be adjusted for sensors with a non-standard size by quantifying the time from when the partially shaded sensor deviates from the values recorded by other sensors to the time when the output of the sensor drops to values below the total uncertainty of the DNI measurement.

c) The difference in all of the DNI measurements should be smaller than the uncertainty of the measurement plus the variability of the irradiance. In general, it may be that the values may be required to be consistent with 10 % on a clear day. For hazy or partly cloudy days, the variability of the irradiance may be estimated from the maximum and minimum values recorded for each sensor for several minutes before and after the measurement in question. Identifying the specific criteria can be a little challenging. Especially, it may be useful to use absolute variation rather than relative and to put a minimum value on data that will be flagged because conditions that provide DNI < 400 W/m^2 also show large variations.

Annex B
(informative)

Best practices for power plant energy measurement

– Multiple NIPs should be deployed across the site to achieve the overall averaging of the site.
– NIPs should be mounted on separate trackers suitable for meteorological measurements.
– If such separate trackers are not available, mount one NIP on an East facing tracker and one on a West facing tracker used to track the CPV arrays. If possible, mount NIPs on top of the trackers to reduce shading impact.
– In any case, the trackers should have an overall minimum accuracy of 0,5° with 0° to 90° of allowable elevation and 360° of rotational azimuth capability.
– Placement of sensors should be standardized (if possible) at the plant.
– Site sensor calibration should occur minimally at one-year intervals. Calibration before and after testing is recommended.
– NIPs are particularly sensitive and may need additional verification during the test (monthly/quarterly).
– Multiple weather stations should be deployed next to or included with site monitor stations.

Annex C
(normative)

Optionally derived parameters

C.1 General

The following parameters may optionally be derived from the measurements and included in the report.

C.2 Energy Production Rate (*EPR*)

The Energy Production Rate (EPR) indicates the net AC energy or net DC energy produced by the DUT per kilowatt hour per square metre of DNI energy. The AC Energy Production Rate (EPR_{AC}) is calculated according to Formula (C.1). The DC Energy Production Rate (EPR_{DC}) is calculated according to Formula (C.2).

$$EPR_{AC} = \frac{E_{net,AC}}{E_{DNI}} \quad \left[\frac{kWh}{kWh/m^2} = m^2\right] \tag{C.1}$$

$$EPR_{DC} = \frac{E_{net,DC}}{E_{DNI}} \quad \left[\frac{kWh}{kWh/m^2} = m^2\right] \tag{C.2}$$

C.3 Capacity Factor (CF)

The Capacity Factor (CF) is the ratio of the net AC energy produced by the DUT during the test period to the energy that would have been generated if the DUT ran at its CSTC power according to IEC 62670-1 for the entire period. As shown in Formula (C.4) it is calculated as the ratio of final yield $Y_{f,AC}$ (see Formula (7)) to the overall test duration expressed in hours $t_{Test,duration}$ (see Formula (C.3)).

$$t_{Test,duration} = t_{Test,end} - t_{Test,begin} \quad [h] \tag{C.3}$$

$$CF = \frac{Y_{f,AC}}{t_{Test,Duration}} \quad [\%] \tag{C.4}$$

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