

# INTERNATIONAL STANDARD

Photovoltaic system performance –  
Part 1: Monitoring

This document is a preview generated by EVS



## THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2017 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office  
3, rue de Varembe  
CH-1211 Geneva 20  
Switzerland

Tel.: +41 22 919 02 11  
Fax: +41 22 919 03 00  
[info@iec.ch](mailto:info@iec.ch)  
[www.iec.ch](http://www.iec.ch)

### About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

### About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

#### IEC Catalogue - [webstore.iec.ch/catalogue](http://webstore.iec.ch/catalogue)

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

#### IEC publications search - [www.iec.ch/searchpub](http://www.iec.ch/searchpub)

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

#### IEC Just Published - [webstore.iec.ch/justpublished](http://webstore.iec.ch/justpublished)

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

#### Electropedia - [www.electropedia.org](http://www.electropedia.org)

The world's leading online dictionary of electronic and electrical terms containing 20 000 terms and definitions in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

#### IEC Glossary - [std.iec.ch/glossary](http://std.iec.ch/glossary)

65 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

#### IEC Customer Service Centre - [webstore.iec.ch/csc](http://webstore.iec.ch/csc)

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: [csc@iec.ch](mailto:csc@iec.ch).

# INTERNATIONAL STANDARD

## Photovoltaic system performance – Part 1: Monitoring

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

ICS 27.160

ISBN 978-2-8322-3988-9

**Warning! Make sure that you obtained this publication from an authorized distributor.**

## CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	9
2 Normative references .....	9
3 Terms and definitions .....	10
4 Monitoring system classification .....	13
5 General.....	13
5.1 Measurement uncertainty.....	13
5.2 Calibration.....	14
5.3 Repeated elements.....	14
5.4 Power consumption.....	14
5.5 Documentation.....	14
5.6 Inspection.....	14
6 Data acquisition timing and reporting.....	15
6.1 Sampling, recording, and reporting .....	15
6.2 Timestamps .....	16
7 Measured parameters.....	16
7.1 General requirements .....	16
7.2 Irradiance .....	20
7.2.1 On-site irradiance measurement.....	20
7.2.2 Satellite remote sensing of irradiance .....	25
7.3 Environmental factors .....	26
7.3.1 PV module temperature .....	26
7.3.2 Ambient air temperature .....	27
7.3.3 Wind speed and direction .....	27
7.3.4 Soiling ratio .....	28
7.3.5 Rainfall.....	30
7.3.6 Snow .....	30
7.3.7 Humidity .....	30
7.4 Tracker system .....	31
7.4.1 Single-axis trackers .....	31
7.4.2 Dual-axis trackers for >20x systems .....	31
7.5 Electrical measurements.....	31
7.6 External system requirements.....	32
8 Data processing and quality check .....	32
8.1 Daylight hours.....	32
8.2 Quality check .....	33
8.2.1 Removing invalid readings.....	33
8.2.2 Treatment of missing data .....	33
9 Calculated parameters.....	33
9.1 Overview .....	33
9.2 Summations.....	34
9.3 Irradiation .....	34
9.4 Electrical energy.....	35
9.4.1 General .....	35
9.4.2 DC output energy .....	35

9.4.3	AC output energy.....	35
9.5	Array power rating .....	35
9.5.1	DC power rating.....	35
9.5.2	AC power rating.....	35
9.6	Yields .....	35
9.6.1	General .....	35
9.6.2	PV array energy yield .....	36
9.6.3	Final system yield.....	36
9.6.4	Reference yield .....	36
9.7	Yield losses .....	36
9.7.1	General .....	36
9.7.2	Array capture loss .....	36
9.7.3	Balance of systems (BOS) loss.....	36
9.8	Efficiencies .....	37
9.8.1	Array (DC) efficiency .....	37
9.8.2	System (AC) efficiency .....	37
9.8.3	BOS efficiency.....	37
10	Performance metrics.....	37
10.1	Overview .....	37
10.2	Summations.....	38
10.3	Performance ratios .....	38
10.3.1	Performance ratio.....	38
10.3.2	Temperature-corrected performance ratios .....	39
10.4	Performance indices .....	40
11	Data filtering.....	41
11.1	Use of available data .....	41
11.2	Filtering data to specific conditions .....	41
11.3	Reduced inverter, grid, or load availability .....	41
Annex A (informative)	Sampling interval .....	42
A.1	General considerations .....	42
A.2	Time constants .....	42
A.3	Aliasing error .....	42
A.4	Example .....	43
Annex B (informative)	Module backsheet temperature sensor selection and attachment .....	44
B.1	Objective .....	44
B.2	Sensor and material selection .....	44
B.2.1	Optimal sensor types .....	44
B.2.2	Optimal tapes .....	44
B.2.3	Cyanoacrylate adhesives and backsheet integrity .....	44
B.3	Sensor attachment method .....	45
B.3.1	Permanent versus temporary .....	45
B.3.2	Attachment location .....	45
B.3.3	Sensor attachment.....	45
Annex C (informative)	Derate factors .....	48
Annex D (normative)	Systems with local loads, storage, or auxiliary sources .....	49
D.1	System types .....	49
D.2	Parameters and formulas .....	51

Bibliography.....	57
Figure 1 – Possible elements of PV systems.....	7
Figure 2 – Sampling, recording, and reporting.....	15
Figure B.1 – Sensor attachment, permanent .....	46
Figure B.2 – Sensor attachment, temporary .....	46
Figure B.3 – Sensor element wire strain relief.....	46
Figure D.1 – Energy flow between possible elements of different PV system types .....	49
Table 1 – Monitoring system classifications and suggested applications .....	13
Table 2 – Sampling and recording interval requirements .....	16
Table 3 – Measured parameters and requirements for each monitoring system class.....	18
Table 4 – Relation between system size (AC) and number of sensors for specific sensors referenced in Table 3 .....	20
Table 5 – Sensor choices and requirements for in-plane and global irradiance .....	21
Table 6 – Irradiance sensor alignment accuracy .....	22
Table 7 – Irradiance sensor maintenance requirements .....	23
Table 8 – PV module temperature sensor maintenance requirements .....	26
Table 9 – Ambient air temperature sensor maintenance requirements .....	27
Table 10 – Wind sensor maintenance requirements .....	28
Table 11 – Inverter-level electrical measurement requirements .....	32
Table 12 – Plant-level AC electrical output measurement requirements .....	32
Table 13 – Calculated parameters .....	34
Table 14 – Performance metrics .....	38
Table D.1 – Elements of different PV system types .....	50
Table D.2 – Parameters and equations for different system types .....	51

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

**PHOTOVOLTAIC SYSTEM PERFORMANCE –****Part 1: Monitoring****FOREWORD**

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 61724-1 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This first edition cancels and replaces the first edition of IEC 61724, published in 1998. This edition constitutes a technical revision.

This edition (in conjunction with IEC TS 61724-2:2016 and IEC TS 61724-3:2016) includes the following significant technical changes with respect to IEC 61724:

- a) IEC 61724 is now written with multiple parts. This document is IEC 61724-1, addressing PV system monitoring. IEC TS 61724-2 and IEC TS 61724-3 address performance analysis based on the monitoring data.
- b) Three classes of monitoring systems are defined corresponding to different levels of accuracy and different intended applications.
- c) Required measurements for each class of monitoring system are stated, along with the required number and accuracy of sensors.

- d) Options for satellite-based irradiance measurement are provided.
- e) Soiling measurement is introduced.
- f) New performance metrics are introduced, including temperature compensated performance ratios and others.
- g) Numerous recommendations and explanatory notes are included.

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

FDIS	Report on voting
82/1215/FDIS	82/1248/RVD

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

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

A list of all parts in the IEC 61724 series, published under the general title *Photovoltaic system performance*, can be found on the IEC website.

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

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

A bilingual version of this publication may be issued at a later date.

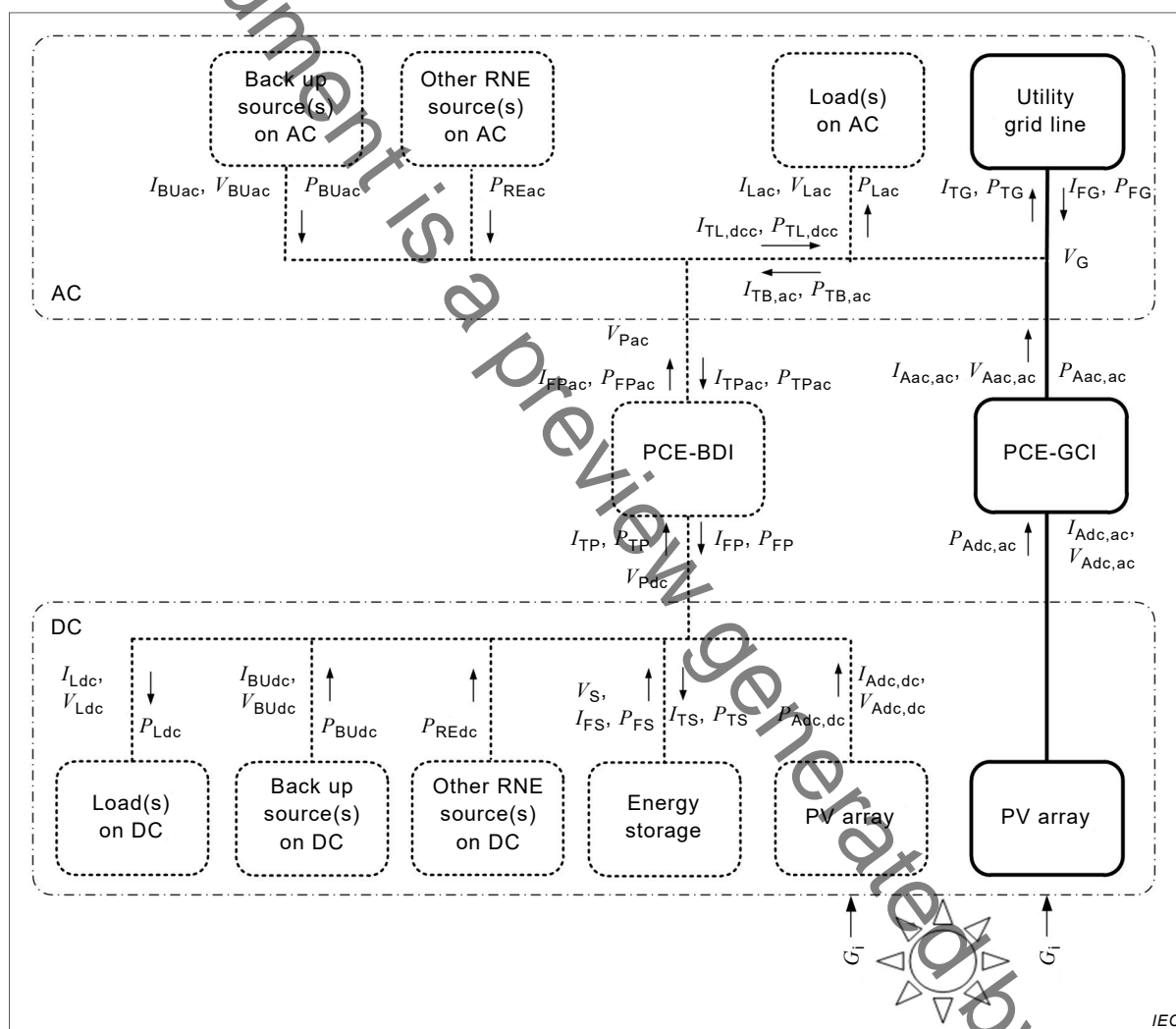


## INTRODUCTION

This International Standard defines classes of photovoltaic (PV) performance monitoring systems and serves as guidance for various monitoring system choices.

Figure 1 illustrates possible major elements comprising different PV system types. The PV array may include both fixed axis and tracking systems and both flat plate and concentrator systems. Module-level electronics, if present, may be a component of the monitoring system.

For simplicity, the main clauses of this document are written for grid-connected systems without local loads, energy storage, or auxiliary sources, as shown by the bold lines in Figure 1. Annex D includes details for systems with additional components.



### Key

- RNE renewable energy
- PCE power conditioning equipment
- BDI bi-directional inverter
- GCI grid-connected inverter

Bold lines denote simple grid-connected system without local loads, energy storage, or auxiliary sources.

**Figure 1 – Possible elements of PV systems**

The purposes of a performance monitoring system are diverse and can include the following:

- identification of performance trends in an individual PV system;
- localization of potential faults in a PV system;
- comparison of PV system performance to design expectations and guarantees;
- comparison of PV systems of different configurations; and
- comparison of PV systems at different locations.

These diverse purposes give rise to a diverse set of requirements, and different sensors and/or analysis methods may be more or less suited depending on the specific objective. For example, for comparing performance to design expectations and guarantees, the focus should be on system-level data and consistency between prediction and test methods, while for analysing performance trends and localizing faults, there may be a need for greater resolution at sub-levels of the system and an emphasis on measurement repeatability and correlation metrics rather than absolute accuracy.

The monitoring system should be adapted to the PV system's size and user requirements. In general, larger and more expensive PV systems should have more monitoring points and higher accuracy sensors than smaller and lower-cost PV systems. This document defines three classifications of monitoring system with differentiated requirements which are appropriate to a range of purposes.

This document is a preview generated by EVS

## PHOTOVOLTAIC SYSTEM PERFORMANCE –

### Part 1: Monitoring

#### 1 Scope

This part of IEC 61724 outlines equipment, methods, and terminology for performance monitoring and analysis of photovoltaic (PV) systems. It addresses sensors, installation, and accuracy for monitoring equipment in addition to measured parameter data acquisition and quality checks, calculated parameters, and performance metrics. In addition, it serves as a basis for other standards which rely upon the data collected.

#### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60050-131, *International Electrotechnical Vocabulary – Part 131: Circuit theory*

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

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

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

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

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC 61557-12, *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Part 12: Performance measuring and monitoring devices (PMD)*

IEC 62053-21, *Electricity metering equipment (a.c.) – Particular requirements – Part 21: Static meters for active energy (classes 1 and 2)*

IEC 62053-22, *Electricity metering equipment (a.c.) – Particular requirements – Part 22: Static meters for active energy (classes 0,2 S and 0,5 S)*

IEC 62670-3, *Photovoltaic concentrators (CPV) – Performance testing – Part 3: Performance measurements and power rating*

IEC 62817:2014, *Photovoltaic systems – Design qualification of solar trackers*

ISO/IEC Guide 98-1, *Uncertainty of measurement – Part 1: Introduction to the expression of uncertainty in measurement*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

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

ISO 9488, *Solar energy – Vocabulary*

ISO 9846, *Solar energy – Calibration of a pyranometer using a pyrliometer*

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

WMO No. 8, *Guide to meteorological instruments and methods of observation*

ASTM G183, *Standard Practice for Field Use of Pyranometers, Pyrliometers and UV Radiometers*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-131, IEC TS 61836, ISO 9488 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

#### 3.1

##### **sample**

data acquired from a sensor or measuring device

#### 3.2

##### **sampling interval**

time between samples

#### 3.3

##### **record**

data recorded and stored in data log, based on acquired samples

#### 3.4

##### **recording interval**

$\tau$

time between records

#### 3.5

##### **report**

aggregate value based on series of records

#### 3.6

##### **reporting period**

time between reports