

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Photovoltaic system performance –
Part 1: Monitoring**

**Performances des systèmes photovoltaïques –
Partie 1: Surveillance**



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2021 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.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

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

Tel.: +41 22 919 02 11
info@iec.ch
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 corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform

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 It also gives information on projects, replaced and withdrawn publications.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

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

IEC Customer Service Centre - 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: sales@iec.ch.

IEC online collection - oc.iec.ch

Discover our powerful search engine and read freely all the publications previews. With a subscription you will always have access to up to date content tailored to your needs.

Electropedia - www.electropedia.org

The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 18 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC

Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Recherche de publications IEC -

webstore.iec.ch/advsearchform

La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études, ...). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et une fois par mois par email.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: sales@iec.ch.

IEC online collection - oc.iec.ch

Découvrez notre puissant moteur de recherche et consultez gratuitement tous les aperçus des publications. Avec un abonnement, vous aurez toujours accès à un contenu à jour adapté à vos besoins.

Electropedia - www.electropedia.org

Le premier dictionnaire d'électrotechnologie en ligne au monde, avec plus de 22 000 articles terminologiques en anglais et en français, ainsi que les termes équivalents dans 16 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Photovoltaic system performance –
Part 1: Monitoring**

**Performances des systèmes photovoltaïques –
Partie 1: Surveillance**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 27.160

ISBN 978-2-8322-1002-5

**Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
1 Scope.....	10
2 Normative references.....	10
3 Terms and definitions	11
4 Monitoring system classification	15
5 General	16
5.1 Measurement precision and uncertainty	16
5.2 Calibration	16
5.3 Repeated elements	16
5.4 Power consumption	16
5.5 Documentation	16
5.6 Inspection	16
6 Data acquisition timing and reporting	16
6.1 Samples, records, and reports	16
6.2 Timestamps	18
6.3 Parameter names	18
7 Required measurements	18
8 Irradiance	23
8.1 Sensor types	23
8.2 General requirements	23
8.2.1 Overview	23
8.2.2 Sensor requirements	23
8.2.3 Sensor locations	24
8.2.4 Recalibration.....	25
8.2.5 Soiling mitigation	25
8.2.6 Dew and frost mitigation.....	25
8.2.7 Inspection and maintenance	26
8.2.8 Sensor alignment	26
8.3 Measurements	26
8.3.1 Global horizontal irradiance.....	26
8.3.2 In-plane irradiance	26
8.3.3 In-plane rear-side irradiance.....	27
8.3.4 In-plane rear-side irradiance ratio.....	27
8.3.5 Horizontal albedo	27
8.3.6 Direct normal irradiance	27
8.3.7 Diffuse horizontal irradiance	27
8.3.8 Spectrally matched irradiance	27
8.3.9 In-plane irradiance for concentrator systems.....	28
8.3.10 Spectral irradiance for concentrator systems	29
8.3.11 Circumsolar measurements for concentrator systems.....	29
8.3.12 Satellite remote sensing of irradiance	30
9 Environmental factors	31
9.1 PV module temperature.....	31
9.2 Ambient air temperature	31

9.3	Wind speed and direction	32
9.4	Soiling ratio.....	32
9.5	Rainfall	33
9.6	Snow	33
9.7	Humidity	33
10	Tracker system.....	33
10.1	Single-axis trackers.....	33
10.2	Dual-axis trackers	33
10.2.1	Monitoring.....	33
10.2.2	Pointing error sensor alignment.....	33
11	Electrical measurements.....	34
11.1	Inverter-level measurements	34
11.2	Plant-level measurements	34
12	Data processing and quality check	35
12.1	Night.....	35
12.2	Quality check	35
12.2.1	Removing invalid readings	35
12.2.2	Treatment of missing data	35
13	Calculated parameters.....	36
13.1	Overview.....	36
13.2	Summations	36
13.3	Irradiation	36
13.4	Electrical energy	37
13.4.1	General	37
13.4.2	DC output energy.....	37
13.4.3	AC output energy	37
13.5	Array power rating.....	37
13.5.1	DC power rating.....	37
13.5.2	AC power rating	38
13.6	Yields	38
13.6.1	General	38
13.6.2	PV array energy yield.....	38
13.6.3	Final system yield	38
13.6.4	Reference yield.....	39
13.6.5	Bifacial reference yield.....	39
13.7	Yield losses	39
13.7.1	General	39
13.7.2	Array capture loss	39
13.7.3	Balance of systems (BOS) loss.....	40
13.8	Efficiencies	40
13.8.1	Array (DC) efficiency.....	40
13.8.2	System (AC) efficiency	40
13.8.3	BOS efficiency	40
14	Performance metrics.....	41
14.1	Overview.....	41
14.2	Summations	41
14.3	Performance ratios.....	41
14.3.1	Performance ratio	41

14.3.2	Temperature-corrected performance ratios	42
14.3.3	Bifacial performance ratios	44
14.4	Performance indices	44
15	Data filtering	45
15.1	Use of available data	45
15.2	Filtering data to specific conditions	45
15.3	Reduced inverter, grid, or load availability	45
Annex A	(informative) Sampling interval	46
A.1	General considerations	46
A.2	Time constants	46
A.3	Aliasing error	46
A.4	Example	47
Annex B	(informative) Module temperature sensor selection and attachment	48
B.1	Objective	48
B.2	Sensor and material selection	48
B.2.1	Optimal sensor types	48
B.2.2	Optimal tapes	48
B.2.3	Cyanoacrylate adhesives and backsheet integrity	49
B.3	Sensor attachment	49
B.3.1	Permanent versus temporary	49
B.3.2	Attachment location	49
B.3.3	Bifacial modules	49
B.3.4	Method	49
Annex C	(normative) Soiling measurement using clean and soiled PV reference device pair	52
C.1	Overview	52
C.2	Equipment	52
C.3	Normalization	52
C.4	Measurement method 1 – max power reduction due to soiling	53
C.5	Measurement method 2 – short-circuit current reduction due to soiling	53
C.6	Non-uniform soiling	53
C.7	Daily average value	54
C.8	Renormalization	54
Annex D	(informative) Derate factors	55
Annex E	(normative) Systems with local loads, storage, or auxiliary sources	57
E.1	System types	57
E.2	Parameters and formulas	59
Bibliography		66
Figure 1	– Possible elements of PV systems	8
Figure 2	– Samples, records and reports	17
Figure B.1	– Sensor attachment, permanent	50
Figure B.2	– Sensor attachment, temporary	50
Figure B.3	– Sensor element wire strain relief	51
Figure E.1	– Energy flow between possible elements of different PV system types	57
Table 1	– Sampling and recording interval requirements	18

Table 2 – Measured parameters and requirements	20
Table 3 – Multiplier referenced in Table 2	23
Table 4 – Irradiance sensor requirements	24
Table 5 – Inverter-level electrical measurement requirements	34
Table 6 – Plant-level AC electrical output measurement requirements	34
Table 7 – Calculated parameters	36
Table 8 – Performance metrics	41
Table E.1 – Elements of different PV system types	58
Table E.2 – Parameters and formulas for different system types	59

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 second edition cancels and replaces the first edition, published in 2017. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- Monitoring of bifacial systems is introduced.
- Irradiance sensor requirements are updated.
- Soiling measurement is updated based on new technology.
- Class C monitoring systems are eliminated.
- Various requirements, recommendations and explanatory notes are updated.

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

FDIS	Report on voting
82/1904/FDIS	82/1925/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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 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.

INTRODUCTION

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

Figure 1 illustrates major elements comprising different PV system types. 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 E includes some details for systems with additional components.

The PV array may include both fixed-axis and tracker systems and both flat-plate and concentrator systems.

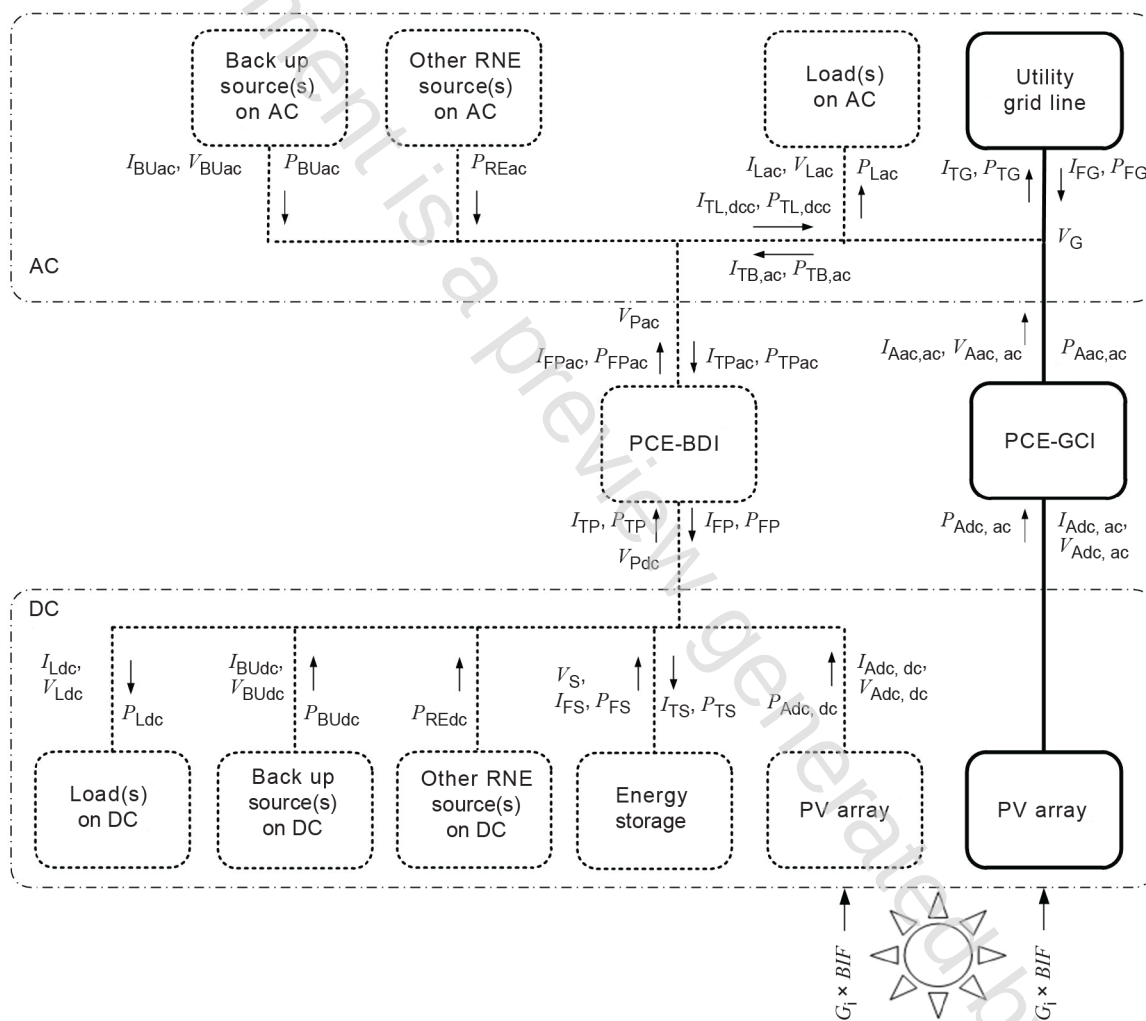


Figure 1 – Possible elements of PV systems

The purposes of a performance monitoring system are diverse and could include comparing performance to design expectations and guarantees as well as detecting and localizing faults.

For comparing performance to design expectations and guarantees, the focus should be on system-level data and consistency between prediction and test methods.

For detecting and localizing faults there should be greater resolution at sub-levels of the system and an emphasis on measurement repeatability and correlation metrics.

The monitoring system should be adapted to the PV system's size and user requirements. In general, larger PV systems should have more monitoring points and higher accuracy sensors than smaller and lower-cost PV systems.

PHOTOVOLTAIC SYSTEM PERFORMANCE –

Part 1: Monitoring

1 Scope

This part of IEC 61724 outlines terminology, equipment, and methods for performance monitoring and analysis of photovoltaic (PV) systems. It also 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 (IEV) – Part 131: Circuit theory*

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

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 60904-7, *Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices*

IEC 61215 (all parts), *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*

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

IEC TS 61724-2, *Photovoltaic system performance – Part 2: Capacity evaluation method*

IEC TS 61724-3, *Photovoltaic system performance – Part 3: Energy evaluation method*

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

IEC 62053-22, *Electricity metering equipment – Particular requirements – Part 22: Static meters for AC active energy (classes 0,1S, 0,2S and 0,5S)*

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 9060:2018, *Solar energy – Specification and classification of instruments for measuring hemispherical solar and direct solar radiation*

ISO 9488, *Solar energy – Vocabulary*

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

3.4

recording interval

τ

time between records

3.5

report

aggregate value based on series of records

3.6

reporting period

time between reports

3.7

front side

side of a surface which normally faces the sky

3.8

rear side

side of a surface which normally faces the ground

3.9

monofacial PV device

PV device in which only the front side is used for power generation