

<b>STN</b>	<b>Fotovoltické súčiastky</b> <b>Časť 1: Meranie fotovoltických voltampérových charakteristík</b>	<b>STN</b> <b>EN IEC 60904-1</b>  36 4604
------------	--	--

Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics

Táto norma obsahuje anglickú verziu európskej normy.  
This standard includes the English version of the European Standard.

Táto norma bola oznámená vo Vestníku ÚNMS SR č. 05/21

Obsahuje: EN IEC 60904-1:2020, IEC 60904-1:2020

Oznámením tejto normy sa od 30.10.2023 ruší  
STN EN 60904-1 (36 4604) z júna 2007

**132709**



EUROPEAN STANDARD

**EN IEC 60904-1**

NORME EUROPÉENNE

EUROPÄISCHE NORM

November 2020

ICS 27.160

Supersedes EN 60904-1:2006 and all of its amendments  
and corrigenda (if any)

English Version

**Photovoltaic devices - Part 1: Measurement of photovoltaic  
current-voltage characteristics  
(IEC 60904-1:2020)**Dispositifs photovoltaïques - Partie 1: Mesurage des  
caractéristiques courant-tension des dispositifs  
photovoltaïques  
(IEC 60904-1:2020)Photovoltaische Einrichtungen - Teil 1: Messen der  
photovoltaischen Strom-/Spannungskennlinien  
(IEC 60904-1:2020)

This European Standard was approved by CENELEC on 2020-10-30. 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 CEN-CENELEC Management Centre 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 CEN-CENELEC Management Centre has the same status as the official versions.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.



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

**CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels**

**EN IEC 60904-1:2020 (E)****European foreword**

The text of document 82/1760/FDIS, future edition 3 of IEC 60904-1, prepared by IEC/TC 82 "Solar photovoltaic energy systems" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 60904-1:2020.

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) 2021-07-30
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2023-10-30

This document supersedes EN 60904-1:2006 and all of its amendments and corrigenda (if any).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC shall not be held responsible for identifying any or all such patent rights.

**Endorsement notice**

The text of the International Standard IEC 60904-1:2020 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60904-1-1	NOTE	Harmonized as EN 60904-1-1
IEC 61829	NOTE	Harmonized as EN 61829

## Annex ZA (normative)

### Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where 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](http://www.cenelec.eu).

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60891	-	Photovoltaic devices - Procedures for temperature and irradiance corrections to measured I-V characteristics	EN 60891	-
IEC 60904-2	-	Photovoltaic devices - Part 2: Requirements for photovoltaic reference devices	EN 60904-2	-
IEC 60904-3	-	Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data	EN IEC 60904-3	-
IEC 60904-4	-	Photovoltaic devices - Part 4: Reference solar devices - Procedures for establishing calibration traceability	EN IEC 60904-4	-
IEC 60904-5	-	Photovoltaic devices - Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method	EN 60904-5	-
IEC 60904-7	-	Photovoltaic devices - Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices	EN IEC 60904-7	-
IEC 60904-9	-	Photovoltaic devices - Part 9: Classification of solar simulator characteristics	-	-
IEC 60904-10	-	Photovoltaic devices - Part 10: Methods of linear dependence and linearity measurements	-	-

**EN IEC 60904-1:2020 (E)**

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC/TR 60904-14 <sup>1</sup>	-	Photovoltaic devices - Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions		
IEC 61215	series	Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval	-	-
IEC/TS 61836	-	Solar photovoltaic energy systems - Terms, definitions and symbols	CLC/TS 61836	-
IEC 61853-1	-	Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating	EN 61853-1	-
IEC/TR 63228	-	Measurement protocols for photovoltaic devices based on organic, dye-sensitized or perovskite materials	-	-
ISO 9060	-	Solar energy; specification and classification of instruments for measuring hemispherical solar and direct solar radiation	-	-

---

<sup>1</sup> Under preparation.



IEC 60904-1

Edition 3.0 2020-09

# INTERNATIONAL STANDARD

# NORME INTERNATIONALE



---

**Photovoltaic devices –  
Part 1: Measurement of photovoltaic current-voltage characteristics**

**Dispositifs photovoltaïques –  
Partie 1: Mesurage des caractéristiques courant-tension des dispositifs  
photovoltaïques**





## THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2020 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](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 corrigendum or an amendment might have been published.

#### IEC publications search - [webstore.iec.ch/advsearchform](http://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](http://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](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: [sales@iec.ch](mailto:sales@iec.ch).

#### Electropedia - [www.electropedia.org](http://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 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

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

67 000 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.

### 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](http://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](http://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](http://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](mailto:sales@iec.ch).

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

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

67 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.





IEC 60904-1

Edition 3.0 2020-09

# INTERNATIONAL STANDARD

# NORME INTERNATIONALE



**Photovoltaic devices –  
Part 1: Measurement of photovoltaic current-voltage characteristics**

**Dispositifs photovoltaïques –  
Partie 1: Mesurage des caractéristiques courant-tension des dispositifs  
photovoltaïques**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

COMMISSION  
ELECTROTECHNIQUE  
INTERNATIONALE

ICS 27.160

ISBN 978-2-8322-8814-6

**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 .....	4
1 Scope .....	6
2 Normative references .....	6
3 Terms and definitions .....	7
4 General requirements .....	8
4.1 General .....	8
4.2 Measurements .....	9
4.3 Stabilisation .....	10
4.4 Equivalence to steady-state performance .....	10
4.5 Reporting conditions .....	10
4.6 Translation from test conditions to reporting conditions .....	11
5 Apparatus .....	11
6 Measurements in natural sunlight .....	12
6.1 General .....	12
6.2 Test procedure .....	13
7 Measurement in simulated sunlight .....	14
7.1 General .....	14
7.2 Test procedure .....	15
8 Data analysis .....	16
8.1 Translation from test conditions to reporting conditions .....	16
8.2 Extracting $I$ - $V$ curve parameters .....	17
8.3 Evaluating measurement uncertainty .....	17
9 Test report .....	18
Annex A (informative) Device area measurement .....	19
A.1 General .....	19
A.2 Definition of device area .....	19
A.2.1 General .....	19
A.2.2 Total area ( $A_t$ ) .....	19
A.2.3 Aperture area ( $A_{ap}$ ) .....	19
A.2.4 Designated illumination area ( $A_{da}$ ) .....	19
A.3 Area measurement of PV devices .....	19
Annex B (informative) Measurement of current-voltage characteristics for PV devices with capacitance .....	22
B.1 General .....	22
B.2 Definitions .....	22
B.3 Relative error due to capacitance .....	22
B.4 Methodologies to suppress the measurement error .....	24
B.4.1 General .....	24
B.4.2 Measurement at steady-state conditions .....	24
B.4.3 Measurement at quasi-steady-state conditions .....	25
B.4.4 Common methods for characterisation of capacitive PV devices .....	25
B.5 Report .....	26
B.6 Reference documents .....	26
Annex C (informative) Measurement of photovoltaic current-voltage characteristics without illumination (dark $I$ - $V$ ) .....	28

C.1	General.....	28
C.2	Apparatus .....	29
C.3	Procedure .....	29
C.3.1	General .....	29
C.3.2	Dark $I$ - $V$ curve measurements.....	30
Annex D (informative)	Influence of spatial non-uniformity of irradiance on $I$ - $V$ curve parameters .....	31
D.1	General.....	31
D.2	Reference documents .....	32
Bibliography	.....	33

Figure 1 – Schematic current-voltage characteristic ( $I$ - $V$ curve) depicting typical $I$ - $V$ curve parameters short-circuit current ( $I_{SC}$ ), open-circuit voltage ( $V_{OC}$ ), maximum power ( $P_{max}$ ), voltage at maximum power ( $V_{Pmax}$ ) and current at maximum power ( $I_{Pmax}$ ).....	8
Figure 2 – Schematic power-voltage characteristic ( $P$ - $V$ curve) depicting typical $I$ - $V$ curve parameters open-circuit voltage ( $V_{OC}$ ), maximum power ( $P_{max}$ ) and voltage at maximum power ( $V_{Pmax}$ ) .....	9
Figure A.1 – PV module (rectangular) .....	20
Figure A.2 – PV module of different geometries (pentagon, trapezoid).....	20
Figure A.3 – PV cell (cut corners) .....	21
Figure A.4 – PV cell (rounded corners, circle).....	21
Figure B.1 – Equivalent circuit diagram for device exhibiting a capacitance effect.....	23
Figure B.2 – Three $I$ - $V$ curves (steady-state, forward sweep and reverse sweep) showing the effect of device capacitance on the curve shape.....	23
Figure B.3 – Deviation of maximum power ( $P_{max}$ ) determined from $I$ - $V$ curve due to the effect of device capacitance with respect to steady-state result as a function of sweep rate.....	24
Figure C.1 – $I$ - $V$ characteristics without illumination (dark $I$ - $V$ curve).....	28
Figure C.2 – $I$ - $V$ characteristics under illumination ( $I$ - $V$ curve).....	29
Figure D.1 – Monte-Carlo simulation of a 60-cell PV module with high shunt cell type .....	32

# INTERNATIONAL ELECTROTECHNICAL COMMISSION

---

## PHOTOVOLTAIC DEVICES –

### Part 1: Measurement of photovoltaic current-voltage characteristics

#### 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 60904-1 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This third edition cancels and replaces the second edition published in 2006. This edition constitutes a technical revision.

The main changes with respect to the previous edition are as follows:

- Updated scope to include all conditions.
- Added terms and definitions.
- Reorganised document to avoid unnecessary duplication.
- Added data analysis clause.
- Added informative annexes (area measurement, PV devices with capacitance, dark  $I$ - $V$  curves and effect of spatial non-uniformity of irradiance).

The text of this International Standard is based on the following documents:

FDIS	Report on voting
82/1760/FDIS	82/1786/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 of IEC 60904 series, under the general title *Photovoltaic devices*, 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.

**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.**

## PHOTOVOLTAIC DEVICES –

### Part 1: Measurement of photovoltaic current-voltage characteristics

#### 1 Scope

This part of IEC 60904 describes procedures for the measurement of current-voltage characteristics ( $I$ - $V$  curves) of photovoltaic (PV) devices in natural or simulated sunlight. These procedures are applicable to a single PV solar cell, a sub-assembly of PV solar cells, or a PV module. They are applicable to single-junction mono-facial PV devices. For other device types, reference is made to the respective documents, in particular for multi-junction devices to IEC 60904-1-1 and for bifacial devices to IEC TS 60904-1-2. Additionally informative annexes are provided concerning area measurement of PV devices (Annex A), PV devices with capacitance (Annex B), measurement of dark current-voltage characteristics (dark  $I$ - $V$  curves) (Annex C) and effects of spatial non-uniformity of irradiance (Annex D).

NOTE The methods provided in this document can also be used as guidance for taking  $I$ - $V$  curves of PV arrays. For on-site measurement refer to IEC 61829.

This document is applicable to non-concentrating PV devices for use in terrestrial environments, with reference to (usually but not exclusively) the global reference spectral irradiance AM1.5 defined in IEC 60904-3. It may also be applicable to PV devices for use under concentrated irradiation if the application uses direct sunlight and reference is instead made to the direct reference spectral irradiance AM1.5d in IEC 60904-3.

The purposes of this document are to lay down basic requirements for the measurement of  $I$ - $V$  curves of PV devices, to define procedures for different measuring techniques in use and to show practices for minimising measurement uncertainty. It is applicable to the measurement of  $I$ - $V$  curves in general.  $I$ - $V$  measurements can have various purposes, such as calibration (i.e. traceable measurement with stated uncertainty, usually performed at standard test conditions) of a PV device under test against a reference device, performance measurement under various conditions (e.g. for device temperature and irradiance) such as those required by IEC 60891 (for determination of temperature coefficients or internal series resistance), by IEC 61853-1 (power rating of PV devices) or by IEC 60904-10 (for determination of output's linear dependence and linearity with respect to a particular test parameter).  $I$ - $V$  measurements are also important in industrial environments such as PV module production facilities, and for testing in the field. Further guidance on  $I$ - $V$  measurements in production facilities is provided in IEC TR 60904-14.

The actual requirements (e.g. for the class of solar simulator) depend on the end-use. Other standards referring to IEC 60904-1 can stipulate specific requirements. Where those requirements are in conflict with this document, the specific requirements take precedence.

#### 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 60891, *Photovoltaic devices – Procedures for temperature and irradiance corrections to measured  $I$ - $V$  characteristics*

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

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

IEC 60904-4, *Photovoltaic devices – Part 4: Photovoltaic reference devices – Procedures for establishing calibration traceability*

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 60904-9, *Photovoltaic devices – Part 9: Solar simulator performance requirements*

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

IEC TR 60904-14, *Photovoltaic devices – Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions*

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

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

IEC 61853-1, *Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating*

IEC TR 63228, *Measurement protocols for photovoltaic devices based on organic, dye-sensitized or perovskite materials*

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

**koniec náhľadu – text ďalej pokračuje v platenej verzii STN**