

AS/NZS IEC 60904.1:2023
IEC 60904-1:2020



Australian/New Zealand Standard™

Photovoltaic devices

Part 1: Measurement of photovoltaic current-voltage characteristics



AS/NZS IEC 60904.1:2023

This Joint Australian/New Zealand Standard™ was prepared by Joint Technical Committee EL-042, Renewable Energy Power Supply Systems & Equipment. It was approved on behalf of the Council of Standards Australia on 24 May 2023 and by the New Zealand Standards Approval Board on 03 May 2023.

This Standard was published on 30 June 2023.

The following are represented on Committee EL-042:

Australasian Fire and Emergency Service Authorities Council
Australian Energy Council
Australian Energy Market Operator
Australian Industry Group
Australian PV Institute
Better Regulation Division (Fair Trading, SafeWork NSW, TestSafe)
Clean Energy Council
Clean Energy Regulator
Communications, Electrical and Plumbing Union — Electrical Division
Consumer Electronics Suppliers Association
Consumers Federation of Australia
CSIRO
Electrical Compliance Testing Association of Australia
Electrical Regulatory Authorities Council, Australia
Electrical Safety New Zealand
Electricity Authority of New Zealand
Electricity Engineers Association of New Zealand
ElectroComms & Energy Utilities Industry Skills Council
Energy Efficiency & Conservation Authority of New Zealand
Energy Networks Australia
Engineers Australia
Institute of Electrical and Electronics Engineers
Institute of Electrical Inspectors
Institution of Fire Engineers (NZ Branch)
Joint Accreditation System of Australia & New Zealand
Master Electricians Australia
National Electrical and Communications Association
Office of the Technical Regulator (SA)
Smart Energy Council
Solar Energy Industries Association Inc
Sustainable Electricity Association New Zealand
University of New South Wales
Vector
Wellington Electrical Association
WorkSafe New Zealand

This Standard was issued in draft form for comment as DR AS/NZS IEC 60904.1:2023.

Keeping Standards up-to-date

Ensure you have the latest versions of our publications and keep up-to-date about Amendments, Rulings, Withdrawals, and new projects by visiting:

www.standards.org.au

www.standards.govt.nz

ISBN 978 1 76139 221 4

Australian/New Zealand Standard™

Photovoltaic devices

Part 1: Measurement of photovoltaic current-voltage characteristics

First published as AS/NZS IEC 60904.1:2023.



© IEC Geneva Switzerland 2023 — All rights reserved

© Standards Australia Limited/the Crown in right of New Zealand, administered by the New Zealand Standards Executive 2023

All rights are reserved. No part of this work may be reproduced or copied in any form or by any means, electronic or mechanical, including photocopying, without the written permission of either the IEC or the publisher, unless otherwise permitted under the Copyright Act 1968 (Cth) or the Copyright Act 1994 (New Zealand). If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please see the contact details on the back cover or the contact us page of the website for further information.

Preface

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EL-042, Renewable Energy Power Supply Systems and Equipment.

The objective of this document is to describe 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).

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 documents referring to AS/NZS IEC 60904-1 can stipulate specific requirements. Where those requirements conflict with this document, the specific requirements take precedence.

This document is identical with, and has been reproduced from, IEC 60904-1:2020, *Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics*.

As this document has been reproduced from an International Standard, the following applies:

- (a) In the source text “this part of IEC 60904” should read “this document”.
- (b) A full point substitutes for a comma when referring to a decimal marker.

Australian or Australian/New Zealand Standards that are identical adoptions of international normative references may be used interchangeably. Refer to the online catalogue for information on specific Standards.

The terms “normative” and “informative” are used in Standards to define the application of the appendices or annexes to which they apply. A “normative” appendix or annex is an integral part of a Standard, whereas an “informative” appendix or annex is only for information and guidance.

NOTES

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*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 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

sweep rate

temporal rate of change of the voltage applied to the measured PV device

Note 1 to entry: The term ramp rate is also used interchangeably.

3.2

sweep direction

direction of change of applied voltage during I - V measurements; a positive sweep rate is referred to as forward or direct sweep (I_{sc} to V_{oc} direction), while a negative sweep rate is referred to as reverse or backward sweep (V_{oc} to I_{sc} direction)

3.3

time delay

time interval between the change of voltage applied to PV device and the measurement of PV device current

4 General requirements

4.1 General

For illustration purposes a schematic current-voltage characteristic (I - V curve) is shown in Figure 1 and the corresponding power-voltage characteristic (P - V curve) in Figure 2.

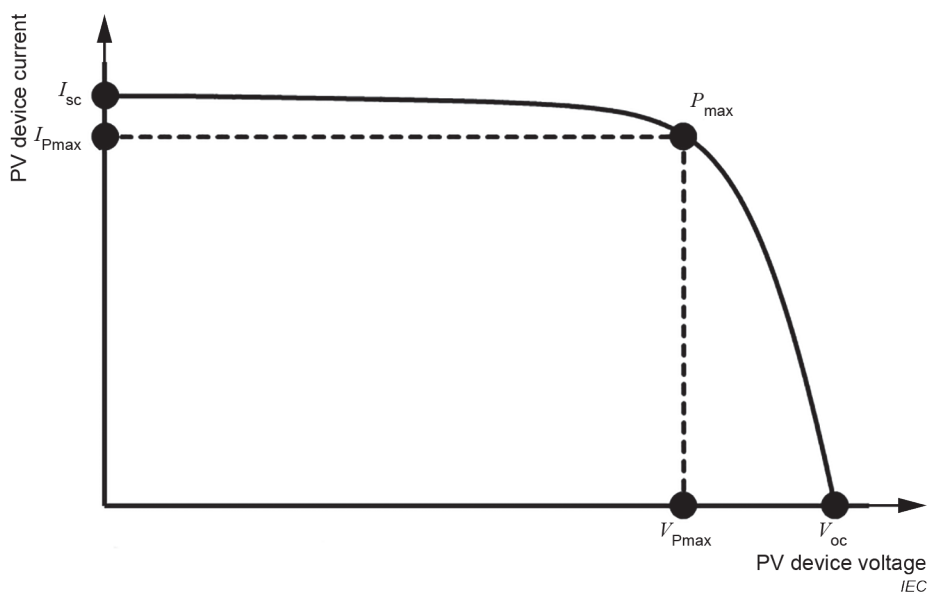


Figure 1 – Schematic current-voltage characteristic (I - V curve) depicting typical I - V curve parameters short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), maximum power (P_{max}), voltage at maximum power (V_{Pmax}) and current at maximum power (I_{Pmax})