

TECHNICAL SPECIFICATION

**Renewable energy off-grid systems –
Part 9-5: Integrated systems – Laboratory evaluation of stand-alone renewable
energy products for rural electrification**

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

RENEWABLE ENERGY OFF-GRID SYSTEMS –**Part 9-5: Integrated systems –
Laboratory evaluation of stand-alone
renewable energy products for rural electrification****FOREWORD**

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IEC TS 62257-9-5 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is a Technical Specification.

This fifth edition cancels and replaces the fourth edition issued in 2018. This edition constitutes a technical revision.

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

- a) Decreased the sample size to 2 for QTM tests and changed the minimum stock for warehouse sampling to 150 units regardless of the number of samples selected.
- b) Defined a new renewal test method that is distinct from the market check method.

- c) Removed the example product specification template.
- d) Added the PV module wiring inspection, partial shading test, bending or folding test, and visual inspection steps for PV modules.
- e) Simplified the visual screening procedure by removing requirements to measure or record unnecessary information and convey information using photos when possible.
- f) Made the light distribution test, charging efficiency test, and continuation of the lumen maintenance test to 2 000 h optional.
- g) Improved accuracy of the solar operation efficiency calculation for products that do not fully utilize the PV module energy generation capacity.
- h) Added steps to S.4.2.5 to minimize battery discharge before the full-battery run time test.
- i) Added a detailed procedure for assessment of conformal coatings on printed circuit boards.
- j) Removed the PV overvoltage protection test procedure for products with batteries that cannot be disconnected in normal operation.
- k) Removed the dynamic measurement for DC ports; added procedures for steady-state measurement of USB ports supporting fast-charging protocols such as USB Power Delivery.
- l) Added power consumption measurement for computers; modified television set power consumption test conditions to better match typical use.
- m) Corrected the energy service calculations for appliance combinations including lights that automatically step down to a lower setting.

The text of this Technical Specification is based on the following documents:

Draft	Report on voting
82/2289/DTS	82/2312/RVDTS

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 Technical Specification 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/publications.

A list of all parts in the IEC 62257 series, published under the general title *Renewable energy off-grid systems*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

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, or
- revised.

INTRODUCTION

The IEC 62257 series provides support and strategies for institutions involved in rural electrification projects. It documents technical approaches for designing, building, testing, and maintaining off-grid renewable energy and hybrid systems with AC nominal voltage below 500 V, DC nominal voltage below 750 V and nominal power below 100 kVA.

These documents are recommendations to support buyers who want to connect with good quality options in the market:

- to choose the right system for the right place,
- to design the system, and
- to operate and maintain the system.

These documents are focused only on technical aspects of rural off-grid electrification concentrating on, but not specific to, developing countries. They are not considered as all inclusive to rural electrification. The documents do not describe a range of factors that can determine project or product success: environmental, social, economic, service capabilities, and others. Further developments in this field could be introduced in future steps.

This consistent set of documents is best considered as a whole, with different parts corresponding to items for safety, sustainability of systems, and costs. The main objectives are to support the capabilities of households and communities that use small renewable energy and hybrid off-grid systems and inform organizations and institutions in the off-grid power market.

The purpose of this document is to specify laboratory test methods for evaluating the quality assurance of stand-alone renewable energy products. This document is specifically related to renewable energy products that are packaged and made available to end-use consumers at the point of purchase as single, stand-alone products that do not require additional system components to function.

The term "stand-alone renewable energy product" is used in this document to describe this class of products. Other equivalent terms, including "off-grid solar" or "rechargeable," are often used by manufacturers, distributors, and other stakeholders to describe these products. Many of these systems meet the definition of type T₂I (individual electrification systems with energy storage) in IEC TS 62257-2.

The intended users of this document are:

- Market support programmes that support the off-grid lighting market with financing, consumer education, awareness, and other services;
- Manufacturers, distributors, and other companies in order to verify the quality and performance of products;
- Bulk procurement programmes that facilitate or place large orders of products; and,
- Trade regulators such as government policymakers and officials who craft and implement trade and tax policy.

This document establishes the framework for creating a product specification, the basis for evaluating quality for a particular context. Product specifications include minimum requirements for quality standards and warranty requirements. Products are compared to specifications based on test results and other information about the product. The product specification framework is flexible and can accommodate the goals of diverse organizations and institutions. The tests and inspections are designed to be widely applicable across different markets, countries, and regions.

RENEWABLE ENERGY OFF-GRID SYSTEMS –

Part 9-5: Integrated systems – Laboratory evaluation of stand-alone renewable energy products for rural electrification

1 Scope

This part of IEC 62257, which is a Technical Specification, applies to stand-alone renewable energy products having the following characteristics:

- All components required to provide basic energy services are sold and installed as a kit or integrated into a single component, including at a minimum:
 - A battery, batteries or other energy storage device(s)
 - Power generating device, such as a solar panel, capable of charging the battery, batteries or other energy storage device(s)
 - Cables, switches, wiring, connectors and protective devices sufficient to connect the power generating device, power control unit(s) and energy storage device(s)
 - Loads (optional), such as lighting, load adapter cables (e.g. for mobile devices), and appliances (television, radio, fan, etc.).
- The PV module maximum power point voltage and the working voltage of any other components in the kit do not exceed 35 V. Exceptions are made for AC-to-DC converters that meet appropriate safety standards.

NOTE This voltage limit corresponds to the definition of decisive voltage classification A (DVC-A) for wet locations in Table 6 of IEC 62109-1:2010.

- The peak power rating of the PV module or other power generating device is less than or equal to 350 W.
- No design expertise is required to choose appropriate system components.

This document was written primarily for off-grid renewable energy products with batteries and PV modules with DC system voltages not exceeding 35 V and peak power ratings not exceeding 350 W. The tests contained herein are capable in many cases of adequately assessing systems at either higher voltages or power ratings, or both. In situations where the specifying organization agrees to apply these tests to products with higher voltages and power ratings, the test laboratory is responsible for ensuring that adequate safety measures are employed to protect technicians and test equipment. The specifying organization is also responsible for defining the consumer safety requirements of these products.

This document includes provisions related to safety; however, it is not intended to be a comprehensive safety standard. In particular, this document is not intended to be used as an alternative to safety standards such as IEC 62368-1 or IEC 60335 (all parts) for appliances such as radios and televisions that are included with stand-alone renewable energy products. Nor is it intended to replace the safety requirements of IEC 62281 or UN 38.3 for battery safety during transport, or safety requirements of IEC 61730-1 and IEC 61730-2 for PV modules intended for use outside the context of stand-alone renewable energy products.

This document does not address electromagnetic compatibility (EMC). Field experience has not shown EMC to be a major concern in typical applications of stand-alone renewable energy products within the scope of this document. In applications where EMC is a concern (e.g. systems that include medical devices), the standards relevant to the specific application should be referenced.

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 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60598-1, *Luminaires – Part 1: General requirements and tests*

IEC 60891:2021, *Photovoltaic devices – Procedures for temperature and irradiance corrections to measured I-V characteristics*

IEC 60904-1:2020, *Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics*

IEC 60904-9, *Photovoltaic devices – Part 9: Classification of solar simulator characteristics*

IEC 61056-1:2012, *General purpose lead-acid batteries (valve-regulated types) – Part 1: General requirements, functional characteristics – Methods of test*

IEC 61215-1, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements*

IEC 61215-2, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 2: Test procedures*

IEC 61427-1:2013, *Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 1: Photovoltaic off-grid application*

IEC 61951-2:2017, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary sealed cells and batteries for portable applications – Part 2: Nickel-metal hydride*

IEC 61960-3:2017, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for portable applications – Part 3: Prismatic and cylindrical lithium secondary cells and batteries made from them*

IEC 62087-2:2023, *Audio, video, and related equipment – Determination of power consumption – Part 2: Signals and media*

IEC 62087-3:2023, *Audio, video, and related equipment – Determination of power consumption – Part 3: Television sets*

IEC 62087-6:2015, *Audio, video, and related equipment – Determination of power consumption – Part 6: Audio equipment*

IEC TS 62257-12-1, *Recommendations for renewable energy and hybrid systems for rural electrification – Part 12-1: Laboratory evaluation of lamps and lighting appliances for off-grid electricity systems*

IEC 62509:2010, *Battery charge controllers for photovoltaic systems – Performance and functioning*

IEC 62623, *Desktop and notebook computers – Measurement of energy consumption*

CIE 13.3, *Method of measuring and specifying colour rendering properties of light sources*

CIE 15, *Colorimetry*

CIE 084, *The measurement of luminous flux*

CIE 127, *Measurement of LEDs*

CIE 177, *Colour rendering of white LED light sources*

ANSI/IES LM-78, *Approved method: total luminous flux measurement of lamps using an integrating sphere photometer*

ANSI/IES LM-79, *Approved method: Optical and electrical measurements of solid-state lighting products*

ANSI/IES LM-80, *Approved method: measuring lumen maintenance of LED light sources*

JCGM 100, *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.

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

luminous flux

time rate of flow of radiant energy, evaluated in terms of a standardized visual response

Note 1 to entry: The luminous flux of a light source represents the total radiant power emitted in all directions, weighted by a standardized function representing the response of the human eye to different wavelengths, and is measured in lumens (lm). In this document, the term “luminous flux” refers to the total luminous flux calculated using the CIE photopic luminous efficiency function, $V(\lambda)$. For further details, refer to IEC 60050-845, 845-21-035, or ANSI/IES LS-1-22, 3.2.

[SOURCE: ANSI/IES LS-1-22, 3.2, modified – Note 1 has been added, and the formula and paragraph describing photopic and scotopic luminous flux have been omitted.]

3.2

illuminance

E_v

areal density of the luminous flux incident at a point on a surface

Note 1 to entry: In the SI system of units, illuminance is expressed in lux (lx) or lumens per square metre (lm/m²).

[SOURCE: ANSI/IES LS-1-22, 3.3.1, modified – The note is taken from IEC 60050-723:1997, 723-08-30]

3.3

capacity

<for cells or batteries> electric charge which a cell or battery can deliver under specified discharge conditions

Note 1 to entry: The SI unit for electric charge, or quantity of electricity, is the coulomb ($1\text{ C} = 1\text{ A}\cdot\text{s}$) but in practice, capacity is usually expressed in ampere hours (Ah).

[SOURCE: IEC 60050-482:2020, 482-03-14]

3.4

DUT

device under test

particular item that is being measured or observed

Note 1 to entry: Depending on context, the DUT can be an entire product or a subset such as an individual component (e.g. an appliance, main unit, or PV module), a group of components (e.g. a PV module supplying power to a main unit), or a part of a component (e.g. a battery).

3.5

lux

lx

SI unit of illuminance

Note 1 to entry: 1 lx is equal to the illuminance produced on a surface of area 1 m^2 by a luminous flux of 1 lm uniformly distributed over that surface

[SOURCE: IEC 60050-845:2020, 845-21-085, modified – Notes 2 and 3 have been omitted.]

3.6

colour rendering index

CRI

measure of the degree to which the psychophysical colour of an object illuminated by the test illuminant conforms to that of the same object illuminated by the reference illuminant, suitable allowance having been made for the state of chromatic adaptation

[SOURCE: IEC 60050-845:2020, 845-22-109, modified – The notes have been omitted.]

3.7

correlated colour temperature

CCT

absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source

Note 1 to entry: The correlated colour temperature is expressed in kelvin (K).

[SOURCE: ANSI/IES LS-1-22, 4.6.4.2, modified – Note 1 has been added.]

3.8

full width half maximum

FWHM

range of a variable over which a given characteristic is greater than 50 % of its maximum value

Note 1 to entry: FWHM may be applied to characteristics such as radiation patterns, spectral linewidths, etc. and the variable may be wavelength, spatial or angular properties, etc. as appropriate.

[SOURCE: IEC 60050-731:1991, 731-01-57]

3.9**multimeter**

multi-range multi-function measuring instrument intended to measure voltage, current and sometimes other electrical quantities such as resistance

[SOURCE: IEC 60050-312:2001, 312-02-24]

3.10**illuminance meter**

instrument for measuring illuminance

[SOURCE: IEC 60050-845:2020, 845-25-020, modified – The note has been omitted.]

3.11**photometer**

instrument for measuring light

[SOURCE: IEC 60050-845:2020, 845-25-019, modified – The term “photometric quantities” has been replaced by “light,” and the note has been omitted.]

3.12**pyranometer**

radiometer normally used to measure global irradiance on a horizontal plane

Note 1 to entry: A pyranometer can also be used to measure diffuse irradiance when used with a shade ring or disc.

Note 2 to entry: A pyranometer can also be used to measure total irradiance on an inclined plane, which would include radiation reflected from the foreground.

[SOURCE: IEC TS 61836:2016, 3.5.7.2]

3.13**integrating sphere**

Ulbricht sphere

hollow sphere, the interior of which is formed from, or coated with, a diffusely-reflecting material that is as spectrally neutral and as spatially uniform as possible

Note 1 to entry: Owing to the internal reflections within the sphere, the illuminance on any part of the inside surface of the sphere for which the direct flux is hidden is theoretically proportional to the luminous flux entering the sphere or produced inside the sphere. The illuminance of the internal sphere wall can be measured via a small window.

Note 2 to entry: An integrating sphere is used to determine the total luminous flux (lumen output) of a lighting device.

[SOURCE: IEC 60050-845:2020, 845-25-028, modified – Notes 2 and 3 have been omitted and a new note 2 has been added.]

3.14**goniophotometer**

photometer for measuring the directional light distribution characteristics of sources, luminaires, media or surfaces

[SOURCE: IEC 60050-845:2020, 845-25-026, modified – The note has been omitted.]

3.15**power supply**

electric energy converter which draws electric energy from a source and supplies it in a specified form to a load

[SOURCE: IEC 60050-151:2001, 151-13-76]

3.16**overvoltage protection**

protection intended to operate when the power system voltage is in excess of a predetermined value

[SOURCE: IEC 60050-448:1995, 448-14-32]

3.17**IP code**

coding system to indicate the degrees of protection provided by an enclosure against access to hazardous parts, ingress of solid foreign objects, ingress of water and to give additional information in connection with such protection

Note 1 to entry: In this document, certain IP Codes can be estimated using procedures in IEC TS 62257-9-5, which provides a simplified and lower-cost alternative to IEC 60529. The procedure in IEC TS 62257-9-5 evaluates protection against ingress of solid foreign objects and water, but not protection against access to hazardous parts.

[SOURCE: IEC 60529, 3.4, modified – note 1 has been added.]

3.18**portable**

connected in a way that makes a product or subsystem easy for an individual to carry

Note 1 to entry: Products or subsystems are portable when two or more of the main components (energy source, energy storage, and light source) are connected in this way.

3.19**fixed**

designed for permanent or semi-permanent mounting and use in place

Note 1 to entry: Products or subsystems are fixed when the main components (energy source, energy storage, and light source) are designed in this way.

3.20**separate**

without PV module or with a PV module connected to other components via a cable that is sufficiently long to allow the PV module to collect energy outdoors while the other product components remain indoors

3.21**integrated**

with a PV module incorporated into another component or connected to another component (other than a fixed outdoor component) via a cable that is too short to allow the PV module to collect energy outdoors while the other product components remain indoors

3.22**metadata**

information that relates a test result to a specific sample and provides context about the result (e.g. specific test method used)

3.23**LED****light emitting diode**

solid-state device embodying a p-n junction, emitting incoherent optical radiation when excited by an electric current

[SOURCE: IEC 60050-845:2020, 845-27-050, modified – The notes have been omitted.]

3.24

low-voltage disconnect

LVD

battery voltage at which the load terminals of the charge controller are switched off to prevent the battery from reaching a problematically low state of charge (SOC)

Note 1 to entry: This is a specific case of a "load disconnect point" as defined by IEC 62509:2010, 3.11.

3.25

standby loss

current drawn from a product's battery with the product switched off

3.26

appliance

device that performs a specific function providing service to an end user, such as a light, radio, mobile device, or television set

3.27

mobile device

basic mobile phone, feature phone, smartphone, tablet computer, or similar portable communication or computing device having an internal rechargeable battery

Note 1 to entry: Larger portable devices, such as laptop computers, can also be considered mobile devices, but some provisions (e.g. related to charging current and ports) may not be applicable.

Note 2 to entry: A mobile device is an appliance.

3.28

port

connector (typically a socket) on a component that can supply power to an appliance

Note 1 to entry: This definition applies when the word "port" is used without qualification in this document. The word "port" can also be used more generally to refer to any socket (receptacle).

3.29

power control unit

component of a stand-alone renewable energy product that includes a battery and one or more ports plus, typically, the associated battery management, voltage regulation and overload protection components

Note 1 to entry: In the case of a product with a single power control unit, the power control unit is often referred to as the "main unit" or "control box." A power control unit can include appliance functionality such as a light or built-in radio. A portable appliance (such as a light) with internal battery is a power control unit if it includes a port.

3.30

main unit

component or assembly including an input for connecting the primary energy source (e.g. solar, grid or mechanical charger), a battery, and one or more built-in appliance(s) or port(s).

Note 1 to entry: A power control unit can be a main unit, though a main unit does not necessarily have a port.

Note 2 to entry: A product can contain more than one main unit.

3.31

standard operating voltage

standardized voltage corresponding to a typical battery operating point during discharge

3.32**typical battery discharge voltage**

battery voltage corresponding to the "typical operating point" (e.g. the operating point resulting in the average value of power) during discharge

Note 1 to entry: The typical battery discharge voltage is an outcome of the full-battery run time test, while the standard operating voltage depends only on the battery chemistry and number of cells.

3.33**appliance operating voltage**

voltage supplied to an appliance by a port when the appliance is operating at a particular setting and the power control unit battery is at the typical battery discharge voltage

3.34**product specification**

document containing quality and warranty requirements

Note 1 to entry: IEC TS 62257-9-8 is an example of a product specification. Throughout this document, "product specification" can refer to IEC TS 62257-9-8 or to any other product specification.

Note 2 to entry: A product specification can be developed by a national or international standards body, a market development programme, a distributor or other organization making a bulk procurement, or any other entity using this document.

3.35**foldable module**

PV module that is separated into distinct PV sections nominally of the same size and connected by a section that can be folded and does not contain cells, but has the interconnecting busbars

[SOURCE: IEC TS 63163:2021, 3.2, modified – the phrase "that can be folded" has been added]

3.36**component**

<of a product> constituent part of a product which cannot be physically divided into smaller parts as part of normal installation and use

Note 1 to entry: Examples of components include main units, power control units, appliances, PV modules, external batteries, and cables.

[SOURCE: IEC 60050-151:2001, 151-11-21, modified – "device" has been replaced with "product" and "without losing its particular function" with "as part of normal installation and use," and the note has been added.]

3.37**company**

entity who provides the product for testing (who can be the maker of the product or a supplier, importer, distributor, reseller, etc.)

4 Product components and characteristics

4.1 Components

4.1.1 Overview

A stand-alone renewable energy product typically comprises:

- The main components:
 - one or several energy sources:
 - a) solar photovoltaic module (integrated, supported by or completely separate from the casing),
 - b) electromechanical charger (hand crank, pedal power, or other), or
 - c) general DC power input (normally used with a central charging station or AC-DC converters to charge via grid power).
 - one or several light sources (typically compact fluorescent light (CFL) or LED),
 - power control unit(s) (see 3.29), which can be integrated into the same casing as the light sources or in a separate enclosure,
 - battery or batteries, and
 - loads (optional), such as appliances (lighting, television, radio, fan, etc.), and load adapter cables (e.g. for mobile devices).

NOTE In more complex products, some loads can include their own battery and power control unit.

- The enclosure and other components:
 - casing or several casings (including some translucent parts in many cases),
 - circuits (battery charge and discharge controller, regulated voltage and current sources),
 - wiring to connect the circuits to each other and the main components,
 - fasteners to secure components in the casings,
 - switches for light control or selection,
 - cables and connectors,
 - protective devices,
 - status indicators or user feedback,
 - accessories (auxiliary power outlet, mobile device charging or other appliance interface, radio, fan, television set, etc.), or
 - hardware for mounting.

Throughout this document, the terms "product" and "stand-alone renewable energy product" refer to the complete product or kit as described in 4.1.1.

4.1.2 Component categories

Components of stand-alone renewable energy products can be placed into five categories based on the arrangement of components. The four general categories are fixed indoor, fixed outdoor, portable separate, and portable integrated; photovoltaic modules are in an additional, separate category. It is important to categorize components because components in different categories have different inherent utility to the user and will encounter different environmental conditions based on their design.

Different quality standards may apply to different categories.

Each product can contain components from multiple categories. Appliances included with the product may also be categorized with this same system.

The first word in each category name refers to the portability of the system.

- Fixed components are designed for permanent or semi-permanent mounting and use in place. In addition to many large battery packs and installed light points, certain appliances, such as television sets, are typically considered to be fixed.
- Portable components are inherently portable and generally contain an internal energy source. For example, a stand-alone renewable energy product can include a portable light with a battery that can be charged from the PV module or from another battery in a fixed enclosure.

Fixed components are further classified based on the expected use location:

- a) Fixed indoor components are not inherently portable and are used indoors. If a fixed indoor component is connected to a component that is intended to be used outdoors (such as a PV module), the cable connecting the two components shall be sufficiently long to place the outdoor component outdoors in an appropriate location while the indoor component remains indoors. Otherwise, the fixed outdoor category shall apply. See Figure 1 for an example.

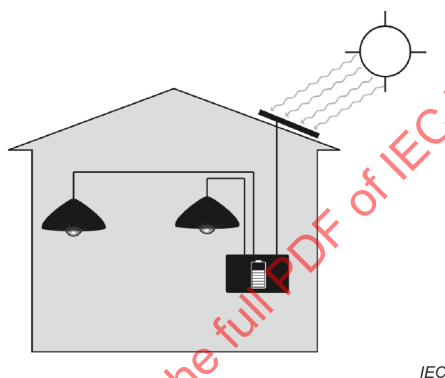


Figure 1 – Fixed indoor components and PV module – Example

- b) Fixed outdoor components are not inherently portable and are intended to be used outdoors or are connected to components intended to be used outdoors by a cable that is too short to allow the component in question to be placed indoors. Fixed outdoor components may contain integrated PV modules; however, PV modules without additional components form their own category. See Figure 2 for an example.

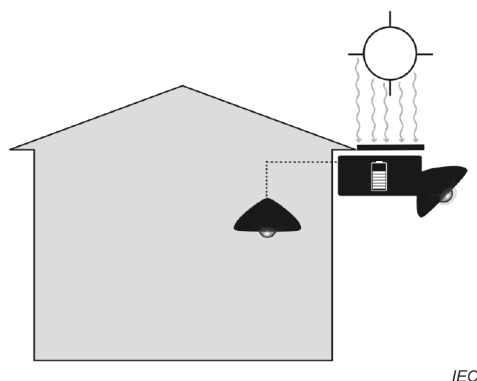


Figure 2 – Fixed outdoor components with an indoor light point – Example

Portable components are further classified by the presence or absence of an integrated PV module:

- a) Portable separate components are portable, with a battery and load permanently or temporarily joined. If the component is intended to be connected to a fixed outdoor or portable integrated component or a PV module, the cable connecting the two components shall be sufficiently long to place the outdoor component outdoors in an appropriate location while the indoor component remains indoors; otherwise, the portable integrated category shall apply. See Figure 3 for an example.

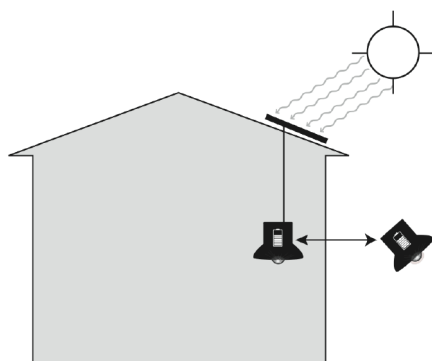


Figure 3 – Portable separate components – Example

- b) Portable integrated components are portable and are charged with a PV module that is integrated in the casing or is otherwise designed so that the whole component is left outdoors to charge via the PV module. This includes portable components that are intended to be connected to fixed outdoor or portable integrated components, or a PV module, by a cable that is too short to allow the component in question to be placed indoors. Portable integrated components may contain PV modules; however, PV modules without additional components form their own category. See Figure 4 for an example.

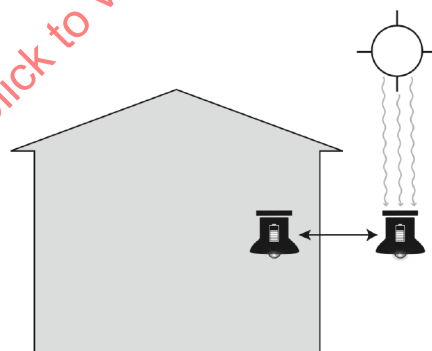


Figure 4 – Portable integrated components – Example

PV modules may be subjected to different standards for durability (including physical and water ingress protection), and are therefore considered a separate category:

- a) PV modules include one or more PV cells surrounded by encapsulating or laminating materials with a transparent glass or plastic covering, plus a junction box mounted on the back of the module for electrical connections. A PV module can be surrounded by a frame, typically of metal or plastic, and can include mounting brackets or other hardware. This category applies only to PV modules; assemblies containing one or more PV modules plus additional electrical or electronic components, such as circuit boards or batteries, shall be considered fixed outdoor components.

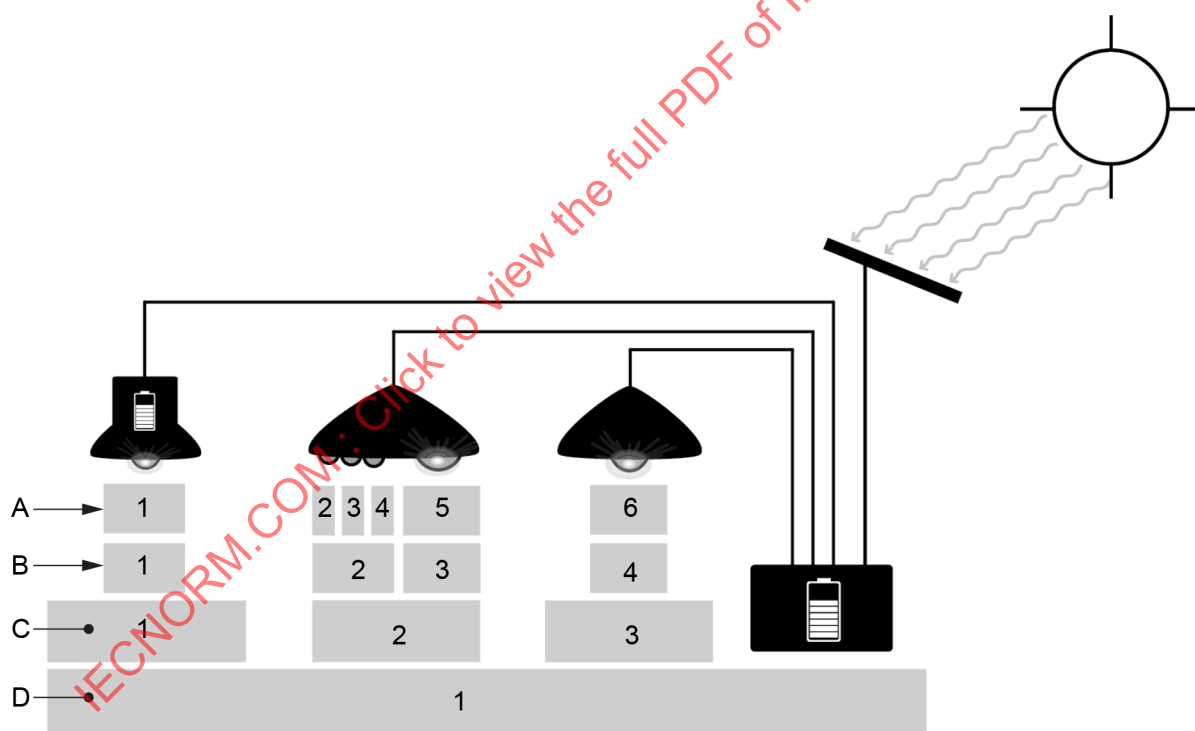
NOTE The requirement regarding assemblies containing PV modules is not intended to apply to PV modules with small circuit boards or discrete electronic components such as diodes installed in their junction boxes.

4.1.3 Lighting parts definitions

The portion of the product which provides lighting can also be divided into several subsystems, as defined in the following. The subsystems are nested beginning with the smallest subsystem and working up to a complete product.

- a) Light source(s): individual LED, CFL, or other light emitting components.
- b) Array(s): single or grouped light sources that can be controlled independently from other arrays.
- c) Light point(s) or lighting appliance(s): house one or more arrays and can be moved with respect to other light points, if there are more than one.
- d) Stand-alone renewable energy product: the overall package of integrated components, including one or several energy sources (e.g. PV modules), main units, and potentially other components such as light points and other appliances.

Figure 5 illustrates how a hypothetical product can be subdivided. The levels of division are labelled with letters, corresponding to the descriptions above. There are six light sources (A) in this product divided among four arrays (B). Two of the three light points (C) have one array; the third light point (in the middle – C2) has two arrays. Note that one of the arrays – the one with three light sources – is turned off and the other is on. Both units are included in a single product (D). Note that although only lights are illustrated below, other appliances are often included as part of the product.



IEC

Figure 5 – Division of a product into subsystems – Illustrative example

4.1.4 Appliance definitions

Some products may include or advertise compatibility with one or more appliances, such as lights, radios, and mobile devices. Two categories of appliances are addressed in this document:

- Included appliances are packaged with and sold as part of the product, so their performance (e.g. power consumption) can be measured directly by the test laboratory.
- Advertised appliances are not included as part of the product but are mentioned in the accompanying advertising material, such as the product packaging or the company's website. This advertising can be a simple statement that the appliance can be used with the product, or an estimate of the run time or service provided by the appliance with a full battery or after a day of solar charging. Methods are provided for evaluating these claims even though the appliances are not provided to the test laboratory.

In addition, appliances can be categorized by how they are connected to the other components of the product:

- Removable appliances can be powered or charged from the product by plugging a cable into a port and can be disconnected when not in use.
- Built-in appliances are integrated into another component of the product so that they are not intended to be removed by the end user. These appliances include built-in radios and lights. The following are also considered built-in appliances for the purposes:
 - appliances (such as light points) connected to the product by a permanently attached cable that is not intended to be removed by the end user;
 - appliances (such as light points) that can be removed, but that depend on a circuit or assembly internal to another part of the product for their functionality. For example, a light point where some or all of the driver or ballast circuit is internal to the power control unit of the product is considered a built-in appliance. In some cases, such appliances can be tested as removable appliances with some modifications to the test procedures; see EE.4.2.5.

In some cases, an appliance can be considered both "built-in" and "removable." For example, a product could have external lights that can be plugged into specially designated ports with brightness controls or into general-purpose appliance ports. These appliances may be tested as built-in appliances or removable appliances; the decision should be made based on how the appliance is likely to be used most often. It is not necessary to test such appliances using both sets of test methods (for built-in and removable appliances).

Removable appliances can be further divided into appliances with and without internal batteries. Different test methods for power consumption and voltage compatibility apply to these two categories. (The term "appliance with internal battery" in this document does not refer to built-in appliances.)

4.1.5 Additional system elements

In addition to technical elements, a system can also include:

- packaging with information about the product,
- user manual(s),
- various advertising for the product across media: print, radio, television, internet, and others,
- warranty support from the company, and
- hardware for mounting the PV module and other components.

4.2 System measurements and observations

4.2.1 General

Subclause 4.2 describes aspects of an off-grid lighting product that can be measured or observed to ascertain its quality and performance. The aspects are grouped into categories, and each aspect begins with a description of its relevance. The description of each aspect concludes with a description of the result from the test procedure, the units, and an example result. In some cases, multiple pieces of information are grouped in a single aspect for clarity and concision.

4.2.2 Product design, manufacture, and marketing aspects

4.2.2.1 Arrangement of components

The arrangement of components is a critical aspect to observe because it determines the product category. Different arrangements will offer different utility to the end user.

- a) Test procedure(s): Annex F: visual screening.
- b) Result: qualitative description of each separate electronic enclosure and what is housed in or mounted on each.
- c) Units: qualitative description.

EXAMPLE Enclosure A contains the battery and has a gooseneck light point protruding from the top. Enclosure B is a remote lighting point with ambient, omnidirectional LEDs mounted on the outside; it is connected to Enclosure A with a 5 m cable. A PV module with a 6 m cable powers Enclosure A.

4.2.2.2 Charging system information

This notes all the available options for charging the product or component. The key items to note are whether the product or component can be charged by "central" charging (e.g. via electric grid connection or at a central charging station), "independent" charging (e.g. via an included photovoltaic or electromechanical generator), or both. The available charging options can help determine the utility of the product for users based on the performance aspects (see 4.2.8).

- a) Test procedure(s): Annex F: visual screening, Annex D: company self-reported information.
- b) Result (for each charging option): charger type; central or independent.
- c) Units: qualitative type.

EXAMPLE Two charging options: independent solar charging via the included module, and central grid charging via an auxiliary input designed for use with mobile phone chargers (not included).

4.2.2.3 Lighting system information

This describes the types of light sources used in the product and their arrangement. This is important for understanding the general product design.

- a) Test procedure(s): Annex F: visual screening, Annex D: company self-reported information.
- b) Result: qualitative description of the type, number, and arrangement of light sources.
- c) Units: qualitative description.

EXAMPLE See 4.1.3.

4.2.2.4 Energy storage system information

This describes the type and number of energy storage systems included in the product.

- a) Test procedure(s): Annex F: visual screening, Annex D: company self-reported information.
- b) Result: the type and number of batteries in the system.
- c) Units: qualitative description.

EXAMPLE Unit A has a 3,7 V lithium-ion battery with a rating of 2,0 Ah; Unit B has a 3,7 V lithium-ion battery with a rating of 1,0 Ah.

4.2.2.5 Battery easy replaceability

This is an assessment of whether a low-skill technician can easily replace the battery with only a screwdriver (i.e. no soldering). It is important for considering the relevance of battery replacement information.

- a) Test procedure(s): Annex F: visual screening.
- b) Result: a yes or no result on whether it is "easy" to replace the battery.
- c) Units: yes/no.

4.2.2.6 Battery general aspects

These are the aspects of the battery(-ies) that are important for understanding selection of replacement batteries.

- a) Test procedure(s): Annex F: visual screening, Annex D: company self-reported information or reference component rating.
- b) Result (for each battery present): battery chemistry; nominal voltage; package type; package size; connection type.
- c) Units: qualitative type.

EXAMPLE A sealed lead-acid 4 V prismatic package, 20 mm × 20 mm × 60 mm, wire lead connections.

4.2.2.7 Packaging and user manual information

Information about the packaging, user manual, and other consumer-facing information helps establish a baseline for comparing measured values in truth-in-advertising assessments. Certain programmes require particular information to be included in the manual, such as instructions for end-of-life disposal, particularly for batteries and other potentially hazardous components; thorough documentation of the packaging, user manual, and other consumer-facing information allows compliance with these requirements to be assessed.

- a) Test procedure(s): Annex F: visual screening.
- b) Result: there are five types of result:
 - 1) photographic documentation of the packaging and manual (or digital copies of the original proofs);
 - 2) notes on the type of manual and which languages are included;
 - 3) description of the method or pathway for replacing components, including the battery;
 - 4) specifications of components that could require replacement (fuses, batteries, PV);
 - 5) instructions for PV and product installation and operation.
- c) Units: qualitative type and photographs.

4.2.2.8 Warranty information

The terms and duration of warranty coverage provided to end users are important factors for engendering confidence in stand-alone off-grid lighting and trying to prevent early failure. In practice, servicing warranties is highly variable depending on the structure of supply and service chains.

- a) Test procedure(s): Annex F: visual screening, Annex D: company self-reported information.
- b) Result: detailed warranty terms and a "concise" version that highlights the key points of coverage and duration.
- c) Units: qualitative description.

EXAMPLE Detailed warranty terms are documented in scanned attachments to test report. Coverage is against manufacturing defects or under normal use conditions. The product in general is covered for 24 months from the time of purchase; the PV module is warranted for 5 years.

4.2.2.9 Auxiliary outlets, ports and adapters information

This notes all the auxiliary outlets and ports present on the product. The inclusion of USB ports, outlets or mobile device adapters can be an important purchasing factor for a consumer.

- a) Test procedure(s): Annex F: visual screening, Annex D: company self-reported information.
- b) Result: list of included auxiliary outlets, ports and adapters, including receptacle type and nominal voltage.
- c) Units: qualitative description.

EXAMPLE The product includes two 12 V ports with barrel jacks (5,5 mm outer diameter; 2,5 mm pin diameter) and three 5 V USB ports (type A receptacle).

4.2.2.10 Appliances information

This notes all the appliances included with the product and all appliances the product is advertised to support. Some products include appliances such as radios. Others include advertising stating that they support certain appliances or making claims as to how long they can power certain appliances.

- a) Test procedure(s): Annex F: visual screening, Annex D: company self-reported information.
- b) Result: list of included appliances and list of claims related to supporting appliances.
- c) Units: qualitative description.

4.2.2.11 Other visual screening results

This incorporates various other important results obtained from visual screening (Annex F), including, but not limited to, component dimensions, component masses, the number of light settings, and provided specifications.

- a) Test procedure(s): Annex F: visual screening, Annex D: company self-reported information.
- b) Result: various results including qualitative descriptions and quantitative measurements.
- c) Units: qualitative descriptions and quantitative measurements.

4.2.3 Product durability and workmanship aspects

4.2.3.1 Functionality and workmanship

This encompasses whether the product can perform its basic functions, and whether there are any easily identified safety issues or other deficiencies of workmanship. External and internal aspects are considered, including the durability and function of certain mechanical parts and connectors, safety and durability of PV modules, and the quality of electronic components, wiring, and batteries.

- a) Test procedure(s): Annex F: visual screening.
- b) Result: a quantitative workmanship score and qualitative notes about observed deficiencies, safety concerns and functionality issues.
- c) Units: The deficiencies score and workmanship score are unitless.

4.2.3.2 Water protection – enclosure

This provides a description of the product enclosure's ability to keep out water in terms of IP code. For components intended to be either used or charged outside, or both, water protection is important for product function as well as user safety.

- a) Test procedure(s): Annex U: Physical and water ingress protection test in accordance with IEC 60529 or the alternative methods if the alternative method results are unequivocal.
- b) Result: pass or fail for IP code (second digit) and a description of degree of water protection provided by enclosure.
- c) Units: pass or fail and qualitative description.

EXAMPLE The portable lamp included with the product passes IPX3. The lamp's enclosure contains tight fitting components, all of which have gaskets to prevent water intrusion. The battery, charge controller and TV are all fixed indoor components that do not require water ingress protection.

4.2.3.3 Water protection – circuit protection and drainage

This provides a description of either any drainage means incorporated into a product or circuit board, any protection methods used in the product, or both. The incorporation of drainage or circuit board protection is crucial for products intended to be portable or used outdoors that have enclosures providing little to no water intrusion protection.

- a) Test procedure(s): Annex F: visual screening combined with Annex D: company self-reported information.
- b) Result: qualitative description of drainage or circuit protection methods used.
- c) Units: qualitative description.

EXAMPLE The product has a conformal coating on its circuit board as well as drainage holes in the base of the enclosure to allow drainage of collected water.

4.2.3.4 Water protection – overall

This combines the protection afforded by the enclosure, circuit protection, and consumer labelling to assess the overall protection from water exposure.

- a) Test procedure(s): Annex V: level of water protection.
- b) Result: descriptive assessment of exposure protection by enclosure only, technical means, and overall system. The assessment categories are "no protection," "occasional rain," "frequent rain," "permanent rooftop installation for PV modules," and "permanent outdoor exposure."
- b) Units: qualitative type.

EXAMPLE Enclosure only: no protection. Technical means: occasional rain. Overall: occasional rain.

4.2.3.5 Water protection – PV module

This provides a description of an external PV module's ability to keep out water in terms of IP code. (If the PV module is integrated into the product enclosure, then 4.2.3.2 already covers the PV module.) It is necessary to leave PV modules outside to collect solar energy; therefore, water protection is important for PV module function as well as user safety.

- a) Test procedure(s): Annex U: Physical and water ingress protection test in accordance with IEC 60529 or using the alternative methods (U.4.4) if the alternative method results are unequivocal.
- b) Result: pass or fail for IP code (second digit) and a description of degree of water protection.
- c) Units: pass or fail and qualitative description.

EXAMPLE The product's PV module passes IPX4; the PV module is well sealed, providing an adequate level of protection against water ingress.

4.2.3.6 Physical ingress protection

This provides a description of the degree of protection from the intrusion of foreign objects a component's enclosure provides in terms of IP code. Physical ingress protection is important for user safety as well as product functionality.

- a) Test procedure(s): Annex U: Physical and water ingress protection test in accordance with IEC 60529 or using the alternative methods (U.4.3) if the alternative method results are unequivocal.
- b) Result: pass or fail for IP code (first digit) and description of degree of physical ingress protection.
- c) Units: pass or fail and qualitative description.

EXAMPLE The product components pass IP 2x; the product enclosure's components fit together well, with vents smaller than 12,5 mm.

4.2.3.7 Physical ingress protection – PV module

This provides a description of an external PV module's ability to prevent the intrusion of foreign objects in terms of IP code (if the PV module is integrated into the product enclosure, then 4.2.3.6 already covers the PV module). It is necessary to leave PV modules outside to collect solar energy; therefore, physical ingress protection is important for PV module function as well as user safety.

- a) Test procedure(s): Annex U: Physical and water ingress protection test in accordance with IEC 60529 or using the alternative methods (U.4.4) if the alternative method results are unequivocal.
- b) Result: pass or fail for IP code (first digit) and description of degree of physical ingress protection.
- c) Units: pass or fail and qualitative description.

EXAMPLE The product's PV module is estimated to pass IP 3x; the PV module is well sealed so that only small particles could intrude.

4.2.3.8 Drop resistance

This provides an evaluation of a product's robustness and ability to withstand being dropped. Drop resistance is important for product functionality and user safety and satisfaction in portable components.

- a) Test procedure(s): Annex W: mechanical durability test.
- b) Result: pass or fail for functionality, damage, and the presence of user safety hazards.
- c) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE When dropped, the product stopped working and its glass LED cover shattered, presenting a safety hazard to the user. Functional: fail. Damage: fail. Safety hazard: fail.

4.2.3.9 Gooseneck and moving part durability

This provides an evaluation of a product's gooseneck or other moving part's robustness and ability to withstand being torqued through its expected range of motion. Gooseneck and moving part durability is important for product functionality and user safety and satisfaction.

- a) Test procedure(s): Annex W: mechanical durability test.
- b) Result: a pass or fail for functionality, damage, and the presence of user safety hazards.
- c) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE After the gooseneck and moving part test, the LEDs worked properly but there was visible damage (a cracked housing) that did not pose a hazard. Functional: pass. Damage: fail. Safety: pass.

4.2.3.10 Connector durability

This provides an evaluation of a product's connectors' robustness and ability to withstand plug cycling. Connector durability is important for product functionality and user safety and satisfaction.

- a) Test procedure(s): Annex W: mechanical durability test.
- b) Result: a pass or fail for functionality, damage, and the presence of user safety hazards.
- b) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE After 400 cycles in the connector test, the PV module's barrel plug socket detached from the enclosure, rendering the PV module connector unusable. Functional: fail. Damage: fail. Safety: pass.

4.2.3.11 Switch durability

This provides an evaluation of a product's switches' robustness and ability to withstand switch cycling. Switch durability is important for product functionality and user safety and satisfaction.

- a) Test procedure(s): Annex W: mechanical durability test.
- b) Result: a pass or fail for functionality, damage, and the presence of user safety hazards.
- c) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE After 600 cycles in the switch test, the light switch stopped turning on the DUT. Functional: fail. Damage: fail. Safety: pass.

4.2.3.12 Strain relief durability

This provides an evaluation of a product's strain reliefs' robustness and ability to withstand being pulled. Strain relief durability is important for product functionality and user safety and satisfaction.

- a) Test procedure(s): Annex W: mechanical durability test.
- b) Result: a pass or fail for functionality, damage, and the presence of user safety hazards.
- c) Units: a pass or fail result on whether the DUT functions, incurred damage, and presented a safety hazard to the user.

EXAMPLE The strain reliefs all withstood the strain relief test without incurring any damage. Functional: pass. Damage: pass. Safety: pass.

4.2.3.13 Battery protection strategy

This provides a quantitative evaluation of a product's battery discharge-recharge protection strategy or algorithm, which is important for battery longevity as well as user safety.

- a) Test procedure(s): Annex S: charge controller behaviour test or Annex FF: appliance tests.
- b) Result: deep discharge and overvoltage protection voltages.
- c) Units: quantitative description.

4.2.3.14 Robustness of screw connections

Non-plug-and-play products can have screws that are intended to be tightened during installation. These screws are tested to confirm they can be screwed and unscrewed without damage.

- a) Test procedure(s): Annex X: Screw connections test.
- b) Result: a pass or fail for each applicable test and photographs of any damage.
- c) Units: n/a.

4.2.4 Lighting durability aspects

4.2.4.1 LED lumen maintenance

This is a measure or estimate of the amount of light degradation after constant operation for a specified duration, which can provide valuable insight into the quality of the LEDs and the product's circuit design. The value can be assessed by direct measurement for 500 h, 1 000 h, or 2 000 h, or through estimation using ANSI/IES LM-80 data, a 500 h test, and product measurements.

- a) Test procedure(s): Annex J: lumen maintenance test.
- b) Result: percentage of lumen output maintained after 500 h, 1 000 h, or 2 000 h of constant operation.
- c) Units: percentage (%).

4.2.4.2 Fluorescent light durability

These are additional checks of durability for fluorescent lights that account for their unique characteristics.

- a) Test procedure(s): Cycling test of IEC TS 62257-12-1.
- b) Result: a pass or fail for the cycling test of IEC TS 62257-12-1.
- c) Units: pass or fail.

4.2.5 Battery performance aspects

4.2.5.1 Battery capacity

This is a measure of the quantity of electricity (electric charge), usually expressed in ampere-hours (Ah), which a fully charged battery can deliver under specified conditions, which affects the run time of products.

- a) Test procedure(s): Annex K: battery test (all chemistries), Annex D: company self-reported information or reference component rating.
- b) Result: capacity of the battery at a particular discharge rate.
- c) Units: ampere-hours (Ah) at a discharge rate expressed in terms of I_t A (as defined in K.4.1).

EXAMPLE 3,5 Ah at 0,2 I_t A.

4.2.5.2 Battery round-trip energy efficiency

This is a measure of how efficient the battery is at storing energy to deliver for later use.

- a) Test procedure(s): Annex K: battery test.
- b) Result: storage efficiency of the battery pack.
- c) Units: percentage (%).

4.2.5.3 Battery storage durability

This is a measure of battery capacity degradation from storage, which can indicate batteries that could degrade prematurely under typical use.

- a) Test procedure(s): Annex BB: battery durability test.
- b) Result: percent capacity loss from storage.
- c) Units: percentage (%).

4.2.5.4 Battery nominal voltage

This is important for matching to the other components and determines, along with the battery ampere-hour capacity, the energy capacity of the battery. It depends on the battery chemistry (what materials are used to store energy) and the number of electrochemical cells that are in series.

- a) Test procedure(s): Annex F: visual screening, Annex D: company self-reported information or reference component rating.
- b) Result: nominal voltage of the battery pack.
- c) Units: voltage (V).

4.2.6 PV module aspects

4.2.6.1 Solar I-V curve parameters

These are the key parameters describing PV module performance at standard test conditions (STC: AM 1,5, 25 °C ± 2 °C cell temperature, 1 000 W/m² irradiance) and typical module operating temperature (TMOT: AM 1,5, 50 °C ± 2 °C cell temperature, 1 000 W/m² irradiance).

- a) Test procedure(s): Annex Q: photovoltaic module I-V characteristics test, IEC 60904-1.
- b) Result (for both STC and TMOT):
 - 1) Open circuit voltage (V_{oc}).
 - 2) Short circuit current (I_{sc}).
 - 3) Maximum power voltage (V_{mpp}).
 - 4) Maximum power current (I_{mpp}).
 - 5) Peak power (P_{mpp}).
 - 6) Voltage temperature coefficient (relative to the open-circuit voltage at STC).
- c) Units: volts (V), amperes (A), watts (W), percent per degree Celsius (%/°C).

EXAMPLE STC values: $V_{oc} = 7,5$ V, $I_{sc} = 0,55$ A, $V_{mpp} = 5,8$ V, $I_{mpp} = 0,50$ A, and $P_{mpp} = 2,9$ W. The module's voltage temperature coefficient is -0,42 %/°C.

4.2.6.2 Cable length

The length of PV module cables and other cables connected to fixed outdoor components are important because it is one aspect that determines the product category; a minimum length is typically specified for products to "qualify" as having separate PV modules to ensure that a user can place the PV module, or other component, outdoors while the other components remain indoors. This has implications for the degree of water protection in quality standards.

- a) Test procedure(s): Annex F: visual screening.
- b) Result: There are two main outputs:
 - 1) the length of any cables that connect a portable component or fixed indoor component to a PV module; and
 - 2) the length of any cables that connect any fixed outdoor or portable integrated component to any other component (other than another fixed outdoor component).
- c) Units: metres (m).

4.2.6.3 PV safety and durability

Basic safety and durability testing of PV modules helps confirm that PV modules are safe and appropriate for use in off-grid solar products. Testing covers key issues that can be identified during the visual inspection including inspecting the PV module for burrs or sharp edges.

- a) Test procedure(s): Annex F: visual screening.
- b) Result: identification of any safety hazards and a workmanship quality rating of "good", "fair" or "poor" with a focus on safety issues.
- c) Units: n/a.

4.2.6.4 PV wiring

The PV cable is measured to confirm it can safely carry the current produced by the PV module.

- a) Test procedure(s): Annex A: Photovoltaic module wiring inspection.
- b) Result: a pass or fail result along with metrics used to determine the result:
 - 1) Maximum short-circuit current (A).
 - 2) Conductor material.
 - 3) Insulation type or temperature rating (°C).
 - 4) Diameter of single strand (mm), number of strands, measured cross-sectional area (mm²) or resistance per unit length (Ω/km).
- c) Units: amperes (A), degrees Celsius (°C), millimetre (mm), millimetres squared (mm²), ohm per kilometre (Ω/km).

4.2.6.5 Partial shading of photovoltaic modules

When an individual cell of a PV module is shaded, that cell no longer generates power and instead acts as a load which can cause thermal damage and lead to a safety hazard. PV modules with a rated maximum PV power greater than 100 W are tested under partial shading conditions.

- a) Test procedure(s): Annex B: Partial shading test for photovoltaic modules.
- b) Result:
 - 1) The infrared images used to select the tested cells.
 - 2) Visual images documenting the location of the shading applied.
 - 3) The percent shading applied to each of the selected cells (%).
 - 4) Any damage that occurred during the test, with photos if applicable.
 - 5) The power degradation (%).
- c) Units: percentage (%).

4.2.6.6 Bending and folding PV modules

Modules that are intended to be bent or folded during use are tested to confirm that bending or folding does not result in damage to the module.

- a) Test procedure(s): Annex C: Bending or folding test for photovoltaic modules.
- b) Result: a pass or fail result, percent of power degradation, and note of any intermittent faults.
- c) Units: percentage (%).

4.2.7 Electrical characteristics

4.2.7.1 Appliance voltage compatibility

This provides an assessment of whether an included appliance can safely and properly operate over the entire set of operating conditions of the DUT, including discharging with a deeply discharged battery and charging with a nearly full battery.

- a) Test procedure(s): Annex FF: appliance tests.
- b) Result: pass or fail for functionality, damage, and safety.
- c) Units: pass/fail; qualitative description.

4.2.7.2 Power consumption

The power consumed by an appliance or lighting appliance in use is an important metric for off-grid applications in which the supply of energy is limited. The power consumption is measured in order to calculate the run time for systems with included appliances. Appliances with internal batteries will have a power consumption when in use, and a different power consumption when charging; the latter is measured in the appliance charging efficiency test.

- a) Test procedure(s): Annex FF: appliance tests.
- b) Result: DC power.
- c) Units: watts (W).

4.2.7.3 Circuit and overload protection

This provides an assessment of the system's PV overvoltage protection, output overload protection, and safeguards against miswiring in systems that include ports or outlets.

- a) Test procedure(s): Annex DD: protection tests, Annex D: company self-reported information.
- b) Result: a pass or fail result on whether the unit had adequate protection, functioned, or showed damage or safety hazards after tests. Tables with quantitative and qualitative results of the overvoltage, overload, and miswiring protection tests.
- c) Units: volts (V), pass or fail results on whether the unit had adequate protection, functioned, or showed damage or safety hazards after test.

EXAMPLE The DUT uses appropriately sized fuses to provide adequate circuit protection. Spare fuses are included, and the fuse size is noted on the product casing.

4.2.7.4 Battery-charging circuit efficiency

The battery-charging circuit efficiency, or generator-to-battery charging efficiency, is a measure of how efficient the electronics are at feeding generated energy into the battery.

- a) Test procedure(s): Annex R: solar charge test,
- b) Result: battery-charging circuit efficiency.
- c) Units: percentage (%).

4.2.7.5 DC ports

This provides an assessment of the system's DC ports.

- a) Test procedure(s): Annex EE: assessment of DC ports.
- b) Result: minimum and maximum port voltages, tables and plots of voltage, current, power and efficiency of each port.
- c) Units: volts (V), amperes (A), watts (W), percentage (%).

4.2.7.6 Appliance charging efficiency

The charging efficiency and power consumed by an appliance during charging is an important metric for use in off-grid applications in which the supply of energy is limited. Unless estimated with default values, the charging efficiency is measured for appliances with internal batteries charging from the main unit and the power consumption during charging is measured in order to calculate the run time for systems with included appliances that have internal batteries.

- a) Test procedure(s): Annex FF: appliance tests.
- b) Result: appliance charging efficiency, DC power.
- c) Units: percentage (%), watts (W).

4.2.8 Performance aspects

4.2.8.1 General

Energy availability, component run times and light output characteristics are key elements of performance for stand-alone renewable energy products. Some of the aspects listed in the following will be different for different light settings and appliance combinations.

4.2.8.2 Daily energy service

The daily energy service is the quantity of energy provided to end users after one day of solar charging and depends on the system-level performance for a particular setting. The standard solar charging day is defined as an incident solar resource of 5 kWh/m². This is an important metric because it is an estimate of the day-to-day services users can expect in ideal charging conditions. The daily energy service depends on the system-level performance for a particular light setting and combination of appliances.

- a) Test procedure(s): Annex M: full-battery run time test, Annex R: solar charge test, Annex FF: appliance tests, Annex GG: energy service calculations.
- b) Result: watt-hours per day of energy available after a battery is charged from a fully discharged state of charge, as defined in Annex N, for one standard solar day.
- c) Units: watt-hours (Wh).

4.2.8.3 Solar-day lighting run time

The solar-day run time is the duration of service provided to end users from one day of solar charging and depends on the system-level performance for a particular setting. The standard solar charging day is defined as an incident solar resource of 5 kWh/m². This is an important metric because it is an estimate of the day-to-day services users can expect in ideal charging conditions. It is important to note that variations in available solar energy (due to climate, weather, or user behaviour) will result in commensurate differences in actual run time from solar charging.

- a) Test procedure(s): Annex R: solar charge test; or Annex M: full-battery run time test, Annex R: solar charge test, and Annex GG: energy service calculations.
- b) Result: hours of operation to 70 % of the initial brightness after the battery is charged for one standard solar day.
- c) Units: hours (h).

4.2.8.4 Solar-day appliance run time

The solar-day run time is the duration of service provided to end users from one day of solar charging and depends on the system-level performance for a particular setting. The standard solar charging day is defined as an incident solar resource of 5 kWh/m². This is an important metric because it is an estimate of the day-to-day services users can expect in ideal charging conditions. It is important to note that variations in available solar energy (due to climate, weather, or user behaviour) will result in commensurate differences in actual run time from solar charging.

- a) Test procedure(s): Annex R: solar charge test; or Annex M: full-battery run time test, Annex R: solar charge test, Annex FF: appliance tests, and Annex GG: energy service calculations.
- b) Result: hours of operation after the battery is charged for one standard solar day.
- c) Units: hours (h).

4.2.8.5 Solar charging time

The solar charging time is the duration of solar charging required for the product to receive a full charge. The standard solar charging day is defined as an incident solar resource of 5 kWh/m². This is an important metric because it is an estimate of the day-to-day services users can expect in ideal charging conditions. It is important to note that variations in available solar energy (due to climate, weather, or user behaviour) will result in commensurate differences in actual run time from solar charging.

- a) Test procedure(s): Annex R: solar charge test; or Annex M: full-battery run time test, Annex R: solar charge test, Annex FF: appliance tests, and Annex GG: energy service calculations.
- b) Result: hours of solar charging required for a product's fully discharged battery(-ies), as defined in Annex N, to receive a full charge.
- c) Units: hours (h).

4.2.8.6 Main unit full-battery run time

The main unit full-battery run time is the duration of service provided to end users from a fully charged battery and depends on the system-level performance for a particular setting. This is an important metric because it is an estimate of the services that can be provided by the product's main battery. If a product is submitted with no lighting appliances, other included or generic appliances may be used to determine the main unit's full-battery run time.

- a) Test procedure(s): Annex M: full-battery run time test, alone or in conjunction with Annex GG: energy service calculations.
- b) Result: hours of operation to 70 % of the initial brightness when beginning with a fully charged battery; sometimes also known as "autonomous run time."
- c) Units: hours (h).

4.2.8.7 Appliance full-battery run time

The appliance full-battery run time is the duration of service provided to end-users from a fully charged appliance battery, such as a lantern, radio, fan or TV with an internal battery. This is an important metric because it is an estimate of the services that can be provided by the appliance once it receives full charge from the main system.

- a) Test procedure(s): Annex M: full-battery run time test or Annex FF: appliance tests (measurement in accordance with Clause FF.9 or calculation in accordance with FF.6.9.5).
- b) Result: hours of operation to the run time endpoint after the battery is fully charged.
- c) Units: hours (h).

4.2.8.8 Grid-charge time

The grid-charge time is the time required for a full charge of the battery for DUTs that are centrally charged (i.e. with a central charging station or the grid). This is an important metric to characterize the expected run time from grid charging.

- a) Test procedure(s): Annex O: grid charge test.
- b) Result: grid-charge time.
- c) Units: hours (h).

4.2.8.9 Electromechanical charger power or energy output

The electromechanical charger power output is an important metric because it allows one to estimate the duration of user effort required each day for a given level of service for an electromechanically charged product (e.g. one with a hand crank or bicycle pedals). In some products, as detailed in Annex P, energy is a more appropriate metric than power.

- a) Test procedure(s): Annex P: electromechanical charge test.
- b) Result: power output of the electromechanical charger.
- c) Units: watts (W) or watt-hours (Wh).

4.2.8.10 Standby loss

The standby loss measurement quantifies the current drawn by a DUT when not in use. If the standby loss is substantial, it can affect the use of the DUT.

- a) Test procedure(s): Annex S: charge controller behaviour test.
- b) Result: average current over 10 min period.
- c) Units: amperes (A).

4.2.9 Light output aspects

4.2.9.1 Luminous flux output

Luminous flux (3.1) is measured when the DUT is operated at the typical battery discharge voltage or when an individual lighting appliance is operated at the appliance operating voltage. This is a key benchmark for comparison of products.

- a) Test procedure(s): Annex I: light output test.
- b) Result: average luminous flux.
- c) Units: lumens (lm).

4.2.9.2 Full width half maximum (FWHM) angles

The full width half maximum angle is a metric used to understand the light distribution of a DUT and is the total included angle for which the illumination is greater than half the illumination at the brightest point in the plane.

- a) Test procedure(s): Annex T: light distribution test.
- b) Result: vertical and horizontal FWHM angles.
- c) Units: degrees (°).

4.2.9.3 Average light distribution characteristics

A light distribution is the illuminance "map" of a DUT. This metric is useful for determining the utility with respect to task lighting. The test is done with the DUT operating at the average operating point from the full-battery run time test.

- a) Test procedure(s): Annex T: light distribution test.
- b) Result: constant-voltage usable area at a specified distance, and illuminance on a work surface of 0,3 m × 0,4 m.

NOTE The work surface dimensions were selected to correspond to two adjacent sheets of A4 paper.

- c) Units: square metres (m²) and lux (lx).

EXAMPLE The usable area at a distance of 0,75 m is 0,76 m² and the work surface illuminance is 40 lux.

4.2.9.4 Colour characteristics

The colour characteristics of light include the colour rendering index (CRI) and the correlated colour temperature (CCT).

- a) Test procedure(s): Annex I: light output test.
- b) Result: CRI value and colour temperature.
- c) Units: CRI is unitless and the colour temperature is in kelvins (K).

4.2.10 Self-certification aspects

4.2.10.1 Product and company information

Company-reported product and company information is important for tracking purposes as well as for ensuring the test lab has up-to-date product information.

- a) Test procedure(s): Annex D: company self-reported information.
- b) Result: various qualitative and quantitative information.
- c) Units: qualitative and quantitative.

4.2.10.2 Warranty coverage

Warranty coverage goes beyond the terms of a warranty and provides detail on coverage in a particular location. It is typically only provided in cases where it is necessary to verify coverage in a particular town or region.

- a) Test procedure(s): Annex D: company self-reported information.
- b) Result: qualitative description.
- c) Units: qualitative description.

EXAMPLE The support in [region name] is provided by a small network of technicians who have been trained to repair products by [company or distributor name]. For repairs that are beyond the scope of their capabilities, replacement products are provided. The consumers in [region name] can access warranty service by dialling a phone number that is on a sticker placed on the original packaging.

4.2.10.3 Third-party marks and certifications

Third-party marks and certifications (e.g. UL or ISO) can be an important aspect in the eyes of consumers and investors, alike.

- a) Test procedure(s): Annex D: company self-reported information.
- b) Result: qualitative marks and certifications.
- c) Units: qualitative description.

4.3 Constructions not specifically covered

If it is evident from the design and construction of the stand-alone renewable energy product that a particular test is not applicable, the test is either not made or reasonable adjustments may be made to apply the test to the product. Any modifications shall provide a level of accuracy equivalent to the original method and shall be fit for the intended use. All modifications shall be documented in the test report. The need for additional detailed requirements to cope with new situations should be brought promptly to the attention of the appropriate committee.

5 Product specification

5.1 General

Quality and warranty requirements are used to interpret the measurements and observations made about a product using the test methods described in this document. Together they form a product specification.

- Quality requirements set a minimum level of durability and protect buyers and users from false advertising claims.
- Warranty requirements set a minimum level of user protection from early failure.

The test methods in this document are designed to be used with the requirements specified in the most recent version of IEC TS 62257-9-8. However, an organization may prefer to refer to a different specification or include modifications (additions or deletions) to the requirements in IEC TS 62257-9-8. Throughout this document, the phrase “product specification” can refer to IEC TS 62257-9-8 or to any other product specification.

The requirements should be appropriate for the goals of the organization or individual who is using them as a framework for quality assurance and should consider the following factors:

- availability of products on the market with the necessary quality and performance;
- ability of buyers to pay for the products;
- diversity of end user needs;
- tolerance for manufacturing variation.

5.2 Applications

Product specifications that include some combination of quality and warranty requirements can support a broad range of quality assurance needs. Table 1 lists examples of how they are applied depending on the type of quality assurance framework.

Table 1 – Applications of product specifications

Type of QA framework	Example(s) of applying Clause 5
General market support	Use quality and warranty requirements to qualify for institutional market support. Use requirements to qualify for "verified product" programs. Use requirements to qualify for investment or financing.
Manufacturing/distribution	For product manufacturers: incorporate requirements from market support programmes or distributors in the design and production QC processes. For distributors: set minimum quality and warranty requirements for products to identify suppliers.
Bulk procurement	Set minimum quality and warranty requirements for products to qualify in a request for offers. If the project is in a specific location, the warranty requirements may also include specific levels of service in that particular area.
Trade regulation	Set minimum quality requirements for tax exemption or customs.

5.3 Quality assurance principles

The quality assurance framework presented in this document and IEC TS 62257-9-8 is designed to support broad types of programmes and institutions in the off-grid lighting market. The following key principles guide the framework.

- Balance quality and affordability for price-sensitive buyers – it does not matter how well products perform if the target users cannot afford them.
- Encourage innovation and technological diversity. Wherever possible, be open-ended in the technical approaches that are allowed.
- Empower buyers to choose the right product for their needs and budget by focusing product specifications and communication on outcomes for end users.
- Use low-cost, rigorous, targeted tests to match the general affordability requirements for the market and accommodate both incremental and innovative changes to product design. The tests should be feasible for use by a broad set of potential users.
- Focus quality standards on elements of a product that are difficult for typical buyers to assess themselves, like truth-in-advertising and durability.
- Focus warranty requirements on providing a baseline of support.

6 Quality test method

6.1 General

The quality test method (QTM) is a rigorous set of tests that uses randomly procured samples. It is the most stringent set of tests in this document and is appropriate for:

- qualification for market support programmes, and
- generating information for third-party verified specification sheets.

The QTM is appropriate for all products.

The required testing also varies depending on the design of the product. For instance, products with ports, such as DC power outlets, sockets, jacks, receptacles and USB charging ports, are subject to tests that simpler lanterns are not.

6.2 Applications

QTM tests can support a broad range of quality assurance needs where rigorous, unbiased test results are required. Table 2 lists examples of how they are applied depending on the type of quality assurance framework.

Table 2 – Applications of QTM results

Type of QA framework	Example(s) of applying Clause 6
General market support	Require QTM results for qualifying for market support. Accept QTM results from any accredited laboratory. Use QTM results to produce standardized specification sheets.
Manufacturing/distribution	Use QTM results to assess the full production/supply chain. Require QTM results for assessing potential business partners. Accept QTM results from any accredited laboratory.
Bulk procurement	Require QTM results for assessing potential suppliers. Accept QTM results from any accredited laboratory.
Trade regulation	Require QTM results for trade policies such as tax exemption or importation requirements. Accept QTM results from any accredited laboratory.

6.3 Sampling requirements

6.3.1 General

The product samples should be selected and shipped to the test lab in accordance with the random sampling guidelines outlined in Annex E.

The recommended number of samples to procure for QTM testing is 9: two each for two parallel batches, one for protection testing, one for IP testing plus three spares. Spares or the “least modified” samples at the end of testing may be used for the mechanical durability tests.

To minimize the in-kind cost of products and shipping costs for larger products, an alternative to sampling 9 complete kits is to sample the following numbers of individual components, along with the packaging for the kit. The recommended numbers of samples of each individual component to procure for QTM testing are as follows:

- PV module: 5 (2 for general testing, 1 for IP testing and 2 spares).
 - Two additional samples shall be collected if the partial shading test (Annex B) is required.
 - One additional sample shall be collected if the bending and folding of PV modules test is required (Annex C).
 - If modules meet all requirements of IEC 61215-1 and IEC 61215-2, only 3 samples are required – 2 for general testing (I-V characteristics testing and wiring inspection) and to provide connectors for the solar charge test, and 1 spare. If modules referencing IEC 61215-1 and IEC 61215-2 will also undergo strain relief testing, an additional spare sample should be collected.
- PV mounting material, if applicable: 1 (for IP testing).
- Control box with battery: 9 (2 for general testing, 2 for lumen maintenance/battery durability, 1 for protection testing, 1 for IP testing, and 3 spares).
- Included lighting appliances: select a minimum of 9 of each type, using the following formula for cases where more than two lights of a given type are included in with the product: 5 of each type, plus an additional 2 multiplied by the number of that light type that are included in the kit.

EXAMPLE 1 If a product includes five light points, three of Type A and two of Type B, select 11 samples of Type A and 9 samples of Type B. If a product only includes one of each light type, select 9 samples of each type (2 for general testing, 2 for lumen maintenance, 2 for mechanical durability, 1 for IP testing and 2 spares).

- Included non-lighting appliances (or lighting appliances that are not required to undergo the lighting tests): 7 of each type (2 for general testing, 2 for mechanical durability, 1 for IP testing, and 2 spares).
- Included lighting appliance with its own battery: 9 of each type (2 for general testing, 2 for lumen maintenance, 2 for mechanical durability, 1 for IP testing and 2 spares).

These recommendations assume that 2 to 3 spares are sufficient to conduct the potentially destructive tests, such as the drop test, miswiring test, output overvoltage protection test, PV overvoltage protection test, and switches and connectors test. If additional samples are required, they may be procured during the testing process.

6.3.2 Consumer-facing product documentation

At least one hard copy of the packaging and other consumer-facing product documentation (user manuals, warranty cards, user agreements, data sheets, quick start guides, or similar) should be collected when products are sampled. If hard copies of the documentation are not available at the time of sampling, digital versions may be submitted to the test lab for evaluation. When digital versions are included in a test report, organizations evaluating compliance with the product specification may require proof of printing (for instance by sending photos of the printed materials or via a warehouse inspection) of the final materials following testing.

The following documentation should be collected:

- a) For stand-alone products (such as a single lantern with an integrated PV module):
 - 1) Product packaging;
 - 2) User manual;
 - 3) Warranty information, whether included in the user manual, a user agreement, or provided on a separate warranty card;
 - 4) Any other documentation provided with the product, such as a user agreement, technical data sheet, or quick start guide.
- b) For kits with multiple components (typically a main unit, PV module and light points; can have other appliances):
 - 1) Product packaging for the entire kit, for each kit being tested;
 - 2) User manuals for each entire kit being tested;
 - 3) Warranty information for each component in the kit, whether included in a user manual or user agreement for the entire product, or separate user manuals for each component, or provided on a separate warranty card;
 - 4) Any other documentation provided with the product, such as a user agreement, technical data sheet, or quick start guide.
- c) For product families (product lines including multiple kits that can be created with "mix-and-match" components):
 - 1) Product packaging for the entire kit, for each kit being tested;
 - 2) Component packaging for each component in the family that is packaged separately, or kit packaging for a kit that includes that component;
 - 3) User manuals for each entire kit being tested;
 - 4) User manuals for each component in the family with a separate manual, or a user manual for a kit that includes that component;
 - 5) Warranty information for each component, whether included in a user manual or user agreement covering all kits, or separate user manuals for each component, or provided on a separate warranty card;
 - 6) Any other documentation provided with the product, such as a user agreement, technical data sheets, or quick start guides.

6.3.3 Exceptions

When only certain components of a product are being tested, it is sometimes necessary to obtain additional components to support the operation of the components under test. If variations in the performance of the supporting components are unlikely to have significant effects on the test results, these supporting components may be procured without random sampling.

For example, if a lamp or other appliance is being tested for use with a previously tested product, and the lamp cannot operate unless connected to the previously tested power control unit, the power control unit may be obtained without random sampling. Supporting components can also include cables, connectors, remote controls, etc. required for the operation of the components under test. The entity applying this exception should consider the potential for intentional or unintentional variations in the supporting components to affect the test results.

6.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described in the following and accredited by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025). The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer or laboratory accreditation organization.

6.5 Testing requirements

Table 3 lists the test procedures that should be conducted on each product, along with the sample size required and applicability to specific product types or components. In Table 3, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated. The product specification may define categories of components or appliances that may be excepted from certain tests.

The table is organized in order of the aspects described in 4.2 and notes which aspects are measured by a given test. It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way.

For products with multiple settings, at least one set of test results should fully characterize the performance on the brightest light setting. Additional settings may be measured at the discretion of the test laboratory to verify truth in advertising statements from the company when other light settings are advertised, or as required in the product specification.

NOTE Table 3 includes columns with requirements for the renewal test method, initial screening method (ISM) and market check method (MCM) primary check testing (PCT) and includes comments regarding accelerated verification method testing. These tests are described in Clauses 7, 8, 9 and 10. An additional method is described in Clause 11 for testing pay-as-you-go (PAYG) products, but sample sizes and requirements are given in Table 8.

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Table 3 – QTM testing requirements

Test	Aspect reference(s)	Applicability	Sample size				Test method annex	Comments
			QTM (n=2)	Renewal (n=2)	PCT ^a (n=2)	ISM (n=1)		
Product design, manufacture, and marketing aspects	4.2.2							
Visual screening – Properties, features and information; Specifications	4.2.2.1, 4.2.2.2, 4.2.2.3, 4.2.2.4, 4.2.2.5, 4.2.2.6, 4.2.2.7, 4.2.2.8, 4.2.2.9, 4.2.2.10, 4.2.2.11	All products	1	1	1	1	Annex F	The visual screening should be done before any other tests and before the samples are altered to prepare them for other tests.
Product durability and workmanship aspects	4.2.3							
Visual screening – Functionality and quality inspection	4.2.3.1, 4.2.6.3	All products	2	2	2	1	Annex F	The visual screening should be done before any other tests and before the samples are altered to prepare them for other tests. This portion of the visual screening is conducted on multiple samples. Some tests are conducted on all samples that undergo any testing, and others are conducted on a subset, in accordance with the sample size specified in this table.
Water ingress protection test and level of water protection	4.2.3.2, 4.2.3.3, 4.2.3.4, 4.2.3.5	All products	1	1	1	1	Annex U, Annex V	Physical and water ingress protection shall be assessed on samples that have the least amount of impact or adulteration from the testing process. Unused spares should be the preferred samples for this assessment. The assessment of a technical level of water protection – circuit protection and drainage is only conducted at the request of the testing client.
Physical ingress protection test	4.2.3.6, 4.2.3.7	All products	1	1	1	1	Annex U	It is best to save destructive testing to the end of the test programme to ensure sufficient samples are available in other tests. These tests may be performed on spare samples. If samples have no damage or water ingress after testing, they may be used to conduct the mechanical durability tests, but samples that have experienced water ingress or other damage should not be used for further testing.

Test	Aspect reference(s)	Applicability	Sample size				Test method annex	Comments
			QTM (n=2)	Renewal (n=2)	PCT ^a (n=2)	ISM (n=1)		
Mechanical durability – Drop test	4.2.3.8	Portable components, excluding appliances such as TVs and other specified products or appliances that are not typically expected to meet durability standards	2	2	2	1	Annex W	In general, it is best to save destructive testing to the end of the test programme to ensure sufficient samples are available in other tests. These tests may be performed on spare samples or samples that have finished all other testing. It is preferable to do durability testing (switches, connectors, gooseneck/moving part, and drop test) on the "spare" samples that have not been altered for testing. However, it is often infeasible to accomplish this if the unadulterated spares are required for other tests. In this case, the "least modified" samples should be used. Note there are different drop test procedures for portable lighting products and non-lighting portable appliances (radios, razors, etc.).
Mechanical durability - Gooseneck and moving part test	4.2.3.9	Products with a gooseneck/moving part	2	2	2	1	Annex W	See notes for drop test.
Mechanical durability - Connector test	4.2.3.10	All products	2	2	2	1	Annex W	See notes for drop test.
Mechanical durability - Switch test	4.2.3.11	All products	2	2	2	1	Annex W	See notes for drop test.
Mechanical durability - Strain relief test	4.2.3.12	All products	2	2	2	1	Annex W	See notes for drop test.
Charge controller behaviour test	4.2.3.13	All products	2	2	2	1	Annex S	The deep-discharge protection charge controller measurement may be incorporated into the full-battery run time. The overcharge protection charge controller measurement requires independent testing but is required to be conducted prior to the full-battery run time test for all battery chemistries except NiMH.
Robustness of screw connections	4.2.3.14	All non-plug-and-play products with screws intended to be tightened during installation	1	1	1	1	Annex X	This test is only applicable for certain non-plug-and-play products. See notes for drop test.

Test	Aspect reference(s)	Applicability	Sample size				Test method annex	Comments
			QTM (n=2)	Renewal (n=2)	PCT ^a (n=2)	ISM (n=1)		
Lighting durability aspects								
Lumen maintenance test – 500 h	4.2.3.14							
	4.2.4.1	All products required to undergo lighting tests	-	-	2	1	Annex J	Samples shall not have undergone any other testing prior to lumen maintenance testing. This test is long-term and is carried out in parallel with general testing. The 500 h test is appropriate for accelerated verification method – verification entry (AVM-VE), initial screening method (ISM), and certain market check method (MCM) tests.
	4.2.4.1	All products required to undergo lighting tests	2	2	-	-	Annex J	Samples shall not have undergone any other testing prior to lumen maintenance testing. This test is long-term and is carried out in parallel with those tests undergoing general testing. Products undergoing QTM or renewal testing shall undergo either the 1 000 h test or the alternative test using ANSI/IES LM-80 data.
Lumen maintenance test – 1 000 h	4.2.4.1	All products required to undergo lighting tests	2	2	-	-	Annex J	Samples shall not have undergone any other testing prior to lumen maintenance testing. This test is long-term and is carried out in parallel with those tests undergoing general testing. The alternate method using ANSI/IES LM-80 data is designed to shorten the time required to test a product prior to market entry and is offered as an alternative to the 1 000 h test. There may be restrictions regarding which products are eligible to use this method. Products undergoing QTM or renewal testing shall undergo either the 1 000 h test or the alternative test using ANSI/IES LM-80 data.
Lumen maintenance test – Alternate method using ANSI/IES LM-80 data	4.2.4.1	All products required to undergo lighting tests	2	2	-	-	Annex J	Samples shall not have undergone any other testing prior to lumen maintenance testing. This test is long-term and is carried out in parallel with those tests undergoing general testing. The alternate method using ANSI/IES LM-80 data is designed to shorten the time required to test a product prior to market entry and is offered as an alternative to the 1 000 h test. There may be restrictions regarding which products are eligible to use this method. Products undergoing QTM or renewal testing shall undergo either the 1 000 h test or the alternative test using ANSI/IES LM-80 data.
Fluorescent light durability	4.2.4.2	Products with fluorescent light required to undergo lighting tests	2	2	2	1	Cycling test of IEC TS 62 257-12-1	If fluorescent lights are included with the product, these shall undergo additional checks of durability as described in IEC TS 62257-12-1.

Test	Aspect reference(s)	Applicability	Sample size				Test method annex	Comments
			QTM (n=2)	Renewal (n=2)	PCT ^a (n=2)	ISM (n=1)		
Battery performance aspects	4.2.5							
Battery test – Battery capacity	4.2.5.1	All products	2	2	2	1	Annex K	The battery tests should be done before any system-level run time tests to ensure the batteries are "refreshed" from any time they spent in storage before testing. Recommended practices are presented in Annex L.
Battery test – Battery round-trip energy efficiency	4.2.5.2	All products	2	2	2	1	Annex K	See note for battery capacity.
Battery durability test	4.2.5.3	All products required to undergo lighting tests	2	2	2	1	Annex BB	While the lighting appliances of samples are connected to power supplies for the lumen maintenance test, the batteries of the same samples are tested for durability during storage. This test is long-term and is carried out in parallel with general testing.
Battery test – Battery nominal voltage	4.2.5.4	All products	2	2	2	1	Annex F	The nominal voltage is not a measured value. It is recorded in the visual screening.
PV module aspects	4.2.6							
Photovoltaic module I-V characteristics test	4.2.6.1	All products	2	2	2	1	Annex Q	Since outdoor solar PV module testing is subject to the availability of a clear "solar window", this is often the most "opportunistic" test in the programme. Alternatives are described for using indoor test methods. For amorphous PV modules, it is important to begin sun soaking the modules immediately after they are received, since at least 30 days of outdoor exposure are necessary before the tests commence.
Visual screening – Cable length	4.2.6.2	All products	2	2	2	1	Annex F	Cable length is measured during the visual screening.
Photovoltaic module wiring inspection	4.2.6.4	All products with separate PV modules	2	2	2	1	Annex A	This test does not apply to conductors internal to a main unit or modules that are integrated into another component.
Partial shading of photovoltaic modules	4.2.6.5	All PV modules >100W	1	-	-	1	Annex B	This test is not appropriate for PV modules with power ratings exceeding 240 W, open-circuit voltages exceeding 35 V, or short-circuit currents exceeding 8 A. These are required to undergo testing to the hot-spot endurance test in IEC 61730-2 or IEC 61215-2.
Bending and folding PV modules	4.2.6.6	All bendable or foldable PV modules	1	-	-	1	Annex C	This test is not applicable to PV modules that are neither flexible nor foldable, and only applies to PV modules that are intended to be bent or folded during installation or use.

Test	Aspect reference(s)	Applicability	Sample size				Test method annex	Comments
			QTM (n=2)	Renewal (n=2)	PCT ^a (n=2)	ISM (n=1)		
Electrical characteristics	4.2.7							
Appliance tests – Appliance operating voltage range test	4.2.7.1	All products with appliances	1	1	1	1	Annex FF	In general, it is best to save destructive testing to the end of the test programme to ensure sufficient samples are available in other tests. This test may be performed on spare samples or samples that have finished all other testing. The voltage range compatibility of included appliances is measured in Annex FF.
Appliance tests – Power consumption test	4.2.7.2	All products with appliances	2	2	2	1	Annex FF Annex M	The power consumption of included appliances is measured in Annex FF. In some cases, the power consumption test may be omitted for built-in appliances or appliances with internal batteries that have undergone a full-battery run time test (Annex M) or appliance full-battery run time test (Clause FF.9) with no other appliance plugged in; see FF.6.10.2.
Protection tests – Output overload protection test	4.2.7.3	All products with ports; not required for appliances	1	1	1	1	Annex DD	This test assesses whether the DUT is protected against excessive load or short circuits applied to the appliance receptacles. The test is not dependent on any other tests, but is required to be conducted prior to the assessment of DC ports in Annex EE. The test is potentially destructive and should be conducted on either samples that have finished all other tests, or spare samples that are not required for any other tests.
Protection tests – PV overvoltage protection test	4.2.7.3	All products with ports; not required for appliances	1	1	1	1	Annex DD	This test assesses whether the DUT can withstand a PV overvoltage condition when the battery is disconnected. This test is conducted on only one sample and shall be conducted after performing the photovoltaic module I-V performance test (Annex Q). The test is potentially destructive and should be conducted either on samples that have finished all other tests, or on spare samples.
Protection tests – Miswiring protection test	4.2.7.3	All products with ports; not required for appliances	1	1	1	1	Annex DD	This test assesses whether the DUT is protected against improper wiring. The test is not dependent on any other tests, but is potentially destructive and should be conducted on either samples that have finished all other testing, or spare samples that are not required for any other tests.
Solar charge test	4.2.7.4	All products	2	2	2	1	Annex R	The battery-charging circuit efficiency and the solar charging efficiency is determined during the solar charge test. The solar charge test shall be commenced after the sample is fully discharged in accordance with the full discharge procedure in Annex N.

Test	Aspect reference(s)	Applicability	Sample size				Test method annex	Comments
			QTM (n=2)	Renewal (n=2)	PCT ^a (n=2)	ISM (n=1)		
Assessment of DC ports	4.2.7.5	All products with ports; not required for appliances	2	2	2	1	Annex EE	The ports test is dependent on the result of the output overload protection test described in Annex DD. The port efficiencies are inputs to the energy service calculations.
Appliance tests – Charging efficiency test	4.2.7.6	Appliances with internal batteries, if requested by company	-	-	-	-	Annex FF	This measures the efficiency of appliance charging from the main unit and the power consumed from the main unit during charging. Default values are used unless the test is requested by the company. If testing is conducted the sample size used for the energy service calculations should be used.
Performance aspects								
Energy service calculations	4.2.8.2, 4.2.8.3, 4.2.8.4, 4.2.8.5	All products	2	2	2	1	Annex GG	The energy service calculations are used to estimate the system-level run time at a given utility level (e.g. lumens of light, or volume of radio play). The calculations use values from the battery test (Annex K), the solar charge test (Annex R), the assessment of DC ports (Annex EE), generic appliances (Annex HH), Appliance tests (Annex FF), and full-battery run time test (Annex M). All of these tests shall be conducted prior to finalizing the energy service calculations.
Full-battery run time test	4.2.8.6	All products	2	2	2	1	Annex M	Cycle the batteries (as is done in the battery capacity measurements) and fully charge them before this test. It is often convenient to do the full-battery run time test directly after the battery capacity measurements.
Appliance tests – Appliance full-battery run time	4.2.8.7	All appliances with internal batteries	2	2	2	1	Annex FF	See notes for full-battery run time test.
Grid-charge test	4.2.8.8	Products with AC input or advertised DC charging time (see comments)	2	2	2	1	Annex O	The grid charge test shall be performed if the product includes an AC-DC power supply or if charging time from an external DC power source (e.g. a user-supplied USB power adapter) is advertised. Grid-charge testing shall be commenced after the sample is fully discharged in accordance with the full discharge procedure in Annex N. The grid charge test may be omitted for products that can charge from an external DC power source (e.g. USB) if the time required to charge the battery from this power source is not advertised.

Test	Aspect reference(s)	Applicability	Sample size				Test method annex	Comments
			QTM (n=2)	Renewal (n=2)	PCT ^a (n=2)	ISM (n=1)		
Electromechanical charge test	4.2.8.9	Electro-mechanically charged products	2	2	2	1	Annex P	Electromechanical charge testing shall be commenced after the sample is fully discharged in accordance with the full discharge procedure in Annex N. The electromechanical charge power or energy value determined by the electromechanical charge test is used to determine the electromechanical charging ratio in Annex GG.
Charge controller behaviour test – Standby loss measurement	4.2.8.10	All products	2	2	2	1	Annex S	The standby loss measurement may be conducted independently of other charge controller tests.
Light output aspects								
Light output test	4.2.9.1	All products required to undergo lighting tests	2	2	2	1	Annex I	The light output test is not strictly on components, but of a system including a driver, light source, and optical components. However, the system may be treated as a single component if it is separable from the other main components while maintaining the same electrical and thermal characteristics that are present when the product is fully assembled. The light output test procedure should be done after the full-battery run time test and is presented in Annex I.
Light distribution test – Full width half maximum (FWHM) angles	4.2.9.2	Only required at request of specification	-	-	-	-	Annex T	If this test is requested, it may be performed on a single sample, unless otherwise specified. Like the light output test, the light distribution test is not strictly on components, but of a system including a driver, light source, and optical components. However, the system may be treated as a single component if it is separable from the other main components while maintaining the same electrical and thermal characteristics that are present when the product is fully assembled. The light distribution test procedure should be done after the full-battery run time test.
Light distribution test – Average light distribution characteristics	4.2.9.3	Only required at request of specification	-	-	-	-	Annex T	If this test is requested, it may be performed on a single sample, unless otherwise specified.
Light output test – Colour characteristics	4.2.9.4	All products required to undergo lighting tests	2	2	2	1	Annex I	The CCT and CRI are collected as part of the light output test.

Test	Aspect reference(s)	Applicability	Sample size				Test method annex	Comments
			QTM (n=2)	Renewal (n=2)	PCT ^a (n=2)	ISM (n=1)		
Self-certification aspects	4.2.10							
Company self-reported information	4.2.10.1, 4.2.10.2, 4.2.10.3	All products	n/a	n/a	n/a	n/a	Annex D	If it has not already been done, the company (or their proxy) should be contacted to ask for self-certification information that is outlined in Annex D and to inform them the test samples were received.
^a The requirements of the market check method (MCM) primary check test (PCT) may also be used for the AVIM follow-up test. See Clause 10 for more details. The only difference between the QTM test plan and the renewal test is that some PV durability tests are waived in the renewal test. The only difference between the renewal test and the MCM PCT is that the lumen maintenance testing requirements differ.								

6.6 Recommended tests programme

6.6.1 General

The following programme, illustrated in Figure 6, is one strategy to accomplish all the tests in a timely manner for products that do not have ports. Figure 7 illustrates a strategy to complete all the required tests for products with ports. If conducting the ports test and energy service calculations, the assessment of DC ports and appliance power consumption tests should be conducted after the charge controller behaviour tests and before the miswiring and PV overvoltage protection tests. The results from the tests in "Group A" will be used in the energy service calculations.

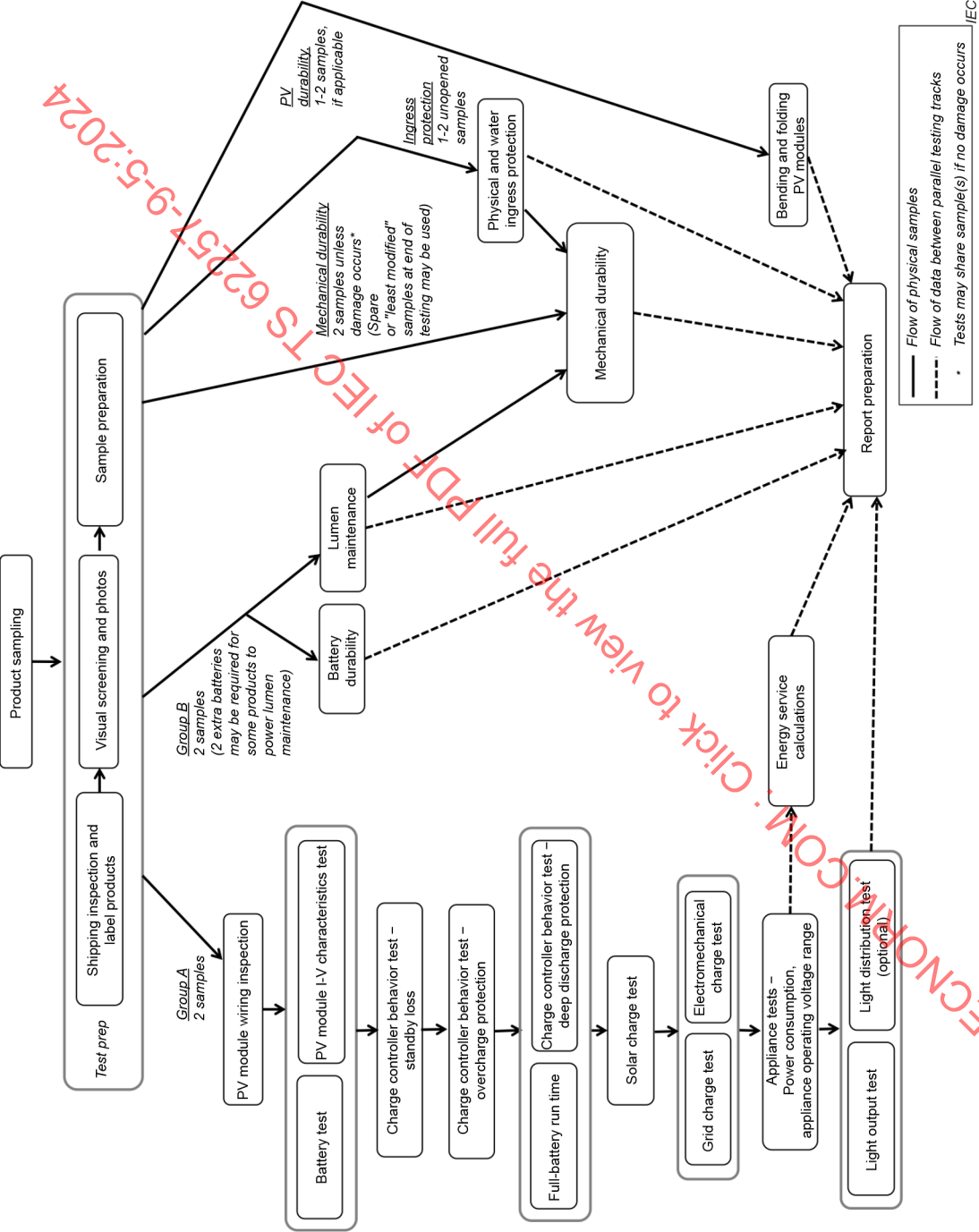


Figure 6 – Recommended sequence of testing for QTM for products without ports

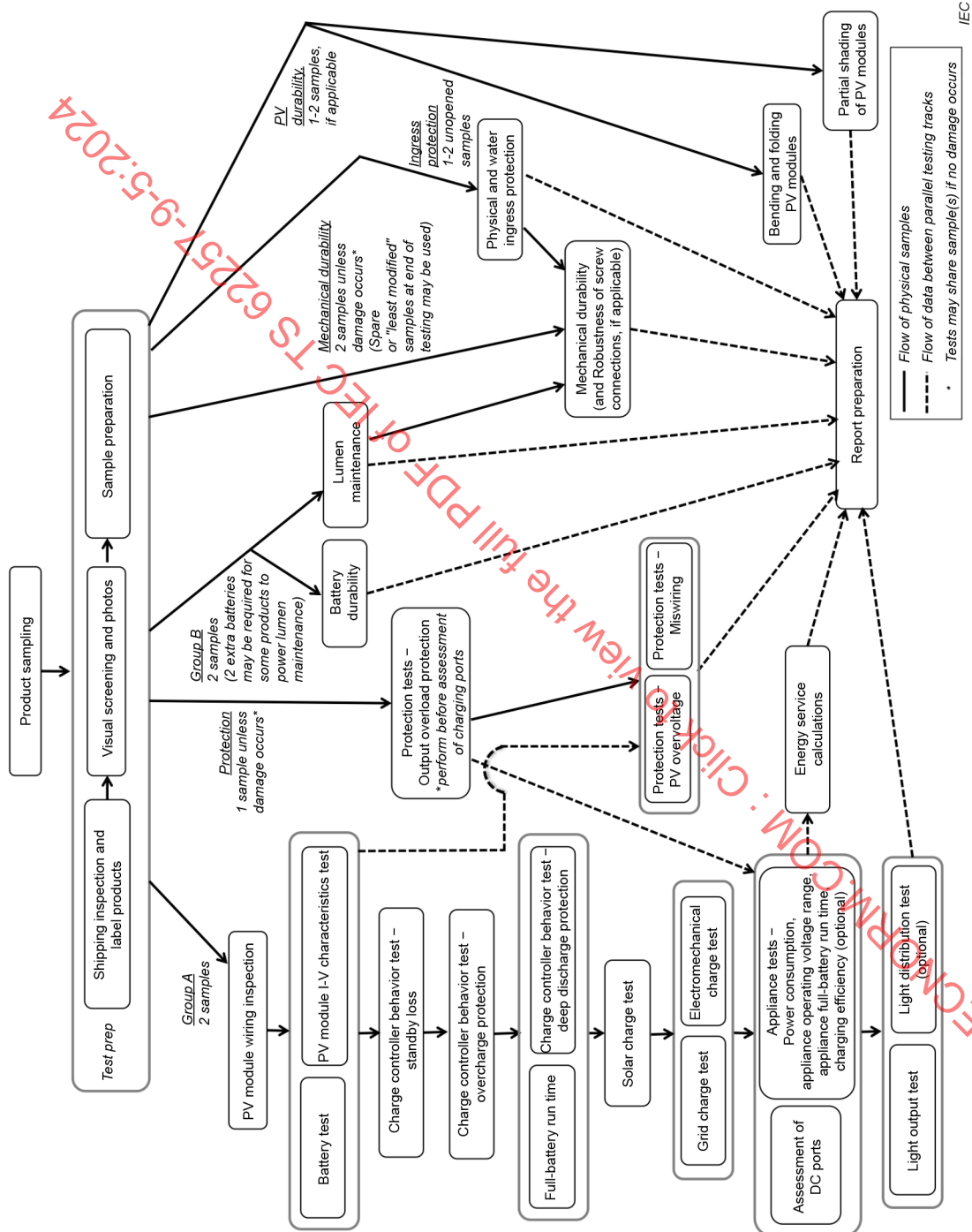


Figure 7 – Recommended sequence of testing for QTM for products with ports

6.6.2 Test preparation

The initial intake steps involve ensuring the samples are intact, preparing them for further tests, and requesting self-certification information from the company. As shown in Figure 6 and Figure 7, the tests included in a specific batch may differ from what is described in the following depending on the testing requirements. Initial steps required for all products include:

- Conduct test sample intake and shipping inspection: the samples should all be inspected for shipping damage, unambiguously labelled for identification during the testing process, and placed into batches.
- Solicit and record company self-reported information and self-certification aspects.
- Conduct the visual screening tests.
- Prepare samples for further testing. Many samples will require partial disassembly to provide easy access to various components. Sample preparation procedures are presented in Annex G. All samples, except for spares, shall be prepared.

6.6.3 Batch A tests

As shown in Figure 6 and Figure 7, it is recommended that tests be conducted in batches to minimize the time required for testing. Typically, Batch A undergoes the main set of tests in approximately the following order:

- Energy component tests:
 - Battery test
 - Photovoltaic module I-V characteristics test
- Run time tests:
 - Full-battery run time test(s)
 - Charge controller behaviour test
 - Full discharge procedure
 - Solar charge test, grid charge test, and electromechanical charge test (as applicable)
- Lighting tests:
 - Light output test
 - Light distribution test (optional)
- Energy service tests:
 - Ports test (if applicable)
 - Appliance power consumption test (if applicable)
 - Appliance charging efficiency tests (optional)
 - Appliance full-battery run time tests (if applicable)
 - Energy service calculations

6.6.4 Batch B tests

Batch B undergoes long-term lumen maintenance testing and the battery durability test in parallel with Batch A testing.

6.6.5 Batch C – potentially destructive tests

In general, it is best to save destructive testing to the end of the test programme to ensure sufficient samples are available in other tests. The only exception is the output overload protection test, which is performed before the ports test for products with ports. Potentially destructive tests may be performed on spare samples or batch A or B samples that have finished all other testing. Most potentially destructive tests are performed on only one sample, though the mechanical durability tests are performed on multiple samples. The following tests are to be performed:

- Physical and water ingress protection tests
- Mechanical durability tests (if applicable):
 - Switch and connector test
 - Gooseneck and moving part test
 - Strain relief test
 - Drop test
- Circuit protection tests (if applicable):
 - Output overload protection test
 - Miswiring protection test
 - PV overvoltage protection test
- Appliance voltage range test (if applicable)

6.6.6 Report preparation

After testing is complete and the results are validated, a report is generated and checked for accuracy before submission to the client.

6.6.7 Failures during testing

If a sample stops functioning or develops a safety hazard as a result of normal use during testing but after the visual screening (Annex F), the visual screening results including workmanship quality and safety shall be updated to reflect the failure or hazard. The report should distinguish between failures on initial inspection and subsequent failures. Failures that occur as a result of testing conditions not representative of normal use, such as damage that occurs as a result of disassembly or errors made by the laboratory, shall be noted in the report, but shall not be considered in the workmanship quality or safety outcomes of the visual screening.

EXAMPLE 1 If a battery fails during the grid charge test when the product is being charged from the included grid charger, this is considered a functionality failure, since the product is being charged under conditions representative of normal use.

EXAMPLE 2 If a product is damaged during the light output test because the power supply is accidentally set to the wrong voltage, this is not considered a functionality failure, because the abnormal voltage would not occur during normal use.

In some cases it is not possible to determine conclusively whether a failure was caused by conditions representative of normal use. The laboratory may use their discretion to determine whether the failure should be considered in the visual screening results.

EXAMPLE 3 A product charges normally from the PV module during the initial functionality check, but does not charge after disassembly and reassembly. The laboratory determines that there is a broken solder joint in the PV module. The laboratory can consider the design of the product, the difficulty of disassembly, photos taken during intake and testing, and other factors in determining whether the failure was the result of a pre-existing defect or damage during disassembly.

If a sample fails before testing on that sample is complete, the laboratory may substitute a different sample for subsequent testing. Results of previous testing unaffected by the failure should be reported. If outcomes of tests conducted on the damaged sample are used as inputs for tests conducted on the replacement sample, the laboratory may repeat the tests or use the original results, subject to the following guidelines:

- a) If the test results for the previous sample will be directly compared or related to results for the new sample, or variability between samples would invalidate the results, the tests should be repeated.

EXAMPLE 4 Luminous efficacy should not be calculated using the luminous flux for one sample and the power for a different sample.

- b) Otherwise, the laboratory may, at their discretion and with approval from the testing client, use the results from the failed sample.

EXAMPLE 5 The energy service calculations may be performed using full-battery run time and solar charge test results from a failed sample and port characteristics from a replacement sample.

The laboratory may repair a failed sample by combining parts with a replacement sample, if this is approved by the testing client and noted in the test report. For example, the battery from the failed sample may be installed in the replacement sample, or a failed appliance may be replaced by another sample of the same appliance. Repairs may also be made using materials supplied by the laboratory if the repairs are not likely to affect test results.

EXAMPLE 6 A wire or component that is accidentally broken off a circuit board may be resoldered.

6.7 Reporting

The report for QTM testing should support any activities that depend on the information from QTM testing.

At a minimum, the report should include the following elements.

- a) Informative cover page.
- b) Summary page(s).
- c) Detailed test reports that include results for the aspects described in 6.5 that were measured at the primary test lab. Required results are listed at the end of each annex.
- d) Detailed test reports for tests performed at other labs (e.g. ingress protection test results done at a specialty IP test lab).
- e) Annexes that include either supplementary images or other supporting information, or both.
- f) Annexes that indicate company-provided information and self-certification evidence (e.g. certificates of compliance).

7 Renewal test method

The renewal test method is used to confirm and update a previously tested product's results. The renewal test method is identical to the QTM as described in Clause 6 except that some of the PV safety tests are not required, as indicated in Table 3. The requirements of Clause 6 shall apply.

8 Market check method

8.1 General

The market check method (MCM) is a flexible set of tests that is designed for market monitoring and enforcement. The MCM may comprise all the QTM tests, or a targeted subset of the QTM tests. The tests are designed for use in the following situations:

- when a program wants to monitor the on-going quality and performance of previously tested products;
- when there is suspicion that products on the market are substandard compared to those that were originally tested for programme qualification or the production of a standardized specification sheet;

MCM testing may be implemented as a two-stage process. In the first stage, which is referred to as a primary check test (PCT), a test with a sample size of two is conducted with products that are randomly sampled as outlined in Annex E.

If results from these tests meet or exceed performance from prior QTM testing, no further action is required. However, if the results indicate possible deficiencies relative to either the product specification or prior QTM test results, or both, additional testing may be used to confirm the problem. This subsequent testing, which is referred to as secondary check testing, may focus only on the aspects of the product that appeared to have deficiencies according to the primary check testing results. The required sample size and allowable test classes for secondary check testing using the MCM should be the same as those required for QTM testing of the same aspect (see 6.5).

Alternatively, if a product is partially updated or only suspected to be substandard in particular aspects, a program may choose to forego the first stage of primary check testing and conduct targeted secondary check testing on only those aspects.

8.2 Applications

MCM tests may have a narrower focus than QTM tests – they may be targeted for determining if a deviation has occurred from previous QTM results for particular aspects. Table 4 lists examples of how MCM tests are applied depending on the type of quality assurance framework.

Table 4 – Applications of MCM results

Type of QA framework	Example(s) of applying MCM testing
General market support	Use MCM results for market monitoring and enforcement.
Manufacturing and distribution	Use MCM results for market monitoring.
Bulk procurement	n/a
Trade regulation	Use MCM results for market monitoring and enforcement.

8.3 Sampling requirements

The test samples should be randomly procured from retail outlets in the market in accordance with procedures in Annex E. In select cases, samples may be randomly selected from a company's warehouse in accordance with procedures in Annex E.

The recommended number of samples for primary check testing is identical to the guidance provided for QTM testing (6.3) and the exceptions of 6.3.3 apply.

The recommended number of samples for secondary MCM testing will be dependent on the specific test plan, though the required sample size for secondary MCM testing should be the same as those required for QTM testing of the same aspect (see 6.5). Enough samples should be provided or selected so it is possible to complete the tests in a timely manner and account for unforeseen needs of additional samples.

8.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described in the following and accredited by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025). The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer or laboratory accreditation organization.

8.5 Testing requirements

Most of the specific test requirements for MCM tests will depend on the aspects that are being tested.

If a full primary check test (PCT) is being conducted, as indicated in Table 3, each of the aspects listed in the PCT column should be measured where they are applicable to a product. It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way. A general description of the test method family for each aspect is listed for informative purposes only. In Table 3, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated. The product specification may define categories of components or appliances that may be excepted from certain tests.

For products with multiple settings, at least one set of test results should fully characterize the performance on the brightest light setting. Additional settings may be measured at the discretion of the test laboratory to verify advertising statements from the company when other light settings are advertised, or as required in the product specification.

The particular test plan for secondary MCM testing is case-dependent and up to the judgement of the organization or institution who initiates the testing. The following recommendations should be kept in mind when creating MCM test plans.

- Always include a visual screening test to uncover any unexpected changes to the product; be ready to augment the original test plan pending the visual screening results.
- Consider system-level impacts of component changes.

8.6 Recommended tests programme

See 6.6. The MCM PCT test is nearly identical to a full QTM test, though the PV safety and lumen maintenance tests differ as indicated in Table 3.

8.7 Report requirements

The report for MCM testing should support any activities that depend on the information from MCM testing. See 6.7 for minimum reporting requirements, though the report should cover aspects described in 8.5.

9 Initial screening method

9.1 General

The initial screening method (ISM) is appropriate for preliminary testing and providing quick feedback on product design and performance in absolute terms.

9.2 Applications

ISM tests should be used for obtaining quick, preliminary results to help inform subsequent rounds of testing that confirm the preliminary results. Table 5 lists examples of how they are applied depending on the type of quality assurance framework.

Table 5 – Applications of ISM results

Type of QA framework	Example(s) of applying Clause 9
General market support	Use ISM results to filter potential organizations/products for targeted support, followed up by QTM testing for those with promise. Use ISM results to trigger MCM testing when there is suspicion of a change in the quality or performance of products in the market.
Manufacturing/distribution	Use ISM results for batch-to-batch monitoring of production runs of shipments.
Bulk procurement	Use ISM results for batch-to-batch monitoring shipments.
Trade regulation	Use ISM results to make preliminary decisions, followed up with QTM testing to confirm results.

9.3 Sampling requirements

The test samples may be provided directly by a company (or their proxy) or may be randomly procured from the market in accordance with procedures in Annex E.

Enough samples should be provided or selected so it is possible to complete the tests in a timely manner and account for unforeseen needs of additional samples.

The recommended number of samples for ISM testing is four: one each for two parallel batches, one for IP testing, and one spare. An additional sample is recommended if the product has ports. It may be necessary to obtain additional spares if the product fails more than one of the potentially destructive tests. (If shipping products to the test lab is difficult, provision of extra spares at the start of testing is recommended).

To minimize the in-kind cost of products and shipping costs for larger products, an alternative to sampling complete kits is to sample the following numbers of individual components, along with the packaging for the kit. The recommended numbers of samples of each individual component to procure for ISM testing are as follows:

- PV module: 3 (1 for general testing, 1 for IP testing and 1 spare).
 - One additional sample should be collected if the partial shading test (Annex B) is required.
 - One additional sample should be collected if the bending and folding of PV modules test is required (Annex C)
 - If modules meet all requirements of IEC 61215-1 and IEC 61215-2, only 2 samples are required – 1 for general testing (I-V characteristics testing and wiring inspection) and to provide a connector for the solar charge test, and 1 spare. If modules referencing IEC 61215-1 and IEC 61215-2 will also undergo strain relief testing, an additional sample should be collected.)
- PV mounting material, if applicable: 1 (1 for IP testing).
- Control box with battery: 4 (1 for general testing, 1 for lumen maintenance/battery durability testing, 1 for IP testing and 1 spare). If the product has ports, an additional sample is recommended. If batteries are required during the lumen maintenance test, an additional battery should be provided or procured, but these batteries may be procured without random sampling.

- Included lighting appliances: 3 of each type, plus an additional one multiplied by the number of that light type that are included in the kit. For instance, if a product includes five light points, three of Type A and two of Type B, select 6 samples of Type A and 5 samples of Type B. If a product only includes one of each light type, select 4 samples of each type (1 for general testing, 1 for lumen maintenance, 1 for IP testing and 1 spare).
- Included non-lighting appliances (or lighting appliances that are not required to undergo the lighting tests): 4 of each type (1 for general testing, 1 for mechanical durability, 1 for IP testing and 1 spare).
- Included lighting appliance with its own battery: 4 of each type (1 for general testing, 1 for lumen maintenance, 1 for IP testing and 1 spare).

These recommendations assume that 1 spare is sufficient to conduct the potentially destructive tests, such as the drop test, miswiring test, output overvoltage protection, PV overvoltage protection, and switches and connectors test. If additional samples are required, they may be procured during the testing process.

Guidance regarding product documentation to submit is provided in 6.3.2.

If random sampling is used, the exceptions of 6.3.3 apply.

9.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described in the following. The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer.

9.5 Testing requirements

As indicated in Table 3, each of the aspects listed in the ISM column should be measured where they are applicable to a product. It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way. A general description of the test method family for each aspect is listed for informative purposes only. In Table 3, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated. The product specification may define categories of components or appliances that may be excepted from certain tests.

For products with multiple settings, at least one set of test results should fully characterize the performance on the brightest light setting. Additional settings may be measured at the discretion of the test laboratory to verify advertising statements from the company when other light settings are advertised, or as required in the product specification.

9.6 Recommended tests programme

See 6.6.

9.7 Reporting

The report for ISM testing should support any activities that depend on the information from ISM testing. See 6.7 for minimum reporting requirements, though report should cover aspects described in 9.5.

10 Accelerated verification method

10.1 General

The accelerated verification method (AVM) is an optional pathway to enable expedited entry to market or market support programmes. The AVM includes a 2-step process of a verification entry (AVM-VE) test and follow-up test. Results from AVM-VE testing may qualify a product for market support until the results are verified through a randomly sampled follow-up test. It is recommended that this pathway only be offered to companies who meet specified eligibility criteria. The three elements of the AVM – eligibility criteria, verification entry testing, and follow-up testing – are described as follows:

- Eligibility should be based on a company's experience and historical performance with the off-grid lighting market support programme. Recommended eligibility criteria should consider the number of products that a company has successfully tested with the programme, any recent instances in which the company's products were tested and did not meet the quality standards, as well as the company's conduct in the market and communication with the market support programme.
- AVM-VE testing is equivalent to a QTM test (6.5) with the random sampling requirement of QTM testing waived.
- Follow-up testing is conducted shortly after AVM-VE testing is finished and the product is commercially available in markets. The AVM follow-up test is equivalent to a typical market check method (MCM) primary check test (PCT) as described in Clause 7. Follow-up MCM testing shall be conducted on commercially available products within six months of the preceding QTM testing. Sampling procedures for the MCM (8.3) shall be followed.
- Poor performance in follow-up tests may be accompanied by penalties enacted by the market support programme to incentivize compliance. Recommended penalties include loss of programme support, loss of eligibility to use the AVM pathway and monetary penalties.

10.2 Applications

The AVM pathway is only recommended for companies who meet specified eligibility criteria and for products that are reasonably expected to meet the rigors of the QTM test. The AVM enables these select products to undergo initial, expedited testing with samples that are representative of the products the company plans to distribute but are not necessarily from a full production run. Table 6 lists examples of how AVM tests are applied depending on the type of quality assurance framework.

Table 6 – Applications of AVM results

Type of QA framework	Example(s) of applying AVM testing
General market support	Require AVM-VE test results for qualifying for temporary market support. Use follow-up test results to continue market support. Accept AVM results from any accredited laboratory. Use AVM-VE test results to produce standardized specification sheets. Update these standardized specification sheets with results from the follow-up test.
Manufacturing/distribution	Use AVM-VE test and follow-up test results to assess the full production/supply chain. Require AVM-VE test and follow-up test for assessing potential business partners. Accept AVM results from any accredited laboratory.
Bulk procurement	Require AVM-VE test and follow-up tests for assessing potential suppliers. Accept AVM results from any accredited laboratory.
Trade regulation	Require AVM-VE test and follow-up test results for trade policies such as tax exemption or importation requirements. Accept AVM results from any accredited laboratory.

10.3 Sampling requirements

10.3.1 General

Testing for the AVM is segmented into two parts: AVM-VE testing and follow-up testing.

10.3.2 Verification entry testing

The test samples for AVM-VE testing may be provided directly by a company (or their proxy).

The company shall provide a declaration to accompany the products which states: "a) the samples provided for testing are an accurate representation of the final production model that they plan to distribute, and b) the product is expected to meet the quality standards of the off-grid lighting market support programme." The off-grid lighting market support programme may also require the company to submit documentation to assist with follow-up testing and routine market check testing. Documentation may include, but is not limited to:

- an annual report listing the main markets in which their quality-verified products are being sold, differentiated by product model name,
- the names and contact details of the principal distributors to whom they sell their products,
- annual shipment figures (for the previous year) of quality-verified products, and
- the intended markets and distributors that will be used for the product under test.

Enough samples should be provided or selected so it is possible to complete the tests in a timely manner and account for unforeseen needs of additional samples.

AVM-VE tests are equivalent to a QTM test with a sample size of two, with the random sampling requirement of QTM testing waived. The recommended number of samples for AVM-VE testing is identical to the guidance provided for QTM testing (6.3) and the exceptions of 6.3.3 apply.

10.3.3 Follow-up testing

The test samples for follow-up testing should either be randomly procured from retail outlets in the market or randomly sampled from a company's warehouse in accordance with procedures in Annex E.

The follow-up test should use a sample size of two, equivalent to a typical market check method (MCM) primary check test (PCT). See 8.3 for sampling requirements.

The exceptions of 6.3.3 apply.

10.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described in the following and accredited by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025). The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer or laboratory accreditation organization.

10.5 Testing requirements

10.5.1 General

Testing requirements for the AVM are segmented into two parts: AVM-VE testing and follow-up testing.

10.5.2 Verification entry testing

Each of the aspects listed in the QTM column of Table 3 should be measured where they are applicable to a product.

It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way. A general description of the test method family for each aspect is listed for informative purposes only. In Table 3, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated. The product specification may define categories of components or appliances that may be excepted from certain tests.

For products with multiple settings, at least one set of test results should fully characterize the performance on the brightest light setting. Additional settings may be measured at the discretion of the test laboratory to verify truth in advertising statements from the company when other light settings are advertised, or as required in the product specification.

10.5.3 Follow-up testing

Each of the aspects listed in the PCT column of Table 3 should be measured where they are applicable to a product.

It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way. A general description of the test method family for each aspect is listed for informative purposes only. In Table 3, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated. The product specification may define categories of components or appliances that may be excepted from certain tests.

For products with multiple settings, at least one set of test results should fully characterize the performance on the brightest light setting. Additional settings may be measured at the discretion of the test laboratory to verify truth in advertising statements from the company when other light settings are advertised, or as required in the product specification.

10.6 Recommended tests programme

See 6.6.

10.7 Report requirements

The report for AVM testing should support any activities that depend on the information from AVM testing. See 6.7 for minimum reporting requirements, though report should cover aspects described in 10.5.

11 Pay-as-you-go (PAYG) method

11.1 General

The PAYG method provides a set of targeted tests to verify key parameters that may be affected by adding PAYG or fee-for-service technology to a product. In some cases a product is sold in both a PAYG enabled version and a non-PAYG version. The provider of PAYG technology may be the same organization that designs and sells the energy system or may be a third-party "business to business" provider of PAYG. In either case, targeted testing may be appropriate rather than requiring that all aspects of the otherwise similar product be retested. Targeted testing is composed of:

- Visual inspection, including internal assessment.
- Durability testing on any aspects that may have been impacted by the addition of the PAYG option (e.g. new ports or changes to the existing casing).
- An estimate of the parasitic consumption or additional standby loss due to the addition of the PAYG option.

11.2 Applications

The PAYG method is appropriate for targeted testing of fee-for-service or PAYG-enabled versions of products that previously qualified for market entry or market support programmes through the process of QTM or AVM testing. Fee-for-service or PAYG-enabled products that are not versions of an otherwise identical product that already meets a programme's quality standards should be fully tested in accordance with the QTM or AVM to either qualify for market support programmes or produce a standardized specification sheet, or both. In cases where PAYG-enabled versions of products are similar, but not identical to the previously tested non-PAYG version, those aspects which differ shall be tested. Table 7 lists examples of how PAYG tests are applied depending on the type of quality assurance framework.

Table 7 – Applications of PAYG method results

Type of QA framework	Example(s) of applying PAYG testing
General market support	Require PAYG test results for qualifying for market support in cases where a non-PAYG version of the product already qualifies for market support. Accept PAYG results from any accredited laboratory. Use PAYG results to update standardized specification sheets to include the PAYG-enabled version of a product.
Manufacturing/distribution	Require PAYG for assessing potential business partners in cases where a non-PAYG version of the product has already been tested. Accept PAYG results from any accredited laboratory.
Bulk procurement	Require PAYG test results for qualification screening on bidders in procurements that will include a PAYG element, accepting a combination of non-PAYG and targeted PAYG testing as appropriate. Accept PAYG results from any accredited laboratory.
Trade regulation	Require PAYG test results for qualification screening on products that are subject to trade regulation, accepting a combination of non-PAYG and targeted PAYG testing as appropriate. Accept PAYG results from any accredited laboratory.

11.3 Sampling requirements

The test samples may be provided directly by a company (or their proxy) or may be randomly procured from the market in accordance with procedures in Annex E.

Enough samples should be provided or selected so it is possible to complete the tests in a timely manner and account for unforeseen needs of additional samples.

The recommended number of samples for PAYG testing is four: two each for two parallel tests.

In cases where PAYG-enabled versions of products are similar, but not identical to the previously-tested non-PAYG version, those aspects which differ will require testing using samples that are procured in accordance with the sampling requirements of the QTM or AVM.

Guidance regarding product documentation to submit is provided in 6.3.2.

If random sampling is used, the exceptions of 6.3.3 apply.

11.4 Laboratory requirements

The test laboratory should be properly trained to undertake the test methods described in 11.5. The measurement equipment should be calibrated against reference instruments annually, or as directed by the equipment manufacturer.

11.5 Testing requirements

Each of the aspects listed in Table 8 should be measured where they are applicable to a product. It is not necessary that each aspect be measured on each sample under test, but it is important to note in the test results which samples were the source of each result in an unambiguous way. A general description of the test method family for each aspect is listed for informative purposes only. In Table 8, the designation "all products" indicates that the aspect should be measured for all types of products, including components or appliances, unless otherwise indicated.

In cases where PAYG-enabled versions of products are similar, but not identical to the previously-tested non-PAYG version, those aspects which differ shall be tested. For example, if a PAYG-version of a product includes an updated LED, it would be necessary to conduct the lighting and run time tests with sample sizes appropriate for the QTM or AVM.

Table 8 – PAYG testing requirements

Test	Aspect Reference(s)	Applicability	Sample size	Test method Annex
Product design, manufacture, and marketing aspects	4.2.2			
Visual screening – Properties, features and information; Specifications	4.2.2.1, 4.2.2.2, 4.2.2.3, 4.2.2.4, 4.2.2.5, 4.2.2.6, 4.2.2.7, 4.2.2.8, 4.2.2.9, 4.2.2.10, 4.2.2.11	All products	1	Annex F
Product durability and workmanship aspects	4.2.3			
Visual screening –Functionality and Internal Inspection	4.2.3.1	All products	2	Annex F
Water ingress protection test and level of water protection	4.2.3.2, 4.2.3.3, 4.2.3.4, 4.2.3.5	All products if enclosure differs from originally tested product	2	Annex U, Annex V
Physical ingress protection – enclosure(s) and PV module	4.2.3.6, 4.2.3.7	All products if enclosure differs from originally tested product	2	Annex U
Mechanical durability – Drop test	4.2.3.8	Portable components, excluding TVs or other specified products or appliances that are not typically expected to meet durability standards if enclosure differs from originally tested product	2	Annex W
Mechanical durability -Gooseneck and moving part test	4.2.3.9	Products with a gooseneck/moving part if moving parts differ from originally tested product	2	Annex W
Mechanical durability -Connector test	4.2.3.10	All products if connectors differ from originally tested product	2	Annex W
Mechanical durability -Switch test	4.2.3.11	All products if switches differ from originally tested product	2	Annex W
Mechanical durability -Strain relief test	4.2.3.12	All products if cables differ from originally tested product	2	Annex W
Performance aspects	4.2.8			
Charge controller behaviour test – Standby loss measurement	4.2.8.10	All products	2	Annex S
Self-certification aspects	4.2.10			
Company self-reported information	4.2.10.1, 4.2.10.2, 4.2.10.3	All products	n/a	Annex D

11.6 Recommended tests programme

See 6.6, though only applicable tests are required as described in 11.5.

11.7 Reporting

The report for PAYG testing should support any activities that depend on the information from PAYG testing. See 6.7 for minimum reporting requirements, though report should cover aspects described in 11.5.

Annex A

(normative)

Photovoltaic module wiring inspection

A.1 General

The conductors that connect any PV module to any other component, such as a main unit, shall be sized to safely carry the maximum short-circuit current of the PV module. Compliance shall be assessed using the following procedure.

This test does not apply to:

- a) Conductors internal to a main unit or other component other than a PV module;
- b) Photovoltaic modules physically integrated into another component.

NOTE The above exception does not apply to photovoltaic modules that have an external cable between the module and the main unit but are classified as “integrated” only because the cable length is less than the minimum specified in the product specification.

A.2 Equipment requirements

The following equipment and supplies are required. Equipment shall meet the accuracy requirements of Clause CC.2.

- Wire stripper;
- Wire cutter;
- File, scribe, or sandpaper;
- For direct dimensional measurement: micrometer (or calliper as described in the following);
- For resistance measurement:
 - four-wire resistance-measuring instrument;
 - thermometer to measure the ambient temperature of the test room.

The accuracy of the resistance-measuring instrument shall be sufficient that the measurement uncertainty shall be no greater than the result that would be obtained from the direct dimensional measurement.

In general, a micrometer is the preferred measuring instrument for the direct dimensional measurement. For large conductors or conductors that are sufficiently oversized that there is little doubt that the current-carrying capacity will be sufficient, a calliper can be used as described in the procedure.

A.3 Procedure

A.3.1 General

The following steps shall be performed.

- a) Identify and record the insulation temperature rating from markings on the wire or the wire manufacturer's specification sheet. If the temperature rating cannot be determined, assume a value of 70 °C for polyvinyl chloride (PVC) insulation (or if the insulation material is unknown) and a value of 90 °C for cross-linked polyethylene (XLPE) or ethylene propylene rubber (EPR) insulation.

- b) Determine the maximum short-circuit current of the PV module, defined as 1,25 times the rated short-circuit current at STC. If there is no rated value, use the greatest measured STC value over all tested samples.

NOTE The maximum is used instead of the mean value as the mean is sensitive to the effect of individual defective samples, e.g. samples with cracked cells.

- c) Select the PV module conductor to inspect. If there are multiple conductors of different sizes or insulation types, the conductor giving the least favourable result shall be inspected. It can be necessary to inspect multiple conductors to determine which conductor is least favourable.
- d) Determine the conductor material. Abrade the surface of the conductor to distinguish between copper and copper-clad aluminium or other metals. For large conductor diameters, this can be done with a steel scribe; for small conductor diameters, a file or abrasive material such as sandpaper can be used.
- e) Based on the conductor size and measurement uncertainty, determine the measurement method to use.

A.3.2 Direct dimensional measurement

The following steps shall be performed.

- a) Remove the insulation from a section of the wire without cutting any strands of the conductor.
- b) Using a calliper or micrometer, measure the diameter of a single strand of the conductor. Be careful not to deform the wire by applying excessive pressure. Do not measure the location where the conductor was cut or abraded.
- c) Calculate the area of the measured strand.
- d) Multiply the area of a single strand by the number of strands to calculate the total cross-sectional area of the conductor.

To reduce uncertainty, the area should be calculated by averaging the results of multiple diameter measurements.

A.3.3 Resistance measurement

In this procedure, the conductor size is derived from a measurement of the electrical resistance of a section of conductor. The calculation uses values of resistivity derived from IEC 60228, which can differ from the actual resistivity of the conductor. Therefore, the resulting cross-sectional area should be regarded as a value that can be compared to the nominal cross-sectional areas defined in IEC 60228, rather than an accurate measurement of the physical dimensions of the conductor. Since the current-carrying capacities given in Table A.2 are ultimately derived from IEC 60228 as well, the result of this procedure is consistent with the specification of the current-carrying capacity values.

The following steps shall be performed.

- a) Cut a section of the conductor to be measured. A longer section will result in a smaller relative uncertainty in the length measurement.
- b) Strip the insulation from both ends of the conductor.
- c) Allow the wire to come to thermal equilibrium with the test environment.
- d) Connect a four-wire resistance-measuring instrument to the ends of the conductor. The sense leads (those that measure voltage) should be located between the force leads (those that apply current), or clips that apply both force and sense leads (i.e. Kelvin clips) may be used.
- e) Measure the resistance using the resistance-measuring instrument.
- f) Measure the length of the wire between the locations where the sense leads were connected. (If the sense leads are placed as close to the insulation as possible, then the length of the insulated section can be measured.)

- g) If the conductor being measured is part of a twisted pair or group of wires, and it is not practical to straighten the wires before measurement, the length measurement may be multiplied by a correction factor determined using the following formula:

$$C = \sqrt{1 + \left(\frac{\pi \cdot D}{L} \right)^2}$$

where:

- C is the correction factor to be applied to the measured length;
 L is the length of lay of the twisted pair or group of wires (i.e. the length of one complete turn of the helix formed by one cable component);
 D is the outer diameter of a single wire (including the insulation).

NOTE Rather than measuring the length of lay directly, it can be more accurate to measure the length of a section of conductor and divide by the integer number of complete turns in that section.

- h) Correct the resistance to the reference temperature of 20 °C using the following formula:

$$R = \frac{R_m}{1 + \alpha \times (T_m - 20 \text{ °C})}$$

where:

- R is the corrected resistance;
 R_m is the measured resistance;
 T_m is the measured ambient temperature;
 α is the temperature coefficient of resistance of the conductor material: 0,003 93 K⁻¹ for copper or 0,004 03 K⁻¹ for aluminium.

- i) Calculate the cross-sectional area of the conductor using the following formula:

$$A = \frac{\rho \times L}{R}$$

where:

- A is the cross-sectional area of the wire, in square millimetres (mm²);
 ρ is the resistivity of the conductor material, in Ω·mm²/m;
 L is the length of the wire, in metres (m);
 R is the resistance of the wire, in ohms (Ω).

In this formula, the resistivity is as specified in Table A.1.

Table A.1 – Resistivity values for cross-sectional area calculation

Cable type	Resistivity $\Omega \cdot \text{mm}^2/\text{m}$		
	Copper	Metal-coated (e.g. tinned) copper	Aluminium
Flexible cables (IEC 60228 class 5 or 6)	0,019 7	0,020 3	-
Cables of types intended for fixed installation (IEC 60228 class 1 or 2)	0,018 3	0,018 5	0,028 8

NOTE These values of resistivity for copper conductors are derived from IEC 60228 by taking the average value of resistivity for conductors with nominal cross-sectional areas of 0,5 mm² through 6 mm². For aluminium, the value is derived from IEC 60364-5-52:2009, Annex G.

A.3.4 Determination of current-carrying capacity

The following steps shall be performed.

- If the wire size was determined by direct dimensional measurement (A.3.2), multiply the cross-sectional area of the conductor by 1,1. This correction is intended to account for the difference between the nominal dimensions defined in IEC 60228 and used in IEC 60364-5-52 to calculate current-carrying capacity and the actual physical dimensions being measured by this procedure. If a resistance measurement was used, no correction is necessary.
- Calculate the expanded measurement uncertainty ($k = 2$) in the corrected cross-sectional area using the method defined in JCGM 100, including the following uncertainty contributions for each measuring instrument used:
 - Measuring instrument accuracy from instrument manufacturer's specifications
 - Measuring instrument calibration uncertainty
 - Measuring instrument resolution

Additional factors, such as repeatability, may be included but are not required.

- Identify the column in Table A.2 corresponding to the insulation temperature rating. (If the temperature rating is other than 70 °C or 90 °C, linear interpolation between the two values is permitted.)

Table A.2 – Current-carrying capacity for two-conductor cables

Nominal cross-sectional area mm ²	Current-carrying capacity at 50 °C in amperes			
	Copper conductors		Aluminium conductors	
	70 °C rating (PVC insulation)	90 °C rating (XLPE or EPR insulation)	PVC insulation	XLPE or EPR insulation
0,1	2,4	3,0	-	-
0,2	3,6	4,5	-	-
0,5	6,2	7,7	-	-
0,75	7,8	9,7	-	-
1	10,7	15,4	-	-
1,5	13,8	19,7	-	-
2,5	19,2	27,1	14,9	21,3
4	25,6	36,9	19,9	28,7
6	32,7	47,6	25,6	36,9
10	44,7	65,6	34,8	50,8
16	60,4	87,7	46,9	68,9
25	79,5	113	58,9	82,8
35	98,0	140	73,1	103

Nominal cross-sectional area mm ²	Current-carrying capacity at 50 °C in amperes			
	Copper conductors		Aluminium conductors	
	70 °C rating (PVC insulation)	90 °C rating (XLPE or EPR insulation)	PVC insulation	XLPE or EPR insulation
50	119	171	88,8	126
70	151	220	113	162
95	183	269	138	197

NOTE 1 Current-carrying capacity is calculated for two-conductor cables mounted on a wall in free air, corrected to an ambient temperature of 50 °C. Values for 0,1 mm² to 0,75 mm² are based on IEC 60204-1:2018; values for 1 mm² and greater are based on IEC 60364-5-52:2009.

NOTE 2 Connectors used to terminate aluminium conductors should be tested and approved for this specific use.

- d) Calculate the current-carrying capacity by linear interpolation between the values in the selected column.
- e) Calculate the expanded uncertainty ($k = 2$) in the current-carrying capacity.
- f) If a calliper was used for the direct dimensional measurement: subtract the measurement uncertainty from the measured current-carrying capacity. If the maximum short-circuit current exceeds this value, repeat the measurement using a micrometer or resistance-measuring instrument.

EXAMPLE Based on a direct dimensional measurement with a calliper, the measured current-carrying capacity is 1,5 A and the expanded measurement uncertainty is 0,5 A. If the maximum short-circuit current is greater than 1,0 A, the measurement is repeated with a more accurate instrument.

- g) If the rated or company-stated wire size is inconsistent with the measurement results, the discrepancy shall be noted in the test report. However, such a discrepancy does not constitute a failure, if the pass criterion of Clause A.4 is met.

A.4 Pass criteria

The sum of the current-carrying capacity and the expanded measurement uncertainty shall be no less than the maximum short-circuit current of the PV module.

A.5 Reporting

Report the following in the PV module wiring inspection report.

If the resistance measurement method was used, the calculated cross-sectional area may be reported. However, the report should indicate that the value is calculated based on a nominal resistivity value and is intended only for comparison to the nominal wire sizes in IEC 60228.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.

- Results for tested DUT aspects for samples 1 through n :
 - maximum short-circuit current (A);
 - conductor material (e.g. copper, metal-coated copper, aluminium);
 - insulation type or temperature rating and source (°C);
 - for direct dimensional measurement:
 - i) diameter of single strand (mm);
 - ii) number of strands;
 - iii) measured cross-sectional area (mm²);
 - for resistance measurement, resistance per unit length (Ω/km);
 - overall result (pass/fail).
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .

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Annex B

(normative)

Partial shading test for photovoltaic modules

B.1 General

This test evaluates the photovoltaic module's endurance under partial shading conditions. When an individual cell of a PV module is shaded, that cell no longer generates power and instead acts as a load. This can cause thermal damage to the PV module and potentially create a fire hazard.

This test procedure is based on the US military standard Test Operations Procedure (TOP) 09-2-291 *Environmental and Performance Testing of Photovoltaic Systems*, which achieves goals similar to those of the hot spot endurance test (MQT 09) of IEC 61215-2. The main difference is that the complex procedure to identify the worst-case shading conditions is replaced with a thermal imaging inspection. Refer to the cited documents for more background information regarding the hot spot endurance test.

This test procedure is applicable to PV modules of class III as defined in IEC 61730-1. At STC, class III PV modules have power ratings not exceeding 240 W, open-circuit voltages not exceeding 35 V, and short-circuit currents not exceeding 8 A. PV modules that do not meet these requirements shall not undergo this test.

B.2 Equipment requirements

The following equipment and materials are required. Equipment shall meet the requirements of Clause CC.2.

- Thermal imaging device (infrared camera).
- Visual camera capable of capturing images of the module to record the location and orientation of cell shading.
- Continuous solar simulator of class BBB or better as defined in IEC 60904-9, or natural sunlight.
- DC ammeter or multimeter.
- Opaque material to shade individual cells in increments of no more than 10 %.
- Surface-mounted thermocouple(s) and a thermocouple reader.
- Means to maintain the module surface temperature in the range of $(50 \pm 10) ^\circ\text{C}$ (measured on the back surface of the module). For example, a fan or blower may be used to cool the module convectively.
- Reference PV cell, silicon pyranometer, or other instrument to measure irradiance.

If simulated sunlight is used and the irradiance cannot be measured continuously throughout the test, the irradiance may be measured intermittently, as long as the temporal instability over the applicable time period is maintained within the requirements of IEC 60904-9 class B (i.e. 2 %).

B.3 Test prerequisites

Before this test, the I-V curve at STC shall be measured using the photovoltaic module I-V characteristics test of IEC TS 62257-9-5, and the short-circuit current and maximum power point current shall be calculated. It is not necessary to calculate the performance at typical module operating temperature (TMOT).

From the measured I-V curve, calculate the worst-case shading current using the following formula:

$$I_{wc} = I_{sc} - \frac{I_{sc} - I_{mpp}}{n}$$

where:

- I_{wc} is the worst-case module current, in amperes (A);
- I_{sc} is the module short-circuit current, in amperes (A);
- I_{mpp} is the module maximum power point current at STC, in amperes (A);
- n is the number of strings of cells in parallel in the module.

NOTE This value occurs when the shaded string is operating at its maximum power point current and the remaining strings are operating at their short-circuit current. This condition typically corresponds to the maximum power dissipation in the shaded cell.

The number of strings in parallel, n , can be determined by any of the following methods:

- visual inspection of the module;
- company-provided information;
- measurement of the open-circuit voltage and short-circuit current and comparison with typical values (e.g. an open-circuit voltage of 0,6 V to 0,7 V and short-circuit current density of 0,03 A/cm² to 0,04 A/cm² for crystalline silicon).

EXAMPLE A visual inspection shows that the module has 44 polycrystalline silicon cells. Each cell has an area of 14 cm², the open-circuit voltage is 14 V, and the short-circuit current is 1 A. The most likely configuration is two strings of 22 cells, giving a cell open circuit voltage of 0,64 V and a short-circuit current density of 0,036 A/cm².

Photograph both sides of the PV module to document any pre-existing visual defects.

B.4 Procedure

Perform the following steps:

- a) Determine the four worst-case cells. The goal of this procedure is to identify the two cells with the lowest shunt resistance and the two cells with the highest shunt resistance. Use the following steps:
 - 1) Short-circuit the PV module.
 - 2) Subject the module to an irradiance of (1 000 ± 100) W/m².
 - 3) Allow the module surface temperature to stabilize at (50 ± 10 °C). The module is considered to be stabilized when the change in temperature after 10 min is less than 2 °C.
 - 4) Use the thermal imaging device to determine the two highest-temperature cells and the two lowest-temperature cells. These are the four cells that will be tested in the remainder of the procedure.

When performing this measurement, take care to identify and disregard reflection from the PV module surface. The detector should be positioned between 5° and 60° from vertical. It is often necessary to adjust the temperature scale settings of the thermal imager manually, especially for outdoor tests, since reflections of the sky will appear to be less than 0 °C (FLIR Systems 2011).

- b) For each cell identified in a), in turn, perform the following procedure to identify the worst-case shading condition for that cell:
- 1) Expose the module to simulated or natural sunlight with an irradiance of $(1\,000 \pm 100) \text{ W/m}^2$.
 - 2) Short-circuit the module and monitor the current.
 - 3) Apply approximately 10 % shading to the selected cell by covering it with a mask of opaque material. The mask shall not shade any portion of adjacent cells.
 - 4) Record the location of the shadow mask with the visual camera. (Ensure that the image clearly shows the position of the cell within the module.)
 - 5) Record the module current. If using natural sunlight, also record the irradiance.
 - 6) Correct the current to an irradiance of $1\,000 \text{ W/m}^2$ using the following formula:

$$I_{\text{corr}} = I_{\text{meas}} \cdot \frac{1\,000 \text{ W/m}^2}{G}$$

where:

I_{corr} is the corrected module current, in amperes (A);

I_{meas} is the measured module current, in amperes (A);

G is the measured irradiance, in watts per square metre (W/m^2);

- 7) Increase the shading in increments of no more than 10 % until the corrected current is less than the worst-case current (I_{wc}) calculated in Clause B.3. Each time, use the visual camera to record the location of the cell shading and the module orientation.
- 8) The worst-case shading level is one level less than the level reached in 6); that is, it is the level that results in the smallest current that is greater than or equal to I_{wc} . However, if the current drops below I_{wc} with only 10 % shading, then 10 % shading is the worst case.

EXAMPLE 1 The worst-case current is 1,50 A. The current at 50 % shading is 1,52 A and the current at 60 % shading is 1,40 A. Therefore, the worst-case shading is 50 %.

EXAMPLE 2 The worst-case current is 1,50 A. The current at 10 % shading is 1,49 A, which is already less than I_{wc} . Therefore, the worst-case shading level is 10 %.

- c) For each cell identified in a), in turn, perform the following procedure using the worst-case shading condition identified for that cell in b):
- 1) Short-circuit the module.
 - 2) Expose the module to the light source and allow the temperature to stabilize at $(50 \pm 10) ^\circ\text{C}$.
 - 3) Apply the worst-case shading condition to the selected cell. Use the visual images taken in steps b) 4) and b) 7) to ensure that the location and orientation of the shading is the same as that used when determining the worst-case shading for the selected cell.
 - 4) Maintain this condition for one hour.
 - 5) Remove the shading.
- d) Inspect the module for any damage, particularly looking for signs of melted solder, openings in the enclosure, delaminations and burn spots. Take photos of any major visual defects (Clause B.6) found. The photos taken before the start of the procedure can be used to confirm that any defects found were a result of the test rather than pre-existing defects that were not previously noticed.
- e) Repeat the I-V curve measurement using the photovoltaic module I-V characteristics test of IEC TS 62257-9-5. It is not necessary to calculate the performance at TMOT.

B.5 Calculations

Calculate the power degradation at STC, relative to the initial value, using the following formula:

$$\delta P = \left(1 - \frac{P_A}{P_B} \right) \times 100 \%$$

where:

δP is the electrical power degradation, in percent (%);

P_A is the maximum power measured at STC after the test, in watts (W);

P_B is the maximum power measured at STC before the test, in watts (W).

B.6 Pass criteria

The power degradation shall be less than 10 % and the module shall show the electrical characteristics of a functional photovoltaic device (based on the I-V curve taken after the test).

The test shall not result in any major visual defects, defined as any of the following:

- a) broken, cracked, or torn external surfaces.
- b) bent or misaligned external surfaces, including superstrates, substrates, frames and junction boxes to the extent that the operation of the PV module would be impaired.
- c) bubbles or delaminations.
- d) evidence of any molten or burned encapsulant, backsheet, frontsheet, diode or active PV component.
- e) loss of mechanical integrity to the extent that the installation and operation of the module would be impaired.
- f) cracked/broken cells.
- g) voids in, or visible corrosion of any of the layers of the active (live) circuitry of the module.
- h) broken interconnections, joints or terminals.
- i) any short-circuited live parts or exposed live electrical parts.
- j) module label or markings are no longer attached, or the information is unreadable.

NOTE This list is derived from the list of major visual defects in IEC 61215-1. Some of these defects are unlikely to be caused by the partial shading test.

B.7 Reporting

The following data shall be included in the test report:

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.

- Results for tested DUT aspects:
 - the infrared images used to select the tested cells, with the location of the selected cells marked;
 - visual images documenting the location of the shading applied during the 1 h exposure period, including a description of the orientation of how the module is oriented in the image relative to features such as the junction box, labels, etc.;
 - the percent shading applied to each of the selected cells during the 1 h exposure period;
 - any damage that occurred during the test, with photos if applicable;
 - the power degradation, in percent.

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Annex C

(normative)

Bending or folding test for photovoltaic modules

C.1 General

The purpose of this test is to verify either flexibility or foldability, or both, of the PV module. This test is not applicable to PV modules that are neither flexible nor foldable (3.35), and only applies to PV modules that are intended to be bent or folded during installation or use. If the company's installation guide allows bending in more than one direction, both directions should be tested. If the module is foldable then it shall be folded and unfolded.

NOTE The procedure for flexible modules is based on the bending test of IEC 61215-2. The procedure for foldable modules is based on the folding test of IEC TS 63163.

C.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements of Clause CC.2.

For flexible modules, the following equipment is required:

- Cylinder with a diameter specified by the module manufacturer over which the flexible modules can be bent is required.
- DC power supply
- DC multimeter or ammeter with the capability to record and display minimum values over a period of time.

C.3 Test prerequisites

Photograph both sides of the PV module to document any pre-existing visual defects. If possible, a PV module free from major visual defects, as defined in Clause B.6, should be used for this test.

C.4 Required test conditions

The test shall be conducted at an ambient temperature of $22\text{ °C} \pm 5\text{ °C}$.

C.5 Procedure

Two variations of the procedure are specified: one for flexible modules and one for foldable modules (3.35).

- a) Measure the I-V curve at STC using the photovoltaic module I-V characteristics test from IEC 62257-9-5 and calculate the power at STC. It is not necessary to calculate the performance at TMOT.
- b) Perform the following steps if the DUT is a flexible module:
 - 1) Equip the module so that the electrical continuity of the internal circuit can be monitored continuously during the test. Apply the following current:
 - i) For crystalline silicon modules: current equal to the STC maximum power point current;

- ii) For thin-film amorphous silicon, cadmium telluride (CdTe), or Cu(In,Ga)(S,Se)_2 modules: 0,1 times the STC maximum power point current. If this value is less than 100 mA, a current of up to 100 mA may be used instead.
- 2) Roll the flexible module from a flat (planar) starting position over the cylinder of the specified radius of curvature. If the module is large enough, it shall roll up on the cylinder in excess of 360° .
- 3) Unroll the module back to the flat/planar position.
- 4) Repeat 1) and 3) for a total of 25 bend-unroll cycles for each direction specified in the user manual or other documentation. If no directions are specified, perform the test with the axis of the cylinder parallel to the longest and shortest dimensions of the module.
- c) Perform the following steps if the DUT is a foldable module:
 - 1) Fold the module from a flat/planar position to where it is fully folded to the minimum allowed radius of curvature.
 - 2) Unfold the module back to the flat/planar position.
 - 3) Repeat 1) and 2) for a total of 25 fold-unfold cycles.
- d) Inspect for any major visual defects, as defined in Clause B.6.
- e) Repeat the STC I-V curve measurement.

C.6 Pass criteria

No major visual defects as defined in Clause B.6 shall occur as a result of this test. The power degradation (calculated in accordance with Clause B.5) shall be less than 10 % and the module shall show the electrical characteristics of a functional photovoltaic device (based on the I-V curve taken after the test). For flexible modules, there shall be no intermittent open-circuit fault detected during the test.

C.7 Reporting

The following data shall be included in the test report:

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - compliance with the bending or folding test;
 - I-V curves before and after the bending or folding test;
 - for flexible modules, presence or absence of intermittent open-circuit fault;
 - number of bending or folding cycles performed;
 - description and photographs of any major visual defects present after testing.

Annex D (normative)

Company self-reported information

D.1 Background

Having proper company information is important for communication throughout the testing process as well as for understanding key product information and any certifications possessed by the company's facility or product. To this end, there are three categories of self-reported information: company information, product information, and company self-certification regarding either the manufacturing facility or the product. Additional information can be necessary for products with pay-as-you-go or fee-for-service features.

D.2 Outcomes

The company self-reported information outcomes are listed in Table D.1.

Table D.1 – Company self-reported information outcomes

Metric	Reporting units	Related aspects	Notes
Company information	Varied	4.2.10.1 Product and company information	Record all provided company information
Product information	Varied	4.2.10.1 Product and company information	Record all provided product information
Self-certification information	Varied	4.2.10.3 Third-party marks and certifications	Record all company or product certifications

D.3 Solicited information

D.3.1 General

At a minimum, the information contained in D.3.2 and D.3.3 should be solicited from the company. At a minimum, report all items marked with an asterisk (*).

D.3.2 Confidential information (not released publicly)

D.3.2.1 Company information

The following confidential company information should be solicited:

- a) company name*;
- b) contact person name*;
- c) contact person position at company (i.e. job title)*;
- d) company physical address*;
- e) contact telephone number(s)*;
- f) contact e-mail address*.

If separate people manage contracting issues and technical testing questions, request contact information for both parties.

D.3.2.2 Product information

The following confidential product information should be solicited:

- a) markets in which the product is for sale (e.g. Kenya, India, China);
- b) free on board (FOB) product price for at least 1 000 units (\$);
- c) typical product shipping point of origin;
- d) product driver type (e.g. resistor, pulse-width modulation);
- e) if the driver uses PWM, request the PWM frequency and a description of when it operates;
- f) PV charge control methods (series regulator, shunt regulator, PWM, MPPT, etc.)^{*};
- g) if the charge controller uses PWM, request the PWM frequency and a description of when it operates;
- h) list of battery protection and charge control methods (i.e. either deep discharge protection or overcharge protection, or both);
- i) description of deep discharge charge control, including the low voltage disconnect threshold and individual cell protection for lithium-ion or lithium iron phosphate batteries with multiple cells (or parallel cellblocks) in series;
- j) description of overcharge protection charge control, including the overcharge protection disconnect voltage and individual cell protection for lithium-ion or lithium iron phosphate batteries with multiple cells (or parallel cellblocks) in series;
- k) battery information sheet from battery manufacturer, preferably showing acceptable deep discharge protection and overcharge protection cutoffs at a minimum;
- l) whether the battery contains internal protection circuitry^{*};
- m) whether the battery or product includes circuitry to monitor the voltage of or balance the individual battery cells, and if so, what type of circuitry is used and where it is located;
- n) description of any special procedures necessary for the test lab to access the battery;
- o) current limit used for overcurrent protection for the system^{*};
- p) type of current protection used^{*};
- q) list of other current protection limits if different overcurrent protection limits are used for individual outlets, inputs or appliances^{*};
- r) USB charging modes supported^{*};
- s) description of how USB charging modes are implemented;
- t) whether the product or any of the included appliances are considered portable separate, and if so, how the company intends to meet water ingress protection requirements;
- u) whether the product or any of the included appliances are considered portable integrated, and if so, how the company intends to meet water ingress protection requirements;
- v) description of special testing considerations, such as any characteristics that would impede the testing process. Characteristics include: an auto-off function that turns the lights or appliances off after a specific number of hours of operation; the product disables if the enclosure is opened; the product connects to a wireless network; the product is tamperproof; the product enters a low-power (standby or sleep) mode after a delay longer than 5 min; the product would not be able to be disconnected from its battery and powered by a laboratory power supply for over 500 h;
- w) expected or rated performance, including:
 - 1) name, luminous flux, full battery run time, and solar run time for each setting for all appliances included with or advertised for use with the product^{*};
 - 2) brightness setting specifications, if publicly advertised or provided to the laboratory by the company^{*};
 - 3) rated power of any appliances included with the product^{*};

- 4) estimated battery capacity, battery type, full battery run time, solar run time, percentage of a full charged received from the power control unit when the power control unit is fully charged and when the power control unit has been charged for a standard solar day, for any appliances with their own batteries*;
- x) the names of the settings the company would wish to be tested.

D.3.3 Public information (may be released publicly)

D.3.3.1 Company information

The following public company information should be solicited:

- a) official customer facing/brand name*;
- b) public company contact information if different from that collected in D.3.2.1*.

D.3.3.2 Product information

The following public product information should be solicited:

- a) product name*;
- b) product model number*;
- c) all product lighting technologies used (e.g. fluorescent tube, LED). If the product uses LEDs, are the LEDs high-power or low-power?
- d) battery chemistry (VRLA, NiMH, etc.)*;
- e) battery package type*;
- f) battery nominal voltage (V)*;
- g) battery capacity (Ah)*;
- h) charge and discharge rate at which the battery capacity is specified*;
- i) all product charging system types (e.g. PV module, AC power, dynamo)*:
 - 1) if the product has AC power charging, whether an adapter is included;
 - 2) if the product has solar charging, the active PV material (e.g. mono-Si, poly-Si, CIS);
 - 3) if the product has solar charging, the peak power rating of the PV module(s) at STC;
- j) all included product features (e.g. mobile device charging, radio)*;
- k) if the product has mobile device charging, are adapters included?*
- l) all optional product features (e.g. mobile device charging, radio)*;
- m) description of any advertised capabilities to charge specific devices or provide specific USB charging modes*;
- n) description of product warranty terms, including duration*; high resolution product photograph on a white or transparent background.

D.3.3.3 Additional information for PAYG products

Testing products that include PAYG or fee-for-service features may require gathering additional information. The following information should be solicited:

- a) quantities that are measured with the PAYG system (e.g. kWh, h);
- b) quantities that are billed with the PAYG system (e.g. \$/kWh, \$/day);
- c) the most common unit of sale (e.g. kWh, h);
- d) internal software rules for enforcement mechanism (i.e. how does the product decide to restrict access to services in the case of non-payment?);
- e) estimate of accuracy, resolution and drift for enforcement mechanism;
- f) statement regarding whether the PV module stays connected so that the product can still receive a charge if the enforcement mechanism is activated*;

- g) statement regarding whether the charge control algorithm operates as normal if the enforcement mechanism is activated*;
- h) description of the battery charged control and protection when the enforcement mechanism is activated*;
- i) description of the payment transaction method;
- j) description of the communication method for verifying payments;
- k) statement whether the product is restricted to use on mobile phone networks and description of any restrictions;
- l) description of software or hardware measures used to prevent tampering with or replacing the battery;
- m) description of how these tamper-prevention features can be disabled for testing;
- n) description of any additional items or actions needed to test the product in a lab in either Europe, the USA or China that is not otherwise described;
- o) desired information to be displayed on a standardized specification sheet for the PAYG feature;
- p) if the product is a PAYG version of a previously tested product, collect the following:
 - 1) product name and information for the previously tested product*;
 - 2) description of any performance differences, aside from the PAYG feature, between the two products (e.g. decreased run time, increased standby loss, etc.)*;
 - 3) description of any physical differences between the two products (e.g. additional port, keypad, etc.).*

D.4 Reporting

Report all items in Clause D.3 that are marked with an asterisk (*).

Annex E (normative)

Product sampling

E.1 Background

Proper product sampling is the first step in the testing process, and it is critical to maintaining the test method's fairness and credibility.

E.2 Test outcomes

The product sampling outcomes are listed in Table E.1.

Table E.1 – Product sampling outcomes

Metric	Reporting units	Related aspects	Remarks
Sample type	Retail or warehouse	n/a	--
Sample procurement agency	Agency name	n/a	The third-party agency that procures the samples
Sample procurement agent	Name	n/a	The name of the person who procures the samples
Sample procurement date	Date	n/a	--
Sample procurement address(es)	Address(es)	n/a	--
Sampling report	n/a	n/a	Reporting details presented in E.5

E.3 Related tests

Testing is predicated upon the product samples already being procured, shipped, and received at the test lab(s).

E.4 Procedure

E.4.1 Retail sampling

E.4.1.1 General

For retail sampling, third-party agents will procure product samples from a variety of retail outlets in the market.

E.4.1.2 Equipment requirements

Retail sampling requires a camera, one or more shipping cartons, and tamper-evident tape or another tamper-evident sealing method.

E.4.1.3 Test prerequisites

Samples shall be procured from a geographically diverse set of retail outlets. Retail outlets include both vendors or retail shops where end users may directly purchase products, and local or regional distributors.

E.4.1.4 Apparatus

No apparatus is required for retail sampling.

E.4.1.5 Procedure

The following steps shall be performed by the third-party sampling agency.

- a) Identify a specified number of retail outlets in the market from either various geographic locations or online retailers, or both.
- b) Select a subset of the retail outlets to procure samples from. The subset of retail outlets should be geographically diverse (i.e. ideally each retail outlet would either be in a different city or country, or both, than the rest of the subset).
- c) Procure the product samples from the various retail outlets. If three or more retail outlets are available, ensure that no more than 40 % of the overall number of procured samples comes from any single retail outlet.
- d) Document the date, locations, sampling agent, and number of samples procured from each location. If possible, photograph the total stock of the product at each location as well as the samples procured. If present, document all serial numbers on the selected samples, either via photographs or by listing in the report, or both. Additionally, note any issues with the sampling, aspects that differ from the sampling request, or items that could be unclear from the report.
- e) Seal the carton(s) containing the selected samples with tamper-evident tape or another tamper-evident sealing method. Photograph the sealed carton(s), showing the tamper-evident seal.
- f) Ship or deliver the products to one or more test labs and report the shipment tracking number(s), when available. Alternatively, the company, distributor, test laboratory, or other party may arrange for shipping or delivery.

Once the samples are received at the test lab(s), the date(s) of reception, test lab name(s), and test lab location(s) should be documented.

E.4.1.6 Calculations

There are no calculations for retail sampling.

E.4.2 Warehouse sampling

E.4.2.1 General

For warehouse sampling, third-party agents will procure samples from a warehouse, distributorship, factory, or other bulk storage location.

E.4.2.2 Equipment requirements

Warehouse sampling requires a camera, one or more shipping cartons, and tamper-evident tape or another tamper-evident sealing method.

E.4.2.3 Test prerequisites

The sampling location should be the main bulk storage location in the region.

There shall be at least 150 products available to select from. In cases where products are being sampled in accordance with the alternative sampling requirements for individual components, there shall be a minimum stock of 150 units of each component.

The sampling agent shall be able to sample from the bulk storage location's entire stock.

E.4.2.4 Apparatus

No apparatus is required for warehouse sampling.

E.4.2.5 Procedure

The following steps shall be performed by the sampling agency.

- a) At least 24 h before the sampling takes place, make contact (e.g. via email or telephone) with representatives at the sampling location to provide proper notice and ensure that the sampling location's total product stock meets the requirements specified in E.4.2.3.
- b) Randomly procure the product samples from the bulk storage location's entire stock (i.e. the entire product stock shall be available to sample from).
- c) Take photographs of the available stock and the selected samples. Photographs of the selected samples should include pictures of at least one of each sampled component as an example showing all identifying features, along with a picture of the packaging and any other items that come in the box (e.g. adapters, cables, user manual). Additional identical samples may be photographed as a group with or without packaging.
- d) If present, document all serial numbers on the selected samples, either via photographs or by listing in the report, or both.
- e) Document the date, location, sampling agent, and number of samples procured. Additionally, note any issues with the sampling, aspects that differ from the sampling request, or items that could be unclear from the report.
- f) Seal the carton(s) containing the selected samples with tamper-evident tape or another tamper-evident sealing method. Photograph the sealed carton(s), showing the tamper-evident seal.
- g) Ship the products to one or more test labs and report the shipment tracking number(s), when available. Alternatively, the company, distributor, test laboratory, or other party may arrange for shipping or delivery.
- h) Once received at the test lab(s), the date(s) of reception, test lab name(s), and test lab location(s) should be documented.

E.4.2.6 Calculations

There are no calculations for warehouse sampling.

E.5 Reporting

Report the following in the product sampling report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name(s);
 - product model number(s);
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Sampling instructions

- Sampling and shipping information:
 - name of sampling agency;
 - name(s) of sampling agent(s);
 - date of sampling;
 - sampling location name(s), address(es), and description(s);
 - amount of stock available to select from, and confirmation that the minimum stock requirements were met;
 - number of samples procured (at each location);
 - photographs as described in E.4.2.5;
 - serial numbers, if present and not captured in photographs;
 - additional notes (if necessary).

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Annex F (normative)

Visual screening

F.1 Background

The visual screening process covers product specifications, properties (such as external measurements), functionality, observations, and internal and external construction quality.

The components, materials, and utilities are categorized and, in some cases, evaluated. The visual screening test provides a thorough qualitative and quantitative assessment of the DUT as received from the company and assigns a unique identifier to each sample. The operation out of the packaging is documented before any modifications are made for subsequent tests.

Product packaging and other consumer-facing product documentation is evaluated during the visual screening. When hard copies of the packaging are not available, digital copies may be evaluated instead, but shall be clearly marked in the test report as having been submitted digitally.

F.2 Test outcomes

The test outcomes of the visual screening process are listed in Table F.1.

Table F.1 – Visual screening test outcomes

Metric	Reporting units	Related aspects	Remarks
DUT specifications	Varied	4.2.2 Product design, manufacture, and marketing aspects	Record all provided specifications
DUT information	Varied	4.2.2 Product design, manufacture, and marketing aspects 4.2.10.1 Product and company information	Record dimensions and qualitative descriptors
Internal DUT inspection	Varied	4.2.3 Product durability and workmanship aspects	Describe/document wiring and electronics fixtures
Internal DUT inspection	Number of defects	4.2.3 Product durability and workmanship aspects	Record the number of soldering or electronics quality defects

F.3 Related tests

Annex F is not related to any of the other annexes.

F.4 Procedure

F.4.1 Properties, features, and information

F.4.1.1 General

Relevant information, such as external measurements and observations, are recorded to capture DUT characteristics. Sufficient comments or photographs should be provided to thoroughly describe or illustrate these characteristics. This part of the procedure may be completed on a single sample; however, if discrepancies between samples are found at any time during testing, they should be noted in the test report.

F.4.1.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Either callipers or ruler, or both.
- Balance (scale).
- Bright task light with good colour rendering.
- Camera.

F.4.1.3 Test prerequisites

The DUT should be new, unaltered, and in its original packaging. Read the packaging box and documentation for instructions on using the product. Consult the company for missing information pertaining to the required observations.

F.4.1.4 Apparatus

The DUT may be positioned under a bright task light in the examination, if necessary.

F.4.1.5 Procedure

All photographs or scans of packaging, documents (e.g. user manual and warranty card), and labels shall be in colour and of sufficient quality that all text is legible (unless illegible in the original document) and all diagrams, icons, and other images are clearly reproduced. All photographs of components shall be in colour and of sufficient quality that all relevant text is legible (unless illegible on the item being photographed) and all relevant icons and images are clearly reproduced. Photographs that document required items shall be labelled (e.g. “PV module serial number label” or “battery label”). In cases where digitally-submitted consumer-facing materials are evaluated, clearly indicate in the test report which materials are digital and which are hard copies.

These steps shall be followed.

- a) Provide the following.
 - 1) Note the date that the samples were received.
 - 2) Note the date and method of sample procurement. If random sampling in accordance with Annex E was conducted, note the sampling agency and sampling report number for reference.
 - 3) Note all available company contact information (e.g. name, address, phone number, email, website, etc.).
 - 4) Photograph or scan all sides of the product’s retail box, if available.
 - 5) Note if a user manual is included with the DUT. If so, report the type of manual it is (e.g. booklet, sheet, etc.), report the language(s) in which it is written, and photograph or scan each page.

- 6) If a warranty is available, record the warranty duration as specified by the company. Photograph or scan the warranty material. Note if there are separate warranty durations for the battery or included appliances.

- 7) Record the product name, brand, company, model number, and serial number(s), if present. Note if this information can be found on the packaging, on documents included in the packaging, or marked on the product. If individual components of the product have different model or serial numbers, record the model or serial number of each component.

The product name and model number stated in the test report should match the information found on the packaging or documentation. In case of discrepancies between the information on the packaging or documentation and the company-provided information such as that found in a testing agreement or contract, or if there are discrepancies between different consumer-facing locations, clarification should be provided in the test report.

- 8) Photograph or scan any other documents included with the DUT.

- b) Provide the following (in the specified units) without disassembling the DUT.

- 1) List each individual component. If the user manual or other consumer-facing information indicates that multiple appliances without internal batteries that provide the same type of service, e.g. lighting, should be connected to a single port (e.g. by daisy-chaining or with a splitter cable), these appliances may be treated as a single appliance component group or as individual appliance component groups. Treatment of the appliances should be consistent throughout the test methods; for instance, if the appliances are treated as a single appliance in the full-battery run time test, they should also be treated as a single appliance in the light output test, appliance tests, and energy service calculations. The product specification may provide further guidance on treatment of these appliances.

- 2) Categorize each component (e.g. as an appliance, main unit, accessory, PV module, etc.).

- 3) Measure the mass, in grams (g), of the entire product with all included components within its original packaging.

- 4) Measure the mass of all included components, in grams (g).

- 5) Photograph any included components, including a scale reference (e.g. a 1 cm grid) in each photo. The dimension of the scale reference shall be visible in the photo or noted in the report.

- c) Observe the following (consult the documentation for any explanations; see 4.1.3 for details on the terminology used in the following steps).

- 1) Measure the length, in metres (m), of any cables connecting a fixed indoor or portable component to a fixed outdoor component or PV module.

- 2) Note if the DUT has any screw terminal connections or if all connections are plug-and-play.

- 3) Note the total number of distinct light points, indicate the technology used in each (LED, fluorescent, incandescent, etc.), and provide a description and photographs of each.

- 4) Photograph each light point type, showing the number of independent light sources (i.e. the total number of LEDs or other emitter types) in each array.

- 5) Note any built-in appliances, as defined in 4.1.4, including lights with some or all of their driver or ballast circuits internal to another component of the product. Lights with any of the following properties should be examined to determine whether they should be treated as a built-in appliance:

- The light has multiple brightness settings that are selected using a control on the main unit;
- The light is to be connected to a port which cannot be used for any other appliance (according to either labels or user documentation, or both);
- Internal inspection of the light point (F.4.3) reveals no electronic components on the PCB except the light sources (e.g. LEDs) themselves.

- The behaviour of the port (e.g. as observed in the assessment of DC ports, Annex EE), is consistent with the output of an LED driver circuit (e.g. a constant-current power supply).

Ports or appliances with security features, and appliances connected to ports with pulse width modulation (PWM), may be tested as built-in or removable appliances; see EE.4.2.5.

- 6) Photograph the arrangement of lamp units, included appliances, battery(-ies), and energy source(s) in terms of housing and cases.
 - 7) Describe the materials that compose the lamp units, battery housing, charge controller housing, included appliances, and any other housings (e.g. plastic, metal, glass, or other) if not evident from photographs of components.
 - 8) Note if the DUT and included appliances have any charge indicators and, if so, include photographs of the indicators and descriptions of indication meanings if not evident from photographs.
 - 9) Note if the DUT has mobile device charging capabilities. If so, photograph the connectors.
 - 10) Indicate if the DUT provides central (e.g. grid, central station) or independent (e.g. electromechanical, solar PV) charging and the specific charging means and describe the robustness of each included charging mechanism.
 - 11) If a grid charger is included, note if it carries any recognized safety marks, such as the CE mark. Note the source and nature of the safety marks and be sure to photograph any labels provided on the grid charger.
 - 12) Note each component's primary form factor (fixed indoor, fixed outdoor, portable separate, portable integrated, or other) and also note any secondary form factors.
 - 13) Provide general comments regarding the product's properties, features, and information, if not evident from photographs and information already recorded.
- d) Measure and observe the following (in the provided units) for the PV module.
- 1) Measure the PV module's overall length and width, in centimetres (cm), including the frame.
 - 2) Measure the active solar material's overall area, in square centimetres (cm²).
 - 3) Note if the PV module is external or integrated into the product's housing.
 - 4) Note the PV module's solar material (e.g. poly-Si, mono-Si, CIS, amorphous).
 - 5) Photograph the PV module, including the back side that does not have PV material.
 - 6) Note any additional information about the PV module (e.g. number of individual cells).
- e) Provide the following information regarding the product's DC ports.
- 1) Number of distinct port types.
 - 2) For each port type:
 - i) brief description of the port (e.g. "USB port 1");
 - ii) receptacle type (e.g. USB 2 type A, barrel jack, cigarette lighter jack);
 - iii) number of identical ports of this type;
 - iv) nominal port voltage, determined from any of the following sources:
 - company-supplied information;
 - user documentation and labelling;
 - if the port is a standardized or conventional connector, the applicable standards or conventions;
 - measurement of the open-circuit voltage and the voltage under load.

- v) rated maximum port current, if any, determined from any of the following sources:
 - measurement of the open-circuit voltage and the voltage under load;
 - company-supplied information;
 - user documentation and labelling;
 - markings on any components, such as a fuse or circuit breaker, if it can be determined that the component limits the current for the port.
 - vi) whether the port is intended or expected to be used for charging or powering appliances (e.g. based on labelling, documentation, or provided adapters);
 - vii) whether the port is powered directly from the PV module.
- 3) For a barrel port's corresponding plugs:
- i) Measure the inner and outer dimensions of the barrel plug;
 - ii) Measure length of barrel plug;
 - iii) If applicable, measure the diameter of the centre pin of the barrel plug.
- 4) Photographs clearly showing the port.
- 5) Photographs of any port specifications or documentation.

F.4.2 Specifications

F.4.2.1 General

All relevant specifications are recorded for later comparison in testing results. This part of the procedure may be completed on a single sample; however, if discrepancies between samples are found at any time during testing, they should be noted in the test report.

F.4.2.2 Equipment requirements

No equipment is required for this part of the visual screening procedure.

F.4.2.3 Test prerequisites

The DUT should be new, unaltered, and in its original packaging. Read the packaging box and documentation for instructions on using the product. Consult the company for missing information pertaining to the required observations.

F.4.2.4 Apparatus

No apparatus is required for this part of the visual screening procedure.

F.4.2.5 Procedure

Examine the packaging, user manual, product website, and components for battery, lamp, charge controller, included appliances and PV module specifications. While obtaining the specifications, the DUT should not be opened or otherwise tampered with in any way. The internal inspection of F.4.3 can reveal more product specifications, which should be included with the specifications from F.4.2 and noted accordingly.

- a) When provided, note the following specifications (in the specified units), indicate and photograph the source(s) of each, and comment on any specification discrepancies. Indicate if the specification is not provided but can be ascertained by observation (e.g. battery chemistry and battery nominal voltage). If the product contains multiple components, record the applicable values for each component.
- 1) Battery chemistry (VRLA, NiMH, Li-Ion, LiFePO₄, or specify other).
 - 2) Rated battery capacity, in ampere hours (Ah).
 - 3) Battery nominal voltage, in volts (V).

- 4) Battery package type (AA cell, 18650, 26650, or specify other).
 - 5) Lamp type (LED, compact fluorescent, linear fluorescent, incandescent, or specify other).
 - 6) Charge controller present (yes/no).
 - 7) PV module maximum power point power (P_{mpp}), in watts (W).
 - 8) PV module open circuit voltage (V_{oc}), in volts (V).
 - 9) PV module short circuit current (I_{sc}), in amperes (A).
 - 10) PV module maximum power point voltage (V_{mpp}), in volts (V).
 - 11) PV module maximum power point current (I_{mpp}), in amperes (A).
 - 12) Daily energy service, in watt-hours (Wh).
- b) For each advertised or included appliance (including lighting appliances), provide the following information:
- 1) Whether or not it is a lighting appliance (yes/no).
 - 2) Whether it is included with the product (yes/no).
 - 3) The name of each setting, a description of each setting, and the total number of settings.
 - 4) Appliance input voltage range (V).
 - 5) Appliance maximum power usage (W).
 - 6) Appliance average power usage (W).
 - 7) Appliance standby power usage (W).
 - 8) For televisions, computers, computer monitors, portable video players, tablets, and similar appliances, the screen size (inches).
 - 9) For fans, the fan rotor diameter in millimetres (mm) and number of speed settings.
 - 10) Where available, note for any other included appliances any relevant specifications on their use.
- c) When provided, record the following run time specifications, in hours (h), indicate and photograph the source(s) of each, and comment on any discrepancies. Be aware that any run time claims reported on the packaging or other consumer-facing information shall be considered to be the solar run time on the brightest (or highest power) setting, unless otherwise specified in the claim.
- 1) Note the number of hours of operation on a full battery charge for all appliance settings (full-battery run time) and all appliance uses specified.
 - 2) Note the number of hours of operation on a battery charge from a day of solar charging for all appliance settings (daily solar run time) and all appliance uses specified.
 - 3) Note the number of hours of operation after a specified electromechanical charge period for all appliance settings (electromechanical run time ratio).
 - 4) Note and describe any specified run times that do not fit into the previous three categories.
 - 5) Note any additional claims regarding charging of mobile phones or other devices, including the number of devices, types of devices, energy availability or hours of charging, etc.
- d) When provided, record the following charging time specifications, in hours (h), indicate and photograph the source(s) of each, and comment on any discrepancies:
- 1) Note the charging time required to fully charge the battery, including appliances as applicable.
 - 2) Note the daily charging time required to achieve any advertised solar run times, including appliances as applicable.
 - 3) Note the duration of charging or amount of effort required for any specified electromechanical run time, including appliances as applicable.

- 4) Note the duration of grid charging required to fully charge the battery.
- 5) Note and describe any specified charging times that do not fit into the previous four categories.
- 6) Note any additional claims regarding charging time.
- e) Where available, note any luminous flux specifications, in lumens (lm), indicate and photograph the source(s) of each, the corresponding lamp setting(s), and comment on any discrepancies.
- f) Note any general comments related to specifications and discrepancies in specifications, if any.

F.4.3 Functionality and quality inspection

F.4.3.1 General

An external and internal inspection is performed to assess the functionality of each component and the quality of the electronics and soldering. The DUT and included appliances fail the inspection if poor workmanship inhibits the DUT and included appliances from properly functioning.

F.4.3.2 Functionality and deficiencies

F.4.3.2.1 Definition of functionality

In the visual screening and throughout testing, the DUT is considered functional if all of the following are true:

- a) all included and built-in appliances turn on and operate as intended;
- b) all ports that are used to power advertised or included appliances operate as intended (as defined in F.4.3.2.2);
- c) for lighting appliances, all individual light sources (e.g. individual LEDs) turn on;
- d) the product charges normally from all available power sources;
- e) the battery has not leaked, inflated, or developed any other unsafe condition.

The DUT is considered non-functional if any of the above are not true.

F.4.3.2.2 Port functionality check

In the visual screening, the primary criterion for evaluation of port functionality is whether the port operates as intended by the company, not whether it meets the requirements of IEC TS 62257-9-8 or another product specification. Compliance with product specifications is assessed in Annex EE. Ports that power included appliances may be considered functional if they can power the corresponding appliances. Ports that do not power advertised appliances may be tested by connecting an advertised appliance or equivalent generic appliance (i.e. a resistor or electronic load; see HH.5.1), or the functionality check may be deferred until the assessment of DC ports is performed.

After the initial inspection, a port should additionally be considered non-functional if the output characteristics change as a result of normal use in a way that would impair operation (for example, if a failure of voltage regulation occurs).

F.4.3.2.3 Deficiencies

In the external and internal inspections, the following types of deficiencies shall be identified:

- a) Soldering: note any poor solder joints, such as cold joints or joints with insufficient or excess solder;
- b) Wiring: note any poor wiring, such as a badly pinched wire;

NOTE 1 The standard IPC-A-610 can be used as a guide in identifying soldering and wiring deficiencies.

- c) Mechanical: note any mechanical deficiencies, such as poorly secured components, poor adhesive joints that are likely to fail, and components or assemblies with inadequate mechanical strength to withstand normal use.
- d) Screw connections: note any loose screws and report as a deficiency if the looseness could create an electrical contact failure or safety hazard (such as a battery lead coming loose and contacting another conductor, resulting in a short circuit);

NOTE 2 Item d) applies to screw connections not made by the user or installer. Screw connections made by the user or installer are evaluated in the screw connections test (Annex X).

- e) Battery: note any battery-related deficiency that does not constitute a safety issue, such as corrosion of battery terminals or if the battery is not adequately fastened, such as with loose connectors;
- f) PV module: include any items marked with * in F.4.3.6 b).
- g) Minor functionality: functional deficiencies include an indicator light or display failing to work, a non-functional accessory (such as extension cable), or a non-functional port other than those used to power included or advertised appliances. Functional deficiencies are not severe enough to result in the product becoming non-functional as defined in F.4.3.2.1, above.

F.4.3.3 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Bright task light with good colour rendering.
- Miscellaneous hand tools (screwdrivers, wrenches, etc.) to disassemble DUT.
- Camera to document characteristics with particular attention to potential points of failure (e.g. cold solder joints).
- DC voltmeter or multimeter for conducting basic electronic integrity and functionality tests
- Optional: DC current clamp meter.

F.4.3.4 Test prerequisites

The DUT and included appliances should be new, unaltered, and in original packaging. Read the retail box and documentation for instructions on using the DUT and included appliances. Consult the company for missing information pertaining to the required observations. If the DUT or appliance instructions require them to be fully charged prior to operation, do so prior to conducting this test.

F.4.3.5 Apparatus

The DUT and included appliances should be positioned under a bright task light for examination.

F.4.3.6 Procedure

F.4.3.6.1 General

All photographs of components shall be in colour and of sufficient quality that all relevant text is legible (unless illegible on the item being photographed) and all relevant icons and images are clearly reproduced.

F.4.3.6.2 Functionality and preliminary safety inspection

The following steps shall be performed on all samples that will undergo any of the tests in this document:

- a) Check the functionality of the DUT and included appliances before disassembling. If a proper charging cable or appliances are not included with the product, the proper charging cable or appropriate appliance shall be obtained by the test laboratory to check for functionality.
 - 1) Do the DUT and included appliances work as described with provided documentation?
 - 2) Do the DUT and included appliances charge as described with provided documentation? Be sure that any included grid charger properly functions. To ensure that the DUT is receiving a charge, the current at the battery should be measured with a DC current clamp meter. The product's charging indicator, if any, should not be used for this assessment as it can turn on even when the battery current is negligible.
 - 3) Check the functionality of all of the switches and connectors on all components of the DUT, including appliances.
 - 4) Check the functionality (as defined in F.4.3.2.2) of all ports that could power included or advertised appliances.
 - 5) Comment on any notable characteristics of the light output (e.g. glare, colour, inconsistency between samples).
 - 6) Comment on any notable characteristics of the functionality of the included appliances.
 - 7) Comment on the proper functioning of either the indicator lights (such as a charging indicator) or informative displays (such as a display showing the battery's state of charge), or both, if applicable.
 - 8) Comment on any faulty operation and provide photographs, if necessary.
- b) Externally inspect all components, including PV modules, for potential hazards or safety issues, such as:
 - bare conductors;
 - sharp points, edges, burrs, etc. that can damage the insulation of conductors or pose a risk of injury (including exposed screws and fasteners with sharp points and edges);
 - plugs that could exceed ampacity ratings if improperly used;
 - electrical situations that could lead to a fire;

Report and photograph any potential hazards or safety issues identified.

As an alternative to visual inspection for sharp edges, the sharp edge test described in IEC 61730-2 MST 06 can be performed to confirm compliance.

F.4.3.6.3 External and internal inspection

The following steps shall be performed on the number of samples specified in Table 3:

- a) In the external inspection, check the functionality and mechanical strength of all mechanical joints, connections, or moving parts that are not subject to the mechanical durability tests (W.5.2, W.5.3, and W.5.4), such as lamp caps and lamp holders, radio and television antennas, stands, handles, battery compartment covers, inflatable components, etc. Connectors should be assessed to the degree practical; for example, if a television includes several different types of audio/video input sockets, it is not necessary to test the functionality of every such socket, but a socket that is obviously damaged or has clearly inadequate mechanical strength should be considered a deficiency.

- b) Carefully inspect each PV module and note and photograph any of the following visual defect conditions. The inspection should be performed with an illumination of at least 1 000 lx on the module surface.
- broken, cracked, or torn external surfaces*;
 - bent or misaligned external surfaces, including superstrates, substrates, frames and junction boxes to the extent that the operation or safety of the module would be impaired*;
 - loss of mechanical integrity or failure of adhesive bonds, to the extent that either the installation or operation of the module, or both, would be impaired*;
 - bubbles or delaminations forming a continuous path between a cell and the edge of the module*;
 - module label or markings are no longer attached or the information is unreadable*;
 - broken or cracked cells;
 - faulty interconnections, terminations, or joints;
 - an individual cell's area is covered by material that blocks light, e.g. by the frame, a label, or another cell;
 - tacky surfaces of plastic materials;
 - exposed live electrical parts;
 - fake cells (e.g. some cells are actually images printed on paper);
 - any other conditions which could affect performance;
 - (for thin film PV modules) voids in, and visible corrosion of any of the thin film layers of the active circuit.

Items marked with * are considered deficiencies in the deficiencies score calculation in F.4.3.6.4.

NOTE 1 Guidance regarding deficiencies that could pose safety issues for PV modules was derived from IEC PAS 62257-10 and IEC 61730-2.

- c) Record the number of instances of each category of deficiencies as defined in F.4.3.2.3 found in the external inspection. Document each type of deficiency with photographs.
- d) Disassemble the DUT and included appliances so the following internal observations can be made.
- 1) Inspect the internal electronics for potential hazards or safety issues such as bare conductors that could touch and short-circuit the product's battery or inflated/leaking batteries. If lithium batteries are inflated or fluid is present, these batteries are dangerous and shall not be used for any additional tests. Dispose of the batteries properly.
 - 2) Make note of and photograph any potential hazards or safety issues identified.
 - 3) Inspect the electronic components' quality and workmanship. Record the number of instances of each category of deficiencies as defined in F.4.3.2.3 found in the internal inspection. Document the workmanship with comments and photographs.
 - 4) Note if the DUT and included appliances have either an easily replaceable battery or easily replaceable printed circuit board (PCB), or both. The battery and PCB are easily replaceable if they can be interchanged without any tools other than screwdriver(s) (i.e. no soldering or splicing) that are used only for the removal and replacement of screws (i.e. no prying). If either the battery or PCB, or both, can be replaced in this manner, it is considered "field replaceable." Note if any instructions are included for replacing either the battery or PCB, or both.
 - 5) Some batteries utilize safety or cell balancing circuitry on the power control unit PCB (external to the battery pack). Note if the battery utilizes a safety or cell balancing circuit external to the battery pack. This arrangement can be observed as additional wire connections between the battery and the PCB. Document with photographs. Consult the company if uncertain.
 - 6) Examine the internal components, especially the batteries, and note any specifications that were not apparent in F.4.2.5.

- 7) Note if the batteries contain any internal circuitry. This type of circuitry typically consists of a small PCB located beneath a plastic jacket encasing the battery. Document with photographs.

NOTE 2 Additional wire connections between the battery and the PCB can have other functions as well; for example temperature sensing. Voltage measurements of the additional wires can be helpful in assessing their function; voltages on wires added for cell monitoring or balancing will be multiples of the cell voltage.

- 8) For lithium-ion or lithium iron phosphate batteries with multiple cells (or parallel cellblocks) in series, note if the appearance of the battery pack and circuitry is generally consistent with the description provided by the company in D.3.2.2 i) and D.3.2.2 j) regarding individual cell protection.

F.4.3.6.4 Workmanship quality determination

Determine the deficiencies score for each component in accordance with the following steps. Components in which more than one function is contained in the same housing will receive a single deficiencies score. For example, a lamp with a built-in battery will receive a single deficiencies score, while in the case of a light point that plugs in to a main unit, the light point and the main unit will each receive a separate deficiencies score.

- a) Sum the number of deficiencies observed between the examined samples for soldering, wiring, fixture, PV, and battery recorded in F.4.3.6.3 c) and d) 3). Sum and triple the number of deficiencies observed between the examined samples for minor functionality recorded in F.4.3.6.3 c) and d) 3). Add these two sums together and divide by the number of samples examined in accordance with F.4.3.6.3 a) through d); this is the total deficiencies score. When a product contains multiple components, the deficiencies score is computed separately for each component.

The deficiencies score is calculated for the number of samples examined in F.4.3.6.3 as indicated in Table 3. If, during the course of testing, deficiencies or minor functionality issues are identified on other samples, the test laboratory may, at their discretion, recalculate the deficiencies score, replacing one of the previously inspected samples with the newly identified sample. The samples included in the calculation should be selected to maximize the resulting deficiencies score; the total number of samples included in the calculation should still be in accordance with Table 3. Deficiencies observed on samples not included in the deficiencies score should be included in the test report comments.

EXAMPLE During the visual screening of a component, samples 1 and 2 are inspected. Sample 1 has one soldering deficiency and sample 2 has one soldering and one wiring deficiency, for a deficiencies score of 1,5. However, during subsequent testing, a third sample (sample 3) is found to have one minor functionality deficiency. The laboratory may recalculate the deficiencies score for the component using samples 2 and 3, giving a result of 2,5.

- b) Determine and note the workmanship quality for each component using the following guidelines:
- good: no deficiencies were observed with the samples examined, and all samples being tested continued to function throughout normal use during testing without any hazards or safety issues;
 - fair: deficiencies score greater than 0 but less than or equal to 1,5, and all of the initially functional samples being tested continued to function throughout normal use during testing. At most, one sample did not function as defined in F.4.3.2 when initially evaluated;
 - poor: deficiencies score greater than 1,5, or one or more initially functional samples being tested became non-functional (as defined in F.4.3.2) throughout normal use during testing, or two or more samples did not function when initially evaluated.

The workmanship quality shall be reassessed upon completion of testing if any samples stop functioning under normal use during a later test. In addition, hazards or safety issues that develop during testing as a result of normal use shall be noted in the report.

NOTE In previous versions of this document, hazards or safety issues resulted in a workmanship rating of “poor.” In the present version, safety issues are not taken into account in the workmanship rating but are a separate outcome of the visual screening.

- c) If testing a complete product, determine the overall workmanship quality for the product as described in 4.1.1:
- good: all components received a deficiencies score of 0;
 - fair: deficiencies were present, but no more than two components had a deficiencies score greater than 1 and all components had a deficiencies score less than or equal to 1,5;
 - poor: more than two components had a deficiencies score greater than 1 or any component had a deficiencies score greater than 1,5.
- d) Provide any additional overall external and internal screening comments as necessary.

F.5 Reporting

Report the following in the visual screening test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- All information listed in Clause F.4.

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Annex G (normative)

Sample preparation

G.1 Background

The product sample shall be prepared before starting the tests. The preparation includes configuring the product to allow connection with a laboratory power supply, as well as taking measurements. For DUTs with multi-cell lithium battery packs, the preparation also includes charging the product.

G.2 Test outcomes

There are no sample preparation outcomes.

G.3 Related tests

The sample preparation procedures shall be performed on all DUTs prior to conducting the light output test (Annex I), lumen maintenance test (Annex J), battery test (Annex K), full-battery run time test (Annex M), grid charge test (Annex O), electromechanical charge test (Annex P), solar charge test (Annex R), charge controller behaviour test (Annex S), light distribution test (Annex T), battery durability test (Annex BB), protection tests (Annex DD), assessment of DC ports (Annex EE), and appliance tests (Annex FF).

G.4 Procedure

G.4.1 General

The DUT is configured in order to make measurements of current and voltage during selected tests, charge the battery via a battery analyser, and simulate a specified battery voltage during selected tests with a laboratory power supply. In some cases, this will mean selecting and attaching the correct plug and receptacle components. In other cases, it will be necessary to modify the DUT by cutting wires and drilling holes to allow electrical connections. When possible, the testing laboratory shall use all cables and connectors that are provided with the DUT and shall configure the system in accordance with product instructions and in way consistent with the normal use of the product. Any modifications shall be kept to a minimum. Additional configuration information can also be found in Annex H; see in particular Figure H.1.

G.4.2 Equipment requirements

The following equipment and supplies, or their equivalent, are required. Equipment and supplies shall meet the requirements in Clause CC.2.

- Plugs and receptacles (e.g. pin-and-socket connectors) that connect to the electrical ports to allow the use of a laboratory power supply and battery analyser with the appliances.
- Insulated stranded copper wire. The conductor size shall be 0,75 mm² or thicker; for many products, it is necessary to use thicker wire to avoid introducing excessive voltage drop. The required conductor size depends on the wire length, the maximum current, and the sensitivity of the product to voltage drop; in all cases, the wire size shall be sufficient to avoid significantly affecting the behaviour of the DUT. Recommended minimum wire sizes are given in Table G.1. It is recommended to use four different colours.
- Wire cutters.
- Wire strippers.

- Soldering iron and solder.
- Heat-shrink tubing and heat gun.
- Screwdrivers or other appropriate tools for opening the DUT.
- Optional for DUTs with multi-cell lithium battery packs: DC power supply.
- Optional: DC current clamp meter.
- In some cases: a power drill with an appropriately sized drill bit to make a hole in the enclosure to fit four extension wires.

**Table G.1 – Recommended minimum conductor sizes
for copper wire used for sample preparation**

Expected maximum current A	Min. wire thickness mm ²	Min. wire thickness (American wire gauge)
≤ 2,0	0,75	--
≤ 2,2	0,82	18
≤ 3,5	1,31	16
≤ 4,0	1,50	--
≤ 5,5	2,08	14
≤ 6,7	2,50	--
≤ 8,8	3,31	12
≤ 10,7	4,00	--
≤ 14,0	5,26	10

G.4.3 Test prerequisites

The visual screening shall be completed prior to performing the sample preparation procedures.

G.4.4 Procedure

The following steps shall be performed.

- For DUTs with lithium battery packs having multiple cells in series, fully charge the product using the product's charging circuitry to ensure the DUT has been given the opportunity to balance the cells of its battery pack. (The battery pack and charge controller may be from different samples.) Use one of the two following options.
 - With the DUT configured for charging (e.g. PV module connected to the power control unit), face the PV module towards the sun until the DUT reaches a full charge. Be sure to protect the DUT from water ingress.
 - Charge the DUT using a power supply. Set the power supply to the DUT's rated maximum power-point voltage and current. For DUTs with external PV modules, use a severed PV connector to deliver the power to the DUT's PV socket. For DUTs with integrated PV modules, open the DUT to access and sever the leads between the PV module and electronics to deliver the power through the DUT's electronics. If the maximum power-point voltage and current values are not rated, contact the company to obtain the values. (This option is less realistic but more convenient for laboratories without access to a secure location with frequent full sun exposure.)

To determine when the DUT is fully charged, the lab may use the included instructions or check that current no longer enters the battery pack with a current clamp meter when the PV module is exposed to sun or power supply is providing power.

- Identify the system components and appliances and determine the method of electrical connections between system components.

- c) Modify the DUT to electrically isolate the battery from the electronics. This will allow the battery to be tested and will also allow the electronics and ports to be powered from a laboratory power supply. If the product has a cell balancing or monitoring circuit that is external to the battery, refer to H.5.6 e) when preparing the product.

- 1) With wire cutters, cut the positive and negative wires individually where the battery connects with the rest of the DUT circuit. To avoid a short circuit, which could result in personal injury, fire, or explosion, do not cut the wires simultaneously. In some cases, additional wires are attached between the battery and circuit for either battery temperature monitoring or cell balancing, or both – do not cut these wires. Some batteries have two wires connected to each battery terminal – keep the wires attached to each terminal together and treat them as one wire end for the remainder of the procedure. Occasionally, multiple batteries or battery cells are connected through the PCB (or other electronics external to the battery). When isolating these batteries, ensure that the cells are connected in an equivalent manner to how they were originally connected through the PCB.
- 2) Extend the four wire ends (two connected to the battery terminals, two connected to the PCB or other electronics) by soldering on additional wires. Make the wire extensions long enough to be extended approximately 6 cm outside the enclosure, but no longer than necessary. To avoid electric shock, keep the battery positive and negative extensions separated. Cover the wire connections with heat-shrink tubing once soldered. To minimize voltage drop, the conductor size of the extension wires added in this step shall be $\geq 0,75 \text{ mm}^2$ (see recommendations in Table G.1) and equal to or larger than the existing DUT battery leads. Wire extensions shall be kept as short as possible. The laboratory shall monitor the behaviour of the DUT to ensure that modifications do not significantly change its performance. Changes in performance can include changes to the power consumption, output, or any other function that is substantially different than the function of the unaltered sample.

NOTE In the American wire gauge (AWG) system, 18 AWG ($0,823 \text{ mm}^2$) is the smallest conductor size meeting this requirement.

- 3) Close the DUT such that the wires can extend outside the enclosure without being pinched.

Some products are designed with openings in their enclosures such that the wires can fit through these openings without physically changing the enclosure.

Some products do not have openings for wire extensions to fit through, in which case a hole shall be drilled into the side of the enclosure. A drill bit with a diameter slightly greater than the combined diameter of all four extension wires should be used. Choose a location on the enclosure to minimize the extension wire length and minimize changes to the enclosure. Be sure that the extension wires do not interfere with the light output.

- 4) Optionally, attach connectors (e.g. pin-and-socket connectors) to the ends of the extension wires for easy use during testing. Attach one connector to the battery positive and negative extension wires and the mating connector to the DUT power supply lead wires. If no connectors are used, be sure to keep the battery positive and negative extensions separate when bare to avoid short-circuiting the battery. Covering the ends of the wires with electrical tape is one method to keep the extensions separate.

The charge controller behaviour test (Annex S), full-battery run time test (Annex M), and solar charge test (Annex R) impose limits on the total series resistance of the measurement apparatus. To meet these requirements, the use of connectors, soldered connections, or screw terminals is recommended. Alligator clips or similar spring-loaded removable connectors can introduce significant resistance and should not be used.

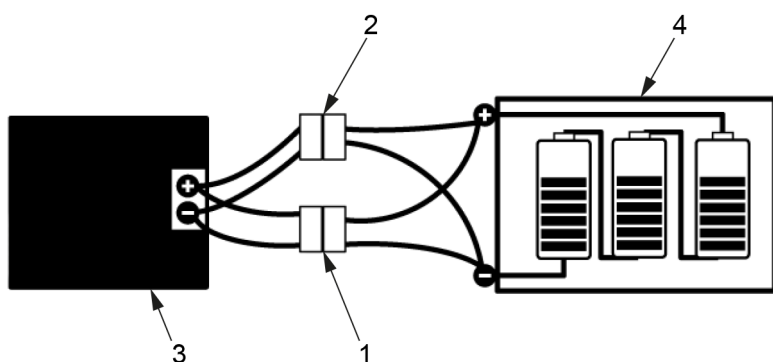
- 5) To ensure the DUT still works after it has been rewired, connect the wire pairs (with connectors or electrical tape) so the original, unaltered circuit is replicated and turn the DUT on. If the DUT does not turn on, check that the wires are connected correctly and that the solder joints connecting wires are good. Some products require having their PV modules attached with light shining on the PV module to get the product to turn on; afterwards, the PV module can be removed, and the product will continue working until its circuit is broken again.

- d) (optional) In some situations, it is acceptable for a test lab to supply a regulated voltage from a power supply directly to an appliance plug or wire end instead of supplying power to the power control unit. This method shall be used only if the appliance is normally supplied power by a voltage-regulated port (constant voltage). Built-in appliances as defined in 4.1.4 and identified in the visual screening (F.4.1.5 c) 5)) cannot be tested by this procedure. If the test lab is uncertain about the voltage regulation of the port, this procedure shall not be used.
- 1) Identify the positive and negative terminals or leads on the DUT's plug and receptacle connectors. This can be done by checking DUT instructions or by measuring the voltage polarities on the connector terminals with the DUT turned ON.
 - 2) Configure plug and receptacle components to mate with the DUT system components and allow the use of a laboratory power supply (to power the appliances) and a battery analyser (to test the battery(-ies)). In cases where suitable plug and receptacles cannot be found, the DUT may be modified by either cutting off connectors or opening DUT enclosures, or both, and proceeding with the DUT modifications outlined above. When possible, use the cables and connector components that are provided with the DUT and intended for normal operation.
- e) Some products that use coulomb counting or similar methods for estimating state of charge will not correctly detect the battery state of charge when a discharge is started immediately after the battery is disconnected and reconnected. This can result in the DUT turning off or reducing brightness prematurely during the full-battery run time test. To avoid these problems, a "secondary" set of wires may be attached to the battery and PCB or other electronics, to allow the DUT to be removed from one test apparatus and transferred to another without breaking the circuit between the PCB and battery. Figure G.1 shows how the secondary set of wires can be incorporated. Instead of mating connectors, a switch may be used on these leads.

When transferring a DUT prepared in this manner from one test apparatus to another, use the following procedure:

- 1) Connect the secondary wires from the PCB to the secondary wires from the battery (or, if using a switch, turn the switch on).
- 2) Disconnect the battery and PCB wires from the first test apparatus.
- 3) Connect the battery and PCB wires to the second test apparatus. If the apparatus includes a relay or switch, ensure that it is closed before proceeding.
- 4) Disconnect the secondary battery and PCB wires (or, if using a switch, turn the switch off).

If it is necessary to start the test (e.g. turn on the DUT or start data collection) in step 3), perform step 4) as quickly as possible to avoid missing current measurements.

**Key**

- 1 Primary wire connection
- 2 Secondary wire connection (or switch)
- 3 DUT electronics
- 4 Battery

Figure G.1 – Connections with secondary set of wires to avoid battery disconnection

G.4.5 Calculations

No calculations are required with the sample preparation procedures.

G.5 Reporting

No reporting is required with the sample preparation procedures.

Annex H (normative)

Power supply setup procedure

H.1 Background

Several of the test procedures replace the battery with an external laboratory (bench) power supply to provide electrical power to the DUT for the duration of the test. Annex H specifies the power supply equipment requirements and setup procedure for these tests.

In order to correctly simulate the battery and provide the DUT accurate direct current (DC) power, the power supply shall be configured properly to eliminate errors that can occur from:

- voltage drops from the resistance of the lead wires, and
- electronic noise in the lead wires from either the DUT or the test environment.

These errors can (in most cases) be eliminated with a 4-wire test configuration and input filter capacitors.

H.2 Test outcomes

The test outcome of the power supply setup procedure is listed in Table H.1.

Table H.1 – Power supply setup test outcome

Metric	Reporting units	Related aspects	Remarks
Standard operating voltage	Volts (V)	n/a	Used when a typical battery voltage during discharge is necessary, in tests (such as the lumen maintenance test) where it is impractical to use the typical battery discharge voltage from the full-battery run time test.

H.3 Related tests

Annex H is related to the light output test (Annex I), the lumen maintenance test (Annex J), the solar charge test (Annex R), the charge controller behaviour test (Annex S), and the light distribution test (Annex T), the protection tests (Annex DD), the assessment of DC ports (Annex EE), and appliance tests (Annex FF). It is necessary to perform the full-battery run time test (Annex M) to determine the typical battery discharge voltage in H.5.2. In some unusual cases (battery types other than lead-acid, NiMH, lithium iron phosphate, or other lithium-ion), it is also necessary to perform the full-battery run time test (Annex M) or battery test (Annex K) in order to determine the standard operating voltage in H.5.2.

H.4 Equipment requirements

The DC power supply shall be capable of delivering a stable, accurate DC input to the DUT. The power supply should have a voltage readout resolution of no more than 0,01 V and a current readout resolution of no more than 0,001 A. The voltage applied to the DUT should be regulated to within $\pm 0,2$ % during photometric measurements, charge controller tests, and solar charging tests and ± 3 % for the duration of lumen maintenance tests. Equipment shall meet the requirements in Clause CC.2.

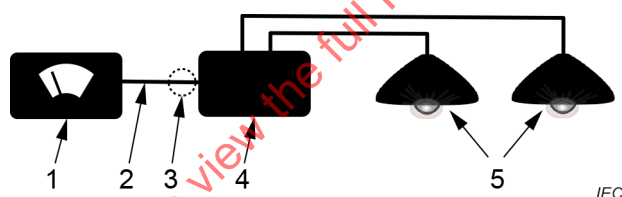
Some test configurations may use power supplies without voltage and current readouts capable of measuring voltage and current values with the required accuracy. For example, a single power supply may be used to run concurrent lifetime tests on multiple DUTs (the DUTs are run in parallel from a single DC voltage rail). For these configurations, voltage measurements may be made at each DUT input using a voltmeter or multimeter and current measurements may be made using a voltage drop measurement on a series shunt resistor using Ohm's law.

H.5 Setup procedure for photometric measurements and lumen maintenance tests

H.5.1 Test setup

The following steps shall be performed.

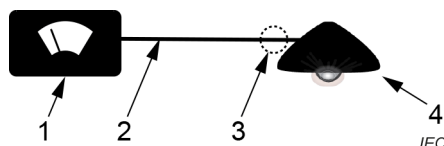
- Configure the power supply and DUT as shown in Figure H.1 or Figure H.2. Input filter capacitors shall be placed at the DUT input in accordance with H.5.5.
- If the product has a PV module, disconnect it, cover it with opaque material, or orient it so that it is not exposed to ambient light.
- Set the voltage level in accordance with H.5.2 and measured in accordance with H.5.4.
- The DUT is powered on and allowed to stabilize for ≥ 20 min in accordance with H.5.3.
- Tests are performed on the DUT.
- During testing, monitor the DUT for erratic behaviour that could indicate a problem with the test setup, including light output flickering, voltage and current instability, and difficulty in start-up.



Key

- DC power supply
- DC power supply lead wires (+ voltage sense wires for light output test)
- Input filter capacitor attachment location
- power control unit (battery is removed or disconnected from DUT electronics; see G.4.4.)
- appliances

Figure H.1 – Power supply setup for powering a power control unit



Key

- DC power supply
- DC power supply lead wires (+ voltage sense wires for light output test)
- Input filter capacitor attachment location
- appliance (appliance battery (when present) is electrically isolated from DUT electronics; see G.4.4.)

Figure H.2 – Power supply setup for directly powering an appliance

H.5.2 DC voltage levels

H.5.2.1 General

The constant DC voltage level for testing a product sample is based on the test requirements and battery characteristics.

When supplying power with a laboratory power supply to the power control unit (Figure H.1), either the typical battery discharge voltage (corresponding to the voltage at the average power operating point found during the full-battery run time test, Annex M) or the standard operating voltage (Table H.2) is used. This simulates the battery voltage. The typical battery discharge voltage is more representative of the typical operating point than the standard operating voltage because it is based on measurements. The typical battery discharge voltage is therefore used in the light output test (Annex I), light distribution test (Annex T), assessment of DC ports (Annex EE), and appliance tests (Annex FF). The standard operating voltage is used for the lumen maintenance test (Annex J), in which it is often impractical for laboratories to drive multiple samples at different voltages and it is desirable to begin testing as soon as possible after receipt of samples. The standard operating voltage is also used for the protection tests (Annex DD) because these tests are conducted on a single sample that might not have undergone the full-battery run time test and the results are less sensitive to the operating voltage. The standard operating voltage is also used for the appliance tests because the typical battery discharge voltage is not always available for the appliance battery.

The standard operating voltage shall not be used in place of the typical battery discharge voltage. If it is necessary to determine a typical battery discharge voltage for a sample that will not undergo the full-battery run time test, the average value for all the samples tested may be used.

When supplying power with a laboratory power supply directly to a light point (and not using the power control unit) (Figure H.2), the appliance operating voltage as determined in Clause FF.5 is used. This simulates the port voltage for that appliance. The standard port operating voltage (H.5.2.3) may alternatively be used for the lumen maintenance test (Annex J) and protection tests (Annex DD).

H.5.2.2 Standard operating voltage of a battery

The standard operating voltage depends on the type, configuration, and number of cells of the battery pack. These characteristics are typically provided by the company but may be determined by testing the discharge profile (Annex K) and inspecting the battery.

The standard operating voltages for several battery chemistries are listed in Table H.2. For unknown or new types of batteries, the typical battery discharge voltage may be used in place of the standard operating voltage, or a typical discharge voltage may be determined from company-provided battery specifications or from the battery test (Annex K), for example by using the average voltage during the final discharge cycle in the battery capacity test.

Table H.2 – Standard operating voltage for several common battery types

Battery type	Standard operating voltage
	V/cell
Lead-acid	2,05
NiMH	1,25
Lithium iron phosphate	3,25
Other lithium ion	3,7
Other battery chemistry	Use the typical battery discharge voltage (Annex M), or use a typical discharge voltage as determined from company-provided battery specifications or the battery test (Annex K).

During testing, some DUTs do not start up at the desired voltage and require an input slightly greater than the desired battery voltage. In this case, incrementally increase the power supply voltage by 0,05 V until the DUT is operational at the desired light setting. After start up, reduce the voltage back to the desired battery voltage and allow the DUT to stabilize. If the DUT will not remain on when the voltage is reduced, repeat this step and run the DUT as close to the desired battery voltage as possible, making note of the issue.

The current drawn by a DUT powered with an external power supply at the typical battery discharge voltage is generally at or near the current measured in the full-battery run time test for the same configuration of appliances and settings at the typical battery discharge voltage. Similarly, the current drawn by an appliance powered at the appliance operating voltage should be close to the value measured during the determination of the appliance operating voltage. Variations greater than 5 % can indicate a problem with the power supply setup and should be noted in the test report.

NOTE For many products, the combination of appliances turned on during photometric testing will differ from the configuration used in the full-battery run time test; in this case, the currents can differ by more than 5 %.

H.5.2.3 Standard port operating voltage

When a removable appliance is tested at the standard operating voltage, there are two options to power the appliance:

- a) Supply power to the power control unit at the standard operating voltage of the battery as described in H.5.2.2, then connect the appliance to the appropriate port on the power control unit and conduct the test. Do not connect a current-sensing element between the port and appliance unless this is required for the particular test being performed.
- b) Alternatively, determine the standard port operating voltage in accordance with the following steps:
 - 1) Supply power to the appliance as in a). Adjust the power supply as necessary to maintain the standard operating voltage during the procedure.
 - 2) Turn on the appliance at the setting under test.
 - 3) Allow the appliance to stabilize in accordance with the appropriate stabilization procedure in the power consumption test (Clause FF.6), or, for lighting appliances, in accordance with H.5.3.
 - 4) Measure the port voltage. If the voltage is varying by less than 0,5 % per minute, a point measurement may be recorded; otherwise, report the average voltage over at least 2 min.
 - 5) The appliance may now be powered at the standard port operating voltage for any tests where use of the standard operating voltage is permitted.
 - 6) A different standard port operating voltage value shall be measured for each appliance and setting to be tested. If it is necessary to change settings after the appliance has already stabilized, a reduced stabilization period may be used if permitted by the applicable subclause of Clause FF.6.

NOTE The main expected application of this procedure is to determine an operating voltage for the lumen maintenance test if the appliance operating voltage has not yet been determined.

H.5.3 Stabilization period

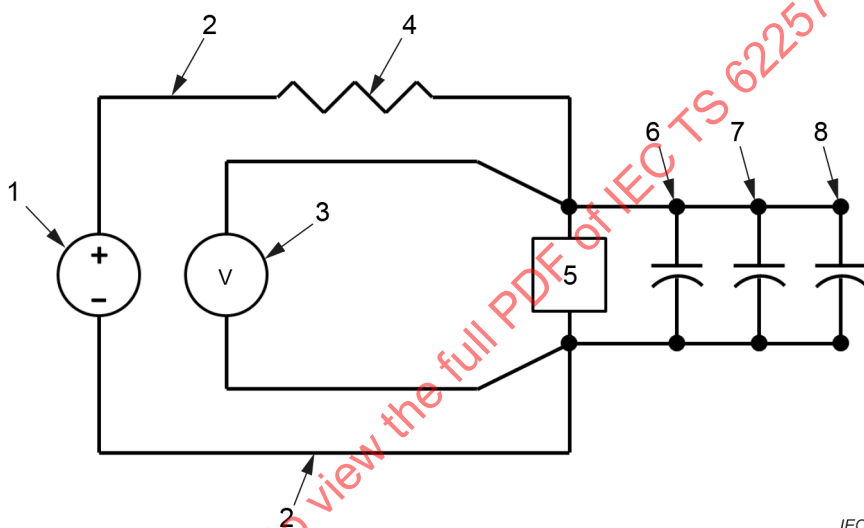
A DUT shall be allowed to stabilize (warm up) before light output measurements are made. There are two approved stabilization procedures:

- a) the DUT is powered on and allowed to stabilize for 20 min, or
- b) the DUT is powered on and is considered stable when three consecutive output measurements, taken 15 min apart, have a variation of $\leq 0,5$ % (based on ANSI/IES LM-79).

In order to facilitate testing of multiple samples, 20 min is specified as the minimum stabilization time and is adequate for most products. Longer times can be necessary for DUTs with large heat sinks or high-powered LEDs. Voltage, current, and light output for a DUT should be monitored to determine if 20 min is an adequate stabilization time. If a longer stabilization time is necessary, procedure b) may be used to determine the stabilization time for a single sample, and this time may then be used to test additional samples of the same type.

H.5.4 4-wire power supply measurements

Current carrying lead wires used to provide power to the DUT should be appropriately sized and as short as possible and shall be separate from the wires used to measure the DUT voltage (Figure H.3). This is typically referred to as a 4-wire test measurement, and eliminates the voltage drop associated with the resistance of the test leads because very little electric current is carried in the voltage sensing wires. Many power supplies are equipped to handle this measurement automatically (also known as remote sensing), although test personnel may make corrections by adjusting the sense voltage manually.



IEC

Key

- 1 DC power supply
- 2 Lead wire
- 3 Voltage sense
- 4 Series shunt resistor (optional)
- 5 DUT
- 6 1 μ F capacitor
- 7 10 μ F capacitor
- 8 100 μ F capacitor

Figure H.3 – 4-wire test configuration with input filter capacitors

H.5.5 Filtering electronic noise

Electromagnetic interference (EMI) generated by the DUT or the test environment can interfere with voltage and current measurements. This can occur from switching power supplies found in some electronic devices and is exacerbated by using long lead wires from the power supply to the DUT. Problems with EMI will typically cause input voltage and current instability, and often can result in light output variation in the DUT.

Input capacitors shall be placed at the DUT input connections, between supply positive and negative leads, as close to the DUT as possible (Figure H.3). Wires connecting the capacitors to the DUT should be at least 0,75 mm² or larger if required by Annex G. The capacitors shall be ceramic or tantalum types and have 1 µF, 10 µF, and 100 µF values. These three capacitor values, used in parallel, will effectively mitigate most EMI problems.

These capacitors may be used during any test that replaces the battery with a power supply, including the protection tests (Annex DD), assessment of DC ports (Annex EE), and appliance tests (Annex FF). Laboratory experience has shown that these capacitors can often be omitted during non-photometric tests, in part because the wires between the power supply and DUT are typically short in these applications.

H.5.6 Troubleshooting

If the DUT will not turn on after replacing its battery with a power supply, the following steps may be performed, in order. If the DUT turns off or drops to a lower brightness setting after a period of time, the following steps may be performed starting with step b). If possible, consult the company to ensure that any troubleshooting steps taken will not damage the product.

- a) Some solar products require power to be applied to the PV module in order to turn on after the battery has been disconnected. The following steps may be performed for these products.
 - 1) Follow the guidelines in H.5.1 for replacing the battery with a power supply.
 - 2) If the product does not have an integrated PV module, plug the PV module into its charging socket.
 - 3) Shine a bright light very close to the PV module. A 100 W incandescent bulb placed as close as possible to the module while illuminating the entire surface is often effective. Alternatively, expose the module to direct sunlight.
 - 4) If the DUT does not turn on, try cycling its on/off switch. After the DUT turns on, the PV module can usually be removed.
 - 5) If these steps are unsuccessful, repeat the procedure, but while the light is being applied to the PV module, increase the power supply voltage to the overcharge protection voltage. If this voltage is not known, use the recommended value from Table L.2. If this is successful, try to reduce the voltage to the correct value once the product has turned on.
- b) If the PV module is not available or it is not possible to expose it to sufficiently bright light, a power supply may be used to simulate the PV module.
 - 1) Follow the guidelines in H.5.1 for replacing the battery with a power supply.
 - 2) For products with external PV modules, connect an additional power supply to the PV module socket. For products with integrated PV modules, cut the leads connecting the PV module to the PCB and connect the power supply to these leads. Be sure to apply the power supply with the correct polarity; otherwise, the DUT can be damaged.
 - 3) Set the additional power supply to the PV module's maximum power point voltage (V_{mpp}) and maximum power point current (I_{mpp}). Use the rated values if the photovoltaic module I-V characteristics test (Annex Q) has not yet been performed. (In some cases, it is necessary to obtain the appropriate voltage and current values from the company.)
 - 4) Follow steps a) 4) and a) 5), above. If necessary, leave the PV socket input connected.

Option b) can sometimes be used if it is necessary to supply the PV input to the DUT for the entire duration of the test, for example if the product has a timer function that turns off the product or changes the setting after a fixed duration regardless of the battery state of charge, or if the product uses coulomb counting to estimate the battery state of charge. However, it is more likely that c) will be successful.

- c) Instead of replacing the battery with a power supply, the battery may be left connected within the DUT. Supply power to the PV socket as in b). Provide a means to measure the battery voltage and current.

When this method is used, the battery voltage cannot be regulated; the battery will charge until the product's charge controller stops the charge cycle. Therefore, the use of this method is subject to the following cautions:

- For products with NiMH batteries, care should be taken to avoid overcharging the batteries during prolonged tests. A battery current of up to $0,05 I_t$ A is generally safe for extended testing. For shorter durations, higher currents (typically up to $0,2 I_t$ A or as specified by the battery manufacturer) can be used without damaging the battery. At rates greater than $0,05 I_t$ A, avoid applying a total quantity of charge greater than 1,6 times the nominal battery capacity (starting with a fully discharged battery).
 - If the product's brightness varies with input voltage, company approval should be obtained before using this method for the lumen maintenance test. For most products, holding the battery at 100 % state of charge is not representative of typical use and can result in faster luminous flux degradation. (However, if it is possible to regulate the PV socket current so that the battery is held at a constant voltage, this caution does not apply. This regulation could be performed using a special-purpose electronic circuit or, in some cases, through manual monitoring and adjustment of the supply current.)
 - If it is not known whether the DUT has appropriate overcharge protection, to ensure safety, the battery voltage should be monitored until it stabilizes.
- d) Follow the instructions in c), but use a battery simulator instead of the battery. This will allow regulation of the simulated battery voltage and avoids the safety issues in c). Therefore, this method may be used in the lumen maintenance test even if the product's brightness varies with battery voltage.
- e) If the product has a cell balancing or monitoring circuit that is external to the battery (i.e. on a PCB external to the battery; see F.4.3.6), it is usually necessary to apply appropriate voltages to the cell balancing inputs. The laboratory should develop a solution in consultation with the company. The following options have been used successfully.
- 1) Connect resistors between the cell voltage inputs in place of the battery cells. The resistor values shall be closely matched so that the balancing function does not operate. Ensure that the current drawn by the resistors does not result in an error of more than 1 % in any current measurement.
 - 2) This option is simpler than 3) and is often effective but is unlikely to succeed if the balancing function continues to operate. Most cell balancers place a low resistance in parallel with the cell, and this will affect the voltages supplied to the inputs unless very low resistor values are used.
 - 3) In some cases, more complex circuitry is necessary to supply stable voltages to the DUT under all operating conditions. One method that has been used successfully is to connect an adjustable shunt voltage regulator in place of each cell. The power supply is then set to constant-current mode, with a current value greater than the current drawn by the DUT, and the shunt regulators determine the voltage. Alternatively, a bipolar power supply or power amplifier capable of either sinking or sourcing current may be used to supply a stable voltage to each cell input.
 - 4) It is also possible to connect a power supply in parallel with the battery. The power supply voltage and current shall be set to values within the safe operating limits of the battery in accordance with the battery manufacturer's specifications. To increase the voltage, the battery is allowed to charge until the voltage stabilizes; to decrease the voltage, the battery is discharged, for example by using the included appliances. This method is not recommended for long-term or unsupervised operation (e.g. the lumen maintenance test) because of the possibility of battery overcharging or overvoltage leading to a risk of fire (e.g. if the power supply is inadvertently set to an excessive voltage).

It is sometimes necessary to use option e) in combination with one of options a) through d) to turn the DUT on.

Options b) through d) are not recommended for use with the following test procedures if it is necessary to supply power continuously through the PV input, unless the PV current can be reduced to a negligible value and it is possible to regulate the battery voltage for the duration of the test:

- Light output test (Annex I)

NOTE If the luminous flux is independent of voltage, the light output test can be conducted. For products without a DC-DC converter, the PV socket and battery current can be summed to estimate the total current at the battery terminals during use. The voltage at the battery terminals can then be multiplied by the total current to calculate power and luminous efficacy. This calculation is not valid for products with DC-DC converters.

- Output overload protection test (DD.4.2)
- Assessment of DC ports (Annex EE)

H.6 Reporting

The voltage and current for tests using an external power supply shall be reported in accordance with Table H.3.

Table H.3 – Voltage and current reporting requirements

	Notes
Standard operating voltage	Determined from Table H.2 (required if standard operating voltage is used during testing)
DC voltage	Regulated to within $\pm 0,2$ % during photometric measurements and ± 3 % for the duration of lifetime tests
DC current	Measured using the power supply readout or series shunt resistor. Readout resolution should be $\geq 0,001$ mA

Annex I (normative)

Light output test

I.1 Background

The total luminous flux of a solar LED light is a key parameter as products that do not provide a sufficient amount of light have limited value.

Total luminous flux measurements (luminous flux, light output or lumen output) typically require the use of an integrating sphere or goniophotometer. An additional luminous flux measurement technique, referred to as the multi-plane method, involves conducting illuminance measurements on six planes that define a "box" around a test product and uses these measurements to calculate total luminous flux. The multi-plane method is unique to IEC 62257 and is described in I.4.4.

Laboratories may measure total luminous flux using an integrating sphere, goniophotometer, or the multi-plane method.

The luminous flux of all lighting appliances to be tested shall be measured individually. If more than one identical lighting appliance is included with the product, it is sufficient to measure one unit of each type of identical lighting appliances. The product specification may define categories of lighting appliances that are exempt from the light output test (e.g. accessory lights as defined in IEC TS 62257-9-8).

I.2 Test outcomes

The test outcomes of the light output test are listed in Table I.1.

Table I.1 – Light output test outcomes

Metric	Reporting units	Related aspects	Notes
Luminous flux	Lumens (lm)	4.2.9.1 Luminous flux output	Measured using a DC power supply, light sensor, and integrating sphere or goniophotometer (or using a multi-plane measurement).
Correlated colour temperature (CCT)	Kelvin (K)	4.2.9.4 Colour characteristics	Measured using equipment capable of characterizing spectral distribution
Colour rendering index (CRI)	0-100 (unitless)	4.2.9.4 Colour characteristics	Measured using equipment capable of characterizing spectral distribution

I.3 Related tests

The light output test is related to the full-battery run time test (Annex M) and the light distribution test (Annex T).

The light output test allows several alternatives for determining luminous flux. The multi-plane method described in I.4.4 and a goniophotometer may be used to generate information on the distribution of the DUT (necessary for Annex T) as well as information on luminous flux. When these methods are utilized, data may also be used by Annex T to calculate illuminance on a plane, illuminance about an axis, and full width half maximum (FWHM) angles as described in T.5.3.6.

I.4 Luminous flux measurement techniques

I.4.1 General

The luminous flux of all the lighting appliances supplied with the product shall be measured. If more than one identical appliance is included with the product, only one of each set of identical appliances should be tested.

These steps shall be followed:

- a) Determine the method of supplying power to the lighting appliance(s). The appliance shall be connected either to a port on the power control unit or directly to a laboratory power supply. See Annex H for additional information on selecting an appropriate method to power the lighting appliance.
- b) Prepare the test sample for lighting evaluation as described in Annex G. Set up a power supply to drive the DUT as described in Annex H. Measurements shall be taken in a conditioned space such that the air temperature is $22\text{ °C} \pm 5\text{ °C}$.
- c) When connecting a lighting appliance to a port on the power control unit, use the typical battery discharge voltage (Annex M) to supply power from a laboratory power supply to the power control unit. Do not turn on any appliances other than the lighting appliance under test.

When a product has multiple lights, these lighting appliances should be tested individually (for example, one lighting appliance is placed inside an integrating sphere and the others are left outside the sphere during the test). For products with multiple identical lighting appliances, it is only necessary to measure one of each type of identical lighting appliances.

EXAMPLE 1 The product includes three different types of lighting appliances (e.g. a tube light, four ambient light points, and two more focused light points). In this case, three of the seven lighting appliances would be measured during testing – one of each lighting appliance type.

- d) When connecting a lighting appliance directly to a laboratory power supply, use the appliance operating voltage (Clause FF.5). The DUT shall be powered on and set to the highest output setting. It is only necessary to measure one of each type of identical lighting appliance.

All luminous flux measurements shall be performed with the DUT(s) set to the highest output setting, unless otherwise specified in the product specification or requested by the client. Additional settings may be tested at the laboratory's discretion.

- e) Allow the DUT to stabilize in accordance with H.5.3.
- f) Record the voltage and current drawn by the DUT at the input connector.
- g) When powering lighting appliances with a power control unit, record the voltage and current at the power control unit's battery input connector.

In cases where multiple lighting appliances can be connected to a single port, as identified in F.4.1.5 b) 1), the combination of appliances may be treated as a single appliance or as individual appliances. If treated as a single appliance, all lighting appliances in the combined appliance should be powered on during the test; however, only one light point should be measured at a time. If the lighting appliances in the combination are identical, it is only necessary to measure one appliance in the combination for each sample. If the appliances are daisy-chained, the first and last of the identical appliances in the chain should be tested (on different samples) if possible.

NOTE "Daisy-chained" means that one appliance is connected directly to the power control unit and each successive appliance is connected to a port on the previous appliance.

EXAMPLE 2 A product has three daisy-chained lights powered by a single port, being tested as a single combined appliance, and two samples are being tested. The light closest to the power control unit could be tested on sample 1, and the light farthest from the power control unit could be tested on sample 2.

I.4.2 Calculation for lighting appliances tested in accordance with IEC TS 62257-12-1

If a lighting appliance without an internal battery has been tested in accordance with the light output test method of IEC TS 62257-12-1, these test results may be used provided that the appliance operating voltage as determined in FF.6.3 is within the range of voltages at which relative light output was measured during the input voltage range test of IEC TS 62257-12-1.

The relative light output and luminous flux measurements shall have been made at the setting for which luminous flux is to be calculated. (For example, the relative light output measured at the high setting shall not be used to calculate the luminous flux at the medium setting.) The CRI and CCT values measured in the light output test of IEC TS 62257-12-1 may be used without correction even if the drive voltage was not equal to the appliance operating voltage.

To calculate luminous flux for such a lighting appliance, use the following procedure:

- a) Calculate, using linear interpolation, the relative light output at the appliance operating voltage (Clause FF.5), using the relationship between voltage and relative light output measured in the input voltage range test of IEC TS 62257-12-1. (The relative light output at the standard operating voltage defined in IEC TS 62257-12-1 is always 100 %.)

NOTE The standard operating voltage from IEC TS 62257-12-1 is not necessarily the same as the standard operating voltage defined in H.5.2.

- b) Multiply the relative light output value calculated in a) by the luminous flux value measured in the light output test of IEC TS 62257-12-1.

I.4.3 Luminous flux measurements with an integrating sphere or goniophotometer

Refer to the following standard test methods for the measurement of luminous flux with an integrating sphere or goniophotometer:

- CIE 084;
- CIE 127;
- ANSI/IES LM-78;
- ANSI/IES LM-79.

I.4.4 Luminous flux measurements using the multi-plane method

I.4.4.1 General

1 lux is equal to 1 lumen per square metre. This relationship is used in this method to obtain total lumen output by determining the average illuminance (lux) on a 1 m² surface at six surfaces (left, right, front, back, top, and bottom) that completely encompass the DUT and summing up the zonal lumen output from each of these six surfaces. This method is similar conceptually to the method by which lumen output is calculated by summing zonal lumen output for goniophotometric measurements.

Only one lighting appliance can be tested at a time with this procedure. If the product's design requires other lighting appliances to be turned on, they shall be covered or otherwise arranged so that no light from these appliances reaches the measurement plane.

I.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Illuminance meter.
- Multi-plane test apparatus (described in I.4.4.4).
- DC power supply.
- DC voltmeter or multimeter.
- DC ammeter.

I.4.4.3 Test prerequisites

See general procedure (I.4.1).

I.4.4.4 Apparatus

The test requires a lighting distribution grid surface that can hold an illuminance meter over a 1 m^2 surface with $0,1 \text{ m}$ spacing – an 11×11 grid with 121 points (Figure I.1). The 81 interior points each represent 100 cm^2 of surface area, the 36 edge points each represent 50 cm^2 of surface area, and the four corner points represent 25 cm^2 of surface area. The light is fixed $0,5 \text{ m}$ away from the centre of the grid surface (the $0,5 \text{ m}$ is measured from the centre of the light source itself).

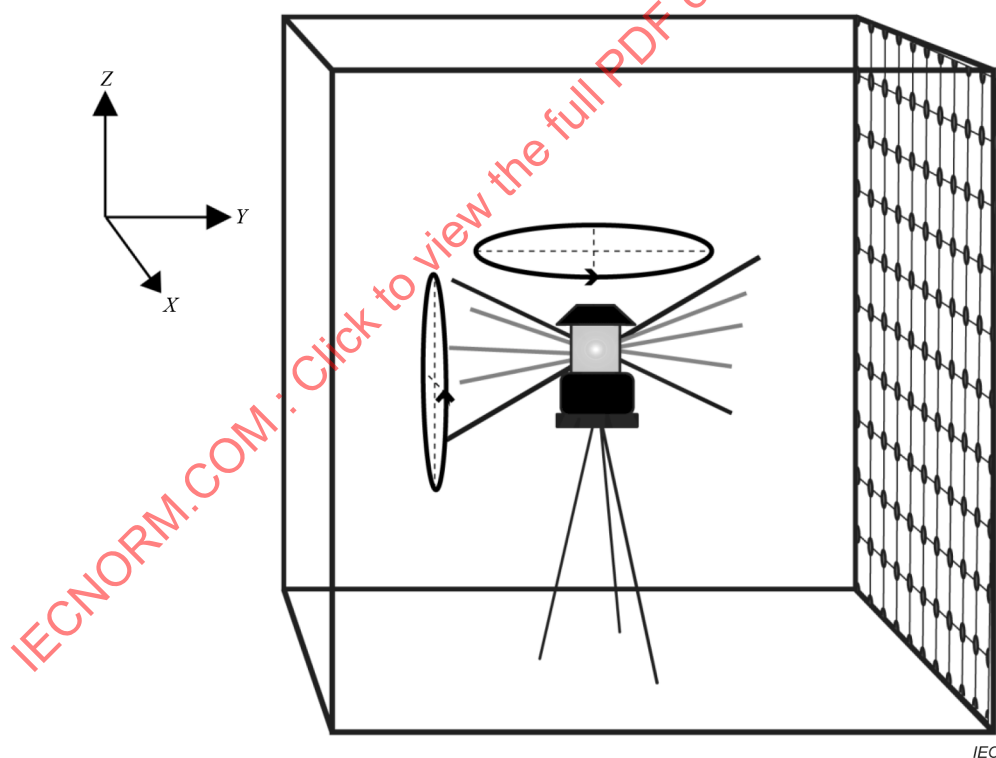


Figure I.1 – Conceptual schematic of the light output test setup, including the 11×11 grid, Cartesian coordinate axes for rotation reference, and the DUT

I.4.4.5 Procedure

In general, the light shall be situated so the first surface that is measured is the one that contains the peak of the overall light distribution. Subsequently, the light is carefully rotated to capture the other five surface measurements. Three of the remaining five positions are achieved by rotating the lamp exactly 90° about the vertical (Z) axis between each measurement. The remaining two positions are achieved by rotating the light about the horizontal (X) axis (see Figure I.1). After every rotation, the centre point of the light source should be exactly 0,5 m from the illuminance meter's sensor when it is placed in the centre of the measurement plane. The DUT shall be mounted using a turntable (rotating platform) or a clamping system.

Be sure no stray light hits the photometer and no reflections from other surfaces in the room interfere with the readings. Installing a black curtain around the test setup and having the test operator wear all black are recommended.

The following steps shall be performed.

- a) Arrange the room and prepare the DUT, ensuring the stand can hold the DUT steadily and enables precise rotation.
- b) Supply power to the DUT and allow the DUT to stabilize in accordance with I.4.1.
- c) Position the DUT such that the centre of its light source is 0,5 m away from the centre of the grid surface as shown in Figure I.1.
- d) The centre of the grid surface shall read the highest illuminance provided by the DUT at a 0,5 m distance.
- e) Measure illuminance levels at every 0,1 m distance on the grid surface, with the illuminance meter co-planar to the measurement grid (not normal to the light source). Measurements may be omitted if the illuminance will be less than or equal to the resolution of the illuminance meter or 0,2 % of the maximum lux reading from the first surface measured.
- f) For the first surface only: If the minimum illuminance in the four points adjacent to the centre is less than half the illuminance of the centre point, additionally measure points at 0,05 m intervals in the 0,4 m square centred around the centre of the grid. (This adds 56 intermediate measurements, for a total of 177 points on the first surface.)
- g) Rotate the DUT 90° clockwise, repositioning the DUT, if necessary, such that the centre point of the light source is exactly 0,5 m from the illuminance meter's sensor. It is also permissible to rotate the measurement grid about the DUT. Repeat steps d) through g) for the two remaining side faces until reaching the initial position.
- h) Tilt the DUT 90° down (about the X axis) and reposition the DUT, if necessary, such that the centre point of the light source is exactly 0,5 m from the illuminance meter's sensor. It is also permissible to rotate the measurement grid about the DUT.
- i) Measure illuminance levels for the grid points that read a lux value greater than the resolution of the illuminance meter and greater than 0,2 % of the maximum lux reading from the first surface measured.
- j) Tilt the DUT 180° up (about the X axis) and reposition the DUT, if necessary, such that the centre point of the light source is exactly 0,5 m from the illuminance meter's sensor. It is also permissible to rotate the measurement grid about the DUT.
- k) Measure illuminance levels for the grid points that read a lux value greater than the resolution of the illuminance meter and greater than 0,2 % of the maximum lux reading from the first surface measured.

If necessary for unusual light distributions, additional measurements may be made at the laboratory's discretion.

[illegible]

Table I.3 – Area represented by each illuminance measurement on the first surface when additional measurements are made for narrow light distributions

Area in cm²

Position (cm)	-50	-40	-30	-20	-15	-10	-5	0	5	10	15	20	30	40	50
-50	25	50	50	50	-	50	-	50	-	50	-	50	50	50	25
-40	50	100	100	100	-	100	-	100	-	100	-	100	100	100	50
-30	50	100	100	100	-	100	-	100	-	100	-	100	100	100	50
-20	50	100	100	56,25	37,5	37,5	37,5	37,5	37,5	37,5	37,5	56,25	100	100	50
-15	-	-	-	37,5	25	25	25	25	25	25	25	37,5	-	-	-
-10	50	100	100	37,5	25	25	25	25	25	25	25	37,5	100	100	50
-5	-	-	-	37,5	25	25	25	25	25	25	25	37,5	-	-	-
0	50	100	100	37,5	25	25	25	25	25	25	25	37,5	100	100	50
5	-	-	-	37,5	25	25	25	25	25	25	25	37,5	-	-	-
10	50	100	100	37,5	25	25	25	25	25	25	25	37,5	100	100	50
15	-	-	-	37,5	25	25	25	25	25	25	25	37,5	-	-	-
20	50	100	100	56,25	37,5	37,5	37,5	37,5	37,5	37,5	37,5	56,25	100	100	50
30	50	100	100	100	-	100	-	100	-	100	-	100	100	100	50
40	50	100	100	100	-	100	-	100	-	100	-	100	100	100	50
50	25	50	50	50	-	50	-	50	-	50	-	50	50	50	25

- b) Sum the luminous flux measurements over the entire surface.
- c) Repeat steps a) and b) to calculate the luminous flux for the remaining five sides.
- d) Total the luminous flux estimates over all six sides to obtain an estimated constant-voltage total luminous flux emitted from the DUT.
- e) Multiply the result by 10 000 cm²/m² to convert from lx/cm² to lumens (lx/m²). Alternatively, the individual area values or intermediate luminous flux values can be converted.

I.5 Correlated colour temperature (CCT) measurement

Measurement of correlated colour temperature shall be made in accordance with CIE 15.

I.6 Colour rendering index (CRI) measurement

Measurement of colour rendering index (R_a) shall be made in accordance with CIE 13.3 and CIE 177.

I.7 Calculation of luminous efficacy

Luminous efficacy in lumens per watt (lm/W) shall be calculated for each lighting appliance by dividing the luminous flux for that lighting appliance by the power measured in the power consumption test (Clause FF.6). If multiple light points are treated as a combined appliance during the power consumption test, sum the luminous flux of each light point in the combination.

I.8 Reporting

Report the following in the light output test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - DUT setting;
 - test room temperature (°C);
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - drive current (A);
 - drive voltage (V);
 - stabilisation time (min);
 - total constant-voltage luminous flux (lm);
 - correlated colour temperature (K);
 - colour rendering index;
 - luminous efficacy (lm/W).
- Average of n sample results for each DUT aspect tested.
- DUT's rating for aspects tested, if available.
- Deviation of the average result from the DUT's rating for each aspect tested, if available (%).
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .

Annex J (normative)

Lumen maintenance test

J.1 Background

An important performance metric for LED lights is consistent luminous flux over the product's lifetime. The lifetime of LEDs is strongly influenced by electrical operating conditions and thermal management. Further criteria which can accelerate degradation include the quality of the phosphor used in white LEDs, component level chip design and LED packaging materials and processes, and the environmental stability of secondary optical components in the product housing. Assuming that an overall lifetime of 5 years and a daily burn time (DBT) of 4 h are achieved, this results in a total operation time of 7 300 h.

Examination of the lumen maintenance of LED light sources and products is performed in a long-term test of either the individual LED components or the entire LED product. LED components are sometimes tested by the LED manufacturer for a minimum of 6 000 h under ANSI/IES LM-80. Because of time constraints, however, it is generally not practical to measure a complete LED lighting product over its entire expected lifespan.

The test method described in this document takes two different approaches to estimating lumen maintenance. The first monitors the DUT's luminous flux over a period of 1 000 h (approximately six weeks) to identify and flag products that are found to suffer significant lumen depreciation. Optionally, the test may be extended to 2 000 h (approximately 12 weeks).

Several of the tests used to evaluate solar LED products are relatively short-term, thus allowing a single test sample to be used on several different tests. Because the lumen maintenance test requires a sample to be dedicated for such a long period of time (typically six weeks), test samples should be dedicated to this test until the test is completed. In cases where the lumen maintenance test can be conducted without the DUT battery, that battery can be used for other testing (e.g. battery durability testing).

The second approach is an alternate method for estimating lumen maintenance that uses an ANSI/IES LM-80 test report from the manufacturer of the LED component. The temperature of the LED(s) in the DUT is measured and compared to the LM-80 data for the component LED(s) and an estimate is reported. The test monitoring luminous flux for 500 h is still performed, but no further lumen maintenance tests are required. This method therefore can represent a faster assessment of a product's lumen maintenance performance.

J.2 Test outcomes

The lumen maintenance test outcomes are listed in Table J.1.

Table J.1 – Lumen maintenance test outcomes

Metric	Reporting units	Related aspects	Notes
Measured lumen maintenance at 500 h, 1 000 h, or 2 000 h	%	4.2.4.1 LED lumen maintenance	The percentage of initial luminous flux (time = 0 h, after the initial 60 min warm-up period) that the product generates after an elapsed time of 500 h, 1 000 h, or 2 000 h.
Estimated lumen maintenance at 2 000 h	%	4.2.4.1 LED lumen maintenance	The percentage of initial luminous flux that the product generates after an elapsed time of 2000 h. This value is estimated using ANSI/IES LM80 data and an LED temperature measurement.

J.3 Related tests

Annex J is not related to any of the other annexes.

J.4 Procedure

J.4.1 General

Similar to the full-battery run time test (Annex M), the lumen maintenance test requires an accurate measurement of relative light output over time. Measurements shall be taken in a conditioned space such that the air temperature is $22\text{ °C} \pm 5\text{ K}$. There are three approved methods for making these measurements:

- Fixed geometry method (J.4.4.1).
- Photometer box method (J.4.4.2).
- Integrating sphere method (J.4.4.3).

For DUTs with multiple identical lighting appliances, it is only necessary to measure one of each type of identical lighting appliance; therefore, it is not necessary for all the product's lighting appliances to be running during the duration of the test. The lighting appliances shall be measured individually (i.e. one lighting appliance is placed inside the test enclosure and the others are powered on but left outside the enclosure during the measurement).

EXAMPLE The DUT includes three different types of lighting appliances (e.g. a tube light, four ambient light points, and two more focused light points). In this case, three of the seven lighting appliances would be measured during testing – one of each lighting appliance type.

Interruptions (e.g. due to power outages) are permitted as long as the cumulative time used to establish the 2 000 h or 1 000 h lumen maintenance level represents the actual run time (ON time) of the DUT. The OFF time during interruptions shall not count towards the 2 000 h or 1 000 h run time. When returning power to the DUT after an interruption, a 20 min warm-up period shall be observed before restarting the cumulative time.

Two tests are defined: a general-purpose lumen maintenance characterization in which DUTs are tested for 1 000 h with an optional extension to 2 000 h, and a 500 h screening test. The measurement schedule for the 1 000 h and 2 000 h tests are given in Table J.2, and the schedule for the 500 h screening test is given in Table J.3. In the tables, values with no tolerances represent the maximum allowed intervals between measurements; more frequent measurements are acceptable. Measurements with tolerances shall be made at the time indicated.

Table J.2 – Measurement schedule for 1 000 h test and optional 2 000 h extension

Measurement number	Required or optional?	Time interval h	Cumulative time h
1	required	1 h ± 5 min	0
2	required	24	24
3	required	48	72
4	required	48	120
5	required	48	168
6	required	48	216
7	required	168	384
8	required	168	552
9	required	168	720
10	required	168	888
11	required	112	1 000 ⁺²⁴ ₀
12	optional	224	1 224
13	optional	168	1 392
14	optional	168	1 560
15	optional	168	1 728
16	optional	168	1 896
17	optional	104	2 000 ⁺²⁴ ₀

Table J.3 – Measurement schedule for 500 h screening test

Measurement number	Time interval h	Cumulative time h
1	1 h ± 5 min	0
2	24	24
3	48	72
4	48	120
5	48	168
6	48	216
7	168	384
8	116	500 ⁺²⁴ ₀
NOTE The alternate procedure using ANSI/IES LM-80 data (J.6) requires only measurements 1 and 8.		

J.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC power supply.
- DC voltmeter or multimeter.
- DC ammeter, or current shunt and voltmeter or multimeter.
- Illuminance meter (unless using an integrating sphere system).
- Fixed-geometry apparatus, photometer box, or integrating sphere system.

Since the current-sensing element is left in place for the duration of the test, it is generally most convenient to use a current-sensing resistor (current shunt) for each DUT. The voltage across the resistor can be measured with a multimeter when each measurement is taken.

J.4.3 Test prerequisites

The DUT shall have been prepared as described in Annex G.

J.4.4 Test methods

J.4.4.1 Fixed geometry method

J.4.4.1.1 Apparatus

The apparatus for the method is simply any dedicated space in which the DUT and the photometer are secured so they do not move relative to one another during testing and so no outside light is received. This could be a dedicated area in a "dark room" in which the photosensor and DUT are secured, or another similar setup.

J.4.4.1.2 Procedure

The following steps shall be performed.

- a) Supply power to the lighting appliance in accordance with I.4.1, except that the standard operating voltage (H.5.2) shall be used in place of the typical battery discharge voltage or appliance operating voltage, and a fixed stabilization period of 60 min $\pm$ 5 min shall be used.
- b) Place the DUT and the illuminance meter in fixed locations relative to one another for the duration of the test. Ensure that the DUT and the photometer are secured such that exactly the same alignment is maintained for each measurement and that no stray light (e.g. ambient light, light from other test samples, etc.) is able to reach the light sensor.
- c) Refer to Table J.2 or Table J.3 for the minimum frequency at which the relative illuminance of the DUT, ambient temperature, voltage, and current are measured and recorded. The voltage measurement shall be made as close to the DUT as possible. A data logger or a lux meter with a data-logging function may be used to record the illuminance, or the measurements may be taken manually.

J.4.4.2 Photometer box method

J.4.4.2.1 Apparatus

The apparatus for the method is a photometer box, as described in the full-battery run time test (Annex M).

J.4.4.2.2 Procedure

The following steps shall be performed.

- a) Supply power to the lighting appliance in accordance with I.4.1, except that the standard operating voltage (H.5.2) shall be used in place of the typical battery discharge voltage or appliance operating voltage, and a fixed stabilization period of 60 min $\pm$ 5 min shall be used.
- b) The relative illuminance is measured using the photometer box.
- c) The location of the DUT in the photometer box shall be accurately noted to ensure exact replication of alignment and orientation for each measurement. A printed photograph of the DUT placement within the box is a useful reference. Alignment marks may also be used to ensure repeatability.
- d) For the following measurements, the DUT shall be placed in the photometer box with exactly the same alignment and orientation.
- e) Refer to Table J.2 or Table J.3 for the minimum frequency at which the relative illuminance of the DUT, ambient temperature, voltage, and current are measured and recorded. The voltage measurement shall be made as close to the DUT as possible. In the case that the DUT remains in the box throughout the duration of the test, a data logger or a lux meter with a data-logging function may be used to record the illuminance, or the measurements may be taken manually.

J.4.4.3 Integrating sphere method

The following steps shall be performed.

- a) Supply power to the lighting appliance in accordance with I.4.1, except that the standard operating voltage (H.5.2) shall be used in place of the typical battery discharge voltage or appliance operating voltage, and a fixed stabilization period of 60 min $\pm$ 5 min shall be used.
- b) The luminous flux is measured using an integrating sphere system.
- c) Refer to Table J.2 or Table J.3 for the minimum frequency at which the luminous flux of the DUT, ambient temperature, voltage, and current are measured and recorded. The voltage measurement shall be made as close to the DUT as possible.

J.5 Calculations

Lumen maintenance is calculated by dividing the final illuminance reading by the initial illuminance reading and is expressed as a percentage. Lumen maintenance is always reported along with the test duration.

The lumen maintenance percentage may be calculated by linearly interpolating between the two measurements that bracket the target time (e.g. 2 000 h, 1 000 h, or 500 h), provided that the measurement schedule in Table J.2 or Table J.3 is followed. If the measurement is made within 8 h of the target time, the measured value may be reported without correction.

J.6 Alternate method for testing lumen maintenance using ANSI/IES LM-80

J.6.1 Background

The lumen maintenance of an LED or LED array contained in a lighting product can be estimated by measuring the LED case temperature(s) (T_s). This measurement is compared to ANSI/IES LM-80 data from the LED manufacturer to estimate the DUT's lumen maintenance at 2 000 h.

The LED case temperature (T_s) measurement location, also referred to as the LED temperature measurement point (TMP), is established by the LED manufacturer. T_s is related to the temperature of the LED die and is measured by attaching a thermocouple to the TMP using solder or a thermally conductive adhesive. This measurement location may be one of the LED solder points, a location on the surface of the LED component, or a location on the printed circuit board adjacent to the LED. The LED manufacturer will have information on the correct TMP for the LED that was used during the ANSI/IES LM-80 tests. The company shall identify a TMP for the LEDs in the product that matches the T_s measurement location used for the ANSI/IES LM-80 tests. This is often done by using the same printed circuit board pad configuration that was used for the ANSI/IES LM-80 tests in the design of the DUT.

This LED temperature procedure tests the instantaneous LED temperature during normal operation to make an LED lumen maintenance assessment. It does not test longer duration operation of the LED or LED drive circuitry. To assess the ability of the DUT electronics to drive the LED(s) over a longer time period, a 500 h screening test is also performed.

J.6.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Thermocouple meter and thermocouple
- DC ammeter or multimeter
- DC power supply
- DC voltmeter or multimeter
- Soldering apparatus or thermally conductive adhesive/epoxy
- White tape or heat-shrink tubing

Small gauge type T thermocouples (wire diameter $\leq 0,13$ mm) are recommended and can be readily soldered to copper circuit board pads. Other thermocouples are acceptable when using thermal adhesives but require the appropriate soldering flux and can be difficult to attach by soldering.

Equipment requirements for the 500 h test, performed in J.6.4 h), are given in J.4.2.

J.6.3 Test prerequisites

This test shall not be performed unless all of the following criteria are met.

- The company has supplied the DUT LED component specification(s), including the complete component number and the LED specification document from the LED manufacturer.
- The company has supplied ANSI/IES LM-80 test data for the LED(s) used in the lighting product. ANSI/IES LM-80 testing is typically done by the LED manufacturer. The laboratory performing the ANSI/IES LM-80 test shall be accredited to do this type of testing.
- The company has supplied an LED drive current measurement at the brightest light setting of the lighting appliance.
- The ANSI/IES LM-80 test data includes an LED case temperature (T_s) and LED drive current higher than the DUT's LED case temperature and drive current.
- The DUT is designed in such a way as to allow temperature measurement of the LED T_s as specified by the LED manufacturer.
- The company has provided instructions and diagrams showing the appropriate attachment point for thermocouples used during the test.

Additional requirements may be stated in the product specification.

J.6.4 Procedure

Perform the following procedure.

- a) Review documentation supplied by the company to confirm that the DUT qualifies for testing using this method.
- b) Prepare the DUT for LED testing as outlined in J.6.5.
- c) Attach thermocouples to one or more LED(s) as outlined in J.6.5.
- d) Reassemble the product and orient in its normal operating position. The DUT shall be operated in a $22\text{ °C} \pm 5\text{ K}$ still air environment free from drafts, fans, and other air currents that could produce forced air convective currents and contribute to the cooling of the product.
- e) Supply power to the lighting appliance according to I.4.1, except that the standard operating voltage (H.5.2) shall be used in place of the typical battery discharge voltage.
- f) Allow the product to thermally stabilize for a minimum of 1 h. The LED case temperatures should be monitored to confirm thermal stabilization.
- g) Record the LED case temperature (T_s).
- h) Prepare the DUT for initial screening and perform a 500 h test as described in J.4.1. Only two measurements are required: one at the end of the stabilization period ($60\text{ min} \pm 5\text{ min}$), and a final measurement at 500 h (not including the stabilization time).

J.6.5 DUT preparation and LED thermocouple attachment guidelines

The LED(s) in the DUT shall be accessed to allow the attachment of thermocouple wires. When opening the DUT optical housing to access the LED(s), the normal operating environment shall be preserved to the maximum degree possible. Holes drilled into compartments should be as small as possible and covered with tape to prevent additional air movement during operation. The TMP location of the LED(s) shall be accessible to allow thermocouple attachment without disturbing the normal operation of the array.

A thermocouple shall be attached to an LED's temperature measurement point by soldering or gluing using a thermally conductive adhesive/epoxy. The attachment method shall ensure adequate thermal contact between the thermocouple and the TMP. The thermocouple attachment, including any additional solder or epoxy, shall be as small as possible to prevent an additional heat conduction pathway that could artificially contribute to the heat sinking of the LED component. LED(s) with large thermal pads or heat sinks can require preheating to facilitate soldering the thermocouple to the TMP.

Thermocouple wire should either be routed away from direct illumination by the LED(s) or should be shielded from direct light to prevent artificial heating of the wire, or both. This can usually be accomplished with white tape or white heat-shrink tubing. Tape, tubing, or epoxy should not cover the LED in a way that could increase the self-heating of the LED component.

When testing a DUT with multiple LEDs in an LED array, the test lab shall attempt to identify the LED in the array that will experience the highest temperature in operation. In practice, this is often an LED located in the centre of the array. Measurements on multiple LEDs in an array can be warranted to adequately identify the T_s value used for an ANSI/IES LM-80 assessment.

J.6.6 Calculations

The ANSI/IES LM-80 test report for the DUT LED(s) shall contain lumen maintenance data for LED temperature measurements at two or more case temperatures, at least one of which shall be 55 °C or 85 °C . These measurements shall contain test data at 2 000 h.

The test lab shall compare the ANSI/IES LM-80 data and T_s to estimate the lumen maintenance of the product. The test lab shall use the nearest ANSI/IES LM-80 data point above the duration ($\geq 2\text{ 000 h}$), DUT T_s , and LED drive current.

EXAMPLE If the DUT T_s is measured at 65 °C, LM-80 data at 85 °C (or greater than 65 °C when available) would be used. If the DUT LED drive current is 65 mA, the LM-80 data would be at drive currents greater than 65 mA.

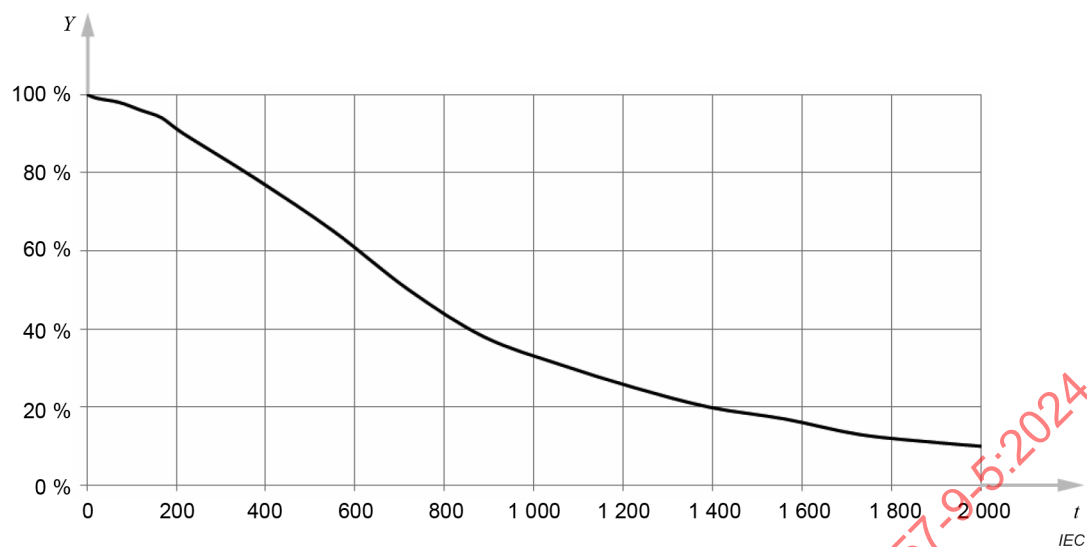
The test lab shall report the lumen maintenance of the DUT as the lumen maintenance measured by the nearest (higher conditions for T_s and drive current) ANSI/IES LM-80 test data as specified above.

J.7 Reporting

Report the following in the lumen maintenance test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - DUT setting;
 - test room temperature (°C);
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - drive current (A);
 - drive voltage (V);
 - stabilisation time (min);
 - lumen maintenance (note if measured at 2 000 h, 1 000 h, 500 h, or estimated at 2 000 h from ANSI/IES LM-80 data) (%);
 - if applicable, LED case temperature (T_s).
- Average of n sample results for each lumen maintenance aspect tested.
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .
- Figures:
 - plot of lumen maintenance (see example in Figure J.1).

The data set consisting of all illuminance or flux, ambient temperature, voltage, and current measurements shall be made available to the testing client upon request but may be omitted from the report.



Key

t Time (h)

Y Relative luminous flux

Figure J.1 – Example lumen maintenance plot

Annex K (normative)

Battery test

K.1 Background

The battery test is used to determine the DUT's actual battery capacity and round-trip energy efficiency. This information is useful to determine if a battery is mislabelled or damaged. During the test, the battery is connected to a battery analyser, which performs charge-discharge cycles on the battery. The last charge-discharge cycle data from the battery test is analysed to determine the actual battery capacity and battery round-trip energy efficiency.

K.2 Test outcomes

The test outcomes of the battery test are listed in Table K.1.

Table K.1 – Battery test outcomes

Metric	Reporting units	Related aspects	Note
Battery capacity (C_b)	Ampere-hours (Ah) at a specific discharge current	4.2.5.1 Battery capacity	-
Battery round-trip energy efficiency (η_b)	Percentage (%)	4.2.5.2 Battery round-trip energy efficiency	At least two complete charge-discharge cycles are required for the calculation.

K.3 Related tests

The battery test results are inputs to the full-discharge procedure (Annex N), the solar charge test (Annex R), the battery durability test (Annex BB), and the energy service calculations (Annex GG).

K.4 Procedure

K.4.1 General

Table K.2 contains battery testing information specific to the five common types (i.e. chemistries) of batteries. This information is pertinent to K.4.2.4, K.4.3.4, K.4.4.4, and K.4.5.4.

New or improved battery technologies could emerge for which Table K.2 does not contain information. The test lab should sufficiently research the new or improved battery technology to determine appropriate recommended battery practices for that new or improved battery technology. Communication directly with the supplier of the battery is recommended. For example, if the battery under test is a lithium battery but is not the lithium ion (3,7 V nominal voltage) or lithium iron phosphate chemistry, alternative charging and discharging rates and end-of-cycle voltage parameters should be obtained, preferably from the battery supplier.

In this document, I_t A is defined as the current obtained by dividing the nominal capacity of the battery in Ah by one hour; this definition is consistent with IEC 61960-3 and IEC 61951-2.

Table K.2 – Recommended battery testing parameters

Battery type	Charging				Discharging	
	Charge rate I_t A	Maximum charge voltage V/cell ^a	End-of-charge rate ^b I_t A	End-of-charge time with constant voltage ^d h	Discharge rate I_t A	End-of-discharge voltage V/cell
Lead-acid	0,1	2,40	0,05	10	0,1	1,80
Lithium-ion	0,2	4,20	0,05	1	0,2	3,00
Lithium iron phosphate	0,2	3,65	0,01 ^c	1	0,2	2,50

Battery type	Charging			Discharging	
	Charge rate I_t A	Overcharge (charge factor)	Partial charge duration ^e h	Discharge rate I_t A	End-of-discharge voltage V/cell
Nickel-metal hydride	0,1	1,6	9	0,2	1,00

^a For safety, never exceed the battery supplier's specified maximum allowable voltage.

^b The constant-voltage phase of the charge cycle is terminated when the current reaches this value.

^c This value may be increased up to 0,05 I_t A if necessary due to limitations of the testing equipment.

^d After a battery is charged to the maximum charge voltage, it may be charged at constant voltage until the current decreases to the recommended end-of-charge rate, or alternatively the battery may be charged at constant voltage until the recommended end-of-charge time has elapsed.

^e This value is used for measuring the battery efficiency only.

If cell balancing or individual cell monitoring circuitry is external to the battery, or a battery protection circuit other than the one incorporated into the DUT is used during the procedure, the usable capacity of the battery may differ when measured without the DUT's circuitry included or with cell monitoring circuitry supplied by the laboratory. In cases where the test results are disputed for this reason, the battery capacity may also be evaluated by disassembling the battery pack and performing the test on a single cell (or parallel cellblock). The positions of the cells or cellblocks to test should be selected randomly in a way that maximizes coverage. The capacity of the entire pack may be assumed to be equal to the capacity of the selected cell or parallel cellblock. If the battery under test is to be used for further testing, all cells of the battery shall be returned to a balanced state of charge prior to further testing, e.g. by fully discharging or charging the cells under test to match the state of charge of the other cells in the pack.

K.4.2 Lead-acid battery test

K.4.2.1 General

The valve-regulated or flooded lead-acid battery is cycled on a battery analyser, and the data from the final charge-discharge cycle is used to determine the actual battery capacity and round-trip energy efficiency.

If the DUT is a flooded lead-acid battery that was shipped dry, add acid in accordance with the following directions:

- Fill the battery with battery acid. The correct volume and density shall be determined from either the company-supplied information or the battery packaging. If the values from these two sources conflict, consult the company.

- b) Measure the voltage and density immediately after filling the battery, and again 30 min after filling.
- c) If after 30 min, the voltage is greater than 2,0 V/cell, continue with the lead-acid battery test procedure (K.4.2.4).
- d) If after 30 min the voltage is less than 2,0 V/cell, the density has dropped, and the battery temperature has increased, then the negative electrode (Pb) is likely oxidized. If the negative electrode is oxidized, remove the oxidation by overcharging using a 24 h IU charge (a constant-current charge followed by a constant-voltage charge, with a total duration of 24 h). A charge rate of $0,1 I_t$ A (calculated using the battery's rated capacity) shall be used for the I phase (constant-current), and a voltage of 2,45 V shall be used for the U phase (constant-voltage). The relatively high voltage and duration of this charge can cause the battery to produce hydrogen and oxygen, a combustible gas mixture. Conduct this procedure outdoors or in a well-ventilated room.

If, after 30 min, the battery voltage is less than 2,0 V/cell, but the density has not dropped or the temperature has not risen, the battery could have defects that cannot be addressed by overcharging. Attempt the overcharging procedure but note that the battery conditions indicate possible defects.

K.4.2.2 Equipment requirements

A battery analyser meeting the requirements in Clause CC.2 is required.

A DC power supply is necessary in some cases, depending on the battery tested and the battery analyser in use.

K.4.2.3 Test prerequisites

The battery may be taken out of the DUT for this test, if desired. The DUT shall have been prepared as described in Annex G. The test shall be carried out at $22\text{ °C} \pm 5\text{ K}$.

K.4.2.4 Procedure

Perform the capacity test from IEC 61427-1:2013, 8.1 (which references IEC 61056-1), with the following modifications.

- Perform a minimum of five charge-discharge cycles to ensure that the battery is sufficiently exercised prior to determining capacity and to ensure that enough data are available to calculate round-trip energy efficiency. Use the final charge-discharge cycle to calculate the battery's actual capacity and round-trip energy efficiency.
- Carry out the test at $22\text{ °C} \pm 5\text{ K}$.
- The battery shall be kept at open circuit for 1 h to 24 h after charging before starting each discharge. (It is not necessary to wait 5 h as required by IEC 60156-1.)
- Equipment may meet the requirements of Clause CC.2 in this document in place of the accuracy requirements of IEC 61427-1 or IEC 61056-1.
- Record the current at an interval of 1 min or less.
- The capacity test from IEC 61056-1, as referenced by IEC 61427-1, may be used for flooded lead-acid batteries; it is not necessary to use the test from IEC 60896-11.

If the battery contains internal circuitry (refer to F.4.3.6) and either the battery analyser will not start the test or the tester decides that the results from the test are unexpected or faulty in some way, the test may be repeated with the battery analyser connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so.

If the battery will be stored after undergoing this test, charge the battery using the charge information in Table K.2 and disconnect the battery from the DUT. Charge the battery every six months, or every three months if stored at a temperature greater than 30 °C .

If the battery analyser does not recognize the battery upon starting any of the above steps, the battery voltage could have dropped below the battery analyser's minimum threshold. If this is the case, a power supply can be used to charge the battery in accordance with IEC 61427-1 before the battery capacity is determined. Alternatively, the battery may be connected back into the DUT to receive a charge via solar or other means in accordance with the product user manual.

K.4.2.5 Calculations

Perform the following calculations.

- a) Determine the total energy input into the battery during the final charge cycle (E_c) using the following formula:

$$E_c = \sum (V_c \cdot I_c \cdot \Delta t)$$

where

E_c is the energy entering the battery during the charge cycle, in watt-hours (Wh);

V_c is the voltage recorded during the charge cycle, in volts (V);

I_c is the current recorded during the charge cycle, in amperes (A);

Δt is the time interval between measurements, in hours (h).

- b) Determine the total energy output from the battery during the final discharge cycle using the following formula:

$$E_d = \sum (V_d \cdot I_d \cdot \Delta t)$$

where

E_d is the battery's energy output during the discharge cycle, in watt-hours (Wh);

V_d is the voltage recorded during the discharge cycle, in volts (V);

I_d is the current recorded during the discharge cycle, in amperes (A);

Δt is the time interval between measurements, in hours (h).

- c) Determine the battery capacity with data from the final discharge cycle using the following formula:

$$C = \sum (I_d \cdot \Delta t)$$

where

C is the measured battery capacity, in ampere-hours (Ah);

I_d is the current recorded during the discharge cycle, in amperes (A);

Δt is the time interval between measurements, in hours (h).

- d) For lead-acid batteries only, correct the capacity to the reference temperature of 25 °C using the following formula (from IEC 60896-21), with λ set to 0,006 K⁻¹:

$$C_a = C / (1 + \lambda(T - 25 \text{ °C}))$$

where

C_a is the actual battery capacity, in ampere-hours (Ah);

C is the measured battery capacity, in amperes (A);

λ is 0,006 K⁻¹;

T is the battery temperature at the start of the final discharge cycle, in degrees Celsius (°C).

e) Determine the battery round-trip energy efficiency using the following formula:

$$\eta_b = \frac{E_d}{E_c}$$

where

η_b is the battery's round-trip energy efficiency;

E_d is the battery's energy output during the final discharge cycle, in watt-hours (Wh);

E_c is the energy input to the battery during the final charge cycle, in watt-hours (Wh).

Report the actual capacity (i.e. the value that has been corrected to 25 °C).

K.4.3 Nickel-metal hydride battery test

K.4.3.1 General

The nickel-metal hydride battery is cycled on a battery analyser, and the data from the final charge-discharge cycle is used to determine the actual battery capacity and battery round-trip energy efficiency.

The nickel-metal hydride battery test procedure refers to the overcharge charging method, whereby the battery is charged at constant current for a fixed duration given by the following formula:

$$T_c = OC \cdot \frac{C_b}{I_c}$$

where

T_c is the duration of the charge cycle, in hours (h);

OC is the overcharge (charge factor) value given in Table K.2;

C_b is the measured or rated battery capacity, in ampere-hours (Ah);

I_c is the charge current, in amperes (A).

K.4.3.2 Equipment requirements

A battery analyser meeting the requirements in Clause CC.2 is required.

K.4.3.3 Test prerequisites

The battery may be taken out of the DUT for this test, if desired. The DUT shall have been prepared as described in Annex G. The test shall be carried out at 22 °C ± 5 K. As specified in IEC 61951-2, the test shall be carried out at a relative humidity of 65 % ± 20 %.

K.4.3.4 Procedure

Perform the capacity test from IEC 61951-2:2017, 7.3.2, using the charging and discharging parameters given in Table K.2, with the following modifications.

- Perform a minimum of five charge-discharge cycles to ensure that the battery is sufficiently exercised prior to determining capacity. Use the final charge-discharge cycle to calculate the battery's actual capacity.

- Record the current at an interval of 1 min or less.

Measure the round-trip energy efficiency using the following procedure:

- Charge the battery at constant current for a fixed duration, using the charge rate and partial charge duration given in Table K.2. After charging, the battery shall be stored in an ambient temperature of $22\text{ °C} \pm 5\text{ K}$ for not less than 1 h and not more than 24 h.
- Discharge the battery using the discharge information in Table K.2.
- Repeat steps a) and b) once more. Calculate the battery storage efficiency in accordance with K.4.2.5 using the data from this final charge-discharge cycle.

If the battery contains internal circuitry (refer to F.4.3.6) and either the battery analyser will not start the test or the tester decides that the results from the test are unexpected or faulty in some way, the test may be repeated with the battery analyser connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so.

If the battery analyser does not recognize the battery upon starting any of the above steps, the battery output could have dropped to 0 V. If this is the case, a constant-current charge as specified in Table K.2 of Annex K from a power supply may be used to bring the battery out of a 0 V state of charge before the battery capacity is determined. Alternatively, the battery may be connected back into the DUT to receive a charge via solar or other means in accordance with the product user manual.

Nickel-based batteries may be stored in a partly or fully discharged state; however, batteries should be disconnected from the DUT prior to long-term storage to avoid polarity reversal. It is often convenient to end the battery test with a charge to allow for further testing.

K.4.3.5 Calculations

Perform the calculations listed in K.4.2.5, omitting step d). Use the partial charge-discharge cycles conducted in K.4.3.4 a) through c) in the calculation of round-trip energy efficiency.

K.4.4 Lithium-ion battery test

K.4.4.1 General

The lithium-ion battery is cycled on a battery analyser, and the data from the final charge-discharge cycle is used to determine the actual battery capacity and battery round-trip energy efficiency.

K.4.4.2 Equipment requirements

A battery analyser meeting the requirements in Clause CC.2 is required.

For battery packs containing more than one cell in series, a protection circuit that monitors the voltage of each cell (or each set of cells connected in parallel) should be used during charging, if this functionality is not incorporated into the battery pack. This functionality may be built into the battery analyser or may be a separate piece of equipment. The voltage of each individual cell (or each set of cells connected in parallel) should not be allowed to exceed the maximum battery testing voltage given in Table L.2 unless company-provided battery specifications indicate that such operation can be performed safely. The temperature of each individual cell should not be allowed to exceed 45 °C . Care should be taken that any voltage drop introduced by the protection circuit (e.g. relay contact resistance) does not affect the results.

K.4.4.3 Test prerequisites

The battery may be taken out of the DUT for this test, if desired. The DUT shall have been prepared as described in Annex G. The test shall be carried out at $22\text{ °C} \pm 5\text{ °C}$. As specified in IEC 61960-3, the test shall be carried out in still air. Batteries with multiple cells (or parallel cellblocks) in series shall be prepared in accordance with G.4.4 a).

K.4.4.4 Procedure

Perform the capacity test from IEC 61960-3:2017, 7.3.1, with the following modifications.

- Perform a minimum of five charge-discharge cycles to ensure that the battery is sufficiently exercised prior to determining capacity and to ensure that enough data are available to calculate round-trip energy efficiency. Use the final charge-discharge cycle to calculate the battery's actual capacity and round-trip energy efficiency.
- Charge and discharge the battery using the information in Table K.2 – calculated using the battery's rated capacity.
- Record the current at an interval of 1 min or less.

If the battery contains internal circuitry (refer to F.4.3.6) and either the battery analyser will not start the test or the tester decides that the results from the test are unexpected or faulty in some way, the test may be repeated with the battery analyser connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so.

If the battery will be stored after undergoing this test, charge the battery using the charge rate specified in Table K.2 for 2,5 h (i.e. store at 50 % state of charge) and disconnect the battery from the DUT.

If the battery analyser does not recognize the battery upon starting any of the above steps, the battery could have been disconnected by its internal protection circuit. In this case, the voltage at the battery terminals will be zero, which can prevent the battery analyser from recognizing the battery. In this situation, a current-limited constant-voltage charge, at a current no higher than that specified in Table K.2 of Annex K from a power supply may be required to re-enable the battery before the battery capacity is determined. If the cell voltage has decreased below 2,5 V for lithium iron phosphate or 3,0 V for other lithium-ion, perform the charge at $0,1 I_t$ A. The voltage shall not exceed the value given in Table K.2. It is recommended to set the power supply to the lowest possible voltage that will allow the battery analyser to recognize the battery and complete the charge cycle. Alternatively, the battery may be connected back into the DUT to receive a charge via solar or other means in accordance with the product user manual. If the battery is suspected to be damaged, it should not be charged using either method. It can be necessary to bypass the battery's internal protection circuit to perform this step; in this case, the cell voltage should be measured prior to charging the battery to ensure that it has not dropped below the minimum battery testing voltage given in Table L.1. If the battery voltage has dropped below the minimum battery testing voltage, charging the battery can be unsafe; the test laboratory should discontinue the test if in the tester's discretion it would be unsafe to continue.

K.4.4.5 Calculations

Perform the calculations listed in K.4.2.5, omitting step d).

K.4.5 Lithium iron phosphate battery test

K.4.5.1 General

The lithium iron phosphate battery is cycled on a battery analyser, and the data from the final charge-discharge cycle is used to determine the actual battery capacity and battery round-trip energy efficiency.

K.4.5.2 Equipment requirements

A battery analyser meeting the requirements in Clause CC.2 is required.

For battery packs containing more than one cell in series, a protection circuit that monitors the voltage of each cell (or each set of cells connected in parallel) should be used during charging, if this functionality is not incorporated into the battery pack. This functionality may be built into the battery analyser or may be a separate piece of equipment. The voltage of each individual cell (or each set of cells connected in parallel) should not be allowed to exceed the maximum battery testing voltage given in Table L.2 unless company-provided battery specifications indicate that such operation can be performed safely. The temperature of each individual cell should not be allowed to exceed 45 °C. Care should be taken that any voltage drop introduced by the protection circuit (e.g. relay contact resistance) does not affect the results.

K.4.5.3 Test prerequisites

The battery may be taken out of the DUT for this test, if desired. The DUT shall have been prepared as described in Annex G. The test shall be carried out at 22 °C ± 5 °C. As specified in IEC 61960-3, the test shall be carried out in still air.

K.4.5.4 Procedure

Follow the procedure in K.4.4.4.

K.4.5.5 Calculations

Perform the same calculations listed in K.4.2.5.

K.5 Reporting

Report the following in the battery test report.

- Metadata:
 - report title
 - procedure(s) used
 - company
 - product name
 - model number
 - name of test laboratory
 - identification of the person(s) authorizing the report
 - date of issue of the report
- Results for tested DUT aspects for samples 1 through n :
 - battery capacity (Ah) and corresponding discharge current (in terms of I_t A);
 - battery round-trip energy efficiency (%).
- Average of n sample results for each DUT aspect tested.
- DUT's rating for aspects tested, if available.
- Deviation of the average result from the DUT's rating for each aspect tested, if available (%).
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .

Annex L (informative)

Battery testing recommended practices

L.1 Background

Several tests in this document involve charging or discharging a battery:

- During the charge controller behaviour test (Annex S), the battery is either charged or discharged to determine if the DUT has appropriate deep discharge protection and overcharge protection.
- During the grid charge test (Annex O), solar charge test (Annex R), and electromechanical charge test (Annex P), the battery is charged.
- During the full-battery run time test (Annex M), the battery is discharged.
- In the appliance full-battery run time test with deep discharge protection (Clause FF.9), if performed, the appliance's internal battery is discharged.
- In the preparation for the appliance operating voltage range test (Clause FF.8) or measurement of steady-state port characteristics (EE.4.2), each appliance's internal battery, if present, is charged and discharged.

In some cases, it is not known whether the DUT provides sufficient protection to avoid damage to the battery or test apparatus or injury to test laboratory personnel. Annex L provides recommended charging and discharging practices to prevent damage to the DUT and ensure safety of test personnel.

A variety of battery chemistry types are used in products meeting the scope of this document, potentially including types that were not in common use at the date of publication. The information in Table L.1 and Table L.2 is intended to prevent damage to the DUT and test apparatus and ensure safety of test personnel for most common battery types. When possible, battery specifications should be obtained from the battery manufacturer to evaluate whether the protection strategy used by the DUT is appropriate for the specific battery used.

L.2 Deep discharge protection specifications by battery type

Table L.1 contains recommended battery deep discharge protection voltages and minimum battery voltages for four common types (i.e. chemistries) of batteries. If the company or battery manufacturer has not provided an appropriate deep discharge protection voltage cutoff design value for the battery in the company self-reported information (Annex D), the information in Table L.1 may be used when determining if the DUT has appropriate deep discharge protection.

Table L.1 contains two voltage values for each battery type. The "recommended deep discharge protection voltage" is the recommended setpoint for the deep discharge protection (low voltage disconnect). The tolerance given is intended to account for measurement uncertainty both in the DUT and in the laboratory apparatus. The "minimum battery testing voltage" is intended to ensure laboratory personnel safety and prevent immediate, permanent damage to the battery. The test laboratory should immediately stop discharging a battery if the battery voltage reaches the minimum testing voltage.

If the DUT does not have appropriate deep discharge protection, the battery can be damaged during the full-battery run time and the charge controller behaviour tests. As an option, the tester may incorporate a low-voltage disconnect device that will stop the discharge when the battery reaches the minimum battery testing voltage specified in Table L.1.

Table L.1 – Recommended battery deep discharge protection voltage specifications

Battery type	Deep discharge protection voltage			Min. battery testing voltage V/cell
	Recommended	Min.	Max.	
Lead-acid	$\geq 1,87$	1,82	--	none
Lithium-ion	$\geq 3,00$	2,95	--	2,50
Lithium iron phosphate	$\geq 2,50$	2,45	--	2,00
Nickel-metal hydride	$= 1,00$	0,95 ^a	1,10 ^b	0,80 ^a

^a These limits for NiMH batteries only apply to batteries with multiple cells in series. There is no personnel safety risk from discharging batteries below this limit, but there is a risk of polarity reversal, which can cause irreversible damage to the battery. There is no lower voltage limit for single-cell NiMH batteries.

^b The intent of this upper limit is to prevent reversible capacity loss due to voltage depression ("memory effect") resulting from partial discharge.

L.3 Overcharge protection specifications by battery type

Table L.2 contains recommended battery overcharge protection voltages and maximum battery voltages and cell temperatures specific to four common types (i.e. chemistries) of batteries. If the company or battery manufacturer has not provided an appropriate overcharge protection voltage cutoff or maximum cell temperature design value for the battery in the company self-reported information (Annex D), the information in Table L.2 may be used when determining if the DUT has appropriate overcharge protection. The maximum cell temperature should not be exceeded at any time when the battery is being charged.

Table L.2 contains two voltage values for each battery type. The "recommended overcharge protection voltage" is the recommended setpoint for the overcharge protection (overvoltage protection). The tolerance given is intended to account for measurement uncertainty both in the DUT and in the laboratory apparatus. The "maximum battery testing voltage" is intended to ensure laboratory personnel safety and prevent immediate, permanent damage to the battery. The test laboratory should immediately stop charging a battery if the battery voltage reaches the maximum testing voltage.

Table L.2 – Recommended battery overcharge protection voltage and temperature specifications

Battery type	Overcharge protection voltage			Max. battery testing voltage V/cell	Max. charging temperature °C
	Recommended	Min.	Max.		
Lead-acid	$= 2,40$	2,35	2,45	2,60	45
Lithium-ion	$\leq 4,20$	--	4,25	4,26	45
Lithium iron phosphate	$\leq 3,65$	--	3,70	3,85	45
Nickel-metal hydride	$\leq 1,45$	--	1,50	1,51	60

Annex M (normative)

Full-battery run time test

M.1 Background

The full-battery run time captures one of the key system-performance metrics from a user's perspective. It combines the relationship between battery capacity, circuit efficiency, and lighting system power consumption under realistic operating conditions.

A stand-alone renewable energy product can often power several appliances, some of which may have variable power settings. Full-battery run time depends on which appliances are running and at what power settings. The full-battery run time test involves completing a full discharge in at least one configuration. Calculations to estimate the full-battery run time in additional configurations may be performed in accordance with the energy service calculations (Annex GG).

The typical configuration of the full-battery run time test involves operating the DUT with all of its lighting appliances without internal batteries connected and set to the brightest setting. In the case of a simple portable product with a built-in light, the light would be set to the brightest setting. The DUT begins the test with a fully charged battery and runs until the relative light output has decreased to some pre-defined minimum value (70 % in this case). The full-battery run time in this case is defined as when $\Phi_{v,rel}$ reaches 70 % relative to the initial luminous flux $\Phi_v(t_{init})$.¹

$$\Phi_{v,rel} = \Phi_v(t) / \Phi_v(t_{init})$$

where

$\Phi_{v,rel}$ is the relative light output;

$\Phi_v(t)$ is the luminous flux at time t ;

$\Phi_v(t_{init})$ is the initial luminous flux, measured 20 min into the discharge to account for initial voltage drop.

NOTE Although relative light output is defined here in terms of luminous flux, it is often more practical to measure illuminance as a proxy for luminous flux; see Clause M.6.

If a product does not include any lighting appliances, the test is conducted using other included appliances or generic appliances, as described in Clause M.8. For such products, the key test outcome is the energy removed from the battery during the discharge. A full-battery run time in hours is calculated for these products as an intermediate step, but for these appliances it is usually more appropriate to assess the full-battery run time using the energy service calculations (Annex GG), as this allows the full-battery run time to be estimated for each appliance individually and for multiple combinations of appliances.

The full-battery run time test (Annex M) applies to main units and is also used to assess the full-battery run time of included lighting appliances with internal batteries, and other power control units. For included non-lighting appliances with internal batteries, such as fans, television sets, or radios, the full-battery run time for each appliance may be estimated using one of two options described in Annex FF.

¹ This limit was chosen since a decrease of more than 30 % is clearly visible for human eyes according to the Alliance for solid-state illumination systems and technologies (ASSIST).

M.2 Test outcomes

The test outcomes of the full-battery run time test are listed in Table M.1.

Table M.1 – Full-battery run time test outcomes

Metric	Reporting units	Related aspects	Notes
Lighting full-battery run time, to L_{70}	Hours (h)	4.2.8.6 Main unit full-battery run time 4.2.8.7 Appliance full-battery run time	Run time to 70 % of initial luminous flux. This metric also applies to lighting appliances with internal batteries.
Typical battery discharge voltage and current	Voltage (V) and current (mA)	4.2.9.1 Luminous flux output 4.2.7.2 Power consumption 4.2.7.6 Appliance charging efficiency	This is the operating point at which the power consumption is equal to the average over the run time. This operating point is used to make luminous flux, power consumption and charging efficiency measurements.
Average power over the full-battery run time	Watts (W)	4.2.8.6 Main unit full-battery run time	Average power consumption over the run time (for products with lighting appliances, while relative light output is greater than 70 %).
Energy removed from the battery over the L_{70} run time	Watt-hours (Wh)	4.2.8.6 Main unit full-battery run time 4.2.8.7 Appliance full-battery run time	Total energy removed over the run time while relative light output is greater than 70 %. This outcome can be used as an input to the energy service calculations (Annex GG). This metric also applies to lighting appliances with internal batteries.
Energy removed from the battery until the DUT reaches a low-voltage disconnect or other stopping criterion	Watt-hours (Wh)	4.2.8.6 Main unit full-battery run time	Total energy removed over the run time until the DUT reaches an active deep discharge protection threshold, the test is stopped for safety concerns, or the DUT reached an alternate stopping criterion. This value shall be determined for all DUTs that have active deep discharge protection and any products that do not include lighting appliances. This outcome can be used as an input to the energy service calculations (Annex GG).
Active deep discharge protection	Yes/no	4.2.3.13 Battery protection strategy	This metric can also apply to lighting appliances with internal batteries.
Deep discharge protection voltage	Volts (V)	4.2.3.13 Battery protection strategy	Measured only if the DUT has active deep discharge protection. This metric can also apply to lighting appliances with internal batteries.
Passive deep discharge protection	Yes/no	4.2.3.13 Battery protection strategy	This metric can also apply to lighting appliances with internal batteries.
Passive deep discharge protection battery voltage at 24 h	Volts per cell (V/cell)	4.2.3.13 Battery protection strategy	Required only if tested for passive deep discharge protection. This metric can also apply to lighting appliances with internal batteries.

M.3 Related tests

Annex M is related to the charge controller behaviour test (Annex S) and the energy service calculations (Annex GG). The typical battery discharge voltage from Clause M.9 is used to set up the light output test (Annex I) and light distribution test (Annex T).

M.4 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- If the test is being conducted with lighting appliances:
 - Integrating sphere, or other approved measurement cavity.
 - Data-logging illuminance meter.
- Battery analyser.
- Voltage data logger.
- Current data logger (e.g. voltage data logger and current transducer).
- Low-voltage disconnect device that will stop the discharge when the battery reaches a specified voltage (recommended).

The total series resistance added by the test apparatus and all measurement equipment shall be no more than 60 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4). Alternatively, the resistance may exceed 60 mΩ if the total voltage drop between the battery and DUT does not exceed 0,01 V.

This test involves a calculation of electrical power; see Clause CC.3 for related recommendations. In most cases, the use of separate instruments to measure current and power is acceptable. If the current or voltage is observed to vary too rapidly to be captured by the current and data-logging devices, the sampling interval should be decreased or a power-measuring instrument should be used, as described in Clause CC.3.

M.5 Test prerequisites

If the DUT has a lead-acid battery (either flooded or VRLA), cycle the battery in accordance with the procedures in the battery test (Annex K) and the information in the battery testing recommended practices (Annex L).

If the test is being conducted on a product without lighting appliances, and any of the appliances used in the test (see step M.8 a)) have internal batteries, discharge the appliance batteries in accordance with FF.8.3.

If the product has an adjustable depth-of-discharge setting, the depth of discharge should be left at the default setting for the full-battery run time test; however, the active deep discharge protection test (S.4.1) should be conducted with the depth of discharge set to the maximum possible value.

During the full-battery run time test, the PV module shall be disconnected, covered with opaque material, or oriented so it is not exposed to light greater than 100 lx.

M.6 Apparatus

For products with lighting appliances, the full-battery run time test requires an accurate measurement of relative light output over time. In practice, this means using an integrating sphere or a fixed-geometry measurement cavity to measure the illuminance level² under constant conditions. Three approved measurement cavities are listed in the following in order of preference³. The illuminance measurement is taken indirectly (reflected) in the first two types, while it is taken directly in the last type. The enclosure should be large enough to allow heat from the DUT to be dissipated effectively.

- Integrating sphere.
- A self-built photometer box with a baffled measurement of illuminance on a port (i.e. an "integrating cube" as shown in Figure M.1).
- A darkened room or cabinet with direct illuminance measurement under fixed geometry.

If the test is being conducted without lighting appliances, an integrating sphere or other approved measurement cavity is not required. Instead, the product and appliances shall be set in a secure location to avoid disturbance during the test.



Figure M.1 – Interior view of photometer box with suspended light

M.7 Definition of full-battery run time endpoint

The full-battery run time is defined as the duration of the time period in the full-battery run time test starting when the product is turned on and ending when the full-battery run time endpoint, defined in the following, is reached.

- a) For products with lighting appliances, the full-battery run time endpoint occurs when the relative light output first reaches 70 %.

² A measurement of illuminance in a fixed geometry (such as a dark room or isolated box) is always directly proportional in a linear fashion to the total luminous flux of a lamp. Therefore, fixed-geometry measurements of illuminance may be used in place of luminous flux measurements for this test, which relies on relative light output to indicate the end of a discharge cycle.

³ Any of these cavities can result in identical estimates for full-battery run time. The preference order is related to the degree of operator care required to maintain a fixed geometry in each, with a preference for cavities whose relative measurement is less sensitive to small changes in the system (e.g. from accidentally bumping into the cavity during a test).

- b) For products without lighting appliances, the full-battery run time endpoint is the time at which one of the following events first occurs:
- 1) Active deep discharge protection turns off the DUT;
 - 2) All connected appliances reach any of the endpoint criteria for the appliance full-battery run time test with deep discharge protection (FF.9.5 f));
 - 3) The battery voltage falls below the value set on the optional low-voltage disconnect device;
 - 4) The power drawn from the battery is 10 % or less of the power measured 20 min after the start of the test. (This endpoint should only be used if none of the other options are applicable.)

M.8 Procedure

Before measurement, fully charge the battery using one of the two procedures depending on the battery chemistry:

- If the battery is of NiMH chemistry, then use the procedures in the nickel-metal hydride battery test (K.4.3.1).
- Otherwise, use the procedures in the active overcharge protection test (S.4.2). If the PV module has not yet been tested, then set up the apparatus in accordance with Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp} . If the rated I_{mpp} is not available, apply a current that results in a battery charge rate as specified in Table K.2. This current value shall be set at the beginning of the charge cycle and not adjusted during the charge cycle.

The full-battery run time test shall be started between 1 h and 24 h after the DUT has finished receiving its full charge. When performing this procedure, take note of the operating current, which may be used to ensure the DUT is operating at the same setting during other tests.

Use the following procedure:

- a) Identify the configuration(s) to test.
- 1) If the product includes lighting appliances that do not have their own batteries, at minimum, the DUT shall be tested with all lighting appliances without batteries (including built-in appliances as defined in 4.1.4) connected and set to the brightest setting. In cases where, as identified in F.4.1.5 b) 1), multiple lighting appliances can be connected to a single port, these lights may be plugged in to separate ports or a single port. Additional guidance may be provided by the product specification. The configuration should be consistent with that used in the light output test (Annex I) and appliance tests (Annex FF).

If there are more lighting appliances than ports, and no splitters or similar devices are included with the product, use the brightest lighting appliances. If the configuration determined using these requirements is impractical for use (for example, if it causes an overload protection device to activate), the most appropriate setting and configuration should be determined by the test laboratory in consultation with the company.

Some products have multiple built-in arrays of light sources that cannot be used simultaneously; in this case, test only the highest luminous flux array.

- 2) If the test is being conducted without measuring relative light output (i.e. the product does not include any lighting appliances without batteries), use the following procedure to determine the appropriate configuration:
 - i) Choose all the appliances (including any built-in appliances and lighting appliances with internal batteries) that the DUT can power. Use appliances that are provided with the DUT when possible. If an appliance is not provided with the DUT (i.e. the packaging advertises that the product can power a radio, but a radio is not provided with the product), then use the appropriate generic appliance, as defined in Annex HH, to simulate its power consumption. Do not plug in a combination of appliances that will exceed the maximum sustained current for any port or combination of ports, as measured in the output overload protection method (DD.4.2). To ensure that the product's full discharge to the LVD is measured, at least one appliance without an internal battery shall be chosen. If all appliances have internal batteries, replace the appliance with the highest power consumption with a similar generic appliance with no timer, as defined in Annex HH.
 - ii) If the DUT has fewer appliance ports than the number of appliances identified in M.8 a) 2) i), then use the following criteria to determine which appliances to use during the full-battery run time test.
 - Prioritize appliances that are included with the DUT.
 - If more appliances are included with the DUT than the number of ports, then choose appliances that will maximize the power consumption from the main battery.
 - If fewer appliances are included with the DUT than number of ports, but the additional advertised appliances exceed the number of ports, then use all appliances possible that are included with the DUT and populate the remaining ports with appropriate generic appliances, as defined in Annex HH, that will maximize the power consumption from the main battery.
 - 3) If no appliances are included and no appliances are advertised, the tester may use his or her discretion in determining the combination of appliances to use during the full-battery run time test, or may consult the relevant product specification.
 - 4) Some appliances may interfere with data collection or pose other difficulties for inclusion in the test, for example by generating voltage spikes that result in incorrect readings. If this occurs, generic appliances (Annex HH) may be substituted for included appliances.
 - 5) In cases where the main unit includes multiple separate batteries, the testing configuration will depend on the relationship of the batteries to the appliances. If each battery is dedicated to specific loads during discharge (i.e. there are two lights with internal batteries that both connect to a PV module to charge), then conduct a separate full-battery run time test on each battery. If the batteries are connected in parallel during discharge, then conduct a single full-battery run time test with the batteries connected.
 - 6) In cases where, as identified in F.4.1.5 b) 1), multiple appliances without internal batteries that provide the same type of service, e.g. lighting, can be connected to a single port, these appliances may be treated as a single appliance or as individual appliances. The appliances should be connected in a configuration that is consistent with the configurations used in other tests.
- b) Configure the DUT using the configuration identified in a) but do not yet turn it on.
 - c) Secure the DUT inside the test cavity such that it is stable and cannot be jostled. When using an integrating sphere or photometer box, position the DUT so that only reflected light reaches the detector. This can be accomplished by either pointing the light point(s) away from the detector or by using baffles to shield the detector from direct light, or both. When using a darkened room or cabinet with fixed geometry, direct the light toward the detector. In either case, it is extremely important that the DUT and apparatus do not move during the test.

- d) Prepare the voltage data logger to measure voltage across the power control unit battery terminals at intervals of 1 min or less. Prepare the current data logger to measure the current at the negative battery terminal at intervals of 1 min or less. If it is unclear if the DUT has deep discharge protection, the tester may prepare the low-voltage disconnect device so that it stops the discharge if the battery reaches the minimum battery testing voltage specified in Annex L.
- e) Some DUTs that use coulomb counting or similar methods for estimating state of charge will not correctly detect the battery state of charge when a discharge is started immediately after the battery is disconnected. This can result in the DUT turning off or reducing brightness prematurely during the full-battery run time test. The procedure in G.4.4 e) may be used for these products. If this procedure is not used, appropriate steps shall be taken, prior to starting the discharge, to reset the DUT's battery gauge. For example, in some products, charging the product for a few minutes via the PV input using a solar array simulator or power supply configured as described in S.4.2.5 will reset the battery gauge. The test laboratory should consult with the company to determine an appropriate reset procedure. After the reset procedure, the battery shall not be disconnected from the DUT prior to starting the discharge in step f).
- f) Switch on the DUT in the correct configuration and at the correct setting and start taking measurements. Relative light output (luminous flux for the integrating sphere; illuminance for other measurement devices) should be recorded every minute, at a minimum, if applicable. If not measuring relative light output, skip steps g) and h).
- g) Determine the initial light output time (t_{init}). This defines the point at which relative light output (RLO) is 100 %. If the DUT steps down to a lower setting after less than 20 min, then t_{init} is the time at which the last luminous flux or illuminance measurement was recorded at the initial setting. Otherwise, t_{init} is 20 min.
- h) Note the luminous flux or illuminance at time t_{init} .
- i) Continue the test until active deep discharge protection is observed, as defined in S.4.1.5 c). If no active deep discharge protection is observed:
 - 1) If the product could have passive deep discharge protection (e.g. for most products without ports; see S.4.3.1), continue the test until at least 24 h after the FBRT endpoint (Clause M.7).
 - 2) Otherwise, continue the test until the battery voltage decreases below the minimum discharge voltage permitted by the battery manufacturer. The test should be discontinued before the battery voltage drops to a value at which the battery can be damaged or become unsafe. Recommended minimum battery testing values are given in Table L.1.
 - 3) If deep discharge protection is not being assessed, the discharge may be stopped after t_{fin} (step M.9 j)) is reached.
 - 4) If the test has continued for 24 h after t_{fin} (Clause M.9, step j)) with no deep discharge protection detected, the laboratory may discontinue the test and report that no deep discharge protection was found, or continue the test at their discretion. The laboratory should communicate with the company before discontinuing the test to determine whether the current is expected to decrease further in a reasonable time.
 - 5) If all DUT functionality has stopped, but it is necessary to continue the discharge to test for active deep discharge protection, the DUT may be moved from the test cavity if necessary to make the equipment available for testing other products. The discharge may be interrupted for this purpose if it can be confirmed that the discharge resumes after the interruption (i.e. that the decrease in current that is identified as active deep discharge protection was not caused by the interruption).
- j) If the DUT turns off due to a timer feature designed into the DUT (see D.3.2.2 v)) that turns the product off after a fixed amount of time regardless of the battery state of charge, turn the product back on within 24 h and continue the test. Repeat this step as necessary until the deep discharge protection (active or passive) is detected as in i).
- k) If active deep discharge protection is observed, perform step S.4.1.5 d) before turning off the DUT or stopping data logging.

- l) Some products are designed to stop the discharge at a nonzero state of charge in order to reserve some energy for the next day in case the battery cannot be charged fully due to weather or other conditions. In this case, a single discharge cycle can be insufficient to assess the product's deep discharge protection; the laboratory should consult the company to determine how to test the deep discharge protection. The other full-battery run time test outcomes should be calculated based on the first discharge cycle.
- m) Record and photograph any damage or unsafe conditions (e.g. fire, venting, or explosion of the battery) that occur as a result of the test.

If the data-logging equipment cannot be read out while the test is in progress, it can be impractical to record the exact values of t_{init} and initial light output while the test is in progress. In this case, an approximate value of the initial RLO or initial power may be used to determine when to stop the test. If insufficient data was recorded to determine the full-battery run time and (if necessary) the deep discharge protection voltage, the test shall be repeated.

M.9 Calculations

Analyse the time-series data to estimate the full-battery run time, average power, typical battery discharge voltage, energy removed from the battery over the full-battery run time, and energy removed from the battery until the DUT reaches a low-voltage disconnect or other stopping criterion.

- a) Determine the full-battery run time (t_{FBRT}) as defined in Clause M.7. If the DUT was restarted in step M.8 j), subtract the duration of the intervals during which the product was turned off. For products with lighting appliances, report the result, expressed in hours (h). For products without lighting appliances, the full-battery run time is an intermediate step in the calculation of energy removed from the battery and may be omitted from the report.

EXAMPLE The DUT turned off due to a timer feature after 8 h, was turned on again at $t = 22$ h, turned off again at $t = 30$ h, was turned on again at $t = 46$ h, and turned off after reaching its active deep discharge protection at $t = 50$ h. The illuminance remained above L_{70} during the periods when it was on. The full-battery run time is $(50 \text{ h} - (22 \text{ h} - 8 \text{ h}) - (46 \text{ h} - 30 \text{ h})) = 20 \text{ h}$.

- b) For products with lighting appliances, the recorded data should be presented in a graph of RLO vs. time, as in Figure M.2. The graph should include the full discharge, beginning at 0 min, and can include RLO values greater than 100 %. If more than one brightness level was tested, prepare a separate graph for each test. For products without lighting appliances, a graph of power vs. time should be presented.
- c) Determine the average power over the full-battery run time (P_{FBRT}) using the following formula. Exclude from the sum any measurements that were made while the DUT was turned off due to a timer feature.

$$P_{\text{FBRT}} = \frac{1}{n} \cdot \sum_{t_i < t_{\text{FBRT}}} (I_{\text{b},i} \cdot V_{\text{b},i})$$

where

P_{FBRT} is the average power from the battery over the full-battery run time, in watts (W);

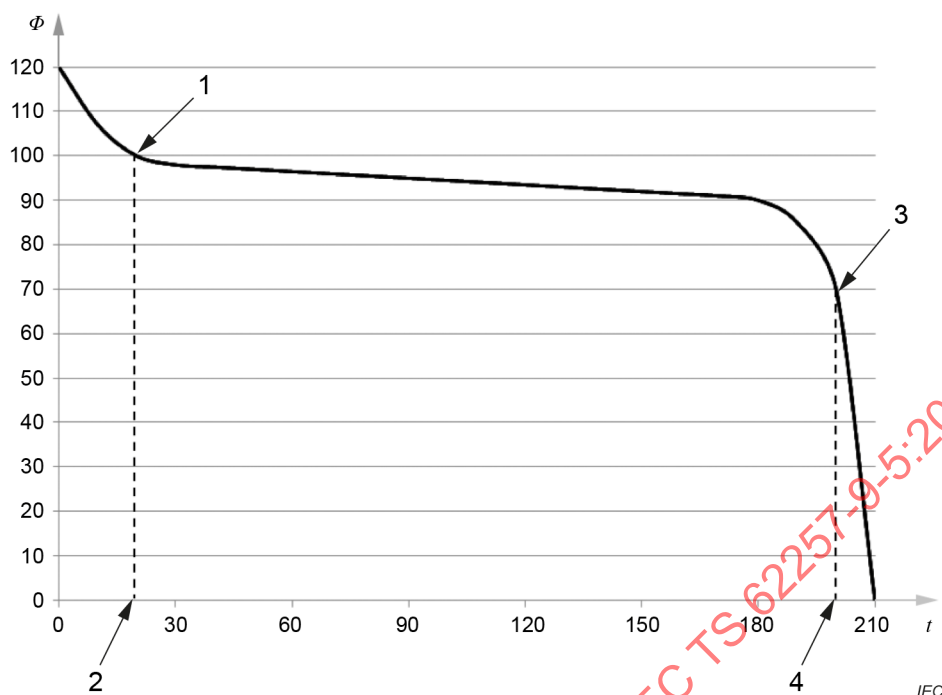
t_i is the elapsed time at measurement i ;

t_{FBRT} is the full-battery run time, in hours (h);

$I_{\text{b},i}$ is the battery current at measurement i , in amperes (A);

$V_{\text{b},i}$ is the battery voltage at measurement i , in volts (V);

n is the total number of current and voltage measurements over the full-battery run time (unitless).



Key

t Time (min)

Φ Relative light output (%), which is directly proportional to the luminous flux output

1 Initial light output (RLO of 100 %)

2 t_{init} , time when RLO is defined as 100 % (20 min)

3 L_{70} reached (RLO is 70 %)

4 t_{70} , time when RLO is 70 %

Figure M.2 – Plot of example results for a product with lighting appliances

- d) For products with lighting appliances, determine the energy removed from the battery over the L_{70} run time ($E_{b,70}$), including measurements that were made while the DUT was turned off due to a timer feature, using the following formula:

$$E_{b,70} = \sum_{t_i < t_{70}} (I_{b,i} \cdot V_{b,i} \cdot \Delta t_i)$$

where

$E_{b,70}$ is the energy delivered by the battery over the L_{70} run time, in watt-hours (Wh);

$I_{b,i}$ is the battery current at measurement i , in amperes (A);

$V_{b,i}$ is the battery voltage at measurement i , in volts (V);

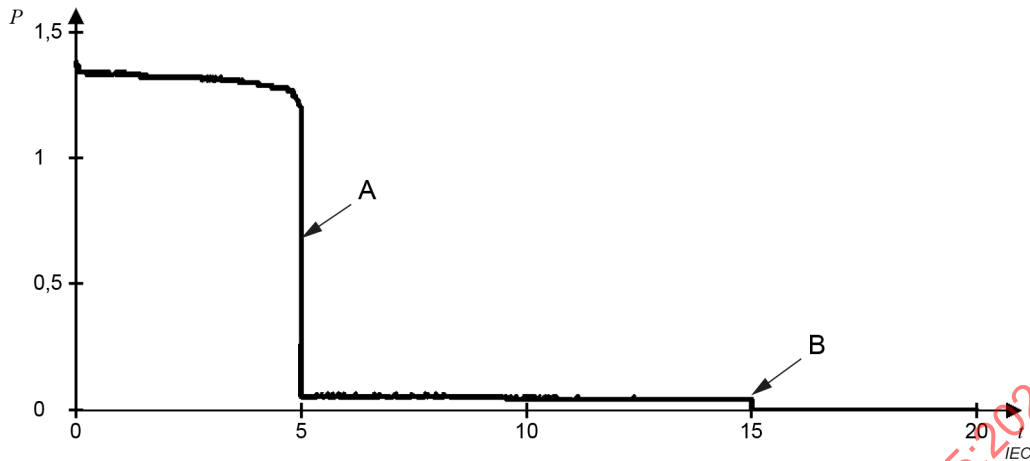
Δt_i is the duration associated with each current and voltage point over the L_{70} run time, in hours (h).

- e) If the DUT is not being assessed for deep discharge protection, skip steps f) through i) and proceed to step j).
- f) Use S.4.1.5 c) and e) to determine if the DUT has active deep discharge protection incorporated into its charge controller and determine the active deep discharge protection voltage. If the DUT has active deep discharge protection, report the active deep discharge protection voltage, in volts (V), and report whether the protection is internal to the battery.

- g) If the DUT does not have active deep discharge protection, the product could have passive deep discharge protection (defined and described in S.4.3.1). If no active deep discharge protection was detected, and passive deep discharge protection is appropriate for the product (see S.4.3.1), follow S.4.3.5 e) and f) to determine if the DUT has passive deep discharge protection. The test period mentioned in S.4.3.5 is the full duration of the full-battery run time test until 24 h after the DUT reaches L_{70} , or, for products without lighting appliances, until the 24 h after the DUT reaches any of the stopping criteria listed in Clause M.7.
- h) If the DUT has passive deep discharge protection, report the passive deep discharge protection voltage.
- i) If the low-voltage disconnect device provided by the laboratory stopped the discharge during the test, record that the battery voltage reached the minimum battery testing voltage and that no deep discharge voltage was observed. If the battery contains internal circuitry (refer to F.4.3.6) and the measured deep discharge protection voltage is outside of the targets specified by the company (D.3.2.2) or the battery falls below the recommended deep discharge protection voltage specified in Annex L, the test may be repeated with the voltage data logger connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so. In the test report, note where the reported voltage value was measured.

NOTE 1 If the test is to be repeated for this reason, the active deep discharge protection test (S.4.1.5) or passive deep discharge protection test (S.4.3.5) can be used to reduce the time necessary for re-testing.

- j) Determine the endpoint time (t_{fin}) for the calculation of $E_{b,LVD}$.
 - 1) If the DUT has a low-voltage disconnect (LVD), t_{fin} is typically the time when the LVD occurs. However, see the next step for an exception.
 - 2) In some cases, even after an apparent low-voltage disconnect occurs and the lights and other appliances turn off, the battery voltage continues to decrease, and the actual low-voltage disconnect occurs at a lower voltage. In this case, t_{fin} is the time when all appliances, lights, and ports have turned off.
 This behaviour is illustrated in Figure M.3: the lights and other appliances turn off at the time labelled A, when the power drops to a small but nonzero value, and the discharge stops at the time labelled B. In the period between A and B, while the lights, appliances and other functions are turned off, some functionality of the DUT is still active; for example, it could display a low-battery indication. In this example, time A is t_{fin} .
 - 3) If the DUT does not have a low-voltage disconnect, t_{fin} is the time when the test stopping criterion of Clause M.8, step i) occurs.

**Key**

t Time (h)
 P Power (W)

- A Time when all DUT functionality turns off (t_{fin})
 B Time when the actual low-voltage disconnect occurs

Figure M.3 – Example plot of power vs. time for a product that turns off before the low-voltage disconnect occurs

- k) Calculate the low-battery voltage to be used as an input for the assessment of DC ports:
- 1) Determine the voltage V_{fin} at time t_{fin} . (This is typically, but not always, equal to the deep discharge protection voltage.)
 - 2) Calculate the low-battery voltage using the following formula:

$$V_{low} = 0,1 \times (V_{OCP} - V_{fin}) + V_{fin}$$

where

V_{low} is the low-battery voltage, in volts (V);

V_{OCP} is the maximum battery voltage measured during the active overcharge protection test (S.4.2), or, if the DUT will not undergo the active overcharge protection test, the maximum battery voltage observed during the solar charge test (Annex R), in volts (V);

V_{fin} is the voltage determined in the previous step, in volts (V);

NOTE 2 This voltage typically corresponds to a remaining run time of approximately 5 % to 10 % of the full-battery run time.

If the low-battery voltage resulting from the formula above is greater than the typical battery discharge voltage, set the low-battery voltage equal to the typical battery discharge voltage. The reason for this result should be investigated, as a low-battery voltage greater than the typical battery discharge voltage can indicate an error in data collection or analysis or unusual behaviour that requires special provisions for testing.

- l) Determine the energy removed from the battery until the DUT reaches a low-voltage disconnect or other stopping criterion ($E_{b,LVD}$), including measurements that were made while the DUT was turned off due to a timer feature, using the following formula:

$$E_{b,LVD} = \sum_{t_i < t_{fin}} (I_{b,i} \cdot V_{b,i} \cdot \Delta t_i)$$

where

- $E_{b,LVD}$ is the energy exiting the battery until the DUT reaches a low-voltage disconnect or other stopping criterion, in watt-hours (Wh);
- t_{fin} is the endpoint time identified in step j), in hours (h);
- $I_{b,i}$ is the current exiting the battery at measurement i , in amperes (A);
- $V_{b,i}$ is the voltage of the battery at measurement i , in volts (V);
- Δt_i is the duration associated with each current and voltage point, in hours (h).

- m) Perform the following steps to determine the typical battery discharge voltage (see H.5.2):
 - 1) Calculate the average voltage during the full-battery run time (V_{avg}). Exclude any measurements that were made while the DUT was turned off due to a timer feature.
 - 2) Create a table listing the power and current as a function of voltage operating point for the steady-state operating period – defined as the period beginning 20 min into the tests until the end of the full-battery run time. The table should list each operating voltage during the period in increments of 0,01 V. The average power should be found based on all the steady-state points that fall into each voltage "bin".
 - 3) Linearly interpolate between points in the table created in step 2) to identify all the values of voltage for which the power is equal to the average power P_{FBRT} .
 - 4) If more than one voltage was identified in 3), select the voltage closest to the average voltage (V_{avg}) calculated in 1). This is the typical battery discharge voltage (V_{tbd}).
 - 5) Note the current (I_{tbd}) at the same point selected in 4). This is the current at the typical battery discharge voltage. (This current can be calculated by dividing P_{FBRT} by V_{tbd} .)
- n) Optionally, for products with lighting appliances, determine the average relative light output during the L_{70} run time (RLO_{avg}). Exclude any measurements that were made while the DUT was turned off due to a timer feature.

M.10 Reporting

Report the following in the full-battery run time test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - DUT setting;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.

- Results for tested DUT aspects for samples 1 through n :
 - run time to L_{70} (h), for products with lighting appliances;
 - typical operating point that corresponds to the average power (P_{FBRT}), described by the typical battery discharge voltage V_{tbd} (V) and current I_{tbd} (A);
 - average power over the full-battery run time (W);
 - energy removed from the battery over the L_{70} run time (Wh), for products with lighting appliances;
 - energy removed from the battery until the DUT reaches a low-voltage disconnect or other stopping criterion (Wh);
 - presence of active deep discharge protection, if applicable (yes/no);
 - active deep discharge protection voltage, if applicable (V);
 - whether active deep discharge protection is internal to the battery (yes/no);
 - presence of passive deep discharge protection, if applicable (yes/no);
 - passive deep discharge protection voltage at 24 h, if applicable (V);
 - presence of damage or safety hazard during the test (yes/no);
- Average of n sample results for run time, average power, and energy results.
- DUT's rating for aspects tested, if available.
- Deviation of the average result from the DUT's rating for run time, average power, and energy results, if available (%).
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .
- Figures:
 - plot of relative light output (%) or power vs. elapsed time (min), as in Figure M.2;
 - plot of voltage and current vs. elapsed time (min).

Annex N (normative)

Full discharge procedure

N.1 Background

Some test procedures require that the DUT be fully discharged. When performing the full-battery run time test (Annex M), a DUT is considered fully discharged when it reaches L_{70} . This is the point at which the DUT provides 70 % of the initial light output where the initial light output is the luminous flux or illuminance reading typically taken at minute 20 of the full-battery run time test. For products without included lighting appliances, the product is considered fully discharged when it reaches its low-voltage disconnect, all the appliances no longer function, the battery voltage falls below the value set on the optional low-voltage disconnect device, or the power drawn from the battery is 10 % or less of the power measured 20 min after the start of its full-battery run time test, whichever occurs first.

The grid charge test (Annex O), electromechanical charge test (Annex P), and solar charge test (Annex R) use a specified charge cycle and the initial state of charge will influence the DUT's performance during the charge. It is important that the DUT be set to a prescribed state of charge to simulate a full discharge prior to commencing the selected run time tests so the results are repeatable and comparable across products.

N.2 Test outcomes

There are no outcomes of the full discharge procedure.

N.3 Related tests

The full discharge procedure shall be performed on all DUTs prior to conducting the grid charge test (Annex O), electromechanical charge test (Annex P), and solar charge test (Annex R).

N.4 Procedure

N.4.1 General

Each DUT is fully discharged prior to starting any of the tests listed in Clause N.3.

N.4.2 Equipment requirements

One of the following three pieces of equipment is required for the full discharge procedure. Equipment shall meet the requirements in Clause CC.2.

- a) Battery analyser meeting the requirements in Clause CC.2.
- b) Electronic load with timer function, meeting the accuracy requirement for battery analysers in Clause CC.2.
- c) Timer disconnect device consisting of a digital timer and a relay that can break the connection between the DUT's circuit and its battery (e.g. an AC digital timer combined with an AC-actuated mechanical relay).

N.4.3 Test prerequisites

Before performing the procedure, fully charge the battery using one of the following two procedures depending on the battery chemistry and circuit protection.

- If the battery is of NiMH chemistry, then use the procedures in the nickel-metal hydride battery test (K.4.3.1).
- If the cell balancing or individual cell monitoring circuitry is external to its battery, use the procedures in the active overcharge protection test (S.4.2). If the PV module has not yet been tested, then set up the apparatus in accordance with Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp} .
- Otherwise, use either of the following:
 - a) the procedures in the active overcharge protection test (S.4.2). If the PV module has not yet been tested, then set up the apparatus in accordance with Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp} .
 - b) the battery test procedures appropriate to the battery chemistry (Annex K) with the following modification: set the maximum charge voltage to the overcharge protection voltage measured in the active overcharge protection test (S.4.2).

In the case where the DUT significantly continues to charge after reaching its overcharge protection voltage, avoid using option a) or stop the charge as soon as the DUT reaches its overcharge protection voltage.

Any following steps shall be started between 1 h and 24 h after the DUT has finished receiving its full charge.

N.4.4 Procedure

N.4.4.1 General

Products generally have one of five types of discharge curves.

- a) A constant brightness with a sharp turn-off when the product reaches its low-voltage disconnect (LVD) such that the relative light output does not drop below 70 % prior to turning off.
- b) A relatively constant brightness that begins to decrease just prior to experiencing a sharp turn-off when the product reaches its LVD such that the relative light output drops below 70 % before the product turns off.
- c) A series of decreasing brightness steps during its discharge, often reaching an LVD after providing some light in its lowest setting.
- d) A gradually decreasing brightness as the product discharges, reaching an LVD after reaching L_{70} .
- e) A gradually decreasing light output as the product discharges with no LVD.

If the product discharges as type a), proceed with N.4.4.2 if using the product's low-voltage disconnect, N.4.4.3 if using a battery analyser or electronic load, or N.4.4.4 if using a timer disconnect device. If the product discharges as type b), c), d), or e), proceed with N.4.4.3 or N.4.4.4; do not use N.4.4.2.

If the product does not include lighting appliances and its full-battery run time test was stopped by active deep discharge protection, any of the three methods, N.4.4.2, N.4.4.3 or N.4.4.4, may be used. If the product does not include lighting appliances and its full-battery run time was stopped due to one of the other stopping criteria, N.4.4.2 shall not be used.

For products that use coulomb counting or similar methods for estimating state of charge, for which special preparation was required during the full-battery run time test in Clause M.8, step e), ensure that the same preparation is carried out prior to starting the discharge procedure, if the battery has been disconnected from the DUT at any time after the product was fully charged in accordance with N.4.3 or if otherwise required by the product's design.

If the full-battery run time test has been conducted for multiple settings or configurations of appliances, use the results for the setting or configuration described in step M.8 a) (i.e. all lighting appliances without batteries, set to the brightest setting). If the same sample is required to undergo the full discharge procedure multiple times (e.g. a sample is tested on high setting and again on low setting), the same channel of the battery analyser or electronic load should be used each time to improve the consistency of the results.

N.4.4.2 Procedure using the product's low-voltage disconnect

The following steps shall be performed.

- a) Set the DUT in a secure location.
- b) Turn the DUT on in the same configuration that was used in the full-battery run time test.
- c) Allow the DUT to discharge uninterrupted until its LVD automatically turns it off.
- d) After the DUT finishes discharging, wait at least 1 h but no longer than 24 h prior to commencing the selected charging test.

N.4.4.3 Procedure using a battery analyser or electronic load

The following steps shall be performed.

- a) Calculate the average discharge current measured from the battery during the full-battery run time test (Annex M) until it reached L_{70} . For products that do not include lighting appliances, calculate the average discharge current measured from the battery during the full-battery run time test until one of the stopping criteria in step M.9 m) 2) is met.
- b) Use the battery analyser or electronic load to discharge the DUT at the average discharge current calculated in step a) for a duration equal to its full-battery run time to L_{70} , measured in Annex M. For products that do not include lighting appliances, use the duration equal to the full-battery run time until one of the stopping criteria was met.
- c) After the DUT finishes discharging, wait at least 1 h but no longer than 24 h prior to commencing the selected charging test.

N.4.4.4 Procedure using a timer disconnect device

The following steps shall be performed.

- a) Program the timer for a duration equal to the full-battery run time to L_{70} , measured in Annex M. For products that do not include lighting appliances, use the duration equal to the full-battery run time until one of the stopping criteria was met.
- b) Connect the DUT to the timer device such that the timer device relay will disconnect the DUT circuit from the battery upon reaching the programmed discharge time. Turn the DUT on in the same configuration that was used in the full-battery run time test, as described in Clause M.8, step a).
- c) After the DUT finishes discharging, wait at least 1 h but no longer than 24 h prior to commencing the selected charging test.

N.4.5 Calculations

No calculations are required with the full discharge procedure.

N.5 Reporting

No reporting is required with the full discharge procedure.

Annex O (normative)

Grid charge test

O.1 Background

The possibility of grid charging improves the usability of an LED lighting product, even if it is designed for use in remote areas. Annex O describes the method for measuring the duration of grid charging required to fully charge the battery.

In this test, the DUT is grid charged via the provided power adapter. The test is also applicable to products that charge from a DC power source, such as a USB port, even if the power supply is not included. Table 3 specifies which products are required to undergo this test.

O.2 Test outcomes

The test outcomes of the grid charge test are listed in Table O.1.

Table O.1 – Grid charge test outcomes

Metric	Reporting units	Related aspects	Notes
Grid-charge time	hours (h)	--	The total duration of grid charge, starting from the state of charge corresponding to the end of the full-battery run time and ending at a state of charge close to 100 %

O.3 Related tests

The grid charge test requires the full-battery run time test (Annex M) to be performed before the test. Also, if the charge controller behaviour test (Annex S) is performed before the grid charge test and it is determined the DUT has overcharge protection, no overcharge protection device is required during the grid charge test.

O.4 Procedure

O.4.1 General

The sample is charged by the grid or external DC power supply to determine the grid charge time.

O.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- For products with AC power input:
 - AC power adapter supplied with the DUT.
 - AC power supply.
- For products with DC power input, DC power supply with voltage and current as specified in the product specification. This can be a laboratory power supply or instrument or a consumer product (e.g. a USB PD fast charger).

- DC voltage data logger.
- DC current data logger (e.g. voltage data logger and current transducer).
- Overcharge disconnect device (if necessary).
- Surface-mounted thermocouple(s) and a thermocouple reader (optional).

If the utility voltage and frequency available at the laboratory match the requirements of the AC power adapter supplied with the DUT, then utility power may be used to supply power to the AC adapter, and it is not necessary to use a separate AC power supply. Many products are supplied with "universal" AC adapters that accept wide voltage and frequency ranges. The type of AC power supply used should be noted in the test report, but it is not necessary to record the AC voltage, current, or power.

O.4.3 Test prerequisites

The following steps shall be performed.

- Discharge the battery in accordance with the full discharge procedure (Annex N).
- If it is unknown whether the DUT has an overcharge protection disconnect, an overcharge protection disconnect device should be used to protect the battery during the test.
- If the product has a PV module, disconnect it, cover it with opaque material, or orient it so that it is not exposed to ambient light.

O.4.4 Apparatus

A suitable location for the DUT to be undisturbed for 8 h while grid charging is required.

O.4.5 Procedure

The following steps shall be performed.

- If it is unknown whether the DUT has an overcharge protection disconnect, integrate the overcharge protection disconnect device into the setup. Optionally, monitor the battery temperature to ensure that it does not exceed a safe value. The maximum allowable voltage setpoint for the overcharge disconnect device and the maximum allowable cell temperature may be selected from Table L.2. If temperature monitoring is used, lithium-based batteries shall not be allowed to exceed 45 °C unless higher temperatures are allowed by the battery manufacturer.
- Set up the current and voltage sensors to monitor the charge into the battery and set data logging for 1 min intervals or shorter.
- Connect the DUT to the AC or DC power supply.
- Allow charging to continue until the battery current decreases to less than 0,05 I_t A (defined in K.4.1). For products with NiMH batteries that do not have active deep discharge protection, stop the test when the energy supplied to the battery exceeds the product of the battery capacity and the overcharge factor given in Table K.2.

O.4.6 Calculations

The following calculations shall be made:

- Find the instantaneous power for each data point by multiplying current and voltage.
- For products with active overcharge protection, the grid-charge time is the time from the start of the charge cycle to the point when the current reaches 0,05 I_t A.

- c) For NiMH products without active overcharge protection, the grid-charge time is the time from the start of the charge cycle to the point when the battery is fully charged. However, it can be difficult to determine when a NiMH battery is fully charged, especially if the battery contains multiple cells in series. The laboratory may use any of the following events to indicate that the battery is fully charged:

- 1) The battery voltage reaches a peak value and decreases slightly;
- 2) The battery voltage stops increasing and remains approximately constant;
- 3) The battery temperature increases;
- 4) An indicator on the DUT indicates that the battery is full.

Some of these signals occur gradually rather than instantaneously, and the magnitude of the signals depends on several factors including battery size and construction, ambient temperature, and charge rate. The laboratory should use their judgement to determine when the battery is fully charged.

In the test report, describe how the endpoint was determined and include a plot of the relevant quantities (e.g. voltage or temperature) vs. time, with annotations showing the grid-charge time endpoint.

- d) If a product with a battery chemistry other than NiMH does not have overcharge protection, the grid-charge time is the time from the start of the charge cycle to the point when the battery voltage reaches the maximum charging voltage specified by the battery manufacturer.
- e) Plot the cumulative energy supplied by the battery vs. time; include this plot in the test report.

O.5 Reporting

Report the following in the grid charge test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - grid-charge time (h).
- Figures
 - plot of cumulative energy vs. time;
 - additional plots for NiMH batteries.
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .

Annex P (normative)

Electromechanical charge test

P.1 Background

A number of lighting products provide mechanical crank-charging as an alternative to grid or PV module charging.

Annex P describes a procedure for measuring the power generated by electromechanical charging under predetermined conditions. This value can be used in the energy service calculations (Annex GG) to determine the service (e.g. run time) provided by a specified period of electromechanical charging.

P.2 Test outcomes

The test outcomes of the electromechanical charge test are listed in Table P.1.

Table P.1 – Mechanical charge test outcomes

Metric	Reporting units	Related aspects	Notes
Electromechanical charger power or energy output	Watts (W) or watt-hours (Wh)	4.2.8.9 Electromechanical charger power or energy output	--

P.3 Related tests

The electromechanical charge test requires the full-battery run time test (Annex M) to be performed before the test.

P.4 Procedure

P.4.1 General

The sample is electromechanically charged for 5 min with measurements of the current and voltage available to charge the battery.

P.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Voltage data logger.
- Current data logger.
- Stopwatch or clock.

This test involves a calculation of electrical power; see Clause CC.3 for related recommendations. If the electromechanical charger does not produce a constant current or voltage, a power-measuring instrument should be used, as described in Clause CC.3.

P.4.3 Test prerequisites

The battery should be discharged in accordance with full discharge procedure (Annex N).

P.4.4 Apparatus

No particular apparatus is required. For electromechanical chargers that require a fixed position (e.g. bicycle crank chargers), it can be necessary to build or use a special apparatus.

If the product has a PV module, disconnect it, cover it with opaque material, or orient it so that it is not exposed to ambient light.

P.4.5 Procedure

The following steps shall be performed.

- a) Attach the voltage and current sensors to the product to measure charge into the battery. Set the data-logging interval for 2 s or less and begin logging.
- b) Electromechanically charge the DUT for 5 min at a speed (or other operating condition) corresponding to typical operation of the charging mechanism, following instructions in the user documentation if provided. Typically, a rotational speed of 120 rpm for a hand crank or 60 rpm for a bicycle crank charger is appropriate. If the DUT provides user feedback regarding the speed or operating conditions (e.g. an indicator light that illuminates when the crank is being turned at the correct speed), follow the guidance provided by the feedback mechanism. Note either the speed or other operating conditions, or both, in the test report.
- c) Download the data and check for consistency.

P.4.6 Calculations

The following calculations shall be made.

- a) Find the actual duration of the time series based on the data set.
- b) Calculate the instantaneous power input to the battery for each data point in the time series by multiplying current and voltage.
- c) Find and report the average power input over the charging period.

P.4.7 Modifications for atypical products

The procedure given in P.4.5 and P.4.6 is appropriate for products in which the electromechanical charging action is performed continuously for a duration of time, such as hand-crank or bicycle crank chargers, and charges a battery (or another electrical or electrochemical storage device, such as a supercapacitor). However, many variations on this model are possible. For alternative products, the following modifications may be used:

- For products in which a single action (e.g. lifting a weight) initiates the electromechanical operation, which then continues for a period of time, the energy provided by a single operation may be reported instead of the average power over five minutes. In this case, also report the duration of service provided by the action, as well as any information necessary to replicate the test.

EXAMPLE Lifting the 10 kg weight provides 0,012 Wh of energy to the battery over a period of 1 h.

- For products without a battery, in which the electromechanical generator directly powers the appliances, report the power or energy at an appropriate location, typically the output of the generator, under the load conditions defined in the full-battery run time test (Annex M). For such products, the following modifications may be made to the other test procedures in this document:
 - In the protection tests (Annex DD) and assessment of DC ports (Annex EE), and any other test requiring the battery to be replaced by a power supply, connect the power supply to the location where the power or energy output of the electromechanical generator was measured.
 - In place of the typical battery discharge voltage, use the voltage corresponding to the average power output of the generator, calculated using a procedure analogous to that in Clause M.9.
 - The concept of standby loss (S.4.5) is generally not applicable to these products.

NOTE Many electromechanically powered products without batteries fall outside the scope of this document, since they do not include an energy storage device. However, products can include a mechanical form of energy storage, and it can be useful to test such devices using the test methods in this document.

P.5 Reporting

Report the following in the electromechanical charge test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - electromechanical charger power or energy.
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .

Annex Q (normative)

Photovoltaic module I-V characteristics test

Q.1 Background

The purpose of the photovoltaic (PV) module I-V characteristics test is to validate the company's PV module data (if available) and determine the PV module's I-V characteristic curve under standard test conditions (STC) and at typical module operating temperature (TMOT).

Solar LED lamp units are often powered by PV modules with power ratings as low as 0,3 W.⁴ When selecting a measurement instrument, it is important to ensure that it is able to make accurate measurements of modules in the desired size range. This is particularly important for modules rated at less than 3,0 W since most measurement equipment is not designed for very small modules.

The PV module may be measured with a solar simulator in accordance with IEC 60904-1 and corrected to STC and TMOT with IEC 60891. This is the preferred technique for characterizing PV modules and laboratories with access to a solar simulator should use this procedure. The test may also be performed with an instrument that is designed to make outdoor performance measurements of small PV modules.

Q.2 Test outcomes

The test outcomes of the photovoltaic module I-V characteristics test are listed in Table Q.1.

Table Q.1 – Photovoltaic module I-V characteristics test outcomes

Metric	Reporting units	Related aspects	Notes
Short-circuit current (I_{sc}) at STC	Amperes (A)	4.2.6.1 Solar I-V curve parameters	Report at STC
Open-circuit voltage (V_{oc}) at STC	Volts (V)	4.2.6.1 Solar I-V curve parameters	Report at STC
Maximum power point power (P_{mpp}) at STC	Watts (W)	4.2.6.1 Solar I-V curve parameters	Report at STC
Maximum power point current (I_{mpp}) at STC	Amperes (A)	4.2.6.1 Solar I-V curve parameters	Report at STC
Maximum power point voltage (V_{mpp}) at STC	Volts (V)	4.2.6.1 Solar I-V curve parameters	Report at STC
Short-circuit current ($I_{sc, TMOT}$) at TMOT	Amperes (A)	4.2.6.1 Solar I-V curve parameters	Report at TMOT
Open-circuit voltage ($V_{oc, TMOT}$) at TMOT	Volts (V)	4.2.6.1 Solar I-V curve parameters	Report at TMOT
Maximum power point power ($P_{mpp, TMOT}$) at TMOT	Watts (W)	4.2.6.1 Solar I-V curve parameters	Report at TMOT
Maximum power point current ($I_{mpp, TMOT}$) at TMOT	Amperes (A)	4.2.6.1 Solar I-V curve parameters	Report at TMOT
Maximum power point voltage ($V_{mpp, TMOT}$) at TMOT	Volts (V)	4.2.6.1 Solar I-V curve parameters	Report at TMOT

⁴ This is the nominal power a PV module shows under standard test conditions (STC). Since being at STC is extremely rare in practice, the achieved power is usually lower.

Metric	Reporting units	Related aspects	Notes
Relative temperature coefficient of open-circuit voltage	Percent per degree Celsius (%/°C)	4.2.6.1 Solar I-V curve parameters	Based on temperature variation in V_{oc} .
STC I-V curve data set	Volts (V), Amperes (A)	4.2.6.1 Solar I-V curve parameters	Delimited data set

Q.3 Related tests

Annex Q should be completed before the solar charge test (Annex R).

Q.4 Procedure

Q.4.1 Test programme using a solar simulator

Q.4.1.1 Test prerequisites

If the PV module is amorphous silicon or otherwise could be subject to degradation (e.g. because it is thin film or of unknown technology), it shall sun-soak for 30 days prior to performing this test.

Q.4.1.2 I-V curve measurements

Use the procedure defined in IEC 60904-1, with the following modifications.

- The spectral mismatch correction described in IEC 60904-1:2020, 4.6, may be omitted if the reference device is a PV cell or module made using the same cell technology or using optical filtration to achieve a spectral response typical of the cell technology of the DUT. For example, a monocrystalline PV cell with KG5 glass window may be used with an amorphous silicon DUT.
- For measurements in steady-state simulated sunlight, the irradiance monitor of IEC 60904-1:2020, Clause 5, item b), may be omitted.
- For temperature measurements, a single thermocouple, meeting the accuracy requirements of Q.4.2.2 and positioned directly behind a cell near the centre of the module, may be used. If the back of the module is inaccessible, the front-mounted thermocouple procedure detailed in the outdoor test procedure (Q.4.2.5.3) shall be used for the indoor test.
- Bifacial PV modules shall be tested in the same manner as monofacial PV modules, with no rear irradiance and no correction for bifaciality.
- If the PV module is connected to the main unit with a cable, measure the I-V curve from the end of the cable that plugs into the main unit for charging by cutting the connector from the end of the PV module cable, leaving as much of the cable connected to the PV module as possible, and strip the wire ends. However, if the PV module's performance deviates from the advertised values by more than the truth-in-advertising tolerance specified in the product specification, the I-V curve test may be repeated measuring the I-V curve from the PV module's junction box (before the PV module's charging cable). The results from the original test shall be used as input for the solar charge test and both sets of results shall be reported for the photovoltaic module I-V characteristics test.

If the junction box contains components that prevent the I-V curve measurement from being carried out at the end of the cable, the I-V curve may be measured at or as close as possible to the junction box or at another point that enables the measurement to be performed. Record the location of the measurement in the test report.

Take note of the special instructions in R.4.2.3.3 that apply when the I-V curve is not measured at the end of the cable.

Q.4.1.3 I-V curve adjustment for STC and TMOT

Q.4.1.3.1 General

The I-V curve measured in Q.4.1.2 shall be adjusted to STC ($25\text{ °C} \pm 2\text{ K}$ cell temperature, solar irradiance of $1\,000\text{ W/m}^2$, and air mass 1,5) and TMOT ($50\text{ °C} \pm 2\text{ K}$ cell temperature, solar irradiance of $1\,000\text{ W/m}^2$, and air mass 1,5) using either of the following two procedures, ensuring that all voltage measurements are taken with the same instrument and all temperature measurements are taken with the same instrument. (If the temperature is within the stated tolerances for STC and TMOT, the measured curves may be used without correction.)

Q.4.1.3.2 Procedure using IEC 60891

Use any of the correction procedures defined in IEC 60891, subject to the following limitations and recommendations:

a) For IEC 60891 correction procedures 1 and 2:

- 1) These procedures require additional I-V curve measurements and data analysis to determine certain parameters of the PV module. Therefore, they are typically not practical for this application.
- 2) Both the temperature and irradiance corrections depend on the series resistance R_s in the single-diode PV model. Therefore, these procedures shall not be used unless the resistance of the PV cable is negligible compared to the series resistance of the PV module.

b) For IEC 60891 correction procedure 3:

- 1) This procedure is a linear interpolation or extrapolation using two measured I-V curves.
- 2) This procedure typically performs well when no irradiance correction is necessary and the desired temperatures (25 °C and 50 °C) are between the temperatures at which the two I-V curves are measured.
- 3) If irradiance correction is necessary:
 - Three I-V curves may be used as described in IEC 60891:2021, 4.4.3, or
 - The current may be corrected to $1\,000\text{ W/m}^2$ in accordance with Q.4.2.5.4 b), and then the IEC 60891 procedure applied to correct for temperature.
- 4) Correction procedure 3 has been used successfully by test laboratories and is generally the preferred procedure. It is applicable to most PV technologies. However, it can produce incorrect results in the following cases:
 - Current and voltage data points are irregularly spaced;
 - Significant noise exists in the current values, especially near short circuit;
 - There is a blocking diode in the PV module junction box.

These problems can usually be detected by visual inspection of the measured and corrected I-V curves.

c) For IEC 60891 correction procedure 4:

- 1) The PV material shall be crystalline silicon;
- 2) The irradiance correction depends on the value of R_s . Therefore, correction procedure 4 shall not be used unless either
 - no irradiance correction is necessary, or
 - the I-V curve is measured at or as close as possible to the junction box (see R.4.2.3.3).
- 3) The procedure should not be used on PV modules with low shunt resistance (R_{sh}), which can be identified by a nonzero slope of the I-V curve near short circuit.
- 4) The procedure shall not be used with degraded, faulty, or partially shaded PV modules.

- 5) The temperature coefficient of short-circuit current may be measured in accordance with Clause 5 of IEC 60891:2021 or assumed to be $0,000\,45\text{ K}^{-1}$ as stated in IEC 60891, or the value from the PV module manufacturer's data sheet or IEC 61215-2 test report may be used.
- d) All correction procedures should be used with caution if the I-V curve suggests the presence of defects such as cracked cells. Modules with cracked cells typically show one of the following characteristics:
- an inflection point in the I-V curve between short circuit and the maximum power point, or
 - a sudden decrease in short-circuit current as temperature is increased.

NOTE The PV module parameters R_s and R_{sh} are not the same as the PV simulation parameters R_s and R_p used in Annex R and Annex S.

For temperature coefficient measurements, a single thermocouple, meeting the accuracy requirements of Annex CC and positioned directly behind a cell near the centre of the module, may be used. If the back of the module is inaccessible, the front-mounted thermocouple procedure detailed in the outdoor photovoltaic module I-V characteristics test (Q.4.2.5.3) shall be used.

Q.4.1.3.3 Procedure using temperature coefficient of open-circuit voltage

Measure the temperature coefficient of voltage ($T_{c,voc}$) using the procedure defined in Q.4.2, under either natural or simulated sunlight, then use the calculations in Q.4.2.5.4 to adjust the curve to STC and TMOT.

Some PV modules include a Zener diode in the junction box to limit the open-circuit voltage. For these modules, this procedure cannot be used, because the temperature coefficient of open-circuit voltage is determined by the Zener diode characteristics and does not reflect the behaviour of the PV module at the typical operating point. These modules can be tested using IEC 60891 correction procedure 3 or by measuring the I-V curve at the junction box with the Zener diode removed. Modules with Zener diodes can be identified by physical inspection of the junction box or by measurement of the relative temperature coefficient of open-circuit voltage (β_{rel}). Zener diodes used for this application typically have temperature coefficients in the range of $-0,1\text{ \%/}^{\circ}\text{C}$ to $+0,1\text{ \%/}^{\circ}\text{C}$, compared to $-0,5\text{ \%/}^{\circ}\text{C}$ to $-0,2\text{ \%/}^{\circ}\text{C}$ for typical PV modules.

Q.4.1.4 Extraction of parameters

The following parameters shall be extracted from the adjusted I-V curves and reported for STC and TMOT:

- Short-circuit current (I_{sc})
- Open-circuit voltage (V_{oc})
- Maximum power (P_{mpp})
- Maximum power point voltage (V_{mpp})
- Maximum power point current (I_{mpp})

In some cases, depending on the equipment used to measure the I-V curve, it is not possible to obtain a corrected data point at exactly short-circuit ($V = 0$) or open-circuit ($I = 0$). In this case linear interpolation should be used to calculate these parameters. If two points that bracket $V = 0$ or $I = 0$ are not available, the closest available point should be used.

NOTE This approach is less accurate than that allowed by other standard test methods but allows for the use of low-cost test equipment. The values of I_{sc} and V_{oc} are of less importance than P_{mpp} in assessing the overall performance of a solar lighting product.

The maximum power point voltage (V_{mpp}) should be calculated by fitting a curve to the measured data. The following method, based on ASTM E948-15:2015, 8.5, is recommended, but modifications may be made as appropriate:

- Calculate the power at each point on the corrected I-V curve by multiplying the current and voltage values.
- Identify the point (I_m, V_m) on the corrected I-V curve with the highest power value (P_m).
- Identify the points on the corrected I-V curve meeting the following criteria:

$$0,75 I_m \leq I \leq 1,15 I_m$$

$$0,75 V_m \leq V \leq 1,15 V_m$$

- Perform a fourth-order polynomial least-squares curve fit to the P vs. I data.
- Calculate the derivative of the polynomial obtained in d).
- Find the root of the derivative obtained in e) using V_m as the initial guess. The Newton-Horner method with deflation is recommended. The value of this root is V_{mpp} .
- Substitute V_{mpp} into the polynomial determined in d) to calculate P_{mpp} .
- Divide P_{mpp} by V_{mpp} to find I_{mpp} .

In some cases, especially when the data points measured by the I-V curve analyser are not equally spaced, the polynomial curve fit can be inaccurate due to overfitting. In some cases, it is appropriate to use additional data points or a lower-order polynomial to correct this problem. However, overfitting often indicates that the test should be repeated with higher resolution.

If the relative temperature coefficient of open-circuit voltage (β_{rel}) has not yet been determined in the process of correcting the I-V curves to STC and TMOT, it shall be determined and reported using the following formula (or alternatively by following the procedure in IEC 60891:2021, Clause 5). The two measurements of V_{oc} may be performed separately (as in Q.4.2.5), or, if the I-V curve was measured at two different temperatures in Q.4.1.2, the V_{oc} measurements extracted from the measured curves may be used.

$$\beta_{rel} = \frac{1}{V_{oc,STC}} \times \frac{V_{oc,1} - V_{oc,2}}{T_1 - T_2} \times 100 \%$$

where

- β_{rel} is the relative temperature coefficient of open-circuit voltage, in percent per degree Celsius (%/°C);
- T_1 is the temperature at which the first measurement of open-circuit voltage is performed, in degrees Celsius (°C);
- T_2 is the temperature at which the second measurement of open-circuit voltage is performed, in degrees Celsius (°C);
- $V_{oc,1}$ is the measured open-circuit voltage at T_1 , in volts (V);
- $V_{oc,2}$ is the measured open-circuit voltage at T_2 , in volts (V);
- $V_{oc,STC}$ is the calculated open-circuit voltage at STC, in volts (V).

The value of β_{rel} for PV modules is typically between -0,5 %/°C and -0,2 %/°C; results falling outside this range should be investigated and noted in the test report. A Zener diode or other components in the junction box (Q.4.1.3) can cause this behaviour.

Q.4.2 Outdoor photovoltaic module I-V characteristics test

Q.4.2.1 General

The PV module is tested outdoors to obtain its characteristic I-V curve, from which the maximum power (P_{mpp}), open-circuit voltage (V_{oc}), and short-circuit current (I_{sc}) are determined.

Q.4.2.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Outdoor I-V curve analyser. The analyser may include an integrated pyranometer, provided it is fast-response (i.e. silicon PV-based pyranometer).
- Fast-response (i.e. silicon PV-based) pyranometer.
- Voltmeter or multimeter.
- Surface-mounted thermocouple(s) and a thermocouple reader.

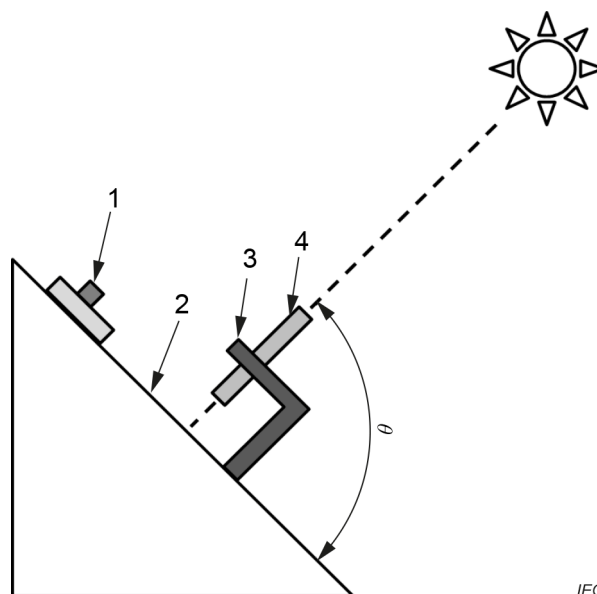
Q.4.2.3 Test prerequisites

The following prerequisites shall be met.

- Constant atmospheric conditions (i.e. a clear, sunny day with no clouds).
- Incident solar irradiance between 850 W/m^2 and $1\,150 \text{ W/m}^2$ and an ambient temperature between 15°C and 35°C .
- Air mass less than or equal to 2.
- If the PV module is amorphous silicon or otherwise could be subject to degradation (e.g. because it is thin film or of unknown technology), it shall sun-soak for 30 days prior to performing this test.

Q.4.2.4 Apparatus

There should be an appropriate stand to hold the PV module and pyranometer in the same plane, directly normal to the sun. The PV module should be placed as close as possible to the pyranometer to ensure that each device "sees" the same sky view. A sighting tube with bracket may be used to ensure the stand is directly normal to the sun (Figure Q.1).

**Key**

- 1 Pyranometer
- 2 Board or another flat surface
- 3 Bracket
- 4 Sighting tube
- θ 90°

Figure Q.1 – PV module I-V curve testing rack**Q.4.2.5 Procedure****Q.4.2.5.1 General**

Determine the appropriate thermocouple mounting technique based on PV panel configuration. If the PV module is separate from the lighting product or can be easily removed without damaging the active PV material and the back of the PV module is accessible, use the back-mounted thermocouple procedure (Q.4.2.5.2). Otherwise, use the front-mounted thermocouple procedure (Q.4.2.5.3).

The procedure of Q.4.1.3.2 (which references IEC 60891) may be used as an alternative means to adjust the I-V curve to STC and TMOT (as opposed to using the methods provided in Q.4.2.5.2 and Q.4.2.5.3). This typically involves taking I-V curve measurements at two different module temperatures, rather than only taking I-V curve measurements when the module has reached thermal equilibrium after warming under natural sunlight. This can result in a more accurate temperature correction, but the benefit can be offset by the need to perform an I-V curve measurement when the temperature is not stable, particularly when using equipment with long sweep times (such as a manually actuated rheostat load).

Bifacial PV modules shall be mounted on an opaque surface during the test so that no irradiance is applied to the rear of the module.

Q.4.2.5.2 Back-mounted thermocouple

The following steps shall be performed.

- a) The following steps shall be performed before the PV module is exposed to sunlight.
 - 1) If the PV module is connected to the main unit with a cable, measure the I-V curve from the end of the cable that plugs into the product for charging by cutting the connector from the end of the PV module cable, leaving as much of the cable connected to the PV module as possible, and strip the wire ends.
 If the PV module's I-V curve results show that the PV module's performance deviates from the advertised values by more than the truth-in-advertising tolerance specified in the product specification, the I-V curve test may be repeated measuring the I-V curve from the PV module's junction box (before the PV module's charging cable). The results from the original test shall be used as input for the solar charge test and both sets of results shall be reported for the photovoltaic module I-V characteristics test.
 If the junction box contains components that prevent the I-V curve measurement from being carried out at the end of the cable, the I-V curve may be measured at or as close as possible to the junction box or at another point that enables the measurement to be performed. Note the location of the measurement in the test report.
 - 2) Connect a voltage meter or multimeter (DC voltage range) to the PV module.
 - 3) Fix the thermocouple to the back of the PV module directly behind a cell near the centre of the active area and affix insulating material (e.g. foil-backed foam tape) over the thermocouple.
- b) Expose the PV module to direct normal sunlight and immediately measure and record the open-circuit voltage ($V_{oc,1}$) and the PV module temperature (T_1).
- c) Leave the PV module in direct normal sunlight until thermal equilibrium is reached (i.e. the PV module temperature is not changing by more than 1 °C/min).
- d) Connect the PV module to the I-V curve analyser per the I-V curve analyser's manufacturer's instructions.
- e) Execute the I-V measurement per the I-V curve analyser's manufacturer's instructions and record the PV module temperature (T) and incident solar irradiance.
- f) After the I-V curve measurement, measure and record the PV module temperature again (T_2) using the same instrument that was used in step a).
- g) Measure the record the PV module's open-circuit voltage at T_2 ($V_{oc,2}$) using the same instrument that was used in step a).

Q.4.2.5.3 Front-mounted thermocouple

The following steps shall be performed.

- a) The following steps shall be performed before the PV module is exposed to sunlight.
 - 1) Perform step Q.4.2.5.2 a) 1).
 - 2) Connect a voltage meter or multimeter (DC voltage range) to the PV module.
 - 3) Fix the thermocouple to the front of the PV module directly over a cell in the centre of the active area and affix insulating material (e.g. foil-backed foam tape) over the thermocouple.
- b) Expose the PV module to direct normal sunlight and immediately measure and record the PV module temperature (T_1), then quickly remove the thermocouple and insulating material from the front of the PV module, and measure and record the open-circuit voltage ($V_{oc,1}$).
- c) After measuring ($V_{oc,1}$), again fix the thermocouple to the front of the PV module directly over a cell in the centre of the active area in the same location as before and affix insulating material (e.g. foil-backed foam tape) over the thermocouple.
- d) Leave the PV module in direct normal sunlight until thermal equilibrium is reached (i.e. the PV module temperature is not changing by more than 1 °C/min).

- e) Connect the PV module to the I-V curve analyser per the I-V curve analyser's manufacturer's instructions.
- f) Remove the thermocouple.
- g) Measure and record the PV module's open-circuit voltage at T_2 ($V_{oc,2}$) using the same instrument that was used in step a).
- h) Immediately after obtaining $V_{oc,2}$, affix the thermocouple and insulating material to the front of the PV module (i.e. the same place as in step a)) and measure and record the temperature of the PV module (T_2 and T) using the same instrument that was used in step a).
- i) Immediately remove the thermocouple and execute the I-V measurement per the I-V curve analyser's manufacturer's instructions.

Q.4.2.5.4 Calculations

The following calculations shall be made.

- a) If correcting for irradiance and temperature using Q.4.1.3.2, perform the temperature and irradiance correction, then skip steps b) through f) and proceed to step g).
- b) Convert all of the current measurements to STC using the following formula:

$$I = I_m \times \frac{1\,000\text{ W/m}^2}{G}$$

where

I is the PV module's current at STC, in amperes (A);

I_m is the PV module's measured current, in amperes (A);

G is the measured incident solar irradiance during the I-V curve measurement, in watts per square metre (W/m^2).

- c) Calculate the open-circuit voltage of the measured I-V data ($V_{oc,m}$) using the guidelines in Q.4.1.4.
- d) Determine the temperature coefficient for the voltage ($T_{c,voc}$) using the following formula:

$$T_{c,voc} = \frac{(V_{oc,1} - V_{oc,2})/V_{oc,m}}{T_1 - T_2}$$

where

$T_{c,voc}$ is the PV module's temperature coefficient for the voltage, per degree Celsius ($1/^\circ\text{C}$);

$V_{oc,1}$ is the PV module's open-circuit voltage immediately after exposure to sunlight, in volts (V);

$V_{oc,2}$ is the PV module's open-circuit voltage after or immediately before the I-V measurement is taken, in volts (V);

$V_{oc,m}$ is the PV module's open-circuit voltage measured during the I-V measurement, in volts (V);

T_1 is the PV module's temperature immediately before exposure to sunlight, in degrees Celsius ($^\circ\text{C}$);

T_2 is the PV module's temperature after or immediately before the I-V curve measurement is taken, in degrees Celsius ($^\circ\text{C}$).

NOTE 1 This temperature coefficient is used only for the temperature correction and is not the value provided in the test report, which is denoted β_{rel} .

e) Convert all of the voltage measurements to STC using the following formula:

$$V = V_m \left[1 + T_{c,voc} (T_{stc} - T) \right]$$

where

- V is the PV module's voltage at STC, in volts (V);
- V_m is the PV module's measured voltage, in volts (V);
- $T_{c,voc}$ is the PV module's temperature coefficient for the voltage, per degree Celsius ($1/^\circ\text{C}$);
- T_{stc} is the temperature at STC, 25°C ;
- T is the PV module's temperature during the I-V curve measurement, in degrees Celsius ($^\circ\text{C}$).

The temperature correction may be omitted if the measured temperature is within the range $25^\circ\text{C} \pm 2\text{ K}$.

- f) Repeat step e) for TMOT in place of STC, where TMOT is defined as $50^\circ\text{C} \pm 2\text{ K}$.
- g) Determine and report the short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), maximum power point power (P_{mpp}), maximum power point current (I_{mpp}), and maximum power point voltage (V_{mpp}) at STC and TMOT and the relative temperature coefficient of open-circuit voltage (β_{rel}) in accordance with Q.4.1.4.

NOTE 2 If Q.4.1.3.2 is not used, the relative temperature coefficient of open-circuit voltage calculated in step g) is equivalent to the temperature coefficient calculated in d) except that $V_{oc,STC}$ is used in the denominator instead of $V_{oc,m}$.

Q.4.3 Arrays of PV modules

Q.4.3.1 General

If multiple PV modules, whether identical or of different types, simultaneously supply power to one main unit, it is sometimes possible to test only a single PV module or to test the modules separately and calculate a combined I-V curve for the array. The following cases are possible.

In any of these cases, it is also permitted to measure the I-V curve of the entire array. If the power or other parameters of the individual modules are advertised, it will be necessary to measure the I-V curve of one module of each type to assess truth in advertising. If the connection would normally be made inside the main unit or another component, it may be made externally to enable the measurement.

NOTE Connecting two modules with different current values in series, or two modules with different voltage values in parallel, is not good design practice; however, the procedures given in the following can still be used in these cases.

Q.4.3.2 PV modules connected in parallel at the main unit

In this scenario, each PV module has a separate cable that is connected to a separate input socket or set of terminals on the main unit, and these sockets or terminals are internally connected in parallel. Alternatively, the PV modules can be connected in parallel to the same socket or terminals, for example using a combiner cable that is of negligible length compared to the cable of each module. In this case:

- a) If the PV modules are identical, a single PV module may be measured for each sample and each current value multiplied by the number of identical modules in parallel to calculate the combined I-V curve.

- b) Alternatively, each PV module may be measured individually; the combined current is then calculated as the sum of the individual currents at each voltage. If the measurements of the two modules were made at different voltages, linear interpolation may be used to combine the curves. If necessary, curves may be extrapolated beyond V_{oc} .

Q.4.3.3 PV modules connected in series at the main unit

This scenario is identical to that described in Q.4.3.2 except that the PV modules are connected in series, either inside the main unit or with a short combiner cable. In this case:

- a) If the PV modules are identical, a single PV module may be measured for each sample and each voltage value multiplied by the number of identical modules in series to calculate the combined I-V curve.
- b) Alternatively, each PV module may be measured individually; the combined voltage is then calculated as the sum of the individual currents at each voltage. If the measurements of the two modules were made at different currents, linear interpolation may be used to combine the curves. If necessary, curves may be extrapolated beyond I_{sc} . However, caution should be used because of the possible effects of bypass diode conduction or reverse breakdown. If the values of I_{sc} differ significantly, this method should not be used unless the I-V curve tester can apply a negative voltage sufficient to allow the curves to be combined without extrapolation.

Q.4.3.4 PV modules connected at another location

If multiple PV modules are connected in parallel or series at a location other than the main unit, such that the resistance of the cable between the connection point and the main unit is not negligible, then the array current at a given voltage cannot be calculated by summing the currents or voltages of the individual modules with the shared cable. In this case, two options are available:

- a) measure the combined I-V curve of the entire array, or
- b) perform the I-V curve test at the point where the PV modules are connected. The procedure in Q.4.3.2 or Q.4.3.3 can then be used. The point where the I-V curve is measured will be the "PV socket" in the solar charge test (see R.4.2.3.3).

Q.5 Reporting

Report the following in the photovoltaic module I-V characteristics test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - description of location of test;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.

- Results for tested PV module aspects for samples 1 through n :
 - short-circuit current at STC (A);
 - open-circuit voltage at STC (V);
 - maximum power point power at STC (W);
 - maximum power point current at STC (A);
 - maximum power point voltage at STC (V);
 - short-circuit current at TMOT (A);
 - open-circuit voltage at TMOT (V);
 - maximum power point power at TMOT (W);
 - maximum power point current at TMOT (A);
 - maximum power point voltage at TMOT (V);
 - relative temperature coefficient of open-circuit voltage (%/°C).
- Average of n sample results for each PV module aspect tested.
- PV module's rating for aspects tested, if available.
- Deviation of the average result from the PV module's rating for each aspect tested, if available (%).
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .
- Figures:
 - plot or plots showing the I-V and power-voltage curves for every PV module sample.

Annex R (normative)

Solar charge test

R.1 Background

The solar charge test provides estimates for two key sources of energy loss during solar charging: suboptimal operation of the PV module ("solar operation efficiency") and losses from the internal electronic circuits that charge the battery(-ies) ("battery-charging circuit efficiency"). Along with the battery round-trip energy efficiency (Annex K), these values are used in the daily energy service calculations (Annex GG) to calculate the energy service (e.g. run time) provided in a typical day of solar charging.

A power supply along with two resistors is used to simulate a PV module and charge the battery(-ies). The voltage operating point during the test combined with the solar I-V curve is used to calculate the solar operating efficiency. Measurements of energy input to the solar charging port and battery(-ies) are used to estimate the battery-charging circuit efficiency.

R.2 Test outcomes

The test outcomes of the solar charge test are listed in Table R.1.

Table R.1 – Solar charge test outcomes

Metric	Reporting units	Related aspects	Note
Solar operation efficiency ($\eta_{\text{sol-op}}$)	Percentage	4.2.6 PV module aspects	This is representative of the efficiency with respect to optimal operation of the PV module (where optimal operation is at the maximum power point).
Battery-charging circuit efficiency (η_{bcc})	Percentage	4.2.7.4 Battery-charging circuit efficiency	This is a lump figure for the whole product and is not disaggregated by main unit.
Average charging voltage	Volts (V)	n/a	This value is optionally used in the assessment of DC ports (Annex EE) as a typical charging voltage.
Solar charging system characteristics	n/a	n/a	This describes key features of the solar charging circuit
Energy allocation ratios	Percentage	n/a	Percentage of the total energy delivered to each battery.

R.3 Related tests

The solar charge test is related to the battery test (Annex K), the photovoltaic module I-V characteristics test (Annex Q), the full-battery run time test (Annex M), and the energy service calculations (Annex GG).

R.4 Procedure

R.4.1 General

In this test, the DUT is charged using an apparatus to simulate the PV module during a typical day of solar charging. The PV simulation shall be performed using a resistor network and programmable laboratory power supply or a solar array simulator meeting the requirements of Clause CC.2. The voltage and current at the PV input and battery(-ies) are recorded at one-minute or shorter intervals.

R.4.2 Test method using a resistor network

R.4.2.1 Equipment requirements

R.4.2.1.1 General

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Programmable power supply with constant-voltage and constant-current modes and ability to automatically step through a timed program, or alternative apparatus described in R.4.2.1.5.
- Voltage data loggers (one for the PV input and one for each of the batteries).
- Current data loggers (e.g. voltage data logger and current transducer) (one for the PV input and one for each battery charged during the test).

NOTE Most products have only one battery that is charged during the solar charge test; see R.4.2.2.

- Series and parallel resistors (or variable resistors) for simulating PV input.
- Variable resistor for measuring the I-V curve from the PV simulator (optional).
- Resistance meter or multimeter.
- Surface-mounted thermocouple(s) and a thermocouple reader or other suitable surface-mounted temperature measurement devices (optional).
- Overcharge disconnect device that will stop the charge cycle (e.g. by disconnecting the battery) when the battery reaches a specified voltage (if necessary).

R.4.2.1.2 Recommendations for products with PWM

For products with pulse-width modulation (PWM) charge controllers, or if the current and voltage vary rapidly for any reason, errors in power measurement can occur, as discussed in Clause CC.3. During the “off” interval of the PWM waveform, the PV module voltage will increase to the open-circuit voltage. This will increase the average PV module voltage. However, the battery voltage will (depending on the internal impedance of the battery) remain approximately constant. As a result, the test will overestimate the solar operation efficiency ($\eta_{\text{sol-op}}$) and underestimate the battery-charging circuit efficiency (η_{bcc}), but the product of the two efficiencies will tend to be small and often negligible. Since the results of the solar run time energy service calculations (GG.4.2) depend on the product of the efficiencies, the error in solar run time values due to the current and voltage waveforms is typically small.

A more significant error in the measured efficiencies can occur due to aliasing (CC.3.3), depending on the relationship between the PWM frequency and the sampling interval of the test equipment. If the PWM frequency is known, aliasing can be avoided either by selecting a higher sampling rate or by applying a low-pass filter to the input of the measuring equipment.

A mitigating factor for both types of error associated with PWM is that the PWM function is often active only during the constant-voltage phase of the charge cycle. Typically, about 15 % of the total energy is received during this phase of charging, reducing the overall measurement error in the energy-based efficiency values. For example, a 5 % error in current during this phase could result in an error of less than 1 % in the total energy.

Detailed recommendations regarding the sampling rate or low-pass filter parameters are beyond the scope of this document. However, laboratory experience has shown that a low-pass filter with a cutoff frequency of a few hertz allows testing of most products without special considerations for PWM. Alternatively, a sampling rate of 5-10 times the PWM frequency is sufficient in most cases, and in many cases, a lower frequency will give adequate results. Power-measuring instruments typically have sampling rates of 100 kHz or more, which sufficiently mitigates the aliasing issue for the purposes of this test.

R.4.2.1.3 Power-measuring instrument requirements

If power-measuring instruments are used in place of the current and voltage data loggers, one instrument (or power-measuring element in a multi-channel instrument) is required for the PV socket and one for each battery included in the test.

An instrument with an integration function, to calculate cumulative energy, should be used. The power-measuring instrument should also record voltage and current; if this is not possible, separate instruments may be used for the voltage and current measurements, which are used to calculate the corrected solar operation efficiency in R.4.4 j). Configure the instrument to record average (DC) rather than RMS (AC) voltage and current.

R.4.2.1.4 Series resistance requirements

The series resistance added by the test apparatus and all measurement equipment between the DUT and the battery, shall be no more than 90 m Ω . This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4). Some products, particularly with currents exceeding approximately 1 A and low battery voltages, require a lower resistance to charge normally. Excessive resistance often results in a premature charge cutoff, a reduced current at the higher simulated solar irradiance steps, or intermittent operation. In products with lithium-based batteries containing multiple cells in series, excessive resistance can interfere with the correct operation of cell balancing features, particularly if the balancing circuit is not internal to the battery pack.

Alternatively, if the total voltage drop between the DUT and battery does not exceed 0,01 V, the resistance may exceed the 90 m Ω limit.

The resistance of any wiring between the power supply and resistors shall be kept low enough to meet the power supply voltage accuracy requirement in Clause CC.2. Since the resistance of wiring and instruments between the resistor network and DUT can be lumped into the measured value of the series resistance R_s , there is no maximum permitted value for this resistance, but it should be minimized to the degree practical.

R.4.2.1.5 Alternative PV simulation apparatus

Instead of a programmable power supply, an electronic apparatus designed to simulate the PV module's diode characteristic may be used. The characteristics of the apparatus shall be modelled and incorporated into the circuit simulation described in R.4.2.4 a) and b). An example of an apparatus intended for this purpose is described by Stütz (2014). The use of such an apparatus can improve the curve-fitting accuracy and dynamic performance, especially with DUTs that use pulse-width modulation (PWM) or maximum power point tracking (MPPT). The laboratory shall ensure that any such apparatus has voltage and current accuracy at least equivalent to the overall accuracy of the resistor network with a power supply meeting the requirements above.

R.4.2.2 Test prerequisites

The battery shall be at a state of charge that corresponds to the "end of discharge," which shall be accomplished using procedures in Annex N. Additionally, this test shall be performed after completion of the PV module I-V characteristics measurements (Annex Q), since the I-V curve information from the PV module during that test are necessary to set up the inputs to the power supply for the electronics efficiency test.

Special charging features that do not operate during a normal charge cycle, such as equalization or boost charging, shall not be enabled during this test, unless it is not possible to disable these features. Lights and appliances not containing batteries shall be disconnected and the DUT shall be turned off or set to standby mode (i.e. the mode in which the DUT's functionality is not active but the battery can be charged).

In some cases a product can contain multiple components with batteries that can charge from the PV module. In this case, the test is conducted with the batteries in all power control units that can power appliances other than those built into the power control unit. If multiple configurations of power control units are possible, it is often necessary to perform multiple solar charge tests to facilitate all relevant energy service calculations. Recommended combinations are listed in Clause Z.1.

EXAMPLE 1 A product contains two main units that connect to a single PV module via a splitter cable. Both main units would be connected for the solar charge test.

EXAMPLE 2 A radio, torch, or portable lamp that contains a battery and charges from the main unit battery (e.g. via a USB port) is not connected during the solar charge test.

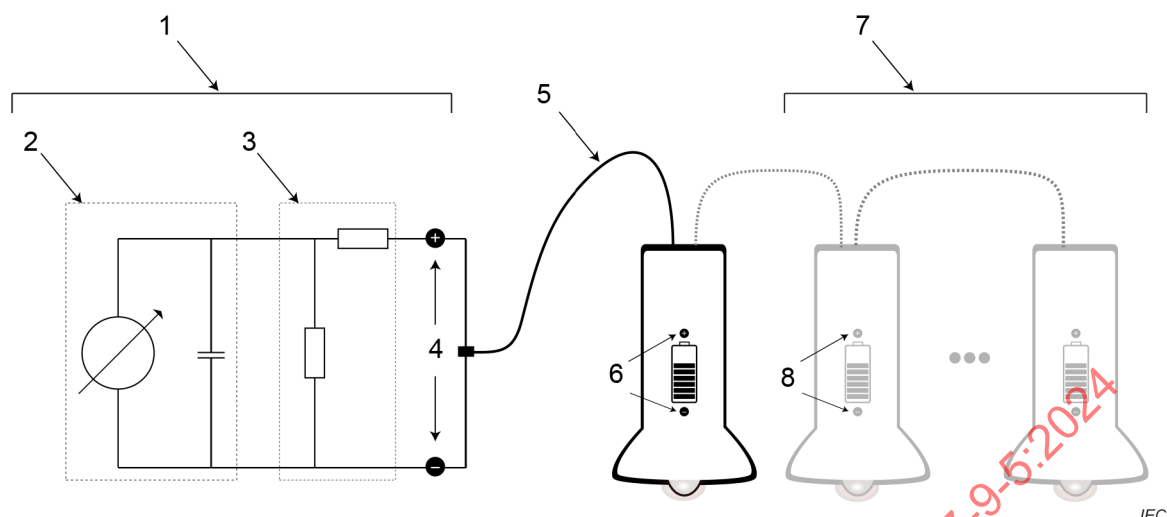
EXAMPLE 3 A product consists of a main unit with a PV module input, a second power control unit that charges from a port on the main unit, lamps and a TV that are powered by the main unit, and additional lamps that are powered by the second power control unit. Both the main unit and second power control unit are charged during the solar charge test. If the main unit can be used independently, without the second power control unit, it should additionally be tested separately.

In some cases, such as unusual configurations of batteries and appliances, the battery preparation procedure and product configuration described above is not applicable or appropriate. In these cases, the laboratory shall determine the most appropriate configuration and sample preparation procedure. The procedure used shall be documented in the test report.

R.4.2.3 Apparatus

R.4.2.3.1 General

The apparatus for the solar charge test is shown schematically in Figure R.1. The PV simulation circuit consists of two resistances (which can be constructed using combinations of either fixed or variable resistors, or both) and a power supply with constant-voltage and constant-current mode and programmable capability. This circuit implements an approximation of the single-diode model for a photovoltaic module.



Key

- 1 PV simulation circuit
- 2 Laboratory power supply
- 3 Series and parallel resistors (or variable resistors)
- 4 PV simulation circuit output (measures current and voltage here during simulated solar charging)
- 5 Connection cable from PV simulation circuit to main unit
- 6 Main unit battery (measures current and voltage here during simulated solar charging)
- 7 [optional] Additional main units with separate batteries that are included with the product
- 8 [optional] Additional main unit battery(-ies) (measure current and voltage here during simulated solar charging)

Figure R.1 – Schematic of the power supply and DUT connection for the solar charge test

The following quantities are measured at intervals of no more than 1 min:

- voltage at the PV input socket, or other location where the PV module connects to the DUT;
- current at the PV input socket, or other location where the PV module connects to the DUT;
- battery voltage for each battery (measured as close as possible to the DUT's printed circuit board);
- battery current for each battery.

R.4.2.3.2 Special instructions for products with cell balancing

For products with cell balancing functionality implemented external to the battery pack (i.e. on the DUT's printed circuit board), particular care should be used, because the resistance of the measurement apparatus can cause the product to detect a spurious out-of-balance condition. If the balancing functionality operates during the test, the measured battery current and the battery-charging circuit efficiency can be incorrect. The following methods may be used to test such products:

- The current and voltage may be monitored at each cell or parallel cellblock. However, this option is often impractical since the resistance of the measurement apparatus can easily result in excessive voltage drop. This method should be used only with caution, especially if the voltage drop cannot be limited to less than approximately 10 mV per cell. Any of the following signs indicate that the results of this method are not usable:
 - operation of the balancing circuit even though the cells are in balance;
 - intermittent charging or behaviour similar to pulse-width modulation (PWM) due to the total pack voltage exceeding the overcharge protection limit.

- The test may be conducted with no current or voltage monitoring, or with voltage monitoring only, at the batteries. The battery-charging circuit efficiency is then calculated using the alternative method given in R.4.5.

If these methods are unsuccessful, alternative methods may be used if the laboratory can demonstrate that the results obtained are equivalent to the result of one of the permitted methods had that method been possible.

R.4.2.3.3 Special instructions for alternative I-V curve measurement locations

When the I-V curve was measured at a location other than the end of the PV module cable, for example because of a Zener diode or anti-tampering device in the PV module junction box, the resistance R_{cable} of the cable and any other components between the I-V curve measurement point and the DUT shall be taken into account in the solar charge test, using one of the following methods.

- Insert the PV module cable, including any electronic components in the junction box that were bypassed or removed in the I-V curve test, between the resistor network apparatus or solar array simulator and the PV input socket. (That is, the PV simulator is placed at the same location in the circuit where the I-V curve was taken.) If the cable cannot be detached non-destructively from the junction box, the cable shall be cut as close to the junction box as practical. The PV simulator current and voltage is measured at the end of the PV cable connected to the PV simulator. If a resistor network is used, the resistance of the cable is not included in the measurement of the series resistance R_s .

If the junction box is potted and contains electronics, it is sometimes necessary to obtain additional samples of the PV module cable and electronics without the potting compound. If the test is subject to a random sampling requirement (Annex E), the additional samples shall be obtained in a way that complies with this requirement; for example, samples could be collected by a sampling agent at the PV module supplier's factory before the potting compound is added.

- The cable (and all other components between the I-V curve measurement location and the DUT) may be replaced by a resistor with resistance $R_{\text{cable}} \pm 1\%$. The measurement of R_{cable} may be made on a single sample; only the omitted portion of the cable (and any other omitted components) should be measured. (For example, if a connector equivalent to the connector at the end of the cable is used to connect the test apparatus to the PV socket, the connector should not be included in the resistance measurement.) A four-wire measurement is typically necessary. The resistor may be constructed using a length of wire having similar characteristics to the PV module cable.
- The cable (and all other components between the I-V curve measurement location and the DUT) may be omitted and a correction applied to each voltage value in the TMOT I-V curve. The resistance of the cable and other components shall be measured as in b); the measurement may be made on a single sample. Use the following formula for the voltage correction:

$$V_{\text{corr}} = V_{\text{TMOT}} - I_{\text{TMOT}} \cdot R_{\text{cable}}$$

where

V_{corr}	is the corrected voltage at each point on the corrected I-V curve, in volts (V);
V_{TMOT}	is the voltage at each point on the TMOT I-V curve, in volts (V);
I_{TMOT}	is the current at each point on the TMOT I-V, in amperes (A);
R_{cable}	is the measured resistance of the PV module cable and all other components between the I-V curve measurement location and the DUT, in ohms (Ω).

Options b) and c) shall not be used if the components between the I-V curve measurement location and the DUT cannot be modelled accurately as a series resistance.

When one of these options is used, the term "PV socket" throughout the solar charge test procedure refers to the I-V curve measurement location.

R.4.2.4 Procedure

The following steps shall be performed.

- a) Use the TMOT I-V curve (from Annex Q) to find appropriate resistor values and power supply set points to simulate the PV module operating at TMOT during the charging cycle. A computer spreadsheet or program should be used for this step.
 - The spreadsheet or program is used to estimate the response curve of the PV simulator circuit over the range of voltages that corresponds to the I-V curve.
 - The input variables to the spreadsheet shall be the following:
 - series resistance;
 - parallel resistance;
 - voltage setpoint;
 - current setpoints corresponding to each level of simulated solar irradiance listed in Table R.2.
 - The circuit simulation shall be based on Ohm's law. When the diode characteristic is simulated using an apparatus other than a laboratory power supply, as described in R.4.2.1, the behaviour of the apparatus shall be included in the circuit model.
 - The spreadsheet or program shall estimate the TMOT current at evenly spaced voltage points by linearly interpolating between points on the measured I-V curve.
 - The spreadsheet or program shall scale the interpolated I-V curve for each level of simulated solar irradiance listed in Table R.2 by multiplying the interpolated current values by the ratio of the desired solar irradiance level to 1 000 W/m²:

$$I_{pv}(V) = I_{interp}(V) \times \frac{G}{1\,000\text{ W/m}^2}$$

where

$I_{pv}(V)$ is the scaled, interpolated current at each solar irradiance level i and voltage V , in amperes (A);

$I_{interp}(V)$ is the interpolated current at TMOT and 1 000 W/m² at voltage V , in amperes (A);

G is the simulated solar irradiance, in watts per square metre (W/m²).

- The spreadsheet or program shall use a non-linear minimization technique to minimize the weighted residual sum of squares (RSS) between the scaled, interpolated TMOT I-V curve values and the simulated I-V curve of the PV simulator by altering the input variables. To give preference for close agreement near the maximum power point, the residual at each point shall be weighted by the product of the duration of each solar irradiance step (from Table R.2) and the power in the scaled TMOT curve:

$$S_{SE,w} = \sum_G \left(\Delta t_G \cdot \sum_V I_{pv,G}(V) \cdot V \cdot (I_{fit,G}(V) - I_{pv,G}(V))^2 \right)$$

where

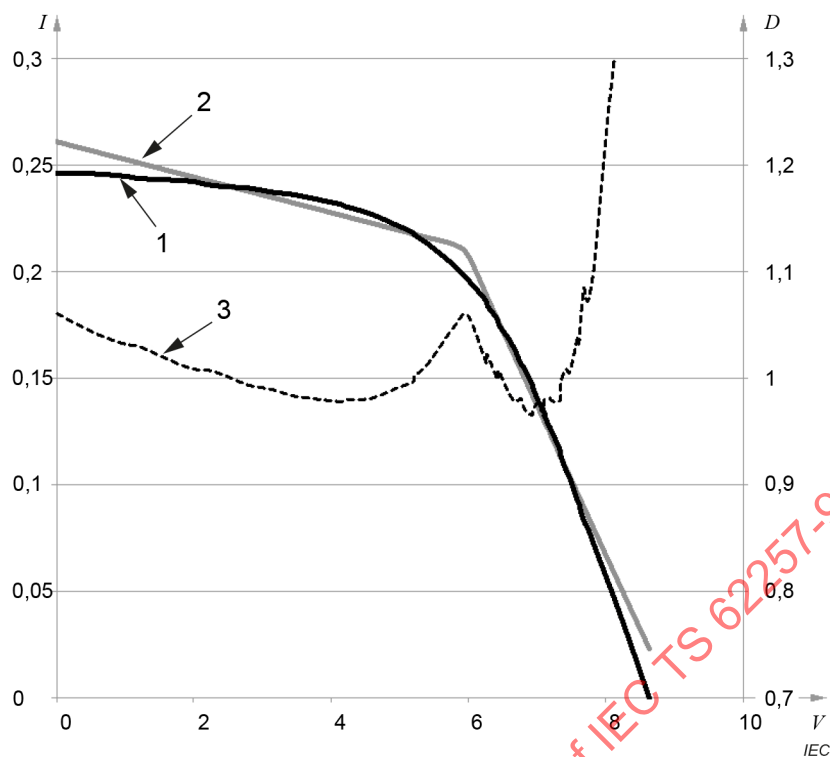
$S_{SE,w}$ is the weighted RSS;

G is the simulated solar irradiance, in watts per square metre (W/m²);

Δt_G is the duration corresponding to each solar irradiance level i , in hours (h);

V is the voltage at each point in the interpolated I-V curve, in volts (V);

- $I_{pv,G}(V)$ is the scaled, interpolated current at solar irradiance level G and voltage V , in amperes (A);
- $I_{fit,G}(V)$ is the fitted simulated current at solar irradiance level G and voltage V , in amperes (A);
- The outcomes of the spreadsheet or program are the best fit input variables:
 - series resistance (R_s);
 - parallel resistance (R_p);
 - voltage setpoint (V_{sim});
 - current setpoints ($I_{sim,1000}$, $I_{sim,900}$, $I_{sim,700}$, $I_{sim,500}$, $I_{sim,300}$).
- b) Build a PV simulator circuit as in Figure R.1 using fixed or variable resistors with appropriate power ratings wired in parallel and series with the power supply. Use a resistance meter or multimeter to verify that the actual resistance values meet the accuracy requirement in Clause CC.2. The measurement of R_s shall include the resistance of the wiring and measuring instruments between the resistor network and the PV socket (or I-V curve measurement point as described in R.4.2.3.3).
- c) For each simulated solar irradiance level, check that the simulated I-V curve is a reasonable approximation of the true curve by calculating the deviation ratio between the simulated and scaled, interpolated TMOT I-V curves. The deviation ratio is defined as the simulated current divided by the scaled, interpolated TMOT current at each voltage point. For this calculation, use the true values of the input variables rounded to the resolution of the test equipment. In the example shown in Figure R.2, the deviation ratio is close to unity (between 0,95 and 1,05, or less than 5 % error) in the key parts of the I-V curve (at and to the left of the maximum power point).
- d) (optional step) Experimentally verify the calculated deviation for the 1 000 W/m² I-V curve, using the following procedure. Alternatively, the I-V curve analyser specified in Annex Q may be used to trace the I-V curve of the simulated PV module.
- 1) Connect data-logging current and voltage sensors to the PV simulator output. Set the sensors to log data at very short intervals, 1 s or less.
 - 2) Simulate a PV module at TMOT and 1 000 W/m². Set the power supply current and voltage setpoints to $I_{sim,1000}$ and V_{sim} .
 - 3) Measure an I-V curve for the PV simulator. Connect a variable resistor between the positive and negative terminals of the PV simulator and slowly sweep from high to low resistance and back.
 - 4) Disconnect the resistor and stop the data collection.
 - 5) Check to ensure the quality of the I-V curve data; cross check with the original (target) I-V curve to ensure the PV simulator is reasonably close, particularly in the region with voltages slightly below the maximum power point. Figure R.2 shows an example comparison. The true I-V curve (line 1) is compared to the simulated I-V curve (line 2).
- e) Set up the prepared DUT (see requirements in R.4.2.2) and PV simulator circuit with current and voltage sensors, ensuring the PV simulator circuit is connected such that it replaces only the part of the PV module assembly included in the I-V curve (i.e. the PV simulator circuit is connected at the same point the I-V curve data were measured). Set the data-logging interval to 1 minute or less. Record the following quantities:
- current entering the battery(-ies), in amperes (A);
 - voltage across the battery(-ies), in volts (V);
 - current provided by the PV simulator circuit, in amperes (A);
 - voltage across the PV simulator circuit output, in volts (V).
- f) Program the power supply to simulate a "standard solar day" of charging using the steps indicated in Table R.2. To facilitate identification of solar irradiance levels during data analysis, short pauses at 0 V may be inserted between steps.



Key

I current with units of amperes on the primary vertical axis

V voltage with units of volts on the horizontal axis

D deviation ratio (unitless) on the secondary vertical axis

1 measured "true" I-V curve, plotted on the primary axis

2 I-V curve from the PV simulator ($I_{\text{fit,G}}(V)$), plotted on the primary axis

3 deviation ratio as a function of voltage, plotted on the secondary axis

Figure R.2 – Example "true" and simulated I-V curves plotted with the deviation ratio

Table R.2 – Simulated solar day power supply settings

Step duration h	Simulated solar irradiance W/m^2	Current setpoint	Voltage setpoint
0,5	300	$I_{\text{sim},300}$	V_{sim}
0,5	500	$I_{\text{sim},500}$	V_{sim}
1	700	$I_{\text{sim},700}$	V_{sim}
1	900	$I_{\text{sim},900}$	V_{sim}
1	1 000	$I_{\text{sim},1000}$	V_{sim}
1	900	$I_{\text{sim},900}$	V_{sim}
1	700	$I_{\text{sim},700}$	V_{sim}
0,5	500	$I_{\text{sim},500}$	V_{sim}
0,5	300	$I_{\text{sim},300}$	V_{sim}

- g) The battery voltage shall be continuously monitored such that the battery voltage shall not exceed a safety limit, either relying on the internal charge controller or based on the judgement of the laboratory. If necessary, integrate the overcharge protection disconnect device into the setup. The overcharge protection device shall disconnect if battery voltage rises above safety limits that are determined by the laboratory. Refer to the battery testing recommended practices (Annex L) for recommended maximum battery testing voltage values (refer to Table L.2). Optionally, monitor the battery temperature to ensure that it does not exceed Table L.2. If temperature monitoring is used, lithium-based batteries shall not be allowed to exceed 45 °C unless higher temperatures are allowed by the battery manufacturer. If the charge cycle is stopped by an overcharge or overtemperature protection device added by the test laboratory, the test results shall be considered invalid.
- h) Check the connections and setpoints, then begin data logging and start the simulated charging cycle. Caution: Do not disconnect the product after having started the simulated charging cycle. The electronics of some DUTs can be damaged if their batteries are disconnected while voltage is applied to the PV input.
- i) After the 7 h charging cycle is complete, stop the power supply, stop the data logging, disconnect the product from the PV simulator, and verify that the current and voltage data are valid with a quick check.

R.4.3 Test method using a solar array simulator (SAS)

R.4.3.1 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Solar array simulator meeting the accuracy requirement specified in Table CC.3, including footnote b.
- Voltage data loggers (one for the PV input and one for each of the batteries).
- Current data loggers (e.g. voltage data logger and current transducer) (one for the PV input and one for each battery charged during the test).

NOTE Most products have only one battery that is charged during the solar charge test; see R.4.2.2.

- Surface-mounted thermocouple(s) and a thermocouple reader or other suitable surface-mounted temperature measurement devices (optional).
- Overcharge disconnect device that will stop the discharge when the battery reaches a specified voltage (if necessary).

If the solar array simulator includes data-logging functionality, this functionality may be used instead of the voltage and current data loggers at the PV input, provided the accuracy and resolution requirements for data loggers (Clause CC.2) are met.

The resistance limits and the recommendations regarding power measurement given in R.4.2.1 apply.

R.4.3.2 Test prerequisites

The test prerequisites are identical to those for the test method using a resistor network (R.4.2.2).

R.4.3.3 Apparatus

The apparatus is identical to that for the test method using a resistor network (R.4.2.3), except the PV simulator circuit (item 1 in Figure R.1) is replaced with a solar array simulator.

R.4.3.4 Procedure

The following steps shall be performed.

- a) Configure the solar array simulator to simulate the I-V curve at TMOT.
- b) If the solar array simulator does not meet the accuracy requirement described in Clause CC.2 according to its manufacturer's specifications, measure the simulator's I-V curve and verify that the simulated current is within the tolerance specified in Clause CC.2 for all applicable voltage values. If the measured current is not within the specified tolerance, the solar array simulator shall not be used for this DUT. If the solar array simulator meets the accuracy requirement described in Clause CC.2 according to its manufacturer's specifications, this step is optional.
- c) Set up the prepared DUT (see requirements in R.4.3.2) and PV simulator circuit with current and voltage sensors, ensuring the PV simulator circuit is connected such that it replaces only the part of the PV module assembly included in the I-V curve (i.e. the PV simulator circuit is connected at the same point the I-V curve data were measured). Set the data-logging interval to 1 min or less. Record the following quantities:
 - Current entering the battery(s), in amperes (A).
 - Voltage across the battery(s), in volts (V).
 - Current provided by the PV simulator circuit, in amperes (A).
 - Voltage across the PV simulator circuit output, in volts (V).
- d) Program the solar array simulator to simulate a "standard solar day" of charging using the steps indicated in Table R.2. To facilitate identification of solar irradiance levels during data analysis, short pauses at 0 V may be inserted between steps. Adjust the curve to the reduced solar irradiance levels by adjusting the current only, using the following formula:

$$I_{\text{SAS}} = I_{\text{TMOT}} \cdot \frac{G_{\text{sim}}}{G_{\text{TMOT}}}$$

where

- I_{SAS} is the current at each point on the simulated I-V curve, in amperes (A);
- I_{TMOT} is the current at each point on the measured I-V curve, adjusted to TMOT, in amperes (A);
- G_{sim} is the simulated solar irradiance from Table R.2, in watts per square metre (W/m²).
- G_{TMOT} is the solar irradiance at TMOT (1 000 W/m²).

- e) The battery voltage shall be continuously monitored such that the battery voltage shall not exceed a safety limit, either relying on the internal charge controller or based on the judgement of the laboratory. If necessary, integrate the overcharge protection disconnect device into the setup. The overcharge protection device shall disconnect if battery voltage rises above safety limits that are determined by the laboratory. Refer to the battery testing recommended practices (Annex L) for recommended maximum battery testing voltage values (refer to Table L.2). Optionally, monitor the battery temperature to ensure that it does not exceed a safe value (refer to Table L.2). If temperature monitoring is used, lithium-based batteries shall not be allowed to exceed 45 °C unless higher temperatures are allowed by the battery manufacturer. If the charge cycle is stopped by an overcharge or overtemperature protection device added by the test laboratory, the test results shall be considered invalid.
- f) Check the connections and setpoints, then begin data logging and start the simulated charging cycle. Caution: Do not disconnect the battery after having started the simulated charging cycle. The electronics of some DUTs can be damaged if their batteries are disconnected while voltage is applied to the PV input.

- g) After the 7 h charging cycle is complete, stop the power supply, stop the data logging, disconnect the battery from the PV simulator, and verify that the current and voltage data are valid with a quick check.

R.4.4 Calculations

The following calculations shall be made.

NOTE 1 In the following procedure, "PV simulator" refers to the resistor network or solar array simulator, whichever is applicable to the test method used.

- a) Determine the maximum power available from the PV simulator ($P_{\max, \text{sim}, G}$) at each simulated solar irradiance level G , using the following formula:

$$P_{\max, \text{sim}, G} = \max_V (I_{\text{pvsim}, G}(V) \cdot V)$$

where

$P_{\max, \text{sim}, G}$ is the maximum power available from the PV simulator at simulated solar irradiance level G , in watts (W);

V is the voltage at each point in the interpolated I-V curve, in volts (V);

$I_{\text{pvsim}, G}(V)$ is the simulated current at solar irradiance level G and voltage V , in amperes (A). If a resistor network is used, this is the fitted current $I_{\text{fit}, G}(V)$ calculated in step a) of R.4.2.4, as a function of voltage. If a solar array simulator is used, this is the I-V curve programmed into the solar array simulator, as a function of voltage.

NOTE 2 Regardless of the test method used, this quantity is the power at the maximum power point of the simulated I-V curve. This quantity is calculated from the simulated I-V curve, not from the measurements performed for this test.

- b) For each measurement at time t , identify the maximum power available from the PV simulator ($P_{\max, \text{sim}}(t)$). This is the maximum available power $P_{\max, \text{sim}, G}$ at the solar irradiance level $G(t)$ corresponding to time t .
- c) For each measurement at time t , compute the power supplied by the PV simulator ($P_{\text{pvsim}}(t)$) using the following formula:

$$P_{\text{pvsim}}(t) = I_{\text{pvsim}}(t) \cdot V_{\text{pvsim}}(t)$$

where

$P_{\text{pvsim}}(t)$ is the power supplied by the PV simulator at time t , in watts (W);

$I_{\text{pvsim}}(t)$ is the current supplied by the PV simulator at time t , in amperes (A);

$V_{\text{pvsim}}(t)$ is the voltage supplied by the PV simulator at time t , in volts (V).

- d) For each measurement at time t and each battery i , compute the power delivered to the battery ($P_{\text{b}, i}(t)$) using the following formula:

$$P_{\text{b}, i}(t) = I_{\text{b}, i}(t) \cdot V_{\text{b}, i}(t)$$

where

$P_{\text{b}, i}(t)$ is the power supplied to the battery at time t , in watts (W);

$I_{\text{b}, i}(t)$ is the current supplied to the battery at time t , in amperes (A);

$V_{\text{b}, i}(t)$ is the voltage across battery i at time t , in volts (V).

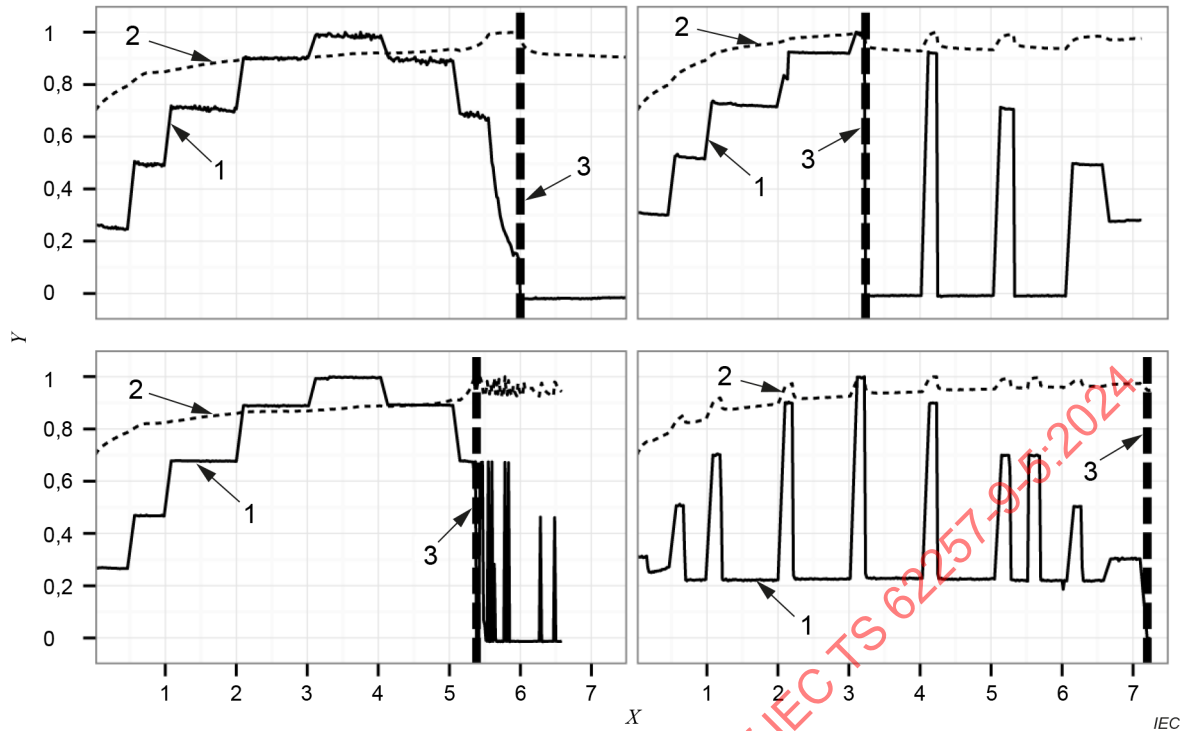
e) If the charge controller terminates the battery charge during the test (for example, if the battery is full), the battery-charging circuit efficiency and solar operation efficiency shall be calculated based on the current and voltage data prior to charge termination. To identify the charge termination time and detect if the event has occurred, the following procedure shall be used.

- 1) For each battery i , identify the battery-specific charge termination time ($t_{\text{end},i}$) by plotting the current into the battery vs. time and identifying the time at which the current drops to zero or becomes negative. If the current does not drop to zero, but there is a clear change in the charging regime as the battery approaches a full charge, the tester may use his or her discretion in determining whether charging has stopped. If the current drops to zero due to a full battery, but then increases (for example, if the battery voltage drops below the overcharge protection voltage and charging resumes), the earliest cutoff time should be used. In any case, the tester may use his or her discretion to determine the most accurate charge termination time. See Figure R.3 for examples.

An automated method, such as a spreadsheet or computer program, may be used to identify a possible value for the charge termination time, provided the result obtained by such a method is checked for correctness by examining the plot of the current vs. time. The tester should also check that the current dropped to zero due to the behaviour of the DUT, not due to a data collection error, loose connection, or other fault in the test apparatus or DUT.

Due to noise or measurement error, the current will sometimes be observed to drop to a low but nonzero value rather than to zero. For this step, the current should be considered to have dropped to zero if it drops to a value that is indistinguishable from zero due to the uncertainty in the current measurement.

If pauses were inserted between solar irradiance steps to facilitate identification of solar irradiance levels, some DUTs could restart charging after a pause, even if charging had previously stopped. In this case, the charge termination time should be the first time that charging stopped, before the pause.



Key

X time with units of hours on the horizontal axis

Y current or voltage in arbitrary units on the vertical axis

1 current into the battery, in arbitrary units

2 battery voltage, in arbitrary units

3 indicates the charge termination time

NOTE 1 The thick dashed line indicates the correct charge termination time for each battery. The battery voltage is also plotted for reference.

NOTE 2 Plotting the battery voltage can be helpful in determining whether the charge has terminated due to the behaviour of the DUT's charge controller or due to a fault in the apparatus or DUT. Usually, the battery voltage will reach a local maximum at the charge termination time and then remain constant or decrease after charging stops.

Figure R.3 Example plots of current vs. time for four different batteries

- 2) Determine the overall data analysis end time (t_{end}) as the largest value of $t_{\text{end},i}$ for all batteries:

$$t_{\text{end}} = \max_i(t_{\text{end},i})$$

where

t_{end} is the overall data analysis end time, in hours (h);

$t_{\text{end},i}$ is the battery-specific data analysis end time for battery i , in hours (h).

- 3) For the remaining calculation steps, all energy totals and overall efficiencies (e.g. $\eta_{\text{sol-op}}$, E_{pvsim} and $E_{\text{b},i}$) shall be calculated using only the values for times less than t_{end} .

- f) Determine the energy supplied by the PV simulator (E_{pvsim}) using the following formula:

$$E_{\text{pvsim}} = \sum_{t=0}^{t_{\text{end}}} (P_{\text{pvsim}}(t) \cdot \Delta t)$$

where

- E_{pvsim} is the energy supplied by the PV simulator, in watt-hours (Wh);
 t is the elapsed time, in hours (h);
 t_{end} is the overall data analysis end time, in hours (h);
 $P_{\text{pvsim}}(t)$ is the power supplied by the PV simulator at time t , in watts (W);
 Δt is the duration of time associated with each measurement, in hours (h).

- g) Determine the energy delivered to each battery ($E_{\text{b},i}$) using the following formula:

$$E_{\text{b},i} = \sum_{t=0}^{t_{\text{end}}} (P_{\text{b},i}(t) \cdot \Delta t)$$

where

- $E_{\text{b},i}$ is the energy delivered to battery i , in watt-hours (Wh);
 t is the elapsed time, in hours (h);
 t_{end} is the overall data analysis end time, in hours (h);
 $P_{\text{b},i}(t)$ is the power delivered to battery i at time t , in watts (W);
 Δt is the duration of time associated with each measurement, in hours (h).

- h) Determine the energy allocation ratio for each battery using the following formula:

$$\alpha_i = \frac{E_{\text{b},i}}{\sum_i E_{\text{b},i}}$$

where

- α_i is the energy allocation ratio for battery i , a unitless ratio;
 $E_{\text{b},i}$ is the energy delivered to battery i , in watt-hours (Wh).

Special case: if there are multiple identical main units, the allocation ratio for each such main unit is the average of the allocation ratios calculated using the formula above for all of the identical main units.

- i) Determine the battery-charging circuit efficiency (η_{bcc}) using the following formula. If the calculated value exceeds 100 %, use a value of 100 %; however, the reason for the result should be investigated. A value of battery-charging circuit efficiency slightly more than 100 % can occur due to measurement error, but often indicates a problem with the test apparatus.

$$\eta_{\text{bcc}} = \frac{\sum_i E_{\text{b},i}}{E_{\text{pvsim}}}$$

where

- η_{bcc} is the battery-charging circuit efficiency;
 $E_{\text{b},i}$ is the energy delivered to battery i , in watt-hours (Wh);
 E_{pvsim} is the energy supplied by the PV simulator, in watt-hours (Wh).

j) Estimate the solar operation efficiency ($\eta_{\text{sol-op}}$):

NOTE 3 The following procedure calculates solar operation efficiency using two different methods. The first method, calculated in step 1), is the ratio of the actual energy delivered by the PV simulator to the maximum possible energy based on the characteristics of the PV simulator. The second method attempts to determine the point at which the actual PV module would have operated, had the DUT been charging using the PV module in sunlight. The correction procedure works well for products without a DC-DC converter or maximum power point tracking; however, it is an approximation since in such products the PV module voltage is a function of the battery charge. Since the maximum power point voltage of the PV simulator apparatus can differ from that of the actual module, the correction procedure can underestimate the efficiency in products with maximum power point tracking that successfully identifies the maximum power point of the PV simulator.

- 1) For each time t , use the following formula to calculate the instantaneous uncorrected solar operation efficiency ($\eta_{\text{sol-op,u}}(t)$):

$$\eta_{\text{sol-op,u}}(t) = \frac{P_{\text{pvsim}}(t)}{P_{\text{max,sim}}(t)}$$

where

- $\eta_{\text{sol-op,u}}(t)$ is the instantaneous uncorrected solar operation efficiency at time t ;
- $P_{\text{pvsim}}(t)$ is the power supplied by the PV simulator at time t , in watts (W);
- $P_{\text{max,sim}}(t)$ is the maximum power available from the PV simulator at time t , in watts (W).

- 2) If the test was conducted using a solar array simulator, the solar operation efficiency $\eta_{\text{sol-op}}(t)$ is equal to the uncorrected solar operation efficiency $\eta_{\text{sol-op,u}}(t)$ and the maximum available power $P_{\text{max}}(t)$ is equal to $P_{\text{max,sim}}(t)$. Skip to step 10).
- 3) For each measurement at time t , identify the maximum power available from the PV module ($P_{\text{max,mod}}(t)$), using the following formula:

$$P_{\text{max,mod}}(t) = P_{\text{mpp, TMOT}} \cdot \frac{G(t)}{G_{\text{TMOT}}}$$

where

- t is the elapsed time, in hours (h);
- $P_{\text{max,mod}}(t)$ is the power available from the PV module, in watts (W);
- $P_{\text{mpp, TMOT}}$ is the maximum power of the PV module at TMOT, in watts (W);
- $G(t)$ is the simulated solar irradiance at time t , in watts per square metre (W/m^2);
- G_{TMOT} is the solar irradiance at TMOT ($1\,000\, \text{W/m}^2$).

- 4) If the test was conducted using a resistor network and an electronic apparatus designed to simulate the PV module's diode characteristic, the apparatus accurately emulates the shape of the measured I-V curve, and $P_{\text{max,sim}}$ is within the range $P_{\text{max,mod}} \pm 1\%$ for all simulated irradiance values, the solar operation efficiency $\eta_{\text{sol-op}}(t)$ is equal to the uncorrected solar operation efficiency $\eta_{\text{sol-op,u}}(t)$ and the maximum available power $P_{\text{max}}(t)$ is equal to $P_{\text{max,sim}}(t)$. Skip to step 10).

- 5) For each measurement at time t , calculate the corrected current at time t using the formula

$$I_{\text{corr}}(t) = I_{\text{pvsim}}(t) \frac{I_{\text{pv},G(t)}(V_{\text{pvsim}}(t))}{I_{\text{fit},G(t)}(V_{\text{pvsim}}(t))}$$

where

- $I_{\text{corr}}(t)$ is the corrected PV simulator current at time t , in amperes (A);
- $I_{\text{pvsim}}(t)$ is the current supplied by the PV simulator at time t , in volts (V);
- $G(t)$ is the simulated solar irradiance level at time t ;
- $I_{\text{fit},G(t)}(V)$ is the fitted current from R.4.2.4 as a function of voltage at the irradiance level $G(t)$, in amperes (A);
- $I_{\text{pv},G(t)}(V)$ is the scaled, interpolated current from R.4.2.4 as a function of voltage at the irradiance level $G(t)$ (i.e. the measured I-V curve, corrected for irradiance), in amperes (A);
- $V_{\text{pvsim}}(t)$ is the voltage supplied by the PV simulator at time t , in volts (V).

NOTE 4 The fraction in the formula is the reciprocal of the deviation ratio defined in R.4.2.4. The corrected current is the current that would be supplied by the PV module at the measured PV simulator voltage.

- 6) For each measurement at time t , compute the corrected PV simulator power ($P_{\text{corr}}(t)$) using the following formula:

$$P_{\text{corr}}(t) = I_{\text{corr}}(t) \cdot V_{\text{pvsim}}(t)$$

where

- $P_{\text{corr}}(t)$ is the corrected PV simulator power supplied by the PV simulator at time t , in watts (W);
- $I_{\text{corr}}(t)$ is the corrected PV simulator current at time t , in amperes (A);
- $V_{\text{pvsim}}(t)$ is the voltage supplied by the PV simulator at time t , in volts (V).

- 7) For each time t , use the following formula to calculate the instantaneous corrected solar operation efficiency ($\eta_{\text{sol-op,corr}}(t)$):

$$\eta_{\text{sol-op,corr}}(t) = \frac{P_{\text{corr}}(t)}{P_{\text{max,mod}}(t)}$$

where

- $\eta_{\text{sol-op,corr}}(t)$ is the instantaneous corrected solar operation efficiency at time t ;
- $P_{\text{corr}}(t)$ is the corrected PV simulator power at time t , in watts (W);
- $P_{\text{max,mod}}(t)$ is the maximum power available from the PV module at time t , in watts (W).

- 8) For each time t , calculate the instantaneous solar operation efficiency ($\eta_{\text{sol-op}}(t)$) and maximum available power ($P_{\text{max}}(t)$):

$$\eta_{\text{sol-op}}(t) = \max(\eta_{\text{sol-op,u}}(t), \eta_{\text{sol-op,corr}}(t))$$

$$P_{\text{max}}(t) = \begin{cases} P_{\text{max,corr}}(t) & \text{if } \eta_{\text{sol-op,corr}}(t) > \eta_{\text{sol-op,u}}(t) \\ P_{\text{max,sim}}(t) & \text{otherwise} \end{cases}$$

where

$\eta_{\text{sol-op}}(t)$ is the instantaneous solar operation efficiency at time t ;

$\eta_{\text{sol-op,u}}(t)$ is the instantaneous uncorrected solar operation efficiency at time t ;

$\eta_{\text{sol-op,corr}}(t)$ is the instantaneous corrected solar operation efficiency at time t as a fraction;

$P_{\text{max}}(t)$ is the maximum available power at time t in watts (W);

$P_{\text{max,sim}}(t)$ is the maximum power available from the PV simulator at time t , in watts (W).

$P_{\text{max,mod}}(t)$ is the power available from the PV module, in watts (W);

- 9) Take note of the number of transitions when $\eta_{\text{sol-op,u}}(t)$ becomes greater than $\eta_{\text{sol-op,corr}}(t)$ or vice versa. For most products, only a small number of transitions will occur. If frequent transitions occur, the laboratory may choose to set $\eta_{\text{sol-op}}(t)$ equal to either $\eta_{\text{sol-op,u}}(t)$ or $\eta_{\text{sol-op,corr}}(t)$, and set $P_{\text{max}}(t)$ equal to the corresponding value ($P_{\text{max,sim}}(t)$ or $P_{\text{max,mod}}(t)$ respectively), for the entire affected portion of the test. The efficiency value should be selected to maximize the overall $\eta_{\text{sol-op}}$ value calculated in step 10).

EXAMPLE 1 During the first 2 h of the test, $\eta_{\text{sol-op,u}}(t)$ is greater than $\eta_{\text{sol-op,corr}}(t)$. For the next 3 h, $\eta_{\text{sol-op,corr}}(t)$ is greater than $\eta_{\text{sol-op,u}}(t)$. For the remaining 2 h, $\eta_{\text{sol-op,u}}(t)$ is greater than $\eta_{\text{sol-op,corr}}(t)$. In this example, two transitions between efficiency values occurred (at $t = 2$ h and $t = 5$ h).

EXAMPLE 2 During the first 2 h of the test, $\eta_{\text{sol-op,u}}(t)$ is greater than $\eta_{\text{sol-op,corr}}(t)$. For the remainder of the test, the value of $\eta_{\text{sol-op,corr}}(t)$ is greater than $\eta_{\text{sol-op,u}}(t)$ except for brief intervals every few minutes during which $\eta_{\text{sol-op,u}}(t)$ is greater than $\eta_{\text{sol-op,corr}}(t)$. In this case, the laboratory could choose to set $\eta_{\text{sol-op}}(t)$ equal to $\eta_{\text{sol-op,corr}}(t)$ and $P_{\text{max}}(t)$ equal to $P_{\text{max,mod}}(t)$ for $t > 2$ h.

NOTE 5 Such frequent transitions could result from PWM charge control operating at a low frequency or other similar functions that interrupt or modulate the charging current.

For some products, the correction procedure can result in an operating point ($V_{\text{pvsim}}(t)$, $I_{\text{corr}}(t)$) that is not reflective of typical operation. In this case, set $\eta_{\text{sol-op}}(t)$ equal to $\eta_{\text{sol-op,u}}(t)$ and set $P_{\text{max}}(t)$ equal to $P_{\text{max,sim}}(t)$.

The plot generated in p) can be useful in making this determination.

- 10) Calculate the solar operation efficiency using the following formula:

$$\eta_{\text{sol-op}} = \frac{\sum_{t=0}^{t_{\text{end}}} P_{\text{max}}(t) \cdot \eta_{\text{sol-op}}(t)}{\sum_{t=0}^{t_{\text{end}}} P_{\text{max}}(t)}$$

where

$\eta_{\text{sol-op}}$ is the solar operation efficiency;

$\eta_{\text{sol-op}}(t)$ is the instantaneous solar operation efficiency at time t ;

$P_{\text{max}}(t)$ is the maximum available power at time t , in watts (W);

t_{end} is the overall data analysis end time, in hours (h).

- k) For each time t , calculate the instantaneous battery-charging circuit efficiency ($\eta_{bcc}(t)$) using the following formula:

$$\eta_{bcc}(t) = \frac{\sum_i P_{b,i}(t)}{P_{pvsim}(t)}$$

where

$\eta_{bcc}(t)$ is the instantaneous battery-charging circuit efficiency at time t ;

$P_{b,i}(t)$ is the power delivered to battery i at time t , in watts (W);

$P_{pvsim}(t)$ is the power supplied by the PV simulator at time t , in watts (W).

NOTE 6 The instantaneous battery-charging circuit efficiency is used to produce the required plots (see Clause R.5) and is not used in any further calculations. The plots produced in Clause R.5 are useful in validating the results of the test and in diagnosing problems. For example, instantaneous solar operation efficiency values exceeding 100 % can indicate a problem with the equipment configuration (e.g. the wrong current or resistance values were used).

- l) Based on the test data, determine whether a DC-DC converter is present in the circuit between the PV module and the battery. If a DC-DC converter is present, one of the following will typically be true:

- The voltage at any battery is greater than the voltage at the PV socket
- The sum of the currents at the batteries is greater than the current at the PV socket

If a DC-DC converter is not present, the battery voltage will be less than or equal to the voltage at the PV input, and the sum of the currents at the batteries will be less than or equal to the current at the PV input. Generally, the difference between the battery and PV current will be small; if the sum of the battery currents is much less than the current at the PV module, and the voltage at the batteries is also less than the voltage at the PV input, there could be a problem with the test; the issue should be investigated.

For products with more than one battery, it is possible for some batteries to charge using a DC-DC converter while others do not.

- m) Optionally, determine whether the product uses a series (linear) voltage regulator and calculate the equivalent resistance and diode characteristics of the circuit. If this type of charge control is present, the sum of the current entering all batteries equals the current delivered from the PV simulator throughout the test. Optionally, plot voltage drop as a function of current and fit a line to determine the approximate resistance and diode characteristics of the circuit. The voltage drop as a function of current in this case will be equal to a constant term (diode) plus a linear term (resistor).
- n) Optionally, for each battery i , calculate the average voltage from the start of the test to $t_{end,i}$. This is the average charging voltage. This voltage can be used to characterize port performance or other aspects during solar charging (see EE.4.2.6 i)), if desired.

Steps o) through q) are optional, but are recommended in order to verify that the test was conducted correctly. The plots generated in these steps may be omitted from the test report.

- o) Plot the measured PV simulator current and voltage values (I_{pvsim} and V_{pvsim}) superimposed on the simulated I-V curve that is calculated from the circuit model or input into the solar array simulator. This step can identify many common errors in conducting the test, including incorrect configuration of the equipment and incorrect detection of the simulated irradiance steps. If the measured operating points do not fall on the calculated curves, the reason for the discrepancy should be investigated.
- p) Plot the corrected PV simulator current (I_{corr}) and PV simulator voltage (V_{pvsim}) superimposed on the scaled I-V curves of the PV module. This step is analogous to o), but can be used to determine whether the corrected PV current corresponds to a realistic, typical operating point of the PV module.

- q) Calculate the PV current from the PV voltage using the circuit model or I-V curve values that were input into the solar array simulator, and plot as a function of time. On the same graph, plot the measured current as a function of time. Any significant difference between the two values should be investigated. This plot can identify many of the same problems as the plot in steps o) and p), but is more useful for showing irradiance steps that were omitted, irradiance step transitions that were not detected correctly, periods in which the DUT did not charge, and periods with missing data.

R.4.5 Alternative method to measure battery-charging circuit efficiency

R.4.5.1 General

The following method may be used to measure battery-charging circuit efficiency for products in which the battery current cannot be measured without influencing the charging behaviour. For these products, the battery-charging circuit efficiency is measured indirectly, by discharging the battery and measuring the energy extracted. This method is not permitted unless a direct measurement of the battery current is known to be impossible, for one of the following reasons:

- The laboratory has attempted the procedure specified in R.4.2 or R.4.3 and demonstrated that the measurement cannot be performed using the laboratory's equipment.
- Prior laboratory experience with the same product, or a product having identical charge control behaviour (e.g. another model in the same series from the same company), has demonstrated that the measurement cannot be performed using the laboratory's equipment.
- The voltage drop calculated from the measured resistance of the laboratory apparatus at the expected charging current is clearly sufficient to interfere with the product's charge control strategy.

R.4.5.2 Procedure

The following steps shall be performed.

- a) Prior to the solar charge test, prepare the product in accordance with G.4.4 e) or use an alternative method to ensure that the connection between the PCB and battery is not broken during the test.
- b) Conduct the solar charge test using the apparatus and procedures in R.4.2 or R.4.3, except do not insert any components in series between the battery and PCB and do not monitor the battery current. The battery voltage may optionally be measured and recorded. Disconnect the DUT from the PV simulator no more than 15 min after the end of the simulated solar charge. Do not disconnect the battery from the PCB.
- c) Allow the DUT to rest for at least 1 h but no more than 24 h.
- d) If it is necessary to transfer the DUT to the full-battery run time test apparatus, do so without disconnecting the battery, for example by using the procedure in G.4.4 e).
- e) Discharge the battery using the procedures in the full-battery run time test (Annex M), but without charging the battery. Do not disconnect the battery from the DUT at any time between the completion of the simulated solar charge cycle and the start of the discharge. Ensure that the configuration of the DUT (e.g. connected appliances and settings) is exactly the same as when the full-battery run time test was carried out.

R.4.5.3 Calculations

Perform the following calculations to determine the battery-charging circuit efficiency, in place of R.4.4 k).

- a) From the full-battery run time test data (not the discharge data from R.4.5.2), identify the current at the full-battery run time endpoint (see Clause M.7; for most products, this is the current at L_{70}).
- b) Determine the discharge duration, Δt_d , defined as the elapsed time in the discharge in R.4.5.2 at which the current identified in a) is reached. (This is often less than the full-battery run time because the DUT is not always fully charged in the solar charge test.)

c) Calculate the battery-charging circuit efficiency using the following formula:

$$\eta_{bcc} = \min \left(100 \%, \frac{\Delta t_d \cdot P_{FBRT}}{E_{pvsim} \cdot \eta_{batt}} \right)$$

where

η_{bcc} is the battery-charging circuit efficiency;

Δt_d is the discharge duration calculated in b), in hours (h);

P_{FBRT} is the average power from the full-battery run time test (Clause M.9), in watts (W);

E_{pvsim} is the energy delivered by the PV simulator, calculated in R.4.4 f), in watts (W);

η_{batt} is the battery round-trip energy efficiency from the battery test (Annex K).

R.4.6 Maximum solar operation efficiency measurement

R.4.6.1 General

The procedures defined in R.4.2 and R.4.3 measure the solar operation efficiency with no loads other than the battery charging. Some main units are designed to supply additional PV energy directly to daytime loads such as appliances, bypassing the battery. For these products the procedures of R.4.2 and R.4.3 underestimate the solar energy available for daytime loads. The procedure defined in R.4.6 can be used to measure the maximum possible solar operation efficiency with daytime loads; this maximum solar operation efficiency is then used in the energy service calculations (GG.4.2) to calculate the maximum energy available for daytime loads.

The maximum solar operation efficiency measurement is performed only by company request. The measurement is unlikely to result in an improvement unless the following are true:

- The product is designed to allow PV energy to be delivered directly to loads, bypassing the battery.
- During the solar charge test, a step increase in simulated solar irradiance does not result in a corresponding increase in power at the PV socket, and results in a decrease in instantaneous solar operation efficiency.
- The product includes or is advertised to power appliances that are used or charged during the day.

In addition to products that meet criteria a) and b) above, products for which a significant percentage of the simulated solar energy is received during the constant-voltage or saturation charge phase (when the battery is charging at less than the maximum possible rate) can also benefit from this procedure.

The maximum solar operation efficiency measurement can be performed on main units without ports, by using the built-in appliances as loads. However, in most cases the procedure will not result in any improvement for such products.

R.4.6.2 Equipment requirements

In addition to the equipment requirements of R.4.2.1 or R.4.3.1, a DC electronic load or adjustable resistive load is required.

If a DC electronic load or variable resistive load cannot be used (for example, because of security features in the DUT), any loads that can operate at approximately constant power can be used. For example, the supplied lights or other appliances (including built-in appliances) or another type of load specified by the company may be used.

A battery simulator may be used in place of the battery. Use of a battery simulator can interfere with active cell balancing; if a battery simulator is used, the charging behaviour should be compared to a charge cycle performed using the actual battery.

If the voltage at the PV input is not constant during each measurement, use of a power-measuring instrument is recommended. Even with DC voltages and currents, use of a power-measuring instrument can simplify the procedure by reducing the number of calculations that are necessary to be made during the test. The power-measuring instrument, if used, shall meet the requirements of Table CC.3. See Clause CC.3 for recommendations related to power measurement.

R.4.6.3 Test prerequisites

Although this test may be performed at any state of charge, it is recommended that the battery be brought to a state of charge at which it will charge at steady state for the duration of the test. Less than 50 % state of charge is recommended.

If the state of charge is too low, the product can turn off when load is applied; if this occurs, charge the battery until the load can be powered. If the state of charge is high, the battery current can start to taper off, resulting in a larger load current and changing load requirements over time.

R.4.6.4 Procedure

The following steps shall be performed.

- a) Set up the resistor network and power supply in accordance with R.4.2 or the solar array simulator in accordance with R.4.3. Measure the current and voltage at the PV input to the DUT. It is not necessary to measure the battery voltage or current; however, it is recommended to measure battery voltage or temperature to confirm that the battery remains within the company-specified operating limits.
- b) Set the power supply or resistor apparatus to simulate an irradiance of 1 000 W/m².
- c) Turn on the power supply and confirm that the battery is charging.
- d) Connect a DC electronic load or variable resistive load to one of the ports on the DUT. The port with the greatest power output should be used if known.
- e) Set the load to its lowest power or current value (or highest resistance).
- f) Increase the load power or current (or decrease the resistance) to the value that maximizes the power input at the PV socket. In some cases, especially at the lower simulated solar irradiance steps, the maximum power input can occur with no load; in this case, disconnect or disable the load.
- g) If the power is not constant during each measurement (e.g. due to PWM, pulse charging, or maximum power point tracking), use the average power over a period of 2 min. It is recommended to use a power-measuring instrument in this case.
- h) If the maximum power capacity of the port is insufficient to maximize the power input at the PV socket, additional loads may be connected to other ports. The additional loads can be fixed resistive loads as described in HH.5.1, in addition to any of the load types described in R.4.6.2.
- i) Once the apparent maximum power has been found, continue increasing the load current until one of the following occurs:
 - 1) No further increase in load is possible;
 - 2) The resistor network or solar array simulator cannot supply additional power (i.e. the instantaneous uncorrected solar operation efficiency is 100 %);
 - 3) A step decrease or nonlinear decrease in power occurs as the load is increased.
- j) Record the voltage and current at the PV input under the conditions that result in the maximum power.

- k) Disable or disconnect the load or loads.
- l) For each of the remaining irradiance steps (900 W/m², 700 W/m², 500 W/m², and 300 W/m²), adjust the power supply settings as indicated in in Table R.2 and repeat steps d) through k).

Because of the variety of possible product designs, the procedure does not specify a particular increment for the load current in step f), and the stopping criteria in step i) are defined qualitatively. The current increment may be determined through a procedure analogous to that in the output overload protection test (DD.4.2.4): use a large increment such as 5 % of the rated port current initially to locate the approximate maximum power, and then use a smaller increment such as 1 % of the rated port current to fine-tune the maximum PV input power estimate.

R.4.6.5 Calculations

The following calculations shall be performed.

- a) Calculate the maximum power available from the PV simulator ($P_{\max, \text{sim}, G}$) at each simulated solar irradiance level G , using the formula in R.4.4 a).
- b) Calculate the measured power at the PV socket at each irradiance step:

$$P_G = I_{\text{pv}, G} \cdot V_{\text{pv}, G}$$

where

P_G is the measured power at simulated solar irradiance level G (W);

$V_{\text{pv}, G}$ is the measured voltage at simulated solar irradiance level G (V);

$I_{\text{pv}, G}$ is the measured current at simulated solar irradiance level G (A).

- c) Calculate the maximum solar operation efficiency using the following formula:

$$\eta_{\text{sol-op}, \max} = \frac{P_{300} + P_{500} + P_{1000} + 2 \times (P_{700} + P_{900})}{P_{\max, \text{sim}, 300} + P_{\max, \text{sim}, 500} + P_{\max, \text{sim}, 1000} + 2 \times (P_{\max, \text{sim}, 700} + P_{\max, \text{sim}, 900})}$$

where

$\eta_{\text{sol-op}, \max}$ is the maximum solar operation efficiency;

P_G is the measured power at simulated solar irradiance level G (W);

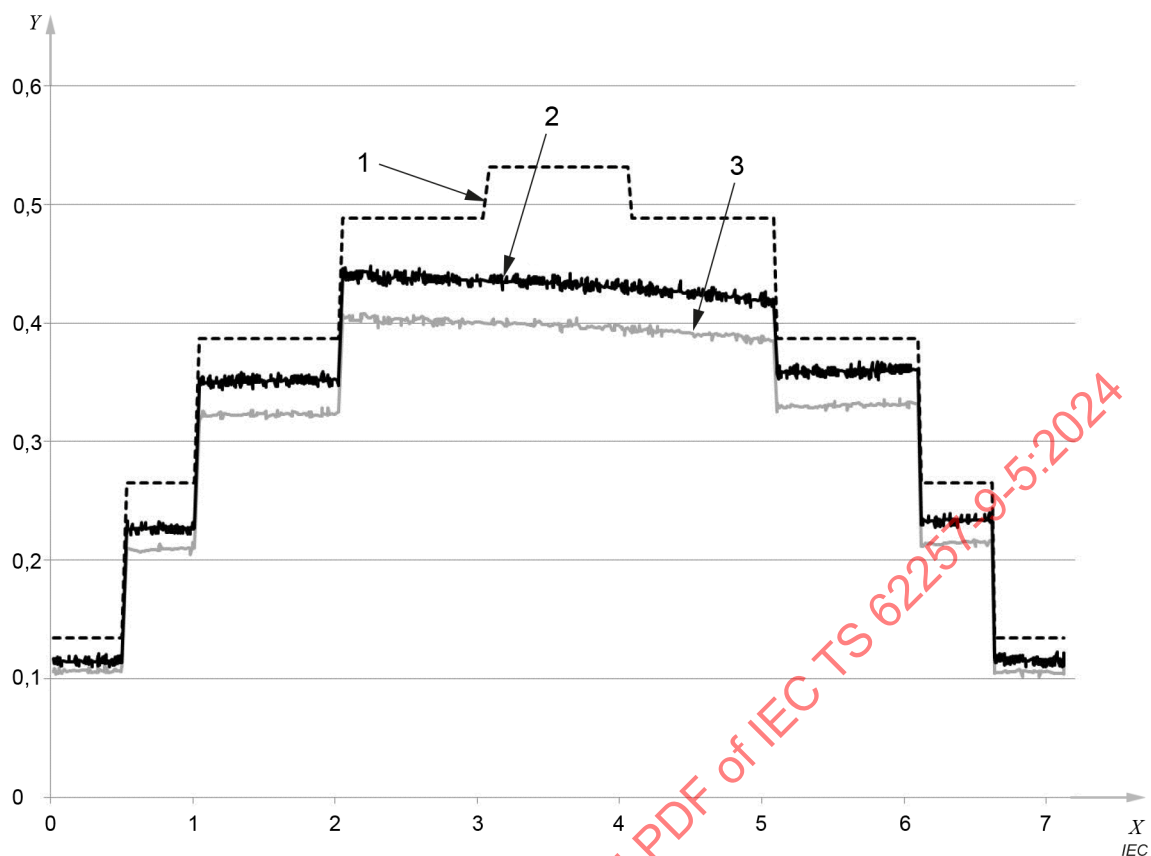
$P_{\max, \text{sim}, G}$ is the maximum possible power at simulated solar irradiance level G (W), from R.4.4 a).

NOTE The power values at 700 W/m² and 900 W/m² are multiplied by 2 because the total duration of these solar irradiance steps in Table R.2 is twice the duration of the other steps.

R.5 Reporting

Report the following in the electronics efficiency test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - battery-charging circuit efficiency (%);
 - solar operation efficiency (%);
 - maximum solar operation efficiency (%), if measured;
 - optionally, average charging voltage for each battery (V)
 - energy allocation ratios (%).
- Average of n sample results for tested DUT aspects
- Solar charging circuit characteristics.
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .
- Figures
 - Plot showing the solar charging cycle for each sample in time series over the 7 h charging period including the maximum power available from the PV simulator ($P_{\max, \text{sim}}(t)$), actual power supplied by the PV simulator ($P_{\text{pvsim}}(t)$), and power delivered to the batteries ($P_{\text{b},i}(t)$) (see Figure R.4 for an example plot). (This may be plotted as the sum over all batteries or separately for each battery.) In a separate plot or on a secondary axis show the instantaneous solar operation efficiency and instantaneous battery-charging circuit efficiency in time series (see Figure R.5 for an example plot).

**Key**

X time with units of hours on the horizontal axis

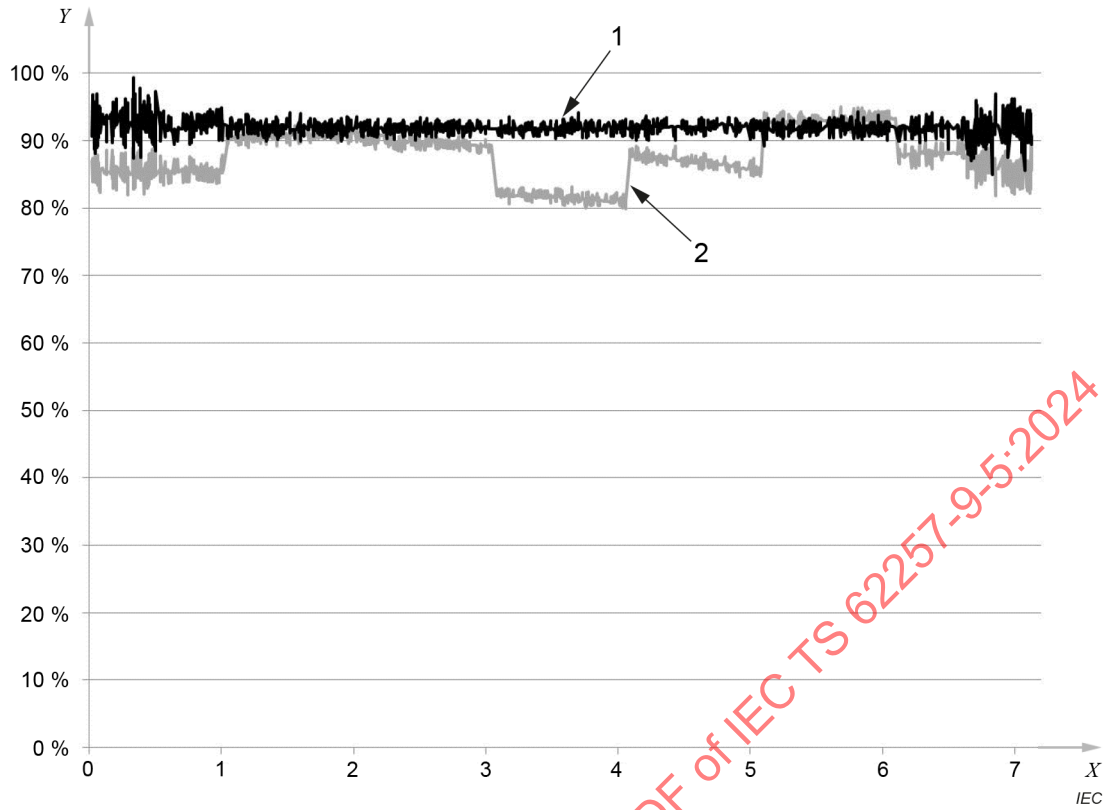
Y power with units of watts on the vertical axis

1 maximum power available from the PV simulator ($P_{\max, \text{sim}}(t)$), in watts

2 actual power supplied by the PV simulator ($P_{\text{pvsim}}(t)$), in watts

3 power delivered to the batteries ($P_{\text{b}, i}(t)$), in watts

Figure R.4 – Example time series plot of the solar charging cycle showing the maximum power available from the PV simulator, actual power supplied by the PV simulator, and power delivered to the batteries



Key

X time with units of hours on the horizontal axis

Y efficiency as a percent on the vertical axis

1 instantaneous battery-charging circuit efficiency ($\eta_{\text{bcc}}(t)$), as a percent

2 instantaneous solar operation efficiency ($\eta_{\text{sol-op}}(t)$), as a percent

Figure R.5 – Example time series plot of the solar charging cycle showing the instantaneous battery-charging circuit efficiency and solar operation efficiency

Annex S (normative)

Charge controller behaviour test

S.1 Background

Deep discharge and overcharge protection is important for user safety and battery longevity. Charge control is most critical for products with lead-acid, Li-ion, and LiFePO₄ batteries.

The charge controller behaviour test contains five methods to examine the charge controller. Every DUT shall be tested with the active deep discharge method, where the DUT is discharged until reaching its low-voltage disconnect (LVD) voltage or appropriately exceeding its recommended deep discharge voltage threshold. Every DUT shall also be tested with the active overcharge protection method, where the DUT is charged until reaching its overvoltage protection (OVP) voltage or appropriately exceeding its recommended OVP voltage threshold. For DUTs that have no active deep discharge protection, the passive deep discharge protection method shall be used when appropriate (see S.4.3.1); in this method, the battery voltage is examined for safety during a long-term discharge. For DUTs with NiMH batteries that have no active overcharge protection, the passive overcharge protection method shall be used, where the long-term charging current is examined for safety.

Every DUT shall also be examined for standby losses. A product's electronics can draw substantial amounts of energy from the battery while the product is not in use, and this standby loss can lead to shorter run times or problems when storing the product for long periods of time.

The choice of test methods and assessment of the appropriateness of charge control should include input from either the battery manufacturer or system integrator, or both, about the approach to charge control and the design values for cutoff or other control algorithms. The best practice for testing is to establish what the design algorithm and setpoints are and measure for those using the appropriate methods. The assessment of whether charge control is present and appropriate shall then be based on the combination of two factors: the appropriateness of the design values and whether the design was accurately realized as shown during the tests.

S.2 Test outcomes

The test outcomes of the charge controller behaviour test are listed in Table S.1.

Table S.1 – Charge controller behaviour test outcomes

Metric	Reporting units	Related aspects	Notes
Active deep discharge protection	Yes/no	4.2.3.13 Battery protection strategy	--
Deep discharge protection voltage	Volts (V)	4.2.3.13 Battery protection strategy	Measured only if the DUT has active deep discharge protection
Active overcharge protection	Yes/no	4.2.3.13 Battery protection strategy	--
Overcharge protection voltage	Volts (V)	4.2.3.13 Battery protection strategy	Measured only if the DUT has active overcharge protection
Passive deep discharge protection	Yes/no	4.2.3.13 Battery protection strategy	--
Passive deep discharge protection battery voltage at 24 h	Volts per cell (V/cell)	4.2.3.13 Battery protection strategy	Required only if tested for passive deep discharge protection
Passive overcharge protection	Yes/no	4.2.3.13 Battery protection strategy	Measured only for NiMH batteries with no active overcharge protection
Passive overcharge protection continuous charging current	Amperes (A)	4.2.3.13 Battery protection strategy	Required only if tested for passive overcharge protection
Standby loss current	Amperes (A)	4.2.3.13 Battery protection strategy	Current that is drawn from a product's battery when the product is switched off when at 50 % state of charge Multiple standby loss current values may be reported for products that switch to low-power modes
Time before switching to low-power mode	Hours (h)	4.2.3.13 Battery protection strategy	Some products may switch to a low-power mode after being turned off for a set period of time

S.3 Related tests

The results of the active deep discharge protection test (S.4.1) may be substituted with results of the full-battery run time test (Annex M).

The results of the passive deep discharge protection test (S.4.3) may be substituted with results of the full-battery run time test (Annex M).

The active overcharge protection test (S.4.2) and passive overcharge protection test (S.4.4) shall be performed after the photovoltaic module I-V characteristics test (Annex Q) for solar-charged products because the active overcharge protection test (S.4.2) requires the I-V curve parameters and the passive overcharge protection test (S.4.4) requires the entire I-V curve data set.

The full-battery run time from the full-battery run time test procedure (Annex M) is required to set the battery to the proper state of charge during the standby loss test.

S.4 Procedure

S.4.1 Active deep discharge protection test

S.4.1.1 General

The DUT is discharged until its battery voltage reaches the LVD voltage or appropriately exceeds its recommended deep discharge voltage threshold.

S.4.1.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC voltmeter or multimeter.
- Voltage data logger (recommended).
- Ammeter or current data logger (e.g. voltage data logger with a current transducer) (current data-logger recommended).
- Low-voltage disconnect device that will stop the discharge when the battery reaches a specified voltage (recommended).

The total series resistance added by the test apparatus and all measurement equipment shall be no more than 60 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4). Alternatively, the resistance may exceed 60 mΩ if the total voltage drop between the battery and DUT does not exceed 0.01 V.

S.4.1.3 Test prerequisites

The DUT shall be either fully charged at the start of the test or charged enough to provide at least 20 min of service before reaching its deep discharge protection voltage or reaching sufficiently below the recommended deep discharge protection voltage threshold for the battery chemistry (see Table L.1 for recommended thresholds).

If it is necessary to charge the battery, use one of the two procedures depending on the battery chemistry.

- If the battery is of NiMH chemistry, then use the procedures in the battery test (Annex K).
- If the battery is of any other chemistry, then use the procedures in the active overcharge protection test (S.4.2). If the PV module has not yet been tested, then set up the apparatus in accordance with Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp} . If the rated I_{mpp} is not available, apply a current that results in a battery charge rate as specified in Table K.2. This current value shall be set at the beginning of the charge cycle and not adjusted during the charge cycle.

Some products are designed to stop the discharge at a nonzero state of charge in order to reserve some energy for the next day in case the battery cannot be charged fully due to weather or other conditions. In this case, a single discharge cycle can be insufficient to assess the product's deep discharge protection. In this case, the laboratory should consult the company to determine how to test the deep discharge protection.

For products with an adjustable depth of discharge setting, the depth of discharge should be set to the maximum possible for this test. (Restore the previous setting before performing further testing.)

S.4.1.4 Apparatus

The DUT shall be set in a secure location such that its parameters can be recorded.

If necessary, a low-voltage disconnect device may be used that monitors the battery voltage and can cut the battery circuit if the voltage drops below a predetermined level.

S.4.1.5 Procedure

The following steps shall be performed.

- a) If it is unclear if the DUT has deep discharge protection for its battery, the tester may prepare the low-voltage disconnect device so that it stops the discharge if the battery reaches the minimum battery testing voltage specified in Annex L.

- b) Secure the DUT in a safe location. Select appliances and configure the DUT following the full-battery run time test procedure (Clause M.8, step a)). Turn on the DUT to begin discharging the battery. All DUT functions shall be turned on and set to the highest setting(s) (i.e. lights at their brightest setting, fan at its fastest speed). Continuously monitor the battery terminal voltage and current at the negative battery terminal. The battery voltage and current shall be collected at intervals less than or equal to 1 min.

In case of pulse-width modulation (PWM) controllers, aliasing effects (CC.3.3) can occur when data logging due to unsynchronised PWM frequency and sampling frequency of the current logger. This can lead to "chaotic" measurements which are difficult to interpret. In this case, the sampling interval may be decreased or the test may be conducted using a power-measuring instrument meeting the requirements in Clause CC.2. It is not necessary to calculate power or to follow the guidelines in Clause CC.3.

- c) Determine if the DUT has active deep discharge protection. If so, one of two behaviours can be observed:

- 1) an abrupt drop will occur in the relative light output (or other appliance operation) and current will quickly decrease to zero, or
- 2) a relatively quick drop will occur in the relative light output (or other appliance operation) and current will ultimately decrease to zero.

In either case, the minimum battery voltage recorded up to the time at which the battery current reaches zero is the active deep discharge protection voltage.

For the determination of deep discharge protection, the current can be assumed to be zero if either of the following is true:

- The measured current is less than $0,000\ 07\ I_t\ \text{A}$ (where $I_t\ \text{A}$ is defined in K.4.1), or
- The measured current is indistinguishable from zero considering the resolution of the measuring instrument.

- d) If active deep discharge protection is observed, perform the following steps before turning off the DUT or stopping data logging:

- 1) If any built-in appliances were not turned on during the test, turn on each such built-in appliance, one appliance at a time. Record whether each appliance turns on.
- 2) If any port types were not used to connect appliances that were turned on during the test, connect an appliance, resistor, or other load to confirm that the port does not function.

NOTE 1 The port can be checked for functionality by measuring the voltage without load. However, the result can be unclear, since output capacitors may retain a nonzero voltage even though the port has shut down and will not function under load. Therefore, measurement under load is recommended.

- 3) If any built-in appliances or ports function, continue the test with the appliance turned on or load connected to the port until the criteria of c) are met or the battery reaches the minimum battery testing voltage (e.g. the voltage specified in Table L.1). Note the appliances turned on in this step in the test report.
- 4) If the test is continued and active deep discharge protection is identified, determine a new active deep discharge protection voltage based on the extended test period.

NOTE 2 The purpose of this step is to verify that the deep discharge protection has disconnected all loads from the battery. Some products disconnect different appliances or ports at different battery voltages or states of charge.

- e) Report whether the deep discharge protection is internal to the battery. Typically, if the deep discharge protection circuit is external to the battery, the battery voltage will remain constant or increase after the deep discharge protection circuit disconnects the battery. If the deep discharge protection is internal to the battery pack, the voltage will drop to zero once the deep discharge protection voltage is reached. (In the latter case, ensure that the reported deep discharge protection voltage occurred before the internal protection circuit isolated the battery. If the battery voltage drops quickly, this can be difficult to determine.)

- f) If the battery contains internal circuitry (refer to F.4.3.6) and the measured deep discharge protection voltage is outside of the targets specified by the company (D.3.2.2) or the battery voltage falls below the recommended deep discharge protection voltage specified in Annex L, the test may be repeated with the voltage data logger connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so. In the test report, note where the reported voltage value was measured.
- g) If no active deep discharge protection is observed:
- 1) If the product could have passive deep discharge protection (e.g. for most products without ports; see S.4.3.1), perform the passive deep discharge protection test (S.4.3).
 - 2) Otherwise, continue the test until the battery voltage equals the minimum discharge voltage permitted by the battery manufacturer. The test should be discontinued before the battery voltage drops to a value at which the battery can be damaged or become unsafe. Recommended minimum battery testing values are given in Table L.1.
- h) If the low-voltage disconnect device stops the discharge during the test, record that the battery voltage reached the minimum battery testing voltage and that no active deep discharge voltage was observed.
- i) Record and photograph any damage or unsafe conditions (e.g. fire, venting, or explosion) that occur as a result of the test.

S.4.1.6 Calculations

There are no calculations for the active deep discharge protection test.

S.4.2 Active overcharge protection test

S.4.2.1 General

The DUT is charged until its battery voltage reaches the OVP voltage or the overcharge protection disconnect device's set point, or if the battery's temperature exceeds a safe value (refer to Table L.2).

S.4.2.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC power supply or solar array simulator.
- DC voltmeter or multimeter.
- DC ammeter or multimeter.
- Voltage data logger (optional).
- Current data logger (e.g. voltage data logger with a current transducer) (optional).
- Series resistor or series and parallel resistors (or variable resistors) for simulating PV input (when testing a main unit using a DC power supply as opposed to a solar array simulator). The accuracy requirement for series and parallel resistors in Table CC.3 applies.
- Surface-mounted thermocouple(s) and a thermocouple reader (optional).
- AC power adapter supplied with the DUT (for DUTs with a grid-charging option and no solar-charging option).
- Overcharge disconnect device that will stop the discharge when the battery reaches a specified voltage (if necessary).

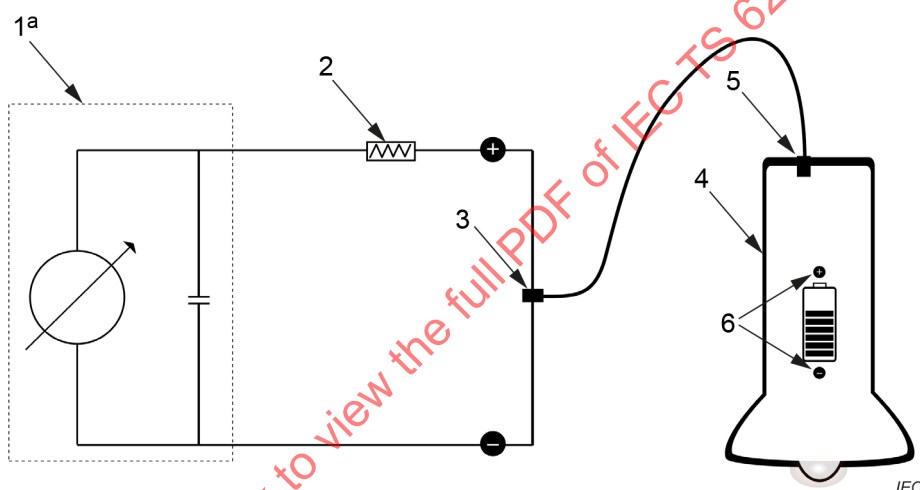
The total series resistance added by the test apparatus and all measurement equipment shall be no more than 90 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4). Alternatively, if the total voltage drop between the DUT and battery does not exceed 0,01 V, the resistance may exceed the 90 mΩ limit.

S.4.2.3 Test prerequisites

The DUT shall be either fully discharged at the start of the test or discharged enough to accept at least 20 min of charging before reaching its overcharge protection voltage or the overcharge disconnect device's cutoff, which may be selected based on information in Table L.2 if the overcharge voltage set point is not supplied by the company.

S.4.2.4 Apparatus

The DUT shall be set in a secure location such that its parameters can be recorded. If the DUT has a solar-charging option, the DUT is charged via the PV module socket from a DC power supply with a series resistor in place (Figure S.1). An alternative is to charge the DUT via the PV module socket from a DC power supply with a series resistor and parallel resistor in place (Figure R.1), or using a solar array simulator. If the PV module is integrated, as opposed to external, charge the DUT by directly connecting to the PV module leads from where the integrated PV module was detached. If the product does not have a solar-charging option, the DUT shall be charged via its provided grid charger or charged via its electromechanical charging process or by a DC power supply configured to simulate the electromechanical charging device.



Key

- 1 DC power supply
- 2 Series protection resistor
- 3 Plug
- 4 DUT
- 5 PV module input socket
- 6 Battery
- a Set current limiting with the maximum power point current at STC, I_{mpp} , from the photovoltaic module I-V characteristics test (Annex Q), or, if the product is charged with other means set the current to the typical delivery current for the charging system.

Figure S.1 – Schematic of the DC power supply-DUT connection using a series protection resistor

S.4.2.5 Procedure

S.4.2.5.1 Procedure for products with solar charging

The following steps shall be performed if the DUT has a solar charging option.

- a) Calculate the daily standby loss as a percentage of battery capacity using the following formula:

$$\delta Q_{sb,24} = \frac{I_{sb} \times 24 \text{ h}}{C_b}$$

where

I_{sb} is the measured standby loss (A) (S.4.5.5);

C_b is the measured battery capacity (Ah) (Annex K);

$\delta Q_{sb,24}$ is the percentage of battery capacity lost over 24 hours due to standby loss.

- b) If the value of $\delta Q_{sb,24}$ calculated in the previous step is greater than 5 %, the intermediate step will be required (step m)). Set the battery to a state of charge of 50 % following the procedure in S.4.5.3.

Exception: the intermediate step is not required in any of the following cases:

- 1) The active overcharge protection test is not being followed by the full-battery run time test (e.g. because the full-battery run time test is not necessary or has already been performed);
 - 2) The battery is disconnected from the DUT (either manually or automatically by the test equipment) immediately after the active overcharge protection test stopping criterion (step l)) is first met;
 - 3) The battery cannot be disconnected from the DUT (e.g. because the product has coulomb counting) and the full-battery run time test is started (either manually or automatically by the test equipment) no more than 2 h after the active overcharge protection test stopping criterion (step l)) is first met.
- c) If the setup includes the parallel resistor (Figure R.1), adjust the current limiting value of the DC power supply to the current setpoint at 1 000 W/m² irradiance, $I_{sim,1000}$, calculated in the solar charge test (Annex R). Also adjust the voltage of the DC power supply, V_{ps} , to the voltage setpoint, V_{sim} , calculated in the solar charge test (Annex R). Also set the series resistance, R_s , and the parallel resistance, R_p , to the values calculated in the solar charge test (Annex R). Skip steps d) through g) and proceed to step h).
- d) If the setup uses a solar array simulator, configure the solar array simulator as for the solar charge test (Annex R) to simulate the I-V curve at an irradiance of 1 000 W/m² and connect the solar array simulator to the PV input of the DUT. Skip steps e) through h) and proceed to step i).
- e) If the setup includes a series resistor only (Figure S.1), adjust the current limiting value of the DC power supply to the PV module's maximum power point current at TMOT, $I_{mpp,TMOT}$ (refer to the results of the photovoltaic module I-V characteristics test (Annex Q)).
- f) Set the power supply output voltage, V_{ps} , to the open-circuit voltage of the PV module at TMOT ($V_{oc,TMOT}$).
- g) Connect the PV module socket of the DUT to the DC power supply in series with a protection resistor. In cases where the DUT has an integrated PV module, connect the positive and negative wires from the DUT that were attached to the PV module to the DC power supply in series with a protection resistor. Set the resistor value based on the following formula:

$$R_s = \frac{V_{oc,TMOT} - V_{mpp,TMOT}}{I_{mpp,TMOT}}$$

where

- $I_{\text{mpp, TMOT}}$ is the PV module's maximum power point current at TMOT, in amperes (A), obtained from the photovoltaic module I-V characteristics test (Annex Q);
- $V_{\text{mpp, TMOT}}$ is the PV module's maximum power point voltage at TMOT, in volts (V), obtained from the photovoltaic module I-V characteristics test (Annex Q);
- $V_{\text{oc, TMOT}}$ is the PV module's open-circuit voltage at TMOT, in volts (V), obtained from the photovoltaic module I-V characteristics test (Annex Q);
- R_s is the resistance of the series resistor, in ohms (Ω).

- h) Ensure the series resistor's power dissipation rating is greater than or equal to the value given by the following formula:

$$P_{\text{rs}} \geq I_{\text{mpp, TMOT}}^2 \cdot R_s$$

where

- P_{rs} is the series resistor's minimum required power dissipation, in watts (W);
- $I_{\text{mpp, TMOT}}$ is the PV module's maximum power point current at TMOT, in amperes (A), obtained from the photovoltaic module I-V characteristics test (Annex Q);
- R_s is the resistance of the series resistor, in ohms (Ω).

- i) If the design of the DUT does not include a DC-DC boost (step-up) converter between the PV input and battery, regardless of the selected apparatus, ensure that the power supply voltage is at least 1,25 times the maximum charging voltage specified by the battery manufacturer. (The value in Table L.2 may be used if the manufacturer-specified voltage is unavailable.) If using a solar array simulator, if necessary, multiply all voltage values in the simulated I-V curve by a constant value so that the open-circuit voltage meets this requirement.

It can be assumed that there is no DC-DC boost converter if the battery voltage is less than the simulated PV voltage throughout the solar charge test (Annex R).

- j) If it is unknown whether the DUT has an overcharge protection disconnect, integrate the overcharge protection disconnect device into the setup. The overcharge protection device shall disconnect if the battery voltage rises above safety limits that are determined by the laboratory. In some cases, the charge controller is designed with an OVP voltage that is greater than the overcharge protection device setpoint; therefore, the tester may allow the battery voltage to proceed above the recommended OVP voltage threshold if deemed safe and necessary. For Li-ion batteries, the battery voltage shall not exceed the maximum safe value specified by the battery supplier, or 4,26 V/cell if no supplier-provided information is available; otherwise there is a risk of explosion. Optionally, monitor the battery temperature to ensure that it does not exceed a safe value (refer to Table L.2). If temperature monitoring is used, lithium-based batteries shall not be allowed to exceed 45 °C unless higher temperatures are allowed by the battery manufacturer.
- k) Charge the DUT while continuously monitoring the battery terminal voltage and current. The battery voltage and current shall be collected at intervals less than or equal to 1 min.

In case of pulse-width modulation (PWM) controllers, aliasing effects (CC.3.3) can occur when data logging due to unsynchronised PWM frequency and sampling frequency of the current logger. This can lead to "chaotic" measurements which are difficult to interpret. In this case, the sampling interval may be decreased or the test may be conducted using a power-measuring instrument meeting the requirements in Clause CC.2. It is not necessary to calculate power or to follow the guidelines in Clause CC.3.

- l) If the DUT automatically stops accepting charge, the DUT has active overcharge protection, and the highest voltage measured during the test is the overcharge protection voltage. For some DUTs, the current will not stop completely, but will begin tapering off when the battery voltage reaches the overcharge protection voltage. Continue monitoring until two measurements of battery voltage, taken six hours apart, show an increase of less than 0,01 V.

- m) If the intermediate step is required (step b)), perform the following steps:
- 1) In the voltage data measured during the previous charge cycle, identify the time at which the active overcharge protection test stopping criterion (step l)) is first met. Record the total duration from the start of the test to this time.
 - 2) Set the battery to 50 % state of charge following the procedure in S.4.5.3.
 - 3) Repeat steps c) through j). Before starting the charge cycle, set the test apparatus to disconnect the battery after the charging duration calculated in step 1) has elapsed.
If the battery cannot be disconnected (e.g. because the product uses coulomb counting), the battery may remain connected after the charging duration has elapsed if the full-battery run time test (Annex M) is started no more than 2 h after the charging duration has elapsed.
 - 4) Repeat step k) to start charging the DUT.
- n) Report whether the active overcharge protection is internal to the battery. Typically, if the overcharge protection circuit is external to the battery, the battery voltage will remain constant or decrease after the overcharge protection circuit disconnects the battery. If the overcharge protection is internal to the battery pack, the voltage will typically increase to the open-circuit voltage of the PV simulator apparatus when the overcharge protection voltage is reached. (In the latter case, ensure that the reported overcharge protection voltage occurred before the internal protection circuit isolated the battery.)
- o) If the battery contains internal circuitry (refer to F.4.3.6) and the measured overcharge protection voltage is outside of the targets specified by the company (D.3.2.2) or the battery voltage exceeds the recommended overcharge protection voltage specified in Annex L, the test may be repeated with the voltage data logger connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so. In the test report, note where the reported voltage value was measured.
- p) If the battery terminal voltage reaches the overcharge protection cutoff device's voltage threshold, record that no active overcharge protection is incorporated into the charge controller.
- q) If in the case of a NiMH battery the battery voltage levels off or begins to decrease before reaching the recommended overcharge protection voltage, but the current does not go to zero, no active overcharge protection is detected.
- r) Record and photograph any damage or unsafe conditions (e.g. fire, venting, or explosion) that occur as a result of the test.

S.4.2.5.2 Procedure for other charging methods

The following steps shall be performed if the DUT does not have a solar charging option (including for batteries in appliances and other components that are not main units). This procedure is also used for products with solar charging to evaluate overcharge protection when the product is charged from a power source other than the PV module.

- a) Follow steps S.4.2.5.1 a) and b) to determine whether the intermediate step is required.
- b) If the DUT charges from a port on another component of the system or a DC power source (e.g. USB), supply power to the DUT using one of the following methods:
 - Supply power from a DC power supply at the appliance operating voltage. If the appliance operating voltage is not known or not applicable, the nominal port voltage (or nominal voltage of the intended power source) may also be used.
 - If the DUT is powered by a port on another component, supply power to that component at its typical battery discharge voltage or standard operating voltage and connect the DUT to the port.
- c) If the DUT has a grid-charging option, plug the AC power adapter supplied with the DUT into an outlet with AC voltage that is suitable for the supplied AC power adapter.

- d) If the DUT does not have a grid-charging option, but has an electromechanical charging option, electromechanically charge the DUT continuously in accordance with the electromechanical charge test procedure (Annex P) or use a power supply to source current that is equal to the charging current measured in the electromechanical charge test.
- e) Follow the procedure in S.4.2.5.1 starting with step i).

S.4.2.6 Calculations

There are no calculations for the active overcharge protection test.

S.4.3 Passive deep discharge protection test

S.4.3.1 General

If the DUT does not have active deep discharge protection, the product could have passive deep discharge protection. In this form of deep discharge protection, the load and battery characteristics are matched so that the load cannot discharge the battery excessively in a reasonable period of time, even though it remains connected. Generally, passive deep discharge protection is not appropriate for products with ports, since the load properties are not known. However, passive deep discharge protection may be used for built-in appliances (such as internal lights or radios) if the ports are separately provided with appropriate active deep discharge protection.

In the passive deep discharge protection test, the DUT is left to discharge for 24 h and the minimum voltage within the 24 h period is recorded. This method is only performed on products that show no active deep discharge protection and for which passive deep discharge protection is appropriate.

S.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC voltmeter or multimeter.
- Voltage data logger (recommended).
- Ammeter or current data logger (e.g. voltage data logger with a current transducer) (optional).
- Low-voltage disconnect device that will stop the discharge when the battery reaches a specified voltage (recommended).

The total series resistance added by the test apparatus and all measurement equipment shall be no more than 60 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4). Alternatively, the resistance may exceed 60 mΩ if the total voltage drop between the battery and DUT does not exceed 0,01 V.

S.4.3.3 Test prerequisites

The DUT shall have undergone the active deep discharge protection test. The battery shall be in the same state of charge as when the DUT reaches L_{70} (70 % of its initial light output during the full-battery run time test), or, for products without lighting appliances, the state of charge corresponding to approximately 24 h before one of the stopping criteria of the appliance full-battery run time test (Clause FF.9) would be met.

S.4.3.4 Apparatus

The DUT shall be placed in a secure location where it can discharge for 24 h.

If necessary, a low-voltage disconnect device may be used that monitors the battery voltage and can cut the battery circuit if the voltage drops below a predetermined level.

S.4.3.5 Procedure

The following steps shall be performed.

- a) Determine the accepted 24 h passive deep discharge battery protection voltage. This voltage may be selected based on information from Table L.1, if it is not supplied by the company or battery manufacturer.
- b) If it is unclear if the DUT has deep discharge protection for its battery, the tester may prepare the low-voltage disconnect device so that it stops the discharge if the battery reaches the minimum battery testing voltage specified in Annex L.
- c) Secure the DUT in a safe location. Select appliances and configure the DUT following the full-battery run time test procedure (Clause M.8, step a)).
- d) Turn on the DUT and discharge the battery for 24 h. For products without lighting appliances, discharge until one of the stopping criteria for the appliance full-battery run time test (Clause FF.9) is met. The appliance(s) shall be on and set to their highest setting(s) (i.e. lights at their brightest setting, fan at its fastest speed). Continuously monitor the battery terminal voltage and optionally monitor the battery current at the negative battery terminal. The battery voltage and optional current shall be collected at intervals less than or equal to 1 min.

In case of pulse-width modulation (PWM) controllers, aliasing effects (CC.3.3) can occur when data logging due to unsynchronised PWM frequency and sampling frequency of the current logger. This can lead to "chaotic" measurements which are difficult to interpret. In this case, the sampling interval may be decreased, or the test may be conducted using a power-measuring instrument meeting the requirements in Clause CC.2. It is not necessary to calculate power or to follow the guidelines in Clause CC.3.

- e) Report if passive deep discharge protection was observed in the DUT. If the DUT has passive deep discharge protection, a gradual decrease will occur in the relative light output (or other appliance operation) and current will gradually decrease to a relatively low value. If the battery voltage remains greater than or equal to the selected deep discharge protection voltage threshold (see Clause L.2) for the full 24 h period, then the product has appropriate passive deep discharge protection, provided that the design of the product allows passive deep discharge protection.
- f) If the DUT has passive deep discharge protection, report the passive deep discharge protection voltage at 24 h, in volts (V). Determine the passive deep discharge protection voltage by identifying the minimum battery voltage during the 24 h test period. (Since the battery voltage typically continues to decrease during the 24 h test period, this is generally the voltage at 24 h.)
- g) If the battery contains internal circuitry (refer to F.4.3.6) and the measured deep discharge protection voltage is outside of the targets specified by the company (D.3.2.2) or the battery voltage falls below the recommended deep discharge protection voltage specified in Annex L, the test may be repeated with the voltage data logger connected on the battery side of the internal circuitry, if the test laboratory determines that it is safe to do so. In the test report, note where the reported voltage value was measured.
- h) If the low-voltage disconnect device provided by the test laboratory stops the discharge during the test, record that the battery voltage reached the minimum battery testing voltage and that no passive deep discharge voltage was observed.
- i) Record and photograph any damage or unsafe conditions (e.g. fire, venting, or explosion) that occur as a result of the test.

S.4.3.6 Calculations

There are no calculations for the passive deep discharge protection test.

S.4.4 Passive overcharge protection test

S.4.4.1 General

This method is only performed on products with NiMH batteries that show no active deep discharge protection.

In some cases, the PV module's short circuit current alone proves that the DUT has passive overcharge protection; otherwise, the DUT is overcharged and the charging current is observed to determine if the DUT has passive overcharge protection. If the product does not have a solar-charging option, the DUT shall be charged via its provided grid charger or charged via its electromechanical charging process.

S.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC power supply or solar array simulator.
- DC ammeter or multimeter.
- Voltage data logger (optional).
- Current data logger (e.g. voltage data logger with a current transducer) (optional).
- Series resistor or series and parallel resistors (or variable resistors) for simulating PV input (when using a DC power supply as opposed to a solar array simulator).
- AC power adapter supplied with the DUT (for products with a grid-charging option and no solar-charging option).
- Surface-mounted thermocouple(s) and a thermocouple meter (optional).

The total series resistance added by the test apparatus and all measurement equipment shall be no more than 90 mΩ. This value includes the resistance of the wires and connectors, if any, added in the sample preparation procedure (G.4.4). Alternatively, if the total voltage drop between the DUT and battery does not exceed 0,01 V, the resistance may exceed the 90 mΩ limit.

S.4.4.3 Test prerequisites

The DUT shall have undergone the active overcharge protection test, such that its battery voltage has just passed its recommended overcharge protection voltage (Table L.2) when charging or, if the battery voltage does not reach the recommended overcharge protection voltage, the battery has reached the maximum voltage observed during the active overcharge protection test (i.e. the battery voltage has levelled off or peaked and begun to decrease).

S.4.4.4 Apparatus

The DUT shall be set in a secure location such that its parameters can be recorded. If the DUT has a solar-charging option, the DUT is charged via the PV module socket from a DC power supply using a series resistor or series and parallel resistor identical to those used in the active overcharge protection test apparatus (S.4.2.4). If the DUT is powered from a port on another component, power the DUT in accordance with S.4.2.5.2.

S.4.4.5 Procedure

The following steps shall be performed if the DUT has a solar charging option and the product's battery-charging circuit does not include a DC-DC converter (see R.4.4, step I)).

- a) Determine the accepted passive overcharge protection continuous battery charging current. A passive overcharge protection continuous battery charging current of less than or equal to 0,2 I_t A is recommended for NiMH batteries.

- b) Compare the PV module's short-circuit current at STC (I_{sc}) to the passive overcharge protection continuous battery charging current (I_{sc} may be obtained from the photovoltaic module I-V characteristics test (Annex Q)). If I_{sc} is the smaller of the two, the DUT has passive overcharge protection and no further testing is necessary.
- c) Plot the PV module's I-V curve at typical module operating temperature TMOT from the photovoltaic module I-V characteristics test (Annex Q).
- d) If the passive overcharge protection test follows the active overcharge protection test using a parallel resistor (Figure R.1), use the same current limiting and voltage values and resistor values that were used in the active overcharge protection test procedure (S.4.2.5).
- e) If the passive overcharge protection test follows the active overcharge protection test using a solar array simulator, use the same solar array simulator configuration that was used in the active overcharge protection test procedure (S.4.2.5.1).
- f) If the passive overcharge protection test follows the active overcharge protection test with a series resistor only (Figure S.1), set the current limiting and voltage values of the DC power supply to the PV module's maximum power point current at TMOT, $I_{mpp, TMOT}$ and $V_{oc, TMOT}$ (refer to the results of the photovoltaic module I-V characteristics test (Annex Q)), respectively. Use the same series resistor value as was used in the active overcharge protection test procedure (S.4.2.5.1).
- g) Connect the DC power supply via the resistor(s) and the product's entire PV cable to the PV module input socket. If the DUT is has an integrated PV module, connect the DC power supply to the ends of the internal leads where the PV module connects to the DUT's circuitry. Let charge for 5 min. After the 5 min period is complete, determine the voltage drop, V_{drop} , between the power supply's output and the battery terminals. Optionally, monitor the battery temperature to ensure that it does not exceed a safe value (refer to Table L.2).
- h) Add V_{drop} to the charge voltage, V_{charge} , which is determined by multiplying the number of battery cells in series by the recommended overcharge protection voltage for NiMH batteries (Table L.2). This sum is the total charge voltage, V_{max} .
- i) Plot a vertical line at V_{max} on the TMOT I-V curve (see step c)) that extends from the voltage axis to the I-V curve.
- j) Plot a horizontal line that intersects the TMOT I-V curve at the same point V_{max} does and extends to the current axis. The current where the horizontal line intersects the current axis is the charging current.
- k) If the charging current is less than or equal to $0,2 I_t$ A, the DUT has passive overcharge protection.

These steps shall be followed if the product does not have a solar charging option or if the product utilizes a DC-DC converter:

- l) Determine the DUT's accepted passive overcharge protection continuous battery charging current. A passive overcharge protection continuous battery charging current of less than or equal to $0,2 I_t$ A is recommended for products with NiMH batteries.
- m) Compare the passive overcharge protection continuous battery-charging current to the average charging current observed over the final 5 min of the active overcharge protection test (S.4.2). If the average charging current is the smaller of the two, the DUT has passive overcharge protection.

For all products, record and photograph any damage or unsafe conditions (e.g. fire, venting, or explosion) that occur as a result of the test.

S.4.4.6 Calculations

There are no calculations for the passive overcharge protection test.

S.4.5 Standby loss measurement

S.4.5.1 General

This measurement quantifies the standby loss of a DUT when not in use. If the standby loss is substantial, it can affect the use of the DUT. The DUT shall be configured to best simulate how it would be left in the home while not in use.

S.4.5.2 Equipment requirements

An ammeter (data-logging functionality is optional) and a timer. Equipment shall meet the requirements in Clause CC.2.

S.4.5.3 Test prerequisites

Set the battery to a state of charge of approximately 50 %. This may be accomplished by the procedure described in the following.

- a) First, fully charge the battery using one of the following:
 - 1) the appropriate charging procedures in the battery test (Annex K), or
 - 2) the procedures in the active overcharge protection test (S.4.2). If the PV module has not yet been tested, then set up the apparatus in accordance with Figure S.1 and set the current limit to the rated maximum power point current at STC, I_{mpp} .
- b) After the battery is fully charged, discharge the battery to a state of charge of approximately 50 % using one of the following:
 - 1) use the appropriate discharging procedures in the battery test (Annex K) modified to end when the battery reaches a 50 % state of charge, or
 - 2) turn the DUT on its brightest setting. Stop the discharge once the discharge duration equals (50 ± 25) % of the full-battery run time.

S.4.5.4 Apparatus

The DUT shall be set in a secure location such that its battery current can be recorded for 15 min.

S.4.5.5 Procedure

The following steps shall be performed.

- a) Configure the DUT to simulate how it would be left in the home while not in use. Connect all the included appliances with no internal battery that can be turned off with an on/off switch to the product. For example, it is unlikely that a user unplugs a light point that has an on/off switch every time he or she wants to turn off the light; it is more likely that the user will turn off the light point via its switch. If the DUT does not have enough ports to connect all the included appliances with no internal battery that have on/off switches, connect the appliances with no internal battery that are estimated to maximize the standby loss. In addition, turn on/off system power switches on. For example, if the power control unit has a system on/off switch that connects the battery to the rest of the system, keep the switch in the on position. It is unlikely that a user will turn the system's power switch off when the system is not in use.
- b) For products with external PV modules, connect the PV module. For all products with PV modules, prevent light from reaching the PV material (e.g. cover the PV module with an opaque dark cloth or turn the module upside down so that its PV material is facing downwards over an opaque surface).
- c) Break the circuit at the battery's negative terminal, connect the current meter in series, and ensure that all power buttons and switches on the DUT are turned off, with the exception of the system power switch, as described in step a).

- d) Turn on one of the appliances, e.g. turn on a light, to check that the DUT is still functioning after connecting it to the current meter. Briefly shining a light on the PV module is sometimes required to activate the DUT after connecting the current meter in series. Turn the appliance off once functionality is confirmed.
- e) Wait 5 min to allow the DUT to stabilize. Then, over a 10 min period, record (or data-log) the current at the battery's negative terminal at intervals less than or equal to 1 min.
- f) Report the average battery current over the 10 min data-collection period.

If the company indicates that the product enters a low-power mode ("sleep mode" or "standby mode") after a delay longer than 5 min (see D.3.2.2 v)), the company may request that the test be repeated after allowing the product to enter the low-power mode. Both sets of results shall be reported. Record the time required for the product to enter the low-power mode.

S.4.5.6 Calculations

There are no calculations for the standby loss measurement.

S.5 Reporting

Report the following in the charge controller behaviour test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - presence of active deep discharge protection (yes/no);
 - active deep discharge protection voltage, if applicable (V);
 - presence of active overcharge protection (yes/no);
 - active overcharge protection voltage, if applicable (V);
 - presence of passive deep discharge protection, if applicable (yes/no);
 - passive deep discharge protection voltage at 24 h, if applicable (V/cell);
 - presence of passive overcharge protection (yes/no);
 - presence of damage or safety hazard during any of the charge controller tests (yes/no);
 - passive overcharge protection continuous charging current (mA);
 - standby loss current (A);
 - time required for product to enter low-power standby mode, if applicable (h).
- Average of n sample results for standby loss current.
- DUT's rating for aspects tested, if available.
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n . In particular, include an assessment of the appropriateness of the charge control strategy given the information available.
- Figures:
 - plots of voltage and current vs. time in the active overcharge test, active deep discharge protection test, and passive deep discharge protection test.

Annex T (normative)

Light distribution test (optional)

T.1 Background

Luminous flux and light distribution are two primary metrics used to assess the performance of a lighting product. Measurements of luminous flux (the total amount of light emitted by a source) are appropriate for any type of light and are discussed in Annex I. Measurements of light distribution are also appropriate for any type of light, with particular relevance to the performance of task lights that have focused light distributions.

The light distribution of lighting appliances can vary greatly, ranging from very narrow-beam task lights to omnidirectional ambient lights. While there is no distribution that is necessarily "ideal," some distributions are more appropriate for certain applications than others. Annex T is intended to characterize a product's light distribution so purchasers can select products that are appropriate for the applications in which they are used.

The most common applications for lighting appliances are:

- ambient lighting,
- task lighting from a mounted or suspended fixture, and
- task lighting from a fixture placed on the surface to be illuminated (e.g. a desk light).

Ambient lights, products that have wide or omnidirectional light distributions, are best characterized by measuring total luminous flux (Annex I). A full width half maximum (FWHM) angle measurement may be used to help categorize a light distribution (ambient or task), and some lights may be considered for both ambient and task lighting applications. In circumstances where it is not clear how to classify a light, the use of both luminous flux and light distribution testing is appropriate.

Task lights that have directed light distributions may be characterized by measuring the illuminance on a specified task plane. The task plane used in the light distribution test is 1 m² and is positioned relative to the DUT depending on the type of task light use (desk light or suspended light).

T.2 Test outcomes

The light distribution test outcomes are listed in Table T.1.

Table T.1 – Light distribution test outcomes

Metric	Reporting units	Related aspects	Notes
Vertical and horizontal full width half maximum (FWHM) angles	Degrees (°)	4.2.9.2 Full width half maximum (FWHM) angle	--
Usable area with illuminance greater than a specified threshold	Square metres (m ²)	4.2.9.3 Average light distribution characteristics	Determined from a specified distance
Work surface illuminance	Lux (lx)	4.2.9.3 Average light distribution characteristics	Maximum possible over testing surface
Luminous flux	Lumens (lm)	4.2.9.1 Luminous flux output	Only obtained when using multi-plane (T.5.3) or goniophotometer (T.5.2) test methods

T.3 Related tests

The light distribution test is related to the light output test (Annex I). Specifically, either the multi-plane method described in I.4.4 or the goniophotometer method described in I.4.2 may be used to gather all necessary data to generate polar plots, surface plots, and FWHM angles for ambient and suspended task lights.

T.4 Substitution of results from IEC TS 62257-12-1

For lighting appliances without internal batteries, the light distribution test of IEC TS 62257-12-1 may be used in place of the light distribution test in this document. Since the voltage supplied to the lighting appliance in IEC TS 62257-12-1 can be different from the appliance operating voltage (Clause FF.5), the results of the IEC TS 62257-12-1 light distribution test shall be adjusted as follows:

- Full width half maximum angles may be used without adjustment.
- Luminous flux values shall be adjusted by multiplying by the relative light output percentage value determined in I.4.2 a).

T.5 Approved test methods

T.5.1 General

Annex T includes multiple test procedures with varying test outcomes, summarized in Table T.2. If more than one identical lighting appliance is included with the product, it is only necessary to test one of each type of identical lighting appliances for each sample. Also, if the product has multiple unique lighting appliances, each unique lighting appliance shall be tested.

The test method to be used should be selected based on the capabilities of the laboratory, the required outcomes (as specified in the product specification), and the product application(s). If only FWHM angles are required by the product specification, the illuminance on a plane and illuminance on a desktop procedures may be omitted. While the turntable method is generally of limited utility for desktop task lights, it may be performed on these products if measurement of the FWHM angles is desired or required by the product specification.

Table T.2 – Summary of testing options for characterizing lamp distributions

Test method	Application(s)	Test outcomes
Goniophotometer or multi-plane	Ambient light Suspended task light Desktop task light	• Vertical and horizontal FWHM angles • Usable area with illuminance greater than a specified threshold • Luminous flux (see Annex I) • Work surface illuminance
Illuminance on a plane	Ambient light Suspended task light	• Usable area with illuminance greater than a specified threshold • Vertical and horizontal FWHM angles, if determined • Work surface illuminance
Turntable	Ambient light Suspended task light	• Vertical and horizontal FWHM angles
Illuminance on a desktop	Desktop task light	• Usable area with illuminance greater than a specified threshold • Work surface illuminance

The following steps shall be performed prior to performing the test by any method.

- a) Determine the "horizontal" and "vertical" planes for the purposes of the light distribution measurement, using the following guidelines. Describe the selected orientation in the test report. Photographs or diagrams can be useful in describing the product orientation but may be omitted if the text description is unambiguous.
 - 1) These guidelines consider two types of light points: omnidirectional and directed. If the distribution of illuminance is measured on an imaginary sphere surrounding an omnidirectional product, the maximum illuminance will occur at the equator and local minima will occur at the poles. For a directional product, the maximum illuminance will occur at one pole and the minimum will occur at the other pole. Typical omnidirectional light points include lanterns and some bulbs; typical directed light points include torches and suspended task lights.
 - 2) For an omnidirectional light point, the horizontal plane is the plane of maximum illuminance, typically parallel to the ground, and the vertical plane is the plane perpendicular to the horizontal plane containing the point of maximum illuminance (Figure T.1). In some cases there are multiple possible choices of vertical plane, if the maximum illuminance value occurs at more than one point. In this case, the test laboratory should select one plane to measure.

The surface of maximum illuminance can be a cone rather than a plane. In that case, the plane containing either the centre of the light point or the vertex of the cone of maximum illuminance should be used.
 - 3) Some directed light points have identifiable top and bottom surfaces. For example, the bottom surface could be flat for desktop mounting and the power button could be located on the top of the light point. In this case, the vertical plane is the plane that contains the point of maximum illuminance and the centres of the top and bottom surfaces of the light point, and the horizontal plane is the plane perpendicular to the vertical plane that contains the point of maximum illuminance. See Figure T.2.
 - 4) For light points with no identifiable top and bottom, the choice of horizontal and vertical planes may be arbitrary.
 - 5) If the light point contains a two-dimensional array of light sources (e.g. LEDs) and multiple choices of either horizontal or vertical planes, or both, are available following the above criteria, it is preferable to align the light point such that the intersections of the horizontal and vertical planes with the array plane are lines of symmetry of the array configuration, if possible. For example, if the product contains LEDs in a grid pattern, the grid lines should be parallel with the horizontal and vertical plane.

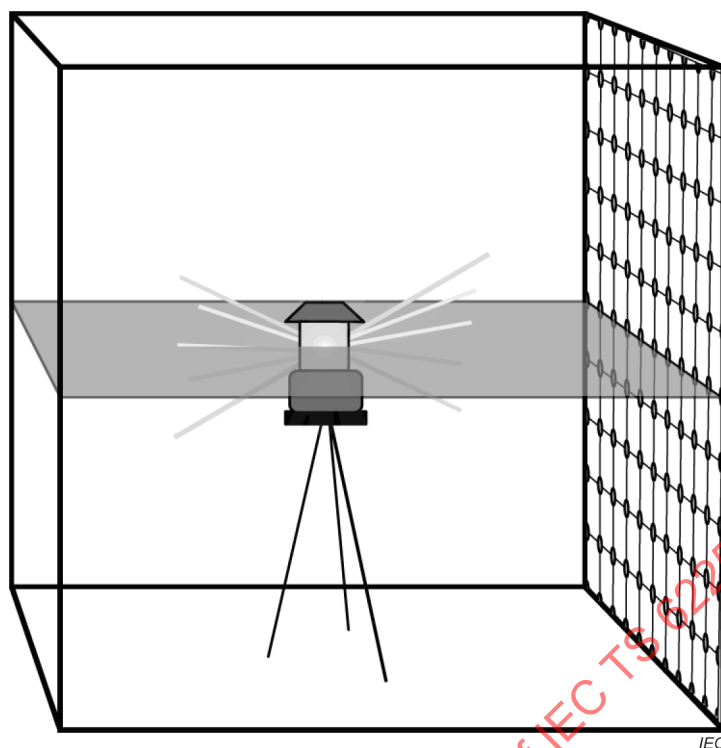


Figure T.1 – Horizontal plane for determining FWHM angle and radial illuminance distribution, for an omnidirectional light point

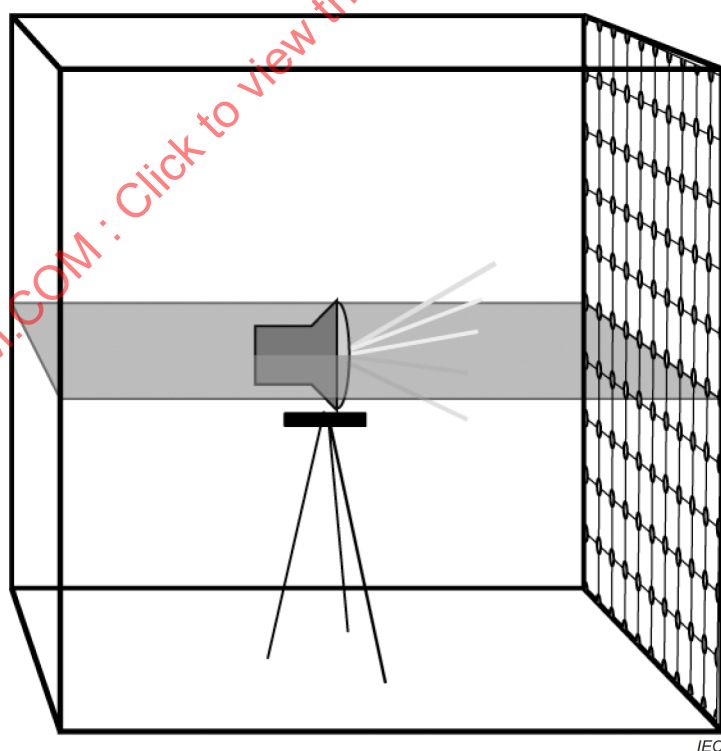


Figure T.2 – Horizontal plane for determining FWHM angle and radial illuminance distribution, for a directed light point

- 6) If the light point contains a three-dimensional array of light sources (e.g. LEDs) and multiple choices of either horizontal or vertical planes, or both, are available following the above criteria, it is preferable to align the light point such that the horizontal and vertical planes are planes of symmetry of the array configuration, if possible. For example, if the light point contains four LED PCBs with outward-facing LEDs at 90° angles, the vertical plane could be chosen to pass through the centres of two of the LED PCBs.
- 7) Typically, except for upward- or downward-directed omnidirectional light points, the intersection of the horizontal and vertical planes contains the line segment that connects the centre of the light source with the point of maximum illuminance.
- 8) Sometimes, as in the case of LED bulbs, it can be difficult to determine whether a light point should be treated as omnidirectional prior to conducting the test. In some cases, it is necessary to perform the test with multiple choices of horizontal and vertical planes. Generally, the radial distribution of illuminance in the vertical plane of an omnidirectional product will have two local maxima at or near 90° and 270°. If a light point is tested as directed but exhibits this characteristic, or if the horizontal and vertical FWHM angles are greater than 180°, the possibility should be considered that the light point should be tested as omnidirectional.
- 9) If, for a particular product, the above guidelines are contradictory or inapplicable, the horizontal and vertical planes may be chosen at the laboratory's discretion, in consultation with the company.

NOTE The terms "horizontal" and "vertical" are used for notational convenience; the horizontal and vertical planes for the purposes of light distribution are not necessarily horizontal and vertical relative to the ground when the light point is in use or when the measurement is being performed. The orientation of the light point in the laboratory does not necessarily correspond to the product's intended use.

b) Prepare the test sample for lighting evaluation as described in I.4.1.

The procedure for calculating FWHM angles presented in T.5.3.6, T.5.4.6, and T.5.5.6 are adequate for most products. For products with unusual distributions for which these procedures do not accurately describe the shape of the distribution, the test laboratory should use its discretion and provide documentation of the procedure used. In such a situation the laboratory may report multiple FWHM angles for different parts of the distribution or may report that the FWHM angles could not be determined.

T.5.2 Goniophotometer

A goniophotometer may be used to measure both the light distribution characteristics of a lighting appliance and also the total luminous flux. Operation of a goniophotometer is beyond the scope of this document, and testing with a goniophotometer device should be conducted in accordance with the following standard test methods, with the DUT operated using a laboratory power supply as described in I.4.1:

- CIE 084
- CIE 127
- ANSI/IES LM-79

T.5.3 Multi-plane method

T.5.3.1 General

The multi-plane method, described in I.4.4, can be used to measure luminous flux and characterize light distribution of ambient lights, suspended task lights, and desktop task lights. For characterizing the light distribution of desktop task lights, depending on the details of the intended application, the illuminance on a desktop method (T.5.6) is generally more appropriate; the multi-plane and illuminance on a desktop methods may be used in conjunction to obtain both luminous flux and light distribution characteristics.

T.5.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Multi-plane test apparatus (described in Annex I).
- DC power supply.
- Illuminance meter.
- DC voltmeter or multimeter.
- DC ammeter.

T.5.3.3 Test prerequisites

The product specification may define the distance(s) at which the usable area, work surface illuminance, and radial distribution of illuminance are to be determined; if not otherwise specified, use a value of 0,75 m for the usable area and work surface illuminance measurements and 1 m for the radial distribution of illuminance. Distances shall be specified as the distance from the grid surface to the centre point of the light source. The battery voltage and current corresponding to the average relative light output over the L_{70} run time are required. The DUT shall be prepared for lighting evaluation as described in Annex G. Before measurement, the battery of the DUT shall be replaced by a DC power supply.

T.5.3.4 Apparatus

The multi-plane apparatus is described in I.4.4.

T.5.3.5 Procedure

The test procedures for determining the ambient light characterization are the same procedures as those used to determine total luminous flux and are described in I.4.4.5. It is only necessary to conduct this procedure once per test sample to gather all necessary information necessary to calculate luminous flux (as detailed in Annex I), usable area, work surface illuminance, and FWHM angles.

T.5.3.6 Calculations

Since the multi-plane method requires the DUT to be positioned so that its centre point is at a distance of 0,5 m from the lighting distribution grid surface, the measurements shall be adjusted by performing the following calculations:

- Correct for differences in measurement distance by adjusting the illuminance values to the desired distance for only the measurements on the first surface measured in the multi-plane method (i.e. the surface containing the point of maximum illuminance). Use the following formula:

$$E_{v,adj} = E_{v,surf} \left(\frac{y_{surf}}{y_{spec}} \right)^2$$

where

$E_{v,adj}$ is the illuminance adjusted for distance, in lux (lx);

$E_{v,surf}$ is the measured illuminance on the grid surface, in lux (lx);

y_{surf} is the distance between the centre of the grid surface and the DUT during the test (0,5 m), in metres (m);

y_{spec} is the distance at which usable area and work surface illuminance are to be determined (see T.5.3.3), in metres (m).

- b) Calculate the average of the illuminance adjusted for distance ($E_{v,adj}$) over all possible regions of the first measured 1 m² grid surface that are composed of twelve illuminance values in a four by three configuration. The maximum of the calculated averages is the work surface illuminance.

NOTE 1 The work surface dimensions were selected to correspond to two adjacent sheets of A4 paper.

- c) Count the number of illuminance values equal to or greater than the specified minimum illuminance (see T.5.3.3). Each value corresponds to 0,01 m². Multiply the number of values by 0,01 m² to obtain the total usable area. (A maximum usable area of 1,21 m² is achievable when taking 121 measurements.)
- d) Repeat step c) for a range of minimum illuminance values. See Table T.3 for an example of determining the usable area for a range of minimum illuminance values.
- e) Plot the usable area as a function of minimum illuminance. Plot the values for each of the tested settings on the same plot. The domain of the plot shall include the maximum illuminance value for the brightest setting. See Figure T.8 for an example of a plot showing usable area as a function of minimum illuminance.
- f) Create a three-dimensional surface plot showing the illuminance values on the brightest surface of the 1 m² grid. See Figure T.9 for an example of a three-dimensional surface plot.

In order to generate polar plots of the distribution and to calculate FWHM angles, it is necessary to adjust the data collected by the multi-plane method to estimate the illuminance on the inner surface of a virtual sphere centred on the light source. These calculations are only valid if the distance from the light source to the illuminance meter is at least five times the longest dimension of the emissive surface of the DUT. If this condition is not met, the polar plots shall be generated and FWHM angles determined using the goniophotometer (T.5.2) or turntable (T.5.5) method.

- a) Correct the original, measured illuminance values ($E_{v,surf}$) for differences in measurement angle so that the illuminance values represent the illuminance on an imaginary surface normal to the line connecting the DUT and the illuminance meter:

$$E_{v,rad} = \frac{E_{v,surf}}{\cos \theta} = E_{v,surf} \frac{\sqrt{x^2 + z^2 + y_{surf}^2}}{y_{surf}}$$

where

$E_{v,rad}$ is the illuminance on a surface normal to the line connecting the DUT and the illuminance meter, in lux (lx);

$E_{v,surf}$ is the measured illuminance on the grid surface, in lux (lx);

θ is the angle between a line connecting the DUT and the illuminance meter and a line connecting the DUT and the centre of the grid;

x is the horizontal position of the illuminance meter relative to the centre of the grid, in metres (m);

z is the vertical position of the illuminance meter relative to the centre of the grid, in metres (m);

y_{surf} is the distance between the centre of the grid surface and the DUT during the test, in metres (m).

NOTE 2 The coordinate axes are oriented as shown in Figure I.1, with the origin at the light source; that is, at the centre of the grid, $x = 0$, $z = 0$, and $y = y_{surf}$.

It is only necessary to correct those values that will be used in further calculations. Typically, this is the set of values lying in the horizontal and vertical planes, as described in steps c) and d).

- b) Correct the angle-corrected illuminance values ($E_{v,rad}$) for differences in measurement distance, so that the illuminance values represent the illuminance on the inner surface of a sphere of radius R centred at the light source, by adjusting each measured illuminance value to a constant distance from the DUT using the following formula:

$$E_{v,sphere} = E_{v,rad} \frac{x^2 + z^2 + y_{surf}^2}{R^2}$$

where

- $E_{v,sphere}$ is the illuminance on the virtual sphere, in lux (lx);
- $E_{v,rad}$ is the illuminance on a surface normal to the line connecting the DUT and the illuminance meter, as calculated in a), in lux (lx);
- x is the horizontal position of the illuminance meter relative to the centre of the grid, in metres (m);
- z is the vertical position of the illuminance meter relative to the centre of the grid, in metres (m);
- y_{surf} is the distance between the centre of the grid surface and the DUT during the test (0,5 m), in metres (m);
- R is the distance at which the radial distribution of illuminance is to be determined (see T.5.3.3), in metres (m).

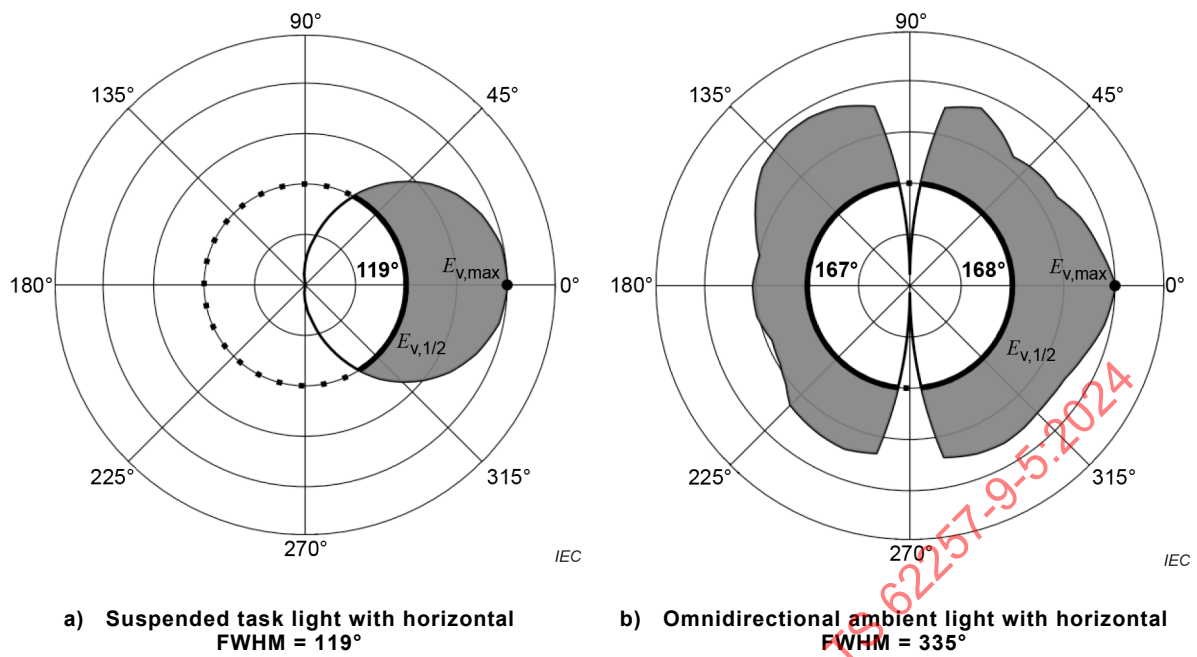
NOTE 3 The numerator of the fraction in the formula is the square of the distance, in metres, from the illuminance meter to the DUT.

- c) Calculate the horizontal FWHM angle using the following steps.

- 1) Identify the illuminance values on the virtual sphere ($E_{v,sphere}$) that lie on the horizontal plane (as defined in T.5.1) that intersects the centre of the brightest surface of the 1 m² grid (Figure T.1 and Figure T.2). The point of maximum illuminance should fall on this plane.
- 2) For each illuminance value in the horizontal plane, calculate the angle between the Y axis (as defined in Figure I.1, with the origin of the coordinate system at the centre point of the light source) and the line connecting the centre point of the light source and the location of the illuminance measurement. Tabulate the illuminance ($E_{v,sphere}$) as a function of angle.
- 3) Calculate the half-maximum illuminance ($E_{v,1/2}$), which is half of the maximum value of $E_{v,sphere}$ in the plane identified in step 1).
- 4) Linearly interpolate between adjacent illuminance values (as a function of angle) to identify the regions over which the illuminance $E_{v,sphere}$ is greater than $E_{v,1/2}$.
- 5) Calculate the FWHM angle as the total angle subtended by the regions where $E_{v,sphere}$ is greater than $E_{v,1/2}$. If there are multiple regions over which the illuminance is greater than $E_{v,1/2}$, the FWHM angle is the sum of the angles subtended by all such regions. If there are no points where the illuminance is less than $E_{v,1/2}$, the FWHM angle is 360°. See Figure T.3 for examples.

- d) To calculate the vertical FWHM angle, repeat the previous step using the vertical plane that intersects the centre of the brightest surface of the 1 m² grid, as defined in T.5.1. However, if the distribution in the vertical plane consists of multiple lobes, as in Figure T.4, the vertical FWHM angle is the average, not the sum, of the FWHM angles for all of the lobes. Report horizontal and vertical FWHM angles separately.

- e) Plot the radial distribution of illuminance in the horizontal and vertical planes (as defined in T.5.1) on two separate polar plots. See Figure T.10 for an example of a polar plot.



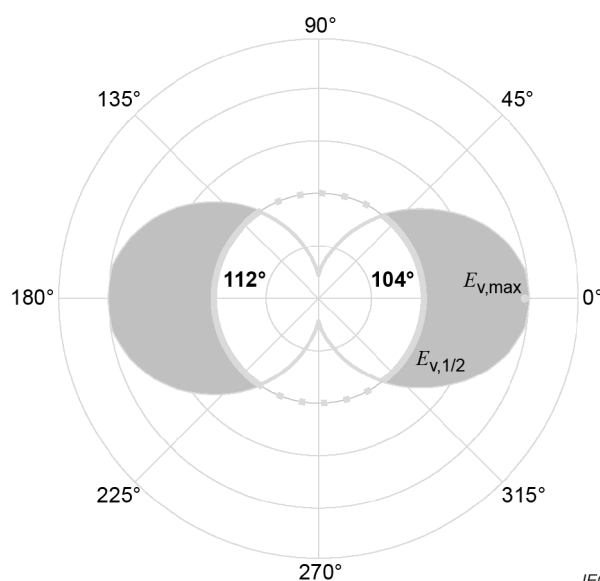
Key

$E_{v,max}$ Maximum illuminance (lx)

$E_{v,1/2}$ Half-maximum illuminance (lx)

NOTE The half-maximum illuminance ($E_{v,1/2}$) is indicated by the dotted line. The illuminance exceeds $E_{v,1/2}$ in the shaded areas. The sum of the angles subtended by the shaded areas is the FWHM angle.

Figure T.3 – Radial illuminance distributions in the horizontal plane for two example products, showing the calculation of the horizontal FWHM angle

**Key**

$E_{v,max}$ Maximum illuminance (lx)

$E_{v,1/2}$ Half-maximum illuminance (lx)

NOTE The half-maximum illuminance ($E_{v,1/2}$) is indicated by the dotted line. The illuminance exceeds $E_{v,1/2}$ in the shaded areas. The average of the angles subtended by the shaded areas is the vertical FWHM angle.

Figure T.4 – Radial illuminance distribution in the vertical plane for an example omnidirectional ambient light with vertical FWHM = 108°

T.5.4 Illuminance on a plane method

T.5.4.1 General

In this test, the illumination level is measured on a surface of 1 m². This test measures the usable area and work surface illuminance. If the light distribution is sufficiently narrow, the FWHM angles can also be measured using this method. To measure wider FWHM angles, or if plots of the radial illuminance distribution are desired, this method may be used in conjunction with the turntable method (T.5.5). This test is appropriate for ambient and suspended task lights; ambient lights with very wide-angle or omnidirectional output should be tested using the goniophotometer (T.5.2), multi-plane method (T.5.3), or turntable method (T.5.5).

T.5.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC power supply.
- DC voltmeter or multimeter.
- DC ammeter.
- Illuminance meter.
- Lighting distribution grid testing surface.

T.5.4.3 Test prerequisites

The product specification may define the distance(s) at which the usable area, work surface illuminance, and radial distribution of illuminance are to be determined and the minimum illuminance to be used in the usable area calculation; if not otherwise specified, use a value of 0,75 m for the usable area and work surface illuminance measurements and 1 m for the radial distribution of illuminance. The battery voltage and current corresponding to the average relative light output over the L_{70} run time are required. The DUT shall be prepared for lighting evaluation as described in Annex G. Before measurement, the battery of the DUT shall be replaced by a DC power supply. Measurements shall be taken in a conditioned space such that the air temperature is $22\text{ °C} \pm 5\text{ K}$.

T.5.4.4 Apparatus

The apparatus for this test consists of a 1 m^2 measurement target with 121 evenly-spaced measurement points (10 cm apart), an illuminance meter, and a mechanism to mount the DUT at the specified distance from the measurement target (see Figure T.5). Testing shall be done in a completely dark space, except for illumination provided by the DUT. The test operator should wear all-black clothing if required to be near to the measurement surface.

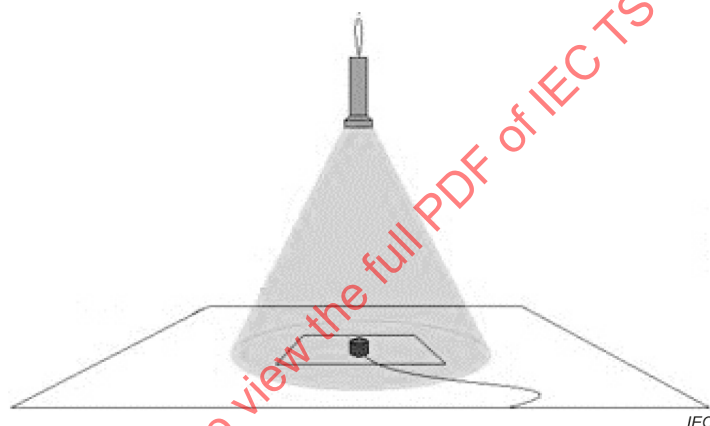


Figure T.5 – Schematic of a task light suspended above an illuminance meter

T.5.4.5 Procedure

The following steps shall be performed.

- Supply power to the DUT using a DC power supply as described in I.4.1. Follow power supply guidelines in the power supply set up procedure (Annex H).
- If at the desired voltage the DUT will not operate in the desired setting, increase the power supply voltage by increments of 0,05 V until the DUT is able to operate in the desired setting, then attempt to reduce the voltage to the desired level.
- Position the DUT as shown in Figure T.5 so that the point of maximum illuminance is in the centre of the grid. The distance from the light source to the grid shall be equal to the distance at which the usable area and work surface illuminance are to be determined (see T.5.4.3). (The vertical orientation of the DUT in Figure T.5 is intended as a schematic illustration only; the DUT may be mounted horizontally or in any other orientation.)
- Operate the DUT for at least 20 min at the desired setting before the first measurement is started.
- Measure illuminance at each of the 121 measurement points on the test plane. However, illuminance measurements may be omitted for the grid points at which the illuminance is less than the resolution of the illuminance meter or less than 0,2 % of the maximum illuminance reading on the grid.

T.5.4.6 Calculations

The following calculations shall be made.

- a) Calculate the average illuminance over all possible regions of the 1 m² grid surface that are composed of twelve illuminance values in a four by three configuration. The maximum of the calculated averages is the work surface illuminance.

NOTE 1 The work surface dimensions were selected to correspond to two adjacent sheets of A4 paper.

- b) Count the number of illuminance values equal to or greater than the specified minimum illuminance (see T.5.4.3). Each value corresponds to 0,01 m². Multiply the number of values by 0,01 m² to obtain the total usable area (a maximum usable area of 1,21 m² is achievable when taking 121 measurements).
- c) Repeat step b) for a range of minimum illuminance values. See Table T.3 for an example of determining the usable area for a range of minimum illuminance values.
- d) Plot the usable area as a function of minimum illuminance. Plot the values for each of the tested settings on the same plot. The domain of the plot shall include the maximum illuminance value for the brightest setting. See Figure T.8 for an example of a plot showing usable area as a function of minimum illuminance.
- e) Create a three-dimensional surface plot showing the illuminance values on the entire grid. See Figure T.9 for an example of a three-dimensional surface plot.

For products with sufficiently narrow light distributions, FWHM angles can be determined from the illuminance on a plane method. In order to calculate FWHM angles, it is necessary to adjust the data collected by the illuminance on a plane method to estimate the illuminance on the inner surface of a virtual sphere centred on the light source. These calculations are only valid if the distance from the light source to the illuminance meter is at least five times the longest dimension of the emissive surface of the DUT. If this condition is not met, the FWHM angles shall be determined using the goniophotometer (T.5.2) or turntable method (T.5.5). If the FWHM angle cannot be determined because the distribution is too wide, the FWHM angles shall be determined using the goniophotometer (T.5.2), multi-plane method (T.5.3), or turntable method (T.5.5).

- a) Using the formulae in T.5.3.6 a) and b), adjust the measured illuminance values to calculate the illuminance on the inner surface of a sphere of radius R centred at the light source.
- b) Calculate the horizontal FWHM angle using the following steps:
 - 1) Identify the illuminance values on the virtual sphere ($E_{v,sphere}$) that lie on the horizontal plane (defined in T.5.1) that intersects the centre of the brightest surface of the 1 m² grid (Figure T.1 and Figure T.2). The point of maximum illuminance should fall on this plane.
 - 2) For each illuminance value on the horizontal plane, calculate the angle between the Y axis (as defined in Figure I.1, with the origin of the coordinate system at the DUT) and the line connecting the light source and the location of the illuminance measurement. Tabulate the illuminance ($E_{v,sphere}$) as a function of angle.
 - 3) Calculate the half-maximum illuminance ($E_{v,1/2}$), which is half of the maximum value of $E_{v,sphere}$ in the plane identified in step 1).
 - 4) Linearly interpolate between adjacent illuminance values (as a function of angle) to identify the regions over which the illuminance $E_{v,sphere}$ is greater than $E_{v,1/2}$.
 - 5) Calculate the FWHM angle as the total angle subtended by the regions where $E_{v,sphere}$ is greater than $E_{v,1/2}$. If there are multiple regions over which the illuminance is greater than $E_{v,1/2}$, the FWHM angle is the sum of the angles subtended by all such regions. If the illuminance at the leftmost or rightmost point is greater than $E_{v,1/2}$, the FWHM angle cannot be determined using the illuminance on a plane method. See Figure T.3 for examples.

- 6) To calculate the vertical FWHM angle, repeat the previous step using the vertical plane that intersects the centre of the brightest surface of the 1 m² grid, as defined in T.5.1. However, if the distribution in the vertical plane consists of multiple lobes, as in Figure T.4, the vertical FWHM angle is the average, not the sum, of the FWHM angles for all of the lobes. Report horizontal and vertical FWHM angles separately.

NOTE 2 It is unlikely that the illuminance on a plane method would be appropriate for a product having a vertical-plane light distribution with multiple lobes.

T.5.5 Turntable method

T.5.5.1 General

This test measures the radial distribution of illuminance at a constant distance from the DUT. This method may be used in conjunction with the illuminance on a plane method to determine the FWHM angles, usable area, and work surface illuminance.

T.5.5.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Turntable (see Figure T.6) or equivalent apparatus as described in T.5.5.4.
- DC power supply.
- Illuminance meter.
- DC voltmeter or multimeter.

T.5.5.3 Test prerequisites

The product specification may define the distance at which the radial distribution of illuminance is to be determined; if not otherwise stated, use a value of 1 m. The DUT shall be prepared for lighting evaluation as described in Annex G. Before measurement, the battery of the DUT shall be replaced by a DC power supply. Measurements shall be taken in a conditioned space such that the air temperature is 22 °C ± 5 K.

T.5.5.4 Apparatus

This test is performed using a turntable (see Figure T.6). The DUT is placed on the turntable and illuminance is measured at the distance determined in T.5.5.3 (from the centre of the light source to the illuminance meter sensor). Testing shall be done in a completely dark space, except for illumination provided by the DUT. The test operator should wear all-black clothing if required to be near to the measurement surface.

Ensure that the centre of the light source is at the same height as the illuminance meter during the test and that the illuminance meter is positioned at the point of maximum illuminance. If tilting the DUT to position the illuminance meter at the point of maximum illuminance would result in an inaccurate measurement of the FWHM angle and radial illuminance distribution (for example, if the DUT is an omnidirectional ambient light), the DUT or illuminance meter may be raised or lowered instead.

As an alternative to a turntable, an apparatus in which the illuminance meter is rotated or positioned at points at a constant distance around a stationary DUT may be used.

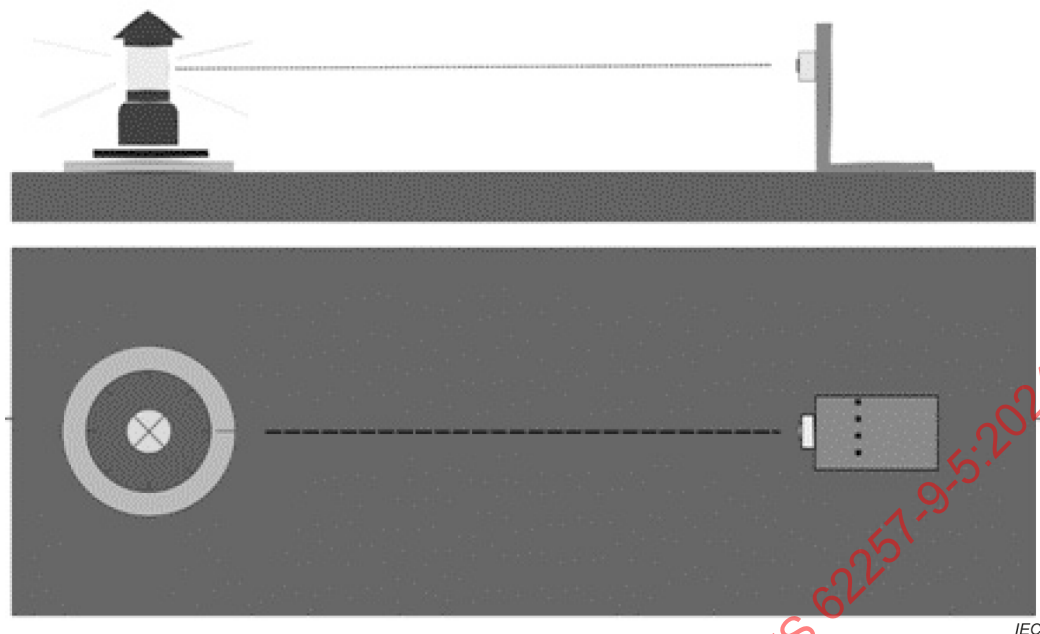


Figure T.6 – Schematic of turntable setup, with the DUT shown

T.5.5.5 Procedure

The following steps shall be performed.

- a) Supply power to the DUT using a DC power supply as described in I.4.1. Follow power supply guidelines in the power supply setup procedure (Annex H). The distance from the centre of the light source to the illuminance meter should be equal to the distance at which the radial distribution of illuminance is to be measured (see T.5.5.3).
- b) If at desired voltage the DUT will not operate at the desired setting, increase the power supply voltage by increments of 0,05 V until the DUT is able to operate at the desired setting, then attempt to reduce the voltage to the desired level.
- c) Secure the DUT to the turntable so that the measured illuminance values lie in the horizontal plane shown in Figure T.1 and Figure T.2, with the illuminance meter at the point of maximum illuminance. Generally, omnidirectional lighting appliances such as lanterns can simply be set on the turntable and secured to prevent movement; for directed lighting appliances, a clamp or other special apparatus is often required to secure the DUT. Ensure that the DUT cannot move relative to the turntable.
- d) Operate the DUT for at least 20 min at the desired setting before the first measurement is started.
- e) Measure illuminance levels at least every 10° for the full 360° angle. However, measurements may be omitted for angles at which the illuminance value is known to be less than the resolution of the illuminance meter or less than 0,2 % of the illuminance at the brightest point. Further, if the FWHM angles are captured after measuring the illuminance levels over the brightest 180°, additional measurements may be omitted.
- f) Repeat the procedure with the DUT resting at an orientation normal to the “horizontal” orientation, such that the measurement points lie in the vertical plane defined in T.5.1. A special apparatus may be required to secure the DUT in this orientation. Ensure that the DUT cannot move relative to the turntable.

T.5.5.6 Calculations

The following calculations shall be made.

- a) Calculate the horizontal FWHM angle using the following steps.
 - 1) Calculate the half-maximum illuminance ($E_{v,1/2}$), which is half of the maximum illuminance value from the horizontal sweep.
 - 2) Identify the regions from the horizontal sweep over which the measured illuminance is greater than $E_{v,1/2}$. If the angular resolution of the measurements performed in T.5.5.5 is coarser than 2° , linearly interpolate between measurements (as a function of angle) to obtain finer resolution.
 - 3) Calculate the FWHM angle as the total angle subtended by the regions where the measured illuminance is greater than $E_{v,1/2}$. If there are multiple regions over which the illuminance is greater than $E_{v,1/2}$, the FWHM angle is the sum of the angles subtended by all such regions. If there are no points where the illuminance is less than $E_{v,1/2}$, the FWHM angle is 360° . See Figure T.3 for examples.
- b) To calculate the vertical FWHM angle, repeat the previous step using the measurements from the vertical sweep, except that if the distribution in the vertical plane consists of multiple lobes, as in Figure T.4, the vertical FWHM angle is the average, not the sum, of the FWHM angles for all of the lobes. Report horizontal and vertical FWHM angles separately.
- c) Plot the illuminance values over the “horizontal” and “vertical” sweeps as two separate polar plots. See Figure T.10 for an example of a polar plot.

T.5.6 Illuminance on a desktop method

T.5.6.1 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

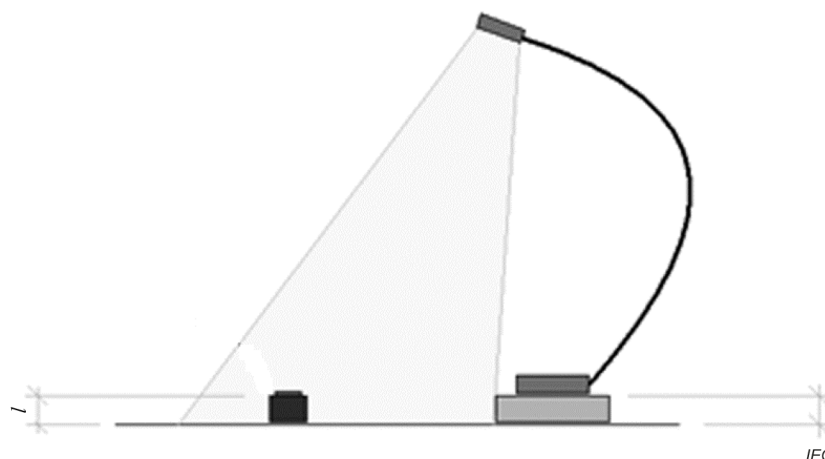
- DC power supply.
- Illuminance meter.
- Lighting distribution grid testing surface.

T.5.6.2 Test prerequisites

The battery voltage and current corresponding to the average relative light output over the L_{70} run time is required. The DUT shall be prepared for lighting evaluation as described in Annex G. Before measurement, the battery of the DUT shall be replaced by a DC power supply. Measurements shall be taken in a conditioned space such that the air temperature is $22^\circ\text{C} \pm 5\text{ K}$.

T.5.6.3 Apparatus

Figure T.7 shows a side view of the desktop light measuring setup. The test operator should wear all-black clothing if required to be near to the measurement surface. Testing shall be done in a completely dark space, except for illumination provided by the DUT.

**Key**

l Height of illuminance meter head and desktop light spacer

Figure T.7 – Side view of desktop light measuring setup

T.5.6.4 Procedure

The following steps shall be performed.

- Supply power to the DUT using a DC power supply as described in I.4.1. Follow power supply guidelines in the power supply set up procedure (Annex H).
- If at the desired voltage the DUT will not operate at the desired setting, increase the power supply voltage by increments of 0,05 V until the DUT is able to operate at the desired setting, then attempt to reduce the voltage to the desired level.
- Operate the DUT at least for 20 min at the desired setting before the first measurement is taken.
- Place the DUT on the surface using a spacer to compensate for the height of the illuminance meter head. The height of the spacer shall be equal to the height of the measurement plane of the illuminance meter (see Figure T.7). The DUT shall be oriented in the manner that it would be used by the consumer, to the best of the tester's ability, using the provided stand or mounting mechanism, if any. The DUT shall be located at the position that the tester estimates will maximize the usable area that falls on the grid (as defined in T.5.4.6 step b)).
- Measure the illuminance at 121 evenly spaced points, 10 cm apart, on a 1 m × 1 m horizontal grid surface. Measure illuminance levels for the grid points that read an illuminance value greater than the resolution of the illuminance meter and greater than 0,2 % of the maximum illuminance reading.

T.5.6.5 Calculations

The calculations for the illuminance on a desktop method are identical to the calculations for the illuminance on a plane method (refer to T.5.4.6). Omit steps a) and b). (Do not calculate FWHM angles or generate polar plots.)

T.6 Reporting

Report the following in the light distribution test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - DUT setting;
 - test room temperature (°C);
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - drive current (A);
 - drive voltage at product (V);
 - waiting time (min);
 - vertical FWHM angle (°);
 - horizontal FWHM angle (°);
 - average usable area through L_{70} (m²);
 - work surface illuminance (lux).
- Average of n sample results for each DUT aspect tested.
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .
- Figures:
 - plot of illuminated area vs. minimum illuminance (see Figure T.8 for an example);
 - surface plots of illuminance on either a plane or polar plots of the radial illuminance distribution, or both (see Figure T.9 and Figure T.10 for examples).

Table T.3 – Table of example illuminance measurements on the brightest “face” of the 1 m² grid and usable area as a function of minimum illuminance

Illuminance measurements lx											Min. illuminance lx	Usable area m ²
13,6	17,3	21,0	24,5	26,6	27,8	26,6	22,7	19,7	16,5	13,5	10	1,21
16,9	22,1	28,0	33,5	38,5	41,1	38,1	33,2	27,7	21,5	16,6	20	1,06
20,6	27,1	35,8	44,4	52,7	54,7	51,6	43,0	34,7	26,9	20,0	30	0,69
24,1	32,4	44,3	57,4	69,3	74,3	68,4	55,9	42,5	32,0	23,3	40	0,46
26,4	36,8	52,1	66,9	82,7	88,7	81,9	66,1	49,1	35,4	25,1	50	0,34
27,4	38,2	54,5	71,1	88,1	95,0	87,0	69,5	52,1	36,9	26,2	60	0,21
27,0	36,7	51,2	66,7	81,8	87,4	80,8	64,9	49,4	34,9	24,3	70	0,12
24,0	32,2	43,4	56,5	66,7	70,5	66,2	55,4	41,6	30,0	22,0	80	0,09
20,8	26,8	35,7	43,7	49,6	52,2	50,3	41,6	32,7	25,1	18,4	90	0,01
17,3	21,9	27,6	32,6	36,9	38,1	35,9	31,4	25,6	20,2	15,4	100	0,00
13,8	17,0	20,3	23,3	25,6	26,1	25,4	22,6	18,9	15,2	12,3		

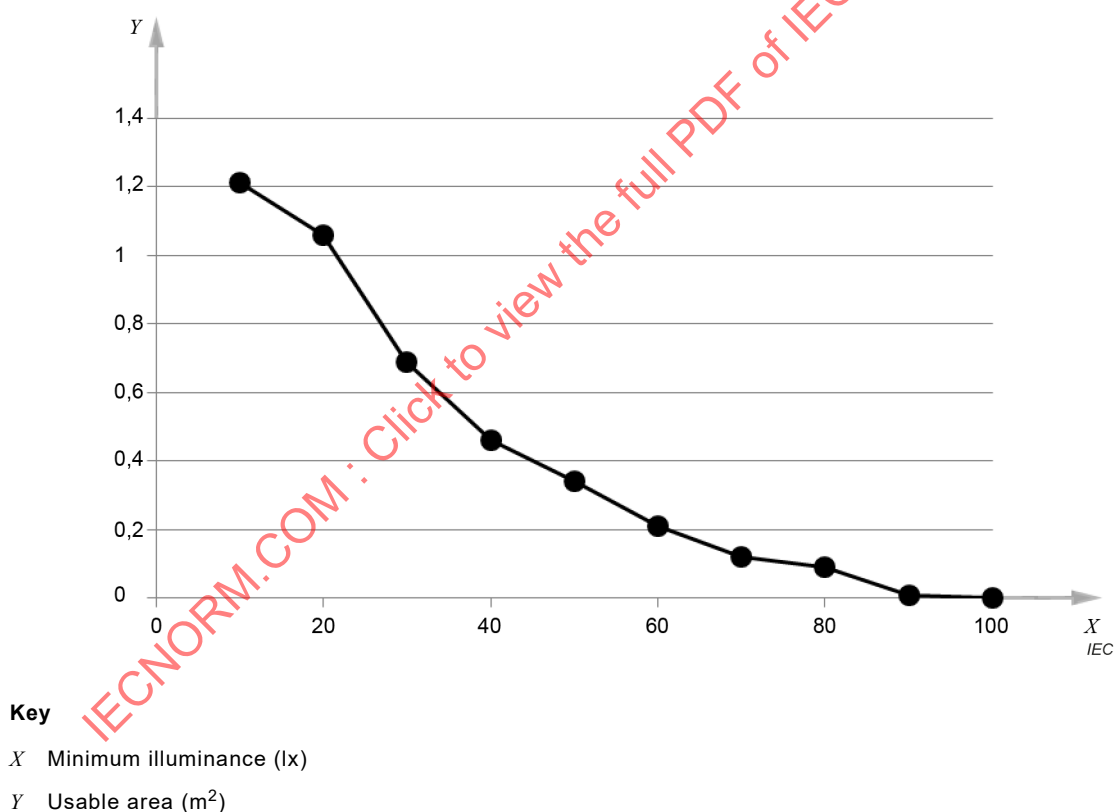
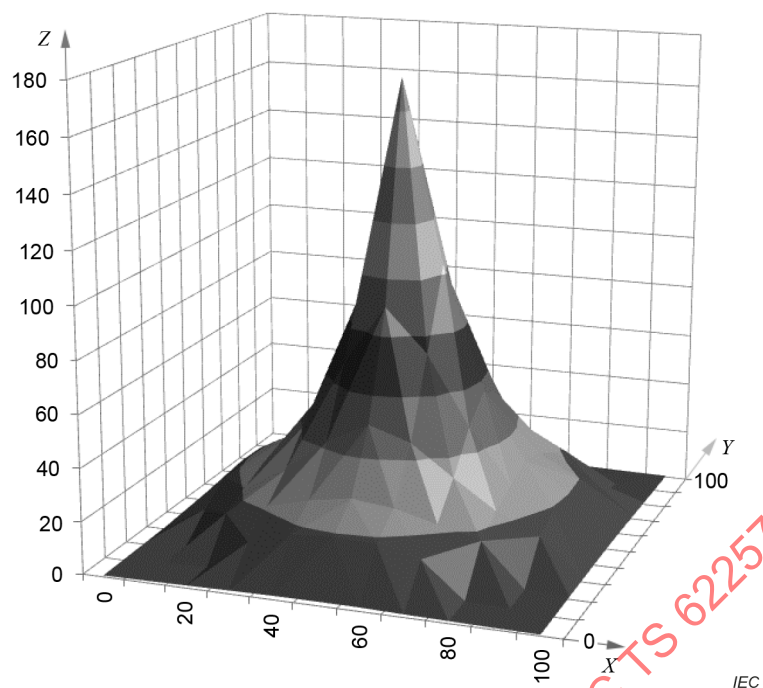


Figure T.8 – Example plot of usable area as a function of minimum illuminance



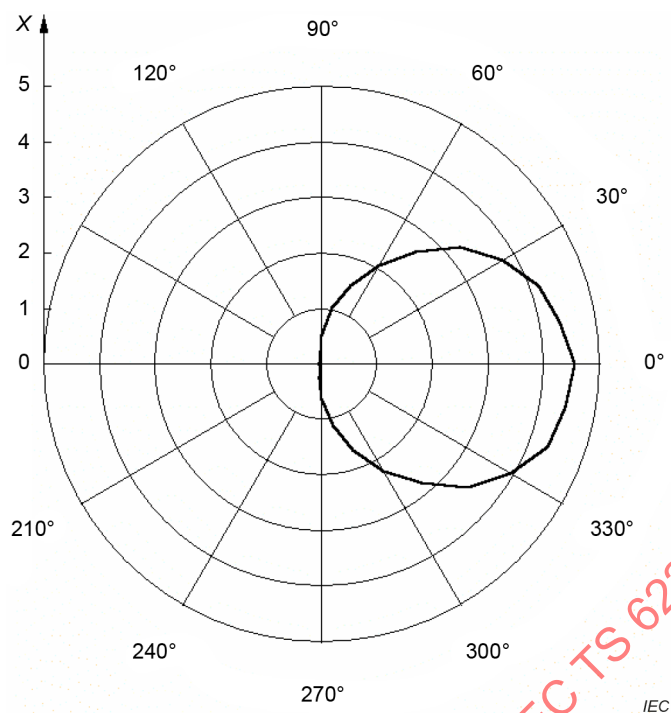
Key

X Horizontal position (cm)

Y Vertical position (cm)

Z Illuminance (lx)

Figure T.9 – Example of resulting surface plot of light distribution from the brightest “face” of the multi-plane method or illuminance on a plane method

**Key**

X Illuminance (lx)

Figure T.10 – Example of a polar plot of the radial illuminance distribution

Annex U (normative)

Physical and water ingress protection test

U.1 Background

Ingress protection (IP) testing determines the degrees of protection provided by the enclosures of a product's components. The IP rating uses two numerals to define the degrees of protection. The first numeral identifies the degree the component has protection against solid foreign objects. The second numeral identifies the degree the component has protection against ingress of water with harmful effects.

This test applies to all enclosures of the DUT that contain electronics or electrical connections, including the primary enclosure(s) of the main unit(s), the PV module(s), and any appliances included with the product. Note that the test requirements for enclosures may be specified based on the component category (fixed outdoor, portable integrated, portable separate, fixed indoor or PV module) as described in 4.1.2. If more than one identical component or appliance is included with the product, only one of each set of identical appliances should be tested. In the procedure, the term DUT refers to the component, appliance, or enclosure being tested, not necessarily the entire product submitted for testing. Different requirements can be applicable to different components of a product. In Annex U, unless otherwise specified, the term electronic component means an individual resistor, capacitor, integrated circuit, LED, switch, or the like; otherwise, the term component is used as defined in 3.36.

U.2 Test outcomes

The water exposure and physical ingress protection test outcomes are listed in Table U.1.

Table U.1 – Water exposure and physical ingress protection test outcomes

Metric	Reporting units	Related aspects	Notes
IP2X	Pass/fail	4.2.3.6 Physical ingress protection 4.2.3.7 Physical ingress protection – PV module	12,5 mm diameter probe
IP3X	Pass/fail	4.2.3.6 Physical ingress protection 4.2.3.7 Physical ingress protection – PV module	2,5 mm diameter probe
IP4X	Pass/fail	4.2.3.6 Physical ingress protection 4.2.3.7 Physical ingress protection – PV module	1 mm diameter probe
IP5X	Pass/fail	4.2.3.6 Physical ingress protection 4.2.3.7 Physical ingress protection – PV module	No ingress of dust Shall be tested by a laboratory that has been accredited to test in accordance with IEC 60529 or IEC 60598-1. Laboratories shall use the procedure in IEC 60529 or IEC 60598-1; no simplified alternative is acceptable.
IPX1	Pass/fail	4.2.3.2 Water protection – enclosure 4.2.3.3 Water protection – circuit protection and drainage	Vertically dripping water

Metric	Reporting units	Related aspects	Notes
IPX3	Pass/fail	4.2.3.2 Water protection – enclosure 4.2.3.3 Water protection – circuit protection and drainage	Direct sprays of water from within 60° of vertical
Modified IPX4	Pass/fail	4.2.3.5 Water protection – PV module	Splashes of water from any direction
IPX5	Pass/fail	4.2.3.2 Water protection – enclosure 4.2.3.3 Water protection – circuit protection and drainage	Water projected in jets Shall be tested by a laboratory that has been accredited to test in accordance with IEC 60529 or IEC 60598-1. Laboratories shall use the procedure in IEC 60529 or IEC 60598-1; no simplified alternative is acceptable.
IPX7		4.2.3.2 Water protection – enclosure 4.2.3.3 Water protection – circuit protection and drainage	Temporary immersion between 0,15 m and 1 m

U.3 Related tests

Annex U is related to the level of water protection (Annex V).

For lighting appliances without batteries, the physical ingress and water protection test of IEC TS 62257-12-1 may be used in place of Annex U, provided that the IEC TS 62257-12-1 test method defines procedures for estimating or testing the IP codes for which testing is necessary in accordance with either the product specification or the assessment of level of water protection (Annex V), or both.

U.4 Procedure

U.4.1 General

The IP code may be assessed either by sending samples to a laboratory that has been accredited to test in accordance with IEC 60529 or IEC 60598-1 or by estimating the IP code in accordance with the following methods, except that in the case of testing for IPX5 or IP5X, the enclosure shall be tested by a laboratory that has been accredited to test in accordance with IEC 60529 or IEC 60598-1. When testing for IPX5 or IP5X, laboratories shall use the procedure in IEC 60529 or IEC 60598-1; no simplified alternative is acceptable.

The procedures of IEC 60529 may be used to assess IP codes for all components. For lighting appliances or components containing built-in lighting appliances, the procedures of IEC 60598-1 may alternatively be used.

U.4.2 IP testing at a laboratory that has been accredited to test in accordance with IEC 60529 or IEC 60598-1

U.4.2.1 General

Samples are sent to a laboratory that has been accredited to test in accordance with IEC 60529 or IEC 60598-1 to determine the passing or failing for the desired IP requirements.

U.4.2.2 Guidance on working with external IP testing laboratory

Many international IP testing laboratories will require two samples for testing. These should be samples that have not been altered in any way.

This test is destructive. Do not perform any additional tests on the samples after testing.

For water ingress testing, specify to the laboratory that has been accredited to test in accordance with IEC 60529 or IEC 60598-1 how the enclosure shall be oriented during testing. It shall be oriented in the way that the enclosure is most likely to be used.

NOTE The test used to assess PV modules for ingress of water with harmful effects is modified from the test described in IEC 60529. The modified IPX4 assessment for water ingress protection follows the same procedure to test for IPX4 as described in IEC 60529 with the exception of the angle of spray. In IEC 60529, the PV module is sprayed at angles $\pm 180^\circ$ from vertical, while in the following modified method the PV module is sprayed at angles $\pm 90^\circ$ from vertical.

U.4.3 Simplified IP inspection for ingress of solid foreign objects

U.4.3.1 General

The DUT is visually inspected for protection against ingress of solid foreign objects to determine the passing or failing result for the desired IP requirement. This method may be performed to estimate IP codes IP2X, IP3X, and IP4X.

U.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- 1 mm, 2,5 mm, or 12,5 mm diameter rigid probe.
- Camera.

U.4.3.3 Test prerequisites

The sample tested should have not been altered in any way.

U.4.3.4 Apparatus

No apparatus is required for this test.

U.4.3.5 Procedure

U.4.3.5.1 Procedure for testing component enclosures

The following steps shall be performed.

- a) Before the measurement, be sure that the DUT is properly functioning and that it is sufficiently charged to check for functionality during the test.
- b) If the DUT is required to pass IP2X, select the 12,5 mm probe. If the DUT is required to pass IP3X, select the 2,5 mm probe. If the DUT is required to pass IP4X, select the 1 mm probe.
- c) Explore the DUT's entire surface to test for penetration with the selected probe.
- d) If the 12,5 mm probe can enter a part of the enclosure that contains electronic components, electrical connections or circuits, with minimal force, the DUT is estimated to fail the IP2X assessment.
- e) If the 2,5 mm probe can enter a part of the enclosure that contains electronic components, electrical connections or circuits, with minimal force, the DUT is estimated to fail the IP3X assessment.

- f) If the 1 mm probe can enter a part of the enclosure that contains electronic components, electrical connections or circuits, with minimal force, the DUT is estimated to fail the IP4X assessment.
- g) If the probe can enter an external jack, this is not considered a failure, unless it can enter the enclosure through the external jack. Document any failures with photographs and text.

U.4.3.5.2 Procedure for testing a product's external PV module (if applicable)

PV modules that have been tested in accordance with and meet all requirements of IEC 61215-1 and IEC 61215-2 may be exempted from this test. Test results provided by the company may be accepted if the tests were performed at a laboratory accredited to perform the tests by a recognized accrediting body (e.g. an ILAC MRA signatory, to ISO/IEC 17025). Integrated PV modules that were tested as part of the DUT may be exempted from this test, except in cases similar to the roof light described in c).

- a) Before the measurement, be sure that the PV module is properly functioning and that the enclosure or junction box has not been opened previously.
- b) It is only necessary to assess most PV modules for IP3X. To estimate IP3X, select the 2,5 mm probe; to estimate IP2X, select the 12,5 mm probe.
- c) Explore the PV module's entire surface to test for penetration with the selected probe. For a product that is designed to be installed on the roof with the main unit attached inside the structure directly below, the portion of the product that is designed to be outside shall be assessed for IP3X, while the portion of the product designed to be inside shall be assessed for IP2X.
- d) If the 12,5 mm probe can enter a part of the PV module's enclosure that contains electronic components, electrical connections or circuits, with minimal force, the PV module is estimated to fail the IP2X assessment.
- e) If the 2,5 mm probe can enter a part of the PV module's enclosure that contains electronic components, electrical connections or circuits, the PV module is estimated to fail the IP3X assessment for ingress of solid foreign objects.
- f) If the probe can enter an external jack, this is not considered a failure, unless it can enter the PV module's enclosure through the external jack. Document any failures with photographs and text.

NOTE Since the PV module junction box is not opened until the following enclosure inspection steps, it is not always possible to determine whether the DUT passes or fails this test until after the enclosure inspection steps are performed.

- g) Enclosure inspection: Open the junction box or PV enclosure of the PV module to determine if a circuit board or other sensitive electronics are present. (This can be destructive.) If no circuit boards or sensitive electronics are present or if the junction box or PV enclosure is completely potted with silicone or similar sealant, the PV module is estimated to pass for protection from water ingress and it is not necessary for the tester to assess the PV module for water ingress. Simple screw-type terminals or a single diode, not soldered to a circuit board, are not considered "sensitive electronic components". Any printed circuit board shall be considered "sensitive".
- h) If a circuit board or other sensitive electronic components are present within the junction box or PV enclosure, the water ingress test should be conducted on a new PV module sample that has not been opened.

U.4.3.6 Calculations

No calculations are made for the ingress of solid foreign objects IP test.

U.4.4 Simplified IP preliminary inspection for ingress of water with harmful effects

U.4.4.1 General

The enclosure is visually inspected for protection against ingress of water with harmful effects to determine if it is likely to pass or fail with respect to the desired IP requirement. This method may be performed to estimate IP ratings IPX1, IPX3, a modified IPX4, and IPX7.

NOTE The test used to assess PV modules for ingress of water with harmful effects is modified from the test described in IEC 60529. The modified IPX4 assessment for water ingress protection follows the same procedure to test for IPX4 as described in IEC 60529 with the exception of the angle of spray. In IEC 60529, the DUT is sprayed at angles $\pm 180^\circ$ from vertical, while in the following modified method the DUT is sprayed at angles $\pm 90^\circ$ from vertical.

U.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Controlled water source.
- Camera.

U.4.4.3 Test prerequisites

This test is destructive. Do not perform any additional tests on the sample after testing. The sample tested should have not been altered in any way.

U.4.4.4 Apparatus

No apparatus is required for this test.

U.4.4.5 Procedure

U.4.4.5.1 Procedure for testing enclosures

- a) Before the measurement, be sure that the DUT is properly functioning and that it is sufficiently charged to check for functionality during the test.
- b) The DUT should be oriented in the way that it is most likely to be used. Reference the product's packaging, user manual, and website to determine the orientation in which the DUT is most likely to be used. Record the selected orientation.
- c) If the DUT is to be evaluated to IPX1, sprinkle water from the controlled water source over the DUT so that the water drops are vertical to the DUT. The water flow rate should be close to 1 mm/min. Let the water drip over the DUT for 10 min while rotating the DUT at approximately 1 rpm about its vertical axis. The distance between the water source and DUT should be approximately 0,2 m.
- d) If the DUT is to be evaluated to IPX3, spray water from the controlled water source over the DUT in all practical directions at an angle less than or equal to 60° from vertical. The water flow rate should be close to 10 l/min. Spray the water over the DUT for approximately 1 min per square metre of enclosure surface area for a minimum of 5 min. The distance between the water source and the DUT should be between 0,3 m and 0,5 m.
- e) If the DUT is to be evaluated to IPX7, completely immerse the DUT in water so that the following conditions are satisfied:
 - 1) The lowest point of enclosures with a height less than 850 mm is located 1 000 mm below the surface of the water;
 - 2) The highest point of enclosures with a height greater than 850 mm is located 150 mm below the surface of the water;
 - 3) The duration of the test is 30 min;
 - 4) The water temperature does not differ from that of the DUT by more than 5 K.

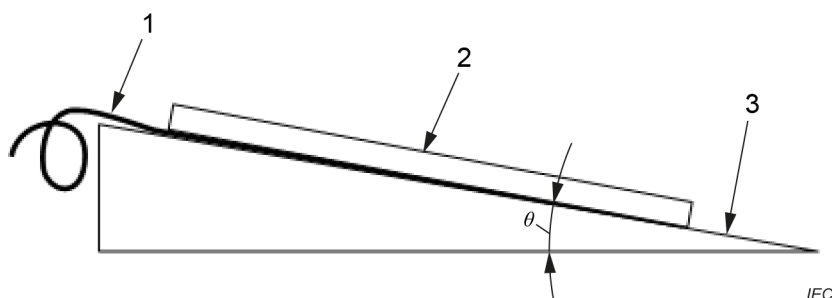
- f) After exposing the DUT to water, dry the enclosure's exterior with a towel without moving the DUT from its orientation during testing.
- g) Enclosure inspection: While keeping the product in the same orientation from testing, open the enclosure with the proper screwdriver(s) or other tools. If any water is found inside the DUT's electronics enclosure, the DUT fails the test for ingress of water with harmful effects. Document with photographs and text. Water found on the external electrical contacts or external surfaces of enclosure-mounted ports, receptacles, and switches shall not constitute a failure if no water penetrates into the inside of the enclosure.

U.4.4.5.2 Procedure for testing a product's external PV module (if applicable)

PV modules that have been tested in accordance with and meet all requirements of IEC 61215-1 and IEC 61215-2 may be exempted from this procedure. Test results provided by the company may be accepted if the tests were performed at a laboratory accredited to perform the tests by a recognized accrediting body (e.g. an ILAC MRA signatory, an ILAC MRA signatory, to ISO/IEC 17025). Integrated PV modules that were tested as part of the DUT may be exempted from this test, except in cases similar to the roof light described in c).

- a) Be sure that before the measurement, the junction box of another sample's external PV module has already been opened to determine if a circuit board or other sensitive electronics are present. (This can be destructive.) Also, visually inspect the module for any unsealed penetrations around the frame which could allow water to potentially reach the active material of the PV module. If no circuit boards or sensitive electronics are present or if the junction box is completely potted with silicone or similar sealant, and no unsealed penetrations are identified, the PV module passes for protection from water ingress with harmful effects and it is not necessary for the tester to further assess the PV module for water ingress.
- b) Before the measurement, be sure that the PV module is properly functioning and that the enclosure or junction box has not been opened previously.
- c) Place the PV module with the active PV area facing up on a smooth, solid, flat surface that is tilted at a 10° angle from the horizontal (Figure U.1). The DUT should be placed in the least favourable orientation on the surface. The placement is intended to resemble common rooftop installations and allow for the possibility that water would run behind the module. This will typically be accomplished by allowing the PV cord to rest under the frame as could occur when installed. For a product that is designed for its PV module to be installed on the roof with the main unit attached inside the structure directly below, install the unit as per the product's instructions on a smooth, solid, flat surface.

NOTE 1 The least favourable orientation is typically the one in which the cable exits the junction box on the upslope side.



Key

- 1 PV module cable
- 2 PV module
- 3 Flat surface
- θ 10° incline

Figure U.1 – Side view of the apparatus for testing an external PV module for protection against water ingress

- d) Spray water from the controlled water source over the PV module in all practical directions (at angles up to 90° from vertical). The water flow rate should be close to 10 l/min. Spray the water over the PV module for approximately 1 min per square metre of enclosure surface area for a minimum of 5 min. The distance between the water source and the PV module should be between 0,3 m and 0,5 m.
- e) After spraying water over the PV module, dry the PV module's exterior on all sides with a towel without tilting the PV module.
- f) Open the junction box or the PV module's enclosure protecting its electronic components with the proper screwdriver(s) or other tools. (This can be destructive.)

NOTE 2 Some external PV modules do not have a typical junction box, but rather the connections are within an enclosure around the module itself.

- g) After opening the PV module's junction box or enclosure, note if there are any unsealed penetrations around the PV module's frame through which water reaches the active material of the PV module.
- h) If no water is found inside the junction box, enclosures or any unsealed penetrations, the PV module is estimated to pass for modified IPX4 protection from water ingress with harmful effects.
- i) If any water is found inside the junction box, enclosures or any unsealed penetrations, document with photographs and text. For the DUT to pass, electronic components and the active material of the PV module shall be adequately protected in accordance with the technical aspects outlined in Annex V. Adequate protection is evaluated by an organization with expertise in product design, failure analysis, energy systems, and general engineering practices. This requirement cannot be met through labelling or consumer-facing documentation.

U.4.4.6 Calculations

No calculations are made for the ingress of water with harmful effects IP test performed through visual inspection.

U.5 Reporting

Report the following in the water exposure and physical ingress protection test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report;
 - component name.
- Results for tested DUT aspects for samples 1 through n :
 - IP levels tested and ratings for the ingress of solid foreign objects;
 - IP levels tested and ratings for the ingress of water with harmful effects;
 - Result of enclosure inspection of PV module junction box; specify if a circuit board or other sensitive electronics are present and if junction box is completely potted with silicone or similar sealant.
 - pass/fail for the IP rating for the ingress of solid foreign objects, if applicable;
 - pass/fail for the IP rating for the ingress of water with harmful effects, if applicable.
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .
- Figures:
 - photographs to evidence the ingress of solid foreign objects or water, as necessary.

Annex V (normative)

Level of water protection

V.1 Background

The enclosure of a component of a stand-alone renewable energy product can prevent water and solid foreign objects from coming in contact with internal electronic circuits, electronic components, wires, and batteries. The degree of protection provided by the enclosure is determined through ingress protection (IP) as outlined in Annex U. IP testing does not, however, assess the actual or potential damage caused to circuit elements by water exposure.

Alternate means of protection exist for circuit elements exposed to water. These alternate means can allow manufactures to reduce the cost of their product(s) to the consumer, thereby increasing consumer access to modern lighting technology. Annex V outlines procedures for assessing overall water exposure protection based on IP test results combined with alternate protection means.

Annex V does not attempt to characterize the damage caused by water exposure to sensitive circuit components. Rather, Annex V provides a framework to assess the likelihood, during the service life of a product, that unprotected internal circuit components will be exposed to water that could negatively affect product operation.

In Annex V, electronic component means an individual resistor, capacitor, integrated circuit, LED, or the like; circuit element means one of the items listed in V.5.3.4.2; and component used without a modifier is as defined in 3.36 (e.g. a main unit, light point, radio, television, PV module, etc.).

V.2 Test outcomes

The procedures in Annex V may be used to establish a component's water exposure protection level. The five levels are:

- a) No protection – The component has no water protection and could be damaged by any water exposure.
- b) Occasional rain – The component can be exposed to occasional light rain without damage.
- c) Frequent rain – The component can be exposed to frequent rain without damage.
- d) Permanent rooftop installation for PV modules – (PV modules only) when installed on a roof, the product's PV module can be exposed to frequent heavy rain without damage.
- e) Permanent outdoor exposure – The component can be exposed to frequent heavy rain without damage.

The water exposure and physical ingress protection test outcomes are listed in Table V.1.

Table V.1 – Level of water protection assessment outcomes

Metric	Reporting units	Related aspects	Notes
Overall level of water protection	Qualitative (from list above)	4.2.3.2 Water protection – enclosure 4.2.3.3 Water protection – circuit protection and drainage 4.2.10.1 Product and company information 4.2.2.7 Packaging and user manual information	This is the level of water protection that is achieved when considering user instructions and labels in addition to the technical elements of the product.
Technical level of water protection	Qualitative (from list above)	4.2.3.2 Water protection – enclosure 4.2.3.3 Water protection – circuit protection and drainage 4.2.3.5 Water protection – PV module 4.2.10.1 Product and company information	This is the level of water protection provided by only the technical elements of the product – the enclosure, circuits, and other physical aspects.
Enclosure-only level of water protection	Qualitative (from list above)	4.2.3.2 Water protection – enclosure 4.2.3.5 Water protection – PV module	This only refers to the IP rating of the enclosure.

V.3 Related tests

Annex V is related to the physical and water ingress protection test (Annex U) and visual screening (Annex F).

V.4 Laboratory requirements

The assessments in Annex V are typically done by an organization with broad experience in the off-grid lighting sector, including technical and field experience.

Assessments regarding the technical level of water protection should be completed by an organization with expertise in product design, failure analysis, energy systems, and general engineering practices.

Assessments of the overall level of water protection (incorporating consumer labelling information) should be completed by a committee with expertise in communication and end user behaviour in the off-grid lighting market.

V.5 Procedure

V.5.1 General

The following procedures establish a product's level of water protection. All of the procedures in Annex V require an IP test result as specified in Annex U. Additional factors, such as product labelling or specific product design features, may also be considered when determining the level of water protection.

V.5.2 Level of water protection for enclosure only

This procedure uses a product's IP rating, and only its IP rating, to determine the level of water protection. No other tests are required. The level of water protection by IP rating is determined in accordance with Table V.2.

Table V.2 – Enclosure-only level of water protection requirements

Enclosure level of water protection	IP rating requirement
No protection	IPX0
Occasional rain	IPX1
Frequent rain	IPX3
Permanent rooftop installation for PV modules	Modified IPX4
Permanent outdoor exposure	IPX5
NOTE The modified IPX4 assessment for water ingress protection follows the same procedure to test for IPX4 as described in IEC 60529 with the exception of the angle of spray. IEC 60529 requires that the DUT be sprayed at angles $\pm 180^\circ$ from vertical, while the following modified method requires that the DUT be sprayed at angles $\pm 90^\circ$ from vertical.	

V.5.3 Level of water protection from technical aspects

V.5.3.1 General

This procedure describes an assessment of the technical aspects of a component to establish the level of water protection that is achieved by a product from an engineering design standpoint. The aspects included in this holistic assessment are:

- the enclosure,
- circuit design and protection,
- internal draining,
- manufacturing processes, and
- other innovative approaches.

The overall product design shall be assessed on a case-by-case basis to determine the technical level of water protection. The assessment includes information from lab tests, field experience, and statements supplied by the company.

The company is responsible for providing information about product design and manufacture that is part of a water protection strategy. This information is used to establish a technical level of water protection for the product. Companies that successfully demonstrate additional water protection may have the enclosure-only level of water protection category (Table V.2) increased by one level. For example, a product may move from "no protection" to "occasional rain," from "occasional rain" to "frequent rain," or from "frequent rain" to "permanent outdoor exposure" (Table V.3).

PV modules that fail the modified IPX4 test (U.4.4.5.2) may also achieve the permanent rooftop installation for PV modules category if the company successfully demonstrates that the sensitive electronic components (as defined in U.4.3.5.2) have additional water protection.

Table V.3 – Adjusted level of water protection for products with additional technical water protection

Enclosure-only level of water protection	Technical level of water protection	Requirement
No protection (IPX0)	Occasional rain	Assessment indicates the enclosure and other technical aspects will protect from occasional rain, equivalent to IPX1 protection.
Occasional rain (IPX1)	Frequent rain	Assessment indicates the enclosure and other technical aspects will protect from frequent rain, equivalent to IPX3 protection.
Frequent rain (IPX3)	Permanent outdoor exposure	Assessment indicates the enclosure and other technical aspects will protect from permanent outdoor exposure, typically requiring an enclosure with at least IPX3 protection and additional circuit protection.
The PV module failed the modified IPX4 test (U.4.4.5.2)	Permanent rooftop installation for PV modules (Modified IPX4)	Assessment indicates the enclosure and other technical aspects will protect the module from permanent outdoor exposure in the context of a rooftop installation, equivalent to a modified IPX4 protection.

V.5.3.2 Gathering product design information from lab testing

Results and observations from the following tests are relevant for this assessment:

- Annex U (physical and water ingress protection test);
- Annex F (visual screening).

V.5.3.3 Gathering field and experiential information

Information from field trials and using samples of the product in a variety of environmental conditions may supplement other information and provide unique, targeted insights.

V.5.3.4 Gathering product design information from the company**V.5.3.4.1 General**

The company is responsible for providing information about product design and manufacturing that is part of a water protection strategy.

Ask the company to provide product design data and explanations justifying a technical level of water protection. This data should include the following.

- Written descriptions of the product design elements and materials that will protect the circuit elements from water exposure damage.
- Photographs or video clips showing the relevant design features.
- Specification sheets for materials used for protection.
- Written descriptions of protection for each circuit element in V.5.3.4.2.
- Written descriptions of relevant manufacturing processes employed for circuit element protection.
- Written descriptions of quality control processes relevant to circuit element protection.
- Descriptions of tests performed by the company to demonstrate protection of circuit elements from damage caused by water exposure.

V.5.3.4.2 Circuit design information

The relevant circuit elements to provide information about include:

- a) printed circuit boards,
- b) electronic component solder joints,
- c) wire to board solder joints,
- d) wire to board connectors,
- e) wire to battery terminal solder joints,
- f) wire to battery terminal connectors,
- g) LEDs, and
- h) switches.

V.5.3.4.3 Manufacturing quality control information

The company should describe quality control processes that are in place to ensure consistent application of coatings, use of gaskets, etc.

V.5.3.4.4 Water-resistant coatings

V.5.3.4.4.1 General

Polymer coatings (conformal coatings or encapsulants) on printed circuit boards, wire solder joints, connectors, and electronic components have been shown to reduce or eliminate the negative effects of water exposure to energized circuit elements. In order to be effective, it is necessary to apply a coating to clean substrates in a quality-controlled manufacturing process. To qualify for an adjusted level of technical water protection due to a conformal coating or encapsulant (Table V.3), the company shall provide documentation and the coating shall be assessed for adequate coverage and adhesion.

V.5.3.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2

- UV-A inspection lamp
- Scribe tool, dental pick, dental scaler, or similar rigid pointed tool with a sharp tip
- Tweezers

V.5.3.4.4.3 Coating documentation requirements

The company shall provide the following information.

- a) A material specification sheet or other documentation indicating that the conformal coating or encapsulant is intended and appropriate for electrical or electronic protection;
- b) A description of the coating coverage area. The coverage area shall include the circuit elements listed in V.5.3.4.2 unless the company provides other product design information or field/experiential information that supports a credible water protection strategy for these uncoated circuit elements;
- c) Either or both of the following:
 - 1) A description or indication of a board cleaning procedure prior to the application of the coating;
 - 2) Information suggesting the coating, as applied, will adhere properly to the substrate;
- d) A description of the coating application procedure;
- e) A description of the coating inspection procedure.

V.5.3.4.4.4 Coating inspection procedure requirements

A company shall specify an inspection procedure that is part of a quality control process used to confirm the proper application of the coating. Most inspection procedures are expected to be performed manually by personnel trained to visually inspect the coating of each manufactured circuit board or circuit element. Automated machine inspection procedures are also possible and acceptable for this requirement.

The coating inspection procedure provided by the company shall meet the following requirements.

- a) The inspection procedure shall require a manual visual inspection or machine inspection to confirm coating of all of the exposed electronic components and circuit elements included in the coating coverage area.
- b) For conformal coatings with a UV indicator, manual procedures shall require visual inspection performed with a UV inspection light in a darkened room or booth.
- c) Transparent conformal coatings without a UV indicator can be very difficult to inspect and companies shall be required to show a robust, technically feasible inspection procedure for these types of coatings. For transparent coatings without a UV indicator, manual inspection procedures shall include either of the following:
 - 1) a process that compares the appearance, gloss level, or other visual indicator of a coated PCB with the appearance, gloss level, or other visual indicator of an uncoated PCB, or
 - 2) a process that would allow an inspector to adequately identify the presence and coverage of the conformal coating on the required coverage areas.

The inspection procedure for transparent conformal coatings without a UV indicator shall be properly documented with example photographs or other information to indicate how coverage failures would appear to an inspector.

V.5.3.4.4.5 Coating test procedure

- a) A visual inspection of the coating shall be performed according to the following procedure.
 - 1) Perform a visual inspection of the coating coverage area as outlined in company-provided documentation to confirm complete coverage. For coatings that contain a UV indicator, use a UV light to illuminate the DUT in a sufficiently darkened space to allow for identification of covered and uncovered portions of the coverage area. The conformal coating should show uniform fluorescent intensity over all covered areas of the PCB. If there is not a UV indicator, use an illuminated magnifier and visible light to help make the conformal coating more visible. Look for a clear, glossy coating over the parts of the PCB in the coverage area. In most cases the difference between coated and uncoated areas can be identified by viewing the surface at different angles and either looking for differences in the gloss level or identifying the visible coating edge lines between coated and uncoated areas, or both.
 - 2) Take photos of the PCB lit with either UV or visible light, as appropriate, to capture areas of the PCB that are improperly coated or uncoated. If the coating does not have a UV indicator, take pictures of the PCB at angles where the glossiness from the conformal coating is visible to demonstrate coverage.
 - 3) The coating should be unblemished and glossy in all application areas. A coating that has visual imperfections could indicate improper coverage or poor adhesion and close inspection is necessary. Make a note in the test report of any of the following coating imperfections.
 - i) Cracking: A coating that has been applied too thickly or too thinly could result in cracking or wrinkling.
 - ii) De-wetting: The failure of a coating material to adhere to a surface. The coating appears as either droplets or sheets of liquid with rounded edges. This issue arises when the coating does not adhere to the PCB properly, and areas become exposed.

- iii) Corrosion: Abnormal discoloration or rusting of sensitive electronics and base materials may be a result of corrosion. Corrosion indicates that the electronics are not adequately protected from water damage.
- iv) Orange peel: If the surface coating is dull or textured in appearance this is a sign of orange peel. This occurs from inconsistent thickness or drying.
- v) Fish eyes, bubbles, foam and pinholes: These deficiencies occur when a small area of coating does not adhere to the surface. Fish eyes are small bubbles that form in the coating. This results from debris or chemical residue present on the surface of the PCB causing a small area not to adhere to the surface. Bubbles are trapped air inside the coating, foam is a cluster of bubbles, and pinholes are popped bubbles that appear as small holes in the coating. These can all be the result of an inadequate application process, or improper cleaning of the surface before application of the coating.

Most coatings will exhibit some degree of imperfection, particularly bubbles which become trapped around electronic component leads. A small number of isolated imperfections or bubbles is permissible. Larger areas of imperfections or clusters of bubbles, however, indicates a problem with the coating.

The DUT shall fail the visual inspection if the test laboratory identifies uncoated circuit elements or electronic components within the company-supplied coverage area. The DUT shall also fail the visual inspection if the test lab, using its best judgement, identifies significant visual imperfections according to step a) 3).

- b) A coating adhesion scratch test shall be performed according to the following procedure.
 - 1) Using a scribe tool or dental pick, apply moderate pressure and scrape the surface of the coating over areas representing the circuit elements listed in V.5.3.4.2, giving preference to locations with imperfections identified in step a) 3). Apply enough pressure to damage, scratch, or tear the surface of the coating without damaging the coating substrate. Cosmetic scratches on the substrate surface are not considered damage for the purposes of this test. In areas where the coating separates from the substrate, place the tip of the tool in between the coating and the substrate and attempt to pry the coating up and off of the circuit board or electronic component. A coating with proper adhesion will have surface damage from the tool but will not substantially separate from the substrate.
 - 2) Using tweezers, grab and pull any uplifted edges of coating that remain on the DUT in an attempt to peel the coating off of the substrate.
 - 3) Photograph the DUT and any coating flakes that were removed. Include a scale in the photographs to allow for size measurements of removed coating pieces.

The DUT shall fail the coating adhesion scratch test if any removed coating piece measures 5 mm or more in any dimension or, in the opinion of the test laboratory, the coating exhibits substantially poor adhesion by easily separating from the substrate.

V.5.3.4.5 Novel design approaches

Other means are available to protect circuit elements from water exposure damage. For example, the product could be designed to allow water to drain from the case and not collect on circuit elements. These novel approaches shall be outlined and explained by the company with supporting documentation justifying a level of water protection as outlined in Table V.3.

V.5.3.5 Assessment of technical level of water protection

The final assessment of the technical level of water protection should include information from each of the sources listed above.

The assessment details should include an evaluation of protection for circuit elements on a piece-by-piece basis. Reference should be provided where appropriate to the company supplied data. See Table V.4 for an example product where the company is using conformal coatings and silicone sealants to protect internal circuit elements:

Table V.4 – Example detailed assessment supporting technical level of water protection

Circuit element	Method of protection	Company reference material	Notes
Printed circuit boards	Conformal coating	Pcb_coating1.jpg	
Electronic component solder joints	Conformal coating	Pcb_coating2.jpg	
Wire to board solder joints	None		Wire to board solder joints are not sealed or encapsulated
Wire to board connectors	N/A		None used
Wire to wire connectors	N/A		None used
Wire to battery terminal solder joints	Silicone encapsulant	Battery_coating1.jpg	
Wire to battery terminal connectors	N/A		None used
LED electronic components	Case design	LED_lens1.jpg	Company statement
Switch electronic components	None		Switch is not sealed

V.5.4 Overall level of water protection

V.5.4.1 General

The overall level of water protection assessment accounts for consumer labelling and instructions in combination with either the technical or enclosure-only level of water protection.

If appropriate consumer information is provided, the level of water protection is increased relative to the technical or enclosure-only findings.

This assessment shall not result in an increase to the permanent outdoor exposure level, since products that are permanently mounted outdoors are not protected from water by the end user.

Table V.5 lists the requirements for assessing the overall level of water protection.

Table V.5 – Overall level of water protection requirements

Technical level of water protection or Enclosure-only level of water protection	Overall level of water protection without consumer labelling	Overall level of water protection with consumer labelling
No protection	Same	Occasional rain
Occasional rain	Same	Frequent rain
Frequent rain	Same	Same
Permanent rooftop installation for PV modules	Same	Same
Permanent outdoor exposure	Same	Same

V.5.4.2 Assessing consumer labels and information

V.5.4.2.1 General

Subclause V.5.4.2 describes a framework for assessing consumer labels and instructions for appropriateness.

The overall requirement for consumer labels and instructions is that the communication strategy should be designed and implemented so that a typical user understands both the degree of protection from water for the product and what they should do to maintain the product in an instance of water exposure.

The factors to consider are:

- language and literacy of expected end users,
- prominence of information, and
- clarity of presentation.

V.5.4.2.2 Gathering information on water protection messages

Information from visual screening (Annex F) and additional inspection of the packaging should be used to establish the messages to buyers and end users concerning water protection.

Potential locations (not inclusive) of information:

- Labels and pictograms on packaging.
- Instructions in the user manual.
- Information on the warranty card.
- Advertising and media.

V.6 Reporting

Report the following in the equivalent IP water exposure protection report.

- Metadata:
 - name of test;
 - procedures used to qualify for level of water protection (IP rating, labelling and product design);
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Main findings:
 - overall level of water protection;
 - technical level of water protection;
 - enclosure-only level of water protection.

- Supporting information:
 - IP rating for enclosure;
 - description of other technical approaches (if applicable);
 - suitability of consumer labelling for communicating level of technical water protection and steps to protect the product.
- Company supplied data (Include all company supplied data in the test report).
- Assessment of company supplied data.
- Comments:
 - individual comments, as necessary, on the specific material provided by the company demonstrating an equivalent IP level protection;
 - overall comments, as necessary, for the collective set of materials provided by the company demonstrating an equivalent level of IP protection.

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Annex W (normative)

Mechanical durability test

W.1 Background

The mechanical durability test captures the DUT's robustness in withstanding the rigors of expected daily usage. The mechanical durability test includes the drop test, the switch and connector test, the gooseneck and moving part test (if applicable), and the strain relief test (if applicable). This test should be conducted on all appliances included with the product, in addition to the primary components of the product.

During the drop test, the DUT is dropped from a height of 1 m onto a concrete surface. The number of times each sample is dropped depends on the type of component. During the switch and connector test, each switch and connector of the DUT is cycled. The gooseneck and moving part test is only conducted on DUTs with goosenecks or moving parts, and it requires the gooseneck or other moving part of the DUT to be bent through its feasible range of usage. Switches, connectors, goosenecks and moving parts that are intended for regular use are cycled 1 000 times, while any of these mechanisms that are expected to be used primarily during installation are cycled only 100 times. (Product specifications may require additional cycles.) The strain relief test involves attaching a 2 kg weight onto any permanently attached cable ends (i.e. cable ends without connectors) for 60 s at three different strain angles. Throughout all four tests, the DUT is examined for functionality, damage, and the presence of user safety hazards.

W.2 Test outcomes

The test outcomes of the mechanical durability test are listed in Table W.1.

Table W.1 – Mechanical durability test outcomes

Metric	Reporting units	Related aspects	Notes
Drop test sample functionality	Yes/no	4.2.3.8 Drop resistance	--
Drop test user safety hazard(s) present	Yes/no, description	4.2.3.8 Drop resistance	--
Drop test sample damage	Yes/no, description	4.2.3.8 Drop resistance	--
Switch and connector test cycles achieved	Cycles	4.2.3.10 Connector durability 4.2.3.11 Switch durability	--
Switch and connector test sample functionality	Yes/no	4.2.3.10 Connector durability 4.2.3.11 Switch durability	--
Switch and connector test user safety hazard(s) present	Yes/no, description	4.2.3.10 Connector durability 4.2.3.11 Switch durability	--
Switch and connector test sample damage	Yes/no, description	4.2.3.10 Connector durability 4.2.3.11 Switch durability	--
Gooseneck/moving part test cycles achieved	Cycles	4.2.3.9 Gooseneck and moving part durability	--
Gooseneck/moving part test sample functionality	Yes/no	4.2.3.9 Gooseneck and moving part durability	--
Gooseneck/moving part test user safety hazard(s) present	Yes/no, description	4.2.3.9 Gooseneck and moving part durability	--
Gooseneck/moving part test sample damage	Yes/no, description	4.2.3.9 Gooseneck and moving part durability	--

Metric	Reporting units	Related aspects	Notes
Strain relief time achieved for each weight and strain angle	Seconds (s)	4.2.3.12 Strain relief durability	--
Strain relief test sample functionality	Yes/no	4.2.3.12 Strain relief durability	--
Strain relief test user safety hazard(s) present	Yes/no, description	4.2.3.12 Strain relief durability	--
Strain relief test sample damage	Yes/no, description	4.2.3.12 Strain relief durability	--

W.3 Related tests

Annex W is not related to any of the other annexes.

For lighting appliances without batteries, the mechanical durability tests of IEC TS 62257-12-1 may be used in place of Annex W.

W.4 Defect categories

W.4.1 General

The following defect categories are defined for the procedures in Annex W.

W.4.2 Major defects

The following major defects constitute a failure of the test:

- User safety hazards such as glass shards, sharp edges, or short circuits;
- Damage that impairs functionality, use, or protection from ingress of water or foreign objects;
- Failure to function after the test;
- Exposed cores of cables (e.g. due to the cable sheath pulling out of a cord anchorage).

NOTE A core in this context can be a bare conductor or an assembly comprising a conductor with its own insulation, i.e. one of the individual insulated conductors within a cable.

W.4.3 Minor defects

The following minor defects shall be noted in the test report, but shall not be grounds for failure:

- Dislodged or disassembled parts that can be reassembled without any permanent damage and without the use of tools or supplies such as glue or tape. Reassemble these parts before testing functionality.
- Superficial damage (e.g. minor scrapes or cracks in decorative elements) not meeting the criteria of W.4.2.

W.5 Procedures

W.5.1 Drop test

W.5.1.1 General

The DUT is dropped on different sides from a height of 1 m onto a level concrete surface and examined for functionality, user safety hazards, and damage. The number of times each sample is dropped depends on the type of component.

W.5.1.2 Equipment requirements

The camera is required.

W.5.1.3 Test prerequisites

At the start of the drop test, the DUT shall be minimally altered (ideally unaltered), fully functional, and have sufficient charge to check for functionality throughout the test.

If the product has multiple components, determine an appropriate order to test the components for which the drop test is necessary. Portable components (e.g. torches, lanterns, desktop lamps, etc.) shall be drop tested. Components that are portable but are expected to meet less rigorous durability standards (non-lighting appliances such as radios, razors, portable fans, etc.) should be drop tested under less rigorous criteria as outlined in W.5.1.5 a) 2).

It is not necessary to drop test components that are intended to be stationary (e.g. separate control boxes, lamp units intended to be mounted) and PV modules. It is not necessary to drop test portable appliances that are not typically expected to meet the same durability standards, such as TVs.

This test is destructive. Do not carry out additional tests with the tested samples.

W.5.1.4 Apparatus

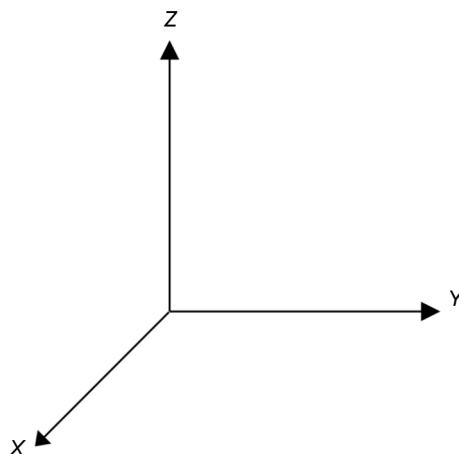
The drop test should be performed in a location with a smooth, level concrete surface with ample space to avoid personal injury from a DUT projectile (e.g. glass or plastic shards). A height of 1 m shall be established from the ground to begin the drop.

W.5.1.5 Procedure

The following steps shall be performed.

a) Drop the DUT from a height of 1 m as indicated in the following:

- 1) For testing portable lighting components (lighting appliances, components containing a built-in lighting appliance, and power control units used to power a lighting appliance), drop the DUT six times – once on each of the six “faces” of the product, taking care to drop the DUT on parts deemed mechanically weak (e.g. handles, loose parts). Using the three-dimensional system shown in Figure W.1, the DUT should be rotated after each drop as follows: The DUT is rotated by 90° along the x-axis following each of the first three drops, rotated by 90° along the y-axis from its initial drop orientation for the fifth drop, and rotated 180° along the y-axis from its fifth drop orientation for the sixth drop.



IEC

Figure W.1 – Three-dimensional Cartesian coordinate system for drop test reference

- 2) For testing non-lighting portable appliances (radios, razors, etc.) and other components not included in 1):
 - i) If the product specification requires testing two samples, drop each sample two times—once on each of two of the six “faces,” taking care to drop the sample on parts deemed mechanically weak (e.g. handles, loose parts, etc.). Rotate the angle of drop between samples so that after the second sample, four of the six sides are tested.
 - ii) If the product specification requires testing only one sample (such as for the ISM), drop the sample six times—once on each of the six “faces” taking care to drop the sample on parts deemed mechanically weak (e.g. handles, loose parts, etc.). It is recommended to drop the non-lighting appliance sample six times during a one-sample test for informative purposes only. If the test is being used for other purposes, such as program entry or qualification for subsidies, it can be more appropriate to only consider the results from the first two drops.

For radios, the antenna should not be extended.

- b) After each of the drops, examine the DUT for any of the defects specified in Clause W.4.

W.5.1.6 Pass criteria

After all drops are completed, there shall be no major defects as defined in W.4.2. Minor defects (W.4.3) are permitted.

W.5.2 Switch and connector test

W.5.2.1 General

Each switch or connector intended for regular use is cycled 1 000 times (unless otherwise specified in the product specification) and examined for functionality, user safety hazards, and damage. Each switch or connector that is expected to be used primarily during installation is cycled 100 times (unless otherwise specified in the product specification) and examined for functionality, user safety hazards, and damage. The product specification should provide guidance on how to distinguish between these two cases, and list any types of connectors that are exempt from this test. The switch and connector test does not apply to connections that are subject to the screw connections test (Annex X).

Connections not subject to the mechanical durability test should be assessed in the visual screening (F.4.3.6 a)).

W.5.2.2 Equipment requirements

A camera is required.

W.5.2.3 Test prerequisites

At the start of the switch and connector test, the DUT shall be fully functional and have sufficient battery charge to check for functionality throughout the test.

This test is destructive. Do not carry out additional tests with the tested samples, with the exception of the gooseneck and moving parts test, the strain relief test, and the drop test (if the DUT is still functional after the switch and connector test).

When it is necessary to test a connector and the mating connector is not included with the product, the laboratory should obtain a mating connector. The laboratory may obtain this connector, without random sampling, from the company or from another source. The laboratory should ensure that the connector obtained is as similar as possible to a connector that would likely be used by the end user when the product is used as intended. The laboratory may determine the connector type by requesting connector specifications from the company, by measuring the connector dimensions, or by visual inspection.

If a connector that is not part of the DUT fails during the test, the test result depends on the reason for the failure:

- If the connector failure is unrelated to any aspect of the DUT, the laboratory should continue the test with a new connector. (If the failure was caused by the laboratory-supplied connector but has damaged the DUT, the laboratory may substitute a different sample and restart the test.)
- If the connector failure was caused by an aspect of the design of the DUT, the DUT fails the test.

EXAMPLE 1 If the DUT includes a USB type A receptacle but no cable or component with a USB plug, the laboratory can obtain a USB type A plug and use it to test the socket.

EXAMPLE 2 If in the product of example 1 the plug supplied by the laboratory contains a manufacturing defect and as a result is damaged during the test, the laboratory would replace the defective plug and continue the test.

EXAMPLE 3 If in the product of example 1 the plug supplied by the laboratory is damaged, and close inspection reveals that the damage occurred because the dimensions of the USB receptacle in the DUT do not conform to the USB specification, resulting in excessive stress on the plug, the product fails the test.

W.5.2.4 Apparatus

No apparatus is required for the switch and connector test.

W.5.2.5 Procedure

The following steps shall be performed.

- Cycle each of either the unique switch(es) or connector(s), or both, 1 000 times or 100 times, or as specified in the product specification, depending on the expected use of the switch or connector. This test can be done manually or by using a mechanical device. A unique switch or connector is one that is not identical to any other switch or connector of the product. If the product has two or more identical switches or connectors, only one of those identical switches is considered unique and shall be cycled. A cycle consists of actuating a switch through all possible positions or mechanical states or fully inserting and removing a connector; at the end of the cycle, the switch or connector should be in the same mechanical state as at the start of the cycle. For example:
 - For a slide, rocker, rotary, or toggle switch with three positions, a cycle could start in position 1 and cycle through positions 2, 3, 2, and back to 1;
 - For a momentary pushbutton switch, a cycle consists of pressing and releasing the button once, even if the product changes state (e.g. brightness setting);
 - For a mechanically latching (push-on-push-off) switch, a cycle consists of pressing and releasing the button twice to return the switch to its initial mechanical state.
- If the product has at least two identical switches or connectors and more than one sample is being tested (e.g. two samples are tested using the QTM), the selection of the unique switch or connector to be tested within the set of identical switches or connectors on any single sample shall rotate between the identical switches or connectors (e.g. if a product has three identical barrel plug sockets and the product is undergoing QTM testing, each sample should have a different barrel plug socket tested).
- If damage is observed during the testing, record the observations with descriptions and photographs.
- Continue testing until the product fails to function, a user safety hazard develops (e.g. short circuit), or the targeted number of cycles is achieved. If potential damage cannot instantly be observed during testing (e.g. damage to a PV module or mobile device connector), check for DUT functionality after every 100 cycles.

W.5.2.6 Pass criteria

After the required cycles are completed, there shall be no major defects as defined in W.4.2. Minor defects (W.4.3) are permitted.

W.5.3 Gooseneck and moving part test

W.5.3.1 General

This test is applicable to moving parts if the motion of the part affects electrical conductors or if the part is essential for one of the primary or advertised functions of the product. Other moving parts are assessed in the visual screening (F.4.3.6 a)). Examples of moving parts that are subject to this test include:

- Goosenecks or hinged parts that contain wires
- Hinged PV modules consisting of two separate modules connected by a hinge and not meeting the definition of foldable modules (3.35).

If applicable, each gooseneck or other moving part intended for regular use is bent 1 000 times (unless otherwise specified in the product specification) through its feasible range of usage. Each gooseneck or other moving part that is expected to be used primarily during installation is bent 100 times (unless otherwise specified in the product specification) through its feasible range of usage. The product specification should provide guidance on how to distinguish between these two cases, and list any types of moving parts that are exempt from this test.

W.5.3.2 Equipment requirements

A camera is required.

W.5.3.3 Test prerequisites

At the start of the gooseneck and moving part test, the DUT shall be fully functional and have sufficient battery charge to check for functionality throughout the test.

This test is destructive. Do not carry out additional tests with the tested samples, with the exception of the switch and connector test, the drop test, and the strain relief test (if the DUT and PV modules are still functional after the gooseneck and moving parts test).

W.5.3.4 Apparatus

No apparatus is required for the gooseneck and moving part test.

W.5.3.5 Procedure

The steps shall be followed.

- a) Bend the gooseneck or moving part 1 000 times through its feasible range of usage 1 000 times or 100 times, or as required by the product specification, depending on the expected use of the gooseneck or moving part. This can be done manually or by using a mechanical device.
- b) If damage is observed during the testing, record the observations with descriptions and photographs.
- c) Continue testing until the product fails to function, a user safety hazard develops (e.g. short circuit), or the targeted number of bends is achieved.

W.5.3.6 Pass criteria

After the required cycles are completed, there shall be no major defects as defined in W.4.2. Minor defects (W.4.3) are permitted.

W.5.4 Strain relief test

W.5.4.1 General

If applicable, each permanent cable end (i.e. cable ends without connectors) is subjected to a 2 kg weight for 60 s at various strain angles. The product specification may identify alternative tests or certificates that would exempt components from undergoing this test.

W.5.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Camera.
- Clamp or other means of holding DUTs in place.
- Calibrated 2 kg weight.
- Protractor or other means of determining the strain angle.
- Stopwatch.

W.5.4.3 Test prerequisites

At the start of the strain relief test the DUT should be fully functional and shall have sufficient battery charge to check for functionality throughout the test.

This test is destructive. Do not carry out additional tests with the tested samples, with the exception of the switch and connector test, the drop test, and the gooseneck and moving part test (if the DUT is still functional after the strain relief test).

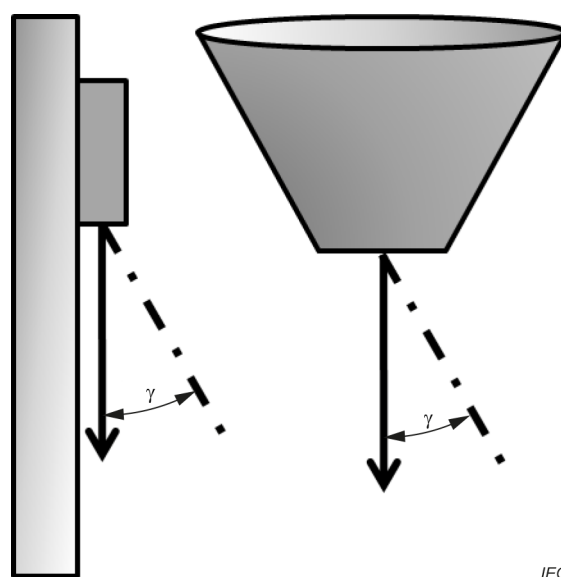
W.5.4.4 Apparatus

A clamp or other means of securely holding a 2 kg weight and the DUT in place is required.

W.5.4.5 Procedure

The following steps shall be performed.

- a) Determine which cable ends are permanently attached (i.e. do not have a connector end) to the DUT.
- b) Clamp the DUT in place and attach the 2 kg weight to the cable so that the strain angle (γ) is 0° relative to the direction from which the cable protrudes from the DUT (see Figure W.2).

**Key**

γ Cable strain angle (°)

Figure W.2 – Cable strain angle (γ) schematics for a PV module junction box (left) and a separate light point (right)

- c) Observe the DUT for 60 s. After 60 s, record the DUT functionality, any physical damage, and the presence of safety hazards.
- d) Repeat steps b) and c) for strain angles of 45° and 90°.
- e) Repeat step b) through step d) for each permanently-attached cable end found in step a).

W.5.4.6 Pass criteria

After all steps are completed, there shall be no major defects as defined in W.4.2. Minor defects (W.4.3) are permitted.

W.6 Reporting

Report the following in the mechanical durability test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - drop tests:
 - i) functions after each drop (pass/fail);
 - ii) no damage present after each drop (pass/fail);
 - iii) no user safety hazard present after each drop (pass/fail).

- switch/connector tests:
 - i) cycles achieved for each switch or connector;
 - ii) functions after test (pass/fail);
 - iii) no damage present after test (pass/fail);
 - iv) no user safety hazard present after test (pass/fail).
- gooseneck and moving part test:
 - i) cycles achieved for the gooseneck/moving part;
 - ii) functions after test (pass/fail);
 - iii) no damage present after test (pass/fail);
 - iv) no user safety hazard present after test (pass/fail).
- strain relief test:
 - i) time achieved for each strain angle (s);
 - ii) functions after test (pass/fail);
 - iii) no damage present after test (pass/fail);
 - iv) no user safety hazard present after test (pass/fail).
- Comments:
 - individual comments, as necessary, for samples 1 through n for each test;
 - overall comments, as necessary, for collective set of samples 1 through n for each test.
- Figures:
 - photographs of observed user safety hazards or damage.

Annex X (normative)

Screw connections test

X.1 General

Unless otherwise stated in the product specification, this procedure is applied only to non-plug-and-play products, and only to screws that are likely to be tightened during installation. Screws inside components, such as junction boxes of plug-and-play PV modules, where the user or installer is not expected to adjust the screws are not subject to this test.

This test for general screw connections is identical to the screw connections test of IEC 61730-2. Because this procedure is intended to apply to screws tightened by the user or installer, there is no procedure for assessing locking screws. If it is necessary to assess locking screws, the procedure of IEC 61730-2 can be used.

X.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements of Clause CC.2 .

- Test screwdriver or spanner capable of applying a torque as described in Clause X.4.
- Micrometer or calliper for measuring screw dimensions.

X.3 Test prerequisites

Since this test can be destructive, any other testing to be performed on the samples that will undergo the screw connections test, such as the visual screening and the photovoltaic module I-V characteristics test of IEC TS 62257-9-5, shall be performed before the screw connections test is started.

X.4 Procedure

Components such as screws and nuts transmitting contact pressure, or which are likely to be tightened by the user shall be tightened and loosened five times. Screws and nuts of insulating material shall be removed completely during each operation of loosening of the screws.

The test is made by means of a suitable test screwdriver or spanner, applying a torque as shown in Table X.1, except that for screws of insulating material used in cord anchorage and bearing directly on the cable or cord, the torque is 0,5 Nm.

If the company specifies a higher torque in their installation instructions, that torque shall be used for testing. This shall be noted in the test report.

Table X.1 – Torque tests on screws per IEC 61730-2

Nominal outer thread diameter of screw mm	Torque Nm		
	Type 1	Type 2	Type 3
Up to and including 2,8	0,20	0,40	0,40
Over 2,8 up to and including 3,0	0,25	0,50	0,50
Over 3,0 up to and including 3,2	0,30	0,60	0,50
Over 3,2 up to and including 3,6	0,40	0,80	0,60
Over 3,6 up to and including 4,1	0,70	1,20	0,60
Over 4,1 up to and including 4,7	0,80	1,80	0,90
Over 4,7 up to and including 5,3	0,80	2,00	1,00
Over 5,3 up to and including 6,0	–	2,50	1,25
Over 6,0 up to and including 8,0	–	8,00	4,00
Over 8,0 up to and including 10,0	–	17,00	8,50
Over 10,0 up to and including 12,0	–	29,00	14,50
Over 12,0 up to and including 14,0	–	48,00	24,00
Over 14,0 up to and including 16,0	–	114,00	57,00

The shape of the blade of the screwdriver shall suit the head of the screw to be tested. The screws shall not be tightened in jerks. Damage to covers is neglected.

Type 1 of Table X.1 applies to metal screws without heads if the tightened screw does not protrude from the hole.

Type 2 applies to:

- other metal screws and to nuts;
- screws of insulating material
 - having a hexagonal head with the dimensions across flats exceeding the overall thread diameter;
 - having a cylindrical head and a key socket with a cross-corner dimension exceeding the overall thread diameter;
 - having a head with a slot or cross slots, the length of which exceeds 1,5 times the overall thread diameter.

Type 3 applies to other screws of insulating material.

X.5 Pass criteria

During the test, no damage impairing the further use of the fixing or screwed connection shall occur. After the test, it shall still be possible to introduce the screw or nut made of insulation material in the intended manner.

X.6 Reporting

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - compliance with the screw connections test;
 - description and photographs of any damage impairing the further use of the fixing or screwed connection;
 - description and photographs of any damage incurred during the test;

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Annex Y (informative)

Photometer box for relative luminous flux measurements

Y.1 Background

Annex Y includes plans and instructions for building a photometer box (Figure Y.1 and Figure Y.2) – an optical cavity for relative luminous flux measurements that can be used to measure the run time or lumen maintenance of lighting products, but not the absolute luminous flux of lighting products. Photometer boxes can be built for much lower cost than integrating spheres or similar equipment.

The box is a cube that is painted with high-reflectivity, matte white paint inside. The DUT is placed in the centre of the box either by hanging from the top or on a stand. An illuminance meter is placed in one of the corners or sides with a baffle blocking direct light from the DUT. Because the illuminance meter only “sees” reflected light, the measurements of relative illuminance in time are less sensitive to the arrangement of the lighting device and therefore more robust.

For a given product in a fixed orientation, the reading from the illuminance meter is directly proportional to the luminous flux of the DUT but does not represent the absolute luminous flux. The same photometer box and illuminance meter shall be used for any given test, since different boxes and illuminance meters will result in different relative light outputs.



The photometer box depicted here has two screens (baffles); only one screen, in front of the illuminance meter head, is required per Clause Y.3, step y). In this example, the required screen is in the lower left corner of the image.

Figure Y.1 – Interior view of a completed photometer box



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In this example, the illuminance meter head is located in the corner of the box. The illuminance meter head can also be placed on the side of the box to simplify construction.

Figure Y.2 – Exterior view of completed photometer box

Y.2 Plans

Plans for a photometer box are given in Figure Y.3 and Figure Y.4.

TOP VIEW (LID)

PRE-DRILL PILOT HOLES

70

65

4

5

TOP VIEW (INTERIOR)

60

69

21

7

8

3

HOLE FOR ROUTING WIRES TO ELECTRONICS

PAINT ALL INTERIOR SURFACES 10

SCREEN SIDE VIEW

21

2

TEST STAND SIDE VIEW

TYPE WITH SET SCREWS FOR ADJUSTABLE HEIGHT OF TEST STAND

FRONT VIEW

5

2.5

70

30

8

11

BUTT JOINTS GLUED & NAILED

6

9

FOOT (x4)

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Figure Y.3 – Photometer box dimensions

Dimensions in cm

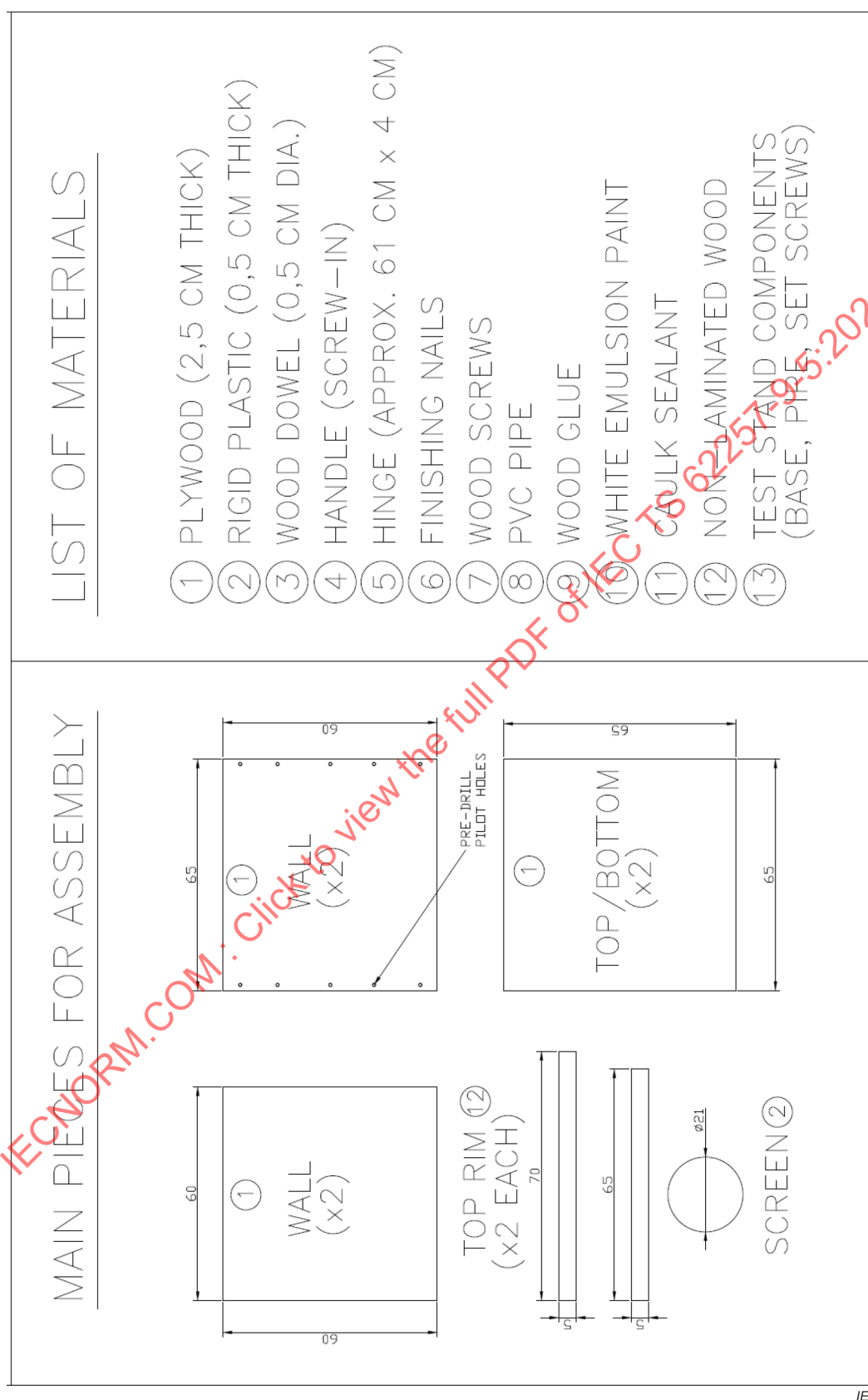


Figure Y.4 – Photometer box assembly pieces and list of materials

Y.3 Instructions for construction

The following steps shall be performed.

- a) Cut the pieces in Figure Y.4 to the dimensions shown in Figure Y.3 – Use a table saw if available.
- b) Pre-drill pilot holes on 65 cm × 60 cm wall pieces.
- c) Apply glue along 2,5 cm × 60 cm area of wall pieces with pilot holes.
- d) Use four clamps (one at top, one at bottom for each side) to hold the four walls together as shown on in the top view of Figure Y.3.
- e) Drive finish nails into pre-drilled pilot holes.
- f) Allow 12 h for glue to cure.
- g) Remove clamps.
- h) Check butt joints for structural integrity.
- i) Apply glue to bottom edges of walls.
- j) Align and clamp bottom piece to walls.
- k) Allow 12 h for glue to cure.
- l) Remove clamps.
- m) Check for structural integrity.
- n) Cut 4 cm × 4 cm feet (as shown in front view of Figure Y.3) and glue to four exterior corners of bottom piece. The weight of the photometer box will hold the feet in place while the glue cures.
- o) Apply glue to 2,5 cm width of “top rim” pieces along top outside perimeter of walls.
- p) Place “top rim” pieces on outside walls as shown in Figure Y.3 and clamp in place.
- q) Allow 12 h for glue to cure.
- r) Remove clamps.
- s) Check for structural integrity.
- t) Drill hole in corner or side of photometer box for placement of PVC section – Use a hole saw if available.
- u) Cut PVC pipe to appropriate length and mitre cut if necessary to tightly fit against hole in photometer box.
- v) Affix PVC section to photometer box with caulk sealant, making sure to seal against all possible light intrusion at joint.
- w) Assemble test stand and attach with wood screws to centre bottom of photometer box as shown in top view.
- x) Cut plastic screens and drill holes for insertion of dowels.
- y) Drill holes at appropriate angles and locations for screen dowels, refer to top view (interior). Only one screen is required, between the DUT and the illuminance meter head.
- z) Insert screen dowels into holes in photometer box walls. No glue should be required.
- aa) Place top lid piece onto photometer box.
- bb) Align hinge as shown in top view (lid).
- cc) Pre-drill pilot holes and attach hinge with wood screws.
- dd) Pre-drill hole for handle (as shown in top view) and attach to lid.
- ee) Paint all interior surfaces of photometer box with white emulsion paint, matte finish. Several light coats are recommended (at least five coats).

Annex Z (informative)

Guidelines for testing products with multiple power control units

Z.1 General

Some products have multiple power control units that can either be charged in parallel or connected in parallel to supply loads greater than the capacity of a single power control unit, or both. These products can have multiple power control units of the same type or of different types (e.g. a main control unit and expansion units). For such products, some tests in this document have to be repeated for different combinations of power control units. The following combinations should be tested:

- a) One individual power control unit of each type, if that power control unit can be used independently (for the solar charge test, it is only necessary to individually test main units with PV inputs);
- b) Each combination of power control units for which run times are advertised; and
- c) The combination necessary to power all appliances in the example usage profile defined in the energy service calculations (Table GG.4).

Additional guidance is given in R.4.2.2 and the introductory paragraphs of GG.4.2.4.

Z.2 Testing guidelines

The following guidelines can be used to apply the tests in this document to products with multiple power control units:

- a) Full-battery run time test (Annex M): full-battery energy should be evaluated for all combinations listed in Clause Z.1.
 - 1) Conduct the full-battery run time test separately for each power control unit and, if a total energy value is necessary in step d) 2), sum the individual energy values; or
 - 2) Conduct the full-battery run time test using each relevant combination of power control units, treating the combination as a single power control unit. This option should be used if the battery-to-port efficiencies for each path from the battery to a load powered by multiple power control units are expected to differ significantly.
- b) Solar charge test (Annex R): each combination listed in Clause Z.1 should be tested (see R.4.2.2).
- c) Output overload protection test (DD.4.2) and assessment of DC ports (Annex EE):
 - 1) Each type of power control unit that can be used independently should be tested individually;
 - 2) In addition, for each port that can be powered by multiple power control units in parallel, the configuration having the maximum possible output current should be tested.
- d) Energy service calculations (Annex GG):
 - 1) For power control units not discharged in parallel, calculations are made for each power control unit tested in the solar charge test, for each combination of power control units charged together;
 - 2) Power control units connected in parallel to power loads can be treated as a single power control unit for the energy service calculations. Port data from the combination described in c) 2) may be used even if the combinations do not match exactly. For example, port data measured with three power control units in parallel may be used to calculate the energy service from two power control units in parallel.

- 3) It is possible for some appliances to receive power from multiple power control units while others receive power from only one power control unit. The energy service calculations in this document do not address this scenario. It is anticipated that the method described in 2) will often give acceptable results since the energy allocated to appliances powered from a single power control unit is likely to be a relatively small portion of the total energy. The results of the calculations should be checked to confirm that the energy allocated to appliances that are powered by an individual power control unit is less than the energy available from that power control unit. If not, the run time of these appliances can be manually reduced. Any modification made to the energy service calculations to address this scenario should be documented in the test report.

Because many different product topologies are possible, it can be necessary to repeat additional tests or make additional modifications to test procedures (in accordance with 4.3) for some products.

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Annex AA

(Void)

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Annex BB (normative)

Battery durability test

BB.1 Background

The battery durability test aims to identify batteries unsuitable for the application in stand-alone renewable energy products. The procedures are related to storage of the stand-alone renewable energy products.

In general terms, the storage procedures use methods to accelerate the ageing mechanisms occurring during storage. This method enables the identification of batteries which age prematurely and are therefore unsuitable for use in stand-alone renewable energy products.

BB.2 Test outcomes

The test outcomes of the battery durability test are listed in Table BB.1.

Table BB.1 – Battery durability test outcomes

Metric	Reporting units	Related aspects	Notes
Capacity loss from storage (δC)	Percentage (%)	4.2.5.3 Battery storage durability	

BB.3 Related tests

The battery durability test is related to the battery test (Annex K).

BB.4 Procedure

BB.4.1 Failed samples

Do not attempt to charge any sample that develops a safety hazard or visible damage (e.g. leakage, venting, swelling, smoke, fire, explosion, or disassembly) during storage. Any sample that is damaged, unsafe, or unable to be charged after storage shall be considered a failed sample. The number of failed samples and the type of failure shall be reported. Include photographs of any visible damage.

This procedure for failed samples is applicable to all battery types.

BB.4.2 Durability storage test for valve-regulated lead-acid batteries

BB.4.2.1 General

The valve-regulated lead-acid battery is stored for 360 h connected to a resistance corresponding to a current of $2 I_t$ A (where I_t A is defined in K.4.1), which causes a deep discharge.

BB.4.2.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Battery analyser.
- Wire cutters.
- Wire strippers.
- Soldering iron and solder.
- Heat-shrink tubing and heat gun, or electrical tape.
- Resistor with resistance corresponding to a current of $2 I_t \text{ A} \pm 10 \%$ and a power rating that is greater than the maximum power dissipated during the test, as specified in IEC 61056-1:2012, 7.9.2.

BB.4.2.3 Test prerequisites

The battery shall be recently received. The battery capacity shall have been determined using the lead-acid battery test (K.4.2). The battery shall have been cycled no more than two times and shall have been stored fully charged for no more than 1 week since undergoing the battery capacity test, but may be discharged before the start of the storage period. The battery shall be removed from the DUT.

For large batteries, the resistance value required by IEC 61056-1 can result in a large current, requiring a resistor with a prohibitively high power rating. In this case, the battery may be discharged by other means (e.g. a battery analyser or DC electronic load) until the voltage is low enough to connect the resistor without exceeding its power limit. The discharge period before connecting the resistor should be as short as possible and shall be included in the storage duration.

BB.4.2.4 Procedure

Perform the charge acceptance after the deep discharge test from IEC 61056-1:2012, 7.9, with the following modifications:

- the requirements of IEC 61056-1:2012, 7.9.1 do not apply;
- capacity before and after storage shall be measured using the method defined in K.4.2. The same channel of the battery analyser should be used for both the before and after capacity tests;
- the battery shall be stored at an ambient temperature of $22 \text{ }^{\circ}\text{C} \pm 5 \text{ K}$. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.

BB.4.2.5 Calculations

Determine the capacity loss using the following formula:

$$\delta C = \left(1 - \frac{C_A}{C_B} \right) \times 100 \%$$

where

- δC is the percent capacity loss experienced by the battery after storage (%);
- C_A is the battery capacity measured after the storage, in ampere-hours (Ah);
- C_B is the battery capacity measured before the storage, in ampere-hours (Ah).

No capacity loss value shall be reported for failed samples (BB.4.1) and these samples shall be excluded from the calculation of average capacity loss.

BB.4.3 Durability storage test for flooded lead-acid batteries

BB.4.3.1 General

The flooded lead-acid battery is stored for 7 days connected to a resistance corresponding to a current of $0,01 I_t$ A (where I_t A is the current corresponding to a 1 h discharge in amperes), which causes a deep discharge. The storage test for flooded lead-acid batteries is based on VW 75073 and AS 4086.

BB.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Battery analyser
- Wire cutters
- Wire strippers
- Soldering iron and solder
- Heat-shrink tubing and heat gun, or electrical tape
- Resistor with resistance corresponding to a current of $0,01 I_t$ A ± 25 % and a power rating that is greater than the maximum power dissipated during the test.

BB.4.3.3 Test prerequisites

The battery shall be recently received and fully charged. If testing a flooded lead-acid battery that was shipped dry, the battery shall have been filled with battery acid in accordance with instructions in K.4.2.1.

The battery capacity shall have been determined using the lead-acid battery test (K.4.2). The product shall have been cycled no more than two times and shall have been stored for no more than 1 week since undergoing the battery capacity test. The battery shall be removed from the DUT. The storage test shall be carried out at $30\text{ °C} \pm 5\text{ K}$.

BB.4.3.4 Procedure

The following steps shall be performed. The battery shall be fully charged at the start of the test (Annex M).

- a) Discharge the battery at a rate of $0,1 I_t$ A until a voltage of 1,8 V/cell is reached. The value of I_t shall be determined using the battery capacity measured in the battery test (Annex K).
- b) Connect across the battery terminals a resistor with resistance and power rating calculated using the following formulae, respectively:

$$R = \frac{V_{\text{nom}}}{0,01 \times I_t}$$

where

R is the resistance corresponding to a current of $0,01 I_t$ A, in ohms (Ω);

V_{nom} is the battery's nominal voltage, in volts (V);

I_t is the current corresponding to a 1 h discharge, in amperes (A).

$$P \geq \frac{V_{\text{initial}}^2}{R}$$

where

P is the resistor's power rating, in watts (W);

V_{initial} is the battery voltage when the resistor is first connected, in volts (V);

R is the resistance of the selected resistor, in ohms (Ω);

- c) Store the battery for 7 days at $30\text{ °C} \pm 5\text{ K}$. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.
- d) Determine the battery capacity in accordance with the lead-acid battery test (K.4.2). The same channel of the battery analyser should be used for both the before and after capacity tests.

BB.4.3.5 Calculations

The calculations required for the storage test for flooded lead-acid batteries are identical to those for valve-regulated lead-acid batteries (BB.4.2.5).

BB.4.4 Durability storage test for nickel-metal hydride batteries

BB.4.4.1 General

The nickel-metal hydride battery is stored for 30 days at $60\text{ °C} \pm 5\text{ K}$ connected to a resistance corresponding to a current of $0,2 I_t\text{ A}$ (where $I_t\text{ A}$ is the current corresponding to a 1 h discharge in amperes), which causes a deep discharge in the battery.

BB.4.4.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Battery analyser.
- Wire cutters.
- Wire strippers.
- Soldering iron and solder.
- Heat-shrink tubing and heat gun, or electrical tape.
- Oven, environmental chamber, or other apparatus capable of maintaining temperature in the required range.
- Resistor with resistance corresponding to a current of $0,2 I_t\text{ A} \pm 25\%$ and a power rating that is greater than the maximum power dissipated during the test.

BB.4.4.3 Test prerequisites

The battery shall be recently received and fully charged. The battery capacity shall have been determined using the nickel-metal hydride battery test (K.4.3). The product shall have been cycled no more than two times and shall have been stored for no more than 1 week since undergoing the battery capacity test. The battery shall be taken out of the DUT. The storage test shall be carried out at $60\text{ °C} \pm 5\text{ K}$.

BB.4.4.4 Procedure

The following steps shall be performed. The battery shall be fully charged at the start of the test (Annex M).

- a) Discharge the battery at a rate of $0,2 I_t$ A until a voltage of 1,0 V/cell is reached. The value of I_t shall be determined using the battery capacity measured in the battery test (Annex K).
- b) Connect across the battery terminals a resistor with resistance and power rating as specified in BB.4.4.2.
- c) Store the battery for 30 days at $60\text{ °C} \pm 5\text{ K}$. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.
- d) Determine the battery capacity in accordance with the nickel-metal hydride battery test (K.4.3). The same channel of the battery analyser should be used for both the before and after capacity tests.

BB.4.4.5 Calculations

The calculations required for the storage test for nickel-metal hydride batteries are identical to those for valve-regulated lead-acid batteries (BB.4.2.5).

BB.4.5 Durability storage test for lithium-ion batteries

BB.4.5.1 General

The lithium-ion battery is stored for 30 days at $55\text{ °C} \pm 5\text{ K}$ at a state of charge of 50 %. The storage test for lithium-ion batteries is an accelerated version of the charge (capacity) recovery after long term storage test from IEC 61960-3:2017, 7.5.

BB.4.5.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Battery analyser.
- Oven, environmental chamber, or other apparatus capable of maintaining temperature in the required range.

BB.4.5.3 Test prerequisites

The battery shall be recently received and fully charged. The battery capacity shall have been determined using the lithium-ion battery test (K.4.4). The product shall have been cycled no more than two times and shall have been stored for no more than 1 week since undergoing the battery capacity test. The battery shall be taken out of the DUT. The storage shall be carried out at $55\text{ °C} \pm 5\text{ K}$.

BB.4.5.4 Procedure

The following steps shall be performed. The battery shall be fully charged at the start of the test (Annex M).

- a) Discharge the battery at a rate of $0,2 I_t$ A for 2 h and 30 min. The battery is then at a state-of-charge of 50 %. The value of I_t shall be determined using the battery capacity measured in the battery test (Annex K).
- b) Store the battery for 30 days at $55\text{ °C} \pm 5\text{ K}$. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.
- c) If the battery has multiple cells (or parallel cellblocks) in series, charge in accordance with G.4.4 a) as a prerequisite to capacity testing in the next step.
- d) Determine the battery capacity in accordance with the lithium-ion battery test (K.4.4). The same channel of the battery analyser should be used for both the before and after capacity tests.

BB.4.5.5 Calculations

The calculations required for the storage test for lithium-ion batteries are identical to those for valve-regulated lead-acid batteries (BB.4.2.5).

BB.4.6 Durability storage test for lithium iron phosphate batteries

BB.4.6.1 General

The lithium iron phosphate battery is stored for 30 days at $55\text{ }^{\circ}\text{C} \pm 5\text{ K}$ at a state of charge of 50 %. The storage test for lithium iron phosphate batteries is an accelerated version of the charge (capacity) recovery after long term storage test from IEC 61960-3:2017, 7.5.

BB.4.6.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- Battery analyser.
- Oven, environmental chamber, or other apparatus capable of maintaining temperature in the required range.

BB.4.6.3 Test prerequisites

The battery shall be recently received and fully charged before undertaking the procedure. The battery capacity shall have been determined using the lithium iron phosphate battery test (K.4.5). The battery shall be taken out of the DUT. The product shall have been cycled no more than two times and shall have been stored for no more than 1 week since the undergoing the battery capacity test. The storage shall be carried out at $55\text{ }^{\circ}\text{C} \pm 5\text{ K}$.

BB.4.6.4 Procedure

The following steps shall be performed. The battery shall be fully charged at the start of the test (Annex M).

- a) Discharge the battery at a rate of $0,2\text{ }I_t\text{ A}$ for 2,5 h. The battery is then at a state of charge of 50 %. The value of I_t shall be determined using the battery capacity measured in the battery test.
- b) Store the battery for 30 days at $55\text{ }^{\circ}\text{C} \pm 5\text{ K}$. Temporary excursions from this range, e.g. due to power outages, are permitted, but the cumulative duration of all such excursions shall not exceed 1 % of the storage period.
- c) If the battery has multiple cells (or parallel cellblocks) in series, charge in accordance with G.4.4 a) as a prerequisite to capacity testing in the next step.
- d) Determine the battery capacity in accordance with the lithium iron phosphate battery test (K.4.5). The same channel of the battery analyser should be used for both the before and after capacity tests.

BB.4.6.5 Calculations

The calculations required for the storage test for lithium-ion batteries are identical to those for valve-regulated lead-acid batteries (BB.4.2.5).

BB.5 Pass criteria

The battery capacity loss and number of failed samples shall not exceed the values specified in the product specification. In addition, no safety hazard or visible damage (e.g. leakage, venting, swelling, smoke, fire, explosion, or disassembly) shall occur in any samples.

The product specification may specify limits for the average battery capacity loss, the capacity loss permitted for an individual sample, or both.

BB.6 Reporting

Report the following in the battery test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - battery manufacturer, if available;
 - battery name, if available;
 - battery model number, if available;
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - capacity loss from storage (%).
- Average of n sample results for each DUT aspect tested.
- DUT's rating for aspects tested, if available.
- Deviation of the average result from the DUT's rating for each aspect tested, if available (%).
- Number of failed samples.
- Photographs of any visible damage.
- Comments:
 - individual and overall comments, as necessary.

Annex CC (normative)

Equipment requirements

CC.1 Overview

Annex CC gives requirements and recommendations for the equipment and materials necessary for the test methods described in this document. These provisions are stated in tabular form in Clause CC.2.

Several test methods in this document involve the calculation of electrical power or energy, which can be complicated by the presence of time-varying voltage or current waveforms. Issues relating to power measurement are discussed in Clause CC.3.

CC.2 Requirements and recommendations for equipment and materials

Table CC.2 through Table CC.8 give requirements and recommendations for the laboratory instruments, apparatus, and materials necessary to perform the tests in this document. Many pieces of equipment can be used for multiple tests; the right side of the table shows which test methods require each item. The symbols used in these columns of Table CC.2 through Table CC.8 are defined in Table CC.1.

In general, an instrument that combines two functions may be used instead of two separate instruments, if the accuracy and other requirements are met. For example, if a DC power supply current readout meets the accuracy requirement, it may be used instead of a separate DC ammeter or multimeter.

All equipment and materials shall meet the specifications given in the “requirements” columns of Table CC.2 through Table CC.8 and should conform with the recommendations given in the “recommendations” column.

Table CC.1 – Symbols used in the tables of Clause CC.2

Symbol	Meaning
No symbol	Equipment is not used for this test.
•	Equipment is required for this test. (Some equipment marked • is required only for certain types of products or appliances.)
○	Equipment is optional for this test. (For tests with multiple procedure alternatives, some of the optional equipment could be required for some of the alternatives.)
A, B, C	Letters indicate alternative sets of equipment to perform the test. For example, the test can be performed using all of the items marked A, or all of the items marked B, but it is not necessary to use both sets of items. The order of the letters is arbitrary and does not indicate an order of preference or ranking of accuracy.

Table CC.2 – Equipment and materials for sample preparation, visual screening and general laboratory use

Equipment	Recommendations and remarks	Requirements	Procedure		
			Sample preparation	Visual screening	General laboratory use
Computer	Depends on equipment to be connected; useful to have multiple USB ports for test equipment I/O. Test equipment often requires Windows®.	Depends on equipment			•
Wire stripper	Conductor size range of 0.2 mm ² to 6 mm ² . Used for stripping laboratory-supplied wire and wire that is part of the DUT.	--	•		•
Wire cutter	--	--	•		•
Soldering iron and solder	Temperature-controlled soldering station with a range of tips.	--	•		•
Heat-shrink tubing and heat gun	1/8 inch (3.2 mm) and 3/8 inch (9.5 mm) diameter before shrinking. Shrink ratio of 3:1 is useful for covering a wider range of wire sizes and can also be used for irregularly shaped terminals.	--	•		•
Screwdrivers	Range of screwdriver types and sizes, including flat, Phillips, hexalobular internal (e.g. ISO 10664), hex, and triangular types.	--	•		•
Power drill with drill bits	--	--	•		•
Insulated copper hook-up wire	Four colours (e.g. red, black, white, green). See recommendations on wire size in Table G.1. A supply of 0.75 mm ² (or 18 AWG) and 1.5 mm ² (or 16 AWG) wire in four colours is sufficient for a wide range of products. Tinned copper conductors can be easier to solder than plain copper.	See G.4.2.	•		•
Connectors (optional, but strongly recommended)	Rated for the maximum current and compatible with the wire size used.	--	•		•
Crimp tool (if necessary for connectors)	It is strongly recommended to use the type specified by the connector manufacturer.	--	•		•
Multimeter	Basic digital multimeter with clamp-on DC ammeter function for voltage and functionality checks and polarity identification.		•	•	•
Camera	--	--		•	•
Stopwatch or timer	--	≤ 1 s resolution			•
Either callipers or ruler, or both	--	--		•	•
Balance (scale)	--	--		•	
Bright task light with good colour rendering	≥ 700 lux and ≥ 85 CRI	--		•	•

Table CC.3 – Specifications for general electrical and thermal test equipment and materials

Equipment	Recommendations and remarks	Requirements	Test method														
			Photovoltaic module IV characteristics	Light output	Light distribution	Full battery run time	Full discharge procedure	Solar charge	Grid charge	Electromechanical charge	Charge controller behaviour	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance	Partial shading	Bending/folding test
DC voltmeter or multimeters ^a	--	≤ 0,5 % accuracy	B	•	•						•	•	•	•	•		•
DC ammeter or multimeters ^a	≥ 10 A current limit Can use DC voltmeter and current shunt resistor if higher currents are necessary.	≤ 1 % accuracy		•	•						•	•	•	•	•	•	•
DC power supply	≤ 0,001 A current resolution Be sure current and voltage are adequate for products tested. Multiple units can be paralleled for higher currents.	≤ 0,01 V voltage resolution Clause J.4: long-term voltage stability ≤ 3 % Other tests: ≤ 0,2 % load regulation		•	•				○		○	•	•	•	•	•	•
DC power supply, with programmable capability	Be sure current and voltage are adequate for products tested. Multiple units may be paralleled if accuracy requirement can be met.	≤ 0,01 V voltage resolution; ≤ 0,001 A current resolution; Programming accuracy: ≤ 0,05 V voltage, ≤ (0,5 % + 5 mA) current						B									
Battery simulator	Apparatus from IEC 62509:2010, 5.1.6.2; 2- or 4-quadrant power supply or power amplifier; or DC power supply and load	--										○		○			
Electronic load or variable and fixed resistors	≥ 20 A current limit ≥ 20 V voltage limit ≥ 250 W power limit constant-current mode	Capable of meeting required steady-state current values within 5 %											•				

[illegible]

Equipment	Recommendations and remarks	Requirements	Test method														
			Photovoltaic module IV characteristics	Light output	Light distribution	Full battery run time	Full discharge procedure	Solar charge	Grid charge	Electromechanical charge	Charge controller behaviour	Protection tests	Assessment of DC ports	Appliance tests	Lumen maintenance	Partial shading	Bending/folding test
AC power supply	Utility (mains) if compatible with DUT, or true sine wave inverter, frequency converter, uninterruptible power supply, or AC power supply with voltage total harmonic distortion (THD) ≤ 5 %.	--							•								
Voltage data logger	Sufficient memory for 3 days at ≤ 1 min intervals	≤ 1 mV resolution; ≤ (2.5 % + 2 mV) accuracy				•		•	•	•	•						
Current data logger, or voltage data logger plus current shunt or transducer	Sufficient memory for 3 days at ≤ 1 min intervals	≤ 1 mA resolution; ≤ 3 % accuracy				•		•	•	•	•						
Overcharge disconnect device	Either temperature or voltage sensing, or both; operating voltage range sufficient for highest expected battery voltage (typically < 20 V).	≤ 0.01 V resolution and ≤ 1 % accuracy for voltage						•	•		•						
Thermocouple meter or other suitable thermometer with surface-mountable sensors	Thermocouple meter and fast-response thermocouples	± 2 °C or better accuracy	•					○	○		○				○	•	
^a Several tests require two simultaneous current measurements and two simultaneous voltage measurements, requiring a total of four multimeters (or equivalent).																	
^b Some commercial solar array simulators are designed for large modules and are not accurate at the low currents typically seen with small stand-alone renewable energy products. For example, an SAS with a rated accuracy of ± (0.2 % + 20 mA) would not meet the accuracy requirement to simulate a module with a maximum power point current of 100 mA. If the rated accuracy is insufficient to meet the requirement, the instrument may be used if the simulated I-V curve is measured to verify that the current accuracy requirement is met at all points where the actual current is greater than half the maximum power point current. This test shall be performed for each sample tested.																	

Table CC.4 – Specifications for photovoltaic module test equipment

Equipment	Recommendations and remarks	Requirements	Test method			
			Photovoltaic module IV characteristics	Wiring inspection	Partial shading	Bending/folding test
Solar simulator	--	Class BBB or better as defined in IEC 60904-9	A		o	
PV reference cell	Calibration should be traceable to applicable national or international standards.	Matched to DUT spectral response (see Q.4.1.2) unless spectral mismatch correction is used	A		A	
Outdoor I-V curve analyser	Current range up to 10 A; voltage range up to 2 times maximum nominal voltage of modules to be tested.	≤ 1 % accuracy for currents > 0,1 A and voltages > 2,5 V	B		B	
Indoor I-V curve analyser, source-measure unit, or similar	Same as for outdoor, unless limited by solar simulator dimensions.	Same as outdoor I-V curve analyser	A		A	
Fast-response pyranometer	Silicon PV- or photodiode-based	≤ 5 % accuracy Response time ≤ 1 s	B		B	
Thermal imaging device (infrared camera)	Thermal sensitivity ^a < 0,08 K Capability to compute temperature statistics for a region of an image or export temperature data to computer software for analysis	Numerical temperature readout			•	
Opaque material to shade cells in increments of 10 % of cell area	Black vinyl electrical tape or similar	--			•	
Micrometer or calliper	Basic accuracy ≤ 0,025 mm	--		A		
Four-wire resistance-measuring instrument	See Clause A.2	--		B		
File, scriber, or sandpaper	--	--		•		

Table CC.5 – Specifications for photometric test equipment

Equipment	Recommendations and remarks	Requirements	Test method			
			Light output	Light distribution	Full battery run time	Appliance tests
Integrating sphere	--	≥ 1 m diameter with auxiliary lamp; set of 3 calibrated lamp standards; spectroradiometer detector with range containing 380 nm to 780 nm	A		A	o
Goniophotometer	--	See I.4.3.	B	^o b		
Multi-plane test apparatus	Black matte paint minimizes surface reflectance. An array of clamp types is useful to hold DUTs in place.	See I.4.4.4.	C	^o b		
DC ammeter	For use with incandescent luminous flux standards, current measurement uncertainty ≤ 0,05 %	≤ 1 % accuracy	A			
Turntable ("rotary disk")	--	--		^o b		
Lighting distribution grid testing surface	Black matte paint minimizes surface reflectance. An array of clamp types is useful to hold DUTs in place.	--		^o b		
Illuminance meter May be the same instrument as the data- logging illuminance meter below.	--	Cosine-corrected; $V(\lambda)$ corrected; ≤ 0,1 lux resolution;	B	^o b		•
Illuminance meter with data-logging capability	Sufficient memory for 3 days at ≤ 1 min time resolution	Cosine-corrected; $V(\lambda)$ corrected; ≤ 0,1 lux resolution;			•	
Appropriate optical cavity or dark room/closet	Photometer box (Annex Y)	Magnitude of stray light's influence on absolute illuminance measurements at most 0,5 % of the minimum illuminance magnitude being measured.			B	•

a The thermal sensitivity of thermal imaging devices is most commonly stated as the noise equivalent temperature difference (NETD) at 30 °C.

b The light distribution test includes multiple test methods, which produce different sets of outcomes and apply to different categories of products. See Annex T for the list of equipment required for each test method, the outcomes generated, and the applicability to different product categories.

Table CC.6 – Specifications for battery test equipment

Equipment	Recommendations and remarks	Requirements	Test method ^a			
			Battery test	Full battery run time	Full discharge procedure	Battery durability
Battery analyser	Accuracy of ± 1 % for voltage, current, and capacity.	DC power accuracy of ≤ 2 % or $\leq 0,02$ W, whichever is greater, at the nominal battery voltage and charge or discharge rate from Table K.2.	•	•	◦	
Resistor	--	≤ 5 % tolerance; size and power rating dependent on DUT's battery				•
Oven or environmental chamber	For $30\text{ °C} \pm 5\text{ K}$, a climate-controlled room can be used.	Able to maintain $60\text{ °C} \pm 5\text{ K}$ and $30\text{ °C} \pm 5\text{ K}$				•
^a The main influence of the battery analyser on the measurement uncertainty of key test outcomes in this document is through the uncertainty of the battery efficiency measurement. Therefore, this document does not specify accuracy requirements for current and voltage individually, but instead only specifies an accuracy rating for the DC power (i.e. the product of current and voltage), which is used to calculate the efficiency.						

Table CC.7 – Specifications for appliance test equipment and materials

Equipment	Recommendations and remarks	Requirements	Test method	
			Appliance tests	
Audio/video signal generation equipment	--	Meets requirements of IEC 62087-2:2023, 6.1, 6.2, 6.3	●	
Dynamic broadcast-content video signal media	--	Provided with IEC 62087-2:2023, 4.1.3	●	
Sound pressure level (SPL) meter	--	Class 2 certified meter; A-weighting ^a	●	
Sine wave audio signal media (e.g. IEC 62087-2:2023, 4.3.1)	--	1 kHz	●	
RF/FM transmitter	--	Able to accept the sine wave signal from the computer or hardware device	●	
Tachometer	Non-contact tachometer or stroboscope	≤ 1 % accuracy	A	
Anemometer	--	Measurement range includes 0,5 m/s. ≤ 0,2 m/s accuracy	B	
^a Sound pressure level meter accuracy classes are specified in IEC 61672-1 and weightings are specified in IEC 60268-1.				

Table CC.8 – Specifications for all water and physical ingress protection and mechanical durability test equipment

Equipment	Recommendations and remarks	Requirements	Test method			
			Physical and water ingress protection	Water-resistant coating inspection	Mechanical durability	Screw connections
Controlled water source	--	rotating head $\pm 60^\circ$	•			
Rigid probes	--	diameters $1^{+0,05}_0$ mm, $2,5^{+0,05}_0$ mm, and $12,5^{+0,2}_0$ mm	•			
Tape measure or ruler	--	≥ 1 m			•	
Weight	--	2 kg			•	
Protractor	--	--			•	
Clamp	--	--			•	
45 degree angle	Wooden block	--			•	
Torque screwdriver or spanner		≤ 5 % accuracy				•
Micrometer or calliper	Basic accuracy $\leq 0,025$ mm	--				•
UV-A inspection lamp	Wavelength 320 nm to 380 nm			•		
Scribe tool, dental scaler, or similar rigid pointed tool with a sharp tip	The same tool can be used in the PV module wiring inspection	--		•		
Tweezers	--	--		•		

CC.3 Guidelines for electrical power measurements

CC.3.1 Background

In several test procedures in this document, it is necessary to measure voltage and current in order to calculate a power value. These test procedures include:

- the full-battery run time test (Annex M) and appliance full-battery run time test with deep discharge protection (Clause FF.9),
- the grid charge test (Annex O),
- the electromechanical charge test (Annex P),
- the solar charge test (Annex R),
- the measurement of steady-state port characteristics (EE.4.2),
- the appliance power consumption test (Clause FF.6), and
- the appliance charging efficiency test (Clause FF.7).

NOTE The photovoltaic module I-V characteristics test (Annex Q) also involves a measurement of power, but the information in Clause CC.3 is generally not applicable.

The best way to perform this measurement is with a power meter (wattmeter) capable of both AC and DC measurements. However, these instruments are expensive, and as a result it can be more convenient for some laboratories to use separate instruments, such as multimeters or a custom data acquisition system, to measure voltage and current and then multiply the resulting values. However, unless appropriate precautions and corrective measures, if applicable, are taken, this method can result in significant measurement error when the current is varying with time. Therefore, the use of separate current and voltage measurements is permitted only if the resulting error is kept to an acceptable level.

CC.3.2 defines a metric to quantify the error associated with the calculation of power from separate measurements of DC current and voltage. A recommended limit for this metric is stated in CC.3.4 and additional recommendations are given in CC.3.5. Due to limited laboratory experience with these methods, Clause CC.3 does not presently give requirements.

CC.3.2 Overview of DC power measurement

When set to measure DC voltage or current, a multimeter displays the average value of the quantity being measured. (Some multimeters also have the ability to display the value of the DC component and the RMS value of the AC components.) The power calculated by multiplying the current and voltage readings of two multimeters is given by:

$$P_{\text{mm}} = I_{\text{avg}} \cdot V_{\text{avg}} = \frac{1}{T^2} \int_0^T I(t) dt \cdot \int_0^T V(t) dt$$

where

- P_{mm} is the power measured using two multimeters or other DC measuring instruments;
- T is the averaging period;
- $I(t)$ is the instantaneous current at time t ;
- $V(t)$ is the instantaneous voltage at time t ;
- I_{avg} is the average current;
- V_{avg} is the average voltage.

This is in contrast to the correct expression for the average power, which is:

$$P_{\text{avg}} = \frac{1}{T} \int_0^T P(t) dt = \frac{1}{T} \int_0^T I(t) \cdot V(t) dt$$

where

P_{avg} is the average power;

T is the averaging period;

$P(t)$ is the instantaneous power at time t ;

$I(t)$ is the instantaneous current at time t ;

$V(t)$ is the instantaneous voltage at time t .

NOTE The average power P_{avg} is identical to the active power defined in IEC 60050-131, 131-11-42. The definition of P_{mm} differs from the definition of apparent power (IEC 60050-131, 131-11-41, in that the apparent power is the product of the RMS, rather than the average, values of current and voltage. The ratio of P_{avg} and P_{mm} is therefore closely related to, but distinct from, the power factor (IEC 60050-131, 131-11-46) in AC systems.

These two quantities are identical if either current or voltage is constant with respect to time. Otherwise, the difference between P_{mm} and P_{avg} will contribute to the overall error in the power measurement. It is useful to quantify the contribution to relative error in power due to the current and voltage waveforms:

$$\delta P = \frac{P_{\text{mm}} - P_{\text{avg}}}{P_{\text{avg}}}$$

where

δP is the relative error in average power due to the current and voltage waveforms;

P_{avg} is the average power;

P_{mm} is the power measured using two multimeters or other DC measuring instruments.

In the case where the power is being measured across a load that uses pulse-width modulation (PWM), the load current will be a pulse train varying between zero and a constant nonzero value. If the load being measured is supplied with power by a voltage source with nonzero output resistance, such as a PV simulator or a DC power supply with a current shunt in series, it can be shown that the value of δP can also be expressed in terms of the voltages during the on and off periods:

$$\delta P_{\text{PWM}} = (1 - D) \cdot \frac{V_{\text{off}} - V_{\text{on}}}{V_{\text{on}}}$$

where

δP_{PWM} is the relative error in average power due to the current and voltage waveforms, when the current waveform is PWM;

D is the duty cycle (the fraction of time when the load is drawing current);

V_{off} is the load voltage when the load is not drawing current;

V_{on} is the load voltage when the load is drawing current.

This form can be more convenient to use since it is not necessary to measure the current waveform quantitatively.

When multiple power measurements are being averaged together, δP may be calculated as a weighted average, using either the general or PWM forms:

$$\delta P = \frac{\sum_i \left(\Delta t_i \cdot \frac{P_{mm,i} - P_{avg,i}}{P_{avg,i}} \right)}{\sum_i \Delta t_i}$$

where

- δP is the relative error in average power due to the current and voltage waveforms;
- Δt_i is the time interval corresponding to measurement i ;
- $P_{avg,i}$ is the average power at measurement i ;
- $P_{mm,i}$ is the power measured using two multimeters or other DC measuring instruments at measurement i .

$$\delta P_{PWM} = \frac{\sum_i \left(\Delta t_i \cdot (1 - D_i) \cdot \frac{V_{off,i} - V_{on,i}}{V_{on,i}} \right)}{\sum_i \Delta t_i}$$

where

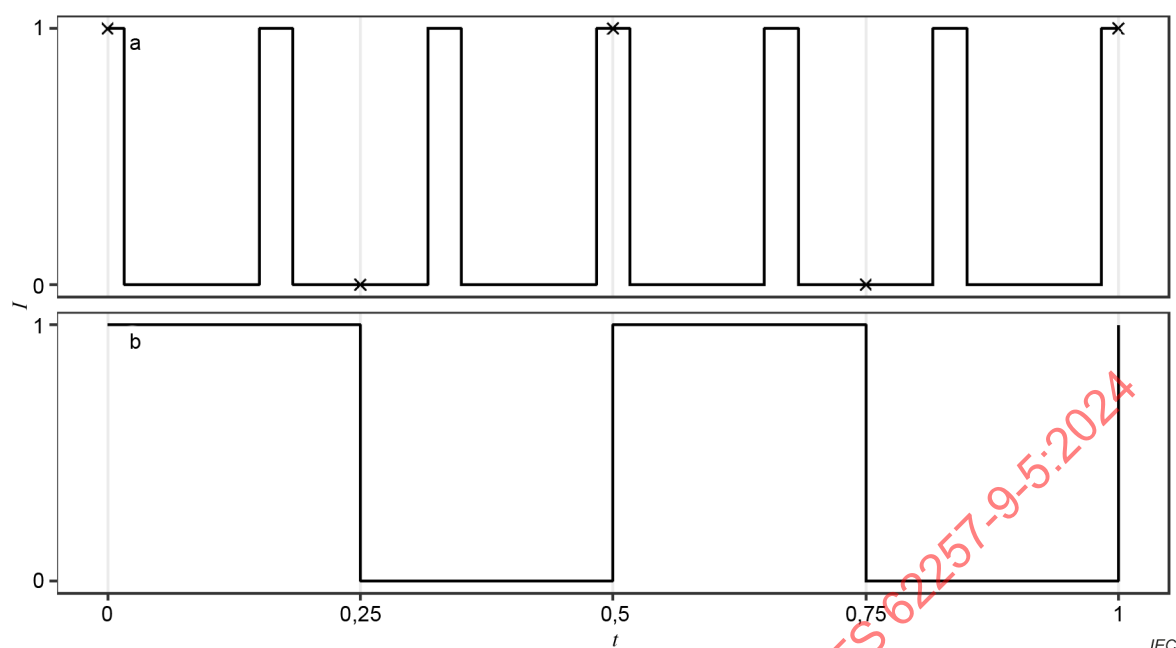
- δP_{PWM} is the relative error in average power due to the current and voltage waveforms;
- Δt_i is the time interval corresponding to measurement i ;
- D_i is the duty cycle (fraction of time when the load is drawing current) at measurement i ;
- $V_{off,i}$ is the load voltage when the load is not drawing current, at measurement i ;
- $V_{on,i}$ is the load voltage when the load is drawing current, at measurement i ;
- $P_{mm,i}$ is the power measured using two multimeters or other DC measuring instruments at measurement i .

Since accurately calculating δP requires an accurate measurement or calculation of the average power, it is generally not beneficial to calculate δP in order to apply a correction to measured data. However, a calculation of δP can be used to determine whether it is acceptable to use lower-cost measuring instruments for a given product. For example, a laboratory could test one sample using a power meter and use the result to determine whether the remaining samples could be tested simultaneously using low-cost instruments. Alternatively, the laboratory could test the samples using the low-cost instruments while observing one sample with an oscilloscope, and use the results to determine whether to repeat the test, one sample at a time, using a power meter.

CC.3.3 Aliasing

Aliasing is another source of measurement error in products with PWM or similar current waveforms. Aliasing occurs with the sampling frequency is too low to capture high-frequency components of the waveform being measured. In practice, this typically occurs with products that use unusually low frequencies for PWM, or that periodically interrupt charging for other purposes. In the special case where the sampling interval is an exact multiple of the PWM period, the measurement will always be made at the same point in the PWM cycle and the PWM will not be detected at all.

An example of the effect of aliasing is shown in Figure CC.1. Further discussion of aliasing in the specific context of the solar charge test is given in R.4.2.1.2.

**Key**

t Time (s)
 I Current (A)

- a DUT current waveform
 b Waveform reconstructed from measured values
 × Measurement

The actual DUT current waveform (top) is a PWM signal with a duty cycle of 20 %, frequency of 6 Hz, and average value of 0,2 A. Sampling at 4 Hz results in a reconstructed waveform (bottom) with a duty cycle of 50 %, frequency of 2 Hz, and average value of 0,5 A (a relative error of 150 %). The points marked with × in the upper plot indicate the measurements made by the data acquisition system.

Figure CC.1 – Example of aliasing in data acquisition of a PWM signal

CC.3.4 Power measurement accuracy recommendations

Power measurements should be performed using a power-measuring instrument meeting the requirements of Clause CC.2, except that two multimeters (or a DC voltmeter and DC ammeter, or a data-logging or data-acquisition system with equivalent functionality) may be used if the absolute value of the relative error contribution (δP) defined in CC.3.2 does not exceed 1 %. If the current and voltage waveforms are not known with sufficient accuracy to enable a direct calculation of δP , the current waveform may be assumed to be PWM with a duty cycle of 10 %; the δP criterion can then be assessed by inspection of the voltage waveform with an oscilloscope. For very low frequencies, a multimeter with pulse width and minimum and maximum voltage features can be used if the response time of this feature is sufficient to meet the accuracy requirement.

Many power meters can calculate DC voltage and DC current in addition to the RMS values, so the same instrument can be used to measure both P_{mm} and P_{avg} simultaneously. This is the recommended method. If δP is determined by comparison between two measurements with different instruments (e.g. a power meter and two multimeters), the comparison is valid only for simultaneous measurements of a single DUT. In addition, the use of different instruments introduces another source of measurement uncertainty.

If a power-measuring instrument is used in test procedures that calculate average power or cumulative energy over a period of time (e.g. the solar charge test), the internal averaging or integration function of the power meter, if present, should be used rather than calculating and integrating the power at each sampling interval, since the power meter uses a high internal sampling rate resulting in a more accurate total or average.

Whenever separate current and voltage measurements are used, any time offset between the two measurements should be taken into account in the calculation of measurement error.

When the voltage and current waveforms are not constant or sinusoidal, many factors can contribute to the total uncertainty of a power measurement. The accuracy requirement in Clause CC.2 applies to DC conditions only.

CC.3.5 Additional guidelines and corrective measures

The following items provide additional guidance on the measurement of power in the test procedures defined in this document. In all cases, the recommendation in CC.3.4 is the definitive criterion for whether a given test method should be considered appropriate.

- It is always acceptable to use a power-measuring instrument meeting the requirements of Clause CC.2.
- If the current is known to be approximately constant (e.g. through observation with an oscilloscope), the criterion in CC.3.4 is likely to be met, so separate current and voltage measurements may be used. This is likely to be the case for most steady-state measurements of appliance power consumption, since even appliances that use PWM internally often include bypass capacitors.
- If the current is not constant, but the voltage is approximately constant, the criterion in CC.3.4 can be met in some cases. It is important to consider the effect of the voltage drop across the ammeter or current shunt when determining whether the voltage remains constant, since the current is varying, the voltage drop will also vary. Using a higher current range can reduce the voltage drop, but can increase the measurement uncertainty.
- If the current and voltage are not constant, but it is desired to use separate voltage and current measurements, the following corrective measures can be attempted to reduce the measurement error to an acceptable level (as specified in CC.3.4):
 - If the appliance is being driven from a power supply and the power measurement is at the power input to the appliance, a power supply with remote sensing may be used to compensate for the varying voltage drop across the current-sensing element. This method is unlikely to be effective at high frequencies and is most suitable for appliances where the change in current is gradual, such as television sets.
 - Current and voltage data loggers or a data acquisition system may be used to record the values of current and power over the averaging period. The instantaneous power is then calculated and the values are averaged. This method can be effective if the change in current is gradual, as with television sets, or if the current is relatively constant for most of the averaging period. The weighted-average form of the δP calculation should be used.

For the measurement of appliance power, a capacitor may be connected across the appliance plug (i.e. in parallel with the voltmeter). The required capacitor value depends on the current waveform, the average values of current and voltage, and the resistance of the ammeter. The value should be chosen based on a circuit model or comparison with a power meter or observation with an oscilloscope. This option shall not be used for the solar charge test or if the capacitor influences the behaviour of the DUT.

CC.4 Alternative apparatus for port loading

The output overload protection test (DD.4.2) and assessment of DC ports (Annex EE) require a variable load to be connected to the port. Typically, it is most convenient to use a DC electronic load. However, a variable resistor or combination of either variable or fixed resistors, or both, may be used instead. This alternative can be appropriate in the following situations:

- The laboratory does not have an electronic load available.
- The overcurrent protection of the DUT is sensitive to load inrush current. Many DC electronic loads have high input capacitance that can result in inrush current that trips overcurrent protection on particularly sensitive products. This can result in an underestimate of the maximum sustained current.
- The DUT uses a protection strategy such as foldback current limiting in which voltage is not strictly a function of current. (However, in this case, an electronic load in constant-voltage or constant-resistance mode can still be more convenient than variable resistors.)

To use resistors in place of an electronic load, the following procedure is recommended. However, other combinations of either fixed or variable resistors, or both, may be used.

NOTE 1 Power resistors often require heat sinks for safe and stable operation. Recommended heat sink types and dimensions are typically stated on the resistor manufacturer's data sheet.

- a) Calculate the safety resistor value, R_{safety} , corresponding to a current of 100 % of the maximum current at the nominal port voltage (from F.4.1.5):

$$R_{\text{safety}} = \frac{V_{\text{nom,port}}}{I_{\text{max,port}}}$$

where

R_{safety} is the safety resistor value, in ohms (Ω);

$V_{\text{nom,port}}$ is the nominal voltage of the port (from F.4.1.5), in volts (V);

$I_{\text{max,port}}$ is the maximum current for the port, in amperes (A).

The safety resistor should have a power rating sufficient to allow the maximum voltage of the port to be applied:

$$P_{\text{Rsafety}} \geq \frac{V_{\text{max,port}}^2}{R_{\text{safety}}}$$

where

P_{Rsafety} is the maximum power rating of the safety resistor, in watts (W);

$V_{\text{max,port}}$ is the maximum expected voltage of the port, in volts (V);

R_{safety} is the safety resistor value, in ohms (Ω).

- b) Calculate the value of the variable resistor R_{variable} . The full-scale resistance of the variable resistor in series with the fixed resistor R_{safety} should result in a current of no more than 10 % of the maximum current for the port (EE.4.1 d)) at the nominal port voltage (F.4.1.5):

$$R_{\text{variable}} \geq \frac{V_{\text{nom,port}}}{0,1 \times I_{\text{max,port}}} - R_{\text{safety}}$$

where

R_{variable} is the variable resistor value, in ohms (Ω);

$V_{\text{nom,port}}$ is the nominal voltage of the port (from F.4.1.5), in volts (V);

$I_{\text{max,port}}$ is the maximum current for the port, in amperes (A);

R_{safety} is the safety resistor value, in ohms (Ω).

The variable resistor should have a maximum current rating sufficient to allow the maximum current of the port to be applied and a resolution sufficient to achieve the required current values.

NOTE 2 Variable resistors are generally rated by the maximum power dissipation of the full resistance element. If a maximum current rating is not given by the resistor manufacturer, the minimum allowable power rating can be calculated based on the full-scale resistance:

$$P_{\text{Rvariable}} \geq I_{\text{max,port}}^2 \cdot R_{\text{variable}}$$

where

$P_{\text{Rvariable}}$ is the maximum power rating of the variable resistor, in watts (W);

$I_{\text{max,port}}$ is the maximum current for the port, in amperes (A);

R_{variable} is the variable resistor value, in ohms (Ω).

- c) Connect the safety and variable resistors, in series, to the output of the loaded port.

Annex DD (normative)

Protection tests

DD.1 Background

Annex DD contains test methods to assess the robustness of the stand-alone renewable energy product to faults, including incorrect wiring and a disconnected battery. To meet the requirements of these tests, the product shall withstand the fault condition without being damaged or presenting a safety hazard.

DD.2 Test outcomes

The test outcomes of the protection tests are listed in Table DD.1.

Table DD.1 – Protection test outcomes

Metric	Reporting units	Related aspects	Remarks
Presence of sufficient miswiring protection	pass/fail	4.2.7.3 Circuit and overload protection	Overall pass/fail result for entire DUT
Miswiring protection test damage	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every tested configuration
Miswiring protection test safety hazard	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every tested configuration
Miswiring protection test repairs necessary	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port
Presence of sufficient output overload protection	pass/fail	4.2.7.3 Circuit and overload protection	One result for every port
Output overload protection test damage	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port
Output overload protection test safety hazard	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port
Output overload protection test repairs necessary	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port
Output overload protection test maximum sustained current	Amperes (A)	4.2.7.3 Circuit and overload protection	One result for every port
Presence of sufficient PV overvoltage protection	pass/fail	4.2.7.3 Circuit and overload protection	Overall pass/fail result for entire DUT
PV overvoltage protection test damage	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port or built-in appliance
PV overvoltage protection test safety hazard	Yes/no, description	4.2.7.3 Circuit and overload protection	One result for every port or built-in appliance
PV overvoltage protection test port allowable voltage limit	Voltage (V)	4.2.7.3 Circuit and overload protection	One result for every port
PV overvoltage protection test port voltage	Voltage (V)	4.2.7.3 Circuit and overload protection	One result for every port

DD.3 Related tests

The protection tests use results from the photovoltaic module I-V performance test (Annex Q). The maximum sustained current calculated in the output overload protection test (DD.4.2) is used in the assessment of DC ports (Annex EE).

DD.4 Procedure

DD.4.1 Miswiring protection test

DD.4.1.1 General

This test assesses whether the DUT is protected against improper wiring and system component connections. In many cases, it is infeasible to test every possible combination of incorrect connections, so this procedure attempts to identify and test configurations that are likely to occur during installation, operation, and routine maintenance.

DD.4.1.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC power supply
- Battery simulator (optional), which, if used, may be one of the following:
 - The battery simulator circuit defined in IEC 62509:2010, Figure 1, with parameters from IEC 62509:2010, 5.1.6.2.
 - A two- or four-quadrant (bipolar) power supply or power amplifier.
 - A commercially available battery simulator.
 - A power supply in constant-current mode placed in parallel with an electronic load in constant-voltage mode. (The power supply current is set to a value greater than the current drawn by the DUT.)

The use of a battery simulator can provide more stable and controllable operating conditions, improving repeatability, but the use of the DUT's battery is permitted as a low-cost option.

DD.4.1.3 Test prerequisites

The visual screening (Annex F) and photovoltaic module I-V characteristics test (Annex Q) shall be performed before performing the miswiring protection test.

If a battery simulator is not used, the DUT's battery shall be partially charged so that the battery will accept charge from the PV input and supply power to the ports and any built-in appliances for the duration of the test. (That is, neither the deep discharge protection limit nor the overcharge protection limit shall be reached during the test. If one of these limits is reached, the battery may be charged or discharged as necessary, and the test continued.)

DD.4.1.4 Procedure

The following steps shall be performed.

- a) Identify the connectors subject to the miswiring protection test. A connector shall be tested if both of the following are true.
 - The connector is accessible to the user or installer during normal installation, operation, and routine maintenance. (A compartment or enclosure is considered “accessible” if it can be opened without the use of any tools, or if it is opened at any time during the normal processes of installation, operation, or routine maintenance.)
 - The connector can be inserted, assembled, or mated incorrectly (for example, backwards) without excessive force or modification, or the connector can be inserted into or mated with a receptacle or connector other than those with which it is intended to be used.

Examples of situations requiring testing:

EXAMPLE 1 The PV module and lighting appliances have the same type of plug, so one can be inserted into the socket intended for the other.

EXAMPLE 2 The battery, mounted in a user-accessible enclosure (as defined above), is connected to the charge controller using quick-disconnect lugs, and the positive and negative leads are physically interchangeable.

Examples of situations not requiring testing:

EXAMPLE 3 The battery is mounted in an enclosure that is not intended to be accessed by the user or installer. In this case, the battery connector does not require testing.

EXAMPLE 4 The product includes several different appliances with USB plugs and four USB sockets intended for connecting appliances. Although a given appliance could be connected to any of the four sockets, this would not be an incorrect connection, so it does not require testing.

EXAMPLE 5 The product includes a non-polarized connector that is designed to function correctly when connected in either direction. (For example, a plug with a symmetrical arrangement of contacts.)

b) Identify each incorrect configuration to be tested, using the following rules.

- In these rules, a pair is defined as a positive and negative lead from the same circuit.
- The following configurations shall be tested.
 - The conductors making up a single pair are swapped (e.g. the battery is connected in reverse polarity).
 - A single connector or pair of conductors is matched with the wrong mating connector, and all other connections are made correctly (e.g. the PV module is connected to an appliance port).
 - Two connectors or pairs of conductors are swapped (e.g. the battery is connected to the PV input and the PV module is connected to the battery input).
 - A single connector is inserted in the wrong orientation (e.g. the battery connector is inserted backwards).
- Combinations of the above situations (e.g. both battery and PV module are connected in reverse polarity) may be omitted.
- If multiple connectors are functionally identical, only one connector is required to be tested. For example, if the DUT includes four identical sockets for connecting appliances, and a PV connector that fits in the appliance sockets, the PV connector shall be tested in one of the four appliance sockets. Testing of the other three sockets is optional.
- All required configurations shall be tested prior to testing any optional configurations, since the test can be destructive.
- In addition to the configurations tested above, the test laboratory should test any additional configurations if, in the tester's judgement, the configuration is likely to occur during installation, use, or routine maintenance.
- If the testing laboratory determines that a configuration will result in a safety hazard to property or personnel, the laboratory should not test that configuration. If this is a required configuration, the DUT fails the test. (For example, if reversing a connector would result in a short-circuit path across the battery with no overcurrent protection, the configuration should not be tested.)
- It is not necessary to test configurations in which excessive force or modifications to the DUT would be required to make connections, provided that no electrical contact occurs unless excessive force is applied or modifications are performed. (For example, if the battery and PV module use connectors of different sizes or shapes, a configuration in which these connectors are swapped may be omitted.) "Excessive force" is defined as sufficient force to physically damage the DUT in a way that would be apparent to a typical user. If a connector can be forced into a socket without causing obvious damage, even if non-obvious damage (e.g. bent pins or contacts) occurs, this configuration shall be tested.

- c) If a PV module input is required for the wiring configuration under test, use a DC power supply set to the maximum power voltage (V_{mpp}) and maximum power point current (I_{mpp}) of the PV module at typical module operating temperature (TMOT). If the PV module of the DUT has not undergone the photovoltaic module I-V characteristics test (Annex Q), the average values of the samples that underwent the photovoltaic module I-V characteristics test (Annex Q) shall be used. Prior to testing, connect the power supply to the PV input and verify that the DUT charges correctly.
- d) For each incorrect wiring configuration identified in b), the following steps shall be performed:
 - 1) Configure the DUT with the incorrect wiring configuration under test. (If necessary for safety, disconnect either the battery or PV input, or both, before making wiring configuration changes.)
 - 2) If the configuration under test involves a power source applied to a port intended as a power output for included appliances, and there are other ports of the same type, one included appliance of each type shall be connected to these ports. If the appliances cannot be connected simultaneously, the test shall be repeated to test all the appliances.

NOTE The purpose is to ensure that appliances can withstand the voltage applied by the power source.

- 3) Reconnect and turn on the power supply simulating the PV module.
- 4) Turn on any DUT functions necessary to achieve the worst-case operating condition for the wiring configuration under test, in the judgement of the test laboratory. (If it is unclear whether the worst-case operating condition occurs with a particular function turned on or turned off, test both conditions for 20 min each.)
- 5) Allow the DUT to remain connected for 20 min, unless a safety hazard develops (e.g. smoke or a burning smell). The DUT is not required to function correctly while configured incorrectly.
- 6) Restore the DUT to the correct wiring configuration. (If necessary for safety, disconnect either the battery or PV input, or both, before making wiring configuration changes.)
- 7) If a safety hazard develops, disconnect the battery and PV input from the DUT and discontinue the test.
- 8) Test the functionality of the DUT. If the DUT no longer functions:
 - i) If the problem can be identified and repaired by following instructions in the user documentation (e.g. replacing a blown fuse, resetting a tripped circuit breaker, disconnecting and reconnecting the battery or battery simulator), using no tools except a screwdriver used to remove and insert screws, without creating a safety hazard and without invalidating the warranty, repair the fault. Only spare parts included with DUT (or their equivalent, in case the supply of included spare parts is exhausted through repeated testing) may be used. (For example, if a fuse is blown, and the company did not supply replacement fuses, the DUT fails the test.) If the repair requires cycling the power source (disconnecting and reconnecting the battery or ON/OFF cycling of the battery simulator), the DUT shall fail the test unless the DUT battery can be disconnected and reconnected using no tools except a screwdriver, following instructions in the user documentation, and without invalidating the warranty. If the DUT is functional after the repair, and the repair can be conducted without exposing the person conducting the repair to a safety hazard, the DUT does not fail the test.
 - ii) If the problem can be easily identified and repaired by the test laboratory, but requires steps not documented in the user documentation, tools other than a screwdriver used to remove and insert screws, or spare parts not included with the DUT, the DUT fails the test. However, the test laboratory may, at its discretion, repair the fault and continue the test. (For example, if a replacement fuse is required, the test laboratory may replace the fuse, continue the test, and state in the report that the DUT failed the test, but would have passed the test had spare fuses been included).
 - iii) In the test report, describe any repairs made.

- 9) Record whether the DUT remains functional at the end of the test, whether any damage occurred, and whether any user safety hazard is present. Describe any failures and take photographs of any visible damage or safety hazards.

DD.4.1.5 Pass criteria

The DUT shall pass the miswiring protection test if all of the following are true.

- The DUT remains functional after the final incorrect configuration is tested. Any repairs necessary to restore functionality shall meet the requirements set forth in DD.4.1.4 d) 8) i).
- No damage occurred and no safety hazards developed during the test.

The DUT may shut down or operate abnormally during the test provided that normal operation can be restored after the test is completed, although any abnormal operation should be noted in the test report. If minor cosmetic damage occurs that is not expected to affect the DUT's performance, the DUT shall pass the test. Any damage should be noted in the test report.

DD.4.2 Output overload protection test

DD.4.2.1 General

This test assesses whether the DUT is protected against excessive load or short circuits applied to the appliance ports.

NOTE This test can be conducted using the same apparatus as the assessment of DC ports (Annex EE).

DD.4.2.2 Equipment requirements

DD.4.2.2.1 General

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC power supply.
- Two DC ammeters or multimeters.
- Two DC voltmeters or multimeters.
- Electronic load or fixed and variable resistors (Clause CC.4) as described in the following.

In some cases, it can be necessary to use multiple laboratory power supplies in parallel to achieve the required current. Unless otherwise specified by the power supply manufacturer, a diode should be used at the output of each power supply to prevent backfeeding. If the power supplies do not include current-sharing functionality, set one power supply to constant-voltage mode to control the voltage and set the remaining power supplies to constant-current mode with a voltage limit not exceeding the overcharge protection voltage threshold, as determined in the charge controller behaviour test (Annex S).

If the optional battery simulator specified in DD.4.1.2 can supply sufficient current and meet the voltage regulation requirements for the DC power supply in Clause CC.2, it may be used instead of the DC power supply.

The currents required in this test can exceed the maximum range of many multimeters. In this case, a current transducer or current sense resistor and voltmeter may be used instead of an ammeter or multimeter. The voltage should be measured at the DUT to compensate for the voltage drop across the ammeter or current sense resistor.

DD.4.2.2.2 Load requirements

In this test, a variable load is applied to each port. This variable load may be an electronic load or fixed and variable resistors as described in Clause CC.4. The load should be capable of sinking 125 % of the rated current for the port (see DD.4.2.4 a)) at the nominal port voltage. (Since port voltage can drop under load, and the maximum sustained current determined by this test can be less than 125 % of the rated current, it is sometimes possible to use a load with lower limits if care is taken not to exceed the limits during the test.)

If an electronic load is used, and the electronic load contains current and voltage measurement functionality that meets the requirements for DC ammeters and voltmeters in Clause CC.2 after accounting for any voltage drop between the port and the load, this functionality may be used instead of either an ammeter or voltmeter, or both, at the port.

The electronic load shall be galvanically isolated from the power supply if this is necessary in order to avoid altering the behaviour of the DUT.

DD.4.2.2.3 Load inrush current

Electronic loads can have high inrush current and can cause premature tripping of some types of overcurrent protection. If this behaviour is suspected, any of the following mitigation methods can be used:

- a) Start the electronic load at a low current setting and gradually increase to the target current;
- b) Use the electronic load in a different mode (e.g. constant resistance) and adjust until the required current is obtained;
- c) Connect a resistor in series with the electronic load to limit the inrush current;
- d) Use a variable resistive load (Clause CC.4).

The same method should be used in the assessment of DC ports (Annex EE).

DD.4.2.2.4 Test automation

The steps in DD.4.2.4 describe a manual procedure that can be performed using relatively low-cost equipment. The test procedure may be modified to facilitate automation, provided that the conditions for each measurement (e.g. simulated battery voltage, port current, and stabilization) are as specified in DD.4.2.4.

DD.4.2.3 Test prerequisites

The visual screening (Annex F) shall be performed before performing the output overload protection test.

DD.4.2.4 Procedure

The following steps shall be performed for each port under test. If the DUT has multiple identical ports, or multiple ports that are known (e.g. through visual inspection) to share the same overload protection device, it is only necessary to test one port from each such set of ports. In the following procedure, the term “overload protection device” refers to a fuse, circuit breaker, PTC device, other overcurrent protection device, thermal fuse, thermal switch, or other thermal protection device).

- a) Estimate the rated current (for the purposes of this test) for each port, using the following rules.
 - 1) If the company supplied a maximum current rating or overcurrent protection limit for the port, the rated current is the company-provided value. If more than one value was given by the company (for example, a nominal current value and an overcurrent protection limit), use the largest value.

- 2) If a current rating or overcurrent protection limit for the port is given in the user documentation or product packaging or marked on the product or on an internal component (such as a fuse or circuit breaker), the rated current is the value given in the documentation or marked on the product or component.
 - 3) If no rating was given and no markings can be found, calculate the highest power consumption that could be achieved using a combination of the included and advertised appliances that can be powered simultaneously using the port and all identical ports, plus any splitters or similar components that are included or advertised for use with the port. Use Annex HH to determine the power consumption of appliances not included in the product. Divide the total power consumption by the nominal port voltage (from Annex EE) to calculate the rated current.
- b) Use a laboratory power supply to power the power control unit in accordance with Annex H. Set the power supply to the standard operating voltage as described in H.5.2. Measure the voltage as close to the DUT as possible and adjust the power supply to compensate for voltage drop in the wires, ammeter, and paralleling diodes if used. For ports on appliances without batteries, the appliance may be powered by the power control unit or by a power supply at the standard port operating voltage.
 - c) Turn on the power supply and verify that the DUT is functional.
 - d) Connect an adjustable load to the port under test. The load should have a current and power ratings sufficient to achieve the maximum expected current at the port's output voltage. The load should be used in constant-current mode if available.
 - e) Adjust the load in order to find the largest current that does not result in the trigger of an overload protection device after 20 min of operation. This is the maximum sustained current. It is only necessary to test multiples of 1 % of the rated current up to 100 %, and multiples of 5 % of the rated current thereafter. The following procedure is suggested, but any procedure may be used as long as the required currents are tested:
 - 1) Set the current to the rated current of the port.
 - 2) Turn on the load and allow the DUT to operate for 20 min.
 - 3) Turn off the load.
 - 4) If an overload protection device operates during the 20 min period, reset the overload protection using the instructions in f), reduce the current by an increment of 5 % of the rated current. If the new current has not yet been tested, go back to step 2).
 - 5) If no overload protection device operates during the 20 min period, increase the current by an increment of 5 % of the rated current. If the new current has not yet been tested, go back to step 2). Testing of current values greater than 1,25 % of the rated current is at the laboratory's discretion; the laboratory may stop the test at any time if it is not safe to continue. The laboratory may consult with the company to determine whether a higher value should be used for the rated current.
 - 6) If the greatest current at which no overload protection operates is less than the rated current, continue the procedure using an increment of 1 % of the rated current.
 - 7) The greatest current at which no overload protection operates is the maximum sustained current.

EXAMPLE 1 An example test sequence for a product with rated current 1 A and maximum sustained current 0,97 A would be: 1,00 A (trip), 0,95 A (no trip), 0,96 A (no trip), 0,97 A (no trip), 0,98 A (trip). Only the tests at 0,97 A and 0,98 A are required.

EXAMPLE 2 An example test sequence for a product with rated current 1 A and maximum sustained current 1,10 A would be: 1,00 A (no trip), 1,05 A (no trip), 1,10 A (no trip), 1,15 A (trip). Since 1,10 A is not less than the rated current, it is not necessary to continue with 1,11 A, 1,12 A, etc. Only the tests at 1,10 A and 1,15 A are required.

When possible, the test laboratory should avoid unnecessary operation of the overload protection device, especially if the type of device is not known.

Some ports are unable to maintain a stable voltage even at loads that do not trigger the overload protection device. For example, the load voltage can oscillate between a value within the normal operating voltage range of the port and a very low value, even though a constant current is maintained. In this case, the maximum sustained current is the highest current at which a stable voltage is supplied by the port after 20 min. The laboratory should record both the maximum sustained current and the minimum current at which the overload protection device activates.

- f) If an overload protection device operates, attempt to reset the overload protection device and continue the test using one of the following procedures.
 - 1) Remove the test load and check DUT functionality. Some products will automatically return to normal functionality after the overload condition is removed. For some types of overload protection, it is necessary to allow the DUT to cool before repeating the test.
 - 2) If the overload protection device does not automatically reset but can be reset by following instructions in the user documentation or on product labels (e.g. replacing a blown fuse or resetting a tripped circuit breaker), using no tools except a screwdriver used to remove and insert screws, without creating a safety hazard and without invalidating the warranty, reset the overload protection device. Only spare parts included with DUT (or their equivalent, in case the supply of included spare parts is exhausted through repeated testing) may be used. (For example, if a fuse is blown, and the company did not supply replacement fuses, the DUT fails the test.) If the overload reset requires ON/OFF cycling of the DC power supply or battery simulator, the DUT shall fail the test unless the DUT battery can be disconnected and reconnected using no tools except a screwdriver, following instructions in the user documentation, and without invalidating the warranty. If the DUT is functional after the reset, and the reset can be conducted without exposing the person conducting the reset to a safety hazard, the DUT does not fail the test.
 - 3) If the overload reset can be easily identified and implemented by the test laboratory, but requires steps not documented in the user documentation, tools other than a screwdriver used to remove and insert screws, or spare parts not included with the DUT, the DUT fails the test. However, the test laboratory may, at its discretion, reset the overload and continue the test.
- g) If the port enters a constant-current or other current-limiting mode instead of shutting down when the load resistance is decreased, the laboratory should continue the test by decreasing the load resistance or voltage until the port turns off or a short-circuit condition is reached. Voltage or resistance increments are at the laboratory's discretion. If an electronic load is used, the load can be switched to constant-voltage or constant-resistance mode for this measurement. The DUT shall be operated with the load condition that gives the maximum steady-state current for 20 min, and this current is the maximum sustained current.
- h) If damage occurs or the laboratory stops the test for safety reasons, no overload protection is detected and the maximum sustained current cannot be determined.
- i) Note the functionality of the DUT after operating at the maximum sustained current for 20 min. Be sure to turn off or disconnect the load before checking for functionality.
- j) Record the following.
 - 1) Record whether an overload protection device operated during the test. If the overload protection device is a non-resettable fuse, record whether the product includes spare fuses.
 - 2) Record whether the DUT remains functional after the test is completed. Describe any abnormal operation during or after the test. (If abnormal operation occurred during the test, note whether the behaviour returned to normal when the overload condition was removed.)
 - 3) Record whether the DUT was damaged during the test. Describe and photograph any damage.
 - 4) Record whether any safety hazards developed during the test. Describe and document with photographs where applicable.

DD.4.2.5 Pass criteria

The DUT shall pass the output overload protection test if all of the following are true.

- The DUT remains functional after the test. Any procedures necessary to restore functionality shall meet the requirements set forth in DD.4.2.4 f).
- No damage occurred and no safety hazards developed when the DUT was operated at the maximum sustained current for 20 min.

The DUT may shut down or operate abnormally while an overload condition exists provided that normal operation can be restored after the test is completed.

The DUT can meet the above requirement even if no overload protection device operates (trips) during the test, if the port is designed to limit the short-circuit current to a safe value, whether through an active current-limiting function or a design that passively limits the current.

DD.4.3 PV overvoltage protection test

DD.4.3.1 General

The open-circuit voltage of a PV module can be significantly higher than the normal operating voltage of the system when a battery is connected. If not properly regulated, this has the potential to cause damage if applied to system components. Additionally, if a port voltage exceeds a certain value above the nominal design voltage for that port, appliances connected to that port can be damaged. This voltage is defined here as the allowable port voltage limit.

The PV overvoltage protection test assesses whether the DUT

- can withstand a PV overvoltage condition and
- provides sufficient protection to appliances if the system battery is disconnected

The PV overvoltage protection test may be omitted if the battery is unlikely to become disconnected during normal installation, maintenance, or use; specific conditions for applicability should be defined in the product specification.

In addition, the PV overvoltage protection test is not applicable to the following ports, which may be omitted from the test:

- Ports powered directly from the PV module (without a battery);
- Ports on components that can only be powered from another port on a power control unit, not directly from the PV module (e.g. most ports on appliances).

DD.4.3.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC power supply.
- DC voltmeter or multimeter.
- resistor(s) selected to draw $0,1 \text{ mA} \pm 10 \%$ at the nominal port voltage for each port.

NOTE For voltages of 5 V, 6 V, and 12 V, this requirement can be met using standard resistor values of 51 k Ω , 62 k Ω , and 120 k Ω , respectively, with 5 % tolerance.

DD.4.3.3 Test prerequisites

The visual screening (Annex F) and photovoltaic module I-V performance test (Annex Q) shall be performed before performing the PV overvoltage protection test.

DD.4.3.4 Procedure

The following steps shall be performed.

- a) Determine the allowable port voltage limit for each port, using the following procedure.
 - 1) If the port has a non-standard connector, and no adapter exists to convert the port to a standard connector, the allowable port voltage limit is the minimum value of the maximum input voltage for any included or advertised appliance that can be powered by the port. This value may be specified by the company. In this case, the allowable port voltage shall be used as the maximum voltage in the appliance voltage range test for any appliances powered by the port.
The product specification may define types of connectors that may be considered non-standard.
 - 2) Otherwise, if the nominal voltage of the port (from Annex EE) is listed in Table DD.2, use the allowable port voltage limit from Table DD.2.

Table DD.2 – Allowable port voltage limit by nominal voltage

Nominal port voltage V	Allowable port voltage limit V
5	6,0
6	7,9
12	15,8
other	1,316 7 times the nominal voltage

- b) Calculate the maximum open-circuit voltage of the PV module using the following formula:

$$V_{oc,max} = 2 \times V_{oc,STC} - V_{oc,TMOT}$$

where

- $V_{oc,max}$ is the maximum open-circuit voltage for the PV overvoltage protection test, in volts (V);
- $V_{oc,STC}$ is the measured open-circuit voltage at STC, in volts (V);
- $V_{oc,TMOT}$ is the measured open-circuit voltage at TMOT, in volts (V).

NOTE This is an estimate of the open-circuit voltage at 0 °C.

If the PV module of the DUT has not undergone the photovoltaic module I-V characteristics test (Annex Q), the average values of the samples that underwent the photovoltaic module I-V characteristics test (Annex Q) shall be used.

- c) Disconnect all removable appliances from the DUT.
- d) Disconnect the battery from the DUT.
- e) Connect a DC power supply to the PV input connector of the DUT.
- f) Apply a voltage equal to the maximum open-circuit voltage calculated in b). Set the current limit to the short-circuit current of the PV module measured at STC.
- g) Perform the following steps for one port from each set of identical ports of the DUT.
 - 1) Select a resistor to draw 0,1 mA from the port at the nominal port voltage. (See DD.4.3.2.)
 - 2) Connect the resistor to the port.
 - 3) Perform any actions necessary to turn on the port. (For example, if a DC socket is controlled by a switch, turn the switch on.)
 - 4) Measure and record the voltage at the port.

- h) Turn on any power switches for any built-in appliances, as identified in F.4.1.5 c) 5).
- i) Allow the built-in appliances to remain turned on with the power supply applied for 20 min, regardless of whether the appliance functions, unless a safety hazard develops (e.g. smoke or a burning smell). Record any abnormal operation.
- j) Turn off the power supply.
- k) Reconnect the battery to the DUT.
- l) Test the functionality of the DUT. If the DUT no longer functions, perform the following steps.
 - 1) If the overload protection device can be reset by following instructions in the user documentation (e.g. replacing a blown fuse or resetting a tripped circuit breaker), using no tools except a screwdriver used to remove and insert screws, without creating a safety hazard and without invalidating the warranty, reset the overload protection device. Only spare parts included with DUT (or their equivalent, in case the supply of included spare parts is exhausted through repeated testing) may be used. (For example, if a fuse is blown, and the company did not supply replacement fuses, the DUT fails the test.) If the overload reset requires ON/OFF cycling of the DC power supply or battery simulator, the DUT shall fail the test unless the DUT battery can be disconnected and reconnected using no tools except a screwdriver, following instructions in the user documentation, and without invalidating the warranty. If the DUT is functional after the reset, and the reset can be conducted without exposing the person conducting the reset to a safety hazard, the DUT does not fail the test.
 - 2) If the problem can be easily identified and repaired by the test laboratory, but requires steps not documented in the user documentation, tools other than a screwdriver used to remove and insert screws, or spare parts not included with the DUT, the DUT fails the test. However, the test laboratory may, at its discretion, repair the fault and continue the test.
 - 3) In the test report, describe any repairs made.
- m) Record whether the DUT remains functional at the end of the test, whether any damage occurred, and whether any user safety hazard is present. Describe any failures and take photographs of any visible damage or safety hazards.

DD.4.3.5 Pass criteria

The DUT shall pass the PV overvoltage protection test if all of the following are true.

- All features of the DUT, including built-in appliances, remain functional at the end of the test. Any repairs necessary to restore functionality shall meet the requirements set forth in DD.4.3.4 l) 1).
- No damage occurred and no safety hazard developed during or after the test.
- The voltage measured at each port did not exceed the allowable voltage limit calculated in step DD.4.3.4 a).

The DUT may shut down or operate abnormally during the test provided that normal operation can be restored once the overload is removed, although any abnormal operation should be noted in the test report.

DD.5 Reporting

Report the following in the protection test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - DUT setting;
 - test room temperature (°C);
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Results for tested DUT aspects for samples 1 through n :
 - presence of sufficient protection against miswiring (pass/fail);
 - damage present after miswiring protection test (yes/no);
 - user safety hazard present after miswiring protection test (yes/no);
 - repairs necessary after miswiring protection test (yes/no, description);
 - presence of sufficient protection against output overload (pass/fail);
 - functionality after output overload protection test (yes/no);
 - damage present after output overload protection test (yes/no);
 - user safety hazard present after output overload protection test (yes/no);
 - repairs necessary after output overload protection test (yes/no, description);
 - maximum sustained current for each port during overload protection test (A);
 - presence of sufficient PV overvoltage protection (pass/fail);
 - functionality after PV overvoltage protection test (yes/no);
 - damage present after PV overvoltage protection test (yes/no);
 - user safety hazard present after PV overvoltage protection test (yes/no).
- Tables:
 - table of results from miswiring protection test including configuration description, damage, safety hazard, functionality, and overall pass/fail result after test for each configuration (see Table DD.3 for an example).
 - table of nominal voltage, voltage limit, measured voltage, functionality, and pass/fail result during PV overvoltage protection test for each port and built-in appliance (see Table DD.4 for an example);
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .

Table DD.3 – Example table of miswiring protection test results

Configuration	Sample ID	Damage?	Safety hazard?	Functional ?	Pass/fail	Remarks
PV reverse polarity	1	No	No	Yes	Pass	PV fuse replaced with included spare.
	2	No	No	Yes	Pass	PV fuse replaced with included spare.
Battery reverse polarity	1	Yes	Yes	N/A	Fail	Control box emitted smoke. Test was discontinued.
	2	Yes	No	Yes	Fail	Plastic plug housing showed signs of melting
PV/battery plugs swapped	1	--	--	--	--	Test not performed due to prior failure.
	2	No	Yes	No	Fail	

Table DD.4 – Example table of PV overvoltage protection test results

Port or built-in appliance	Nominal voltage V	Voltage limit V	Sample ID	Measured voltage V	Functional after test?	Pass/fail
USB port	5	6,00	1	5,09	Yes	Pass
			2	6,50	Yes	Fail
Cigarette lighter port	12	15,8	1	21,3	Yes	Fail
			2	21,3	Yes	Fail
5 mm barrel plug	12	15,8	1	21,4	Yes	Fail
			2	21,4	Yes	Fail
Integrated light	--	--	1	--	Yes	Pass
			2	--	No	Fail

Annex EE (normative)

Assessment of DC ports

EE.1 Background

DC ports (also called receptacles or outlets) are a key component of many stand-alone renewable energy products; the specifications of the DC ports determine what appliances can be powered by the product. Annex EE contains test procedures to determine the following properties of DC ports:

- the output voltage range and current-voltage relationship over a variety of operating conditions;
- the efficiency of the path from the battery to the port;
- the ability of included appliances to function at the voltage supplied by the port over a variety of operating conditions.

EE.2 Test outcomes

The test outcomes of the DC ports assessment are listed in Table EE.1.

Table EE.1 – DC ports assessment outcomes.

Metric	Reporting units	Related aspects	Remarks
Minimum port voltage for each port	Volts (V)	4.2.7.5 DC ports	One value for each port
Maximum port voltage for each port	Volts (V)	4.2.7.5 DC ports	One value for each port
Plots of output voltage vs. output current, and associated data, for each port and each simulated battery voltage	Volts (V), amperes (A)	4.2.7.5 DC ports	Three or four plots for each tested port, and associated tabular data.
Plots of output voltage vs. output power, and associated data, for each port and each simulated battery voltage	Volts (V), watts (W)	4.2.7.5 DC ports	Three or four plots for each tested port, and associated tabular data
Plots of battery-to-port efficiency vs. output current, and associated data, for each port and each simulated battery voltage	Percentage, amperes (A)	4.2.7.5 DC ports	Three or four plots for each tested port, and associated tabular data
Plots of battery-to-port efficiency vs. output power, and associated data, for each port and each simulated battery voltage	Percentage, watts (W)	4.2.7.5 DC ports	Three or four plots for each tested port, and associated tabular data
Shared and individual resistances for each set of multiple identical ports	Ohms (Ω)	4.2.7.5 DC ports	These values are used to adjust appliance power consumption and battery-to-appliance efficiency to account for the simultaneous use of multiple appliances.
Power consumption values for each built-in appliance	Watts (W)	4.2.7.2 Power consumption	One value for each built-in appliance
Functionality of each appliance for each simulated battery voltage	Yes/no	4.2.7.1 Appliance voltage compatibility	Three values for each tested appliance
Maximum power for each port	Watts (W)	4.2.7.5 DC ports	One value for each port
Pass/fail for functionality for each port	Yes/no	4.2.7.5 DC ports	One value for each port
Pass/fail for truth in advertising for each port	Yes/no	4.2.7.5 DC ports	One value for each port

EE.3 Related tests

The tests in Annex EE use some of the same equipment as the protection tests (Annex DD), particularly the output overload protection test (DD.4.2), which is a prerequisite. Test laboratories may perform the DC ports tests immediately after the protection tests to take advantage of equipment commonalities. However, since the protection tests are potentially destructive, they are generally not performed on the same samples.

Several other tests, including the visual screening (Annex F), the charge controller behaviour test (Annex S), the solar charge test (Annex R), and the full-battery run time test (Annex M), are used to derive operating parameters for the ports tests.

The efficiencies measured in EE.4.2 are used in the energy service calculations (Annex GG). The voltage vs. current and power data measured in Annex EE are used in the appliance tests (Annex FF), including the determination of appliance operating voltage (Clause FF.5).

EE.4 Procedure

EE.4.1 Preparation

The following steps shall be performed.

- a) Identify the ports to be tested.
 - 1) All ports intended for supplying power, including mobile device charging ports and ports on appliances, shall be tested, except that if the DUT has multiple identical ports it is only necessary to test one port from each group of identical ports. Ports shall be considered identical only if they have identical driver circuitry and identical voltage and current limits.
 - 2) Connectors that are not primarily intended to supply power to appliances may be omitted from testing. Further guidance is provided in IEC TS 62257-9-8.
- b) If multiple samples of the product are being tested, the selected port from each group shall rotate between samples.

EXAMPLE Two samples of a product with three USB ports are to be tested. Port 1 would be tested on sample 1, port 2 on samples 2, and port 3 on sample 1.

- c) If a port has multiple selectable voltage settings, each setting shall be considered a separate "port" for the purposes of testing.
- d) Identify the maximum current for each port, using the following procedure.
 - 1) Use the maximum sustained current, measured in the output overload protection test (DD.4.2), if the value could be determined and no damage or safety hazard occurred at a current less than or equal to the maximum sustained current.
 - 2) If the maximum sustained current could not be determined during the output overload protection test, the advertised or rated maximum current should be used. If there is no advertised or rated maximum current, the test laboratory should request this information from the company. If the company is unable to provide the rated maximum current, the test laboratory should determine an appropriate maximum value. If possible, the value chosen should be at least the maximum current drawn by the advertised or included appliances. The following procedure can be used, if necessary, to determine the current required by an included or advertised appliance:
 - i) Set up the DUT in accordance with EE.4.2.6 a) through c).
 - ii) For included appliances, connect the appliance to the port at the highest setting that will be measured (see Clause FF.6). For advertised appliances, connect an electronic load set to constant-power mode, with the power setpoint determined following the procedure in HH.5.2. If an electronic load with this feature is not available, use constant-current or constant-resistance mode, or use a variable resistor, and adjust the load until the desired power value is achieved.

- iii) Vary the power supply voltage (simulated battery voltage) between the values specified in EE.4.2.6 c), g), and h).
 - iv) Record the highest value of port current measured in steps ii) and iii).
- The method used to determine the appropriate maximum current value shall be documented and reported.
- 3) If the current determined in 1) and 2) could, in the judgement of the test laboratory, result in damage or a safety hazard, the maximum current is the greatest current that can be applied without risk of damage or safety hazard.
 - e) Identify any special procedures required to enable the output on each port. For example, some USB ports require an attached device to be enumerated and negotiate to receive power in excess of a certain limit, and some products use proprietary tamper-proofing strategies to supply power only to authorized appliances. If any such requirements exist, the company should be consulted to develop a plan to test the port.
 - f) Determine whether the port should be treated as a USB port for the purposes of this test. A port shall be considered a USB port if any of the following is true:
 - the port accepts a standard USB connector;
 - the DUT includes an adapter that allows a USB connector to be connected to the port;
 - the port is intended or expected to be used for charging mobile devices with a nominal DC input voltage of 5 V.

EE.4.2 Measurement of steady-state port characteristics

EE.4.2.1 Overview

EE.4.2.1.1 General

This test measures the relationship of output voltage and steady-state battery-to-port efficiency to load current at three or four simulated battery voltages, defined in EE.4.2.6:

- a) the typical battery discharge voltage (from Clause M.9), corresponding to typical operation during discharge;
- b) a voltage corresponding to operation in a deeply discharged state;
- c) (optional) the average charging voltage measured during the solar charge test (Annex R), corresponding to typical operation during solar charging;
- d) a voltage corresponding to operation during solar charging with a nearly full battery.

In addition, several other parameters not directly related to port performance can be measured at the time of this test. These measurements are described in EE.4.2.1.2 and EE.4.2.1.3.

EE.4.2.1.2 Voltage droop measurement

For products with multiple identical ports, a load connected to one port can cause voltage droop at the other ports. This can in turn affect the power consumption of appliances connected to the other ports. The combined load can also affect the efficiency of the port's voltage regulator or DC-DC converter, if present. To measure these effects, the open-circuit voltage of an unloaded port is measured.

EE.4.2.1.3 Concurrent test procedures

The appliance power consumption test procedure for built-in appliances (FF.6.10) and appliance operating voltage range tests (FF.8.8 and FF.8.9) may be performed concurrently with this test, since they use similar apparatus and operating voltages. For further guidance on the differences between the appliance operating voltage test procedures, refer to FF.8.1.

EE.4.2.2 Equipment requirements

The following equipment is required. Equipment shall meet the requirements in Clause CC.2.

- DC power supply with sufficient output current to achieve the maximum current identified in EE.4.1 d).
- Two DC ammeters or multimeters.
- Two DC voltmeters or multimeters.
- Electronic load or variable and fixed resistors (Clause CC.4). If one of the methods of DD.4.2.2.3 was used in the output overload protection test, the same method should be used for the assessment of DC ports.
- Resistor(s) selected to draw a current of $0,1 \text{ mA} \pm 10 \%$ at the nominal port voltage for each port. (The electronic load may be used if it has sufficient resolution.)

NOTE For voltages of 5 V, 6 V, and 12 V, this requirement can be met using standard resistor values of 51 k Ω , 62 k Ω , and 120 k Ω , respectively, with 5 % tolerance.

In some cases, it can be necessary to use multiple laboratory power supplies in parallel to achieve the required current. Unless otherwise specified by the power supply manufacturer, a diode should be used at the output of each power supply to prevent backfeeding. If the power supplies do not include current-sharing functionality, set one power supply to constant-voltage mode to control the voltage and set the remaining power supplies to constant-current mode with a voltage limit not exceeding the battery's overcharge protection voltage threshold, as measured in the charge controller behaviour test (Annex S).

The currents required in this test can exceed the maximum range of many multimeters. In this case, a current transducer or current sense resistor and voltmeter may be used instead of an ammeter or multimeter. The voltage should be measured at the DUT to compensate for the voltage drop across the ammeter or current sense resistor.

If an electronic load is used, and the electronic load contains current and voltage measurement functionality that meets the requirements for DC ammeters and voltmeters in Clause CC.2 after accounting for any voltage drop between the port and the load, this functionality may be used instead of either an ammeter or voltmeter, or both, at the port.

The electronic load shall be galvanically isolated from the power supply if this is necessary in order to avoid altering the behaviour of the DUT.

This test involves a calculation of electrical power; see Clause CC.3 for related recommendations. For most products, the current and voltage will be constant during the test, so it is not necessary to use a power-measuring instrument. However, some products incorporate pulse-width modulation (PWM) controllers, e.g. for dimming lights connected to the ports. For such products, if the PWM function is active during the measurement, a power-measuring instrument should be used, as described in Clause CC.3.

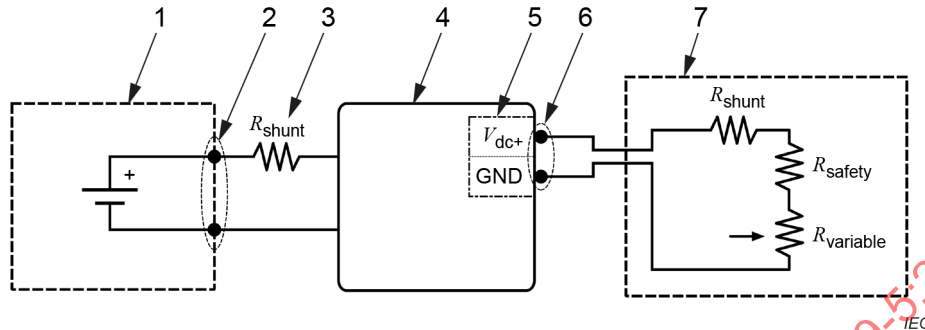
EE.4.2.3 Test prerequisites

The output overload protection test (DD.4.2), charge controller behaviour test (Annex S), and solar charge test (Annex R) shall be performed prior to the measurement of steady-state port characteristics. In addition, if the deep discharge protection voltage is measured during the full-battery run time test (Annex M), this test shall be performed prior to the measurement of steady-state port characteristics.

If the product has a PV module, disconnect it, cover it with opaque material, or orient it so that it is not exposed to ambient light.

EE.4.2.4 Apparatus

Example apparatus for the measurement of port characteristics during discharge is shown schematically in Figure EE.1.



Key

- 1 DC power supply and power supply lead wires in place of battery
- 2 Battery voltage measurement at battery input lead wires
- 3 Battery current measurement (DC multimeter or current shunt)
- 4 DUT power control unit
- 5 DC port
- 6 Port voltage measurement
- 7 Electronic load or load with a fixed resistor to prevent short circuit and variable resistor

Figure EE.1 – Schematic of the example DUT with DC port and USB port and variable resistors connected for the measurement of steady-state port characteristics

EE.4.2.5 Special port features

EE.4.2.5.1 General

Some ports have special features that can complicate the testing process. Procedures are defined for two types of special features: security or anti-tampering functions, and pulse width modulation (PWM). For other special features that interfere with testing, the test laboratory should work with the company to develop a procedure to test the product successfully.

Appliances connected to ports with special features that interfere with testing may be tested as if they were built-in appliances. However, if multiple appliances or combinations of appliances can be connected to such a port, this option should be avoided when possible since each configuration of appliances and settings would then be measured individually as a separate "setting" of the built-in appliance.

EE.4.2.5.2 Ports with security features

Some products include security features so that the ports can only be used to power "authorized" appliances included with the product or sold separately by the company. In this case, the authorized appliances may be used as the load, instead of an electronic load or variable resistor. The measured current values should be as close as possible to the target values specified in EE.4.2.6. If it is not possible to obtain at least three current values by using the authorized appliances, the laboratory should work with the company to determine a way to test additional currents.

If the security feature is implemented by varying the current or voltage, a power-measuring instrument should be used as described in Clause CC.3.

EE.4.2.5.3 Ports with pulse width modulation (PWM)

Some ports have PWM functionality incorporated into the power control unit, for example for dimming a light or controlling the speed of a fan. These ports may be omitted from the assessment of DC ports; appliances connected to the ports can be treated as built-in appliances in further testing.

EE.4.2.5.4 USB fast charging

EE.4.2.5.4.1 Background

USB ports can support fast-charging protocols that allow a device to communicate with the port to negotiate either an increased output voltage or current, or both, enabling the port to deliver higher power. Many smartphones and other portable devices support the USB Power Delivery protocol, which is defined by publicly available standards authored by the USB Implementers Forum and is also published as IEC 62680-1-2. Proprietary protocols are also commonly used; some of these are extensions to or provide compatibility with USB Power Delivery, while others are incompatible.

USB Power Delivery and some other protocols define multiple modes of operation, which can include:

- Fixed source: the source supplies a fixed voltage (within a specified tolerance). The USB Power Delivery specification requires all ports to provide at least one fixed source at 5 V.
- Variable source: the port supplies a poorly regulated voltage; the source informs the sink of the minimum and maximum voltages.
- Battery source: a battery is connected directly to the port with no voltage regulation; the source informs the sink of the minimum and maximum voltages that the battery can supply.
- Programmable power supply and similar modes: the source supplies a voltage that can be finely adjusted, for example in steps of 20 mV for USB Power Delivery PPS sources. This mode can be used to move the voltage regulation function (and associated heat dissipation) from the mobile device to the USB power source, improving battery longevity by reducing the battery temperature.

NOTE The list above provides a simplified overview. For full details, refer to IEC 62680-1-2. In the USB Power Delivery specification, the terms “source” and “sink” are used to refer to the device supplying power and the device consuming power, respectively.

USB Power Delivery revision 2 can be used with both USB Type-A and Type-C connectors, while USB Power Delivery revision 3 can be used only with USB Type-C connectors. Proprietary fast-charging protocols can use type-A or type-C connectors.

USB Power Delivery revision 3 defines two power ranges: Standard Power Range (SPR) supports up to 100 W at voltages up to 20 V and currents up to 3 A, and Extended Power Range (EPR) provides up to 240 W at voltages up to 48 V and currents up to 5 A. EPR requires specially rated cables. The focus of EE.4.2.5.4.3 is on SPR functionality, since loads greater than 100 W are expected to be uncommon within the scope of this document, and specialized test equipment is often necessary for testing EPR functionality.

EE.4.2.5.4.2 Equipment requirements

Fast charging can typically be enabled in one of two ways:

- An electronic load specifically designed for testing USB fast charging, or
- A trigger device that communicates with the port to select the desired fast charging mode and provides terminals for connecting an external load (and sometimes other functions, such as voltage and current measurement).

NOTE 1 Compact USB testers with voltage and current measurement and trigger functions for several different fast-charging protocols are commercially available and can be an economical and convenient testing option. If the voltage and current measurement accuracy meets the requirements of Clause CC.2, the tester can be used to measure these parameters with minimal voltage drop between the port and the measurement point. Some USB testers support connection to a PC for data logging or automation.

NOTE 2 USB tester/trigger devices can consume power from the port under test. The laboratory should ensure that the measured power includes the power consumption of the tester, or that the tester is powered from a separate power source.

The laboratory may use either type of apparatus for the testing required by this document. The apparatus used shall support USB Power Delivery (IEC 62680-1-2) SPR modes. Other fast-charging protocols may be tested; however, test equipment for proprietary fast-charging protocols can be difficult for laboratories to obtain. If a laboratory cannot test a particular fast-charging function, this should be noted in the test report.

EE.4.2.5.4.3 Test procedure

The laboratory shall check USB ports for USB fast charging support if requested by the customer, or as described in IEC TS 62257-9-8 or in the product specification. If USB Power Delivery support is detected, the USB Power Delivery source types offered by the port shall be tested as follows:

- a) All Standard Power Range (SPR) Fixed Supply, Variable Supply, and Battery Supply modes shall be tested in accordance with EE.4.2.6. The procedure in EE.4.2.6 may be modified, if necessary, to use the fast-charging test apparatus, provided that an equivalent level of accuracy is obtained.
- b) SPR Programmable Power Supply (PPS) mode, if supported by the DUT, shall be checked for functionality. The laboratory shall select at least two different voltage and current limit values and confirm that the port adjusts the voltage and current accordingly.
- c) Extended Power Range (EPR) Fixed Supply modes should be tested in accordance with EE.4.2.6 if EPR is supported by the laboratory equipment. The procedure in EE.4.2.6 may be modified, if necessary, to use the fast-charging test apparatus, provided that an equivalent level of accuracy is obtained.
- d) EPR Adjustable Voltage Source (AVS) mode, if supported by the DUT, should be checked for functionality if supported by the laboratory equipment. If this mode is tested, the laboratory shall select at least two different voltage values and confirm that the port adjusts the voltage accordingly. (Unlike PPS, AVS does not provide an adjustable current limit.)
- e) A single measurement of port voltage shall be made at a load of 500 mA (or the maximum possible current, if less than 500 mA) without selecting any fast-charging mode (e.g. Default USB Power). This measurement is made to confirm that the port can power USB appliances that do not support fast charging. To perform this measurement:
 - 1) For USB Type-C ports, enable the output using any of the following methods:
 - i) If an adapter or cable is included that converts the USB Type-C port to a different type, such as a Standard-A receptacle or Micro-B plug, the included adapter may be used.
 - ii) Connect the CC1 or CC2 pin of the port through a $5,1 \text{ k}\Omega \pm 20 \%$ pull-down resistor to the GND pin;
 - iii) Connect a USB Type-C to USB Standard-A receptacle adapter (e.g. the adapter described in IEC 62680-1-3:2020, 3.6.1);
 - iv) Use the functionality of the USB test equipment (e.g. load or trigger device) to select Default USB Power.
 - 2) Connect the port or adapter to a load as described in EE.4.2.6, keeping any cables between the port and voltage measurement point as short as possible. If an adapter cable is used as described in 1) i) and iii), the voltage can be measured upstream of the adapter.
 - 3) Measure the port current and voltage in accordance with EE.4.2.6 at a current of 500 mA.

Testing at the low-battery voltage and overcharge protection test maximum voltage may be omitted for modes other than the 5 V fixed supply mode.

For protocols other than USB Power Delivery, if supported by the laboratory equipment, fixed-voltage modes should be tested in accordance with EE.4.2.6 and adjustable-voltage modes (equivalent to PPS or AVS) should be checked for functionality. If there are multiple modes with the same nominal voltage (e.g. 9 V / 2 A and 9 V / 2,2 A), all modes shall be checked for functionality, but modes with maximum currents less than or equal to another tested mode may be omitted from the steady-state port measurement.

EXAMPLE A port supports USB Power Delivery SPR modes 5 V / 3 A, 9 V / 3 A, 15 V / 2 A, and proprietary operating modes with 9 V / 5 A and 15 V / 5 A. If the laboratory has equipment to test the proprietary operating modes, the 5 V / 3 A, 9 V / 5 A, and 15 V / 5 A modes would undergo the steady-state port measurement, and the 9 V / 3 A and 15 V / 2 A modes are checked for functionality. If the laboratory cannot test the proprietary operating modes, then all three USB Power Delivery SPR modes would undergo the steady-state port measurement and the proprietary modes would not be tested. A product specification can include provisions for assessing the functionality of the proprietary modes, e.g. through evaluation of component data sheets or third-party test reports or certificates.

EE.4.2.5.5 Ports on appliances

If a port is on an appliance with a battery, the appliance is the power control unit.

If a port is on an appliance without a battery, the appliance should be connected to the power control unit and the combination of components is treated as the power control unit for the purposes of testing the port.

If the laboratory does not have samples of the power control unit that powers an appliance without a battery, the procedures in Clause FF.5 can be used to supply power to the appliance, with the following changes:

- a) Substitute the overcharge protection voltage or low-battery voltage for the typical battery voltage in the appropriate parts of the procedure in Clause FF.5.
- b) If using FF.5.3, repeat the iterative procedure every time the load is changed.
- c) The combination of the power supply and appliance is treated as the power control unit in EE.4.2.6.

The results of this test are only valid for the appliance when used with the specific power control unit being tested or simulated.

EE.4.2.5.6 Ports powered directly from a PV module

Ports that are powered directly from a PV module (without a battery) may be tested by supplying power to the PV input using the apparatus from the solar charge test (Annex R) to simulate the PV module performance at TMOT (50 °C and 1 000 W/m²). These ports may also be tested using a solar simulator meeting the requirements of IEC 60904-9 class BBB if the module temperature can be maintained within 50 °C ± 5 K. Natural sunlight may also be used, but maintaining the temperature and irradiance at TMOT could be impractical.

EE.4.2.5.7 Test automation

The steps in EE.4.2.6 describe a manual procedure that can be performed using relatively low-cost equipment. The test procedure may be modified to facilitate automation, provided that the conditions for each measurement (e.g. simulated battery voltage, port current, and stabilization) are as specified in EE.4.2.6.

EE.4.2.6 Procedure

The following steps shall be performed.

- a) Build the test configuration as in Figure EE.1.
- b) Prepare the DUT in accordance with Annex G.
- c) Use a laboratory power supply to power the power control unit in accordance with Annex H. Set the power supply to the typical battery discharge voltage (from Clause M.9).
- d) Measure the current and voltage at the battery leads with no loads applied, using the same instruments that will be used in step e) 11). In the measurement of simulated battery current, the multimeter or ammeter should be set to the same range throughout the test so that any offset will remain constant. Any power switches that do not control individual loads shall be turned on. (For example, if the DUT has a master power switch, turn it on.)
- e) For each port under test, the following steps shall be performed.
 - 1) If there are multiple identical ports of this type, select one to be the "loaded port" and one to be the "unloaded port." This selection may be arbitrary. The loaded port is the port to be characterized, to which the load is connected. The voltage at the unloaded port will be measured to characterize the effect of a connected load on the other ports.
 - 2) Perform any actions necessary to turn on the port. (For example, if the port is controlled by a switch, turn the switch on.) Do not enable any ports that are controlled separately from the port under test.
 - 3) Connect a resistor to the loaded port to draw a current of $0,1 \text{ mA} \pm 10 \%$ at the nominal port voltage (see EE.4.2.2). Alternatively, if an electronic load is used for testing, the load may be set to a value of $0,1 \text{ mA}$ if the programming resolution and accuracy are sufficient to achieve the required current value. If a resistor is used, it may either be removed or remain in place for the duration of the test.
 - 4) Measure the loaded port voltage using the same instrument that will be used in step 11). Record the port voltage and either the port current or the resistor value.
 - 5) Connect a resistor (or load) of the same value calculated in step 3) to the unloaded port (if present).
 - 6) With the resistor connected, measure the unloaded port voltage using the same instrument that will be used in step 11). This is the zero-load voltage.
 - 7) Connect the electronic load or resistors to the loaded port if this was not done in step 3).
 - 8) Adjust the variable resistor or electronic load so that the current is 10% of the maximum current for the port (EE.4.1 d)), with a tolerance of $\pm 5 \%$.
 - 9) Adjust the power supply voltage so that the voltage at the battery terminals remains constant, as close as possible to the value set in c), throughout the test as the load is increased. It is very important to adjust the voltage every time the current is changed to minimize the variation in voltage at the DUT. Any variation in voltage will reduce the accuracy of the voltage droop calculation in EE.4.2.7, which is used to model port behaviour in the energy service calculations (Annex GG).
 - 10) Allow the voltage to stabilize, adjusting the power supply voltage if necessary.
 - 11) Using a DC ammeter and voltmeter, or two multimeters, record the current and voltage at the loaded port. Simultaneously, measure and record the voltage and current at the battery input terminals and the voltage at the unloaded port (if applicable).
 - 12) Repeat steps 8) to 11) with current settings of 20% , 40% , 60% , 80% , and 100% of the maximum current (with a tolerance of 5% of the target current value). Ensure that the voltage remains as close as possible to the value set in c) as the current is varied.

- 13) If the DUT cannot sustain 100 % of the maximum current, reduce the current to a level that can be sustained with a stable port voltage for the duration of the test. (In this case the 5 % tolerance requirement does not apply.) This situation does not in itself result in a failure for functionality or truth in advertising (see EE.4.3). Reduce the current in increments of no more than 2,5 % of the maximum current. Perform a measurement (as in step 11)) at this reduced voltage.
- 14) Perform any additional measurements necessary to verify compliance with the requirements of IEC TS 62257-9-8 or any other applicable product specification.

EXAMPLE 1 For a particular port, IEC TS 62257-9-8 requires a voltage between 4,5 V and 5,5 V at a current of 0,5 A. The port voltage was measured at 4,75 V at 0,42 A and 4,00 V at 0,84 A. Therefore, compliance with the requirements of IEC TS 62257-9-8 cannot be determined by the available measurements; it is necessary to perform an additional measurement at 0,50 A to assess compliance.

- 15) For ports with USB fast charging support, with the power supply at the typical battery discharge voltage, repeat the measurement procedure for each operating mode as described in EE.4.2.5.4.3. In addition, perform the single measurement at 500 mA as described in EE.4.2.5.4.3 e). When this step is repeated with the power supply set to the low-battery voltage, overcharge protection test maximum voltage, and optionally the average charging voltage, only the 5 V fixed supply mode is tested, as described in EE.4.2.5.4.3.
 - 16) Disconnect the resistors or electronic load from the loaded port, and disconnect the resistor from the unloaded port if applicable.
- f) If the power supply voltage is set to the typical battery discharge voltage, the appliance power consumption test procedure for built-in appliances (FF.6.10) can be performed at this time. Otherwise, the appliance operating voltage range test procedures using the power control unit (FF.8.8 and FF.8.9) for both built-in and removable appliances can be performed at this time. Alternatively, these tests can be performed separately. Note that built-in appliances are defined in 4.1.4 and identified in the visual screening F.4.1.5 c) 5); some light points may be considered "built-in" even if they can be unplugged. This step may be omitted for certain built-in appliances that underwent the full-battery run time test or appliance full-battery run time test, as described in FF.6.10.2.
 - g) Change the power supply voltage (simulated battery voltage) to the low-battery voltage, calculated in the full-battery run time test (Clause M.9, step k)), then repeat steps d) through f). If the port will not turn on or will not stay on at the selected voltage:
 - 1) Increase the voltage until the DUT turns on, then decrease the voltage back to the low-battery voltage.
 - 2) If the port still will not remain on at the low-battery voltage, note in the test report that the port does not function at the low-battery voltage.

If the low-battery voltage is equal to the typical battery discharge voltage, it is not necessary to repeat the port measurements.
 - h) Change the power supply voltage (simulated battery voltage) to the maximum battery voltage measured during the active overcharge protection test (S.4.2), or, if the DUT is not subject to the active overcharge protection test, the maximum battery voltage observed during the solar charge test (Annex R). Repeat steps d) through f) at this voltage. (If the DUT will not turn on or stay on at the selected voltage, decrease the voltage in 0,05 V increments to the lowest value for which the DUT remains on.)

For products whose ports cannot be used while the product is charging, use the maximum battery voltage during the full-battery run time test (Annex M) instead of the maximum voltage measured during the active overcharge protection test or the solar charge test, and omit the optional step i). Typically, the maximum voltage during the full-battery run time test is the voltage immediately after the DUT is turned on.
 - i) (optional) Change the power supply voltage (simulated battery voltage) to the average charging voltage measured during the solar charge test (Annex R). Repeat steps d) and e). Step f) may be omitted at this voltage.

EE.4.2.7 Calculations

Perform the following calculations for each simulated battery voltage measured in EE.4.2.

- a) For each operating point tested, calculate the battery input power and port output power by multiplying the current and voltage values.
- b) For each battery voltage setting, calculate the idle power, P_{idle} , by multiplying the current and voltage measured at the battery with no load applied.
- c) For each battery voltage setting, port, and load current, calculate the battery-to-port efficiency using the following formula:

$$\eta_{\text{batt-port}} = \min \left(1, \frac{P_{\text{port}}}{P_{\text{batt}} - P_{\text{idle}}} \right) \times 100 \%$$

where

$\eta_{\text{batt-port}}$ is the battery-to-port efficiency, as a percentage (%);

P_{port} is the port output power, in watts (W);

P_{batt} is the power supplied to the DUT by the simulated battery, in watts (W);

P_{idle} is the idle power, in watts (W).

- d) For each port and each battery voltage setting, plot the following (see Figure EE.2).
 - 1) Output voltage vs. output current.
 - 2) Output voltage vs. output power (P_{port}).
 - 3) Battery-to-port efficiency ($\eta_{\text{batt-port}}$) vs. output current.
 - 4) Battery-to-port efficiency ($\eta_{\text{batt-port}}$) vs. output power (P_{port}).

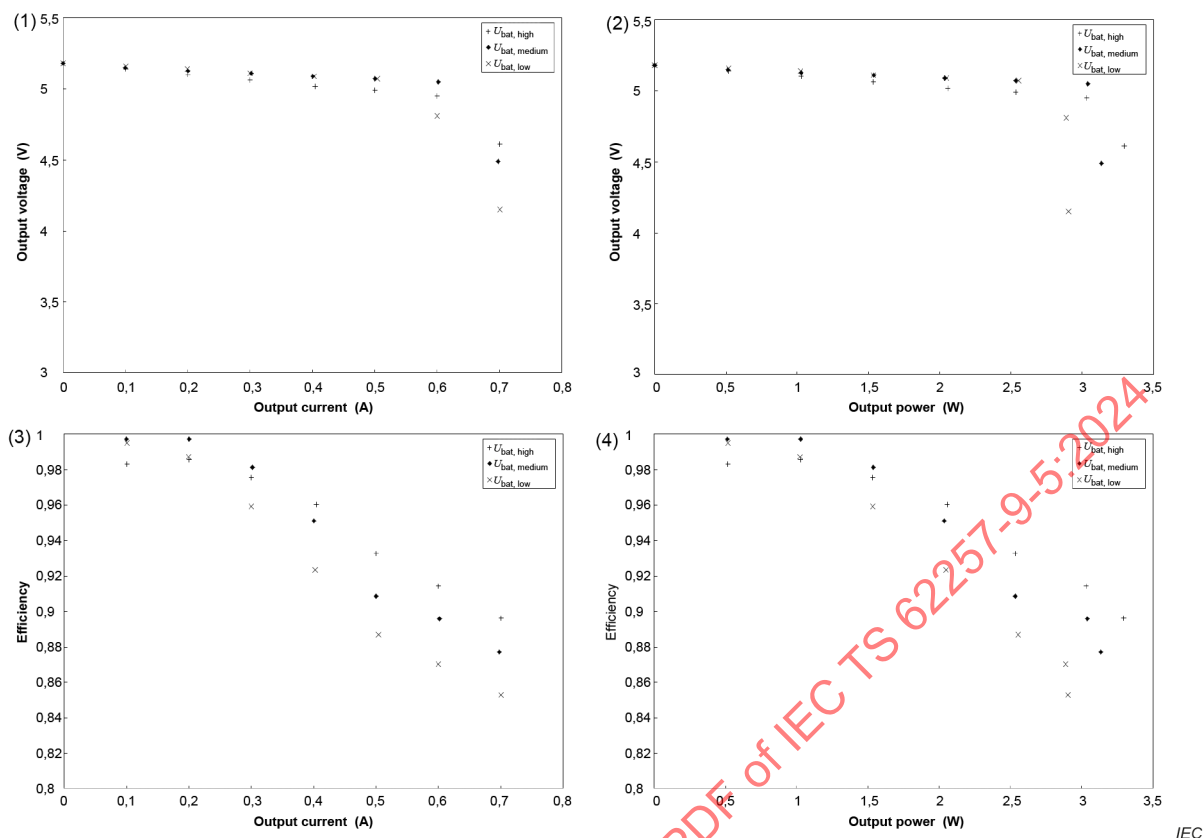


Figure EE.2 – Example of the plots of port characteristics

Perform the following calculations for each set of multiple identical ports at the typical battery discharge voltage only:

- For each measurement condition, subtract the voltage measured at the unloaded port from the zero-load voltage measured in EE.4.2.6 e) 4). This is the shared voltage drop (ΔV_{shared}).
- For each measurement condition, subtract the voltage measured at the loaded port from the voltage measured at the unloaded port. This is the individual voltage drop (ΔV_{indiv}).
- Plot the shared voltage drop (ΔV_{shared}) and individual voltage drop (ΔV_{indiv}) as a function of the current at the loaded port, excluding the measurement at zero current and the highest measured current. Also exclude any additional points that appear to correspond to an unstable or atypical operating condition; typically these points occur at higher currents.
- Fit a line to each set of plotted points. The slope of ΔV_{shared} in volts vs. port current in amperes is the shared resistance (R_{shared}), in ohms, and the slope of ΔV_{indiv} in volts vs. port current in amperes is the individual resistance (R_{indiv}), in ohms.

NOTE The shared and individual resistance values do not necessarily correspond to physical resistances. In particular, either or both values can be negative.

EE.4.3 Pass/fail tests for functionality and truth in advertising

EE.4.3.1 Assessment of functionality

Generally, a port is considered to be functional if the port can supply a stable voltage within a stated range (V_{min} to V_{max}) for load currents within a range from 0,1 mA up to a specified value (I_{min}). The values of V_{min} , V_{max} , and I_{min} should be given in the product specification; recommended values are given in Table EE.2. The product specification may give different values at different states of charge (corresponding to the different simulated battery voltages); the most typical case is to allow a lower port voltage with a deeply discharged battery.

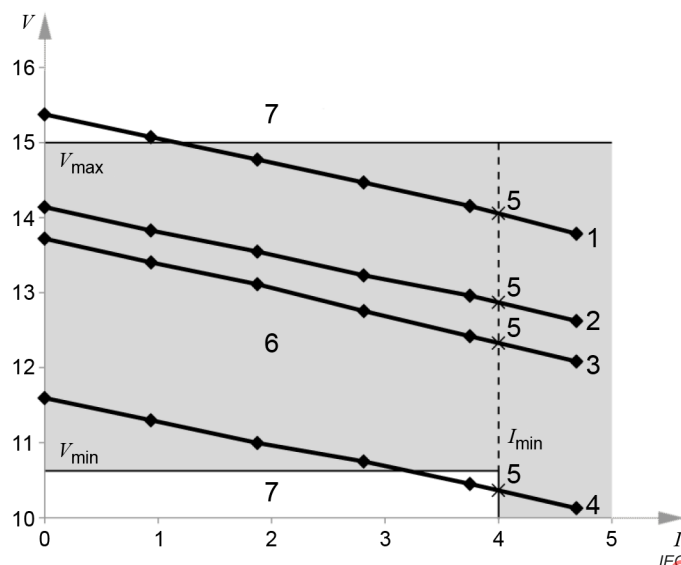
In this assessment, the voltage values under 0,1 mA load, as measured in EE.4.2.6 e) 4), should be used instead of the values at open circuit (which are not measured). This accounts for the fact that some ports can present a high voltage at open circuit, but the voltage can drop to within the permitted range when even a small load is applied.

**Table EE.2 – Recommended voltage and current ranges
for port functionality assessment**

Nominal port voltage V	Nominal port voltage			Remarks
	$V_{\min}$ V	$V_{\max}$ V	$I_{\min}$ A	
5	4,25 deeply discharged 4,50 otherwise	5,50	0,50	None
6	5,25	7,50	See remarks	$I_{\min}$ is the lesser of the consumer-facing rated maximum current and the maximum current measured in EE.4.2. No $V_{\min}$ requirement at deep discharge voltage, if documented in user manual.
12	10,5	15,0	See remarks	

A requirement in this form may be tested using the following procedure (illustrated in Figure EE.3):

- Using linear interpolation within the port voltage vs. port current data collected in EE.4.2, calculate the voltage at a current of $I_{\min}$ at all three (or four) simulated battery voltages.
- For each of the three (or four, if the average charging voltage is used) simulated battery voltages, determine the maximum voltage measurement for all load currents greater than 0,1 mA, including currents greater than $I_{\min}$.
- For each of the three (or four) simulated battery voltages, determine the minimum voltage measurement for load currents within the range (0,1 mA to $I_{\min}$) including the voltage value calculated in EE.4.3.1 a).
- For each simulated battery voltage, determine whether the maximum and minimum values calculated in EE.4.3.1 b) and EE.4.3.1 c) fall within the range permitted by the product specification.



Key

- V Port voltage (V)
- I Port current (A)
- $V_{\max}$ Maximum port voltage permitted by product specification (15 V in this example)
- $V_{\min}$ Minimum port voltage permitted by product specification (10.5 V in this example)
- $I_{\min}$ Minimum permitted value of maximum port current required by product specification (4 A in this example)
- 1 Port current vs. voltage measurements at overcharge protection voltage
- 2 Port current vs. voltage measurements at average charging voltage (optional)
- 3 Port current vs. voltage measurements at typical battery discharge voltage
- 4 Port current vs. voltage measurements at low-battery voltage
- 5 Port voltage at $I_{\min}$ as calculated in EE.4.3.1 b)
- 6 Operating region permitted by product specification (shaded)
- 7 Operating region not permitted by product specification

NOTE In this example, three points fall outside the permitted operating region: two points on curve 1 (at a high battery voltage) and one point on curve 4 (at a low battery voltage). Therefore, the port fails the functionality assessment.

Figure EE.3 – Illustration of functionality assessment

For each port, report whether the port meets the functionality criteria in the product specification. If a port does not meet the criteria, describe the reason for failure and the conditions under which the criteria are not met.

If the port has an advertised power value instead of or in addition to an advertised current value, or to evaluate compatibility with an advertised appliance, power may be substituted for current.

EE.4.3.2 Evaluation of advertising claims

Consumer-facing claims of port performance (e.g. on the product packaging or in user documentation) can take many forms. The following list is intended to provide guidance for evaluating claims of port performance but is not an exhaustive list of every possible or permitted form of advertising claim.

- a) A statement of the form given in EE.4.3.1 may be evaluated using the same procedure as for port functionality. (If a maximum power is given rather than a maximum current, use the port voltage vs. port power data from EE.4.2).

- b) A statement of maximum current or maximum power, given without a voltage range, may be evaluated by comparing the advertised current or power to the maximum current or maximum power measured in EE.4.2.
- c) A claim that the product can power a given appliance is implicitly a claim of port performance. If the product specification gives voltage limits for the port, the claim can be evaluated using the procedure in EE.4.3.1, using the expected power consumption of the appliance in place of $I_{\min}$. Otherwise, the claim can be evaluated as in b). The power value to use depends on the nature of the claim:
 - 1) If the company advertises compatibility with a specific type or model of appliance, and the rated power consumption of that appliance can be determined from the company-supplied information, use the rated power consumption.
 - 2) If no specific type or model is given, use the procedure in HH.5.2 to determine the power value.

To determine which port is intended to power an advertised appliance, use the guidelines in GG.4.1.5 f) 1).

NOTE This truth-in-advertising assessment does not apply to included appliances since their compatibility with the product is tested.

The maximum port power can vary with battery voltage. Generally, the port should be able to meet the advertised performance level (including powering advertised appliances) at all simulated battery voltage levels, but in some cases it can be appropriate to advertise a level of performance that is not met at the low-battery voltage if the advertising or documentation clearly states the limitations in the port's ability to provide the advertised level of performance with a low battery.

For each port, report whether the port capabilities are accurately advertised. If not, describe the reason for failure and the conditions under which the advertised performance is not delivered.

EE.4.3.3 Qualitative assessment

For each port, determine and report the following characteristics. For ports that are not part of a set of identical ports (as defined in EE.4.1), these items are optional.

- a) Determine the type of voltage regulation. This can be one of the following:
 - No regulation: the voltage measured at the port is the battery voltage, less any resistive voltage drop;
 - Linear regulation: the voltage measured at the port is less than or equal to the battery voltage, and the port current is approximately equal to the battery current (minus the current used by the power control unit itself);
 - DC-DC converter: either the voltage or the current at the port is greater than the value at the battery.
- b) For ports with voltage regulation that are part of a set of identical ports (as defined in EE.4.1), determine, if possible, whether the ports share a common voltage regulator or DC-DC converter, or whether each port is independently regulated. This assessment may be made by visual inspection, consultation with the company, or examination of the port behaviour under load. If the unloaded port voltage (EE.4.2.6) is strongly dependent on the loaded port voltage, the ports are likely to share a common voltage regulator or DC-DC converter. In some cases, it is not possible to determine whether the ports share a voltage regulator or DC-DC converter.

EE.5 Reporting

Report the following in the input voltage range test report.

- Metadata:
 - report title;
 - procedure(s) used;
 - company;
 - product name;
 - model number;
 - DUT setting;
 - test room temperature (°C);
 - name of test laboratory;
 - identification of the person(s) authorizing the report;
 - date of issue of the report.
- Plots:
 - three or four plots (depending on whether testing is conducted at the average charging voltage) of port voltage vs. port current for each port;
 - three or four plots of port voltage vs. port power for each port;
 - three or four plots of battery-to-port efficiency vs. port current for each port;
 - three or four plots of battery-to-port efficiency vs. port power for each port;

Multiple characteristic curves may be plotted on the same plot, as long as the results are clearly readable. For example, results from multiple ports for the same operating conditions (e.g. discharging, 14,8 V) may be combined into a single plot; multiple scenarios for the same port may be combined into a single plot; or multiple quantities (voltage and efficiency) may be plotted on the same plot.
- Tables:
 - table of pass/fail functionality and truth in advertising values for each port;
 - table of minimum and maximum voltages and maximum power for each port;
 - table of shared and individual resistances for each set of identical ports;

Multiple tables sharing the same set of row or column headings may be combined into a single table.

The data plotted in the required plots of port voltage and battery-to-port efficiency vs. port current and port power shall be provided to the client upon request. It is generally most useful to provide these data as a computer spreadsheet file or other machine-readable form.
- USB fast-charging aspects
 - presence of USB fast charging support (yes/no/not assessed);
 - list of fast-charging modes supported by each port;
 - functionality of PPS or AVS mode, if supported (yes/no/not assessed);
 - port voltage at 500 mA without fast-charging mode enabled (V);
- Assessment of functionality and truth in advertising:
 - whether each port meets the functionality requirements of the product specification (yes/no);
 - whether each port is accurately advertised (yes/no);

- Qualitative assessment for each port:
 - type of voltage regulation (no regulation/linear regulation/DC-DC converter);
 - whether identical ports are independently regulated (yes/no)
- Comments:
 - individual comments, as necessary, for samples 1 through n ;
 - overall comments, as necessary, for collective set of samples 1 through n .

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Annex FF (normative)

Appliance tests

FF.1 Background

Annex FF applies to any appliances included or advertised for use with stand-alone renewable energy products. Appliances to be tested include light points, fans, televisions, radios, refrigerators and other similar devices. If more than one identical appliance is included with the product, only one of each identical appliance should be tested to represent a single sample.

Annex FF contains four test methods: a power consumption test (Clause FF.6), a charging efficiency test (Clause FF.7), an appliance operating voltage range test (Clause FF.8), and an appliance full-battery run time test with deep discharge protection measurement (Clause FF.9). The charging efficiency test (Clause FF.7) and appliance full-battery run time test with deep discharge protection measurement (Clause FF.9) are only applicable to appliances with internal batteries. The appliance operating voltage range test (Clause FF.8) is applicable to appliances with and without internal batteries, but is necessary only for appliances that were not tested with the product in EE.4.2.6 (for example, new appliances that a company wishes to test for use with a product that has already been tested).

Some included appliances are portable, have internal batteries, or provide light. Specific tests for these appliances are outlined in Clause FF.2.

These test methods can be applied to appliances that are sold separately as accessories for a stand-alone renewable energy product. The laboratory may perform the appliance tests without possessing samples of the other components of the product. However, the operating voltage and other test parameters are determined using the test results for the stand-alone renewable energy product, and the results are not automatically applicable to the same appliance when used with a different product.

FF.2 Appliance testing requirements

Appliances shall be evaluated for specific outcomes depending on the appliance category as summarized in Table FF.1 and described in FF.2 a) through FF.2 l) as follows:

- a) All appliances shall undergo the switch and connector test (W.5.2), the gooseneck and moving part test (W.5.3), the strain relief test (W.5.4), and the simplified IP inspection for ingress of solid foreign objects (U.4.3), as applicable.
- b) Lighting appliances (appliances that are required by the product specification to undergo the lighting tests) shall undergo the light output test (Annex I) and lumen maintenance test (Annex J).
- c) Portable appliances shall also undergo the drop test (W.5.1), as applicable (for example, a television would generally not be expected to pass a drop test and other non-lighting appliances are subject to a modified drop test), and level of water protection assessment (Annex V).
- d) Lighting appliances with an internal battery shall undergo the full-battery run time test (Annex M) and standby loss measurement (S.4.5).

Table FF.1 – Appliance testing requirements

Metric (s)	Test annex	Non-lighting appliances with an internal battery	Non-lighting appliances without an internal battery	Lighting appliances with an internal battery	Lighting appliances without an internal battery
Luminous flux	Annex I	No	No	Yes	Yes
Lumen maintenance	Annex J	No	No	Yes	Yes
Battery capacity	Annex K	Yes	No	Yes	No
Deep discharge protection	Annex S	Yes	No	Yes	No
Overcharge protection	Annex S	Yes	No	Yes	No
Standby loss	Annex S	No	No	Yes	No
Light distribution	Annex T	No	No	Optional	Optional
Physical ingress protection	Annex U	Yes	Yes	Yes	Yes
Level of water protection	Annex V	Yes, if portable	No	Yes, if portable	No
Switch and connector	Annex W	Yes	Yes	Yes	Yes
Gooseneck/moving parts	Annex W	Yes	Yes	Yes	Yes
Strain relief	Annex W	Yes	Yes	Yes	Yes
Drop test	Annex W	Maybe, if portable; see c)	No	Yes, if portable	No
Battery durability	Annex BB	No	No	Yes	No
Miswiring protection test	Annex DD	Ports and connectors on appliances are included in the miswiring protection test.			
Output overload protection test	Annex DD	Yes, unless exempt			
Assessment of DC ports	Annex EE				
Charging efficiency	Annex FF	If requested; see i)	No	If requested; see i)	No
Full-battery run time	Annex M or Annex FF	Maybe; see f)	No	Yes	Likely tested during Lighting FBRT
Power consumption	Annex FF	Maybe; see h)	Yes	No	Yes
Appliance operating voltage range	Annex FF	Yes	Yes	Yes	Yes
Energy service calculations	Annex GG	Yes	Yes	Yes	Yes

- e) Appliance output ports intended for charging or powering other devices shall undergo the assessment of DC ports (Annex EE).
- f) If a non-lighting appliance with battery has ports that will undergo the assessment of DC ports (Annex EE), the appliance full-battery run time test with deep discharge protection measurement (FF.9) shall be performed. Otherwise, the full-battery run time for non-lighting appliances with an internal battery shall be determined using one of the following two methods:

- 1) The appliance full-battery run time test with deep discharge protection measurement (Clause FF.9) may be performed.
 - 2) The measured appliance's battery energy (Wh) may be determined using the battery test (Annex K) current-voltage pairs from the battery's final discharge curve. The measured appliance's power consumption may be determined in accordance with Clause FF.6. The estimated appliance full-battery run time may then be calculated in accordance with FF.6.9.5. If the full-battery run time estimated in FF.6.9.5 deviates from the advertised value by less than the truth-in-advertising tolerance stated in the product specification, then the company's full-battery run time rating shall be used in energy service calculations (Annex GG); otherwise, the run time estimated by the laboratory shall be used. If the estimated value is disputed, the appliance full-battery run time test (Clause FF.9) may be performed.
- g) Appliances without an internal battery shall undergo the power consumption test (Clause FF.6).
- h) The power consumption test may be omitted for notebook and tablet computers and mobile devices. For other non-lighting appliances with internal batteries, the power consumption shall be measured for each setting or operating condition specified in the relevant subclause of Clause FF.6, either as the average power during the full-battery run time or the power measured in the power consumption test.
- If the appliance run time is not advertised or advertised only in terms of a number of full charges of its battery, the appliance power consumption test may be omitted if
- 1) an accepted method to measure appliance power consumption under steady-state conditions does not exist, or
 - 2) the test cannot be performed because of aspects of the appliance design (e.g. the battery cannot be removed from the appliance without damaging it).
- i) Appliances with batteries may undergo the charging efficiency test (Clause FF.7) if requested by the company. If this test is not performed, default values are used in the energy service calculations.
- j) All appliances shall undergo the appliance operating voltage range test (Clause FF.8).
- k) All appliances are included in the energy service calculations (Annex GG).
- l) In cases where multiple appliances without internal batteries that provide the same type of service, e.g. lighting, can be connected to a single port, as identified in F.4.1.5 b) 1), these appliances may be treated as a single appliance or as individual appliances. The product specification may provide further guidance on treatment of these appliances. The same configuration should be used for all procedures in Annex FF.

FF.3 Test outcomes

The appliance test outcomes are listed in Table FF.2.