भारतीय मानक

Indian Standard

IS 16229 : 2024
IEC 62093 : 2022

फोटोवोल्टिक प्रणाली विद्युत रूपांतरण उपकरण — डिजाइन योग्यता और प्रकार अनुमोदन

(पहला पुनरीक्षण)

Photovoltaic System Power Conversion Equipment — Design Qualification and Type Approval

(First Revision)

ICS 27.160

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुर शाह ज़फर मार्ग, नई दिल्ली - 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI - 110002
www.bis.gov.in www.standardsbis.in

July 2024

Price Group 14

This Page has been Intentionally left blank

Solar Photovoltaic Energy Systems Sectional Committee, ETD 28

NATIONAL FOREWORD

This Indian Standard (First Revision) which is identical to IEC 62093 : 2022 'Photovoltaic system power conversion equipment — Design qualification and type approval' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Solar Photovoltaic Energy Systems Sectional Committee and approval of the Electrotechnical Division Council.

This standard was initially published in 2015 which was based on IEC 62093 : 2005. The first revision of this standard has been undertaken to align it with the latest version of IEC 62093 : 2022.

The text of the IEC standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appears referring to this standard, they should be read as 'Indian Standard'; and
b) Comma (,) has been used as a decimal marker, while in Indian Standards the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to International Standards for which Indian Standards also exists. The corresponding Indian Standards, which are to be substituted, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 4892-2 Plastics — Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps	IS 17863 (Part 2) : 2022/ISO 4892-2 : 2013 Plastics — Methods of exposure to laboratory light sources: Part 2 Xenon-Arc lamps	Identical
IEC 60068-2-6 Environmental testing — Part 2-6: Tests — Test Fc: Vibration (sinusoidal)	IS/IEC 60068-2-6 : 2007 Environmental testing: Part 2 Tests, Section 6 Test Fc: vibration (sinusoidal)	Identical
IEC 60068-2-27 Environmental testing — Part 2-27: Tests — Test Ea and guidance: Shock	IS 9000 (Part 7/Sec 1) : 2018/ IEC 60068-2-27 : 2008 Basic environmental testing procedures for electronic and electrical items: Part 7 Impact test, Section 1 Shock (test Ea)	Identical
IEC 60068-2-78 Environmental testing — Part 2-78: Tests — Test cab: Damp heat, steady state	IS 9000 (Part 4) : 2020/IEC 60068-2-78 : 2012 Environmental testing: Part 4 Tests — Test cab: damp heat, steady state	Identical
IEC 60529 : 1989 Degrees of protection provided by enclosures (IP Code) IEC 60529 : 989/AMD1 : 1999, IEC 60529 : 1989/AMD2 : 2013	IS/IEC 60529 : 2001 Degrees of protection provided by enclosures (IP Code)	Identical

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60721-3-3 Classification of environmental conditions — Part 3-3: Classification of groups of environmental parameters and their severities — Stationary use at weather protected locations	IS/IEC 60721 (Part 3/Sec 3) : 2019 Classification of environmental conditions: Part 3 Classification of groups of environmental parameters and their severities, Section 3 Stationary use at weather protected locations	Identical
IEC 60721-3-4 Classification of environmental conditions — Part 3-4: Classification of groups of environmental parameters and their severities — Stationary use at non-weather protected locations	IS/IEC 60721 (Part 3/Sec 4) : 2019 Classification of environmental conditions: Part 3 Classification of groups of environmental parameters and their severities, Section 4 Stationary use at non-weather protected locations	Identical
IEC 61000-3-2 Electromagnetic compatibility (EMC) — Part 3-2: Limits — Limits for harmonic current emissions (equipment input current ≤16 A per phase)	IS 14700 (Part 3/Sec 2) : 2020/ IEC 61000-3-2 : 2018 Electromagnetic compatibility (EMC): Part 3 Limits, Section 2 Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)	Identical
IEC 61180 High-voltage test techniques for low-voltage equipment — Definitions, test and procedure requirements, test equipment	IS 16826 : 2018/IEC 61180 : 2016 High-Voltage test techniques for low-voltage equipment — Definitions, test and procedure requirements, test equipment	Identical
IEC 61557-1 Electrical safety in low voltage distribution systems up to 1 000 V AC and 1 500 V DC — Equipment for testing, measuring or monitoring of protective measures — Part 1: General requirements	IS/IEC 61557-1 : 2019 Electrical safety in low voltage distribution systems up to 1 000 V AC and 1 500 V DC — Equipment for testing, measuring or monitoring of protective measures: Part 1 General requirements	Identical
IEC TS 61836 Solar photovoltaic energy systems — Terms, definitions and symbols	IS 12834 : 2023/IEC TS 61836 : 2016 Solar photovoltaic energy systems — Terms, definitions and symbols (*second revision*)	Identical
IEC 62109-1 : 2010 Safety of power converters for use in photovoltaic power systems — Part 1: General requirements	IS 16221 (Part 1) : 2016/IEC 62109-1 : 2010 Safety of power converters for use in photovoltaic power systems: Part 1 General requirements	Identical
IEC 62116 : 2014 Utility-interconnected photovoltaic inverters — Test procedure of islanding prevention measures	IS 16169 : 2019/IEC 62116 : 2014 Utility-Interconnected photovoltaic inverters — Test procedure of islanding prevention measures	Identical
IEC 62716 : 2013 Photovoltaic (PV) modules — Ammonia corrosion testing	IS 16664 : 2018/IEC 62716 : 2013 Photovoltaic (PV) modules — Ammonia corrosion testing	Identical

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 62852 Connectors for dc-application in photovoltaic systems — Safety requirements and tests	IS 16781: 2018/IEC 62852 : 2014 Connectors for dc application in photovoltaic systems — Safety requirements and tests	Identical
IEC 62894 : 2014 Photovoltaic inverters — Data sheet and name plate IEC 62894 : 2014/ AMD1 : 2016	IS 16798 : 2018/IEC 62894 : 2014 Photovoltaic inverters — Data sheet and name plate	Identical

The Committee has reviewed the provisions of the following international standards referred in this adopted standard and decided that they are acceptable for use in conjunction with this standard.

International Standard	*Title*
IEC 60068-2-2 : 2007	Environmental testing — Part 2-2: Tests — Test B: Dry heat
IEC 60068-2-14	Environmental testing — Part 2-14: Tests — Test N: Change of temperature
IEC 60068-2-52	Environmental testing — Part 2-52: Tests —Test Kb: Salt mist, cyclic (sodium, chloride solution)
IEC 60068-2-60 : 2015	Environmental testing —Part 2-60: Tests — Test Ke: Flowing mixed gas corrosion test
IEC 60068-2-68	Environmental testing — Part 2-68: Tests — Test L: Dust and sand
IEC 60068-3-5 : 2018	Environmental testing — Part 3-5: Supporting documentation and guidance — Confirmation of the performance of temperature chambers
IEC 60068-3-6	Environmental testing — Part 3-6: Supporting documentation and guidance — Confirmation of the performance of temperature/ humidity chambers
IEC 61000-3-12	Electromagnetic compatibility (EMC) — Part 3-12: Limits — Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase
IEC TR 61000-3-14	Electromagnetic compatibility (EMC) — Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems
IEC 62477-1:2012	Safety requirements for power electronic converter systems and equipment — Part 1: General IEC 62477-1 : 2012/AMD1 : 2016
IEC TS 63106-2	Basic requirements for simulator used for testing of photovoltaic power conversion equipment — Part 2: DC power simulator
ISO 12103-1 : 2016	Road vehicles — Test contaminants for filter evaluation — Part 1: Arizona test dust
ISO 22479 : 2019	Corrosion of metals and alloys — Sulfur dioxide test in a humid atmosphere (fixed gas method)

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated expressing the result of a test, shall be rounded off in accordance with IS 2 : 2022 'Rules for rounding off numerical values (*second revision*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

CONTENTS

Indian Standard

PHOTOVOLTAIC SYSTEM POWER CONVERSION EQUIPMENT — DESIGN QUALIFICATION AND TYPE APPROVAL

(First Revision)

1 Scope

This document lays down IEC requirements for the design qualification of power conversion equipment (PCE) suitable for long-term operation in terrestrial photovoltaic (PV) systems.

This document covers electronic power conversion equipment intended for use in terrestrial PV applications. The term PCE refers to equipment and components for electronic power conversion of electric power into another kind of electric power with respect to voltage, current, and frequency. This document is suitable for PCE for use in both indoor and outdoor climates as defined in IEC 60721-3-3 and IEC 60721-3-4. Such equipment may include, but is not limited to, grid-tied and off-grid DC-to-AC PCEs, DC-to-DC converters, battery charger converters, and battery charge controllers.

This document covers PCE that is connected to PV arrays that do not nominally exceed a maximum circuit voltage of 1 500 V DC. The equipment may also be connected to systems not exceeding 1 000 V AC at the AC mains circuits, non-main AC load circuits, and to other DC source or load circuits such as batteries. If particular ancillary parts whereby manufacturers and models are specified in the manual for use with the PCE, then those parts are tested with the PCE.

Exceptions:

a) This document does not address characteristics of power sources other than PV systems, such as wind turbines, fuel cells, rotating machine sources, etc.
b) This document does not address the characteristics of power electronic conversion equipment fully integrated into photovoltaic modules. Separate standards exist or are in development for those types of devices. It is, however, applicable to devices where the manufacturer explicitly specifies the capability of full detachment from and subsequent reattachment to the PV module or if the input and output terminals can be accessed and a specification sheet for the PCE is available. Devices meeting these requirements may be tested as individual samples independent from the PV module.
c) This document does not apply to power conversion equipment with integrated (built-in) electrochemical energy storage (*e.g.* lead acid or lithium-ion). It is, however, applicable to equipment where the manufacturer specifies and permits complete removal of the electrochemical energy storage from the PCE so that stand-alone assessment of the PCE with the storage removed becomes possible.

The object of the test sequences contained herein is to establish a basic level of durability and to show, as far as it is possible within reasonable constraints of cost and time, that the PCE is capable of maintaining its performance after prolonged exposure to the simulated environmental stresses described herein that are based on the intended use conditions specified by the manufacturer. Optional tests contained herein may be selected depending on the intended installation, market, or special environmental conditions that the PCE is anticipated to experience. The categorization imposes differentiated test sequences and test severity levels reflecting the different requirements of mechanical and electrical components in different environments.

PCEs are grouped into categories based on size and installation environment.

The actual life expectancy of components so qualified depends on their design, their environment, and the conditions under which they are operated. Estimation of a lifetime and wear out is not generally covered by this document.

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 60068-2-2:2007, *Environmental testing – Part 2-2: Tests – Test B: Dry heat*

IEC 60068-2-6, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal)*

IEC 60068-2-14, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

IEC 60068-2-27, *Environmental testing – Part 2-27: Tests – Test Ea and guidance: Shock*

IEC 60068-2-52, *Environmental testing – Part 2-52: Tests – Test Kb: Salt mist, cyclic (sodium, chloride solution)*

IEC 60068-2-60:2015, *Environmental testing – Part 2-60: Tests – Test Ke: Flowing mixed gas corrosion test*

IEC 60068-2-68, *Environmental testing – Part 2-68: Tests – Test L: Dust and sand*

IEC 60068-2-78, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state*

IEC 60068-3-5:2018, *Environmental testing – Part 3-5: Supporting documentation and guidance – Confirmation of the performance of temperature chambers*

IEC 60068-3-6, *Environmental testing – Part 3-6: Supporting documentation and guidance – Confirmation of the performance of temperature/ humidity chambers*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP Code)*
IEC 60529:1989/AMD1:1999
IEC 60529:1989/AMD2:2013

IEC 60721-3-3, *Classification of environmental conditions – Part 3-3: Classification of groups of environmental parameters and their severities – Stationary use at weather protected locations*

IEC 60721-3-4, *Classification of environmental conditions – Part 3-4: Classification of groups of environmental parameters and their severities – Stationary use at non-weather protected locations*

IEC 61000-3-2, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)*

IEC 61000-3-12, *Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per phase*

IEC TR 61000-3-14, *Electromagnetic compatibility (EMC) – Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems*

IEC 61180, *High-voltage test techniques for low-voltage equipment – Definitions, test and procedure requirements, test equipment*

IEC 61557-1, *Electrical safety in low voltage distribution systems up to 1 000 V AC and 1 500 V DC – Equipment for testing, measuring or monitoring of protective measures – Part 1: General requirements*

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

IEC 62109-1:2010, *Safety of power converters for use in photovoltaic power systems – Part 1: General requirements*

IEC 62116:2014, *Utility-interconnected photovoltaic inverters – Test procedure of islanding prevention measures*

IEC 62477-1:2012, *Safety requirements for power electronic converter systems and equipment – Part 1: General*
IEC 62477-1:2012/AMD1:2016

IEC 62716:2013, *Photovoltaic (PV) modules – Ammonia corrosion testing*

IEC 62852, *Connectors for DC-application in photovoltaic systems – Safety requirements and tests*

IEC 62894:2014, *Photovoltaic inverters – Data sheet and name plate*
IEC 62894:2014/AMD1:2016

IEC TS 63106-2, *Basic requirements for simulator used for testing of photovoltaic power conversion equipment – Part 2: DC power simulator*

ISO 4892-2, *Plastics – Methods of exposure to laboratory light sources – Part 2: Xenon-arc lamps*

ISO 12103-1:2016, *Road vehicles – Test contaminants for filter evaluation – Part 1: Arizona test dust*

ISO 22479:2019, *Corrosion of metals and alloys – Sulfur dioxide test in a humid atmosphere (fixed gas method)*

3 Terms and definitions

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

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

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

NOTE Symbols and variable names for PCE input and output values follow the terminology of IEC 62894.

3.1
power conversion equipment
PCE
electrical device converting one kind of electrical power from a voltage or current source into another kind of electrical power with respect to voltage, current and frequency

Note 1 to entry: Examples include AC-DC converters, DC-AC inverters, DC-DC charge controllers, frequency converters, etc.

3.2
module-level power electronics: Category 1 PCE
MLPE
referring to PCE that is specified by the manufacturer to operate on a PV module basis, interfacing with up to four individual PV modules

3.3
string-level power electronics: Category 2 PCE
category comprising PCE that is designed to interface more than four series- and/or parallel-connected PV modules and not meeting the conversion power of the Category 3 PCE or Category 4 PCE definition

3.4
large-scale power electronics: Category 3 PCE
category comprising PCE predominantly in a single unit capable of power conversion equal to or greater than 100 kVA and less than 1 000 kVA

Note 1 to entry: This class of PCE may have multiple power conversion units built into the larger containing unit.

3.5
central large-scale power electronics: Category 4 PCE
category comprising PCE predominantly in a single enclosure capable of power conversion equal to or greater than 1 000 kVA

Note 1 to entry: This class of PCE may have multiple power conversion units built into the larger containing unit.

3.6
derating temperature
ambient temperature limit at which the PCE starts to actively curtail its input and output power to maintain a certain maximum operating temperature

Note 1 to entry: This temperature may also depend on input power and other electrical parameters, and thus may not be unique.

3.7
electrically independent inputs
ports for input of power to the PCE that are not ohmically connected to one another internally but serve to supply power to the PCE at different operating points of current and voltage at the same time provided by, for example, a boost converter stage in the PCE for each such electrically independent input

3.8
enclosure
part of the equipment which surrounds internal parts, intended to provide protection against external influences, against the spread of fire, or against access to hazards

Note 1 to entry: Enclosures may be free standing, wall, rack, ceiling, frame or skid mounted.

3.9
maximum total PV array short circuit current
$I_{\text{sc max}}$
absolute maximum total PV array short circuit current (DC) that the PCE is rated to have connected to its PV input, under most severe-case conditions of ambient temperature, irradiance, etc.

Note 1 to entry: This rating of the PCE refers to the absolute maximum current the PV input to the PCE is designed for under conditions of expected use. This differs from the simple sum of the marked I_{sc} ratings of the connected PV modules, since those markings are based on short-circuit conditions under standard test conditions, and may be exceeded at high temperatures or with irradiance above the standard level.

3.10
rated
value assigned, generally by a manufacturer, to a specified operating condition of a component, device or equipment

3.11
rated input voltage
$V_{\mathrm{dc,r}}$
rated input voltage specified by the manufacturer, or if not specified, the midpoint of the maximum power point (MPP) input voltage range of the PCE

3.12
rated power
P_{r}
maximum active power the PCE can deliver in continuous operation

3.13
maximum power point voltage
maximum MPP voltage
$V_{\mathrm{mpp\ max}}$
maximum voltage at the DC input port at which the inverter can deliver its rated power continuously without power curtailing

3.14
minimum MPP voltage
$V_{\mathrm{mpp\ min}}$
minimum voltage at the DC input port at which the inverter can deliver its rated power continuously

3.15
port
location giving access to a device or network where electromagnetic energy or signals may be supplied or received or where the device or network variables may be observed or measured

3.16
photovoltaic array
PV array
assembly of electrically interconnected PV modules, PV strings or PV sub-arrays

Note 1 to entry: For the purposes of this document a PV array is all components up to the DC input terminals of the inverter or other power conversion equipment or DC loads.

Note 2 to entry: A PV array does not include its foundation, tracking apparatus, thermal control, and other such components.

Note 3 to entry: A PV array may consist of a single PV module, a single PV string, or several parallel-connected strings, or several parallel-connected PV sub-arrays and their associated electrical components. For the purposes of this document the boundary of a PV array is the output side of the PV array disconnecting device.

3.17
printed circuit board
PCB
electronic circuit consisting of thin strips of a conducting material such as copper, which have been etched from a layer fixed to a flat insulating sheet; integrated circuits and other components are attached

3.18
terminal
component provided for the connection of a device (equipment) to external conductors

3.19
capacitor temperature
T_C
measured capacitor temperature on its surface

3.20
maximum capacitor temperature
T_{C2}
highest measured capacitor temperature, T_C

3.21
ambient setpoint for maximum capacitor temperature
$T_{amb,set\ C}$
ambient temperature of the test environment (as in the climatic chamber) at which the measured peak capacitor temperature T_{C2} is obtained

3.22
power transistor case or reference temperature
T_I
measured power transistor case or reference temperature

3.23
maximum power transistor case or reference temperature
T_{I2}
highest measured power transistor case or reference temperature

3.24
ambient setpoint for maximum power transistor case or reference temperature
$T_{amb,set\ I}$
ambient temperature of the test environment (as in a climatic chamber) at which the measured highest power transistor case or reference temperature T_{I2} is obtained

4 Sampling

For the test procedure described in Clause 6, a number of test samples according to Table 1 shall be taken at random from a production batch or batches. The PCE samples shall have been manufactured from specified materials and components in accordance with the relevant drawings and process sheets and shall have been subjected to the manufacturer's normal inspection, quality control, and production acceptance procedures. The samples shall be complete in every detail and shall be accompanied by the manufacturer's product specifications, handling, mounting, and connection instructions. When the PCE to be tested are prototypes of a new design and not from production, this fact shall be noted in the test report (Clause 8).

If a Category 3 PCE or Category 4 PCE consists of identical parallel power converters within an enclosure, it is permitted to operate only one of those converters as a sample for testing in order to reduce the cooling requirements of the climate chamber. In such a case, any active cooling capability of the PCE common to the whole enclosure shall be proportionally reduced. For example, if there are three converters and only one is powered in the test, then fans common to all three units shall be blocked in area by two-thirds or powered intermittently only one-third of the time. Applied electrical power to the inputs of the main unit shall also be scaled to one-third.

Testing of PCE in Category 3 PCE and 4 PCE may involve the use of the same sample for the various test sequence if desired, therefore a range of sample count is given. Samples specified in Table 1 may be reused any number of times for optional tests described in Clause 7.

Alternatively, additional samples may be procured for use in optional tests if provided by the party submitting the PCE type for testing.

Table 1 – Testing sample quantity

	MLPE	String-level power electronics	Large-scale power electronics	Central large-scale power electronics
	Category 1 PCE	Category 2 PCE	Category 3 PCE	Category 4 PCE
Number of required samples	4	4 [1]	1-2	1-2

[1] For category 2 PCE with a rated output power of 50 kVA or above, the required number of test samples may be reduced by half.

5 Testing requirements

5.1 General

This Clause describes the testing framework, including categories of environmental service condition that informs the stress level requirements for each test, a table summarizing the test requirements, and figures illustrating the sequence of tests. While test procedures given in the subsequent clauses describe specific restrictions and exception for differing PCE categories, an overview is given here. General testing requirements and apparatus common to the Clause 6 test procedures are described. Finally, the requirements for passing this international design qualification and type approval standard are given.

5.2 Environmental service conditions

5.2.1 General

The test severities are based on environmental service conditions for the PCE that are specified by the manufacturer. This document adopts the terminology used in IEC 62109-1 and IEC 62477-1 and on the classification of environmental conditions in IEC 60721-3-3 and IEC 60721-3-4.

The following environmental service condition classifications for the purpose of this document are summarized here and in Table 2 and are given as guidelines for selection of environmental service condition under which the PCE type will qualify. While it may be convenient for the user of this document to reference and maintain consistency with the table of environmental categories, environmental conditions, and test requirements listed in IEC 62109-1, it is not required by this document. Three environmental service condition categories with requirements for testing from most extreme to least extreme are: outdoor (5.2.2), indoor unconditioned (5.2.3); and indoor, conditioned (5.2.4). PCE qualified for a more extreme condition is implicitly qualified for the lesser extreme conditions.

5.2.2 Outdoor

PCE designed for climatic conditions 4K25 and 4K26 in IEC 60721-3-4 are categorized for Outdoor environments. This category refers to PCE intended for long-term operation in non-weather protected outdoor or general open-air climates. During normal operation, the PCE is fully or partially exposed to direct rain, sun, wind, dust, fungus, ice, radiation to the cold night sky, etc. Severe environmental stress is projected on PCE that fall into this category. The condition of IEC 60721-3-4 climatic condition 4K27, open-air placement in cold and polar climates, is not specifically covered in this document; however, testing to lower temperatures may be selected for testing and reported as specified in Annex A.

5.2.3 Indoor, unconditioned

PCE designed for climatic conditions 3K23 and 3K24 defined in IEC 60721-3-3 are categorized for indoor, unconditioned environments. In this category, the PCE can be localized in the same climates as designated in 5.2.2, but the PCE is fully enclosed by a building or ancillary enclosure to protect it from rain, sun, wind-blown dust, ice, fungus, and radiation to the cold night sky, etc. However, the building or climate is not systematically controlled for temperature and is not controlled for humidity. The equipment may experience condensation and the air may not be filtered.

5.2.4 Indoor, conditioned

PCE designed for climatic conditions 3K20, 3K21, and 3K22 defined in IEC 60721-3-3 are categorized for indoor, conditioned environments. In this category, the PCE is enclosed by a building or ancillary enclosure to protect it from rain, sun, wind-blown dust, fungus, and radiation to the cold night sky, etc. Additionally, the building or enclosure that incorporates the PCE is environmentally controlled for temperature. While humidity may not necessarily be controlled, condensed moisture does not normally occur, nor is it expected. Limited environmental stress is anticipated on PCE falling into this category. The extent of dust present in this environment depends on the level of air filtration.

Table 2 – Environmental condition classifications

	Environmental conditions		
	Outdoor	**Indoor, unconditioned**	**Indoor, conditioned**
Climatic class (IEC 60721-3-3 or 60721-3-4)	4K25 and 4K26	3K23 and 3K24	3K20, 3K21, and 3K22
Temperature[1]	-20 °C to +50 °C	-5 °C to +55 °C	5 °C to +40 °C
Humidity	4 % to 100 % RH (condensing)	5 % to 100 % RH (condensing)	5 % to 85 % RH (non-condensing)
Wet location	Yes	No	No

[1] Some provisions exist in the Clause 6 stress tests for PCE that claim environment condition classifications (environment temperature) that differ from those listed here.

5.3 Test sequences

5.3.1 General

The test sequence with number of required samples and distribution of the samples among the test legs is illustrated in Figure 1. It is applicable for Category 1 PCE to Category 4 PCE. An alternative test sequence for Category 3 PCE and Category 4 PCE is given in Figure 2, which permits testing with a reduced number of samples. Table 3 summarizes the different tests. While an overview of the handling of the different PCE categories is given here, Clause 6 provides the descriptions of the required tests and test procedures, including initial and final measurements, requirements, and exceptions.

Table 4 provides a summary of optional tests that may be applied.

5.3.2 Test conditions for Category 1 PCE (Module level power electronics)

Unlike PCE of Categories 2, 3, and 4, the bus link capacitor and power transistor module thermal tests (6.5 and 6.6) are not implemented for determination of temperatures for performing the dry heat test and thermal cycling test for Category 1 PCE, for which the test temperatures are fixed.

5.3.3 Test conditions for Category 3 PCE–large scale and Category 4 PCE–central large scale power conversion equipment

An alternative test sequence for Category 3 PCE and Category 4 PCE with a minimum requirement of only one sample is shown in Figure 2 with the option for more units for optional tests.

5.3.4 Test conditions for Category 4 PCE (large central power conversion equipment)

Due to their size, weight, and greater power requirements, exceptions allowing for testing of components apply to large central inverters of Category 4 PCE.

The test procedures for 6.8 and 6.10 can be modified for the testing of Category 4 PCE by subdividing the unit into components instead of testing of the complete PCE unit if either the conditions a) or b) and additionally c) below are fulfilled:

a) Each included main PCE component including but not limited to the reactor (AC choke), capacitors (DC link, DC input, and AC, as applicable), switchgear, surge protection devices, transistor (and its module), internal power, control power supply unit, user interface panel or displays, terminal blocks, and cables is tested separately or in assemblies with other components as listed here according to the test condition, including with representative electrical power and loading, indicated in the applicable subclauses of this document.
b) The main circuit component listed in a) is tested, qualified, and approved according to the test condition indicated in the IEC product design qualification type approval standard for that component when it is used in the PCE under test within the qualified parameters and specifications applied in that component-specific standard.
c) The control circuit boards, which consist of computer technology for operation and control of the inverter that interfaces with internal and external measurement points, switches, semiconductors, and similar equipment, shall be connected to a functional actual, simulated, or miniature size PCE with the main circuit inductor and capacitor components that may be proportionally scaled for rating, capacity, or quantity. The control circuit boards shall be installed and tested in the climate test chamber, and the actual, simulated, or miniature size PCE is operated so that the control circuit board is subjected to stress levels (environmental and electrical) as they would experience in the integrated unit according to the requirements of this document.

When using a simulated or miniature PCE, it shall accept or trigger all inputs and outputs to the control circuit board as if it was operated in the actual PCE as indicated in 6.8 and 6.10.

When the component testing is selected, additional exceptions and requirements listed in 6.5 and 6.6 apply.

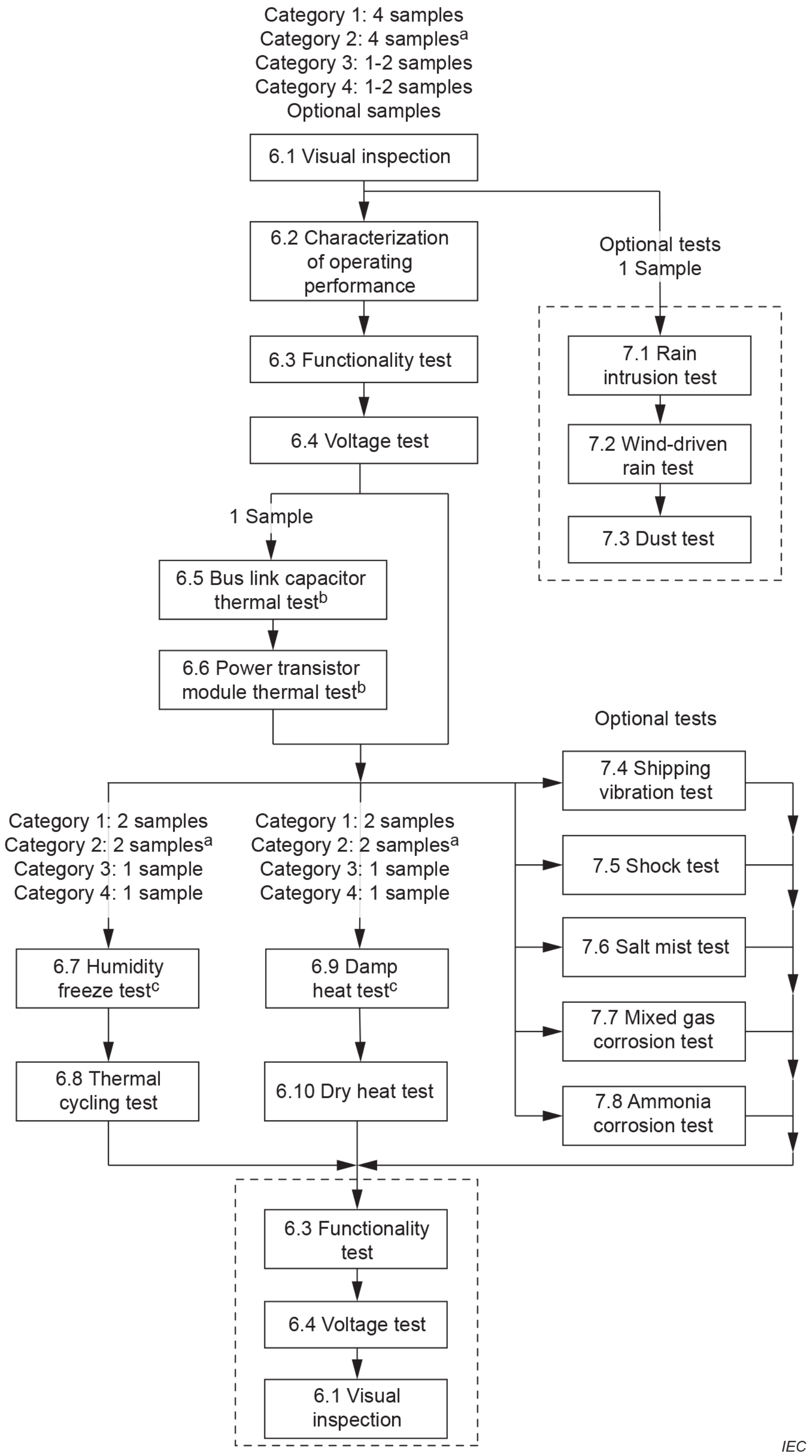
The following tests do not need to be performed for Category 4 PCE:

6.7 Humidity freeze test

6.9 Damp heat test

NOTE 1 In very large central inverters the high thermal masses result in an internal temperature that is usually above the ambient temperature minimizing condensation

NOTE 2 In very large PCE of Category 4 PCE, internal heating as well as dissipated heat from fans and auxiliary converters prevent freezing temperatures inside the PCE in usual operating conditions, resulting in the necessity and utility of the humidity freeze test being lower for Category 4 PCE.



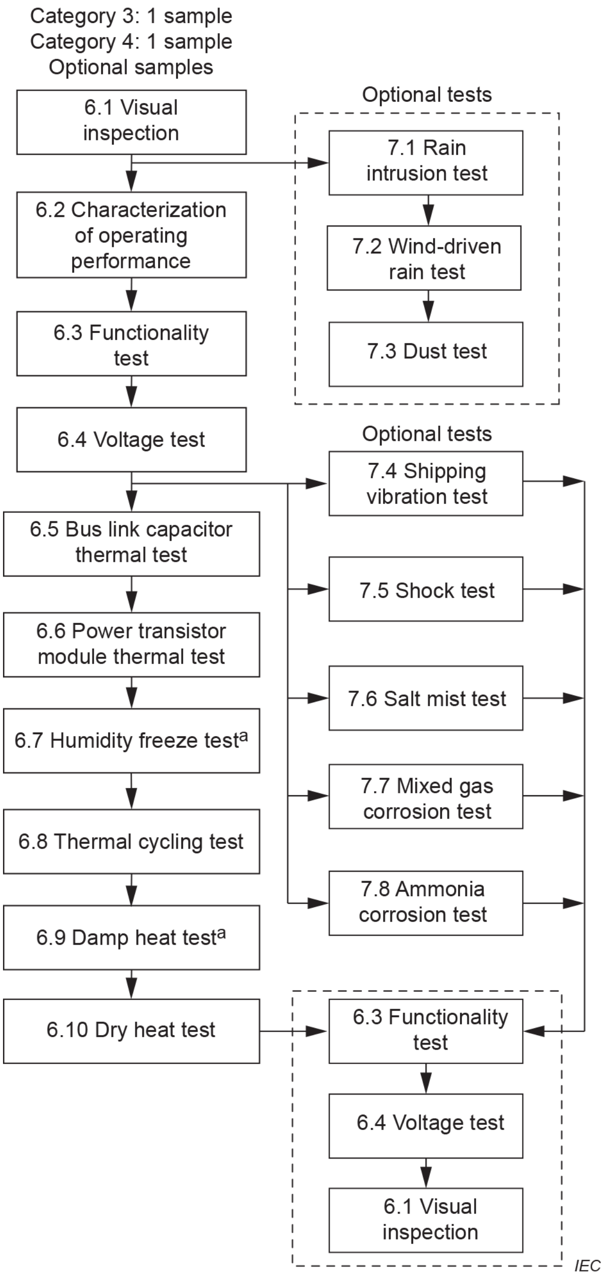
[a] For PCE with a rated output power of 50 kVA or above, the indicated number of test samples may be reduced by half.

[b] Not applicable for Category 1 PCE.

[c] Not applicable for Category 4 PCE .

The optional test group beginning with the rain intrusion test may be performed with samples previously used for the required tests. UV stress tests for PCE parts and components sometimes required are not shown. Test grouped together in hashed line boxes are frequently performed together.

Figure 1 – Test sequence for PCEs of Categories 1 to 4



[a] Not applicable for Category 4 PCE.

The optional test group beginning with the rain intrusion test may be performed with samples previously used for the required tests. UV stress tests for PCE parts and components sometimes required are not shown. Test grouped together in hashed line boxes are frequently performed together.

Figure 2 – Alternative test sequence for Category 3 PCE

Table 3 – Summary of test levels (main test sequence)

Subclause	**Tests,** Environmental condition	**Test conditions**			
		Category 1 PCE (MLPE)	**Category 2 PCE (String-level power electronics)**	**Category 3 PCE (Large-scale power electronics)**	**Category 4 PCE (Large-scale power electronics)**
6.1	**Visual inspection**	According to 6.1.4			
6.2	**Characterization of operating performance**	According to IEC 62894:2014, 4.5.3 Characterization of the operating performance			
6.3	**Functionality test**	Operation at 25° C ambient; P_r; $V_{mpp\,min}$, $V_{mpp\,max}$, and $V_{dc,r}$			
6.4	**Voltage (dielectric strength) test**	Ambient conditions and test conditions according to the voltage test in IEC 62109-1			
6.5	**Bus link capacitor thermal test**				
	Indoor, conditioned	Not performed	2,5 °C/h ramp between max. rated ambient temperature and 25 °C, with $V_{mpp\,max}$ and P_r for determination of the maximum capacitor case temperature T_{C2} and corresponding ambient temperature $T_{amb,set\,C}$.		
	Indoor, unconditioned				
	outdoor				
6.6	**Power transistor module thermal test**				
	Indoor conditioned	Not performed	2,5 °C/h ramp between max. rated ambient temperature and 25°C, with $I_{sc\,max}$ and P_r, for determination of maximum power transistor case temperature T_{I2} and corresponding ambient temperature $T_{amb,set\,I}$		
	Indoor, unconditioned				
	outdoor				
6.7	**Humidity freeze test**				
	Indoor, conditioned	20 cycles, −40 °C[1] to 85 °C, 85 % RH; $V_{mpp\,max}$ and $V_{mpp\,min}$ sequentially for multiple DC inputs, ≥ 0,5 P_r for +T ramp	Not required		
	Indoor, unconditioned		20 cycles from −40 °C[1] to 60 °C, 85 % RH; $V_{mpp\,max}$ and $V_{mpp\,min}$ sequentially for multiple DC inputs, ≥ 0,5 P_r for +T ramp		Not required
	Outdoor				
6.8	**Thermal cycling test**				
	Indoor, conditioned	400 cycles, - 40 °C to 85 °C; $I_{sc\,max}$ during +T ramp and high temperature dwell	400 cycles; -10 °C[1] to T_{I2}; with $I_{sc\,max}$ and P_r during +T ramp and high temperature dwell		
	Indoor, unconditioned		400 cycles; -40 °C[1] to T_{I2}; with $I_{sc\,max}$ and P_r during +T ramp and high temperature dwell		
	Outdoor				
6.9	**Damp heat test**				
	Indoor, conditioned	30 cycles at +85 °C, 85 % RH $V_{mpp\,max}$; 0,1 P_r (pulsed)	10 cycles at 35 °C, 85 % RH $V_{mpp\,max}$ (pulsed)		Not required
	Indoor, unconditioned		20 cycles at 60 °C, 93 % RH $V_{mpp\,max}$; 0,1 P_r pulsed)		
	Outdoor		30 cycles at 60 °C, 93 % RH $V_{mpp\,max}$; 0,1 P_r pulsed)		
6.10	**Dry heat test**				
	Indoor, conditioned /unconditioned	2 000 h at 85 °C, $V_{mpp\,max}$, ≥ 0,1 P_r	T_{C2}, $V_{mpp\,max}$, ≥ 0,1 P_r, 2 000 h		
	Outdoor				

Subclause	**Tests,** Environmental condition	Test conditions			
		Category 1 PCE (MLPE)	**Category 2 PCE (String-level power electronics)**	**Category 3 PCE (Large-scale power electronics)**	**Category 4 PCE (Large-scale power electronics)**
6.11	**UV Weathering test**				
	Indoor, conditioned	Not required			
	Indoor, unconditioned	Not required			
	Outdoor	IEC 62852 test phase G1, Weather resistance: irradiance: 60 W/m^2, wave band: 300 nm to 400 nm, black panel standard temperature: 65 °C, relative humidity: 65 %, cycle: 18 min spraying, 102 min drying with Xenon-lamp, 500 h total; not required if material is qualified elsewhere			
$+T$ ramp refers to a positive temperature ramp in thermal profiles of stress tests.					
[1] Alternatively, minimum specified use temperature.					

Table 4 – Summary of test levels (optional tests)

No.	Test	Test conditions All categories
7.2	**Rain intrusion test**	
	Indoor, conditioned	Not required
	Indoor, unconditioned	Not required
	Outdoor	1 h of water spray descending parallel to each face and 15 min of water spray at 45° downward tilt from each side. Water pressure at nozzle of 200 kPa ± 10 kPa
7.3	**Wind driven rain test**	
	Indoor, conditioned	Not required
	Indoor, unconditioned	Not required
	Outdoor	30 min of rainfall exposure per side at 15 cm/h rainfall rate and 31 m/s wind velocity
7.4	**Dust test**	
	Indoor, conditioned	Not required[1]
	Indoor, unconditioned	Not required [1,2]
	Outdoor	60 °C, 30 % RH and 75 % RH, fine dust transported by 26,8 m/s to 40,2 m/s peak windspeed, 2 h per vertical face
7.5	**Shipping vibration test**	10 Hz to 11,8 Hz; 11,9 Hz to 150 Hz Amplitude: 3,5 mm, acceleration: 2 g 1 octave/min, Duration on each axis: 2 h; overall: 6 h
7.6	**Shock test**	15 g, half-sine, Duration: 11 ms; Sequence: 1 s Number of shocks: 18 (6 × 3)
7.7	**Salt mist test**	According to 60068-2-52 Test method 1
7.8	**Mixed gas corrosion test**	According to IEC 60068-2-60
7.9	**Ammonia corrosion test**	According to IEC 62716
[1] Implement if PCE has door, fan, vent, window, etc.		
[2] Implement outdoor conditions where there is direct ventilation or ducts from PCE cabinet to outdoors.		

5.4 General testing requirements

5.4.1 Installation of testing sample

In general, the equipment shall be installed in accordance with the methods prescribed by the manufacturer in the equipment’s installation manual. Deviations from the prescribed installation method are permitted if influence on the specified test requirements can be ruled out. If several configurations are allowed, the equipment shall be installed under the least favorable combination of test conditions to achieve reasonable worst-case conditions in each particular test. The selected installation method shall be documented for each test in the test report.

If an ancillary part is specified with manufacturer and model in the manual for use with the PCE, then that part shall be tested with the PCE. If ingress protection of the PCE is compromised by lack of connection of an ancillary part, then such ancillary part as specified by the manufacturer shall also be tested with the PCE

5.4.2 Peripherals

External peripherals required or recommended by the manufacturer for actual operation of the PCE in the field (such as transformers, monitoring system, etc.) may be included in the laboratory test setup outside of a climatic chamber if it does not conflict with other requirements in this document.

5.4.3 Connectors and wiring

Only the wires specified by the manufacturer shall be used for connection of the PCE’s input and output terminals to external testing equipment. If the PCE comprises terminals requiring special connectors, the manufacturer’s recommended mating connectors shall be used. Cables or connectors shall be through manufacture-specified cable entries. All terminals, covers, and cord grips should be implemented according to manufacture specifications before further testing.

5.4.4 Measuring instruments and monitoring equipment

Measuring instruments and monitoring equipment and methods shall be chosen in accordance with IEC 61557-1 and applicable parts referenced therein. If other measuring equipment is used, it shall provide an equivalent degree of performance and safety.

5.4.5 Electrical power sources

5.4.5.1 General

For tests during which the PCE sample requires operation under powered conditions, suitable electrical DC power source(s) shall be provided. If multiple input ports with independent power conversion circuitry are present, unique input power sources shall be connected to each input port. The following two options are permitted: a PV array simulator (IEC TS 63106-2) or a controllable DC power supply. In the case where a DC power supply does not provide characteristics for stable operation over the entire range of operation specified by the PCE documentation and in a manner consistent with real-world operation of the PCE, a suitable PV array simulator as described in 5.4.5.2 shall be used. For more information about simulators used for testing of photovoltaic power conversion equipment, see IEC TS 63106-2. In case of a conflict between IEC TS 63106-2 and this document, the requirements of this document shall be implemented.

5.4.5.2 PV array simulator

Refers to a special type of AC to DC power supply with variable output characteristics capable of simulating the IV-curve output characteristics of an actual PV array.

5.4.5.3 DC power supply

Refers to a source of DC current with constant voltage (CV) feedback control output and current limiting characteristics. Alternatively, may refer to a source of DC current with constant current (CC) feedback control output and voltage limitation. Both constant voltage and constant current power supplies are permitted if the input characteristics of the PCE under test permit the usage of those and if their limitations on the test results can be considered negligible. The DC power supply output impedance in constant voltage mode shall be low enough, so that the voltage ripple at the output terminals is within ± 0,1 %. For constant current power supplies, the output impedance shall be high enough so that the current ripple at the output terminals is within ± 0,2 %.

5.4.6 Electrical loads

5.4.6.1 General

For tests during which the PCE sample requires to be operated under powered conditions, a suitable electrical load shall be capable of absorbing the full electric power generated by the PCE. Where any influence on the results of a test can be excluded the below listed three options are permitted. Selected Clause 6 test procedures implement disconnection and connection of the electrical load over the course of the test.

5.4.6.2 Grid-tied operation

PCEs that are designed for grid-tied operation are permitted to be connected and operated at a suitably rated utility grid access point. In this case, a suitably sized transformer may be installed between PCE output terminals and grid access point for isolation and, if required, for voltage matching purposes. The load impedance as seen from the output terminals of the PCE shall be confirmed to be sufficiently low as not to impede with the PCE operation at rated conditions.

5.4.6.3 Active load

Active loads include electronic loads and regenerative power supplies that provide a stable and controlled sink for converted active power from the PCE. The active loading device shall be confirmed to be suitable and compatible with the PCE.

5.4.6.4 Passive load

Passive resistive loads are connected in parallel with a regulated voltage source. The load impedance of the PCE shall be set so that the passive load can absorb all active power when the PCE is operated at its rated power conditions.

5.4.7 Earthing terminals

A protective conductor terminal, if provided, shall be connected to earth.

5.4.8 Controls

Controls that the operator can adjust, unless otherwise specified in this document, shall be set as follows:

– in accordance with the operation manual provided by the manufacturer;

– in accordance with real operating conditions.

5.5 Pass criteria

The PCE design shall be judged to have passed the design qualification tests and therefore to be approved according to this document, if the PCE type meets all of the following criteria:

a) There is no visual evidence of any major defect as defined in 6.1 initially and at all Clause 6 – specified visual inspection points.

b) The testing samples pass the functionality test (6.3) initially and at all Clause 6 – specified test points.

c) The voltage (dielectric strength) test requirements as defined in 6.4 are met initially and at all Clause 6 – specified test points.

d) All specific requirements in subclauses of Clause 6 are fulfilled in the order shown in Figure 1 or Figure 2, and specific requirements in selected optional subclauses in Clause 7 are fulfilled.

e) None of the tested samples exhibit any irreversible open-circuit, short-circuit, or ground fault during the tests, nor any suspensions of operation that require manual intervention on the PCE to resume full operability. Permitted are reversible situations which are triggered by the PCE for the purpose of protecting itself or any other connected device or load that self-corrects. There shall be no permanent damage to the PCE.

f) If two or more PCEs are supplied for each Clause 6 test procedure and one unit fails, one PCE unit of the same design may be replaced for testing again at the start; (6.1) no more than one such equivalent unit may be replaced due to a failure in a Clause 6 or Clause 7 test procedure. If one PCE is supplied for each Clause 6 test procedure and it fails, the qualification test shall be repeated with the number of samples specified in Table 1.

6 Test procedures

6.1 Visual inspection

6.1.1 Purpose

The purpose of this test is to detect any visual defects in the PCE that may cause a risk of reliability loss.

6.1.2 Apparatus

a) A light source capable of producing an illumination of greater than 1 000 lux.

b) A magnifying glass or electronic magnifier tool with an optical magnification of at least 4 times.

c) Photography equipment capable of resolving and recording results of the visual inspection.

6.1.3 Procedure

Carefully inspect the exterior and interior of each sample using a suitable light source with working illumination not less than 1 000 lux. Capture overview photographs of the PCE. The sample shall be opened for the purpose of inspecting its interior, applying the procedures and tools specified by the manufacturer. Use a magnifying glass for inspection and photograph smaller electronic components, such as those mounted on a PCB, that are suspect.

6.1.4 Requirements

Any findings in line with one or more of the criteria listed below constitute a FAIL of the respective test. For the purpose of design qualification, the following are considered to be major visual defects:

– broken, cracked, bent, displaced, torn or detached part of the PCE enclosure;

– broken or damaged wire, cable, busbars incorporated into the PCE;

– broken or cracked electronic and or electromechanical components;

- faulty contacts/leads, openly accessible live parts;
- corrosion of interior part of the PCE (e.g. housing, contacts/leads, on PCB, components);
- failure of adhesive material;
- burn marks, cracks, deformations or detached electrical or electronic components;
- expansion, venting, or gassing of capacitors;
- bubbles or delamination on PCB;
- visible solder defects such as solder joint cracks or solder corrosion;
- coolant leakage (for liquid cooled PCE designs);
- loss of mechanical integrity, to the extent that the installation and/or operation of the component could be impaired;
- any other states or conditions, which can affect the function, performance or safety of PCE.

Visible defects like scratches, rubbed off colour not affecting legibility of markings, or the like that are deemed not to cause a risk of reliability loss do not constitute a fail; however, such visible changes to the PCE shall be indicated in the report and the test after which it was observed.

6.2 Characterization of operating performance

6.2.1 Purpose

Evaluate the published parameters of the PCE at various output power levels

6.2.2 Apparatus

a) PV module/array simulator or other suitable power source according to 5.4.5 which is capable of delivering the voltage versus current characteristic of the largest PV array for which the PCE is rated, with regard to open circuit voltage and short circuit current. For power conditioners operating with fixed input voltage, the DC power source shall be a storage battery or constant voltage power source to maintain the input voltage.
b) Suitable electrical load according to 5.4.6 which is capable of receiving the full amount of produced power at both highest and lowest rated PCE output power.

6.2.3 Procedure

Perform according to IEC 62894:2014, 4.5.3.

6.2.4 Restrictions and exceptions

None.

6.2.5 Requirements

All manufacturer published parameters on the PCE nameplate and technical data sheets shall be within 3 % (relative) of that derived from the measurements performed herein.

NOTE This subclause does not specify what parameter fields the manufacturer shall place on the nameplate or publish, which is the scope of IEC 62894.

6.3 Functionality test

6.3.1 Purpose

This test is to verify the proper functioning of the PCE’s power conversion functionality and that of integrated peripheral devices such as the display, user-interface controls and communication interface before and after environmental stress tests. The functionality tests will be performed before and after the environmental stress test sequences as indicated in Figure 1 and Figure 2 and as specified within the test procedures in Clause 6.

6.3.2 Apparatus

a) PV module/array simulator or other suitable power source according to 5.4.5 which is capable of delivering the voltage versus current characteristic of the largest PV array for which the equipment is rated, with regard to open circuit voltage and short circuit current.

b) Suitable electrical load according to 5.4.6 which is capable of receiving the full amount of produced power at both highest and lowest rated PCE output power.

c) Means for measuring current and voltage at all power terminals of the PCE. For PCE with multi-phase AC output, the test and measurement equipment shall record each phase current and each phase-to-neutral or phase-to-phase RMS voltage. The measurement accuracy shall be 1 % or less of rated PCE rated input/output voltage and 1 % or less of rated PCE input/output current.

d) Means for spot-measurements (at least 50 ms duration) of voltage waveforms with memory or waveform capture function at all connected input and output ports as specified in IEC 62116:2014, 5.1.

e) Means (climatic chamber, test room) for equilibrating the PCE to ambient temperature of 25 °C ± 3 °C for testing.

f) Thermal camera for evaluating location of maximum heatsink temperature and temperature measurement device for continuously monitoring the temperature of that maximum heatsink location.

6.3.3 Procedure

a) Supply any necessary auxiliary power to the control circuitry of the PCE according to the method specified by the manufacturer and verify the basic functioning of integrated peripheral devices. These should include, but are not limited to, any integrated display, user-interface controls and communication interfaces with external peripheral devices when present on the PCE. Establish a list of items to be tested that is based on the included functionality in the PCE. Use the same list for all subsequent tests of the same model.

b) The PCE sample input terminals shall be connected to a suitable power source described in 6.3.2 a) and monitoring equipment to monitor the input current and voltage described in 6.3.2 c) shall be installed at all input terminals.

c) The PCE sample AC or DC output terminals shall be connected to a suitable load as described in 6.3.2 b) and monitoring equipment to monitor the current and voltage terminals as described in 6.3.2 c) shall be installed.

d) Connect measurement equipment described in 6.3.2 d) to perform spot measurements of input and output voltage waveforms.

e) Stabilize the PCE in a 25 °C ± 3 °C environment, monitoring the temperature at a heat sink of the PCE.

f) Operate the PCE in steady state, applying input voltage $V_{\mathrm{dc,r}}$ with sufficient current to achieve the maximum rated generator power conditions P_{r} for 2,5 h or greater. If the PCE turns off due to excess heat or power, restart the equipment at a lower DC input current after a period with the power off and repeat. If not previously performed for the PCE, evaluate location of maximum heatsink temperature with infrared thermography and apply heat measurement device at that location. Evaluate and note the conditions per h), below.

g) Operate the PCE in steady state across the DC input power range in the 25 °C ± 3°C environment. For this, select $V_{\mathrm{mpp\ min}}$, and $V_{\mathrm{mpp\ max}}$, in addition to $V_{\mathrm{dc,r}}$ per 6.3.3 f) and operate the PCE in each operating point at P_{r} of the PCE or as close to P_{r} as possible if limited by the specifications of the PCE (not the test equipment) after reaching temperature and electrical stabilization or 2,5 h, whichever is first, making note of the conditions per h) below. If the rated input voltage is equal to the minimum or maximum input voltage, then two operating points, $V_{\mathrm{mpp\ min}}$, $V_{\mathrm{mpp\ max}}$ are sufficient. For subsequent measurements after performing stress tests, choose the same operating points and test schedule (to achieve repeatable thermal conditions) for performing the functionality test on a given PCE type.

h) After each new setting within both f) and g), collect and record:
   1) Input voltage
   2) Input current
   3) Input power
   4) Output voltage
   5) Output current
   6) Output power
   7) Waveform sample of voltage and current at each powered electrical port at 10 000 Hz or greater sample frequency
   8) Heatsink temperature
   9) Ambient temperature (°C)

Values of AC waveforms are reported as RMS.

6.3.4 Restrictions and exceptions

None.

6.3.5 Requirements

The PCE under this test procedure passed if the following items are satisfied:

a) PCE can successfully operate under all DC input profiles in 6.3.3 f) and g).
b) Functionality of auxiliary services and components (display, user-interface controls and communications, etc.) is not impaired as compared to initial measurements. Functioning is as described by the operation manual.
c) When performed at the end of a test sequence; namely, after the test sequence of 6.8 or 6.10, and after optional testing of Clause 7
   - no major change in waveform is evident as compared to initial measurement, where in the case of AC connections to the PCE, a major change in waveform as obtained in 6.3.3 h)7) is defined as greater than a 2,5 % absolute change in total harmonic distortion (current and voltage) evaluated by the procedure in IEC 61000-3-2, IEC 61000-3-12, IEC TR 61000-3-14, or applicable standard for current and power class of the PCE and,
   - no greater than 5 % reduction in P_r when implementing any of the 6.3.3 g) -specified input voltage levels.

6.4 Voltage (dielectric strength) test

6.4.1 Purpose

In general, dielectric withstand voltage testing is used to determine that the clearances and solid insulation of components and of assembled PCE, which provide protection against electric shock, have adequate dielectric strength to withstand the overvoltage conditions to which the PCE may be exposed in use.

This test is intended to verify that this protection against electric shock is not impaired through environmental and operational stresses.

This test is performed as an initial test and as part of the requirements for some of the stress tests.

6.4.2 Apparatus

A voltage source with a short-circuit current of at least 0,1 A according to IEC 61180.

6.4.3 Procedure

The voltage test shall be performed in accordance with the test requirements of IEC 62109-1:2010. Voltage testing per 6.4 prior to performing the test sequence outlined in Figure 1 and Figure 2 is optional if the sample type is also subject to testing for safety and meeting the pass criteria of the voltage test of IEC 62109-1 separately.

The test is successfully passed if no electrical breakdown occurs during the test and there is no abnormal current flow during the test. Current is considered abnormal if it significantly exceeds the normal current flow expected with all insulation in place and undamaged, or if the current rapidly increases without control after the test voltage has reached the full voltage.

NOTE Some normal amount of current is expected during a test, particularly with an AC test voltage.

6.5 Bus link capacitor thermal test

6.5.1 Purpose

Assessment of the maximum operating case temperature of the bus link capacitors for use in the subsequently performed 6.10 and for evaluation of the adequacy of the bus link capacitors for thermal design and relative long-term reliability based on the maximum temperature exhibited at its operating bus voltage. See Bibliography [1][1] for additional background about application of the bus link capacitor thermal test. This test is applicable to Categories 2, 3 and 4 PCE only.

6.5.2 Apparatus

a) A chamber with automatic temperature control, capable of subjecting one or more PCE in the range of 25 °C to the maximum rated operating temperature of the PCE. Relative humidity control is not required; however, the 25°C ambient relative humidity shall be less than 70 %. Reference IEC 60068-3-5:2018 for information about temperature chambers.

b) Means for mounting or supporting the PCE in the chamber.

c) Means for mitigating climatic chamber air circulating around the PCE and means to evaluate and maintain the air speed to 0,2 m/s ± 0,1 m/s around the PCE.

d) Means for measuring the case temperature of multiple bus capacitors in aggregate, and means for recording the case temperature of two bus capacitors to an accuracy of ± 1 °C. Devices for measuring temperatures that will be useful include thermocouples, thermistors, resistance temperature detectors (RTDs), optical thermography sensors including fiber-optic based devices.

e) A PV array simulator or a power supply in accordance with 5.4.5 capable of delivering the voltage versus current characteristic over the range for which the equipment is rated.

f) An electrical load in accordance with 5.4.6.

g) Means for monitoring the current and voltage (RMS) values at all connected input and output ports.

h) Means for monitoring voltage with 10 000 Hz sampling frequency between the DC bus link and DC neutral.

6.5.3 Procedure

6.5.3.1 Determination of bus link capacitors of highest temperature

The purpose of this part of the procedure is to determine the bus capacitors operating at the highest temperatures. If there are fewer than three bus capacitors, this procedure may be omitted so as to start at 6.5.3.2 directly.

[1] Numbers in square brackets refer to the Bibliography.

a) Instrument PCE so that capacitor temperature may be evaluated while minimally influencing the regular thermal characteristics of the PCE environment. Methods may include temperature measuring device affixed to each capacitor's case, according to the manufacturer's instructions for measuring capacitor temperature, thermography with use of a false enclosure panels with quickly removable portal or portals for line of sight view of the capacitors with apparatus specified in 6.5.3 d) that minimally interfere with intrinsic thermal characteristics, convection, radiative emission, etc., of the PCE. Alternatively, the two DC bus link capacitors exhibiting the highest temperature may be identified via a comprehensive calculation or simulation of the PCE, inclusive of consideration of power dissipation, conductive, convective, and radiative heat transfer, if provided by the manufacturer.

b) Place PCE designed to be on the ground on the floor of the chamber. Mount other PCE to a solid electrical and thermally insulating wall.

c) To the extent required so that wind speed does not exceed 0,2 m/s ± 0,1 m/s at all surfaces around the PCE in the unpowered state, place baffles in front and sides of mounted PCE at a distance of 30 cm to 60 cm from the PCE surfaces. If it can be ensured by adjusting the climate chamber (e.g. air circulation setting) that this air circulation does not exceed the air speed requirements, additional mitigation such as shielding and baffles is not required. Allow natural convection by providing chamber air using gaps in the baffles at their base and top or ducts so that the air temperature at the base of the PCE remains at the specified chamber setpoint temperature.

d) Permit any active cooling (fans, air conditioning, water circulation) of the PCE to operate normally.

e) Set the chamber temperature to 25 °C. Connect the power supply and electrical load to the PCE. Set the power supply to provide $V_{\text{mpp max}}$ to the PCE input(s) and sufficient current to operate the PCE at P_{r}. Verify that any forced air ventilation or cooling system of the PCE is operational.

f) After stable operation for at least 16 h, Evaluate and determine the two bus capacitors exhibiting the highest temperature using instrumentation discussed in 6.5.3.1a).

6.5.3.2 Evaluation of maximum temperature of bus link capacitors during operation

a) Place temperature sensors on the capacitor case locations of two bus capacitors determined in 6.5.3.1 for measurement of T_{C}.

b) Place PCE in the climatic chamber according to 6.5.3.1 b).

c) Apparatus set for windspeed conditions in the climatic chamber according to 6.5.3.1 c).

d) Connect the power supply and electrical load to the PCE. Close any enclosure doors of the PCE. Set the chamber temperature to the maximum rated ambient operating temperature of the PCE. Set power to supply the $V_{\text{mpp max}}$ of the PCE and maintain sufficient current to run the PCE at its rated operating power, P_{r}. Verify that any forced air ventilation or cooling system of the PCE is on and operating.

e) Ramp the climatic chamber temperature at a maximum rate of 2,5 °C/h down to 25 °C, monitoring T_{C} as instrumented in 6.5.3.2 a) and the PCE output power. If a peak temperature point in T_{C} is observed during the ramp (not including endpoints of the ramp), select and record this temperature as T_{C2}. Record the capacitor, measurement location, and climatic chamber setpoint temperature at which the PCE delivers T_{C2} and record it as, $T_{\text{amb,set C}}$.

   If there is no peak in temperature observed during the ramp down in chamber temperature (not including endpoints of the ramp), increase the climatic chamber temperature at the end of the previous step (from 25° C) at a maximum rate of 2,5 °C/h up to the maximum operating temperature as defined by the manufacturer and select and record the maximum T_{C} observed during both ramps (including ramp endpoints), the capacitor, and measurement location, and record it as T_{C2} and record the corresponding climatic chamber setpoint temperature as $T_{\text{amb,set C}}$.

   NOTE Maximum ramp rate is called out to allow for the selection of lower ramp rates in the case of very large inverters with large thermal masses, allowing the for measurements of temperature in conditions closer to equilibrium.

f) Extrapolate the life of capacitor at the maximum temperature T_{C2} evaluated in e), with the rated life L_R at the manufacture-specified rated air temperature T_R either with the manufacturer-specified formula, or if not available, the formulas for electrolytic capacitors:

$$L_{n1} = L_R \, 2^{\frac{T_R - T_{C2}}{10}}$$

or for metal film capacitors,

$$L_{n1} = L_R \, exp^{7000\left(\frac{1}{273,15 + T_{C2}} - \frac{1}{273,15 + T_R}\right)}$$

and for either capacitor type,

$$L_{n2} = L_{n1} \, (V_r / V_o)^n$$

where

n is the manufacturer specified value to adjust the life of the capacitor to the nominal maximum bus voltage V_0 with respect to the capacitor rated voltage V_R;

V_0 is the maximum voltage measured between the positive and negative terminals of the DC bus capacitor bank while applying $V_{mpp\ max}$ to the DC inputs.

If not available from the manufacturer, use n = 2,5 for electrolytic capacitors and n = 3,5 for metallized film capacitors.

6.5.4 Restrictions and exceptions

6.5.4.1 Category 1 PCE

Not performed for Category 1 PCE.

6.5.4.2 Category 4 PCE

When opting for testing of components of category 4 PCE rather than the unit as a whole in the subsequently performed 6.10, record simultaneously the resulting temperature for each component listed in 5.3.4 a). Record the temperature of the individual components measured when the bus link capacitor temperature is T_{C2}. These recorded component temperatures occurring simultaneously with the observation of peak temperature T_{C2} will be referenced for selecting the temperature conditions in the Dry heat test 6.10.

6.5.5 Requirements

Requirement for the bus link capacitor thermal test is as follows:

a) Evaluation of T_{C2}, the peak capacitor temperature observed during the ramp power and the corresponding climatic chamber setpoint temperature at which it occurs $T_{amb,set}$ for implementation as the peak temperature condition in 6.10. Noting the additional measurements specified in the case where 6.5.4.2 applies Category 4 PCE, a plot showing the temperature of the selected capacitors T_C, the climatic chamber temperature, and the input and output power of the PCE as a function of time will be useful for the evaluation of the requirements of this subclause.

b) Extrapolated life of capacitor, L_{n2} evaluated in 6.5.3.2 f) greater than 17 500 h.

NOTE 17 500 value considers the PCE operating 40 % of the time under the maximum temperature found in 6.5.3.1.

6.6 Power transistor module thermal test

6.6.1 Purpose

The purpose of this procedure is to determine the maximum operating temperature of the power transistor module of the PCE running at rated power and environmental conditions at which it manifests. See Bibliography [1] for additional background about application of the power transistor module thermal test. This is performed for Categories 2, 3 and 4 PCE only. The results are used in the subsequent 6.8 Thermal cycling test.

6.6.2 Apparatus

The apparatus requirements follow those of 6.5.2.

6.6.3 Procedure

a) Instrument the PCE so that the power transistor case or reference temperature T_l may be evaluated while minimally influencing the regular thermal and electrical characteristics of the PCE environment. This is usually performed according to the manufacturer's instructions for measuring T_l; for example, using the manufacturer-included thermistor, or other temperature measuring device in conjunction with the manufacturer's recommendation for calculation of T_l, and drilling a narrow diameter hole through the heat sink to place a temperature sensor on the power transistor surface, or if not possible, on the hottest portion of the heat sink as observed with an infrared thermographic imaging camera. If there are multiple such units, each should be examined, preliminarily, or during the course of this testing procedure, to determine which exhibits the highest temperature in operation.

b) Place PCE in the climatic chamber according to 6.5.3.1 b).

c) Set conditions for windspeed in the climatic chamber according to 6.5.3.1 c).

d) Connect the power supply and electrical load to the PCE. Set the chamber temperature to the maximum rated operating temperature of the PCE. Set the input current to the PCE to $I_\mathrm{sc\ max}$ while limiting input voltage as necessary to obtain P_r. Verify that any forced air ventilation or cooling system of the PCE is functioning normally.

e) Ramp the climatic chamber temperature at a maximum rate of 2,5 °C/h down to 25 °C, monitoring T_l and the power at the PCE input and output terminals. If a peak temperature point in T_l is observed during the ramp (not including endpoints of the ramp), select and record this temperature as T_l2. Record the climatic chamber setpoint temperature at which T_l2 is observed as $T_\mathrm{amb,set\ l}$.

f) If there is no peak in temperature observed during the ramp down in chamber temperature (not including endpoints of the ramp), increase the climatic chamber temperature again from 25 °C at a maximum rate of 2,5 °C/h up to the maximum operating temperature as defined by the manufacturer and select and record the maximum T_l observed considering both ramps (including endpoints) and record it as T_l2 and record the corresponding climatic chamber setpoint temperature as $T_\mathrm{amb,set\ l}$.

NOTE Maximum ramp rate is called out to allow for the selection of lower ramp rates in the case of very large inverters with large thermal masses, allowing for the measurements of temperature in conditions closer to equilibrium.

6.6.4 Restrictions and exceptions

6.6.4.1 Category 1 PCE

Determination of maximum operating temperature of the power transistor module is not performed on Category 1 PCE samples.

6.6.4.2 Category 4 PCE

When opting for testing of components of category 4 PCE rather than the unit as a whole in the subsequently performed 6.8, record simultaneously the resulting temperature for each component listed in 5.3.4 a) selected to be individually tested in 6.8 while performing 6.6.3 of the Power transistor module thermal test. Record the temperature of the individual components seen when the reference temperature T_{l} measured in 6.6.3 is T_{l2}. These recorded component temperatures occurring simultaneous with the observation of peak temperature T_{l2} will be referenced for setting maximum temperatures in 6.8 for the testing of those components.

6.6.5 Requirements

Evaluation of T_{l2}, the maximum power transistor case or reference temperature and the corresponding climatic chamber setpoint temperature at which it occurs $T_{\mathrm{amb,set\ l}}$ for use in 6.8. Noting the additional measurements specified in the case where 6.6.4.2 applies, a plot showing the power transistor case or reference temperature T_{l}, climatic chamber temperature, input and output power of the PCE as a function of time will be useful for the evaluation of the requirements of this subclause.

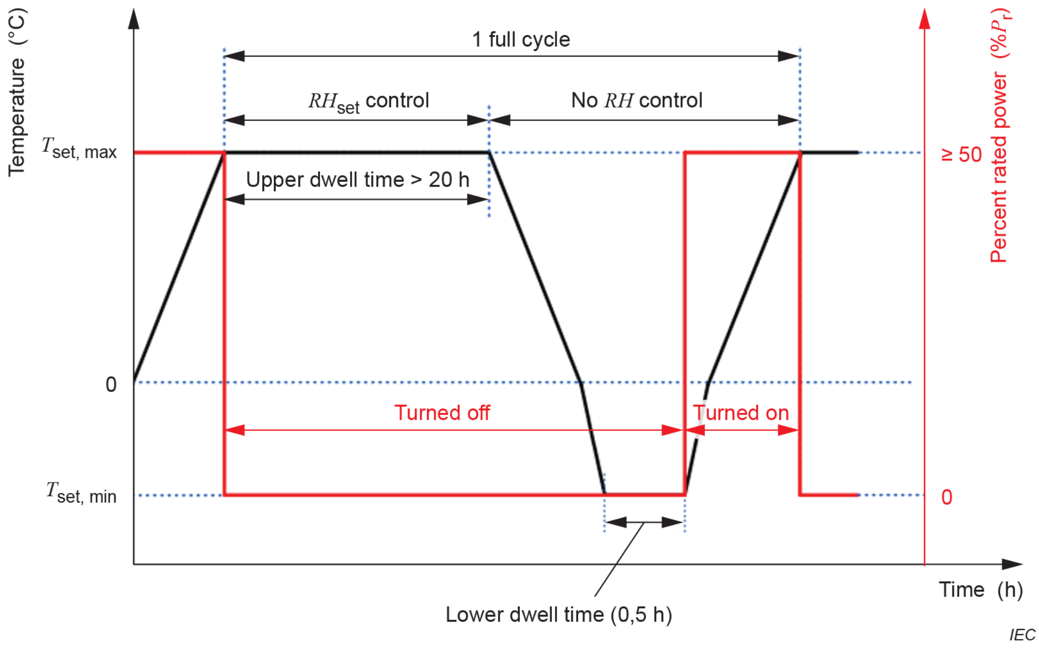
6.7 Humidity freeze test

6.7.1 Purpose

This test consists of exposure to combined elevated temperature and high humidity environment followed by a freeze cycle. In addition to replicating failures such as those listed in the damp heat section, electrical loading during a positive temperature ramp induces additional thermal- and voltage stress to active and passive components. Typical failures besides those listed in 6.1.4 include cracks, corrosion and deformation to the PCE enclosure and other mechanical components and insulation failure due to moisture ingress. This test also includes cold start conditions with differing input power if multiple electrically independent DC inputs exist as may occur due to, for example, snow on some PV module strings. This test also implements applied voltage to the PCE inputs while the load is disconnected, which may simulate a failure of the connected electrical grid.

6.7.2 Apparatus

a) A climatic chamber with automatic temperature and humidity control, capable of subjecting the samples under test to the humidity freeze cycle specified in Figure 3 with levels specified in Table 5. A climatic test chamber which is capable of fulfilling the specifications of IEC 60068-3-6 will be suitable; however, tolerance of measured temperature from specified setpoints is ± 3 °C;
b) Means for mounting or supporting the PCE sample(s) in the chamber according to the method prescribed by the manufacturer. The installation shall allow free circulation of the surrounding air;
c) PV array simulators or a DC power supplies in accordance with 5.4.5 capable of delivering the voltage and current to achieve the requirements of 6.7.2 e);
d) An electrical load in accordance with 5.4.6;
e) Means for monitoring the current and voltage (RMS) values at each connected input and output ports;
f) Fuses or circuit breakers installed at the input and output terminals to protect against possible short circuit during the test;
g) Electrical contactor at the electrical output or other means to physically connect and disconnect the PCE from the load repeatedly during the course of testing.



Refer to Table 5 for temperature (T_{set}) and relative humidity (RH) conditions.

Figure 3 – Chamber temperature/humidity profile and power for humidity freeze test

6.7.3 Procedure

a) Install the PCE sample unit on a rigid mounting structure using the method prescribed by the manufacturer with maximum air circulation of the climatic chamber around the PCE.

b) Connect each input of the PCE sample at the PV array side to a DC power source as described in 6.7.2 c). MPP tracking functionality of the PCE may be disabled if necessary to achieve a stable operating point at the DC input ports.

c) Connect the PCE sample at the electric output terminal to a suitable load according to 6.7.2d) and as described in 5.4.6.

d) Install current and voltage monitoring devices to all input and output ports according to relevant parts of 5.4.4 and 6.7.2 e).

e) Monitor chamber air temperature and relative humidity reading from the environmental chamber controller. The test conditions are controlled on chamber temperature and relative humidity, not with the sample temperature.

f) After closing the chamber, subject the component to complete cycles in accordance with Figure 3 and Table 5. The maximum and minimum temperatures shall be within ± 3 °C of the specified temperature levels in Table 5 and the relative humidity shall be maintained within ± 5 % of the specified relative humidity levels, RH_{set}, indicated in Table 5. Verify that any forced air ventilation or cooling system of the PCE is functional.

   During the positive temperature ramp, the PCE sample shall be powered and operating. In the case of a single input PCE, apply a voltage as close as possible to $V_{mpp\ max}$ to achieve at least 50% of P_{Rated} output from the PCE.

   If there are additional electrically independent inputs, to the second and all even numbered electrically independent inputs, apply minimum rated input voltage $V_{mpp\ min}$ (including, if necessary, a sufficient initial turn-on voltage pulse), and sufficient input current so that the PCE operates. All odd electrically independent inputs shall be connected to a voltage as close as possible to $V_{mpp\ max}$. Power to multiple electrically independent inputs is to be balanced so that all inputs run at non-zero power and the total output power of the PCE is at least 50 % of P_r.

The upper temperature dwell shall be 20 h. Ramp times between the temperature limits shall be as fast as equipment permits, but the durations are undefined. The cycle time is nominally 24 h, but because of various heat capacities of PCE, the cycle time is not constrained considering that the ramp times may be adjusted for the sample under test. Upper and lower dwell times start once the chamber conditions reach the respective dwell conditions according to Table 5. It is acceptable if the PCE normally derates or idles at the higher temperatures of the ramp. During the dwells and negative temperature ramp, the power output from the PCE under test to the load shall be disconnected by means of an electrical contactor while the electrical bias applied to the input of the PCE remains applied throughout the test.

NOTE Disconnection of the load simulates a grid failure or AC disconnection condition.

This test may be performed with doors of the PCE's enclosure opened and the cooling system of the PCE may be controlled independently only to assist in reducing transition times between dwells.

The lower temperature dwell shall be 30 min.

Table 5 – Temperature and humidity limits for humidity freeze test

PCE category	Environmental category	Dwell conditions		Cycles
		$T_{set,min}$	$T_{set,max}$, RH_{set}	
1	– all service categories	-40 °C[1]	85 °C /85 % RH	20
2, 3	– indoor, conditioned	Not required		
	– indoor, unconditioned	-40 °C[1]	60 °C /85 % RH	20
	– outdoor	-40 °C[1]	60 °C /85 % RH	

The test conditions are controlled on the basis of chamber air temperature and relative humidity. Acceptable tolerance for temperature is ± 3 °C. Acceptable tolerance for relative humidity is ± 5 %.

1 Testing with a higher minimum temperature than $T_{set,min}$ shown above in this table is permitted, if the specifications of the PCE do not allow exposure to the above-specified $T_{set,min}$. In this case, the limit $T_{set,min}$ shall be adjusted according to the manufacturers lowest temperature specifications; however, highest value for $T_{set,min}$ shall be -10 °C.

The actual test conditions shall be documented in the test report.

g) The PCE restart shall begin at the end of the low temperature dwell by reconnecting the load.

6.7.4 Restrictions and exceptions

Not required for PCE specified for use only in indoor conditions in the cases of Categories 2 and 3.

Not required for Category 4 PCE.

Automatic output power derating, discontinuous operation and temporary suspension of operation is permitted at all temperatures that exceed the manufacturer's specifications if for functional protection.

6.7.5 Final measurements

None.

6.7.6 Requirements

The requirements are as follows.

None of the testing samples exhibit any irreversible open-circuit, short-circuit, or ground fault during the tests, nor any suspensions of operation that require manual intervention on the PCE to correct. Permitted are reversible situations which are triggered by the PCE for the purpose of protecting itself or any other connected device or load that self-corrects. There shall be no permanent damage to the PCE. Record the nature and duration of any discontinuous or temporary suspension of normal operation of the PCE that may occur during the test.

6.8 Thermal cycling test

6.8.1 Purpose

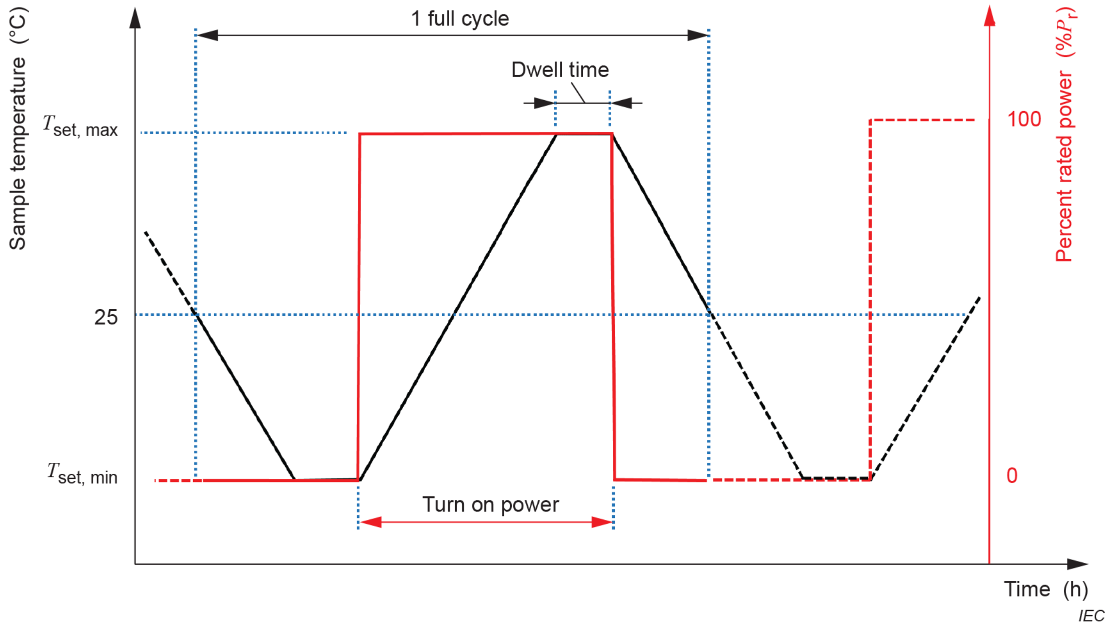
This test consists of repeated exposure to hot and cold temperature extremes with periods of powered operation to accelerate the daily temperature swings seen in field applications. In addition to the effects of electrical stresses applied, thermal cycling also induces thermo-mechanical strain as a result of differences in expansion coefficients between different materials used in PCEs and its components. Components in a PCE that are susceptible to accelerated thermal cycling include power semiconductor devices, integrated circuitry, capacitors, printed circuit boards, mechanical- enclosure and structures as well as wire terminals and connectors.

Typical failure mechanisms that are accelerated by thermal cycling include bond wire fatigue, base-plate solder and chip solder fatigue, interconnection failure, material deformation and cracks, delamination of conformal coat and potting interfaces, etc.

The upper temperature implemented in the thermal cycling test is based on actual upper temperature attained by the power transistor module of the PCE in 6.6. The stress level applied is thus related to the efficiency and thermal management exhibited by the PCE.

6.8.2 Apparatus

a) A chamber with automatic temperature control of circulating air. The climatic chamber shall be sufficiently large to fit the PCE sample including required clearances or spacing as specified by the manufacturer and be capable of subjecting one or more samples to the thermal cycle profile shown in Figure 4 and parameters given in Table 6. A climatic chamber capable of fulfilling the specifications of IEC 60068-2-14, Test Nb will be suitable.
b) Means for mounting or supporting the PCE sample(s) in the chamber according to the method prescribed by the manufacturer. The installation shall allow free circulation of the surrounding air. The thermal conduction of the mount or support structure shall be low (i.e., nonmetallic).
c) Apparatus set for windspeed conditions in the climatic chamber according to 6.5.3.1c).
d) Measurement instrumentation for achieving and recording the PCE power transistor case or reference temperature T_{l} as in 6.6. Tolerance of measured temperature from specified setpoints is ± 3 °C.
e) A PV array simulator or a DC power supply in accordance with 5.4.5 capable of delivering the voltage versus current characteristic of the largest PV array for which the equipment is rated, with regard to open circuit voltage and short circuit current.
f) An electrical load in accordance with 5.4.6.
g) Means for monitoring the current and voltage values (RMS) at all connected input and output ports.



Refer to Table 6 for temperature (T_{set}) and required dwell times.

Figure 4 – Thermal cycling test – Temperature and output power profile

6.8.3 Procedure

The test shall be carried out in accordance with IEC 60068-2-14 with the following additional provisions:

a) The PCE, shall be installed into the test chamber using a suitable mounting or supporting method as described in 6.8.2 a). The equipment is to be mounted in accordance with the manufacturer's instructions. To achieve faster ramp times, the test may be performed with doors of the electrical enclosure opened and during the transition times, the cooling system of the PCE may be used and adjusted as needed to reach the specified setpoints more quickly if agreed to by the manufacturer.

   NOTE 1 If the PCE is internally cooled by fans, testing with open doors or open cover may influence the airflow and cause some components to become more overheated than normal.

b) The PCE sample input terminals shall be connected to a suitable power source as described in 6.8.2 b).

c) The PCE sample AC or DC output terminals shall be connected to a suitable load as described in 6.8.2 d).

d) Install suitable current and voltage monitoring devices as described in 6.8.2 f) to all input and output ports.

e) Connect or implement measurement of power transistor module case or reference temperature T_l as described in 6.8.2 d). In the case of category 1 PCE, monitor temperature at the attachment (mounting) point of the device while mounted . The test conditions are adjusted using this temperature measured on the sample.

f) The PCE is to be subjected to a thermal cycle profile as shown in Figure 4 with specified sample-temperature limits, number of cycles, minimum dwell times, and with options for modification as described in Table 6. There is no limitation on how fast the chamber ambient temperature is allowed to transition during the positive and negative temperature ramp, but a ramp rate between 0,5 °C /min and 2 °C /min is recommended. If Table 6 $T_{\text{set,min}}$ values are below the PCE-specified minimum use temperatures, or the temperature range of the thermal cycling test shall be reduced for any reason, see the footer in Table 6 for how to increase the number of test cycles required based on the reduced temperature range for application of this clause. To reduce testing time, $T_{\text{set,max}}$ may be increased and the number of thermal cycles reduced. In this case, turn off derating if derating occurs at the higher, desired $T_{\text{set,max}}$, and have T_{l} achieve this increased sample upper temperature limit by increasing power to the PCE by increasing input voltage, maintaining current at $I_{\text{sc max}}$. If the power reaches P_{r} and further acceleration with higher $T_{\text{set,max}}$ is sought, then increase chamber temperature, while ensuring power reaches P_{r} during the cycle.

g) During the negative temperature ramp and the low temperature dwell, the power supply connected to the input of the PCE shall supply no power to the PCE. Forced air provided by the PCE's own cooling system, the climatic chamber's circulating air, or additional forced air may be introduced to achieve sample temperature $T_{\text{set,min}}$ more quickly.

h) Maintain a dwell time of 20 min at each extreme.

i) After the low temperature dwell at temperature $T_{\text{set,min}}$, a restart of the PCE is performed at the time of the start of temperature ramp up from the idle or off condition. At restart, set the input power to the PCE to $I_{\text{sc max}}$, limiting input voltage as necessary to obtain P_{r}. Toward the later portions of the ramp and during the upper temperature dwell, the chamber temperature shall be optimized such that $T_{\text{set,max}} = T_{\text{l2}}$ is achieved at the measurement point on the sample.

NOTE 2 In 6.6.3, the T_{l2} relationship with chamber setpoint temperature $T_{\text{amb,set l}}$ was developed for quasi-equilibrium conditions.

j) To account for any delay in the start of energy conversion by the PCE, the PCE may be energized before the end of the prescribed dwell such that the start of energy conversion is realized at the end of the prescribed 20 min. dwell and the start of ramp up in temperature.

k) After the stress test, allow a minimum recovery time of 1 h at at (23 ± 5) °C under unpowered conditions.

Table 6 – Upper and lower temperature limits for thermal cycling test

PCE category	Environmental category	Sample temperature limits[1]			Minimum dwell time	Test cycles[1]
		$T_{\text{set,min}}$ °C	$T_{\text{set,max}}$ °C	ΔT_{set} °C		
1	all service categories	-40	85	125 °C	20 min	400
2, 3, 4	indoor – conditioned	-10	T_{l2}	T_{l2} + 10 °C	20 min	400
	outdoor, indoor – unconditioned	-40	T_{l2}	T_{l2} + 40 °C		

The test conditions are adjusted using this temperature measured on the sample. Acceptable tolerance for temperature is ± 3 °C.

[1] If the minimum rated use temperature as defined by the manufacturer is higher, that minimum rated use temperature may instead be implemented as $T_{\text{set,min}}$. This deviation from the values in the table shall be noted in the test report and a label indicating the higher minimum use temperature indicated on the PCE specification sheet according to Annex A. However, if for any reason, when using a different ΔT_{mod} value than ΔT_{set} specified in Table 6, the number of cycles (N_{mod}) shall be modified according to the following formula:

$$N_{\text{mod}} = 400 \times \left(\frac{\Delta T_{\text{set}}}{\Delta T_{\text{mod}}}\right)^{1,9}$$

where ΔT_{mod} is the temperature span between the implemented $T_{\text{set,min}}$ and $T_{\text{set,max}}$. This formula shall also apply if $T_{\text{set,max}}$ is increased beyond that in the above table for the purpose of reducing test time (cycles).

6.8.4 Restrictions and exceptions

MPP tracking functionality of the PCE may be disabled if necessary to achieve a stable operating point at the DC input ports.

Automatic output power derating, discontinuous operation and temporary suspension of operation is permitted at all temperatures that are outside of the manufacturer's use temperature levels for functional protection. The occurrence of these phenomena shall be noted in the test report.

In the case the thermal cycling test is done within the alternative qualification test sequence for Category 3 PCE and 4 PCE with reduced sample requirement described in 5.3.3, the following 6.8.5 Final measurements and 6.8.6 Requirements are omitted.

When testing Category 4 PCE in components instead of the integral unit, substitute for T_{I2} in Table 6 the actual component temperature measured at the instant the reference temperature T_I is maximum at T_{I2} as described in 6.6.4.2. Perform the thermal cycling test for each component desired to be tested separately such that all components listed in 5.3.4 a) are tested. Use the same temperature measurement devices, mountings, and locations implemented in 6.6.

6.8.5 Final measurements

After a minimum recovery time of 1 h, perform 6.3, 6.4, and 6.1 in such order.

6.8.6 Requirements

The requirements are as follows:

a) The PCE shall successfully operate within its specified operating range throughout the whole test period.
b) None of the testing samples exhibit any irreversible open-circuit, short-circuit, or ground fault during the tests, nor any suspensions of operation that require manual intervention on the PCE to correct. Permitted are reversible situations which are triggered by the PCE for the purpose of protecting itself or any other connected device or load that self-corrects. There shall be no permanent damage to the PCE. Record the nature and duration of any discontinuous or temporary suspension of normal operation of the PCE that may occur during the test.
c) The PCE shall meet the criteria defined in 5.5.

6.9 Damp heat test

6.9.1 Purpose

The damp heat test consists of exposure to combined elevated temperature and high humidity environments with voltage bias. It is intended to accelerate failure mechanisms that are activated by penetration of moisture vapor through protective materials and electric fields that are created by applied voltage to the internal circuitry. The damp heat test is intended to identify component failures that are induced through various forms of galvanic and electrochemical corrosion, electro migration, insulation degradation, etc. Potentially affected components include integrated circuits, power semiconductor devices, capacitors, printed circuit boards, interconnections, wiring and metallic parts such as frame, screws and enclosure. Levels of humidity experienced by the PCE are generally governed by the environmental use condition, thus temperature of the dwells of the thermal profile is controlled according the chamber air temperature in the damp heat test. The damp heat test is not implemented for Category 4 PCE and PCE in the Indoor, conditioned category.

6.9.2 Apparatus

a) A climatic chamber suitable for application of IEC 60068-2-78 and temperature conditions as specified in Table 7. Acceptable tolerance for temperature is ± 3 °C from specified setpoint. Acceptable tolerance for relative humidity is ± 5 % (absolute) from specified setpoint.

b) A PV array simulator or a DC power supply in accordance with 5.4.5 capable of applying the maximum rated input voltage to the PCE input terminals while sourcing current to achieve 10 % of P_r or the minimum operating power $P_{r\ min}$ of the PCE, whichever is greater.

c) An electrical load in accordance with 5.4.6.

d) Means for monitoring of current and voltage (RMS) values at all connected input and output ports.

e) Install fuses or circuit breakers at the input and output terminals to protect against possible short circuit during the test.

6.9.3 Procedure

The test shall be carried out in accordance with IEC 60068-2-78 with the following provisions.

a) The PCE with derating characteristics representative of production equipment not changed in any way for this test shall be introduced at room temperature into the test chamber and installed using a mounting or supporting structure in accordance with the manufacturer's instructions.

b) The PCE sample input terminals shall be connected to a suitable DC voltage source specified in 6.9.2 b).

c) The PCE sample output terminals shall be connected to a suitable electric load as described in 5.4.6.

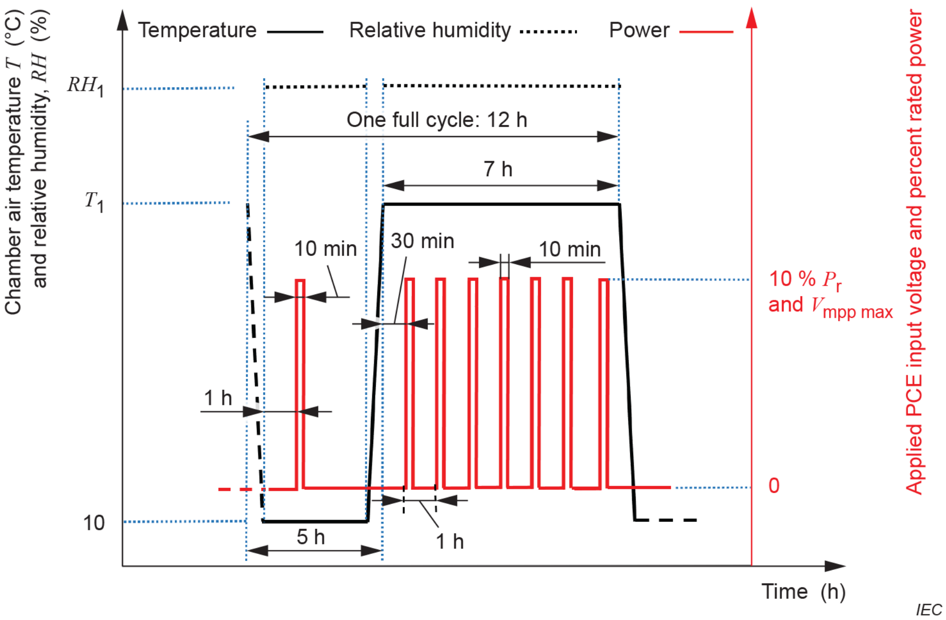
d) Suitable monitoring equipment as described in 6.9.2 f) shall be installed with the function of monitoring and logging the current and voltage at the electrical terminals of the PCE transmitting electrical power to and from the PCE. Monitor chamber temperature and air temperature reading from the environmental chamber controller. The test conditions are controlled on chamber temperature and relative humidity, not with the sample temperature.

e) After closing the chamber, the PCE shall be subjected to 10 °C temperature. After equilibration, ramp humidity to RH_1. Apply temperature and humidity to the PCE according to the profile shown in Figure 5 and conditions listed in Table 7. Relative humidity levels are not specified for periods of temperature ramps. When called for according to the timing indicated in Figure 5, apply $V_{mpp\ max}$ to the input ports of the PCE and sufficient current to achieve 10 % of P_r or the minimum operating power of the PCE when $V_{mpp\ max}$ bias is applied to the input terminals, whichever is greater. If the PCE derates to less than 10 % P_r, reduce the test temperature T_1 (upper dwell temperature) until 10 % of P_r is achieved and increase the test duration to t_2 rounding up to the next integer cycle of 12 h duration according to the footer in Table 7, where T_1 is the temperature listed in Table 7 for the appropriate PCE environmental category, T_2 is the temperature to which the climatic chamber was reduced for the upper temperature level dwell, and t_1 is the time listed in Table 7.

   Figure 5 indicates duration of power applied to the PCE, 10 min pulses. Ensure the PCE is converting power nominally for 10 min by initiating applied power to the PCE earlier in the cycle if necessary, to account for start-up time of the PCE.

f) The low temperature dwell conditions may be allowed to drift associated with the 10 min applied power to the PCE. Outside of this period, additional adjustments to the number of cycles shall be made according to Table 7 notes if 93 % RH cannot be maintained reliably according to IEC 60068-2-78 if and when called for.

g) After the duration of the test specified in Table 7, ramp to ambient conditions by first turning off humidity generation then ramping temperature to 23 °C ± 3 °C. Allow a recovery time between 2 h and 4 h at (23 ± 5) °C and a relative humidity less than 75 %. During recovery time, no voltage shall be applied to the input and output terminals.



Temperature and relative humidity levels are given in Table 7.

NOTE Refer to additional details of 6.9.3 e) when achieving 10 % of P_{rated} with $V_{mpp\ max}$ applied to the input terminals of the PCE cannot be sustained.

Figure 5 – Damp heat test profile

Table 7 – Temperature and humidity limits for damp heat test

PCE category	Environmental category	Upper dwell levels T_1, RH_1	Electrical conditions	Duration (number of 12 h full cycles) h
1	- all service categories	85 °C [1], 85 % RH	$V_{mpp\ max}$ 0,1 P_r [1]	360 (30)
2, 3	- indoor, conditioned	35 °C [1], 85 % RH		120 (10)
	- indoor, unconditioned	60 °C [1], 93 % RH		240 (20)
	- outdoor	60 °C [1], 93 % RH		360 (30)

Acceptable tolerance for temperature is ± 3 °C. Acceptable tolerances for relative humidity is ± 5 %. Control is performed based on the measurements of the test chamber air.

Maximum dwell level for temperature and relative humidity in the climatic test chamber for each PCE and environmental category is as shown in this table under Upper dwell levels T_1, RH_1, whereas the lower dwell level for all PCE is RH_1 and 10 °C.

[1] Reduce temperature if required to maintain conversion for PCE at least 10 % of its nominal rated power, and increase test time according to:

$$t_2 = t_1 \times e^{6963 \times \left(\frac{1}{T_2 + 273\ \mathrm{K}} - \frac{1}{T_1 + 273\ \mathrm{K}}\right)}$$

where

T_1 is temperature listed in this table,

T_2 is the temperature to which the climatic chamber was reduced for the upper temperature level dwell,

t_1 is the duration without temperature reduction, number of cycles × 12 h, according to this table.

If it is deemed that the climatic chamber test equipment cannot maintain 93 % RH reliably according to IEC 60068-2-78 when called for, then use instead relative humidity of 85 % and further adjust the number of cycles up by 27 %, to the next highest 12 h cycle interval.

6.9.4 Restrictions and exceptions

MPP tracking and derating functionality of the PCE may be disabled if necessary to achieve a stable operating point at the DC input ports.

Not required for Category 4 PCE and PCE in the environment category of indoor, conditioned.

6.9.5 Final measurements

None.

6.9.6 Requirements

None of the testing samples exhibit any irreversible open-circuit, short-circuit, or ground fault during the tests, nor any suspensions of operation that require manual intervention on the PCE to correct. Permitted are reversible situations which are triggered by the PCE for the purpose of protecting itself or any other connected device or load that self-corrects. There shall be no permanent damage to the PCE. Record the nature and duration of any discontinuous or temporary suspension of normal operation of the PCE that may occur during the test.

6.10 Dry heat test

6.10.1 Purpose

This test consists of extended exposure to elevated temperature in combination with cyclic application of rated power to the PCE. Components in a PCE that are susceptible to heat include power semiconductor devices, film- and electrolyte capacitors, integrated circuitry, auxiliary circuitry, cooling fans, insulation material, wire terminals and connectors.

Typical failure mechanisms that are accelerated by dry heat testing with the PCE powered include dielectric breakdown, electromigration, insulation degradation, electrolyte evaporation, interconnection failure, fan bearing wear, etc.

The temperature implemented in the dry heat test is based on actual upper temperature attained by the capacitor reaching maximum temperature in 6.5, the bus link capacitor thermal test for PCE of Categories 2, 3 and 4. For these PCE types, the stress level applied is thus related to the efficiency and thermal management.

Derating of the PCE may optionally be shut off for this test and duration of the test shall be adjusted if a different temperature from that prescribed is selected.

6.10.2 Apparatus

A climatic chamber with automatic temperature control or another suitable testing chamber where tolerances for temperature within ± 3 °C from the prescribed setpoint temperature can be maintained.

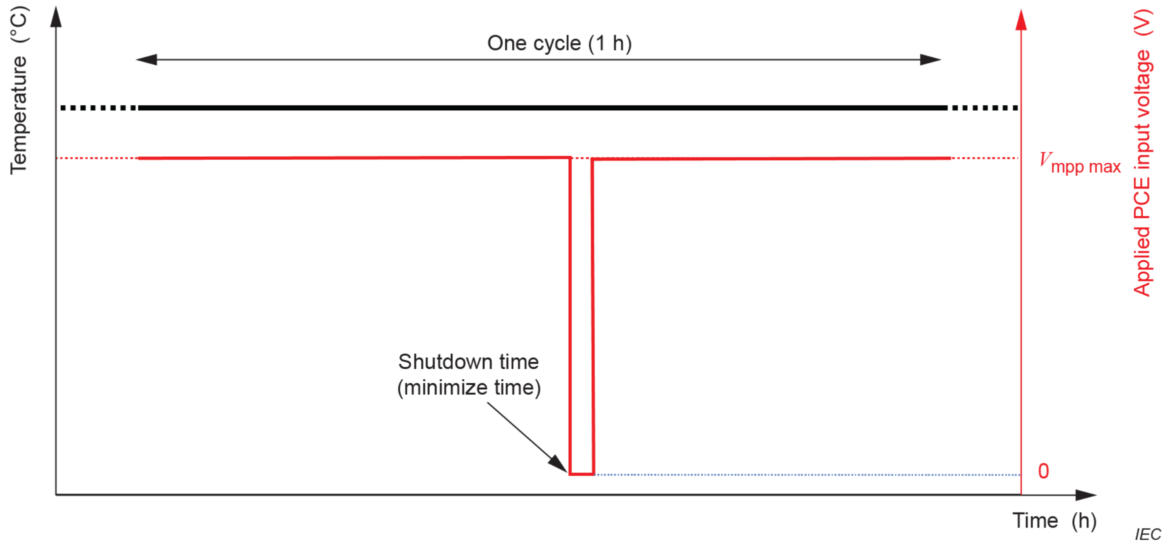
a) The chamber shall be sufficiently large to fit the PCE sample including required clearances as specified by the manufacturer.
b) Means for mounting or supporting the PCE sample according to, representative, and characteristic of the method prescribed by the manufacturer in the installation manual.
c) Apparatus set for windspeed conditions in the climatic chamber according to 6.5.3.1c).
d) Means for monitoring temperature T_C at location of highest measured capacitor temperature as acquired in 6.5.3.2, e). In the case of Category 1 PCE, monitor temperature at the attachment (mounting) point of the device.
e) A PV array simulator or a DC power supply in accordance with 5.4.5 capable at delivering the voltage versus current characteristic of the largest PV array for which the equipment is rated with regard to voltage and current.

f) An electrical load in accordance with 5.4.6.

g) Means for monitoring the current and voltage values (RMS) at all connected input and output ports.

6.10.3 Procedure

The test shall be carried out in accordance with IEC 60068-2-2:2007, 5.4 with the following provisions.



Temperature requirements are given in Table 8.

Figure 6 – Dry heat test – Temperature and input voltage profile

a) The PCE, being at room temperature, shall be introduced and installed into the test chamber or test room using a suitable mounting or supporting structure as described in 6.10.2 b). The equipment is to be mounted in accordance with the manufacturer's instructions. Equipment with active cooling (air conditioning, water circulation) shall be active repeating the configuration used in 6.5.

b) The PCE sample input terminals shall be connected to a suitable power source as described in 6.10.2 e). Suitable monitoring equipment as described in 6.10.2 g) shall be installed with the function of monitoring and logging the input current and voltage.

c) The PCE sample AC or DC output terminals shall be connected to a suitable electric load introduced in 5.4.6. The PCE shall be set to operate at rated output voltage conditions and nominal unity power factor (PF=1) throughout the test. Suitable monitoring equipment as described in 6.10.2 g) shall be installed with the function of monitoring and logging the output current and voltage. The derating characteristics of the PCE shall be representative of production equipment and not changed in any way for this test, excepting if changing derating according to the condition in e), below.

d) The PCE is to be subjected to a minimum number of hours at elevated ambient temperature to achieve capacitor temperature T_{C2} achieved with chamber temperature $T_{amb,set\ C}$ as evaluated in 6.5.3.2 at powered conditions. The chamber operating temperature levels and test durations are selected according to Table 8. All relevant electrical parameters during the test are to be monitored and documented in the test report.

e) Within every hour during the test, the PCE shall be subjected to one power cycle—the restart introduced by an input voltage profile as shown in Figure 6. Specifically, after the power cycle maintaining the shutdown time only long enough to verify zero output power, input voltage shall be set to $V_{mpp\ max}$ with sufficient current supplied so that the PCE can sustain nominal rated power, P_r. Optimization of $T_{amb,set\ C}$ shall be made to achieve $T_C = T_{C2}$.

If under the specified test conditions, the power output of the PCE derates to less than 10 of % P_r. Reduce the test temperature $T_{amb,set\ C}$ until current output is at least 10 % of P_r and increase the test duration to $Duration_{adj}$ associated with the reduced test temperature, T_{adj} (measured at the same capacitor location as T_{C2}), according to the footnotes in Table 8.

Alternatively, to reduce testing time, the temperature T_C may be increased using a higher selected T_{adj}. In this case, turn off derating if derating occurs at the higher, desired capacitor temperature, and have T_C achieve this temperature by increasing power to the PCE by increasing input current, maintaining voltage at $V_{dc,r}$. If the power reaches P_{rated} and further acceleration with higher T_C is sought, then increase the chamber temperature, while ensuring power reaches P_r during the cycle.

Table 8 – Temperature limits for dry heat test

PCE category	Environmental category	Temperature setpoint	Electrical conditions	Duration h
1	all service categories	+85 °C [1]	$V_{mpp\ max} \geq 0{,}1\ P_r$	2 000 [1]
2, 3, 4	indoor – conditioned	T_{C2} [1]	$V_{mpp\ max} \geq 0{,}1\ P_r$	2 000 [1]
	outdoor and indoor – unconditioned	T_{C2} [1]	$V_{mpp\ max} \geq 0{,}1\ P_r$	2 000 [1]

Temperature setpoint is evaluated on Category 1 PCE referencing the temperature measured on its mounting bracket, whereas for Categories 2, 3 and 4, it is on the capacitors' location of highest temperature as found in 6.5. The acceptable tolerances for measured temperature is ± 3 °C.

[1] Maintain sufficiently elevated temperature such that the PCE continues to convert at least 10 % P_r.

Testing at a lower temperature than the above specified setpoint is permitted. Testing at lower temperatures requires an increase of the testing duration according to the following formula:

$$Duration_{adj} = 1000h \times e^{6963 \times \left(\frac{1}{T_{adj} + 273K} - \frac{1}{T_{C2} + 273K}\right)}$$

Where T_{C2} was determined in 6.5 and T_{adj} is the modified test temperature. (This assumes an Arrhenius-relation with an activation energy of 0,6 eV)

This formula shall also apply if the $T_{adj} = T_C$ setpoint is increased beyond T_{C2} to achieve a reduced test duration.

6.10.4 Restrictions and exceptions

MPP tracking functionality of the PCE may be disabled if necessary to achieve a stable operating point at the DC input ports.

Derating of the PCE may optionally be defeated to achieve the specified test conditions.

When testing Category 4 PCE in components and not as a complete unit, substitute for T_{C2} in Table 8 the actual component temperature measured at the instant the reference temperature T_C is maximum at T_{C2} as described in 6.5.4.2. Perform the dry heat test for each component such that all components listed in 5.3.4 a) are tested. Use the same temperature measurement devices, mountings, and locations implemented in 6.5.

6.10.5 Final measurements

After a minimum recovery time of 1 h, perform 6.3, 6.4, and 6.1 in such order.

6.10.6 Requirements

The PCE shall meet the criteria defined in 5.5.

6.11 UV weathering test

6.11.1 Purpose

The weathering test is to evaluate the durability of organopolymeric enclosure materials and labels to UV light at elevated temperature.

6.11.2 Apparatus

Xenon arc lamp(s) in combination with the appropriate optical filter(s) to produce an irradiance spectrum simulating terrestrial sunlight according to the requirements of, and ability to control temperature and relative humidity of the test chamber according to IEC 62852, test phase G1, weather resistance and ISO 4892-2.

6.11.3 Procedure

a) Collect two samples of at least 5 cm × 10 cm of each representative face material of the PCE enclosure or cabinet. Include samples with all marking label types and polymeric window materials. Test representative parts and components such as labels, cable grips, wire harnesses, and other accessories made of polymeric materials that have portions of them external to the enclosure and exposed to the weather mounted held on their enclosure parts with representative cables or wire held within them, if applicable. Gasket material having normally some exposed to sunlight shall be collected in 10 cm strips in the width used in the PCE in two replicas.
b) Measure characteristic dimensions of polymeric parts to 0,1 mm accuracy at 22 °C ± 3 °C.
c) Perform UV weathering test on parts according to requirements of IEC 62852 test phase G1 as follows:
   - Irradiance: 60 W/m^2
   - Wave band: 300 nm to 400 nm
   - Black panel standard temperature: 65 °C
   - Relative humidity: 65 %
   - Cycle: 18 min spraying, 102 min drying with Xenon-lamp
   - Total duration: 500 h.
d) Remeasure characteristic dimensions of polymeric parts to 0,1 mm accuracy at 22 °C ± 3 °C.

6.11.4 Restrictions and exceptions

Parts of materials that have been certified to pass requirements of IEC 62852 do not require the UV weathering test. In cases where compliance can be checked by examination of the construction and of available data regarding the UV resistance characteristics of the enclosure material and any associated protective coating for the intended application as described in IEC 62109-1:2010, 13.6.4, the component will not require the UV weathering test.

Parts without organopolymeric materials are excluded from the requirements of this subclause.

6.11.5 Requirements

The weathered samples shall not exhibit:

– reduction in legibility of printed material of test sample with respect to control (acceptable is a change in color without a change in legibility);
– corrosion of interior part of the sample (do not consider edge of the sample, if cut from the enclosure);
– burn marks, severe discoloration, cracks, crazing, comparing test sample to control;
– bubbles or delamination;

– loss of mechanical integrity;
– deformation and dimensional changes exceeding 2 %.

7 Optional tests

7.1 General

The following tests serve the purpose of additional quality assurance. They aim to address quality concerns that may arise in certain operating environments that introduce specific types of environmental stresses on the PCE and its components. Particular tests are recommended if the corresponding environmental conditions exist at the intended operating locations and if these conditions are permitted by the manufacturer in the specification sheet of the PCE. Pass criteria for each test are according to 5.5. When applied, the optional tests shall be applied on a minimum of one test specimen. The users of this document may optionally choose to reuse a given PCE unit for more than one optional test.

NOTE The optional rain intrusion test, wind driven rain test, and the dust test, 7.2, 7.3, and 7.4 respectively, were developed based on the needs of utility scale PV installations for performing together as a unit for the expressed needs of this market segment.

7.2 Rain intrusion test

7.2.1 Purpose

This test is to determine if the cabinet or enclosure entrances of the PCE (fans, vents, windows, cord grips, pass-throughs, removable panels) will sufficiently protect against water intrusion during rainstorms. This test examines provisions for rainstorm water to be properly guided away from, and not come in contact with, the electronics either during or after the rainstorm.

7.2.2 Apparatus

a) The pressure in spray heads defined in IEC 60529:1989, Figure 5—second characteristic numerals 3 and 4 (spray nozzle)—at a distance of 710 mm from one another (center to center) of sufficient number to exceed the linear dimension of the horizontal enclosure edge of the PCE to be tested. Requirements for this test are in accordance with IEC 60529 second characteristic numeral 4; however, requirements of this document will supersede in case of conflict.
b) The water line at each spray head shall be 200 kPa ± 10 kPa while spraying for all tests in this subclause.
c) Materials and tools for detection of moisture presence and quantity of accumulated water: sponges, syringes, scales.
d) Moisture sensitive colormetric developer or water leak detecting paint (aerosol) for water leak detection.

7.2.3 Procedure

a) Measure the enclosure volume. Enclosure volume shall be based on overall outside dimensions.
b) Spray inside of cabinet or enclosure (doors, interior bottom, interior top, and interior walls) with moisture sensitive colormetric developer or similar water-detecting paint.
c) The enclosure shall be placed at the minimum height with respect to the ground level within the tolerance of the manufacturer’s specified mounting instructions, and at the maximum allowable angle from horizontal that is specified by the instructions.
d) For this test, the drain plugs or taps to discharge water accumulated on the bottom plate of PCE, shall be closed for keeping the water intrusion for this test.
e) Perform eight enclosure door open and close cycles on each access panel or door that can be unlatched by hand or with a tool prior to the following spray procedure, finally placing the enclosure doors in their closed position. All fans and cooling systems shall be operating or in their functional open position (dampers, or movable flaps or louvers) during these tests.

f) Spray water with water spray heads at each enclosure face for 1 h, one or more faces at a time. Each spray head shall be positioned 0,5 m from the closest point of the PCE enclosure and otherwise performed consistently with IEC 60529 second characteristic numeral 4. Immediately afterwards, the interior shall be examined and measured for water penetration. The doors of each side shall be opened, one at a time, and the interior shall be inspected. Document water found inside and its proximity (touching or nearly touching if not for surface tension of water) to the electronics with photographs. Water if found, should be collected and measured for volume.

   If one face of the enclosure is done at a time, repeat for all essentially vertical PCE enclosure faces. The panels shall be dried out after each side is completed prior to going to the next side for exposure. Calculate the total volume of water measured at each step and repeat for all PCE enclosure faces.

g) Rearrange the spray heads so that water contacts all door edges, handles, hinges, locking mechanisms, louvers, feed-through, removable or adhered panel seams of the enclosure, and any location where water ingress may be possible downward at an angle of 45° from horizontal. After spraying each enclosure face for 15 min, the interior shall be examined and measured for water penetration. The doors of each side shall then be opened, one at a time, and the interior shall be inspected. Document water found inside and its proximity to the electronics with photographs. Water if found, should be collected and measured for volume.

7.2.4 Restrictions and exceptions

This test is recommended for any PCE for use in the outdoors that has a door, fan, vent, window, etc. This test is not recommended for PCE classified for indoor environment, however ducting for direct transfer of air between PCE and vents to outdoors shall be included in the testing as part of the PCE. Air transfer, doors, windows, and filtration system of the PCE or housing allowing the PCE to be classified for indoor application shall be specified, designed, coordinated for testing, whether on the PCE, the housing, or the combination of the two.

7.2.5 Final measurements

Collect detailed photos, including linear distance scales in the image, of any water coming in contact or near proximity with electronic devices or components within the enclosure and of water on or near exposed conductors with aid of the moisture sensitive colormetric developer, and water accumulation observed.

Cumulatively calculate the total volume of water measured at each step of opening each enclosure doors or access panel that can be unlatched by hand or with a tool of the inverter for documentation in the test report.

7.2.6 Requirements

After each above-described exposure to water spray, there shall be no evidence of water coming in proximity (touching or potentially touching if not for surface tension of water) with electronic devices or components within the enclosure.

There shall be no evidence that water is impacting creepage requirements in critical areas, as in the case of moisture on circuit board between exposed conductors.

The total accumulation (sum of the measurements) of water in the enclosure shall be less than 1 cm^3 per 0,025 m^3 of enclosure volume.

7.3 Wind driven rain test

7.3.1 Purpose

This test is to determine if the enclosure is capable of preventing water ingress after exposure to rain and wind, any physical deterioration of the PCE caused by the rain, and the effectiveness of any water removal system in the PCE. This test is also to determine the enclosure’s ability to protect from water coming into contact with the electronics inside the enclosure in conditions of wind driven rain.

7.3.2 Apparatus

a) Apparatus with means for blowing air (wind) and a water distribution device within that produces droplets having a diameter range predominantly between 0,5 mm and 4,5 mm. The apparatus shall disperse water droplets completely over the test item when accompanied by the prescribed wind. For steady state rain, use spray nozzles or dispensers at a height sufficient to ensure the drops approach terminal velocity (about 9 m/s). It is not necessary to use de-ionized or distilled water for this test. A power source to heat the PCE or source of chilled water is required so that PCE under test has a temperature equilibrated at 10 °C ± 3 °C above the temperature of the water used for the wind driven rain.

b) The wind source shall be positioned with respect to the test item so that it will cause the rain to beat directly, with variations up to 45° from the horizontal, and uniformly against one side of the test item. Use a wind source that can produce horizontal wind velocities equal to and exceeding 31 m/s. Measure and confirm the required wind velocity at the position of the test item before placement of the test item in the chamber. As part of the apparatus setup, document the location of the wind speed sensor and the test device with photographs. Document the water droplet coverage over the entire exposure surface by means of a photograph. Document the direction of wind driven rain chosen relative to the surface of test item (directly or what variation of degrees from the horizontal).

c) Means for mounting, temperature measurements, and applying electrical loads according to 6.4.2 b) through 6.4.2 f).

d) Means to detect water, such as water detection stickers or other means shall be used to determine if sensitive components are exposed to water. A water-soluble dye such as fluorescein may be added to the water to aid in locating and analysing water leaks.

e) Materials and tools for detection of moisture presence and quantity of accumulated water: sponges, syringes, scales.

f) Moisture sensitive colormetric developer or water leak detecting paint (aerosol) for water leak detection.

g) Instruments suitable for measuring wind driven rain (see Bibliography [2]) and an anemometer.

7.3.3 Procedure

The PCE enclosure shall be placed at the minimum height with respect to the ground level within the tolerance of the manufacturer’s specified mounting instructions, and at the maximum allowable angle from horizontal that is specified by the instructions. All fans and cooling systems shall be operating and in their functional open position (dampers, or movable flaps or louvers) during these tests.

a) Measure the enclosure volume. Enclosure volume shall be based on overall outside dimensions.

b) Spray inside of enclosure (doors, interior bottom, interior top, and interior walls) with moisture sensitive colormetric developer or moisture detecting paint.

c) Place means to detect water, such as water detection stickers or other means to determine if electrical and sensitive components will be exposed to water inside the enclosure.

d) Perform eight enclosure door open and close cycles prior to the following spray procedure, finally placing the enclosure doors in their closed position.

e) If the temperature of the water is less than 10 °C lower than the test item, either heat the test item to a higher temperature than the rainwater such that the test item temperature has been stabilized at 10 °C to 15 °C above the rainwater temperature at the start of each exposure period or cool the water. Restore the test item to its normal physical operating configuration (unpowered) immediately before testing if it had been changed to achieve the temperature requirements.

f) With the test item in its normal physical operating configuration, adjust the rainfall rate and with the first face of the PCE perpendicular to the wind source, initiate the wind at the velocity specified as follows:

- Rainfall 15,0 cm/h ± 2,5 cm/h
- Wind velocity: 31 m/s ± 4 cm/h measured at the PCE within 0,3 m of where the water impacts the PCE under test
- Exposure duration on each wall surface: 30 min.

g) Rotate the test item to the rain and blowing wind source to a subsequent side of the test item or move the wind and rain sources to the next PCE face that could be exposed to blowing rain in deployment.

h) Repeat until all essentially vertical surfaces have been tested.

i) Conduct an inspection for water ingress. The doors or access panels shall be opened one at a time, and the interior shall be examined. Document water found inside and its proximity to the electronics with photographs.

j) Measure any free water found inside the protected areas of the test item by means of weight change of sponge and with volumetric measurements and with documentation of any observed water collected. It may be necessary to empty water from the test item after the wind driven rain test to prevent a safety hazard.

7.3.4 Restrictions and exceptions

The text of 7.2.4 applies.

7.3.5 Final measurements

After test is completed, photographs of each open enclosure door or panel of the PCE shall be documented in test report along with detailed photos of any water accumulation observed.

7.3.6 Requirements

a) The maximum total accumulation of water in the enclosure shall not exceed 1 cm^3 per 0,025 m^3 of enclosure volume.

b) After each above-described exposure to water spray, there shall be no evidence of water coming in proximity (touching or potentially touching if not for surface tension of water) with electronic devices or components within the enclosure.

c) There shall be no evidence that water is impacting creepage requirements in critical areas, as in the case of moisture on circuit board between exposed conductors.

7.4 Dust test

7.4.1 Purpose

Dust and soil depositing on electronic components can lead to development of static charge, alternative current paths, and ventilation blockage that can cause damage and failure of components including the electrical circuit boards, capacitors, terminations, power electronics and contactors.

This test exposes the factors of dust and sand to the PCE enclosure to evaluate its ability to withstand intrusion into the electrically active interior of the enclosure or chamber. This test also serves to evaluate the design for clogging of filters.

7.4.2 Apparatus

a) The apparatus where the PCE is tested shall be capable of providing an air temperature of 60 °C and achieve relative humidity of the air of 30 % relative humidity and 75 % relative humidity and provide airspeed incident to the device under test in the range of 26,8 m/s to 40,2 m/s. Laminar flow is not required.

b) Black high density conductive or antistatic foam tape (or black high density conductive or antistatic foam applied with antistatic or conductive adhesive) for dust collection. Dimensions of the foam shall be in the range of 1,75 cm × 1,75 cm to 2,25 cm × 2,25 cm.

c) ISO 12103-1, A2, Fine test dust.

7.4.3 Procedure

This procedure references IEC 60068-2-68. In case of conflict, the methods explicitly listed here govern.

a) Perform 6.1. Assure no damage is observed that would impair normal operation of the equipment such as doors, latches, and fan motors. Also ensure any fans are operational.

b) Place black foam dust collectors on all horizontal or near horizontal surfaces inside the enclosure at all locations where dust entry is possible: at each seam edge, such as inside enclosure doors at each side and at the mid-point, and around any vents.

c) Place all louvers and vents in their normally open position. Turn on interior and exterior fans for the entirety of the test duration application of dust and sand.

d) Perform eight enclosure door open and close cycles, finally placing the enclosure doors in their closed position.

e) Apply test procedures of IEC 60068-2-68 method Lc1 with ISO 12103-1, A2, Fine test dust with concentration (10,6 ± 7) g/m^3 and severities given in high temperature low humidity:
   - Temperature: 60 °C ± 3 °C
   - Relative humidity: 30 % ± 5 %
   - Wind speed: 26,8 m/s baseline to 40,2 m/s peak gusts
   - Duration: 2 h per vertical face.

f) Apply test procedures of IEC 60068-2-68 method Lc1 with ISO 12103-1, A2, Fine test dust with concentration (10,6 ± 3,0) g/m^3 and severities given in high temperature high humidity:
   - Temperature: 60 °C ± 3 °C
   - Relative humidity: 75 % ± 5 %
   - Wind speed: 26,8 m/s baseline to 40,2 m/s peak
   - Duration: 2 h per vertical face.

g) After 1 h settling time, examine each black foam dust collectors and rate on a 1-8 scale according to the observational standard for evaluating dust accumulation located in Figure 7.

7.4.4 Exceptions and restrictions

This optional test is proposed for any PCE for outdoor use that has a door, fan, vent, window, etc. PCE specified for indoor use is excluded, except where direct ducting from equipment to the outdoors exists or is specified.

7.4.5 Requirements

a) Dust accumulation level according to Figure 7 of 4 or less.

b) Interior and exterior fans function normally for the entirety of the test duration and after the procedure.

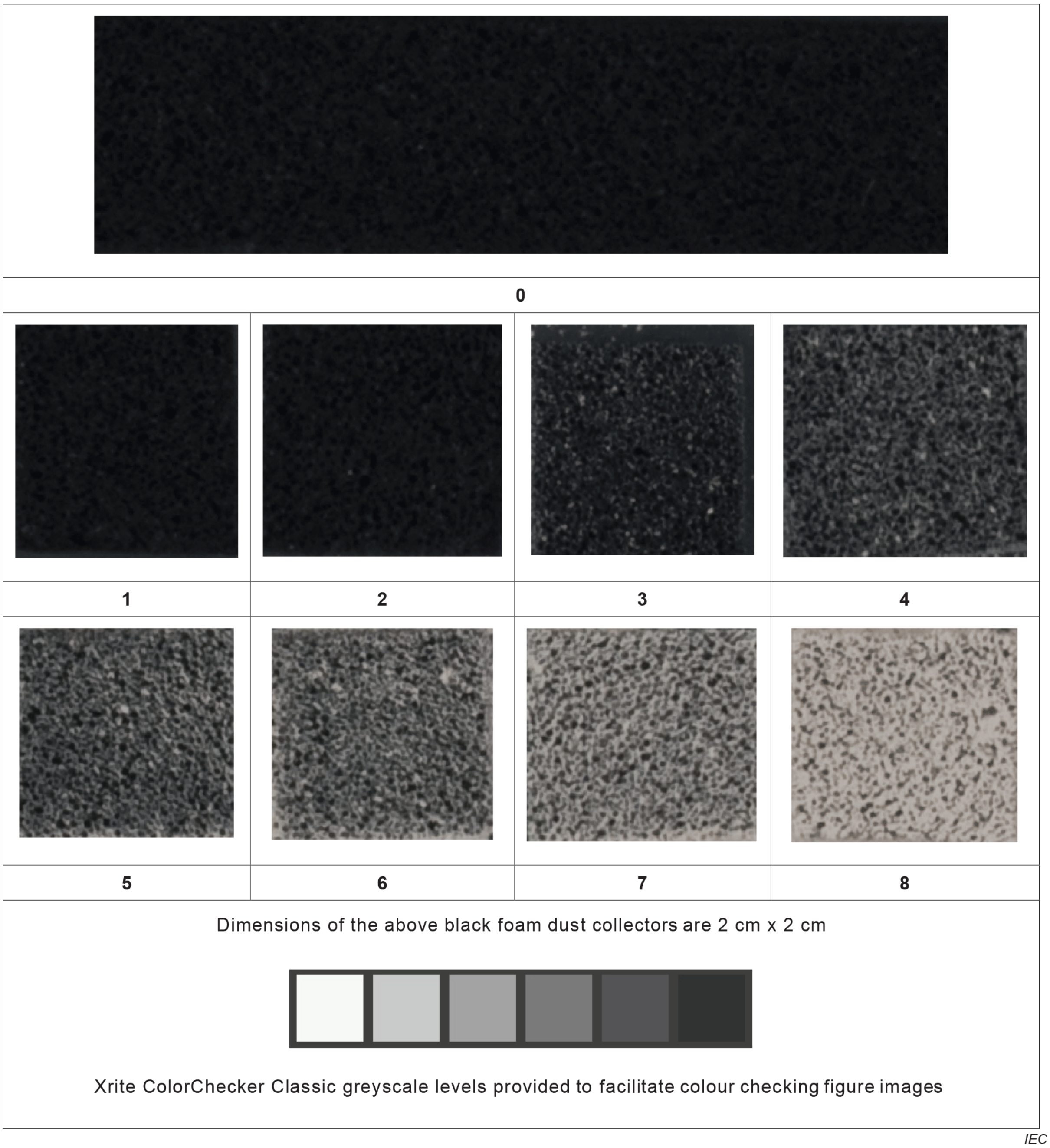


Figure 7 – Reference for dust accumulation evaluation level

7.5 Shipping vibration test

7.5.1 Purpose

The purpose of this test is to identify mechanical weak points and/or to ascertain any deterioration of the specified parameters. According to IEC 60068-2-6, it shall be conducted on structural elements or devices, which are exposed to harmonic vibrations during shipment, such as occur on ships, in aircraft and land vehicles.

7.5.2 Apparatus

Implement the apparatus in IEC 60068-2-6.

7.5.3 Procedure

Implement the procedure in IEC 60068-2-6 with the severities of:

- Frequency range: 10 Hz to 11,8 Hz; 11,9 Hz to 150 Hz
- Constant amplitude: 3,5 mm
- Constant acceleration: 2 g
- Cycling: 1 octave/min
- Duration on each axis: 2 h
- Total test duration: 6 h.

The specimens may be packaged or unpackaged during the test. For packaged testing, the specimen is tested in a condition including all packaging material that is specified by the manufacturer for transport and distribution of the PCE.

The specimens are not energised during the test.

7.5.4 Restrictions and exceptions

7.5.4.1 Category 1-2 PCE

No restrictions apply.

7.5.4.2 Category 3 PCE

May be performed on subassemblies. This fact shall be noted in the test report.

7.5.5 Final measurements

Perform in such order as listed, 6.3, functionality test; 6.4 voltage test; and 6.1, visual inspection.

7.5.6 Requirements

Requirements of 6.3, 6.4 and 6.1 shall be met.

Specify whether the specimens during the test were packaged, unpackaged, or if they were tested in both states in the test report.

7.6 Shock test

7.6.1 Purpose

In conjunction with the previous test, the purpose of this test is to discover mechanical weak points and/or to determine whether the specified parameters are maintained or deteriorate. The tests are conducted in conformance with IEC 60068-2-27.

7.6.2 Apparatus

Implement the apparatus in IEC 60068-2-27.

7.6.3 Procedure

Implement the procedure in IEC 60068-2-27 with severities as follows:

Amplitude of acceleration: 15 g
Type of shock: half-sine
Duration of shock: 11 ms

Sequence of shocks: 1 s
Number of shocks: 18 (6 × 3).

The specimens may be packaged or unpackaged during the test. For packaged testing, the specimen is tested in a condition including all packaging material that is specified by the manufacturer for transport and distribution of the PCE.

The specimens are not energised during the test.

7.6.4 Restrictions and exceptions

7.6.4.1 Category 1-2 PCE

No restrictions apply.

7.6.4.2 Category 3 PCE

Not required.

7.6.5 Final measurements

Perform in such order as listed, 6.3, functionality test; 6.4, voltage test 6.1, visual inspection.

7.6.6 Requirements

Requirements of 6.3, 6.4 and 6.1 shall be met.

7.7 Salt mist test

7.7.1 Purpose

The salt mist test consists of extended exposure of combined high humidity and high atmospheric sodium chloride concentration. It is intended to simulate accelerated exposure in environments with changes between salt and dry atmospheres, such as coastal areas. The salt mist test is intended to produce a corrosive attack on the sample. The main target is to evaluate the integrity of the enclosure and its resistance against corrosive attacks. Components in a PCE that are typically affected by salt mist testing are the mechanical enclosure, and associated mechanical parts. Internal electric circuitry may also be affected if resistance to salt mist corrosion is insufficient or not present.

7.7.2 Apparatus

a) A test chamber according to IEC 60068-2-52.
b) Means for mounting or supporting the PCE sample according to the method prescribed by the manufacturer.

7.7.3 Procedure

a) The tests shall be performed with the PCE fully assembled, and all covers in place and all doors of the enclosure closed. Apply to the test samples the salt mist test as described in IEC 60068-2-52, test method 1 following the general conditions, apparatus, and characteristics of the salt solution, severities and other specifications included. The severity of the salt mist test shall be chosen according to the atmospheric conditions prevailing in the place where the installation of the PCE is intended. Severity (2) is not suitable for PCEs as testing conditions are too weak and shall be avoided when applying this document.
b) Severities are according to IEC 60068-2-52 test method 1; specifically 4, cycles of the following stages:
   - Salt mist 35 °C ± 2 °C, 2 h duration
   - Humid condition 40 °C ± 2 °C 93 % ± 3 % RH, 6 days and 22 h duration.

c) The PCE sample is to be mounted or supported by a suitable structure inside the chamber according to the method prescribed by the manufacturer. The installation shall allow sufficient spacing between sample and chamber walls and uniform salt mist coverage on the sample.
d) The test is to be performed under conditions with the PCE being turned off and no power source or sink being connected to any of its input and output ports.
e) After the test, all samples shall be washed to remove the adherent salt from the exterior of the PCE enclosure using running tap water (not artificially pressurised) for a maximum time of 1 min per sample. Do not open the enclosure during the washing period. Alternatively, a wet cloth may be used to wipe off adherent salt if the IP rating does not permit the use of running water.
f) Once the washing is finished, allow a minimum of 2 h of drying at room temperature. A dry cotton cloth may be used to wipe of remaining drops of water on the PCE exterior after the drying period.

7.7.4 Restrictions and exceptions

This test applies only to PCE intended for outdoor use.

7.7.5 Final measurements

After the drying period, perform in such order as listed, 6.3, functionality test; 6.4, voltage test; and 6.1, visual inspection.

7.7.6 Requirements

Requirements of 6.3, 6.4, and 6.1 shall be met.

7.8 Mixed gas corrosion test

7.8.1 General

The mixed gas corrosion test method 4 of IEC 60068-2-60 is applied for testing of electrotechnical products operated or stored in moderately corrosive environments. The PCE is not energized during the exposure to the corrosive gasses.

7.8.2 Apparatus

The test apparatus consists of a climatic system, test enclosure, gas delivery system and means for measuring gas concentration, in accordance with IEC 60068-2-60.

7.8.3 Procedure

Testing is performed according to IEC 60068-2-60:2015, Clause 7, test procedure 2, with the PCE unpowered. Severities applied are according to IEC 60068-2-60:2015, Table 1, Method 4, for the insertion of insertion of H_2S, NO_2, Cl_2, SO_2, and H_2O into the test chamber. The duration is 21 days.

7.8.4 Restrictions and exceptions

None.

7.8.5 Final measurements

Perform in such order as listed, 6.3, functionality test; 6.4, voltage test; and 6.1 visual inspection.

7.8.6 Requirements

Requirements of 6.3, 6.4, and 6.1 shall be met.

7.9 Ammonia corrosion test

7.9.1 Purpose

This test is highly recommended for micro and string inverters, which shall be mounted in or close to animal farms, e.g. poultry or pig farms. The procedure implemented is according to IEC 62716 for PV modules. The PCE is not energized during the test.

7.9.2 Apparatus

As described in Clause 5 of ISO 22479:2019, modified for ammonia input.

7.9.3 Procedure

a) Place or mount the PCE on an open rack such that air circulation around the PCE is unimpeded.

b) Apply severities of IEC 62716:2013, 7.2, a sequence of 20 cycles each consisting of two test sections:

- 1st test section
  - i) Time: 8 h
  - ii) NH_3 concentration 6 667 ppm
  - iii) Temperature 60 °C ± 3 °C
  - iv) Relative humidity: condensing
- 2nd test section
  - i) Time: 16 h
  - ii) NH3 concentration 0 ppm
  - iii) Temperature 18 °C to 28 °C
  - iv) Relative humidity: 75 %, maximum.

c) Clean residual ammonia on PCE with running water.

7.9.4 Final measurements

Perform in such order as listed, 6.3, functionality test; 6.4, voltage test; and 6.1, visual inspection.

7.9.5 Requirements

Requirement of 6.3, 6.4 and 6.1 shall be met.

8 Report

The report shall contain the detail specification for the PCE under test. Each test report shall include at least the following information:

a) a title;

b) name and address of the test laboratory and location where the tests were carried out;

c) unique identification of the report and of each page;

d) name and address of client, where appropriate;

e) description and identification of the item tested (product model number shall uniquely correspond to the optional parts of this document successfully passed);

f) characterization and condition of the test item;

g) date of receipt of test item and date(s) of test, where appropriate;

h) identification of test method used;

i) reference to sampling procedure, where relevant;

j) any deviations from, additions to, or exclusions from, the test method and any other information relevant to specific tests, such as environmental conditions, additional testing peripherals such as transformers;

k) measurements, examinations and derived results supported by tables, graphs, sketches and photographs as appropriate including:

   – results of the characterization for ascertainment of performed tests;

   – any failures observed;

   – a statement of the estimated uncertainty of the test results (where relevant);

   – a statement indicating if the samples met the requirements of the performed tests;

   – the results according to Annex A for inclusion in the report and specification sheet of the power conversion electronics;

l) a signature and title, or equivalent identification of the person(s) accepting responsibility for the content of the report, and the date of issue;

m) where relevant, a statement to the effect that the results relate only to the items tested;

n) a statement that the report shall not be reproduced except in full, without the written approval of the laboratory.

Annex A
(normative)

Specification of tests performed for reporting

The following serves to clarify that the PCE has met the requirements of this document with respect to the various optional stress tests that the PCE has passed. Items in **bold** are normally transcribed to the products specification sheet. Items not in bold are instructional.

This power conversion equipment has met the requirements of IEC 62093: yyyy.

Category: (indicate **Category 1 PCE–Module-level power electronics** OR **Category 2 PCE–String-level power electronics** OR **Category 3 PCE–Large scale power electronics** OR **Category 4 PCE- central large-scale power electronics**).

Environment Category: (**Outdoor** OR **Indoor, unconditioned**, OR **Indoor conditioned**).

For the case of environment Category **outdoor** OR **indoor, unconditioned** AND IF value is less than or greater than -40 °C **Minimum operating temperature:** ($T_{set\ min}$ temperature [***T*** **° C**]; employed in 6.7 and 6.8; use the greater of the two if different).

List as applicable, consistent with the Clause 8 Report, the Clause 7 **Optional tests that have been performed and meeting IEC 62093 requirements:**

Rain intrusion test
Wind driven rain test
Dust test
Shipping vibration test
Shock test
Salt mist test
Mixed gas corrosion test
Ammonia corrosion test.

Bibliography

[1] P. Hacke, D. Clemens, R. Thiagarajan, J. Flicker, and H. Igarashi, "Evaluation of the DC bus link capacitors and power transistor modules in the qualification testing of PV inverters", *Progress in Photovoltaics: Research and Applications* 29 (7), 2021, pp. 675-683, https://doi.org/10.1002/pip.3341

[2] B. Blocken and J. Carmeliet, "On the accuracy of wind-driven rain measurements on buildings", *Building and Environment* 41, 2006, pp.1798–1810

This Indian Standard has been developed from Doc No.: ETD 28 (21238).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.gov.in

Regional Offices:		*Telephones*
Central	: 601/A, Konnectus Tower -1, 6th Floor, DMRC Building, Bhavbhuti Marg, New Delhi 110002	2323 7617
Eastern	: 8th Floor, Plot No 7/7 & 7/8, CP Block, Sector V, Salt Lake, Kolkata, West Bengal 700091	2367 0012 2320 9474
Northern	: Plot No. 4-A, Sector 27-B, Madhya Marg, Chandigarh 160019	265 9930
Southern	: C.I.T. Campus, IV Cross Road, Taramani, Chennai 600113	2254 1442 2254 1216
Western	: Manakalya, 4th Floor, NTH Complex (W Sector), F-10, MIDC, Andheri (East), Mumbai 400093	283 25838

Branches : AHMEDABAD, BENGALURU, BHOPAL, BHUBANESHWAR, CHANDIGARH, CHENNAI, COIMBATORE, DEHRADUN, DELHI, FARIDABAD, GHAZIABAD, GUWAHATI, HARYANA (CHANDIGARH), HUBLI, HYDERABAD, JAIPUR, JAMMU, JAMSHEDPUR, KOCHI, KOLKATA, LUCKNOW, MADURAI, MUMBAI, NAGPUR, NOIDA, PARWANOO, PATNA, PUNE, RAIPUR, RAJKOT, SURAT, VIJAYAWADA.

Published by BIS, New Delhi