

INTERNATIONAL STANDARD



**Safety of power converters for use in photovoltaic power systems –
Part 1: General requirements**

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CONTENTS

FOREWORD.....	8
INTRODUCTION.....	10
1 Scope and object.....	11
1.1 Scope.....	11
1.1.1 Equipment included in scope	11
1.1.2 Equipment for which other requirements may apply	11
1.2 Object	11
1.2.1 Aspects included in scope	11
1.2.2 Aspects excluded from scope	12
2 Normative references	12
3 Terms and definitions	15
4 General testing requirements.....	25
4.1 General	25
4.2 General conditions for testing.....	25
4.2.1 Sequence of tests.....	25
4.2.2 Reference test conditions	25
4.3 Thermal testing	28
4.3.1 General	28
4.3.2 Maximum temperatures	28
4.4 Testing in single fault condition	31
4.4.1 General	31
4.4.2 Test conditions and duration for testing under fault conditions.....	31
4.4.3 Pass/fail criteria for testing under fault conditions.....	32
4.4.4 Single fault conditions to be applied	33
4.5 Humidity preconditioning.....	36
4.5.1 General	36
4.5.2 Conditions.....	36
4.6 Backfeed voltage protection	36
4.6.1 Backfeed tests under normal conditions.....	37
4.6.2 Backfeed tests under single-fault conditions	37
4.6.3 Compliance with backfeed tests.....	37
4.7 Electrical ratings tests	37
4.7.1 Input ratings	37
4.7.2 Output ratings.....	37
5 Marking and documentation.....	37
5.1 Marking	37
5.1.1 General	37
5.1.2 Durability of markings.....	38
5.1.3 Identification.....	38
5.1.4 Equipment ratings.....	38
5.1.5 Fuse identification	38
5.1.6 Terminals, connections and controls.....	39
5.1.7 Switches and circuit-breakers	39
5.1.8 Class II equipment.....	39
5.1.9 Terminal boxes for external connections.....	40
5.2 Warning markings	40

5.2.1	Visibility and legibility requirements for warning markings.....	40
5.2.2	Content for warning markings	40
5.2.3	Sonic hazard markings and instructions.....	41
5.2.4	Equipment with multiple sources of supply.....	41
5.2.5	Excessive touch current.....	41
5.3	Documentation	42
5.3.1	General	42
5.3.2	Information related to installation.....	42
5.3.3	Information related to operation.....	43
5.3.4	Information related to maintenance.....	44
6	Environmental requirements and conditions.....	44
6.1	Environmental categories and minimum environmental conditions	45
6.1.1	Outdoor	45
6.1.2	Indoor, unconditioned	45
6.1.3	Indoor, conditioned.....	45
6.2	Pollution degree	46
6.3	Ingress protection.....	47
6.4	UV exposure	47
6.5	Temperature and humidity.....	47
7	Protection against electric shock and energy hazards.....	47
7.1	General.....	47
7.2	Fault conditions.....	47
7.3	Protection against electric shock	48
7.3.1	General	48
7.3.2	Decisive voltage classification	48
7.3.3	Protective separation.....	52
7.3.4	Protection against direct contact.....	52
7.3.5	Protection in case of direct contact.....	57
7.3.6	Protection against indirect contact.....	60
7.3.7	Insulation including clearance and creepage distances.....	68
7.3.8	Residual Current Detection (RCD) or Monitoring (RCM) device compatibility	79
7.3.9	Protection against shock hazard due to stored energy.....	80
7.4	Protection against energy hazards	80
7.4.1	Determination of hazardous energy level.....	80
7.4.2	Operator access areas	81
7.4.3	Service access areas	81
7.5	Electrical tests related to shock hazard	81
7.5.1	Impulse voltage test (type test).....	81
7.5.2	Voltage test (dielectric strength test) (type test and routine test).....	83
7.5.3	Partial discharge test (type test or sample test)	87
7.5.4	Touch current measurement (type test)	88
7.5.5	Equipment with multiple sources of supply.....	89
8	Protection against mechanical hazards.....	89
8.1	General.....	89
8.2	Moving parts	90
8.2.1	Protection of service persons	90
8.3	Stability.....	90
8.4	Provisions for lifting and carrying.....	91

8.5	Wall mounting	91
8.6	Expelled parts	92
9	Protection against fire hazards	92
9.1	Resistance to fire	92
9.1.1	Reducing the risk of ignition and spread of flame.....	92
9.1.2	Conditions for a fire enclosure	93
9.1.3	Materials requirements for protection against fire hazard.....	93
9.1.4	Openings in fire enclosures	96
9.2	Limited power sources.....	100
9.2.1	General	100
9.2.2	Limited power source tests	100
9.3	Short-circuit and overcurrent protection.....	101
9.3.1	General	101
9.3.2	Number and location of overcurrent protective devices.....	101
9.3.3	Short-circuit co-ordination (backup protection).....	102
10	Protection against sonic pressure hazards.....	102
10.1	General.....	102
10.2	Sonic pressure and sound level.....	102
10.2.1	Hazardous noise levels.....	102
11	Protection against liquid hazards	103
11.1	Liquid containment, pressure and leakage.....	103
11.2	Fluid pressure and leakage	103
11.2.1	Maximum pressure	103
11.2.2	Leakage from parts.....	104
11.2.3	Overpressure safety device	104
11.3	Oil and grease.....	104
12	Chemical hazards.....	104
12.1	General.....	104
13	Physical requirements	105
13.1	Handles and manual controls	105
13.1.1	Adjustable controls	105
13.2	Securing of parts.....	105
13.3	Provisions for external connections	105
13.3.1	General	105
13.3.2	Connection to an a.c. mains supply	106
13.3.3	Wiring terminals for connection of external conductors	110
13.3.4	Supply wiring space.....	111
13.3.5	Wire bending space for wires 10 mm ² and greater	112
13.3.6	Disconnection from supply sources.....	112
13.3.7	Connectors, plugs and sockets	112
13.3.8	Direct plug-in equipment.....	113
13.4	Internal wiring and connections	113
13.4.1	General	113
13.4.2	Routing.....	113
13.4.3	Colour coding	113
13.4.4	Splices and connections	114
13.4.5	Interconnections between parts of the PCE	114
13.5	Openings in enclosures	114

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13.5.1	Top and side openings	114
13.6	Polymeric materials	116
13.6.1	General	116
13.6.2	Polymers serving as enclosures or barriers preventing access to hazards	117
13.6.3	Polymers serving as solid insulation	117
13.6.4	UV resistance	118
13.7	Mechanical resistance to deflection, impact, or drop	118
13.7.1	General	118
13.7.2	250 N deflection test for metal enclosures	119
13.7.3	7 J impact test for polymeric enclosures	119
13.7.4	Drop test	119
13.8	Thickness requirements for metal enclosures	120
13.8.1	General	120
13.8.2	Cast metal	120
13.8.3	Sheet metal	120
14	Components	122
14.1	General	122
14.2	Motor overtemperature protection	124
14.3	Overtemperature protection devices	124
14.4	Fuse holders	124
14.5	Mains voltage selecting devices	124
14.6	Printed circuit boards	124
14.7	Circuits or components used as transient overvoltage limiting devices	125
14.8	Batteries	125
14.8.1	Battery enclosure ventilation	125
14.8.2	Battery mounting	126
14.8.3	Electrolyte spillage	126
14.8.4	Battery connections	127
14.8.5	Battery maintenance instructions	127
14.8.6	Battery accessibility and maintainability	127
15	Software and firmware performing safety functions	127
Annex A (normative)	Measurement of clearances and creepage distances	128
Annex B (normative)	Programmable equipment	133
Annex C (normative)	Symbols to be used in equipment markings	134
Annex D (informative)	Test probes for determining access	136
Annex E (informative)	RCDs	138
Annex F (informative)	Altitude correction for clearances	140
Annex G (informative)	Clearance and creepage distance determination for frequencies greater than 30 kHz	141
Annex H (informative)	Measuring instrument for touch current measurements (see 7.5.4)	144
Annex I (informative)	Examples of protection, insulation, and overvoltage category requirements for PCE	146
Annex J (normative)	Ultraviolet light conditioning test	150
Figure 1	– Functional summary of protective measures against electric shock	48
Figure 2	– Typical waveform for a.c. working voltage	51

Figure 3 – Typical waveform for d.c. working voltage	51
Figure 4 – Typical waveform for pulsating working voltage.....	52
Figure 5 – Examples for protection against direct contact for DVC-C circuits	56
Figure 6 – Protection by DCV A with protective separation.....	57
Figure 7 – Protection by means of protective impedance	58
Figure 8 – Protection by limitation of discharge energy	59
Figure 9 – Protection by means of voltage limitation	60
Figure 10 – Examples of protective bonding and earthing	61
Figure 11 – Protective bonding impedance test for separate unit with power fed from the PCE with overcurrent protection for the power cable	63
Figure 12 – Protective bonding impedance test for separate unit with accessible parts and with power fed from the PCE without overcurrent protection.....	64
Figure 13 – Voltage test procedures	85
Figure 14 – Fire enclosure bottom openings below an unenclosed or partially enclosed component.....	97
Figure 15 – Fire enclosure baffle construction.....	98
Figure 16 – Examples of cross-sections of designs of openings preventing vertical access	115
Figure 17 – Examples of louver design	115
Figure 18 – Enclosure openings.....	116
Figure 19 – Methods of compliance verification.....	123
Figure A.1 – Narrow groove	128
Figure A.2 – Wide groove	129
Figure A.3 – V-shaped groove	129
Figure A.4 – Rib.....	129
Figure A.5 – Uncemented joint with narrow groove	129
Figure A.6 – Uncemented joint with wide groove.....	130
Figure A.7 – Uncemented joint with narrow and wide grooves.....	130
Figure A.8 – Narrow recess	130
Figure A.9 – Wide recess.....	131
Figure A.10 – Intervening, unconnected conductive part	131
Figure A.11 – Distance for multilayer PWBs.....	132
Figure D.1 – Test finger	136
Figure D.2 – Test pin	137
Figure D.3 – Straight unjointed test finger.....	137
Figure E.1 – Flow chart leading to selection of the RCD/RCM type upstream of a PCE	138
Figure G.1 – Clearance distance determination for frequencies greater than 30 kHz.....	141
Figure G.2 – Creepage distance determination for frequencies greater than 30 kHz	142
Figure H.1 – Measuring instrument	144
Figure H.2 – Alternative measuring instrument.....	145
Figure I.1 – Transformer (basic) isolated PV inverter	147
Figure I.2 – Transformer (basic) isolated PV inverter with SPD to reduce impulse voltage for functional insulation.....	147
Figure I.3 – Isolated PV inverter with SPD to reduce impulse voltage for basic insulation	148

Figure I.4 – Transformer isolated auxiliary circuit with reinforced insulation	148
Figure I.5 – Transformerless PV inverter.....	149
Table 1 – Total temperature limits for transformers, inductors, and other coils and their insulation systems	30
Table 2 – Total temperature limits for materials and components where manufacturer's ratings and component standards do not exist (see 4.3.2.1)	30
Table 3 – Total touch temperature limits for accessible surfaces.....	31
Table 4 – Environmental categories, environmental conditions, and test requirements.....	45
Table 5 – Reduction of the pollution degree of internal environment through the use of additional protection	46
Table 6 – Summary of the limits of the decisive voltage classes	49
Table 7 – Examples of application of insulation and separation.....	50
Table 8 – Insulation between accessible unearthed parts and DVC-A or -B circuits adjacent to DVC-B or -C circuits	55
Table 9 – Values of accessible capacitance and charging voltage (threshold of pain)	59
Table 10 – Test duration for protective bonding test.....	65
Table 11 – External protective earthing conductor cross-section.....	66
Table 12 – Insulation voltage for low voltage circuits	71
Table 13 – Clearance distances.....	73
Table 14 – Creepage distances (mm).....	75
Table 15 – Impulse voltage test	82
Table 16 – Impulse test voltage	83
Table 17 – AC or DC test voltage for circuits connected directly to the mains	84
Table 18 – a.c. or d.c. test voltage for circuits not connected directly to the mains.....	84
Table 19 – Partial discharge test.....	88
Table 20 – Summary of material flammability requirements.....	96
Table 21 – Allowable openings in fire enclosure bottoms	98
Table 22 – Limits for inherently limited power sources	101
Table 23 – Limits for power sources not inherently limited	101
Table 24 – Sizes of conductors.....	108
Table 25 – Physical tests on power supply cords	109
Table 26 – Wire bending space from terminals to obstructions.....	112
Table 27 – Minimum property retention limits after UV exposure.....	118
Table 28 – Thickness of sheet metal for enclosures: Carbon steel or stainless steel.....	121
Table 29 – Thickness of sheet metal for enclosures: aluminium, copper or brass.....	122
Table A.1 – Value of X.....	128
Table C.1 – Symbols.....	134
Table F.1 – Correction factor for clearances at altitudes above 2 000 m (see 7.3.7.4.1).....	140
Table F.2 – Test voltages for verifying clearances at different altitudes.....	140
Table G.1 – Minimum values of clearances in air at atmospheric pressure for inhomogeneous field conditions (Table 1 of IEC 60664-4).....	142
Table G.2 – Minimum values of creepage distances for different frequency ranges (Table 2 of IEC 60664-4)	143

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**SAFETY OF POWER CONVERTERS FOR USE
IN PHOTOVOLTAIC POWER SYSTEMS –**

Part 1: General requirements

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

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

A list of all parts of IEC 62109 series, under the general title, *Safety of power converters for use in photovoltaic power systems*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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INTRODUCTION

This Part of IEC 62109 specifies the safety requirements that are generally applicable to all equipment within its scope. For certain types of equipment, these requirements will be supplemented or modified by the special requirements of one or more subsequent parts (for example IEC 62109-2, IEC 62109-3, etc.) of the standard which must be read in conjunction with the Part 1 requirements.

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SAFETY OF POWER CONVERTERS FOR USE IN PHOTOVOLTAIC POWER SYSTEMS –

Part 1: General requirements

1 Scope and object

1.1 Scope

This part of IEC 62109 applies to the power conversion equipment (PCE) for use in Photovoltaic (PV) systems where a uniform technical level with respect to safety is necessary. This standard defines the minimum requirements for the design and manufacture of PCE for protection against electric shock, energy, fire, mechanical and other hazards.

This standard provides general requirements applicable to all types of PV PCE. There are additional parts of this standard that provide specific requirements for the different types of power converters, such as Part 2 - inverters. Additional parts may be published as new products and technologies are commercialised.

1.1.1 Equipment included in scope

This standard covers PCE connected to systems not exceeding maximum PV source circuit voltage of 1 500 V d.c. The equipment may also be connected to systems not exceeding 1 000 V a.c. at the a.c. mains circuits, non-mains a.c. load circuits, and to other DC source or load circuits such as batteries. This standard may be used for accessories for use with PCE, except where more appropriate standards exist.

Evaluation of PCE to this standard includes evaluation of all features and functions incorporated in or available for the PCE, or referred to in the documentation provided with the PCE, if such features or functions can affect compliance with the requirements of this standard.

1.1.2 Equipment for which other requirements may apply

This standard has not been written to address characteristics of power sources other than photovoltaic systems, such as wind turbines, fuel cells, rotating machine sources, etc.

NOTE 1 Requirements for other sources may be incorporated in the IEC 62109 series in the future.

Additional or other requirements are necessary for equipment intended for use in explosive atmospheres (see IEC 60079), aircraft, marine installations, electromedical applications (see IEC 60601) or at elevations above 2 000 m.

NOTE 2 Requirements are included for adjustment of clearance distances for higher elevations, but not for other factors related to elevation, such as thermal considerations

1.2 Object

1.2.1 Aspects included in scope

The purpose of the requirements of this part of IEC 62109 is to ensure that the design and methods of construction used provide adequate protection for the operator and the surrounding area against:

- a) electric shock and energy hazards;
- b) mechanical hazards;

- c) excessive temperature hazards;
- d) spread of fire from the equipment;
- e) chemical hazards;
- f) sonic pressure hazards;
- g) liberated fluids, gases and explosion hazards.

NOTE Servicing personnel are expected to have the necessary knowledge and skill to use reasonable care in dealing with hazards associated with the operation, repair and maintenance of this equipment. Based upon this premise, this standard provides only limited requirements (for example markings or guarding) intended to protect service personnel from hazards that may not be apparent even to trained personnel.

1.2.2 Aspects excluded from scope

Aspects not covered by this standard include, but are not limited to, the following:

- a) functional reliability, performance or other properties of the equipment not related to safety;
- b) effectiveness of transport packaging;
- c) EMC requirements;
- d) installation requirements, which are covered by local and national installation codes.

NOTE This standard does provide requirements for PCE intended to ensure that the PCE can be installed in a safe manner, including requirements for installation instructions provided with the product.

2 Normative references

The following referenced documents are indispensable for the application 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 60060-1, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60085, *Electrical insulation – Thermal evaluation and designation*

IEC 60112, *Method for the determination of the proof and the comparative tracking indices of solid insulating materials*

IEC 60216-1, *Electrical insulating materials – Properties of thermal endurance – Part 1: Ageing procedures and evaluation of test results*

IEC 60216-2, *Electrical insulating materials – Thermal endurance properties – Part 2: Determination of thermal endurance properties of electrical insulating materials – Choice of test criteria*

IEC 60216-3, *Electrical insulating materials – Thermal endurance properties – Part 3: Instructions for calculating thermal endurance characteristics*

IEC 60216-4-1, *Electrical insulating materials – Thermal endurance properties – Part 4-1: Ageing ovens – Section 1: Single-chamber ovens*

IEC 60216-5, *Electrical insulating materials – Thermal endurance properties – Part 5: Determination of relative thermal endurance index (RTE) of an insulating material*

IEC 60216-6, *Electrical insulating materials – Thermal endurance properties – Part 6: Determination of thermal endurance indices (TI and RTE) of an insulating material using the fixed time frame method*

IEC 60227-1:2007, *Polyvinyl chloride insulated cables of rated voltages up to and including 450/750 V - Part 1: General requirements*

IEC 60245-1:2003, *Rubber insulated cables – Rated voltages up to and including 450/750 V – Part 1: General requirements*

IEC 60309 (all parts), *Plugs, socket-outlets and couplers for industrial purposes*

IEC 60320 (all parts), *Appliances couplers for household and similar general purposes*

IEC 60364-1:2005, *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions*

IEC 60364-5-54, *Electrical installations of buildings – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements, protective conductors and protective bonding conductors*

IEC 60417, *Graphical symbols for use on equipment*

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

IEC 60664-1:2007, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 60664 (all parts), *Insulation coordination for equipment within low-voltage systems*

IEC 60664-3:2003, *Insulation coordination for equipment within low-voltage systems – Part 3: Use of coating, potting or moulding for protection against pollution*

IEC 60664-4:2005, *Insulation coordination for equipment within low-voltage systems – Part 4: Consideration of high-frequency voltage stress*

IEC 60695-2-11, *Fire hazard testing – Part 2-11: Glowing/hot-wire based test methods – Glow-wire flammability test method for end-products*

IEC 60695-2-20, *Fire hazard testing – Part 2-20: Glowing/hot wire based test methods – Hot-wire coil ignitability – Apparatus, test method and guidance*

IEC 60695-11-5, *Fire hazard testing – Part 11-5: Test flames – Needle-flame test method – Apparatus, confirmatory test arrangement and guidance*

IEC 60695-11-10, *Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods*

IEC 60695-11-20, *Fire hazard testing – Part 11- 20: Test flames – 500 W flame test methods*

IEC 60730-1:2010, *Automatic electrical controls for household and similar use – Part 1: General requirements*

IEC 60755, *General requirements for residual current operated protective devices*

IEC 60950-1:2005, *Information technology equipment – Safety – Part 1: General requirements*

IEC 60990:1999, *Methods of measurement of touch current and protective conductor current*

IEC 61032, *Protection of persons and equipment by enclosures – Probes for verification*

IEC 61180-1, *High-voltage test techniques for low voltage equipment – Part 1: Definitions, test and procedure requirements*

IEC 62020, *Electrical accessories – Residual current monitors for household and similar uses (RCMs)*

ISO 178, *Plastics – Determination of flexural properties*

ISO 179 (all parts), *Plastics – Determination of Charpy impact properties*

ISO 180, *Plastics – Determination of Izod impact strength*

ISO 261, *ISO general purpose metric screw threads – General plan*

ISO 262, *ISO general purpose metric screw threads – Selected sizes for screws, bolts and nuts*

ISO 527 (all parts), *Plastics – Determination of tensile properties*

ISO 3746, *Acoustics – Determination of sound power levels of noise sources using sound pressure – Survey method using an enveloping measurement surface over a reflecting plane*

ISO 4892-1, *Plastics – Methods of exposure to laboratory light sources – Part 1: General guidance*

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

ISO 4892-4, *Plastics – Methods of exposure to laboratory light sources – Part 4: Open-flame carbon-arc lamps*

ISO 7000, *Graphical symbols for use on equipment – Index and synopsis*

ISO 8256, *Plastics – Determination of tensile-impact strength*

ISO 9614-1, *Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 1: Measurement at discrete points*

ISO 9614-2, *Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 2: Measurement by scanning*

ISO 9614-3, *Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 3: Precision method for measurement by scanning*

ANSI/ASTM E84, *Standard Test Method for Surface Burning Characteristics of Building Materials*

ANSI UL 746B, *Polymeric Materials – Long Term Property Evaluations*

ANSI UL 746C, *Polymeric Materials – Use in Electrical Equipment Evaluations*

ASTM E162, *Standard Test Method for Surface Flammability of Materials Using a Radiant Heat Energy Source*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE Unless otherwise specified, values of "voltage" and "current" are the r.m.s. values of an alternating, direct or composite voltage or current.

3.1

accessible

able to be touched with the standard access probes when used as specified in 7.3.4

3.2

basic insulation

insulation which provides a single level of protection against electric shock under fault-free conditions

NOTE Basic insulation may serve also for functional purposes.

3.3

battery type

the battery chemistry (e.g. lead-acid) and type (e.g. flooded, gel, etc.) or types of batteries intended for use with the PCE

3.4

battery - sealed

a battery with no provision for the addition of water or electrolyte, and constructed so as to prevent the emission of liquid or gasses under normal operation

3.5

battery - non-sealed

a battery with removable caps or other provision for addition of water and/or electrolyte

3.6

battery - valve regulated

a sealed battery with provision for the release of excessive pressure under abnormal conditions

3.7

bipolar photovoltaic (PV) array

a photovoltaic array that consists of two interconnected arrays where one output connection of one array is connected to the opposite polarity output connection of the other array to create a common electrical node, similar to a centre-tapped transformer

3.8

clearance

shortest distance in air between two conductive parts

3.9

closed electrical operating area

room or location for electrical equipment to which access is restricted to skilled or instructed persons by the opening of a door or the removal of a barrier by the use of a key or tool and which is clearly marked by appropriate warning signs

3.10

comparative tracking index (CTI)

the voltage, as determined under the conditions specified in IEC 60112, that causes a permanent electrically conductive carbon path with the application of 50 drops of electrolyte that is applied at the rate of one drop every 30 s to the specimen

3.11

creepage distance

shortest distance along the surface of the insulating material between two conductive parts

[IEV 151-03-37]

3.12

decisive voltage

the decisive voltage of a circuit is the highest voltage which occurs continuously between any two arbitrary live parts of the PCE during worst-case rated operating conditions when used as intended (see Decisive Voltage Class limits in 7.3.2)

3.13

decorative part

a part of the equipment, outside the enclosure, which has no safety function

3.14

direct plug-in equipment

equipment with a mains plug that is part of the equipment so that the equipment is supported by the mains receptacle

3.15

double insulation

insulation comprising both basic insulation and supplementary insulation

[IEV 195-06-08]

3.16

DVC A

decisive voltage classification (DVC) A as defined in 7.3.2

3.17

DVC B

decisive voltage classification (DVC) B as defined in 7.3.2

3.18

DVC C

decisive voltage classification (DVC) C as defined in 7.3.2

3.19

enclosure

a 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

3.20

environmental category

the set of ambient conditions to which the PCE is exposed in its installation, as defined in Clause 6

3.21

equipotential bonding

provision of electric connections between conductive parts, intended to achieve equipotentiality

[IEV 195-01-10]

NOTE The effectiveness of the equipotential bonding may depend on the frequency of the current in the bonding.

3.22**equipotential bonding conductor**

conductor electrically connecting metal parts to provide equipotential bonding

3.23**EUT**

equipment under test

3.24**Extra Low Voltage (ELV)**

voltage not exceeding the relevant voltage limit of band I specified in IEC 60449

[IEV 826-12-30]

NOTE 1 In IEC 60449 band I is defined as not exceeding 50 V a.c. r.m.s. and 120 V d.c.

NOTE 2 In this international standard, protection against electric shock is dependent on the decisive voltage classification.

3.25**fire enclosure**

a part of the equipment which surrounds internal parts, intended to minimize the spread of fire or flaming materials from within

3.26**fixed equipment**

equipment fastened to a support, or otherwise secured in a specific location

[IEV 826-07-07]

3.27**flammability classification of materials**

the recognition of the burning behaviour of materials and their ability to extinguish if ignited. Materials are classified as in the definitions in this standard, when tested in accordance with IEC 60695-11-10, IEC 60695-11-20, ISO 9772 or ISO 9773

NOTE 1 When applying the requirements in this standard, HF-1 class foamed materials are regarded as better than those of class HF-2, and HF-2 better than HBF.

NOTE 2 Similarly, other materials, including rigid (engineering structural) foam of class 5VA are regarded as better than those of class 5VB, 5VB better than V-0, V-0 better than V-1, V-1 better than V-2, V-2 better than HB40 and HB40 better than HB75.

NOTE 3 Similarly, other materials of class VTM-0 are regarded as better than those of class VTM-1 and VTM-1 better than VTM-2.

NOTE 4 Materials of flammability classes VTM-0, VTM-1 and VTM-2 are considered to be equivalent to materials of flammability classes V-0, V-1 and V-2, respectively, but only for their flammability properties. Their electrical and mechanical properties are not necessarily equivalent.

3.28**functional earth terminal**

terminal by which electrical connection is made to a part or circuit for any functional purpose other than safety

3.29**functional insulation (FI)**

insulation that is necessary only for the correct operation of the equipment

NOTE Functional insulation by definition does not protect against electric shock. It may, however, reduce the likelihood of ignition and fire.

3.30

hand-held equipment

portable equipment intended to be supported by one hand during normal use

3.31

hazard

potential source of harm from any of the mechanisms covered by this standard, such as risk of electric shock, risk of fire, etc.

3.32

hazardous energy level

an available power level of 240 VA or more having a duration of 60 s or more, or a stored energy level of 20 J or more (for example, from one or more capacitors), at a potential of 2 V or more (see 7.4.1)

3.33

hazardous live

capable of rendering an electric shock or electric burn. A circuit or a part that is either a shock or energy hazard as described in Clause 7

3.34

hazardous voltage

a voltage exceeding the limits for shock hazard in 7.3

3.35

homogeneous field (distribution)

a homogeneous field is an electric field which has an essentially constant voltage gradient between electrodes (uniform field), such as that between two spheres where the radius of each sphere is greater than the distance between them

3.36

indoor, unconditioned

equipment environmental classification in which the PCE is fully covered by a building or enclosure to protect it from direct rain, sun, wind-blown dust, fungus, and radiation to the cold night sky, etc., but the building or enclosure is not conditioned in terms of temperature, humidity or air filtration, and the equipment may experience condensation

3.37

indoor, conditioned

equipment environmental classification in which the PCE is fully covered by a building or enclosure to fully protect it from rain, sun, wind-blown dust, fungus, and radiation to the cold night sky, etc., and the building or enclosure is generally conditioned in terms of temperature, humidity and air filtration. Condensation is not expected

3.38

inhomogeneous distribution (of an electric field)

inhomogeneous distribution of an electric field refers to a field which does not have an essentially constant voltage gradient between electrodes (non-uniform field)

3.39

Isc PV

absolute maximum total PV array short circuit current (d.c.) that the PCE is rated to have connected to its PV input, under worst-case conditions of ambient temperature, irradiance, etc.

NOTE 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 Isc ratings of the connected PV modules, since those markings are based on short-circuit conditions under standard test conditions, and may be exceeded in cold temperatures or with irradiance above the standard level.

3.40**limited power source**

a source complying with the requirements in 9.2 of this standard

3.41**live parts**

conductor or conductive part intended to be energized in normal use, including a neutral conductor

3.42 low voltage

a set of voltage levels used for the distribution of electricity and whose upper limit of the line-to-line or line-to-neutral voltage is 1 000 V a.c. or 1 500 V d.c.

3.43**mains**

low-voltage a.c. electricity supply system to which the PCE is designed to be connected

3.44**mains circuit**

circuit which is intended to be conductively connected to the mains

3.45**neutral**

current-carrying conductor, terminal, or circuit point which is intentionally bonded to earth

NOTE The terms earthed neutral and grounded conductor are also in common use. In this standard, the term neutral refers to any power circuit (mains, PV, battery, etc.) not just the mains.

3.46**normal condition**

condition in which all means for protection against hazards are intact and the PCE is installed and operated in accordance with its ratings and installation instructions

3.47**normal use**

operation, including stand-by, according to the instructions for use or for the obvious intended purpose

NOTE In most cases, normal use also implies normal condition, because the instructions for use will warn against using the equipment when it is not in normal condition.

3.48**operator**

person operating equipment for its intended purpose

3.49**operator access area**

a part of the PCE to which, under normal operating conditions, one of the following applies:

- access can be gained without the use of a tool, or
- the means of access is deliberately provided to the operator, or
- the operator is instructed to enter regardless of whether a tool is needed to gain access.

3.50**outdoor**

equipment environmental classification in which the PCE is fully or partly exposed to direct rain, sun, wind, dust, fungus, ice, condensation, radiation to the cold night sky, etc., and to the full range of outdoor temperature and humidity; wet location requirements apply

3.51

overvoltage category (OVC)

numeral designation defining a classification of transient overvoltage conditions

[IEC 60664-1]

NOTE 1 See 7.3.7.1.2 for a description of the four overvoltage categories.

NOTE 2 A transient overvoltage is defined as a 'short duration overvoltage of a few milliseconds or less, oscillatory or non-oscillatory, usually highly damped' [IEV 604-03-13]. It should not be confused with a temporary overvoltage (swell), which is defined as a 'power frequency overvoltage of relatively long duration' [IEV 616-01-16].

3.52

partial discharge extinction voltage (U_e)

lowest peak value of the test voltage at which the apparent charge becomes less than the specified discharge magnitude when the test voltage is reduced below a high level where such discharges have occurred (IEC 60664-1)

NOTE For a.c. tests the r.m.s. value may be used.

3.53

permanently connected

electrically connected by means which can be detached only by the use of a tool

3.54

PELV system

electric system in which the voltage cannot exceed the value of extra low voltage:

- under normal conditions and
- under single fault conditions, except earth faults in other electric circuits

NOTE PELV is the abbreviation for protective extra low voltage.

[IEV 826-12-32]

3.55

photovoltaic (PV)

relating to the conversion of light directly into electrical energy

3.56

photovoltaic (PV) array

an assembly of components such as photovoltaic panels, cables, connectors, combiners, etc., that produces and supplies d.c. electricity by the conversion of solar energy

3.57

pluggable equipment type A

equipment which is intended for connection to the building installation wiring via a non-industrial plug and socket-outlet or a non-industrial appliance coupler, or both

3.58

pluggable equipment type B

equipment which is intended for connection to the building installation wiring via an industrial plug and socket-outlet or an appliance coupler, or both, complying with IEC 60309 or with a comparable national standard

NOTE PV circuits that use connectors are considered pluggable type B or fixed equipment.

3.59

pollution

addition of foreign matter, solid, liquid or gaseous (ionized gases), that may produce a reduction of dielectric strength or surface resistivity

3.60**pollution degree**

classification scheme describing the extent of expected pollution in a micro-environment in or around the equipment

3.61**pollution degree 1**

no pollution or only dry, non-conductive pollution occurs. The pollution has no influence

3.62**pollution degree 2**

normally only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation must be expected

3.63**pollution degree 3**

conductive pollution occurs, or dry, non-conductive pollution occurs which becomes conductive due to condensation which is expected

3.64**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

3.65**portable equipment**

pluggable equipment intended to be moved from place to place

3.66 power conversion equipment (PCE)

an 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 Examples include AC-DC converters, DC-AC inverters, DC-DC charge controllers, frequency converters, etc.

3.67**protective bonding**

electrical connection of accessible conductive parts or of protective screening to provide electrical continuity to the protective conductor terminal

3.68**protective bonding conductor**

a conductor used to interconnect accessible conductive parts or protective screening for the purpose of protective bonding

3.69**protective class I**

protection against electric shock by means of basic insulation and protective earthing of accessible conductive parts, so that accessible conductive parts cannot become live in the event of a failure of the basic insulation

3.70**protective class II**

protection against electric shock that does not rely on basic insulation only, but in which additional safety precautions such as double insulation or reinforced insulation are provided, there being no provision for protective earthing or reliance upon installation conditions

3.71

protective class III

equipment in which protection against electric shock relies upon supply from decisive voltage classification A circuits and in which hazardous voltages are not generated

NOTE For class III equipment, although there is no requirement for protection against electric shock, all other requirements of the standard apply.

3.72

protective earthing

connection of a point in the equipment, system, or installation to earth, for protection against electric shock in case of a fault

3.73

protective earthing conductor

a conductor used to connect an equipment, system, or installation to earth, for protection against electric shock in case of a fault

3.74

protective conductor terminal

terminal which is bonded to conductive parts of an equipment for safety purposes and is provided for the connection of a protective earthing conductor

3.75

protective impedance

component, assembly of components or the combination of basic insulation and a current or voltage-limiting device, whose impedance, construction and reliability are such that, when connected between accessible conductive parts and parts which are hazardous live, it provides protection to the extent required by this standard in normal condition and single fault condition

3.76

protective separation

a construction means to maintain the separation between circuits of different protection levels even in the event of a single fault as described in 7.3.3

NOTE Protective separation is a separation between circuits by means of basic and supplementary protection (basic insulation plus supplementary insulation or protective screening) or by an equivalent protective provision (for example, reinforced insulation or protective impedance).

3.77

rated

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

[IEV 151-04-03]

3.78

rating

set of rated values and operating conditions

[IEV 151-04-04]

3.79

reference test conditions

the electrical, operating, and environmental conditions under which testing is to be performed, as specified in 4.2.2

3.80**reinforced insulation**

single insulation system applied to live parts, which provides a degree of protection against electric shock equivalent to double insulation under the conditions specified

NOTE A single insulation system does not imply that the insulation must be one homogeneous piece. It may comprise several layers which cannot be tested singly as basic or supplementary insulation.

3.81**residual-current**

vector sum of the currents flowing in the normally current carrying conductors of a mains circuit, expressed as an r.m.s. value

3.82**responsible body**

individual or group responsible for the use and maintenance of equipment and for ensuring that operators are adequately trained

3.83**risk**

a combination of the probability of the occurrence of harm and the severity of that harm

3.84**routine test**

test to which each individual device (equipment) is subjected during or after manufacture to ascertain whether it conforms to certain criteria

[IEV 151-04-16, modified]

3.85**safety interlock**

a means either of preventing access to a hazardous area until the hazard is removed, or of automatically removing the hazardous condition when access is gained

3.86**sample test**

tests on a number of devices taken at random from a production batch

3.87**secondary circuit**

a circuit which has no direct connection to a mains circuit and derives its power from a transformer, converter or equivalent isolation device, or from a battery or other power source not connected to the mains (e.g. the PV circuit in isolated PCE)

3.88**SELV system**

electric system in which the voltage cannot exceed the value of *extra low voltage*:

- under normal conditions and
- under single fault conditions, including earth faults in other electric circuits

NOTE SELV is the abbreviation for safety extra low voltage.

[IEV 826-12-31]

3.89**service personnel**

a person having appropriate technical training and experience necessary to be aware of hazards to which that person may be exposed in performing a task and of measures to minimize the risks to that person or other persons

3.90

simple separation

separation between electric circuits or between an electric circuit and local earth by means of basic insulation

[IEV 826-12-28]

3.91

single fault condition

condition in which one means for protection against hazard is defective or one fault is present which could cause a hazard

NOTE If a single fault condition results in other subsequent failures, the set of failures is considered as one single fault condition.

3.92

supplementary insulation

independent insulation applied in addition to basic insulation in order to provide protection against electric shock in the event of a failure of basic insulation

3.93

terminal

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

[IEV 151-01-03, modified]

NOTE Terminals can contain one or several contacts and the term therefore includes sockets, connectors, etc.

3.94

tool

a screwdriver, coin, key, or any other object that is used to operate a screw, latch, or similar fastening means

3.95

transportable equipment

equipment with a mass of less than 18 kg that is not fixed equipment and is intended to be routinely carried by a user

3.96

type test

test of one or more samples (prototypes) of equipment (or parts of equipment) made to a particular design, to show that the design and construction meet one or more requirements of this standard

[IEV 151-04-15, modified]

NOTE This is an amplification of the IEC 151-04-15 definition to cover both design and construction requirements.

3.97

V_{max} PV

maximum rated d.c. input voltage the PCE is designed to withstand from the PV array (i.e. maximum open-circuit voltage) under worst-case conditions of ambient temperature, irradiance, etc.

3.98

wet location

location where water or another conductive liquid may be present and is likely to cause reduced human body impedance due to wetting of the contact between the human body and the equipment, or wetting of the contact between the human body and the environment

3.99

working voltage

voltage which occurs by design in a circuit or across insulation, when the PCE is operated under the worst case combination of highest and lowest rated voltages for each port, and under worst-case normal operating conditions. See 7.3.2.6

4 General testing requirements

4.1 General

Testing is required by this standard to demonstrate that the EUT is fully in accordance with the applicable requirements of this standard. This clause of this standard provides:

- general conditions and requirements under which testing shall be carried out;
- some of the actual tests required to be performed, where those tests are general in nature and are not specifically related to one particular type of hazard (for example thermal tests).

Other test requirements that are specific to a particular type of hazard are located in the appropriate clause elsewhere in this standard.

Tests on subassemblies of the equipment meeting the requirements of the relevant reference standards specified in this standard, and used in accordance with them and in conditions not more severe than those applied during testing to determine compliance with the reference standards, need not be repeated during type tests of the whole equipment.

To ensure that equipment will not become hazardous in expected humidity conditions, as specified in Table 4, the EUT is to be subjected to humidity preconditioning according to 4.5 before certain tests, where specified elsewhere in this standard.

Where a measured value is close to a compliance limit, analysis of the measurement uncertainty shall be done to determine compliance.

Compliance with the requirements of this standard is checked by carrying out all applicable tests in this standard, except that a test may be omitted if examination of the equipment demonstrates conclusively that the equipment would pass the test.

Tests are carried out under reference test conditions (see 4.2.2), and tests under both normal and single fault conditions are specified.

4.2 General conditions for testing

4.2.1 Sequence of tests

The sequence of tests is optional unless otherwise specified in this standard. The EUT shall be carefully inspected for damage creating a possible hazard in the meaning of this standard, after each test. The same sample need not be used for all tests unless otherwise specified in this standard.

4.2.2 Reference test conditions

4.2.2.1 Environmental conditions

Unless otherwise specified in this standard, for example with regard to environmental category as defined in 6.1, the following ambient environmental conditions shall exist in the test location:

- a) temperature of 15 °C to 40 °C;
- b) a relative humidity of not more than 75 % and not less than 5 %;

- c) an air pressure of 75 kPa to 106 kPa;
- d) no frost, dew, percolating water, rain, solar radiation, etc.

4.2.2.2 State of equipment

The product being subjected to type tests shall be physically and electrically representative of the future production products such that the evaluations per this standard adequately represent future production units.

Unless otherwise specified, each test shall be carried out on the equipment assembled for normal use and under the least favorable combination of the conditions given in 4.2.2.1 to 4.2.2.10. If it is impractical to carry out particular tests on a complete EUT, tests on subassemblies are allowed, provided it is verified that the assembled equipment will meet the requirements of this standard.

4.2.2.3 Position of equipment

The equipment shall be installed in accordance with the manufacturer's instructions, in the configuration that results in the worst-case test conditions. Consideration shall be given to effects of ventilation, building into a wall, recess, cabinet, etc., installation in close proximity to structures, other equipment, etc.

4.2.2.4 Accessories

Accessories and operator-interchangeable parts available from, or recommended by, the manufacturer for use with the EUT shall be either connected or not connected, whichever is least favorable.

4.2.2.5 Covers and removable parts

Covers or parts, which can be removed without using a tool, shall be removed or not removed, whichever is least favorable.

4.2.2.6 Mains supply

Tests for which the outcome will not be significantly affected by the mains supply conditions, may be carried out at any rated supply conditions. For tests for which the outcome may be significantly affected by mains supply conditions, the test shall be performed at the worst-case mains supply condition or conditions, taking into consideration multiple rated conditions and tolerances on rated conditions, as specified below

- a) Voltage: Tolerance shall be taken as 90 % to 110 % of the rated voltage(s), unless a wider range is given in the specifications for the EUT in which case the wider range is used. If the EUT will not operate across the full 90 % to 110 % range, the tolerance is taken as specified operating range. Testing under nominal supply conditions, or at supply conditions between the ends of the ranges, is only necessary if testing at the ends of the ranges is not worst-case.
- b) Frequency: Multiple rated frequencies are to be taken into account (e.g. 50 Hz versus 60 Hz), but tolerances around these frequencies do not normally need to be considered.
- c) Polarity: For pluggable equipment type A, consideration is to be given to connection in both normal and reverse polarity conditions, if the outcome of a particular test could be affected.
- d) Earthing: The test supply shall be earthed or not according to the intended supply configuration for the equipment under test. For equipment that may be supplied from either an earthed or un-earthed supply system, the supply system used shall be that which provides a worst-case test condition, or tests shall be done in both configurations.

- e) Over-current Protection: Inputs shall be provided with the over-current protection that will be present in the installation, and this protection shall not operate during any tests in normal conditions, but is allowed to operate to protect the system during tests in single fault conditions.

4.2.2.7 Supply ports other than the mains

Tests shall be performed at the least favorable combination of supply conditions, within the rated range(s) for each supply port, considering voltage, frequency, polarity, earthing, and any other normal condition, where these considerations could affect the outcome of the test.

Inputs shall be provided with the over-current protection that will be present in the installation, and this protection shall not operate during any tests in normal conditions, but is allowed to operate to protect the system during tests in single fault conditions.

For PV and battery inputs, the following additional requirements apply:

4.2.2.7.1 Photovoltaic supply sources

Where the results of a test could be affected by the voltage versus current characteristic of the supply, the PV source used shall simulate the voltage versus current characteristic of the largest PV array for which the equipment is rated, with regard to open circuit voltage ($V_{MAX PV}$) and short-circuit current ($I_{sc PV}$).

Tests performed under abnormal or fault conditions shall be tested with a source capable of 1,25 to 1,5 times the PCE rated maximum input current ($I_{sc PV}$) for that input. If provided, any included or specified PCE overcurrent protective devices shall not be altered or changed.

NOTE When selecting test conditions for the PV supply, consideration has to be given to the characteristic of PV arrays: when maximum voltage is available, the available current is at a minimum, and when maximum current is available, the voltage is at a minimum. It is not expected that any test should be run with both the PV source current and voltage at their maximum values.

4.2.2.7.2 Battery inputs

Battery inputs may be supplied from either a d.c. power supply or from a battery bank, except that for fault testing, where the magnitude of the available fault current could affect the results of the test, a battery bank of the size normally used with the product shall be used.

4.2.2.8 Conditions of loading for output ports

Tests shall be performed under the least favorable loading conditions, within the rated range(s) for each port, considering voltage, frequency, polarity, earthing, load current and type, and any other normal condition, where these considerations could affect the outcome of the test. An a.c. output port shall be loaded with linear load(s) to obtain the maximum rated output power or current, whichever is least favourable. A d.c. output port (for example a battery charging output or a d.c. load port) shall be loaded with resistive load(s) to obtain the maximum rated output power or current, whichever is least favourable. For ports intended for connection to a battery, a battery shall be used in place of or in parallel with the load, if the test results could be affected.

Unless otherwise specified in this standard, loading conditions are to be maintained for a length of time as follows:

- for continuous operation ratings, until steady conditions are established, except that for a test for which the only source of power is the PV input, testing is limited to 7 h at full power (to approximate a single solar day);
- for intermittent operation ratings, cycling until steady conditions are established, using the rated "ON" and "OFF" periods;
- for short-term operation ratings, for the rated operating time.

4.2.2.9 Earthing terminals

A protective conductor terminal, if provided, shall be connected to earth. A functional earth terminal shall be connected or not connected to earth, whichever is least favourable.

4.2.2.10 Controls

Controls which the operator can adjust shall be set to any position except that

- a) mains selection devices shall be set to the correct value unless otherwise noted in this standard;
- b) combinations of settings shall not be made if they are prohibited by the manufacturer's instructions provided with the equipment.

4.2.2.11 Available short circuit current

Where the results of a test could be affected, the short circuit current sourcing capability of the source used during testing shall be taken into consideration. Where high available short circuit current is considered to be the worst-case test condition, the capability of the source shall not be less than the maximum short-circuit current the PCE is rated for.

NOTE For some tests, less than maximum short circuit current may be worst-case, if, for example, it results in longer test duration.

4.3 Thermal testing

4.3.1 General

This subclause specifies requirements intended to prevent hazards due to:

- touchable parts exceeding safe temperatures; and
- components, parts, insulation and plastic materials exceeding temperatures which may degrade safety-related electrical, mechanical, or other properties during normal use over the expected life of the equipment; and
- structures and mounting surfaces exceeding temperatures which may degrade the materials over the expected life of the equipment.

4.3.2 Maximum temperatures

4.3.2.1 General

Materials and components shall be selected so that under the most severe rated operating conditions, the temperatures do not exceed the temperature limits below.

Compliance is verified by measuring temperatures under the conditions given in 4.2 for each rated operating condition or mode of the PCE that could affect the resulting temperatures.

The temperature limits specified below are total temperature limits (not temperature rise limits).

Tests of equipment rated for use in ambient temperatures up to 50 °C may be conducted at any ambient temperature in the range given in 4.2.2.1, in which case the difference between the maximum rated ambient temperature and the actual test ambient is to be subtracted from or added to (as appropriate) the measured temperatures for comparison to the limits specified below.

PCE rated for use in ambient temperatures more than 50 °C shall be tested at the maximum rated ambient temperature ± 5 °C. The difference between the maximum rated ambient temperature and the test ambient is to be subtracted from or added to (as appropriate) the measured temperatures for comparison to the limits specified below.

PCE with different output ratings or with automatic derating for different ambient temperatures shall be tested under as many conditions as are necessary to record worst-case temperatures, including at least the maximum ambient before derating, and the maximum ambient with derating.

During thermal testing within normal conditions protective devices other than automatic output derating systems shall not operate.

Temperatures are to be measured by thermocouples, except that for transformers, inductors, and other coils the change of resistance method may be used.

Temperatures determined by the rise-of-resistance method shall use the formula

$$T = R2/R1 (k + t1) - (k + t2)$$

where

T is the temperature rise in °C

$R1$ is the resistance of the coil at the beginning of the test

$t1$ is the room temperature in °C at the beginning of the test

$R2$ is the resistance of the coil at the end of the test

$t2$ is the room temperature in °C at the end of the test

$k = 234,5$ for copper

$k = 225,0$ for aluminum

For other materials the correct value for the constant “ k ” shall be used.

Limits:

- for coils and their insulation systems, the temperature limits in Table 1 apply
- for other components the measured temperatures shall not exceed the lower of:
 - the limits in the applicable IEC component standards
 - the component or material manufacturer’s rated operating temperature
 - if neither of the above exists, temperature limits are given in Table 2.

Table 1 – Total temperature limits for transformers, inductors, and other coils and their insulation systems

Class of insulation (see IEC 60085)	Limits for surface mounted thermocouple measurements	Limits for resistance method and multiple embedded thermocouple measurements
	°C	°C
Class A (105 °C)	90	95
Class E (120 °C)	105	110
Class B (130 °C)	110	120
Class F (155 °C)	130	140
Class H (180 °C)	150	160
Class N (200 °C)	165	175
Class R (220 °C)	180	190
Class S (240 °C)	195	205

NOTE Surface mounted thermocouples are assumed to not be located on the hot-spot, but will be typically attached to the core, coil, and insulation that is accessible on a completed part. Multiple embedded thermocouples, where the thermocouples are attached during winding of the part, are more likely to record hot-spot temperatures. The resistance method gives an average temperature for the specific winding whose resistance rise was measured.

Table 2 – Total temperature limits for materials and components where manufacturer's ratings and component standards do not exist (see 4.3.2.1)

Materials and components	Limit °C
Capacitors - electrolytic types	65
Capacitors - other than electrolytic types	90
Wiring terminals for external connections ¹	60
Any point on or within a wiring compartment which external conductors are able to contact ¹	60
Insulated conductors internal to the PCE	rated temperature
Fuses	90
Printed circuit boards	105
Insulating materials	90

¹ The temperature observed on the terminals and at points within a terminal box or wiring component of a unit is able to exceed the values specified if the marking of 5.1.9 requires wiring of a suitably high temperature rating. In this case, measured temperatures on the terminals and wiring compartment are limited to the temperature rating of the wiring required by the marking.

4.3.2.2 Touch temperatures

In order to limit the touch temperatures of accessible parts of PCE, the maximum temperature for accessible parts of the PCE shall be in compliance with Table 3.

It is permitted that accessible parts that are required to get hot as part of their intended function (for example heatsinks) may have temperatures up to 100 °C, if the parts are marked with the hot surface marking of symbol 14 of Annex C. For products only for use in a closed electrical operating area the 100 °C limit does not apply.

These limits are in addition to the applicable limits in 4.3.2.1.

Table 3 – Total touch temperature limits for accessible surfaces

Part	Limit °C		
	Metal	Glass, porcelain, and other vitreous material ^a	Plastic and rubber ^a
User operated devices (knobs, handles, switches, displays, etc.) which are continuously held in normal use	55	65	75
User operated devices (knobs, handles, switches, displays, etc.) which are held for short periods only in normal use	60	70	85
Enclosure parts accessible to user by casual contact.	70	80	95
^a Nonmetallic materials shall not be used above their temperature ratings.			

Compliance is checked by the testing in 4.3.2.1.

4.3.2.3 Temperature limits for mounting surfaces

In order to protect against long-term degradation of building materials, surfaces of the PCE that will be in contact with the mounting surface shall not exceed a maximum total temperature of 90 °C.

This limit is in addition to the applicable limits in 4.3.2.1 and 4.3.2.2.

Compliance is checked by the testing in 4.3.2.1 with the PCE mounted according to the manufacturer's instructions, on a softwood surface.

4.4 Testing in single fault condition

4.4.1 General

Testing in single fault condition is done to determine that no hazards result from reasonably expected fault conditions that may arise in normal service or from reasonably expected misuse.

Fault testing shall be done unless it can be conclusively demonstrated that no hazards could arise from a particular fault condition, or unless alternative methods of checking compliance are specified in this standard in place of fault testing.

Compliance is checked by applying the criteria of 4.4.3 after each of the tests specified in 4.4.4 under the conditions specified in 4.4.2.

4.4.2 Test conditions and duration for testing under fault conditions

4.4.2.1 General

The equipment shall be operated under the combination of conditions in 4.2, which is least favourable for the particular fault test being performed.

NOTE When configuring sources for fault testing, consideration shall be given to the fact that for some fault tests, a source limited to less than the maximum rated current or power of that input of the PCE may be more severe than if a maximum rated current source was used. Test duration may be longer, and heating in the fault path may be more severe under limited conditions. For example on a PV input, it may be more severe to test with a simulated array limited to less than I_{sc} PV.

Fault conditions are to be applied only one at a time and shall be applied in turn in any convenient order. Multiple simultaneous faults shall not be applied, but a subsequent fault

may arise as a consequence from an applied fault. Separate samples of the EUT may be used for each separate fault test applied, or the same sample may be used for many tests if damage from previous fault tests has been repaired or will not affect the results of further tests.

4.4.2.2 Duration of tests

The equipment shall be operated until further change as a result of the applied fault is unlikely, as determined by (for example) opening of a device that removes the influence of the fault, stabilization of temperatures, etc.

If a non-resettable, manual, or automatically resetting protective device or circuit operates in such a way as to interrupt or mitigate the fault condition, the test duration is as follows:

- automatic reset devices or circuits: allow the protection to cycle on and off until no further change as a result of the applied fault is likely, until the ultimate result is obtained, or until temperatures stabilize;
- manual reset devices or circuits: three cycles, with the device or circuit reset as soon as possible after tripping;
- non-resettable devices or circuits: one cycle.

4.4.3 Pass/fail criteria for testing under fault conditions

4.4.3.1 Protection against shock hazard

Compliance with requirements for protection against electric shock is checked during and after the application of single faults as follows:

- a) by making measurements to check that no accessible DVC-A circuits have become shock-hazardous using the steady state limits for DVC-A in Table 6 and the short-term limits of 7.3.2.3, and that such circuits remain separated from live parts at voltages greater than DVC A with at least basic insulation. Compliance is checked by the test of 7.5.2 (without humidity preconditioning) for basic insulation; and
- b) by performing a dielectric strength test as per 7.5.2 (without humidity preconditioning) in the following cases:
 - i) on reinforced or double Insulation, using the test level for basic insulation, and
 - ii) on basic insulation in protective class I equipment, using the test level for basic insulation, unless it can be determined that the fault did not result in any damage to the protective earthing conductor or terminal, or to protective bonding means; and
- c) by inspection to ensure a fuse connected between the protective earthing terminal and the protective earthing conductor in the test setup has not opened; the fuse shall be rated 3 A non-time-delay (for equipment rated for use on circuits protected by overcurrent protection rated 30 A or less) or 30 A to 35 A non-time-delay (for equipment rated for use on circuits protected by overcurrent protection rated more than 30 A); the enclosure is not to be contacting earth in any other location during the testing; and
- d) by inspection of the enclosure to ensure that no damage has resulted that allows access to parts that are hazardous live.

4.4.3.2 Protection against the spread of fire

Compliance with requirements for protection against the spread of fire is checked by placing the equipment on white tissue-paper covering a softwood surface and covering the equipment with cheesecloth or surgical cotton during the fault testing. As an alternative, the cheesecloth or surgical cotton may be placed only over the openings of large equipment.

There shall be no emission of molten metal, burning insulation, or flaming or glowing particles from the fire enclosure, and there shall be no charring, glowing, or flaming of the tissue paper or cheesecloth, or glowing or flaming of surgical cotton.

4.4.3.3 Protection against other hazards

Compliance with requirements for protection against other hazards after application of the fault tests is checked as specified elsewhere in this standard.

4.4.3.4 Protection against parts expulsion hazards

Failure of any component within the PCE shall not release parts outside the PCE enclosure with sufficient energy to lead to a hazard, for example, expulsion of material into an area occupied by personnel.

4.4.4 Single fault conditions to be applied

4.4.4.1 Component fault tests

Circuit analysis shall be performed to identify components (including insulation systems) whose failure would result in a fire or electric shock hazard. The analysis shall include the effect of short-circuit and open-circuit conditions of the component. Based on the analysis, faults shall be applied to relevant components in a manner that simulates the manner in which faults would occur in use. Components need only be faulted in a single mode (short-circuit or open-circuit), unless they do not have a predominant mode of failure.

Faults shall be applied using a switching device connected to the terminals of the component or port under test. Conductors used shall be as short as possible and of a cross-section approximately equal to that of the component leads, or equal to the largest conductor size that is specified in the instructions to be used to connect to the port. The switching device for a short-circuit test shall be of adequate current-carrying capacity and low enough impedance (relative to the conductors) to not significantly limit the current flow.

The PCE shall be operating before application of the fault, unless analysis shows that starting operation with the fault already applied will result in worst-case testing.

NOTE 1 In some cases both tests may be required.

The following faults are simulated:

- a) Short circuit or open circuit of relevant components.
- b) Short circuit or open circuit of any components or insulation where failure could adversely affect supplementary insulation or reinforced insulation.
- c) In addition, where required by Method 2 of 9.1.1, components that could result in a fire hazard are to be overloaded unless they comply with the requirements of 9.1.3.

NOTE 2 An overload condition is any condition between normal load and maximum current condition up to short circuit.

NOTE 3 The component fault testing does not need to include components for which equivalent testing is accomplished during other fault tests, such as output short-circuit tests.

4.4.4.2 Equipment or parts for short-term or intermittent operation

Components such as motors, relays, other electromagnetic devices and heaters, which are normally operated only intermittently, shall be operated continuously if continuous operation could occur in a single fault condition.

4.4.4.3 Motors

Motors shall be stopped while fully energized or prevented from starting, whichever is less favorable.

4.4.4.4 Transformer short circuit tests

The output windings of transformers shall be short-circuited one at a time. A transformer damaged during one test may be repaired or replaced before the next test.

4.4.4.5 Output short circuit

Each power output port of the PCE, and each section of a tapped output, shall be tested one at a time, to simulate short circuits in the load or wiring. Overcurrent protection devices as provided in the PCE or as specified in the installation instructions, shall be fitted during the test. All other outputs are loaded or not loaded, whichever load condition of normal use is less favorable.

Testing is required to be performed on all combinations of terminals for the port under consideration, two at a time, including neutral and earth terminals, and one test with all current-carrying terminals of the port shorted together at once. Where analysis shows that the test for one combination is representative of other combinations, tests may be omitted.

In addition to the requirements of 4.4.3, the short-circuit currents are to be recorded and if they exceed the maximum rated current of the circuit, the maximum measured current shall be provided in the installation manual for the purpose of coordination of overcurrent protection of the external circuit conductors (see 5.3.2).

The value(s) to be recorded and to be provided with the PCE instructions are the peak current, and the highest of the RMS current values measured or calculated over a time period as follows:

- a) for AC signals, 3 cycles of the nominal AC frequency for the port under consideration, in which case the value is to be stated as the 3-cycle RMS value;
- b) for all signals, the duration of the short circuit from the time the short circuit is applied, until the time the short circuit current is interrupted by a protective device or other mechanism, in which case the value stated is to include the RMS value and the time period in seconds;
- c) for short circuit tests that result in a continuous non-zero value, the steady-state RMS value, in which case the value is to be stated as a continuous RMS value.

NOTE Where the intended use of the short-circuit current information requires a different type of measurement, additional data may be provided. For example, for AC mains fault current contribution some utilities may prefer a ¼-cycle RMS or other RMS calculation to the 3-cycle RMS above.

4.4.4.6 Backfeed current test for equipment with more than one source of supply

For equipment intended to be connected simultaneously to more than one source of supply, each input of the PCE shall be tested one at a time, to determine if hazardous conditions can result from current from one source of supply flowing into the wiring for another source under fault conditions.

NOTE In this context, the word "source" is not meant to imply a direction of intended power flow into the PCE. "Source" means any circuit that is capable of delivering energy into the PCE or into another external connected circuit, under normal or single fault conditions, regardless of the intended direction of power flow under normal conditions.

With the PCE operating under normal conditions, a short circuit shall be applied at the field wiring terminals of the circuit under consideration, with all intended other sources connected to the PCE through the overcurrent protective devices (if any) intended to be present in the installation.

In addition to the requirements of 4.4.3, the short-circuit currents are to be recorded and if they exceed the maximum rated current for the port, the maximum measured current shall be

provided in the installation manual for the purpose of coordination of overcurrent protection of the external circuit conductors (see 5.3.2).

The values to be reported are as in a) to c) of 4.4.4.5 above.

4.4.4.7 Output overload

Each output of the PCE, and each section of a tapped output, shall be overloaded in turn, one at a time. The other windings are loaded or not loaded, whichever load condition of normal use is less favorable. Overloading is carried out by connecting a variable resistor across the winding. The resistor is adjusted as quickly as possible and readjusted, if necessary, after 1 min to maintain the applicable overload. No further readjustments are then permitted.

If overcurrent protection is provided by a current-sensitive device or circuit, the overload test current is the maximum current which the overcurrent protection device is just capable of passing for 1 h. If this value cannot be derived from the specification, it is to be established by test. Before the test, the device is made inoperative or replaced by a link with negligible impedance.

For equipment in which the output voltage is designed to collapse when a specified overload current is reached, the overload is slowly increased to the point of maximum output power before the point which causes the output voltage to collapse.

In all other cases, the loading is the maximum power output obtainable from the output.

4.4.4.8 Cooling system failure

Equipment cooling shall be faulted as follows, one fault at a time:

- a) air-intakes shall be blocked or partially blocked;
- b) cooling fans shall be stopped or disconnected, one at a time;
- c) cooling by circulation of water or other coolant shall be stopped or partially restricted.

4.4.4.9 Heating devices

In equipment incorporating heating devices, the following faults shall be applied one at a time:

- a) timers which limit the heating period shall be overridden to energize the heating circuit continuously;
- b) temperature control devices or circuits shall have single fault conditions applied such that control over the heater is lost. Over-temperature protection devices meeting the requirements of 14.3 are left operational during the test.

4.4.4.10 Safety interlock systems

Each part of an interlock system for the protection of operators shall be short-circuited or open-circuited in turn to determine if the system continues to prevent access to hazards when a cover, etc. can be removed without the use of a tool.

4.4.4.11 Reverse d.c. connections

Unless the means of connection prevents reversal, external d.c. connections shall be connected with reverse polarity.

4.4.4.12 Voltage selector mismatch

Equipment employing a voltage selector intended to be adjusted or set to match the supply voltage, is to have its voltage selector set in any position with the equipment connected to any of its rated supply circuits.

4.4.4.13 Mis-wiring with incorrect phase sequence or polarity

If connection to the a.c. supply with incorrect phase sequence or incorrect polarity of an earthed single-phase supply could result in a hazard, a mis-wiring test shall be applied.

4.4.4.14 Printed wiring board short-circuit test

Where permitted by 7.3.7.7, functional insulation on PWBs, provided by spacings that are less than those specified in Table 7 and Table 8 (see 7.3.7.7) shall be type tested as described below.

Each location of decreased spacings shall be short-circuited one at a time, and the short-circuit shall be maintained until no further damage occurs. Overcurrent protection integral to the PCE, or required to be used with the PCE, is allowed to open. During and after each test, the PCE shall comply with the requirements of 4.4.3.

4.5 Humidity preconditioning

4.5.1 General

Where required by other clauses of this standard as a pre-condition for another test, the EUT shall be subjected to the following humidity conditioning.

4.5.2 Conditions

The equipment is not operated during preconditioning. Electrical components, covers, and other parts, which can be removed by hand, are removed and subjected to the humidity preconditioning together with the main part.

Preconditioning is carried out in a humidity chamber containing air with a humidity of 92,5 % RH \pm 2,5 % RH. The temperature of the air in the chamber is maintained at 40 °C \pm 2 °C. Before applying humidity, the equipment is brought to a temperature of 42 °C \pm 2 °C, normally by keeping it at this temperature for at least 4 h before the humidity preconditioning. The air in the chamber is stirred and the chamber is designed or controlled so as to prevent condensation from forming on the equipment under test.

The equipment remains in the chamber for 48 h, after which it is removed and allowed a recovery period of 2 h under the environmental conditions of 4.2.2.1, with the covers of non-ventilated equipment removed, before application of the test for which the pre-conditioning was required.

4.6 Backfeed voltage protection

Under normal and single-fault conditions, hazardous voltage or energy shall not be present on the terminals of each source, with that source de-energized or disconnected. Disconnection or de-energizing of the source under test is considered a normal condition, not an applied fault.

The PCE is operated with all sources connected and energized that are intended to be present under normal operation.

Internal sources (for example internal batteries) that cannot be disconnected or de-energized without access to the inside of the PCE requiring use of a tool are not required to be tested.

A semiconductor device used to transfer energy between sources that are intended to be isolated from each other, is to be short circuited, and that short circuit is not considered to be a fault. Additional single faults are to be applied.

4.6.1 Backfeed tests under normal conditions

Each input source shall be tested separately by first disconnecting the source and then by de-energizing the source (if possible).

NOTE De-energizing is intended to simulate conditions where the source provides no voltage or current, but the supply equipment and other loads on that circuit remain connected, which may result in a low impedance presented to the PCE as opposed to the high impedance presented when the source is disconnected. Examples of de-energized sources include a PV array not exposed to light, and a mains outage.

4.6.2 Backfeed tests under single-fault conditions

The tests in 4.6.1 are repeated for each single fault condition under consideration. Faults to be applied are selected based on analysis of schematics of the circuitry with particular attention to devices that control or transfer energy between different sources.

4.6.3 Compliance with backfeed tests

The PCE is compliant with the requirements if during the tests in 4.6.1 and 4.6.2 no hazardous voltage or energy is present on the PCE terminals for the source under test. Measurements are taken 15 s or 1 s after the source is de-energized or disconnected, as follows:

- 15 s for sources that are permanently connected;
- 1 s for sources that are cord-connected or use connectors that can be opened without the use of a tool .

4.7 Electrical ratings tests

4.7.1 Input ratings

While operating under the reference test conditions of 4.2.2, the measured continuous input current or power, as applicable, shall not exceed the marked input ratings by more than 10 %.

4.7.1.1 Measurement requirements for DC input ports

Measurements of the DC input current to an inverter shall be made with a meter that indicates the true RMS sum of the DC and AC components.

NOTE Due to the a.c. component of the current that inverters draw from their d.c. source, the input current shall be measured with an instrument that reads the true RMS sum of the d.c. and a.c. components in order to allow proper selection of the connectors, fuses and conductors that will be connected to the inverter in the installation, to prevent overheating.

4.7.2 Output ratings

While operating under the reference test conditions of 4.2.2, each output port of the PCE shall be capable of providing its marked output power or current ratings, as applicable, without overcurrent protective devices operating and without shutdown due to operation of overtemperature protection systems. The measured continuous output current or power, as applicable, shall not exceed the marked output ratings by more than 10 %.

5 Marking and documentation

5.1 Marking

5.1.1 General

Equipment shall bear markings as specified in 5.1 and 5.2.

Except for marking of internal parts, these markings shall be visible from the exterior after installation, or be visible after removing a cover or opening a door without the aid of a tool, if

the cover or door is intended to be removed or opened by an operator. Markings applying to the equipment as a whole shall not be put on parts which can be removed by an operator without the use of a tool.

For rack- or panel-mounted equipment, markings are permitted to be on a surface that becomes visible after removal of the equipment from the rack or panel.

Graphic symbols may be used and shall be in accordance with Annex C or IEC 60417 as applicable. Graphic symbols shall be explained in the documentation provided with the PCE.

Compliance is checked by inspection.

5.1.2 Durability of markings

Markings required by this clause to be located on the PCE shall remain clear and legible under conditions of normal use and resist the effects of cleaning agents specified by the manufacturer.

Compliance is checked by inspection and by performing the following test for durability of markings on the outside of the equipment. The markings are rubbed quickly by hand, without undue pressure, for 30 s with a cloth soaked with the specified cleaning agent (or, if not specified, with isopropyl alcohol). The markings shall be clearly legible after the above treatment, and adhesive labels shall not have worked loose or become curled at the edges.

5.1.3 Identification

The equipment shall, as a minimum, be permanently marked with:

- a) the name or trade mark of the manufacturer or supplier;
- b) a model number, name or other means to identify the equipment,
- c) a serial number, code or other marking allowing identification of manufacturing location and the manufacturing batch or date within a three month time period.

Compliance is checked by inspection.

5.1.4 Equipment ratings

Unless otherwise specified in another part of IEC 62109, the following ratings, as applicable, shall be marked on the equipment:

- input voltage, type of voltage (a.c. or d.c.), frequency, and maximum continuous current for each input;
- output voltage, type of voltage (a.c. or d.c.), frequency, maximum continuous current, and for a.c. outputs, either the power or power factor for each output;
- the ingress protection (IP) rating as in 6.3 below.

Compliance is checked by inspection.

5.1.5 Fuse identification

Marking shall be located adjacent to each fuse or fuseholder, or on the fuseholder, or in another location provided that it is obvious to which fuse the marking applies, giving the fuse current rating and, where fuses of different voltage rating value could be fitted, the fuse voltage rating.

Where fuses with special fusing characteristics such as time delay or breaking capacity are necessary, the type shall also be indicated.

For fuses not located in operator access areas and for soldered-in fuses located in operator access areas, it is permitted to provide an unambiguous cross-reference (for example, F1, F2, etc.) to the servicing instructions which shall contain the relevant information.

Compliance is checked by inspection.

5.1.6 Terminals, connections and controls

If necessary for safety, an indication shall be given of the purpose of terminals, connectors, controls, and indicators, and their various positions, including any connections for coolant fluids such as water and drainage. The symbols in Annex C may be used, and where there is insufficient space, symbol 9 of Annex C may be used.

NOTE Individual pins of multi-pin signal, control, and communication connectors need not be marked.

Push-buttons and actuators of emergency stop devices, and indicator lamps used only to indicate a warning of danger or the need for urgent action, shall be coloured red.

A multiple-voltage unit shall be marked to indicate the particular voltage for which it is set when shipped from the factory. The marking is allowed to be in the form of a paper tag or any other non-permanent material.

A unit with d.c. terminals shall be plainly marked indicating the polarity of the connections, with:

- the signs “+” for positive and “–” for negative; or
- a pictorial representation illustrating the proper polarity where the correct polarity can be unambiguously determined from the representation.

Compliance is checked by inspection.

5.1.6.1 Protective conductor terminals

The means of connection for the protective earthing conductor shall be marked with:

- symbol 7 of Annex C; or
- the letters "PE"; or
- the colour coding green-yellow.

Compliance is checked by inspection.

5.1.7 Switches and circuit-breakers

The on and off-positions of switches and circuit breakers shall be clearly marked. If a push-button switch is used as the power switch, symbols 10 and 16 of Annex C may be used to indicate the on-position, or symbols 11 and 17 to indicate the off-position, with the pair of symbols (10 and 16, or 11 and 17) close together.

Compliance is checked by inspection.

5.1.8 Class II equipment

Equipment using Class II protective means throughout shall be marked with symbol 12 of Annex C. Equipment which is only partially protected by double insulation or reinforced insulation shall not bear symbol 12 of Annex C.

Where such equipment has provision for the connection of an earthing conductor for functional reasons (see 7.3.6.4) it shall be marked with symbol 6 of Annex C.

Compliance is checked by inspection.

5.1.9 Terminal boxes for external connections

Where required by note 1 of Table 2 as a result of high temperatures of terminals or parts in the wiring compartment, there shall be a marking, visible beside the terminal before connection, of either:

- a) the minimum temperature rating and size of the cable to be connected to the terminals;
- or
- b) a marking to warn the installer to consult the installation instructions. Symbol 9 of Annex C is an acceptable marking.

Compliance is checked by visual inspection and by the temperature measurements of 4.3.

5.2 Warning markings

5.2.1 Visibility and legibility requirements for warning markings

Warning markings shall be visible when the equipment is installed and ready for normal use. If a warning applies to a particular part of the equipment, the marking shall be placed on, or near to, this part.

Warning markings shall be legible, and shall have minimum dimensions as follows:

- Printed symbols shall be at least 2,75 mm high.
- Printed text characters shall be at least 1,5 mm high, whether upper case or lower case, and shall contrast in colour with the background.
- Symbols or text that are moulded, stamped or engraved in a material shall have a character height of at least 2,0 mm, whether upper case or lower case, and if not contrasting in colour from the background, shall have a depth or raised height of at least 0,5 mm.

If it is necessary to refer to the instruction manual to preserve the protection afforded by the equipment, the equipment shall be marked with symbol 9 of Annex C.

Symbol 9 of Annex C is not required to be used adjacent to symbols that are explained in the manual.

Compliance is checked by inspection.

5.2.2 Content for warning markings

5.2.2.1 Ungrounded heatsinks and similar parts

An ungrounded heat sink or other part that may be mistaken for a grounded part and involves a risk of electric shock in accordance with 7.3 shall be marked with symbol 13 of Annex C, or equivalent. The marking may be on or adjacent to the heatsink and shall be clearly visible when the PCE is disassembled to the extent that a risk of contact with the heatsink exists.

Compliance is checked by inspection.

5.2.2.2 Hot surfaces

A part of the PCE that exceeds the temperature limits specified in 4.3.2 shall be marked with symbol 14 of Annex C.

Compliance is checked by inspection and by measurements in accordance with 4.3.

5.2.2.3 Coolant

A unit containing coolant that exceeds 70 °C shall be legibly marked externally where readily visible after installation with symbol 15 of Annex C. The documentation shall provide a warning regarding the risk of burns from hot coolant, and either:

- a) a statement that coolant system servicing is to be done only by service personnel, or
- b) instructions for safe venting, draining, or otherwise working on the cooling system, if these operations can be performed without operator access to hazards internal to the equipment

Compliance is checked by inspection and by measurements in accordance with 4.3.

5.2.2.4 Stored energy

Where required by 7.3.9.2 or 7.4.2 the PCE shall be marked with Symbol 21 of Annex C and the time to discharge capacitors to safe voltage and energy levels shall accompany the symbol.

Compliance is checked by inspection.

5.2.2.5 Motor guarding

Where required by 8.2 a marking shall be provided where it is visible to service personnel before removal of a guard, warning of the hazard and giving instructions for safe servicing (for example disconnection of the source before removing the guard).

Compliance is checked by inspection.

5.2.3 Sonic hazard markings and instructions

If required by 10.2.1 a PCE shall:

- a) be marked to warn the operator of the sonic pressure hazard; or
- b) be provided with installation instructions that specify how the installer can ensure that the sound pressure level from equipment, at its point of use after installation, will not reach a value, which could cause a hazard. These instructions shall include the measured sound pressure level, and shall identify readily available and practicable protective materials or measures which may be used.

Compliance is checked by inspection and by measurements in accordance with Clause 10.

5.2.4 Equipment with multiple sources of supply

A PCE with connections for multiple energy sources shall be marked with symbol 13 of Annex C and the manual shall contain the information required in 5.3.4.

The symbol shall be located on the outside of the unit or shall be prominently visible behind any cover giving access to hazardous parts.

Compliance is checked by inspection.

5.2.5 Excessive touch current

Where required by 7.3.6.3.7 the PCE shall be marked with symbol 15 of Annex C. See also 5.3.2 for information to be provided in the installation manual.

Compliance is checked by inspection.

5.3 Documentation

5.3.1 General

The documentation provided with the PCE shall provide the information needed for the safe operation, installation, and (where applicable) maintenance of the equipment. The documentation shall include the items required in 5.3.2 through 5.3.4, and the following:

- a) explanations of equipment markings, including symbols used;
- b) location and function of terminals and controls;
- c) all ratings or specifications that are necessary to safely install and operate the PCE, including the following environmental ratings along with an explanation of their meaning and any resulting installation requirements:
 - Environmental category as per 6.1
 - Wet locations classification as per 6.1
 - Pollution degree classification for the intended external environment as per 6.2
 - Ingress protection rating as per 6.3
 - Ambient temperature and relative humidity ratings
 - Maximum altitude rating
 - Overvoltage category assigned to each input and output port as per 7.3.7.1.2, accompanied by guidance regarding how to ensure that the installation complies with the required overvoltage categories;

NOTE Installers may not be familiar with the term overvoltage category and its implications. The required guidance is intended to explain the requirements in terms an installer will understand, such as describing appropriate points of connection or specifying transient overvoltage protective means.

- d) a warning that when the photovoltaic array is exposed to light, it supplies a d.c. voltage to the PCE.

Compliance is checked by inspection.

5.3.1.1 Language

Instructions related to safety shall be in a language that is acceptable in the country where the equipment is to be installed.

Compliance is checked by inspection.

5.3.1.2 Format

In general, the documentation shall be provided in printed form and is to be delivered with the equipment.

NOTE An electronic format copy of the documentation may accompany the printed format, but may not replace it.

For equipment which requires the use of a computer for both installation and operation, documentation may be provided in electronic format without accompanying printed format.

Compliance with clauses 5.3.1 to 5.3.3 is shown by inspection.

5.3.2 Information related to installation

The documentation shall include installation and where applicable, specific commissioning instructions and, if necessary for safety, warnings against hazards which could arise during installation or commissioning of the equipment. The information provided shall include:

- a) assembly, location, and mounting requirements;

- b) ratings and means of connection to each source of supply and any requirements related to wiring and external controls, colour coding of leads, disconnection means, or overcurrent protection needed, including instructions that the installation position shall not prevent access to the disconnection means;
- c) ratings and means of connection of any outputs from the PCE, and any requirements related to wiring and external controls, colour coding of leads, or overcurrent protection needed;
- d) explanation of the pin-out of connectors for external connections, unless the connector is used for a standard purpose (e.g. RS 232);
- e) ventilation requirements;
- f) requirements for special services, for example cooling liquid;
- g) instructions and information relating to sound pressure level if required by 10.2.1;
- h) where required by 14.8.1.3, instructions for the adequate ventilation of the room or location in which PCE containing vented or valve-regulated batteries is located, to prevent the accumulation of hazardous gases;
- i) tightening torque to be applied to wiring terminals;
- j) values of backfeed short-circuit currents available from the PCE on input and output conductors under fault conditions, if those currents exceed the max. rated current of the circuit, as per 4.4.4.6;
- k) for each input to the PCE, the maximum value of short-circuit current available from the source, for which the PCE is designed; and

NOTE This input short-circuit current rating applies to ports such as the mains, PV input, and battery circuits, it is not intended for low power signal, control, or communications circuits.

- l) compatibility with RCD and RCM;
- m) instructions for protective earthing of the PCE, including the information required by 7.3.6.3.7 if a second protective earthing conductor is to be installed;
- n) where required by 7.3.8, the installation instructions shall include the following or equivalent wording:

“This product can cause current with a d.c. component. Where a residual current-operated protective (RCD) or monitoring (RCM) device is used for protection in case of direct or indirect contact, only an RCD or RCM of Type B is allowed on the supply side of this product.”
- o) for PCE intended to charge batteries, the battery nominal voltage rating, size, and type;
- p) PV array configuration information, such as ratings, whether the array is to be grounded or floating, any external protection devices needed, etc.

Compliance is checked by inspection.

5.3.3 Information related to operation

Instructions for use shall include any operating instructions necessary to ensure safe operation, including the following, as applicable:

- instructions for adjustment of controls including the effects of adjustment;
- instructions for interconnection to accessories and other equipment, including indication of suitable accessories, detachable parts and any special materials;
- warnings regarding the risk of burns from surfaces permitted to exceed the temperature limits of 4.3.2 and required operator actions to reduce the risk; and
- instructions that if the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

Compliance is checked by inspection.

5.3.4 Information related to maintenance

Maintenance instructions shall include the following:

- intervals and instructions for any preventive maintenance that is required to maintain safety (for example air filter replacement or periodic re-tightening of terminals);
- instructions for accessing operator access areas, if any are present, including a warning not to enter other areas of the equipment;
- part numbers and instructions for obtaining any required operator replaceable parts;
- instructions for safe cleaning (if recommended);
- where there is more than one source of supply energizing the PCE, information shall be provided in the manual to indicate which disconnect device or devices are required to be operated in order to completely isolate the equipment.

Compliance is shown by inspection.

5.3.4.1 Battery maintenance

Where required by 14.8.5, the documentation shall include the applicable items from the following list of instructions regarding maintenance of batteries:

NOTE The exact wording below does not have to be used as long as the intended information is provided.

- Servicing of batteries should be performed or supervised by personnel knowledgeable about batteries and the required precautions.
- When replacing batteries, replace with the same type and number of batteries or battery packs.
- General instructions regarding removal and installation of batteries.
- CAUTION: Do not dispose of batteries in a fire. The batteries may explode.
- CAUTION: Do not open or damage batteries. Released electrolyte is harmful to the skin and eyes. It may be toxic.
- CAUTION: A battery can present a risk of electrical shock and high short-circuit current. The following precautions should be observed when working on batteries:
 - a) Remove watches, rings, or other metal objects.
 - b) Use tools with insulated handles.
 - c) Wear rubber gloves and boots.
 - d) Do not lay tools or metal parts on top of batteries.
 - e) Disconnect charging source prior to connecting or disconnecting battery terminals.
 - f) Determine if battery is inadvertently grounded. If inadvertently grounded, remove source from ground. Contact with any part of a grounded battery can result in electrical shock. The likelihood of such shock can be reduced if such grounds are removed during installation and maintenance (applicable to equipment and remote battery supplies not having a grounded supply circuit).

Compliance is checked by inspection.

6 Environmental requirements and conditions

The manufacturer shall rate the PCE for the following environmental conditions:

- Environmental category, as in 6.1 below
- Suitability for wet locations or not
- Pollution degree rating, as in 6.2 below
- Ingress protection (IP) rating, as in 6.3 below

- Ultraviolet (UV) exposure rating, as in 6.4 below
- Ambient temperature and relative humidity ratings, as in 6.5 below

The documentation provided with the PCE shall include these ratings as per 5.3.1. In addition, the rating, as in 6.3 below shall be marked on the equipment as per 5.1.4.

These parameters are subject to minimum requirements, test, and examination, as given in the following clauses and in Table 4.

Compliance is shown by inspection.

6.1 Environmental categories and minimum environmental conditions

The PCE environmental categories are defined as follows:

NOTE The term environmental category replaces the term “service use” used in IEC 62093 to avoid confusion between two meanings of “service” (use vs. maintenance).

6.1.1 Outdoor

The PCE is fully or partly exposed to direct rain, sun, wind, dust, fungus, ice, condensation, radiation to the cold night sky, etc., and to the full range of outdoor temperature and humidity. Wet location requirements apply.

6.1.2 Indoor, unconditioned

The PCE is fully covered by a building or enclosure to protect it from direct rain, sun, wind-blown dust, fungus, and radiation to the cold night sky, etc., but the building or enclosure is not conditioned in terms of temperature, humidity or air filtration, and the equipment may experience condensation. If the PCE is not rated for and evaluated for wet location use, then the installation instructions shall specify that the installation location must be dry, except for condensation.

6.1.3 Indoor, conditioned

The PCE is fully covered by a building or enclosure to fully protect it from rain, sun, wind-blown dust, fungus, and radiation to the cold night sky, etc., and the building or enclosure is generally conditioned in terms of temperature, humidity and air filtration. Condensation is not expected. If the PCE is not rated for and evaluated for wet location use, then the installation instructions shall specify that the installation location must be dry, including no expected condensation.

Table 4 – Environmental categories, environmental conditions, and test requirements

Rating	Minimum environmental conditions		
	Per the manufacturer’s specifications, subject to the following minimum requirements ⁴		
	Outdoor	Indoor, unconditioned	Indoor, conditioned
Pollution degree ¹	Min. PD3	Min. PD3	Min. PD2
Wet location	Yes	No	No

Rating	Minimum environmental conditions Per the manufacturer's specifications, subject to the following minimum requirements ⁴		
	Outdoor	Indoor, unconditioned	Indoor, conditioned
Ingress protection ²	Min. IP34 ³	Min. IP20	Min. IP20
Ambient service temperature range	-20 °C to +50 °C	-20 °C to +50 °C	+0 °C to +40 °C
Relative humidity range	4 % to 100 % (Condensing)	5 % to 95 % (Non condensing)	5 % to 85 % (Non condensing)
UV exposure	Required	Not required	Not required

¹ This is the pollution degree of the external environment. See also 6.2 regarding reduction of pollution degree in specific areas internal to the equipment.

² These requirements are in addition to the requirements of other clauses of this standard which may be more stringent, concerning access to live parts and mechanical hazards, and containment of fire hazards.

³ Attention is brought to the fact that this IP34 requirement is not as stringent as the IP44 requirement in IEC 62093 for environmental qualification of PV components.

⁴ This table defines the PCE safe environmental operating range and is not intended to specify operational performance.

6.2 Pollution degree

The manufacturer's stated pollution degree rating shall be used when determining the required creepage and clearance distances in 7.3.7. The stated pollution degree rating shall comply with above and with the definitions in 3.60 through 3.63.

NOTE Pollution degree 4 is not covered by this standard. PCE intended for use in pollution degree 4 environments shall be provided with means to reduce the micro-environment to pollution degree 1, 2, or 3.

The pollution degree is increased within certain areas of the equipment where the equipment itself may generate contamination or moisture (for example condensation caused by a cooling system, or conductive contamination from motor brushes).

The pollution degree may be reduced within certain areas of the equipment by the use of encapsulation, conformal coating, etc., as in Table 5 and Clause 7. Reduction of pollution degree within the overall equipment may also be achieved, by the use of enclosures providing protection as in Table 5.

Table 5 – Reduction of the pollution degree of internal environment through the use of additional protection

Additional protection	From pollution degree 2 of external environment to:	From pollution degree 3 of external environment to:	Area to which the reduced pollution degree applies
Enclosure IP5X dust test of IEC 60529 and no internally generated contamination	1	2	entire inside of the enclosure or that portion which meets IP5X

Additional protection	From pollution degree 2 of external environment to:	From pollution degree 3 of external environment to:	Area to which the reduced pollution degree applies
Enclosure IPX7 or IPX8 of IEC 60529	2	2	entire inside of the enclosure or that portion which meets IPX7 or IPX8
Type 1 (see 7.3.7.8.4.2) conformal coating or potting (see 7.3.7.8.6)	1	1	area under the coating or potting
Type 2 (see 7.3.7.8.4.2) conformal coating or potting (see 7.3.7.8.6)	treated as solid insulation	treated as solid insulation	area under the coating or potting
Hermetically sealed enclosure with measures taken to exclude pollution before sealing, and no internally generated contamination	1	1	sealed portion of the enclosure

6.3 Ingress protection

The manufacturer's stated ingress protection rating shall comply with Table 4 and shall be verified in accordance with IEC 60529.

These requirements are in addition to the requirements of other clauses of this standard concerning access to live parts, fire hazards and mechanical hazards.

Compliance is checked by testing in accordance with IEC 60529.

Protection against ingress of water is verified by the applicable tests in IEC 60529, followed by visual inspection, the voltage test of 7.5.2, and the touch current test of 7.5.4 if required by 7.3.6.3.7.

6.4 UV exposure

External plastic parts of equipment for outdoor service shall not be degraded by exposure to UV light to the extent that protection against hazards is reduced below levels given in 13.6.4. If required by Table 4, the polymeric material shall have been evaluated for ultraviolet (UV) radiation resistance as determined in accordance with 13.6.4. If degradation of the parts could not affect the protection provided, this requirement is waived.

6.5 Temperature and humidity

The manufacturer's stated ranges of ambient temperature and relative humidity are used elsewhere in this standard to determine preconditioning and test parameters.

7 Protection against electric shock and energy hazards

7.1 General

This clause 7 defines the minimum requirements for the design and construction of PCE for protection against shock and energy hazards during installation, operation, and maintenance, under normal and single fault conditions, for the expected lifetime of the PCE. Consideration is also given to minimizing hazards resulting from reasonably foreseeable misuse.

7.2 Fault conditions

Protection against electric shock and energy hazards shall be maintained under normal and single fault conditions.

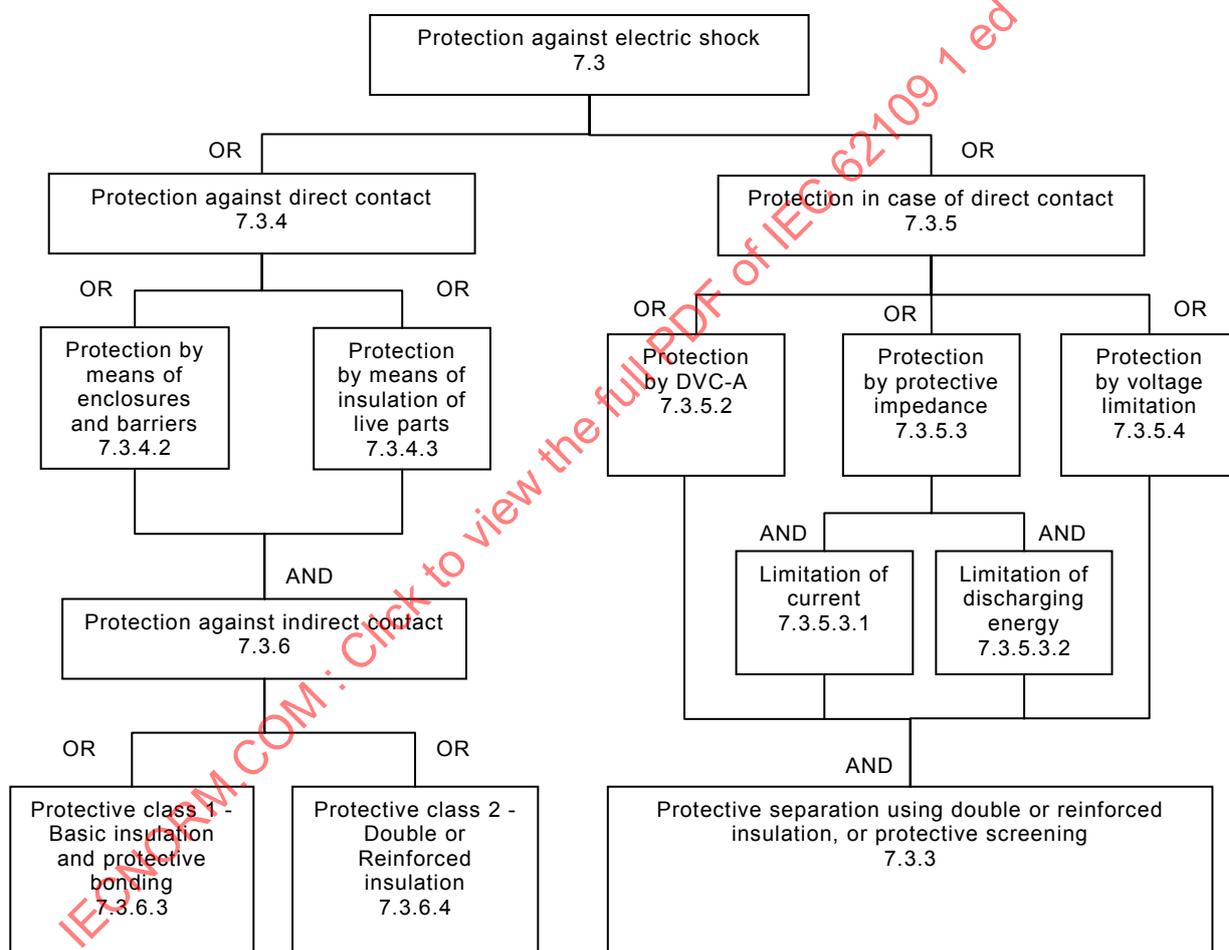
Compliance is checked by inspection, by analysis of normal and fault scenarios, and by the tests of 4.4.

7.3 Protection against electric shock

7.3.1 General

Each circuit under evaluation shall be compliant with Figure 1, which presents a summary of possible design solutions with regard to protection against electric shock arising from direct and indirect contact.

The decisive voltage class of each circuit in the PCE, as per 7.3.2, determines the minimum required level of protection.



IEC 585/10

Figure 1 – Functional summary of protective measures against electric shock

NOTE Different circuits, insulation, and parts of the PCE will use different approaches for protection against shock hazards, and different paths through this flow-chart.

7.3.2 Decisive voltage classification

7.3.2.1 Use of decisive voltage class (DVC)

Protective measures against electric shock depend on the decisive voltage classification of the circuit, which is determined from Table 6 and 7.3.2.4. The decisive voltage classification for a circuit is the least severe classification for which both of the following are complied with:

- the working voltage limits of Table 6, and
- the applicable protective measures of 7.3.2.4.

The DVC in turn indicates the minimum required level of protection for the circuit. Circuits complying with the requirements for DVC-A are considered safe to touch. DVC-B and DVC-C circuits shall not be accessible unless they comply with the requirements for protection in case of direct contact in 7.3.5.

If the protective measures of 7.3.2.4 are not met, the decisive voltage classification of a circuit shall be raised to a more severe classification even if the working voltage limits of Table 6 are met.

If two circuits are connected, or are separated only by functional insulation, they are treated as a single circuit (not as “adjacent circuits”) in determining decisive voltage classification and in applying 7.3.2.4.

7.3.2.2 Limits of DVC

The voltage limits for each DVC level are given in Table 6.

Table 6 – Summary of the limits of the decisive voltage classes

Decisive voltage Classification (DVC)	Limits of working voltage V		
	a.c. voltage r.m.s. U_{ACL}	a.c. voltage peak U_{ACPL}	d.c. voltage mean U_{DCL}
	A*	≤25 (16)	≤35,4 (22,6)
B	50 (33)	71 (46,7)	120 (70)
C	>50 (>33)	>71 (>46,7)	>120 (>70)

The table values in parentheses are to be used for PCE or portions of PCEs rated for installation in wet locations as addressed in 6.1 for environmental categories and minimum environmental conditions.

*DVC-A circuits are allowed under fault conditions to have voltages up to the DVC-B limits, for maximum 0,2 s.

7.3.2.3 Short-term limits of accessible voltages under fault conditions

The non-recurring voltage allowable on accessible live or conductive parts under fault conditions shall not exceed DVC-A limits, except that voltages up to the DVC-B limits are allowed if the duration for which the voltage exceeds DVC-A levels does not exceed 0,2 s.

7.3.2.4 Requirements for protection

Protection shall be provided that ensures that no single fault, including faults to functional, basic, or supplemental insulation, can result in a voltage higher than the DVC-A limits appearing on an accessible circuit or accessible conductive part.

Accessible earthed conductive parts shall be separated from DVC-B and DVC-C circuits by at least basic insulation.

Accessible circuits shall comply with the requirements for protection in case of direct contact in 7.3.5.

Accessible un-earthed conductive parts shall be separated from DVC-B and DVC-C circuits by reinforced or double insulation or by protective separation.

Table 7 shows examples that meet the requirements for the application of functional and basic insulation or protective separation, dependent on the DVC of the circuit under consideration and of adjacent circuits.

NOTE Examples are shown in Annex I.

Table 7 – Examples of application of insulation and separation

DVC of considered circuit	Protection required against direct contact per 7.3.4	Insulation to earthed parts	Insulation to adjacent accessible conductive parts that are not earthed	Insulation to adjacent circuit of DVC:		
				A	B	C
A	No	f	f	f	p ¹⁾	P ²⁾
B	Yes	b	p		B ¹⁾	B ¹⁾
C	Yes	b	p			B ¹⁾

f functional insulation; for adjacent circuits insulation is based on the circuit of higher voltage.
 b basic insulation; for adjacent circuits insulation is based on the circuit of higher voltage.
 p protective separation; for adjacent circuits insulation is based on the circuit of higher voltage.
 1) functional insulation is permitted if both the considered circuit and the adjacent circuit are separated from accessible conductive parts and from DVC-A circuits by insulation or separation that ensures adequate protection based on the circuit of highest voltage.
 2) it is permitted to use basic insulation between the considered circuit and the DVC-B or -C circuit if protection against direct contact with the considered circuit is provided by basic or supplementary insulation or barriers or enclosures. The protection against direct contact with the considered circuit shall be based on the voltage of the DVC-B or -C circuit - see 7.3.4.2 and 7.3.4.3.

7.3.2.5 Connection to PELV and SELV circuits

If it is intended to connect signal, communication, or control ports of the PCE to external PELV or SELV devices or circuits, the compatibility of the different systems shall be determined, such that:

- the PELV or SELV classification of the external circuit is not changed, and
- the DVC classification of the external port of the PCE is not changed.

NOTE Consideration needs to be given to factors such as whether the circuits involved are earthed or not, what the voltages involved are, whether or not direct contact with live parts is possible, single faults in either equipment or the interconnections, etc.

7.3.2.6 Working voltage and DVC

7.3.2.6.1 General

The working voltage used in determining the decisive voltage classification of a given circuit is evaluated by the method set out below.

Working voltage shall be based on operation of the PCE under the worst case combination of highest and lowest rated voltages for each port, and under worst-case normal operating conditions.

NOTE 1 Transients and voltage fluctuations are disregarded.

NOTE 2 Determining worst-case normal operating conditions requires consideration of factors such as loading from open-circuit to full load, operating mode, etc.

Three cases of waveforms are considered.

7.3.2.6.2 AC working voltage (see Figure 2)

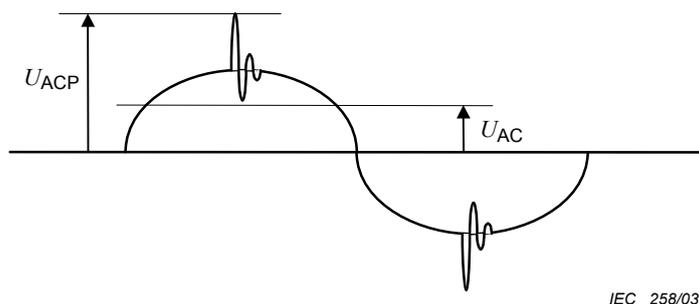


Figure 2 – Typical waveform for a.c. working voltage

The working voltage has an r.m.s. value U_{AC} and a recurring peak value U_{ACP} .

The DVC is that of the lowest voltage row of Table 6 for which both of the following conditions are satisfied.

- $U_{AC} \leq U_{ACL}$
- $U_{ACP} \leq U_{ACPL}$

7.3.2.6.3 DC working voltage (see Figure 3)

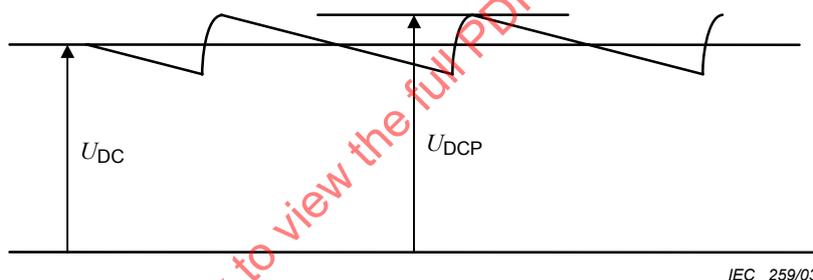


Figure 3 – Typical waveform for d.c. working voltage

The working voltage has a mean value U_{DC} and a recurring peak value U_{DCP} , caused by a ripple voltage of r.m.s. value not greater than 10 % of U_{DC} .

The DVC is that of the lowest voltage row of Table 6 for which both of the following conditions are satisfied.

- $U_{DC} \leq U_{DCL}$
- $U_{DCP} \leq 1,17 \times U_{DCL}$

7.3.2.6.4 Pulsating working voltage (see Figure 4)

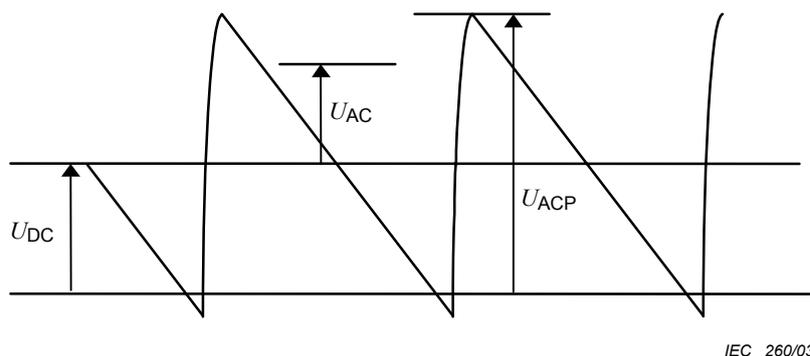


Figure 4 – Typical waveform for pulsating working voltage

The working voltage has a mean value U_{DC} and a recurring peak value U_{ACP} , caused by a ripple voltage of r.m.s. value U_{AC} greater than 10 % of U_{DC} .

The DVC is that of the lowest voltage row of Table 6 for which both of the following conditions are satisfied.

- $U_{AC}/U_{ACL} + U_{DC}/U_{DCL} \leq 1$
- $U_{ACP}/U_{ACPL} + U_{DC}/(1,17 \times U_{DCL}) \leq 1$

7.3.3 Protective separation

Protective separation shall be achieved by:

- double or reinforced insulation,

or

- protective screening, i.e. by a conductive screen connected to earth by protective bonding in the PCE, or connected to the protective earth conductor itself, whereby the screen is separated from live parts by at least basic insulation,

or

- protective impedance comprising limitation of current per 7.3.5.3.1 and of discharged energy per 7.3.5.3.2,

or

- limitation of voltage according to 7.3.5.4.

The protective separation shall be fully and effectively maintained under all conditions of intended use of the PCE.

7.3.4 Protection against direct contact

7.3.4.1 General

Protection against direct contact is employed to prevent persons from touching live parts that do not meet the requirements of 7.3.5 and shall be provided by one or more of the measures given in 7.3.4.2 (enclosures and barriers) and 7.3.4.3 (insulation).

Open type sub-assemblies and devices do not require protective measures against direct contact but the instructions provided with the equipment shall indicate that such measures must be provided in the end equipment or in the installation.

Products intended for installation in closed electrical operating areas, (see 3.9) need not have protective measures against direct contact, except as required by 7.3.4.2.4.

NOTE Some local regulations require guarding against inadvertent contact with hazardous parts even in closed electrical operating areas.

7.3.4.2 Protection by means of enclosures and barriers

The following requirements apply where protection against contact with live parts is provided by enclosures or barriers, not by insulation in accordance with 7.3.4.3.

7.3.4.2.1 General

Parts of enclosures and barriers that provide protection in accordance with these requirements shall not be removable without the use of a tool (see 7.3.4.2.3).

Polymeric materials used to meet these requirements shall also meet the requirements of 13.6.

7.3.4.2.2 Access probe criteria

Protection is considered to be achieved when the separation between the test probes and live parts, when tested as described below, is as follows:

- a) decisive voltage classification A, (DVC A) - the probe may touch the live parts;
- b) decisive voltage classification B, (DVC B) - the probe shall have adequate clearance to live parts, based on the clearance for functional insulation (see Note 1);
- c) decisive voltage classification C, (DVC C) - the probe shall have adequate clearance to live parts, based on the clearance for basic insulation (see Note 2).

NOTE 1 Functional insulation is allowed because inserting a finger into an opening is considered to be the first fault.

NOTE 2 Basic insulation is allowed because inserting a finger into an opening is considered to be the first fault.

NOTE 3 Figure 5 row 4 gives examples of the probe requirements for openings in the enclosure.

7.3.4.2.3 Access probe tests

Compliance with 7.3.4.2.1 is checked by all of the following:

- a) Inspection; and
- b) Tests with the test finger (Figure D.1) and test pin (Figure D.2) of Annex D, the results of which shall comply with the requirements of 7.3.4.2.1 a), b), and c) as applicable. Probe tests are performed on openings in the enclosures after removal of parts that can be detached or opened by an operator without the use of a tool, including fuseholders, and with operator access doors and covers open. It is permitted to leave lamps in place for this test. Connectors that can be separated by an operator without use of a tool, shall also be tested during and after disconnection. Any movable parts are to be put in the most unfavourable position.

The test finger and the test pin are applied as above, without appreciable force, in every possible position, except that floor-standing equipment having a mass exceeding 40 kg is not tilted.

Equipment intended for building-in or rack mounting, or for incorporation in larger equipment, is tested with access to the equipment limited according to the method of mounting detailed in the installation instructions.

c) Openings preventing the entry of the jointed test finger (Figure D.1 of Annex D) during test b) above, are further tested by means of a straight unjointed test finger (Figure D.3 of Annex D), applied with a force of 30 N. If the unjointed finger enters, the test with the jointed finger is repeated except that the finger is applied using any necessary force up to 30 N.

d) In addition to a) to c) above, top surfaces of enclosures shall be tested with the IP3X probe of IEC 60529. The test probe shall not penetrate the top surface of the enclosure when probed from the vertical direction $\pm 5^\circ$ only.

7.3.4.2.4 Service access areas

Where the enclosure is required to be opened and the PCE is energized during installation or maintenance, live parts of DVC B or C that may be unintentionally touched when making adjustments shall be protected against contact by the finger probe of Figure D.1 of Annex D.

7.3.4.3 Protection by means of insulation of live parts

Where the requirements of 7.3.4.2 are not met, live parts shall be provided with insulation if:

- their working voltage is greater than the maximum limit of decisive voltage class A, or
- for a DVC A or B circuit, protective separation from adjacent circuits of DVC C is not provided (see note 2) under Table 7).

The insulation shall be rated according to the impulse voltage, temporary overvoltage or working voltage (see 7.3.7.2.1), whichever gives the most severe requirement. It shall not be possible to remove the insulation without the use of a tool. The insulation shall extend as far as necessary to ensure compliance with the probe test of 7.3.4.2.1.

Any conductive part, which is not separated from DVC-B or DVC-C parts by at least basic insulation is considered to be a live part. A metallic accessible part is considered to be conductive, if its surface is bare or is covered by an insulating layer which does not comply with the requirements of basic insulation.

As an alternative to solid or liquid insulation, a clearance according to 7.3.7.4, shown by L_B and L_R in Figure 5, may be provided.

The grade of insulation – functional, basic, double or reinforced – depends on:

- the decisive voltage class of the live parts or adjacent circuits, and
- the connection of conductive parts to earth by protective bonding.

Three cases are considered:

Case a) Accessible parts are conductive and are connected to earth by protective bonding.

- Basic insulation is required between accessible parts and the live parts. The relevant voltage is that of the live parts (see Figure 5, cells 1)a), 2)a), 3)a)).
- Functional insulation is required between accessible parts and live parts of inaccessible circuits of DVC-A which are separated by only basic insulation from adjacent circuits of decisive voltage class C. The relevant voltage is the highest voltage of the DVC-C adjacent circuit (see Figure 5, cell 3)a)).

Cases b) and c) Accessible parts are non-conductive (case b)) or conductive but not connected to earth by protective bonding (case c)). The required insulation is:

- Double or reinforced insulation between accessible parts and live parts of DVC-B or DVC-C. The relevant voltage is that of the live parts (see Figure 5, cells 1) b), 1) c), 2)b), 2)c)). For the case of non-conductive accessible parts, the accessible part may form all or part of the required insulation if it meets the requirements for solid insulation in 7.3.7.8.
- For the situation where adjacent circuits are involved, the requirements are given in Table 8 (for examples see Figure 5, cells 3)b), 3)c)). For the case of non-conductive accessible parts, the accessible part may form all or part of the required insulation if it meets the requirements for solid insulation in 7.3.7.8.

Table 8 – Insulation between accessible unearthed parts and DVC-A or -B circuits adjacent to DVC-B or -C circuits

Considered circuit (closer to accessible parts)	Adjacent circuit	Insulation between the considered circuit and the adjacent circuit	Insulation between the considered circuit and unearthed accessible parts
DVC-A	DVC-B or DVC-C	Basic ^a	Supplemental ^a
		Reinforced ^a	Functional
DVC-B	DVC-C	Basic ^a	Supplemental ^a
		Reinforced ^a	Reinforced
^a Based on the voltage of the circuit having the higher DVC.			

Examples of insulation configurations for DVC-C live parts are given in Figure 5, which also includes examples of the requirements for apertures.

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Type of insulation	Insulation configuration		
	a Accessible parts conductive and connected to earth by protective bonding	b Accessible parts not conductive	c Accessible parts conductive, but NOT connected to earth by protective bonding
1) Solid or liquid			
2) Totally or partially by air clearance			
3) Insulation for adjacent circuits: "I _c " indicates insulation based on the DVC-C circuit			
4) Requirements for apertures in enclosures			
Key C live part or circuit of DVC-C A adjacent circuit of DVC-A S accessible surface FI functional insulation RI reinforced insulation	L_B clearance for basic insulation L_R clearance for reinforced insulation M conductive part BI basic insulation DI double insulation	T test probe per 7.3.4.2.3 L_S clearance for supplemental insulation I insulation less than basic SI supplementary insulation	
NOTE 1 In row 4), the insertion of the test finger is considered to represent the first fault.			
NOTE 2 This figure shows examples only, and is not intended to cover every situation.			

Figure 5 – Examples for protection against direct contact for DVC-C circuits

7.3.5 Protection in case of direct contact

7.3.5.1 General

Protection in case of direct contact is required to ensure that contact with live parts does not produce a shock hazard.

Protection against direct contact according to 7.3.4 is not required if the accessible circuit

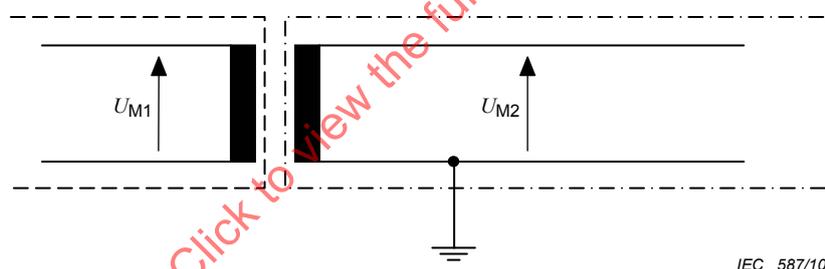
- is of DVC-A and complies with 7.3.5.2, or
- is provided with protective impedance in accordance with 7.3.5.3, or
- is limited in voltage according to 7.3.5.4.

In addition to the measures as given in 7.3.5.2 to 7.3.5.4, it shall be ensured that in the event of error or polarity reversal of connectors no voltages that exceed DVC-A are present on circuits that are not protected against direct contact. This applies for example to plug-in-sub-assemblies or other plug-in devices which can be plugged-in without the use of a tool (key) or which are accessible without the use of a tool.

Compliance is checked by visual inspection and trial insertion.

7.3.5.2 Protection using decisive voltage class A

Circuits of decisive voltage class A do not require protection against direct contact if the circuit has protective separation from circuits of DVC-B or DVC-C in accordance with 7.3.3.



Key

U_{M1} arbitrary, earthed or unearthed

U_{M2} decisive voltage DVC A, earthed or unearthed

----- Protection against direct contact

— — — — — Protective separation from circuits requiring protection against direct contact

Figure 6 – Protection by DCV A with protective separation

7.3.5.3 Protection by means of protective impedance

Circuits and conductive parts do not require protection against direct contact if any connection to circuits of DVC-B or DVC-C is through protective impedance, and the accessible circuit or part is otherwise provided with protective separation from circuits of DVC-B or DVC-C according to 7.3.3.

The protective impedance shall be designed such that the requirements of both 7.3.5.3.1 and 7.3.5.3.2 are met.

7.3.5.3.1 Limitation of current through protective impedance

The current available through protective impedance to earth and between simultaneously accessible parts, measured at the accessible live parts, shall not exceed a value of 3,5 mA a.c. or 10 mA d.c. under normal and single-fault conditions.

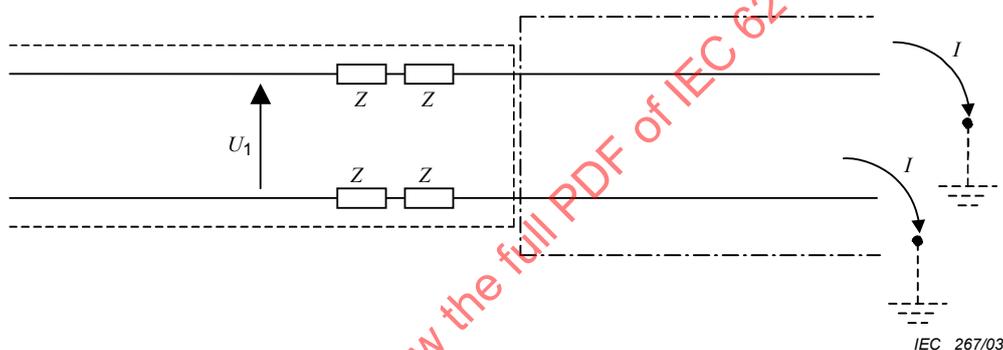
Compliance is checked by inspection, by analysis of the relevant circuit diagrams, and by testing, using the circuit of IEC 60990, Figure 4.

NOTE 1 For convenience, IEC 60990 test Figure 4 is reproduced in Annex H.

NOTE 2 Consideration should be given to the impact on the touch current measurement that capacitance between external test sources and earth could have on the result (for example a d.c. supply with capacitors to earth can increase the measured touch current unless the d.c. supply is not earthed to the same earth as the PCE under test).

The protective impedances shall be designed and tested to withstand the impulse voltages, temporary overvoltage and working voltage of the circuits to which they are connected.

Compliance is checked by the testing of 7.5.1 and 7.5.2.



Key

U_1 : hazardous voltage, earthed or unearthed

Touch current at accessible parts limited to $I \leq 3,5$ mA a.c., 10 mA d.c. from parts to earth and between simultaneously accessible parts

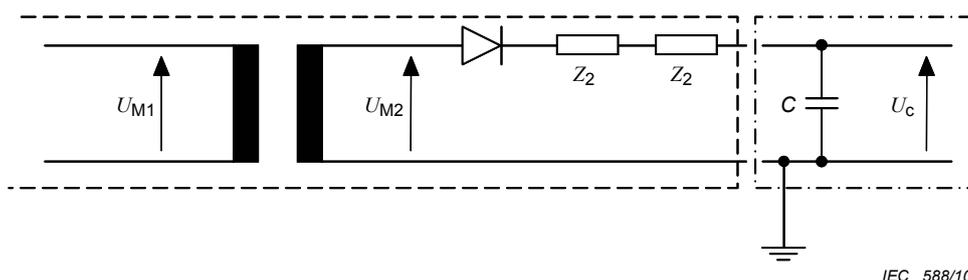
----- Protection against direct contact

----- Protected by protective impedance, and having protective separation from circuits requiring protection against direct contact

Figure 7 – Protection by means of protective impedance

7.3.5.3.2 Limitation of discharging energy through protective impedance

The discharging energy available between simultaneously accessible parts protected by protective impedance shall not exceed the charging voltage and capacitance limits given in Table 9, which applies to both wet locations and dry locations, under normal and single fault conditions. Refer to Figure 8.

**Key**

- Protection against direct contact
 - - - - - Protective separation from circuits requiring protection against direct contact

NOTE For earthed circuits, the charge limitation is applied from accessible parts to earth, and between simultaneously accessible parts.

Figure 8 – Protection by limitation of discharge energy

Table 9 – Values of accessible capacitance and charging voltage (threshold of pain)

Voltage V	Capacitance μF	Voltage kV	Capacitance nF
70	42,4	1	8,0
78	10,0	2	4,0
80	3,8	5	1,6
90	1,2	10	0,8
100	0,58	20	0,4
150	0,17	40	0,2
200	0,091	60	0,133
250	0,061		
300	0,041		
400	0,028		
500	0,018		
700	0,012		

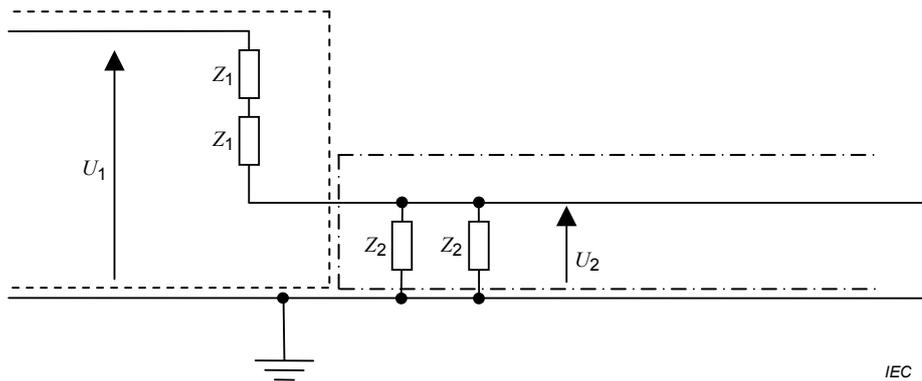
Compliance is checked by performing calculations and/or measurements to determine the voltage and capacitance.

7.3.5.4 Protection by means of limited voltages

That portion of a circuit that has its voltage reduced to DVC-A by a voltage divider that complies with the following requirements, and that is otherwise provided with protective separation from circuits of DVC-B or DVC-C according to 7.3.3, does not require protection against direct contact.

The voltage divider shall be designed so that under normal and single fault conditions, including faults in the voltage division circuit, the voltage across the output of the voltage divider does not exceed the limit for DVC-A.

This type of protection shall not be used in case of protective class II or unearthed circuits, because it relies on protective earth being connected.



Key

U_1 : hazardous voltage, earthed.

U_2 : Decisive voltage DVC A

Figure 9 – Protection by means of voltage limitation

7.3.6 Protection against indirect contact

7.3.6.1 General

Protection against indirect contact is required to prevent shock-hazardous currents being accessible from conductive parts during an insulation failure. This protection shall comply with the requirements for protective class I (basic insulation plus protective earthing), protective class II (double or reinforced insulation) or protective class III (limitation of voltages).

That part of a PCE that meets the requirements of 7.3.6.2 and 7.3.6.3 is defined as protective class I.

That part of a PCE that meets the requirements of 7.3.6.4 is defined as protective class II.

That part of a PCE which meets the requirements of decisive voltage class A and in which no hazardous voltages are derived, is defined as protective class III. No shock hazard is present in such circuits.

Where protection against indirect contact is dependent on means provided during installation, the installation instructions shall provide details of the required means and shall indicate the associated hazards.

7.3.6.2 Insulation between live parts and accessible conductive parts

Accessible conductive parts of equipment shall be separated from live parts by insulation meeting the requirements of Table 7 or by clearances as specified in 7.3.7.4 and creepages as specified in 7.3.7.5.

Compliance is checked measurement of clearances, creepage distances and/or solid insulation.

7.3.6.3 Protective class I - Protective bonding and earthing

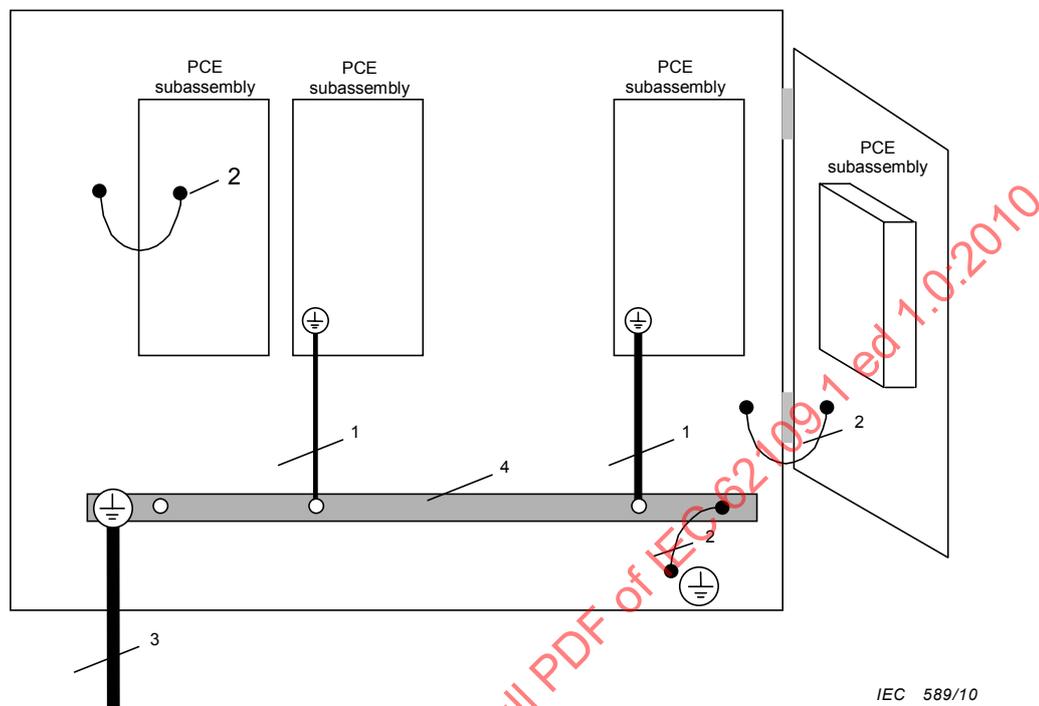
7.3.6.3.1 General

Equipment of protective class I shall be provided with protective earthing, and with protective bonding to ensure electrical contact between accessible conductive parts and the means of connection for the external protective earthing conductor, except bonding is not required for:

- a) accessible conductive parts that are protected by one of the measures in 7.3.5.2 to 7.3.5.4, or

- b) accessible conductive parts that are separated from live parts of DVC-B or -C using double or reinforced insulation.

Figure 10 shows an example PCE and its associated protective earthing and bonding.



Key

- 1 PCE subassembly protective earthing conductors (dimensioned according to the requirements for each subassembly)
- 2 protective bonding (may be a bonding conductor, fasteners, or other means)
- 3 PCE protective earthing conductor (dimensioned according to the requirements for the entire PCE system)
- 4 earthing bus bar

Figure 10 – Examples of protective bonding and earthing

7.3.6.3.2 Requirements for protective bonding

Electrical contact with the means of connection of the external protective earthing conductor shall be achieved by one or more of the following means:

- a) through direct metallic contact;
- b) through other conductive parts which are not removed when the PCE or sub-units are used as intended;
- c) through dedicated protective bonding conductors;
- d) through other metallic components of the PCE.

Where direct metallic contact is used and one or both of the parts involved is painted or coated, the paint or coating shall be removed in the area of contact, or reliably penetrated, to ensure metal to metal contact.

NOTE It is difficult to ensure reliable penetration of some painted surfaces (in particular powder painted surfaces) by means of star washers and the like.

For moving or removable parts, hinges or sliding contacts designed and maintained to have a low resistance are examples of acceptable means if they comply with the requirements of 7.3.6.3.3.

Metal ducts of flexible or rigid construction and metallic sheaths shall not be used as protective bonding conductors, unless the device or material has been investigated as suitable for protective bonding purposes.

7.3.6.3.3 Rating of protective bonding

Protective bonding shall withstand the highest thermal and dynamic stresses that can occur to the PCE item(s) concerned when they are subjected to a fault connecting live parts to accessible conductive parts.

The protective bonding shall remain effective for as long as a fault to the accessible conductive parts persists or until an upstream protective device removes power from the part.

NOTE In cases where the protective bonding is routed through conductors of low cross-section (for example, PWB tracks), particular care should be taken to ensure that no undetected damage to the bonding circuit can occur in the event of a fault.

Protective bonding shall meet following requirements:

- a) For PCE with an overcurrent protective device rating of 16 A or less, the impedance of the protective bonding means shall not exceed $0,1 \Omega$ during or at the end of the test below.
- b) For PCE with an overcurrent protective device rating of more than 16 A, the voltage drop in the protective bonding test shall not exceed 2,5 V during or at the end of the test below.

As alternative to a) and b) the protective bonding may be designed according to the requirements for the external protective earthing conductor in 7.3.6.3.5, in which case no testing is required.

Compliance is checked with the following test:

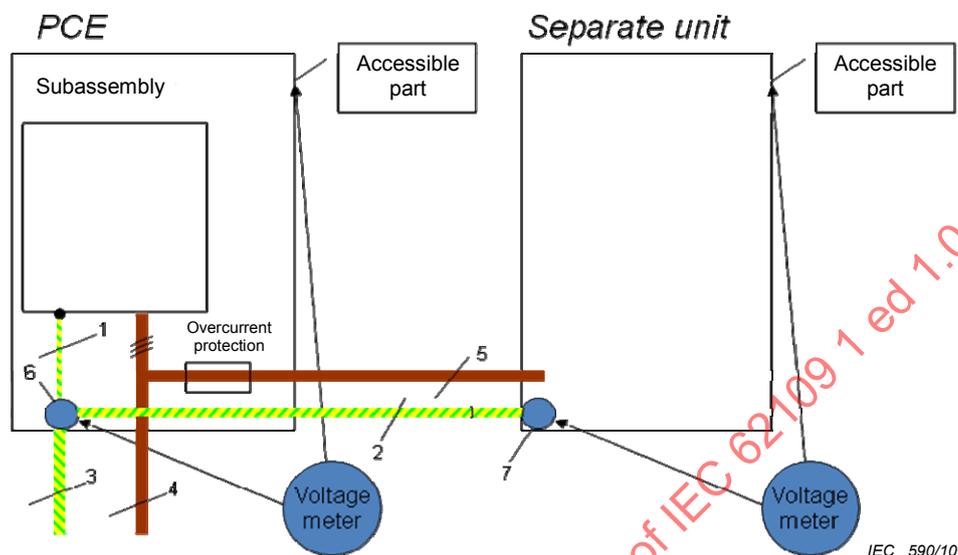
The impedance of protective bonding means shall be checked by passing a test current through the bond for a period of time as specified below. The test current is based on the rating of the overcurrent protection for the equipment or part of the equipment under consideration, as follows:

- a) for pluggable equipment type A, the overcurrent protective device is that provided external to the equipment (for example, in the building wiring, in the mains plug or in an equipment rack);
- b) for pluggable equipment type B and fixed equipment, the maximum rating of the overcurrent protective device specified in the equipment installation instructions to be provided external to the equipment;
- c) for a circuit or part of the equipment for which an overcurrent protective device is provided as part of the equipment, the rating of the provided overcurrent device.

Voltages are measured from the protective earthing terminal to all parts whose protective bonding means are being considered. The impedance of the protective earthing conductor is not included in the measurement. However, if the protective earthing conductor is supplied with the equipment, it is permitted to include the conductor in the test circuit but the measurement of the voltage drop is made only from the main protective earthing terminal to the accessible part required to be earthed.

On equipment where the protective earth connection to a subassembly or to a separate unit is part of a cable that also supplies power to that subassembly or unit, the resistance of the protective bonding conductor in that cable is not included in the protective bond impedance

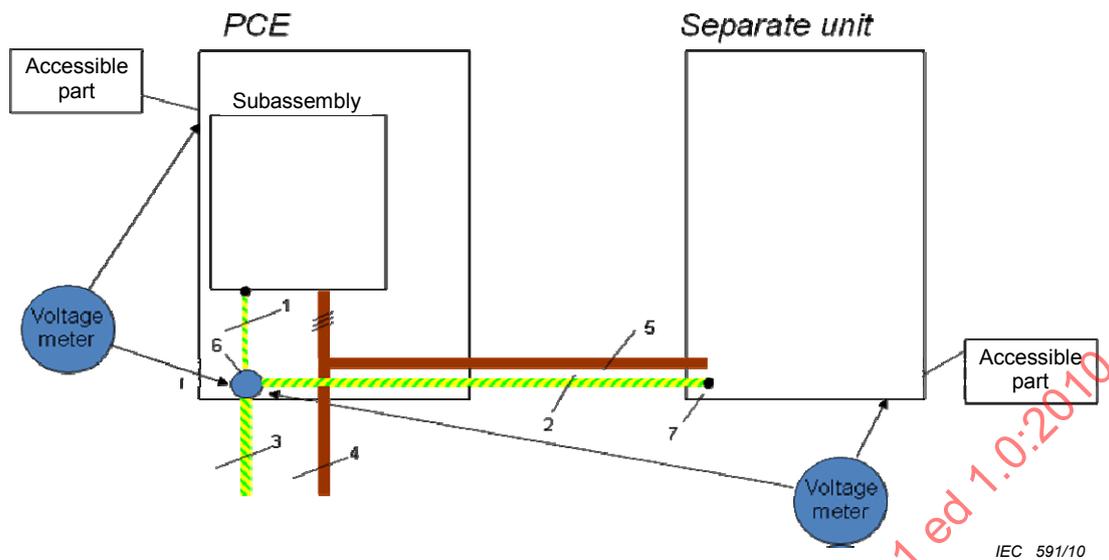
measurements for the subassembly or separate unit, as shown in Figure 11. However, this option is only permitted if the cable is protected by a suitably rated protective device that takes into account the size of the conductor. Otherwise the impedance of the protective bonding conductor between the separate units is to be included, by measuring to the protective earthing terminal where the power source enters the first unit in the system, as shown in Figure 12.



Key

- 1 protective bonding
- 2 protective earthing conductor for the separate unit
- 3 protective earthing conductor for the PCE
- 4 energy supply from the mains
- 5 energy supply from the PCE to the separate unit, with overcurrent protection
- 6 terminal point of the external protective earthing conductor
- 7 terminal point of the protective earthing conductor for the separate unit

Figure 11 – Protective bonding impedance test for separate unit with power fed from the PCE with overcurrent protection for the power cable



IEC 591/10

Key

- 1 protective bonding
- 2 protective bonding for the separate unit
- 3 protective earthing conductor for the PCE
- 4 energy supply from the mains
- 5 energy supply from the PCE to the separate unit, without overcurrent protection
- 6 terminal point of the external protective earthing conductor
- 7 connection point of the bonding to the separate unit (may be >1)

Figure 12 – Protective bonding impedance test for separate unit with accessible parts and with power fed from the PCE without overcurrent protection

7.3.6.3.3.1 Test current, duration, and acceptance criteria

The test current, duration of the test and acceptance criteria are as follows:

- a) For PCE with an overcurrent protective device rating of 16 A or less, the test current is 200 % of the overcurrent protective device rating, but not less than 32 A, applied for 120 s. The impedance of the protective bonding means during and at the end of the test shall not exceed 0,1 Ω .
- b) For PCE with an overcurrent protective device rating of more than 16 A, the test current is 200 % of the overcurrent protective device rating and the duration of the test is as shown in Table 10 below. The voltage drop in the protective bonding means, during and at the end of the test, shall not exceed 2,5 V.
- c) During and after the test, there shall be no melting, loosening, or other damage that would impair the effectiveness of the protective bonding means.

Table 10 – Test duration for protective bonding test

Overcurrent protective device rating	Duration of the test
A	min
>16 to 30	2
31 to 60	4
61 to 100	6
101 to 200	8
> 200	10

The test current is derived from an a.c or d.c supply source, the output of which is not earthed.

As an alternative to Table 10, where the time-current characteristic of the overcurrent protective device that limits the fault current in the protective bonding means is known because the device is either provided in the equipment or fully specified in the installation instructions, the test duration may be based on that specific device's time-current characteristic. The tests are conducted for a duration corresponding to the 200 % current value on the time-current characteristic.

7.3.6.3.4 Protective bonding impedance (routine test)

If the continuity of the protective bonding is achieved at any point by a single means only (for example a single conductor or single fastener), or if the PCE is assembled at the installation location, then the impedance of the protective bonding shall also be tested as a routine test.

The test shall be as in 7.3.6.3.3, except for the following:

- the test current may be reduced to any convenient value greater than 10 A sufficient to allow measurement or calculation of the impedance of the protective bonding means;
- the test duration may be reduced to no less than 2 s.

For equipment subject to the type test in 7.3.6.3.3.1a), the impedance during the routine test shall not exceed 0,1 Ω .

For equipment subject to the type test in 7.3.6.3.3.1b) the impedance during the routine test shall not exceed 2,5 V divided by the test current required by 7.3.6.3.3.1b).

NOTE 1 The use of a supply with an earthed output can produce misleading results.

NOTE 2 The use of larger currents increases the accuracy of the test result, especially with low resistance values, i.e. larger cross-sectional areas and/or shorter conductor length.

NOTE 3 As this is a very low resistance, care should be exercised in positioning the measuring probes.

7.3.6.3.5 External protective earthing conductor

A protective earthing conductor shall be connected at all times when power is supplied to PCE of protective class I. Unless local wiring regulations state otherwise, the protective earthing conductor cross-sectional area shall be determined from Table 11 or by calculation according to IEC 60364-5-54.

If the external protective earthing conductor is routed through a plug and socket, or similar means of disconnection, it shall not be possible to disconnect it unless power is simultaneously removed from the part to be protected.

Table 11 – External protective earthing conductor cross-section

Cross-sectional area of phase conductors of the PCE, S mm ²	Minimum cross-sectional area of the corresponding external protective earthing conductor, S_p mm ²
$S \leq 16$	S
$16 < S \leq 35$	16
$35 < S$	$S/2$

NOTE The values in this table are valid only if the external protective earthing conductor is made of the same metal as the phase conductors. If this is not so, the cross-sectional area of the external protective earthing conductor is to be determined in a manner which produces a conductance equivalent to that which results from the application of this table.

The cross-sectional area of every protective earthing conductor which does not form part of the supply cable or cable enclosure shall, in any case, be not less than:

- 2,5 mm² if mechanical protection is provided;
- 4 mm² if mechanical protection is not provided.

For cord-connected equipment, provisions shall be made so that the protective earthing conductor in the cord shall, in the case of failure of the strain-relief mechanism, be the last conductor to be interrupted.

7.3.6.3.6 Means of connection for the external protective earthing conductor

7.3.6.3.6.1 General

The means of connection for the external protective earthing conductor shall be located near the terminals for the respective live conductors. The means of connection shall be corrosion-resistant and shall be suitable for the connection of cables according to 7.3.6.3.5.

The means of connection for the protective earthing conductor shall not be used as a part of the mechanical assembly of the equipment or for other connections.

A separate means of connection shall be provided for each external protective earthing conductor.

Connection and bonding points shall be so designed that their current-carrying capacity is not impaired by mechanical, chemical, or electrochemical influences. Where enclosures and/or conductors of aluminium or aluminium alloys are used, particular attention should be given to the problems of electrolytic corrosion.

The means of connection for the protective earthing conductor shall be permanently marked with:

- symbol 7 of Annex C; or
- the colour coding green-yellow.

Marking shall not be done on easily changeable parts such as screws.

7.3.6.3.7 Touch current in case of failure of the protective earthing conductor

The requirements of this subclause shall be satisfied to maintain safety in case of damage to or disconnection of the protective earthing conductor.

For pluggable equipment type A, the touch current measured in accordance with 7.5.4 shall not exceed 3,5 mA a.c. or 10 mA d.c.

Compliance is checked by measurement according to 7.5.4.

For all other PCE, one or more of the following measures shall be applied, unless the touch current measured in accordance with 7.5.4 does not exceed 3,5 mA a.c. or 10 mA d.c.

a) Permanently connected wiring, and:

- a cross-section of the protective earthing conductor of at least 10 mm² if copper, or 16 mm² if aluminum;
- or
- automatic disconnection of the supply in case of discontinuity of the protective earthing conductor;
- or
- provision of an additional terminal for a second protective earthing conductor of the same cross-sectional area as the original protective earthing conductor and installation instructions requiring a second protective earthing conductor to be installed.

or

b) Connection with an industrial connector according to IEC 60309 and a minimum protective earthing conductor cross-section of 2,5 mm² as part of a multi-conductor power cable. Adequate strain relief shall be provided.

In addition, the caution symbol 15 of Annex C shall be fixed to the product and the installation manual shall provide details of the protective earthing measures required in the installation as required in 5.3.2.

When it is intended and allowed to connect two or more PCEs in parallel using one common protective earthing conductor, the above touch current requirements apply to the maximum number of PCEs to be connected in parallel, unless one of the measures in a) or b) above is used. The maximum number of parallel PCEs is used in the testing and has to be stated in the installation manual.

Compliance is checked by inspection, and where necessary, by testing in accordance with 7.5.4.

7.3.6.4 Protective class II - Double or reinforced insulation

Equipment or parts of equipment designed for protective class II shall have insulation between live parts and accessible surfaces in accordance with 7.3.4.3. The following requirements also apply:

- equipment designed to protective class II shall not have means of connection for the external protective earthing conductor. However this does not apply if the external protective earthing conductor is passed through the equipment to equipment series-connected beyond it. In the latter event, the external protective earthing conductor and its means for connection shall be insulated with basic insulation from the accessible surface of the equipment and from circuits that employ protective separation, extra-low voltage, protective impedance and limited discharging energy, according to 7.3.5. This basic insulation shall correspond to the rated voltage of the series-connected equipment;
- metal-encased equipment of protective class II may have provision on its enclosure for the connection of an equipotential bonding conductor;

- equipment of protective class II may have provision for the connection of an earthing conductor for functional reasons or for the damping of overvoltages; it shall, however, be insulated as though it is a live part;
- equipment employing protective class II shall be marked according to 5.1.8.

7.3.7 Insulation including clearance and creepage distances

7.3.7.1 General

This subclause gives minimum requirements for insulation, based on the principles of IEC 60664.

Manufacturing tolerances shall be taken into account during measurement of creepage, clearance, and insulation distances in the PCE.

Insulation shall be selected after consideration of the following influences:

- pollution degree
- overvoltage category
- supply earthing system
- insulation voltage
- location of insulation
- type of insulation

Compliance of insulation, creepage distances, and clearance distances, shall be verified by measurement or visual inspection, and the tests of 7.5.

See Annex A for measurement examples. Where this verification is impossible to perform, an impulse voltage test (see 7.5.1) shall be performed between the considered circuits.

7.3.7.1.1 Pollution degree

Insulation, especially when provided by clearances and creepage distances, is affected by pollution that occurs during the expected lifetime of the PCE. The pollution degree rating of the PCE or section of the PCE to be used in judging the requirements of this section shall be the pollution degree determined according to 6.1 and 6.2.

7.3.7.1.2 Overvoltage category and impulse withstand voltage rating

The concept of overvoltage categories is applied to each separate circuit in the PCE, including mains circuits, PV circuits, and other circuits, whether connected to or isolated from the mains and PV circuits, as follows:

a) For equipment or circuits energized from the mains, four categories are considered:

- category IV applies to equipment permanently connected at the origin of an installation (upstream of the main distribution board). Examples are electricity meters, primary overcurrent protection equipment and other equipment connected directly to outdoor open lines

NOTE 1 Mains circuits on Outdoor PCE are not necessarily considered OV category IV. For example, if the point where an outdoor PCE connects electrically is OVC III then the mains port of the PCE is considered OVC III even if the PCE is outdoors. However where a long run of outdoor wiring is required between the OVC III connection point and the physical location of the PCE, transients may be increased back to an OVC IV level, and the PCE designed for OVC III may not be suitable. Note that the OVC is required to be stated in the installation information provided with the PCE.

- category III applies to fixed equipment downstream of, and including, the main distribution board. Examples are switchgear and other equipment in an industrial installation;

- category II applies to equipment not permanently connected to the installation. Examples are appliances, portable tools and other plug-connected equipment;
- category I applies to equipment connected to a circuit where measures have been taken to reduce transient overvoltages to a low level.

Impulse withstand voltage ratings for the mains circuit are assigned based on the above OVC and on the mains system voltage, as in 7.3.7.1.4.

- b) For PV circuits in general, Overvoltage Category II is assumed, and impulse withstand voltage ratings for the PV circuit are assigned based on the PV system voltage as in 7.3.7.1.4, but the minimum impulse voltage to be used is 2 500 V.
- c) For PCE with galvanic isolation between the mains and PV circuits, the impulse voltage withstand ratings of the mains and PV circuits are determined as in a) and b) above, and then the effect of reduction of OVC across the isolation is evaluated as follows:
- The magnitude of impulses from the mains circuit on the PV circuit is determined by reducing the OVC of the mains circuit by one level, and determining the resulting impulse voltage withstand rating based on mains system voltage.
 - The rating to be used on the PV circuit is the higher of the value in b) and the value calculated above.
 - The magnitude of impulses from the PV circuit on the mains circuit is determined by reducing the OVC of the PV circuit by one level, and determining the resulting impulse voltage withstand rating based on PV system voltage.
 - The rating to be used on the mains circuit is the higher of the value in a) and the value calculated above.

NOTE 2 “Reducing the OVC...by one level” means selecting the value from one column to the left in Table 12.

NOTE 3 Where the OVC is already the lowest level (OVCI) the reduction is done by moving up one row in Table 12.

NOTE 4 See Annex I for examples.

- d) For PCE not providing galvanic isolation between the mains and PV circuits, the impulse withstand voltage ratings of the mains and PV circuits are determined as in a) and b) above, and the higher of the two impulse withstand voltage ratings is used for the entire combined circuit. For circuits connected to the combined circuit without galvanic isolation, the impulse withstand voltage rating of the combined circuit applies.
- e) For other circuits the impulse withstand voltage rating is the most severe rating determined by the relationship of the circuit under consideration to the PV and mains circuits, according to the following:
- for circuits connected to the mains without galvanic isolation, the impulse withstand voltage rating of the mains circuit applies;
 - for circuits connected to the PV circuit without galvanic isolation, the impulse withstand voltage rating of the PV circuit applies;
 - where isolation is provided by means of isolation transformers, optocouplers, or similar galvanic isolation devices, between a considered circuit and an adjacent mains or PV circuit, the impulse withstand voltage rating of the considered circuit is reduced by one level from that of the adjacent circuit; if more than one adjacent circuit is involved, the highest resulting impulse withstand voltage rating applies.

NOTE 5 The above requirements consider “other circuits” to be inherently free of impulses. The only impulses on such circuits originate in other circuits such as the mains and PV circuits. Examples are battery circuits and diesel generator circuits. However, where such a source is connected to the system with long cable runs, and particularly long outdoor cable runs, consideration must be given to the likelihood of these circuits having impulse voltages induced in them by nearby lightning strikes, etc. In these cases these “other circuits” may inherently have impulse voltages originating within the circuit. Consideration should be given to treating such circuits in the manner PV circuits are treated above: a minimum 2 500 V impulse withstand voltage rating, which then need to be compared to the impulse withstand voltage rating of the adjacent circuits in the above manner.

- f) The overvoltage categories determined as above apply from circuits to earth. The overvoltage category that applies to functional insulation within each circuit is one category lower (less severe) than the overvoltage category that applies from the circuit to earth.
- g) Application of means to reduce impulse voltages: For basic and functional insulation, if transient reduction means are provided which reduce impulses to lower values, insulation may be designed for the reduced impulse levels. The reduced values to be used are the highest impulses occurring in the testing of 7.5.1.

If such devices are used to reduce the values for design of Basic insulation, and the devices can be damaged by overvoltages or repeated impulses, thus decreasing their ability to reduce impulses, they shall be monitored and an indication of their status provided.

NOTE 6 For low-voltage applications, IEC 61643-12 provides information on the selection and use of such devices.

The requirements for double or reinforced insulation shall not be reduced when measures to reduce impulses are provided.

7.3.7.1.3 Supply earthing systems

Three basic types of earthing system are described in IEC 60364-1. They are:

- TN system: has one point directly earthed, the accessible conductive parts of the installation being connected to that point by protective conductors. Three types of TN system, TN-C, TN-S and TN-C-S, are defined according to the arrangement of the neutral and protective conductors;
- TT system: has one point directly earthed, the accessible conductive parts of the installation being connected to earth electrodes electrically independent of the earth electrodes of the power system;
- IT system: has all live parts isolated from earth or one point connected to earth through an impedance, the accessible conductive parts of the installation being earthed independently or collectively to the earthing system.

7.3.7.1.4 Insulation voltages

Table 12 makes use of the circuit system voltage and overvoltage category to define the impulse withstand voltage and the temporary overvoltage.

Table 12 – Insulation voltage for low voltage circuits

Column 1	2	3	4	5	6
System voltage (7.3.7.2) V	Impulse withstand voltage V				Mains circuit Temporary overvoltage (peak / r.m.s.) (see note 5) V
	Overvoltage category				
	I	II	III	IV	
50 V rms or 71 V dc	330	500	800	1 500	1 770 / 1 250
100 V rms or 141 V dc	500	800	1 500	2 500	1 840 / 1 300
150 V rms or 213 V dc	800	1 500	2 500	4 000	1 910 / 1 350
300 V rms or 424 V dc	1 500	2 500	4 000	6 000	2 120 / 1 500
600 V rms or 849 V dc	2 500	4 000	6 000	8 000	2 550 / 1 800
1 000 V rms or 1 500 V dc	4 000	6 000	8 000	12 000	3 110 / 2 200
NOTE 1 Interpolation is not permitted in mains circuits, but is permitted in other circuits.					
NOTE 2 The last row only applies to single-phase systems, or to the phase-to-phase voltage in three-phase systems.					
NOTE 3 Column 6, temporary overvoltages, only applies to mains circuits.					
NOTE 4 PV circuits are in general OVCII with a minimum impulse voltage of 2 500 V - see 7.3.7.1.2b).					
NOTE 5 These values are derived using the formula $(1\,200 \cdot V + \text{system voltage})$ from IEC 60664-1.					

7.3.7.2 Insulation between a circuit and its surroundings

7.3.7.2.1 General

Basic, supplementary, and reinforced insulation between a circuit and its surroundings shall be designed according to:

- the impulse voltage; or
- the temporary overvoltage; or
- the working voltage of the circuit.

For creepage distances, the r.m.s. value of the working voltage is used.

For clearance distances and solid insulation the voltage used is as described in 7.3.7.2.2 to 7.3.7.2.4.

The impulse voltage and temporary overvoltage are taken from Table 12.

When using Table 12, the system voltage in column 1 is:

- in TN and TT systems: the r.m.s. value of the rated voltage between a phase and earth;

NOTE 1 A corner-earthed system is a TN system with one phase earthed, in which the system voltage is the r.m.s. value of the rated voltage between a non-earthed phase and earth (i.e. the phase-phase voltage).

- in three-phase IT systems:

- for determination of impulse voltage, the r.m.s. value of the rated voltage between a phase and an artificial neutral point (an imaginary junction of equal impedances from each phase);

NOTE 2 For most systems, this is equivalent to dividing the phase-to-phase voltage by 1,732.

- for determination of temporary overvoltage, the r.m.s. value of the rated voltage between phases;
- In single-phase IT systems: the r.m.s. value of the rated voltage between phase conductors.

NOTE 3 Where the supply voltage is rectified a.c., the system voltage is the r.m.s. value of the source a.c. before rectification, taking into account the supply earthing system.

7.3.7.2.2 Circuits connected directly to the mains

Clearances and solid insulation between circuits connected directly to the mains and their surroundings shall be designed according to the impulse voltage, temporary overvoltage, or working voltage, whichever gives the most severe requirement.

NOTE Circuits, which are connected to the mains via protective impedances, according to 7.3.5.3, or via means of voltage limitation, according to 7.3.5.4, are not regarded as connected directly to the mains.

7.3.7.2.3 Circuits other than mains circuits

Clearances and solid insulation between circuits other than the mains and their surroundings shall be designed according to impulse voltage and recurring peak voltage, according to the following:

- the system voltage is
 - for PV circuits, the max rated PV open circuit voltage;
 - for other circuits, the working voltage;
- the impulse voltage is determined from Table 12, using the system voltage above and according to 7.3.7.1.2;
- the working voltage or the impulse voltage, whichever gives the more severe requirement, determines the design of the clearances and solid insulation.

7.3.7.2.4 Insulation between circuits

Insulation between two circuits shall be designed according to the following:

- a) for clearances and insulation, the requirements are determined by the circuit having the higher impulse voltages;
- b) for creepages, r.m.s. working voltage across the insulation determines the requirements.

7.3.7.3 Functional insulation

For insulation within a circuit and for other cases where functional insulation is permitted, the voltage used for insulation requirements is determined as follows:

The overvoltage category shall be determined as in 7.3.7.1.2.

For parts or circuits in overvoltage category I, functional insulation shall be designed according to the working voltage across the insulation.

For parts or circuits in overvoltage category II, III, or IV, functional insulation shall be designed according to the applicable impulse voltage as determined by 7.3.7.1.4.

7.3.7.4 Clearance distances

7.3.7.4.1 Determination

Table 13 defines the minimum clearance distances required to provide functional, basic, or supplementary insulation (see Annex A for examples of clearance distances).

Clearances for use in altitudes above 2 000 m shall be calculated with a correction factor according to Table A.2 of IEC 60664-1, which is reproduced for convenience in Annex F.

To determine clearances for reinforced insulation from Table 13, the value corresponding to the next higher impulse voltage, or 1,6 times the temporary overvoltage, or 1,6 times the working voltage shall be used, whichever results in the most severe requirement.

The compliance of clearances shall be verified by measurement, visual inspection and if necessary by performing the impulse voltage test of 7.5.1 and the a.c. or d.c voltage test of 7.5.2.

Table 13 – Clearance distances

Column 1	2	3	4			5	6
			Minimum clearance mm			Pollution degree	
Impulse voltage (Table 12 and 7.3.7.1.4)	Temporary overvoltage (peak value) for determining insulation between circuits and their surroundings or Working voltage (recurring peak) for determining functional insulation	Working voltage (recurring peak) for determining insulation between circuits and their surroundings					
V	V	V	1	2	3		
N/A	≤ 110	≤ 71	0,01	0,20 ^a	0,80		
N/A	225	141	0,01	0,20	0,80		
330	340	212	0,01	0,20	0,80		
500	530	330	0,04	0,20	0,80		
800	700	440	0,10	0,20	0,80		
1 500	960	600	0,50	0,50	0,80		
2 500	1 600	1 000	1,5				
4 000	2 600	1 600	3,0				
6 000	3 700	2 300	5,5				
8 000	4 800	3 000	8,0				
12 000	7 400	4 600	14,0				

NOTE 1 Interpolation is permitted.

NOTE 2 Examples of clearance distances are given in Annex A.

NOTE 3 Clearances for Temporary overvoltage and Working voltage have been derived from Table A.1 of IEC 60664-1. In column 2, the voltage is approximately 80 % of the withstand voltage; in column 3, the voltage is approximately 50 % of the withstand voltage.

^a 0,1 mm on PWB.

7.3.7.4.2 Electric field homogeneity

The dimensions in Table 13 correspond to the requirements of an inhomogeneous electric field distribution across the clearance, which are the conditions normally experienced in practice. If a homogeneous electric field distribution is known to exist, and the impulse voltage is equal to or greater than 6 000 V for a circuit connected directly to the mains or 4 000 V within a circuit, the clearance may be reduced to not less than that required by Table F.2 Case B of IEC 60664-1. In this case, however, the impulse voltage test of 7.5.1 shall be performed on the clearance.

7.3.7.4.3 Clearance to conductive enclosures

The clearance between any non-insulated live part and the walls of a metal enclosure shall be in accordance with 7.3.7.4.1 following the deformation tests of 13.7.

If the design clearance is at least 12,7 mm and the clearance required by 7.3.7.4.1 does not exceed 8 mm, the deformation tests may be omitted.

7.3.7.5 Creepage distances

7.3.7.5.1 General

Creepage distances shall be large enough to prevent long-term degradation of the surface of solid insulators, according to Table 14.

For functional, basic and supplementary insulation, the values in Table 14 apply directly. For reinforced insulation, the distances in Table 14 shall be doubled.

When the creepage distance determined from Table 14 is less than the clearance required by 7.3.7.4.1 or the clearance determined by impulse testing (see 7.3.7.4.2), then it shall be increased to that clearance.

Creepage distances shall be verified by measurement or inspection (see Annex A for examples of creepage distances).

7.3.7.5.2 Voltage

The voltage in column 1 of Table 14 is the r.m.s. value of the working voltage across the creepage distance. Interpolation is permitted.

7.3.7.5.3 Materials

Insulating materials are classified into four groups corresponding to their comparative tracking index (CTI) when tested according to 6.2 of IEC 60112:

- Insulating material group I CTI \geq 600;
- Insulating material group II $600 > \text{CTI} \geq 400$;
- Insulating material group IIIa $400 > \text{CTI} \geq 175$;
- Insulating material group IIIb $175 > \text{CTI} \geq 100$.

Creepage distances on printed wiring boards (PWBs) exposed to pollution degree 3 environmental conditions shall be determined based on Table 14 Pollution degree 3 under "Other insulators".

If the creepage distance is ribbed, then the creepage distance of insulating material of group I may be applied when using insulating material of group II and the creepage distance of insulating material of group II may be applied when using insulating material of group III.

Except at pollution degree 1 the ribs shall be 2 mm high at least. The spacing of the ribs shall equal or exceed the dimension 'X' in Annex A Table A.1.

For inorganic insulating materials, for example glass or ceramic, which do not track, the creepage distance may equal the associated clearance, as determined from Table 13.

Table 14 – Creepage distances (mm)

Column 1	2	3	4	5	6	7	8	9	10	11	12
RMS Working Voltage (7.3.7.5.2) V	PWBs ^a		Other insulators								
	Pollution degree		Pollution degree								
	1	2	1	2				3			
	b	c	b	Insulating material group				Insulating material group			
I				II	IIIa	IIIb	I	II	IIIa	IIIb	
≤ 2	0,025	0,04	0,056	0,35	0,35	0,35		0,87	0,87	0,87	
5	0,025	0,04	0,065	0,37	0,37	0,37		0,92	0,92	0,92	
10	0,025	0,04	0,08	0,40	0,40	0,40		1,0	1,0	1,0	
25	0,025	0,04	0,125	0,50	0,50	0,50		1,25	1,25	1,25	
32	0,025	0,04	0,14	0,53	0,53	0,53		1,3	1,3	1,3	
40	0,025	0,04	0,16	0,56	0,80	1,1		1,4	1,6	1,8	
50	0,025	0,04	0,18	0,60	0,85	1,20		1,5	1,7	1,9	
63	0,04	0,063	0,20	0,63	0,90	1,25		1,6	1,8	2,0	
80	0,063	0,10	0,22	0,67	0,95	1,3		1,7	1,9	2,1	
100	0,10	0,16	0,25	0,71	1,0	1,4		1,8	2,0	2,2	
125	0,16	0,25	0,28	0,75	1,05	1,5		1,9	2,1	2,4	
160	0,25	0,40	0,32	0,80	1,1	1,6		2,0	2,2	2,5	
200	0,40	0,63	0,42	1,0	1,4	2,0		2,5	2,8	3,2	
250	0,56	1,0	0,56	1,25	1,8	2,5		3,2	3,6	4,0	
320	0,75	1,6	0,75	1,6	2,2	3,2		4,0	4,5	5,0	
400	1,0	2,0	1,0	2,0	2,8	4,0		5,0	5,6	6,3	
500	1,3	2,5	1,3	2,5	3,6	5,0		6,3	7,1	8,0	
630	1,8	3,2	1,8	3,2	4,5	6,3		8,0	9,0	10,0	
800	2,4	4,0	2,4	4,0	5,6	8,0		10,0	11	12,5	d
1 000	3,2	5,0	3,2	5,0	7,1	10,0		12,5	14	16	
1 250	4,2	6,3	4,2	6,3	9	12,5		16	18	20	
1 600	e	e	5,6	8,0	11	16		20	22	25	
2 000			7,5	10,0	14	20		25	28	32	
2 500			10,0	12,5	18	25		32	36	40	
3 200			12,5	16	22	32		40	45	50	
4 000			16	20	28	40		50	56	63	
5 000			20	25	36	50		63	71	80	
6 300			25	32	45	63		80	90	100	
8 000			32	40	56	81		100	110	125	
10 000			40	50	71	100		125	140	160	

^a These columns also apply to components and parts on PWBs, and to other creepage distances with a comparable control of tolerances.

^b All material groups.

^c All material groups except IIIb.

^d Insulating materials of group IIIb are not normally recommended for pollution degree 3 above 630 V.

^e Above 1 250 V use the values from columns 4 to 11, as appropriate.

NOTE Interpolation is permitted.

7.3.7.6 Coating

A coating may be used to provide insulation, to protect a surface against pollution, and to allow a reduction in creepage and clearance distances (see 7.3.7.8.4.2 and 7.3.7.8.6).

7.3.7.7 PWB spacings for functional insulation

Spacings for functional insulation on a PWB which do not comply with 7.3.7.4 and 7.3.7.5 are permitted when all the following are satisfied:

- the PWB has flammability rating of V-0 (see IEC 60695-11-10); and
- the PWB base material has a minimum CTI of 175; and
- the equipment complies with the PWB short-circuit test (see 4.4.4.14).

On a PWB, creepage and clearance distances for *functional insulation* at working voltages less than 80 V (r.m.s.) or 110 V (recurring peak) are permitted to be evaluated according to Pollution degree 1 if the tracks are covered with a suitable coating. The coating is not required to be tested.

7.3.7.8 Solid insulation

7.3.7.8.1 General

Materials selected for solid insulation shall be able to withstand the stresses occurring in the application. These include mechanical, electrical, thermal and climatic stresses which are to be expected in normal use. Insulation materials shall also be resistant to ageing during the expected lifetime of the PCE.

Tests shall be performed on components and subassemblies using solid insulation, in order to ensure that the insulation performance has not been compromised by the design or manufacturing process.

Components that comply with a relevant component standard that provide equivalent requirements to those of this standard do not require separate evaluation. Assemblies containing such components shall be tested according to the requirements of this standard.

7.3.7.8.2 Requirements for electrical withstand capability of solid insulation

7.3.7.8.2.1 Basic, supplemental, reinforced, and double insulation

Solid insulation shall withstand the applicable impulse withstand voltage test according to 7.5.1 and the a.c. or d.c. voltage test according to 7.5.2.

In addition, double and reinforced insulation shall withstand the partial discharge test according to 7.5.3, if the recurring peak working voltage across the insulation is greater than 700 V and the voltage stress on the insulation is greater than 1 kV/mm.

Compliance is shown by impulse withstand voltage test according to 7.5.1 and the a.c. or d.c. voltage test according to 7.5.2, and partial discharge testing according to 7.5.3 if applicable.

NOTE The voltage stress is the recurring peak voltage divided by the distance between two parts of different potential.

These tests shall be performed as type tests except the voltage test is also performed as a routine test. In addition, a sample test shall be performed if the insulation consists of a single layer of material. The sample test may be omitted on parts that comply with a relevant standard (see 14.1) and are manufactured under a quality control system.

Double insulation shall be designed so that failure of the basic insulation or of the supplementary insulation will not result in reduction of the insulation capability of the remaining part of the insulation

7.3.7.8.2.2 Functional insulation

Functional insulation shall comply with the requirements of 7.3.7.3. Testing is not required.

7.3.7.8.3 Thin sheet or tape material

7.3.7.8.3.1 General

This section applies to the use of thin sheet or tape materials in assemblies such as wound components and bus-bars.

Insulation consisting of thin (less than 0,7 mm) sheet or tape materials is permitted, provided that it is protected from damage and is not subject to mechanical stress under normal use.

Where more than one layer of insulation is used, there is no requirement for all layers to be of the same material.

NOTE One layer of insulation tape wound with more than 50 % overlap is considered to constitute two layers.

Thin sheet or tape material shall comply with the requirements for solid insulation in 7.3.7.8.1 and with 7.3.7.8.3.2 or 7.3.7.8.3.3 as applicable.

7.3.7.8.3.2 Material thickness not less than 0,2 mm

- Basic or supplementary insulation shall consist of at least one layer of material, and shall meet the impulse and a.c. or d.c. voltage test requirements of 7.3.7.8.2.1 for basic or supplementary insulation.
- Double insulation shall consist of at least two layers of material. Each layer shall meet the impulse and a.c. or d.c. voltage test requirements of 7.3.7.8.2.1 for basic insulation, and the partial discharge requirements of 7.3.7.8.2.1. The two or more layers together shall meet the impulse and a.c. or d.c. voltage test requirements of 7.3.7.8.2.1 for double insulation.
- Reinforced insulation shall consist of a single layer of material, which will meet the impulse, a.c. or d.c. voltage, and partial discharge test requirements 7.3.7.8.2.1 for reinforced insulation.

NOTE The requirements of this subclause indicate that double insulation will be at least 0,4 mm thick, while reinforced insulation is permitted to be 0,2 mm thick.

7.3.7.8.3.3 Material thickness less than 0,2 mm

- Basic or supplementary insulation shall consist of at least one layer of material, and shall meet the impulse and a.c. or d.c. voltage test requirements of 7.3.7.8.2.1 for basic or supplementary insulation.
- Double insulation shall consist of at least three layers of material. Each layer shall meet the impulse and a.c. or d.c. voltage test requirements of 7.3.7.8.2.1 for basic insulation. Any two layers together shall meet the impulse, a.c. or d.c. voltage, and partial discharge test requirements of 7.3.7.8.2.1 for double insulation.
- Reinforced insulation consisting of a single layer of material less than 0,2 mm thick is not permitted.

7.3.7.8.3.4 Compliance

Compliance is checked by the tests described in 7.5.1 to 7.5.3 applied according to 7.3.7.8.2.

When a component or sub-assembly makes use of thin sheet insulating materials, it is permitted to perform the tests on the component rather than on the material.

7.3.7.8.4 Printed wiring boards (PWBs)

7.3.7.8.4.1 General

Insulation between conductor layers in double-sided single-layer PWBs, multi-layer PWBs and metal core PWBs, shall meet the requirements for solid insulation in 7.3.7.8.

For the inner layers of multi-layer PWBs, the insulation between adjacent tracks on the same layer shall be treated as either:

- a creepage distance for pollution degree 1 and a clearance as in air (see Annex A, figure A.13); or
- as solid insulation, in which case it shall meet the requirements of 7.3.7.8.

7.3.7.8.4.2 Use of coating materials

A coating material used to provide a microenvironment or to provide functional, basic, supplementary and reinforced insulation shall meet the requirement as specified below.

Type 1 protection (as defined in IEC 60664-3) improves the microenvironment (Pollution Degree) of the parts under protection. The clearance and creepage distance of Table 13 and Table 14 for pollution degree 1 apply under the protection. Between two conductive parts, it is a requirement that one or both conductive parts, together with all the spacing between them, are covered by the protection.

Type 2 protection is considered to be similar to solid insulation. Under the protection, the requirements for solid insulation specified in 7.3.7.8 are applicable and spacings shall not be less than those specified in Table 1 of IEC 60664-3. The requirements for clearance and creepage in Table 13 and Table 14 do not apply. Between two conductive parts, it is a requirement that both conductive parts, together with the spacing between them, are covered by the protection so that no airgap exists between the protective material, the conductive parts and the printed wiring boards.

The coating material used to provide Type 1 and Type 2 protection shall be designed to withstand the stresses anticipated to occur during the expected lifetime of the PCE.

Compliance is checked by a type test on representative PWB's, conducted according to IEC 60664-3 Clause 5. For the Cold test (5.7.1), a temperature of -25 °C shall be used, and for the rapid change of temperature test (5.7.3): -25 °C to $+125\text{ °C}$, except that if the temperature rating of the PCE is lower than -25 °C , the low temperature limit for the test is reduced to the rating of the PCE.

7.3.7.8.5 Wound components

Varnish or enamel insulation of wires shall not be used for basic, supplementary, double or reinforced insulation.

Wound components shall meet the requirements of 7.3.7.8.1 and 7.3.7.8.2.

The component itself shall pass the requirements given in 7.3.7.8.1 and 7.3.7.8.2. If the component has reinforced or double insulation, the voltage test in 7.5.2 shall be performed as a routine test.

7.3.7.8.6 Potting materials

A potting material may be used to provide solid insulation or to act as a coating to protect against pollution. If used as solid insulation, it shall comply with the requirements of 7.3.7.8.1 and 7.3.7.8.2. If used to protect against pollution, the requirements for Type 1 protection in 7.3.7.8.4.2 apply.

7.3.7.9 Insulation requirements above 30 kHz

Where voltages across insulation have fundamental frequencies greater than 30 kHz, further considerations apply. Requirements for this are provided in IEC 60664-4, and the more severe of these and the requirements of 7.3.7.1 to 7.3.7.8 shall be applied.

Annex G contains flow-charts for the determination of clearance and creepage distances under these circumstances. For convenience, Tables 1 and 2 of IEC 60664-4 are also included in Annex G.

7.3.8 Residual Current Detection (RCD) or Monitoring (RCM) device compatibility

RCD and RCM devices are used to provide protection against insulation faults in a.c. supply circuits in some domestic and industrial installations, in addition to any protection provided by the installed equipment.

An insulation fault or direct contact with certain types of PCE circuits can cause residual current with a d.c. component to flow and thus reduce the ability of an RCD or RCM of type A or AC to provide this protection for other equipment in the installation (see IEC 60755 and IEC 62020).

Pluggable type A PCE shall be designed so that, under normal and single-fault conditions, any resulting d.c. component in the residual current does not exceed the d.c. current withstand requirements in IEC 60755 and IEC 62020 for RCD and RCM of type A.

PCE that is pluggable type B or fixed equipment, may have a d.c. residual current component present in excess of the d.c. current withstand requirements in IEC 60755 and IEC 62020 for RCD and RCM of type A, if the information required by 5.3.2 item l) is provided in the installation instructions.

Compliance is checked by inspection if the installation instructions, and by the following measurements, to be performed under normal conditions, and during any fault conditions which may result in risk of a d.c. residual current component in the AC current. Faults are selected by analysis of the schematic.

The residual current in the AC input and/or output circuit is measured using a meter or power analyzer or other instrument that can detect only the d.c. component of the residual current. The resulting d.c. residual current component is compared to the limits in IEC 60755 or IEC 62020 as appropriate.

NOTE 1 RCDs of type A according to IEC 61008-1 and IEC 61009-1 are able to tolerate 6 mA smooth d.c. current while keeping their protective functionality, however depending on the design RCD manufacturers may declare much higher values for their products.

NOTE 2 This requirement may be met by protective means in the PCE, for example by incorporating means to disconnect the PCE from the mains in case of excessive d.c. current component.

NOTE 3 Annex E gives guidelines to assist with the selection of the RCD or RCM type.

NOTE 4 For design and construction of electrical installations, care should be taken with RCD of Type B. All the RCD upstream from an RCD of Type B up to the supply transformer should be of Type B.

7.3.9 Protection against shock hazard due to stored energy

7.3.9.1 Operator access area

Equipment shall be so designed that there is no risk of electric shock in operator access areas from stored charge after disconnection of the PCE.

In the case of plugs, connectors, or similar devices that can be disconnected without the use of a tool, the withdrawal of which results in the exposure of conductors (e.g. pins), the discharge time to reduce the voltage to DVC A (see 7.3.2.2) or, for capacitors, to a stored charge level below the limits specified in 7.3.5.3.2, shall not exceed 1 s.

Compliance is checked by inspection of the equipment and relevant circuit diagrams, taking into account the possibility of disconnection with any switch in either position, and if necessary by measuring the voltage with respect to time after disconnection of the source. For a.c. sources, disconnection at the peak of the a.c. voltage waveform is required.

7.3.9.2 Service access areas

Capacitors and other energy storage devices located behind panels that are removable for servicing, installation, or disconnection shall present no risk of electric shock or energy hazard from stored charge after disconnection of the PCE.

Capacitors within a PCE shall be discharged to a voltage less than DVC A (see 7.3.2.2), or an energy level below the limits specified in 7.3.5.3.2, within 10 s after the removal of power from the PCE. If this requirement is not achievable for functional or other reasons, the warning symbol 21 of Annex C and an indication of the discharge time shall be placed in a clearly visible position on the enclosure, the capacitor protective barrier, or at a point close to the capacitor(s) concerned (depending on the construction) (see 5.2.2.4).

For energy storage devices (such as batteries or ultracapacitors) the intended function of which is to maintain charge even with the PCE off and disconnected from external sources, a barrier or insulation shall be provided so that unintentional contact with hazardous live parts is prevented. The warning symbol 21 of Annex C shall be placed in a clearly visible position on or adjacent to the barrier or insulation, where it will be seen before removal of the barrier or insulation.

Compliance is checked by inspection of the equipment and relevant circuit diagrams, taking into account the possibility of disconnection with any switch in either position and non-operation of periodic power consuming devices or components within the PCE. If the discharge time cannot be accurately calculated, the discharge time shall be measured.

7.4 Protection against energy hazards

7.4.1 Determination of hazardous energy level

A hazardous energy level is considered to exist if:

- a) the voltage is 2 V or more, and power available after 60 s exceeds 240 VA.

Compliance is checked by calculations or by the following test:

With the equipment operating under normal operating conditions, a variable resistive load is connected to the parts under consideration and adjusted to obtain a level of 240 VA. Further adjustment is made, if necessary, to maintain 240 VA for a period of 60 s. If the voltage is 2 V or more, the output power is at a hazardous energy level, unless an overcurrent protective device opens during the above test, or for any other reason the power cannot be maintained at 240 VA for 60 s;

Or

- b) the stored energy in a capacitor is at a voltage, U of 2 V or more, and the stored energy, E , calculated from the following equation, exceeds 20 J:

$$E = 0,5 CU^2$$

where

E is the energy, in joules (J);

C is the capacitance, in farads (F);

U is the measured voltage on the capacitor, in volts (V).

7.4.2 Operator access areas

Equipment shall be so designed that there is no risk of energy hazard in operator access areas from accessible circuits.

A risk of injury due to an energy hazard exists if it is likely that two or more bare parts (one of which may be earthed) between which a hazardous energy level exists will be bridged by a metallic object.

The likelihood of bridging the parts under consideration shall be determined. Compliance is shown by means of the test finger of Figure D.1, in a straight position. If it is possible to bridge the parts with this test finger, a hazardous energy level shall not exist.

Barriers, guards, and similar means preventing unintentional contact may be provided as an alternative to limiting the energy.

7.4.3 Service access areas

Energy storage devices located behind panels that are removable for servicing, installation, or disconnection shall present no risk of electric energy hazard from charge stored after disconnection of the PCE.

Energy storage devices within a PCE shall be discharged to an energy level less than 20 J, as in 7.4.1, within 10 s after the removal of power from the PCE. If this requirement is not achievable for functional or other reasons, the warning symbol 21 of Annex C and an indication of the discharge time shall be placed in a clearly visible position on the enclosure, the protective barrier, or at a point close to the energy storage device(s) concerned (depending on the construction).

For energy storage devices (such as batteries or ultracapacitors) the intended function of which is to maintain charge even with the PCE off and disconnected from external sources, a barrier or insulation shall be provided so that unintentional contact with parts at a hazardous energy level is prevented. The warning symbol 21 of Annex C shall be placed in a clearly visible position on or adjacent to the barrier or insulation, where it will be seen before removal of the barrier or insulation.

Compliance is checked by inspection of the equipment and relevant circuit diagrams, taking into account the possibility of disconnection with any switch in either position and non-operation of periodic power consuming devices or components within the PCE. If the discharge time cannot be accurately calculated, the discharge time shall be measured.

7.5 Electrical tests related to shock hazard

7.5.1 Impulse voltage test (type test)

The impulse voltage test is performed with a voltage having a 1,2/50 μ s waveform (see Figure 6 of IEC 60060-1) and is intended to simulate overvoltages induced by lightning or due to switching of equipment. See Table 15 for conditions of the impulse voltage test.

Tests on clearances smaller than required by Table 13 (as allowed by 7.3.7.4.2) and on solid insulation are performed as type tests using appropriate voltages from Table 16.

Tests on components and devices for protective separation are performed as a type test before they are assembled into the PCE, unless the test can be performed on the completed PCE without reducing the stress applied to the protective separation. Testing is performed using the impulse withstand voltages listed in column 3 or column 5 of Table 16.

Where transient limiting means is used to reduce impulse voltage levels as in paragraph g) of 7.3.7.1.2, the reduction provided is verified by a type test. The values of column 2 or column 4 in Table 16 are applied to the PCE, and measurements are made in the circuit after the transient limiting means, to determine the level to which transients have been reduced.

If it is necessary to test a clearance that has been designed for altitudes between 2 000 m and 20 000 m (using Table A.2 of IEC 60664-1), the appropriate test voltage may be determined from the clearance distance, using Table 13 in reverse.

Table 15 – Impulse voltage test

Subject	Test conditions	
Test reference	Clause 19, 20.1.1 and Figure 6 of IEC 60060-1; 6.1.2.2.1 of IEC 60664-1	
Requirement reference	According to 7.3.4.3, 7.3.5.3 and 7.3.7	
Preconditioning	<i>Live parts</i> belonging to the same circuit shall be connected together. Protective impedances shall be disconnected unless required to be tested. Impulse voltage to be applied 1) between circuit under test and the surroundings and 2) between circuits to be tested. Power is not applied to circuits under test.	
Initial measurement	According to specification of PCE, component, or device	
Test equipment	Impulse generator 1,2/50 μ s with an effective internal impedance not higher than 2 Ω for testing clearances and 500 Ω for testing solid insulation and components.	
Measurement and verification	a) Clearances smaller than required by Table 7 Clearances reduced by overvoltage limiting means or by circuit characteristics Solid basic or supplementary insulation	b) Solid reinforced insulation Clearances, components and devices for protective separation
Test voltage	Three pulses 1,2/50 μ s of each polarity in ≥ 1 s interval, peak voltage (± 5 %) according to: column 2 or column 4 of Table 16	column 3 or column 5 of Table 16 When the test is carried out on a clearance at an altitude less than 2 000 m, the test voltage shall be increased according to Table F.5 of IEC 60664-1, which is reproduced as Table F.2 of this international standard.

Compliance is checked via application of the impulse voltage test and is successfully passed if no puncture, flashover, or sparkover occurs.

Table 16 – Impulse test voltage

Column 1	2	3	4	5
System voltage (see 7.3.7.2.1)	Impulse withstand voltage for insulation between circuits not connected directly to the mains and their surroundings according to overvoltage category II		Impulse withstand voltage for insulation between circuits connected directly to the mains and their surroundings according to overvoltage category III	
	Basic or supplementary	Reinforced	Basic or supplementary	Reinforced
V r.m.s.	V	V	V	V
≤50	500	800	800	1 500
100	800	1 500	1 500	2 500
150	1 500	2 500	2 500	4 000
300	2 500	4 000	4 000	6 000
600	4 000	6 000	6 000	8 000
1 000	6 000	8 000	8 000	12 000
-	Interpolation is permitted		Interpolation is not permitted	
	NOTE Test voltages for overvoltage categories I and III can be derived in a similar way from Table 12.		NOTE Test voltages for overvoltage categories II and IV can be derived in a similar way from Table 12.	

7.5.2 Voltage test (dielectric strength test) (type test and routine test)

7.5.2.1 Purpose of test

The test is used to verify that the clearances and solid insulation of components and of assembled PCE has adequate dielectric strength to resist overvoltage conditions. Routine tests are performed to verify that clearances and solid insulation have not been omitted, reduced, or damaged during the manufacturing operations.

7.5.2.2 Value and type of test voltage

The values of the test voltage are determined from column 2 or 3 of Table 17 or Table 18 depending upon whether the circuit under test is mains connected or not mains connected.

The test voltage from column 2 is used for testing circuits with basic insulation.

Between circuits with protective separation (double or reinforced insulation), the test voltage of column 3 shall be applied for type tests. For routine tests between circuits with protective separation the values from column 2 shall be applied, to prevent damage to the solid insulation due to causing partial discharge within the solid insulation.

The values of column 3 shall apply to circuits with protective separation, and between circuits and accessible surfaces of PCE, which are non-conductive or conductive but not connected to the protective earthing conductor.

The voltage test shall be performed with a sinusoidal voltage at 50 Hz or 60 Hz. If the circuit contains capacitors the test may be performed with a d.c. voltage of a value equal to the peak value of the specified a.c. voltage.

Table 17 – AC or DC test voltage for circuits connected directly to the mains

Column 1 System voltage (see 7.3.7.2.1)	2 ^b Voltage for type testing circuits with basic insulation, and for all routine testing		3 ^b Voltage for type testing circuits with protective separation, and between circuits and accessible surfaces (non- conductive or conductive but not connected to protective earth, protective class II according to 7.3.6.4)	
	a.c. r.m.s. ^a	d.c.	a.c. r.m.s.	d.c.
	V	V	V	V
≤ 50	1 250	1 770	2 500	3 540
100	1 300	1 840	2 600	3 680
150	1 350	1 910	2 700	3 820
300	1 500	2 120	3 000	4 240
600	1 800	2 545	3 600	5 090
1 000	2 200	3 110	4 400	6 220

NOTE Interpolation is permitted.

^a Corresponding to 1 200 V + system voltage.

^b A voltage source with a short-circuit current of at least 0,1 A according to 5.2.2.2 of IEC 61180-1 is used for this test.

Table 18 – a.c. or d.c. test voltage for circuits not connected directly to the mains

Column 1 Working voltage (recurring peak) (see 7.3.7.2.3)	2 ^a Voltage for type testing circuits with basic insulation, and for all routine testing		3 ^a Voltage for type testing circuits with protective separation, and between circuits and accessible surfaces (non- conductive or conductive but not connected to protective earth, protective class II according to 7.3.6.4)	
	a.c. r.m.s.	d.c.	a.c. r.m.s.	d.c.
	V	V	V	V
≤71	80	110	160	220
141	160	225	320	450
212	240	340	480	680
330	380	530	760	1 100
440	500	700	1 000	1 400
600	680	960	1 400	1 900
1 000	1 100	1 600	2 200	3 200
1 600	1 800	2 600	2 900	4 200

NOTE 1 Interpolation is permitted.

NOTE 2 Test voltages in this table are based upon 80 % of the withstand voltage for the corresponding clearance of Table 12 as provided by Table A.1 of IEC 60664-1.

^a A voltage source with a short-circuit current of at least 0,1 A according to 5.2.2.2 of IEC 61180-1 is used for this test.

7.5.2.3 Humidity pre-conditioning

For type tests on PCE for which wet locations requirements apply, according to 6.1, the humidity pre-conditioning of 4.5 shall be performed immediately prior to the voltage test.

7.5.2.4 Performing the voltage test

The test shall be applied as follows, according to Figure 13:

- a) Test (1) between accessible conductive part (connected to earth) and each circuit sequentially (except DVC A circuits). Test voltage according to Table 17 and Table 18, column 2, corresponding to voltage of considered circuit under test.

Test (2) between accessible surface (non conductive or conductive but not connected to earth) and each circuit sequentially (except DVC A circuits). Test voltage according to Table 17 and Table 18, column 3 (for type test) or column 2 (for routine test), corresponding to voltage of considered circuit under test.

- b) Test between each considered circuit sequentially and the other adjacent circuits connected together. Test voltage according to Table 17 and Table 18, column 2, corresponding to voltage of considered circuit under test.
- c) Test between DVC A circuit and each adjacent circuit sequentially. Test voltage according to Table 17 and Table 18 column 3 (for type test) or column 2 (for routine test), corresponding to the circuit with the higher voltage. Either the adjacent circuit or the DVC A circuit may be earthed for this test. If basic insulation is required between adjacent DVC A circuits, the basic insulation is required to be tested. Where functional insulation is permitted between adjacent DVC A circuits, that functional insulation is not required to be tested.

It may not be possible to perform type tests of protective insulation at voltages according to column 3 of Table 17 and Table 18 without overstressing Basic insulation between the circuits under test and the chassis. In these cases the type test of insulation used for protective separation shall be performed at voltages according to column 2 of the appropriate Table, or it may be necessary to disassemble the PCE.

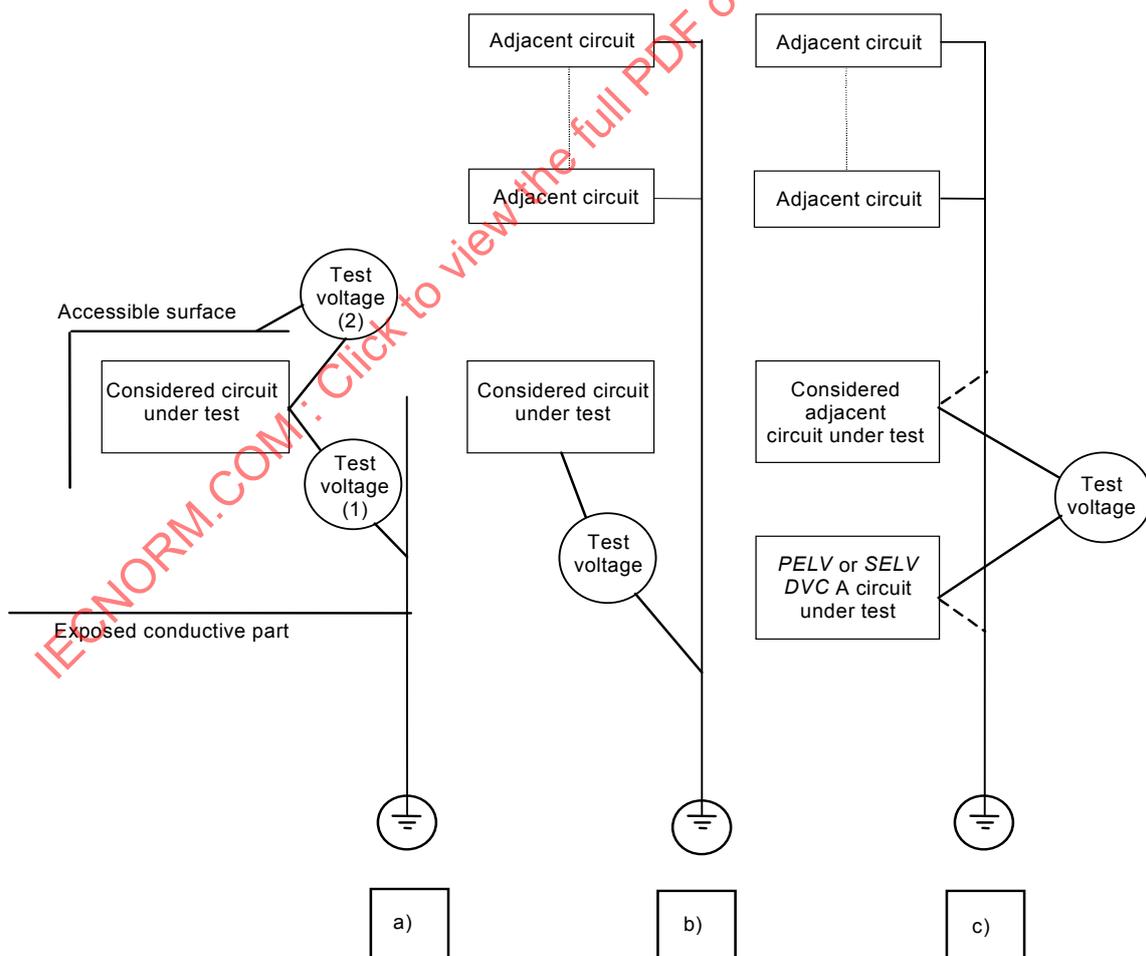


Figure 13 – Voltage test procedures

The tests shall be performed with the PCE fully assembled, and all covers in place and all doors of the enclosure closed.

To create a continuous circuit for the voltage test on the PCE, terminals, open contacts on switches and semiconductor switching devices, etc. shall be bridged where necessary. Before testing, semiconductors and other vulnerable components within a circuit may be disconnected and/or their terminals bridged to avoid damage occurring to them during the test.

Protective devices designed to reduce impulse voltages on the circuits under test (see 7.3.7.2.2 and 7.3.7.2.3, and circuits belonging to monitoring or protection circuits, not designed to sustain the test overvoltage for the duration of the test, shall be disconnected in order to avoid damage and to ensure that the test voltage can be applied without a false indication of failure.

Wherever practicable, individual components forming part of the insulation under test, for example interference suppression capacitors, should not be disconnected or bridged before the test. In this case, it is recommended to use the d.c. test voltage according to Table 17 and Table 18.

Protective impedances according to 7.3.5.3 shall either be included in the testing or the connection to the protectively separated part of the circuit shall be opened before testing. In the latter case, the connection shall be carefully restored after the voltage test in order to avoid any damage to the insulation. Protective screens according to 7.3.3 shall remain connected to accessible conductive parts during the voltage test.

Where the PCE is covered totally or partly by a non-conductive accessible surface, a conductive foil to which the test voltage is applied shall be wrapped around this surface for testing. In this case, the insulation test between a circuit and non-conductive accessible surface may be performed as a sample test instead of a routine test.

Routine testing of the assembled PCE is not required if:

- routine testing of all subassemblies related to the insulation system of the PCE is performed;
and
- it can be demonstrated that final assembly will not compromise the insulation system;
and
- type testing of the fully-assembled PCE was performed successfully.

7.5.2.5 Duration of the a.c. or d.c. voltage test

The duration of the test shall be at least 60 s for the type test and 1 s for the routine test. The test voltage may be applied with increasing and/or decreasing ramp voltage, and the ramp times are not specified, but regardless of the ramp time, the dwell time at full voltage shall be 60 s and 1 s respectively for type and routine tests.

7.5.2.6 Verification of the a.c. or d.c. voltage test

The test is successfully passed if no electrical breakdown occurs and there is no abnormal current flow during the test.

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

7.5.3 Partial discharge test (type test or sample test)

Where required by 7.3.7.8.2, the partial discharge test shall confirm that the solid insulation used within devices applied for protective separation of electrical circuits remains partial-discharge-free within the specified voltage range (see Table 19).

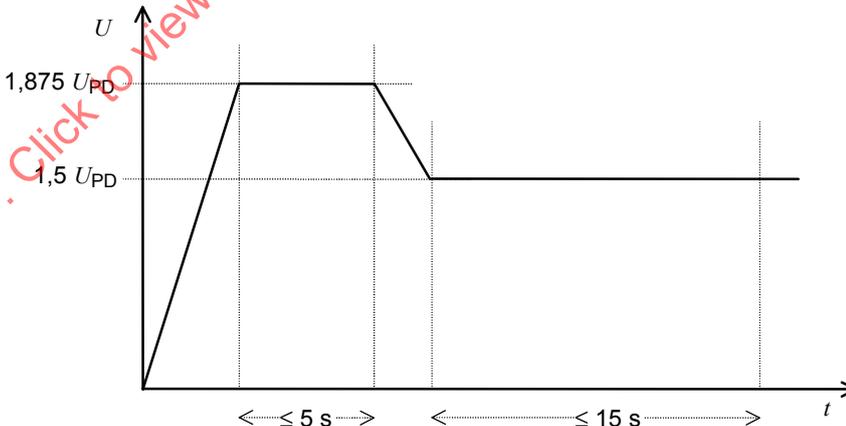
This test shall be performed as a type test and a sample test. It may be deleted for insulating materials, which are not degraded by partial discharge, for example ceramics.

The sample test may be omitted on parts that comply with a relevant standard (see 14.1) and are manufactured under a quality control system.

The partial discharge inception and extinction voltage are influenced by climatic factors (e.g. temperature and moisture), equipment self heating, and manufacturing tolerance. These influencing variables can be significant under certain conditions and shall therefore be taken into account during type testing.

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Table 19 – Partial discharge test

Subject	Test conditions
Test reference	6.1.3.5 of IEC 60664-1
Requirement reference	7.3.7.8
Preconditioning	<p>Samples shall be pre-conditioned according to 6.1.3.2 of IEC 60664-1</p> <p>Live parts belonging to the same circuit shall be connected together</p> <p>It is recommended that the partial discharge test is performed after the impulse voltage test (see 7.5.1) in order that any damage caused by the impulse voltage test is apparent</p> <p>It is advisable that the partial discharge test is performed before inserting the components or devices into the equipment because partial discharge testing is not normally possible when the equipment is assembled</p>
Initial measurement	According to specification of component or device
Test equipment Test circuit Test voltage Test method Calibration of test equipment	<p>Calibrated charge measuring device or radio interference meter without weighting filters</p> <p>C.1 of IEC 60664-1</p> <p>The peak value of a.c. 50 Hz or 60 Hz</p> <p>6.1.3.5 of IEC 60664-1: $F_1 = 1,2$; $F_2, F_3 = 1,25$. Test procedure 6.1.3.5.3 of IEC 60664-1</p> <p>C.4 of IEC 60664-1</p>
Measurement Verification	<p>Starting from a voltage below the rated discharge voltage U_{PD}^a, the voltage shall be linearly increased to 1,875 times U_{PD} and held for a maximum time of 5 s</p> <p>The voltage shall then be linearly decreased to 1,5 times U_{PD} ($\pm 5\%$) and held for a maximum time of 15 s, during which the partial discharge is measured</p> <p>The test shall be considered to have been successfully passed if the partial discharge is less than 10 pC during the measurement period</p>  <p style="text-align: right;">IEC 263/03</p>
<p>^a The rated discharge voltage is the sum of the recurring peak voltages in each of the circuits separated by the insulation.</p>	

7.5.4 Touch current measurement (type test)

The touch current shall be measured if required by 7.3.6.3.7 and shall not be greater than 3,5 mA a.c. or 10 mA d.c. or special measures of protection as given in 7.3.6.3.7 are required.

For type tests on PCE for which wet locations requirements apply according to 6.1, the humidity pre-conditioning of 4.5 shall be performed immediately prior to the touch current test.

Compliance is checked by the following type test. The PCE shall be set up without any connection to the earth and shall be operated under reference test conditions as in 4.2.2. For equipment with multiple sources of supply that may be energized at the same time under normal conditions of use, all supplies shall be connected and energized during the test.

Under these conditions, the touch current shall be measured between the means of connection for the external protective earthing conductor and the external protective earthing conductor itself, using the measurement network of Figure 4 of IEC 60990.

NOTE 1 For convenience, IEC 60990 test Figure 4 is reproduced in Annex H.

NOTE 2 Consideration should be given to the impact on the touch current measurement that capacitance between external test sources and earth could have on the result (for example a d.c. supply with capacitors to earth can increase the measured touch current unless the d.c. supply is not earthed to the same earth as the PCE under test).

- For a PCE to be connected to an earthed neutral system, the neutral of the mains of the test site shall be directly connected to the external protective earthing conductor.
- For a PCE to be connected to an isolated system or impedance system, the neutral shall be connected through a resistance of 1 k Ω to the external protective earthing conductor, which shall be connected to each input phase in turn. The highest value will be taken as the definitive result.
- For a PCE to be connected to a corner earthed system, the external protective earthing conductor shall be connected to each input phase in turn. The highest value will be taken as the definitive result.
- For a PCE with a particular earthing system, this system shall operate as intended during the test.
- If a PCE is intended to be connected to more than one system network, each of these different system networks (or the worst-case, if that can be determined) shall be used to make the leakage current measurement.

7.5.5 Equipment with multiple sources of supply

Hazards, within the meaning of this standard, shall not be present under normal or single fault conditions due to the presence of multiple sources of supply. Actions such as disconnection or de-energizing of an external supply are considered a normal condition.

Compliance is checked by evaluation of circuit diagrams and by the testing of 4.4.4.6 (for backfeed current) and 4.6 (for backfeed voltage).

Information shall be provided with the equipment indicating the presence of multiple sources of supply and giving disconnection procedures (see 5.3.4).

NOTE 1 Examples of the types of hazards that need to be considered are:

- backfeed prevention - preventing voltage, current, or energy available within the PCE or one of its sources from being fed back to any of the input terminals for another source, either directly or by a leakage path, in a manner that results in a hazard;
- touch current levels may be higher with multiple sources connected simultaneously (if that is a normal condition for the equipment);
- hazard resulting from damage to one or more connected sources due to energy from another source.

NOTE 2 Specific requirements may be given in other Parts of IEC 62109.

8 Protection against mechanical hazards

8.1 General

Operation shall not lead to a mechanical hazard in normal condition or single fault condition.

Edges, projections, corners, openings, guards, handles and the like, that are accessible to the operator shall be smooth and rounded so as not to cause injury during normal use of the equipment.

Compliance is checked as specified in 8.2 to 8.6.

8.2 Moving parts

Moving parts shall not be able to crush, cut or pierce parts of the body of an operator likely to contact them, nor severely pinch the operator's skin. Hazardous moving parts of equipment, that is moving parts which have the potential to cause injury, shall be so arranged, enclosed or guarded as to provide adequate protection against the risk of personal injury.

If, during routine maintenance outside normal use, it is unavoidable for technical reasons that an operator has to perform a function, such as adjustment, which requires access to moving parts, which could cause a hazard, access is permitted if all of the following precautions have been taken:

- a) access is not possible without the use of a tool;
- b) the instructions for the responsible body include a statement that operators must be trained before being allowed to perform the hazardous operation;
- c) there are warning markings (see 5.2) on any covers or parts which have to be removed to obtain access, prohibiting access by untrained operators.

Automatic reset thermal cut-outs or overcurrent protection devices, automatic timer starting, etc., shall not be incorporated if unexpected resetting might create a hazard.

Compliance is checked by inspection and where necessary by a test with the test finger of Figure D.1 of Annex D, after removal of operator-detachable parts, and with operator access doors and covers open. Unless additional measures have been taken as specified above, it shall not be possible to touch hazardous moving parts with the test finger, applied without appreciable force in every possible position.

Openings preventing the entry of the jointed test finger of Figure D.1 are further tested by means of a straight unjointed version of the test finger, Figure D.3, applied with a force of 30 N. If the unjointed finger enters, the test with the jointed test finger is repeated, except that the finger is pushed through the opening using any necessary force up to 30 N.

8.2.1 Protection of service persons

Protection shall be provided such that unintentional contact with hazardous moving parts is unlikely during servicing operations. If a guard over a hazardous moving part may need to be removed for servicing, the marking of symbol 15 of Annex C shall be applied on or near the guard.

Compliance is checked by inspection, and where necessary, by ensuring that the IP1X probe of IEC 60529 cannot contact the hazardous moving part with the guard in place.

8.3 Stability

Equipment and assemblies of equipment not secured to the building structure before operation shall be physically stable in normal use.

If means are provided to ensure that stability is maintained after the opening of drawers, etc. by an operator, either these means shall be automatic or there shall be a warning marking (see 5.2).

Compliance is checked by carrying out each of the following tests, if applicable. Containers contain the rated amount of substance that provides the least favourable conditions of normal use. Castors are in their least favourable position of normal use. Doors, drawers, etc. are closed unless otherwise specified.

- a) Equipment other than hand-held equipment, is tilted in each direction to an angle of 10° from its normal position.
- b) Equipment which has both a height of 1 m or more and a mass of 25 kg or more, and all floor-standing equipment, has a force applied at its top, or at a height of 2 m if the equipment has a height of more than 2 m. The force is 250 N, or 20 % of the weight of the equipment, whichever is less, and is applied in all directions except upwards. Jacks used in normal use, and doors, drawers, etc., intended to be opened by an operator, are in their least favourable positions.
- c) Floor-standing equipment has a force of 800 N applied downwards at the point of maximum moment to
 - 1) all horizontal working surfaces;
 - 2) other surfaces providing an obvious ledge and which are not more than 1 m above floor level.

During the tests, the equipment shall not overbalance.

Compliance with the marking requirement is checked by inspection.

8.4 Provisions for lifting and carrying

If carrying handles or grips are fitted to, or supplied with, the equipment, they shall be capable of withstanding a force of four times the weight of the equipment.

Equipment or parts having a mass of 18 kg or more shall be provided with a means for lifting and carrying or directions shall be given in the manufacturer's documentation.

Compliance is checked by inspection and by the following test.

A single handle or grip is subjected to a force corresponding to four times the weight of the equipment. The force is applied uniformly over a 70 mm width at the centre of the handle or grip, without clamping. The force is steadily increased so that the test value is attained after 10 s and maintained for a period of 1 min.

If more than one handle or grip is fitted, the force is distributed between the handles or grips in the same proportion as in normal use. If the equipment is fitted with more than one handle or grip but is so designed that it may readily be carried by only one handle or grip, each handle or grip shall be capable of sustaining the total force.

The handles or grips shall not break loose from the equipment and there shall not be any permanent distortion, cracking or other evidence of failure.

8.5 Wall mounting

Mounting brackets on equipment intended to be mounted on a wall or ceiling shall withstand a force of four times the weight of the equipment.

Compliance is checked after mounting the equipment in accordance with the manufacturer's instructions, using the fasteners and wall construction specified. Adjustable brackets are adjusted to the position that will give the maximum projection from the wall.

If no wall construction is specified, a 10 mm ± 2 mm thick plaster board (drywall) on nominal 50 mm × 100 mm ± 10 mm studs at 400 mm ± 10 mm centres is to be used as the support

surface. Fasteners are applied as specified in the instructions but, if not specified, are positioned in the plasterboard between the studs.

The mounting brackets are then subjected to the weight of the equipment plus a test weight of three times the weight of the equipment, acting vertically through the centre of gravity. The test weight is applied gradually and is increased from zero to full load in 5 s to 10 s, then maintained for 1 min.

After the test, there shall be no damage to the bracket or the mounting surface.

8.6 Expelled parts

Equipment shall contain or limit the energy of parts that could cause a hazard if expelled in the event of a fault.

The means of protection against expelled parts shall not be removable without the aid of a tool.

Compliance is checked by inspection after application of the relevant fault conditions of 4.4.

9 Protection against fire hazards

9.1 Resistance to fire

This subclause specifies requirements intended to reduce the risk of ignition and the spread of flame, both within the equipment and to the outside, by the appropriate use of materials and components and by suitable construction.

NOTE 1 The risk of ignition is reduced by limiting the maximum temperature of components under normal operating conditions and after a single fault (see 4.4), or by limiting the power available in a circuit.

NOTE 2 The spread of flame in the event of ignition is reduced by the use of flame retardant materials and insulation, or by providing adequate separation.

9.1.1 Reducing the risk of ignition and spread of flame

For equipment or a portion of equipment, there are two alternative methods of providing protection against ignition and spread of flame that could affect materials, wiring, wound components and electronic components such as integrated circuits, transistors, thyristors, diodes, resistors and capacitors.

Method 1 – Selection and application of components, wiring and materials that reduce the possibility of ignition and spread of flame and, where necessary, by the use of a fire enclosure. The appropriate requirements are detailed in 9.1.2 and 9.1.3. In addition, the simulated faults of 4.4.4.1 a) and b) are applied, when using this method.

NOTE 1 Method 1 may be preferred for equipment or that portion of equipment with a large number of electronic components.

Method 2 – Application of all of the simulated fault tests in 4.4.4.1 a), b), and c). A fire enclosure is not required for equipment or that portion of equipment for which only Method 2 is used if the fault testing does not result in ignition of components, temperatures that could be sufficient for ignition, or other indication of a risk of fire.

NOTE 2 Method 2 may be preferred for equipment or that portion of equipment with a small number of electronic components.

9.1.2 Conditions for a fire enclosure

A fire enclosure is required for equipment or parts of equipment for which Method 2 is not fully applied and complied with.

9.1.2.1 Parts requiring a fire enclosure

Except where Method 2 is used, or as permitted in 9.1.2.2, the following are considered to have a risk of ignition and, therefore, require a fire enclosure:

- components in mains circuits;
- components in secondary circuits supplied by power sources which exceed the limits for a limited power source as specified in 9.2;
- components in secondary circuits supplied by a limited power source as specified in 9.2, but not mounted on material of flammability class V-1;
- components within a power supply unit or assembly having a limited power output complying with the criteria for a limited power source as specified in 9.2, including overcurrent protective devices, limiting impedances, regulating networks and wiring, up to the point where the limited power source output criteria are met;
- components having unenclosed arcing parts, such as open switch and relay contacts and commutators, in a circuit at hazardous voltage or at a hazardous energy level; and
- insulated wiring, except as permitted in 9.1.2.2.

9.1.2.2 Parts not requiring a fire enclosure

The following do not require a fire enclosure:

- wiring and cables insulated with PVC, TFE, PTFE, FEP, neoprene or polyimide;
- plugs and connectors forming part of a power supply cord or interconnecting cable;
- components, including connectors, meeting the requirements of 9.1.3.2, which fill an opening in a fire enclosure;
- connectors in secondary circuits supplied by power sources which are limited to a maximum of 15 VA under normal operating conditions and after a single fault in the equipment;
- connectors in secondary circuits supplied by a limited power source as specified in 9.2,
- other components in secondary circuits:
 - supplied by a limited power source as specified in 9.2, and mounted on materials of flammability class C.1;
 - supplied by internal or external power sources which are limited to a maximum of 15 VA under normal operating conditions and after a single fault in the equipment and mounted on material of flammability class HB;
 - complying with Method 2 of 9.1.1.

Compliance with 9.1.2.1 and 9.1.2.2 is checked by inspection and by evaluation of the data provided by the manufacturer, and where necessary by measurements or the tests of 9.2. For determining the risk of ignition in cases not specified in 9.1.2, compliance is checked by Method 2 in 9.1.1.

9.1.3 Materials requirements for protection against fire hazard

9.1.3.1 General

Enclosures, components and other parts shall be so constructed, or shall make use of such materials, that the propagation of fire is limited.

Materials of flammability classes VTM-0, VTM-1 and VTM-2 are considered to be equivalent to materials of FLAMMABILITY classes V-0, V-1 and V-2, respectively, for their flammability properties. Their electrical and mechanical properties are not necessarily equivalent.

Where material of flammability class HB or flammability class HBF, is required, material passing the glow-wire test at 550 °C according to IEC 60695-2-11 is acceptable as an alternative.

Where it is not practical to protect components against overheating under fault conditions, the components shall be mounted on materials of flammability class V-1. Additionally, such components shall be separated from material of a class lower than flammability class V-1 by at least 13 mm of air, or by a solid barrier of material of flammability class V-1.

Polymeric materials that serve as the outer enclosure and have surface area greater than 1 m² or a single dimension larger than 2 m, shall have a maximum flame spread index of 100 as determined by ASTM E162 or ANSI/ASTM E84. This requirement applies whether Method 1 or Method 2 is used.

NOTE 1 See also 9.1.3.4.

NOTE 2 In considering how to limit propagation of fire, and what are "small parts", account should be taken of the cumulative effect of small parts when they are adjacent to each other, and also of the possible effect of propagating fire from one part to another.

NOTE 3 The material flammability requirements in 9.1.3 are summarized in Table 20.

Compliance is checked by inspection and by evaluation of relevant data provided by the manufacturer.

9.1.3.2 Materials for fire enclosures

If an enclosure material is not classified as specified below, a test may be performed on the final enclosure or part of the enclosure, in which case the material shall additionally be subjected to periodic sample testing.

The material of a fire enclosure, in the thinnest significant wall thickness used, shall be classified as flammability class 5VB according to IEC 60695-11-20 or shall pass the 5VB test in the end product. Whether classified or tested, the test result shall comply with all of the following:

- a) the sample shall not release either flaming drops or particles capable of igniting the surgical cotton, and
- b) the sample shall not continue to burn for more than 1 min after the fifth application of the test flame, and
- c) there shall be no openings greater than 25 mm after the test.

Materials for components that fill an opening in a fire enclosure shall:

- be of at least V-1 class material and no larger than 100 mm in any dimension; or
- be of at least V-2 class material and either
 - no larger than 25 mm in any dimension, or
 - no larger than 100 mm in any dimension and located at least 100 mm from any part that is a source of fire hazard, or
- be of at least V-2 class material and there is a barrier or device(s) that forms a barrier made of a V-10 class material between the part and a source of fire hazard, or

- comply with a relevant IEC component standard that includes flammability requirements for components that are intended to form part of, or fill openings in, a fire enclosure

Plastic materials of a fire enclosure shall be located more than 13 mm through air from parts that arc under normal conditions such as unenclosed commutators and unenclosed switch contacts.

Plastic materials of a fire enclosure located less than 13 mm through air from non-arcing parts which, under any condition of normal or abnormal operation, could attain a temperature sufficient to ignite the material, shall be capable of passing the hot-wire ignitability test of IEC 60695-2-20. If a sample melts through without igniting, the dimensions of the hole shall comply with the requirements elsewhere in this standard.

Metals, ceramic materials and glass shall be considered to comply without test.

Compliance is checked by inspection of the equipment and material data sheets and, if necessary, by the appropriate test or tests in 9.1.4 or IEC 60695-2-20 and IEC 60695-11-20, as applicable.

9.1.3.3 Materials for components and other parts inside fire enclosures

Requirements for materials in air filters assemblies are in 9.1.3.4.

Inside fire enclosures, materials for components and other parts, (including mechanical and electrical enclosures located inside fire enclosures), shall comply with one of the following:

- be of flammability class V-2 or flammability class HF-2; or
- meet the flammability requirements of a relevant IEC component standard which includes such requirements.

The above requirement does not apply to any of the following:

- electrical components which do not present a fire hazard under abnormal operating conditions when tested according to Method 2 of 9.1.1;
- materials and components within an enclosure of 0,06 m³ or less, consisting totally of metal and having no ventilation openings, or within a sealed unit containing an inert gas;
- one or more layers of thin insulating material, such as adhesive tape, used directly on any surface within a fire enclosure, including the surface of current-carrying parts, provided that the combination of the thin insulating material and the surface of application complies with the requirements of flammability class V-2, or flammability class HF-2;

NOTE Where the thin insulating material referred to in the above exclusion is on the inner surface of the fire enclosure itself, the requirements in 12.8 continue to apply to the fire enclosure.

- electronic components, such as integrated circuit packages, optocoupler packages, capacitors and other small parts that are mounted on material of flammability class V-1;
- wiring, cables and connectors insulated with PVC, TFE, PTFE, FEP, neoprene or polyimide;
- individual clamps (not including helical wraps or other continuous forms), lacing tape, twine and cable ties used with wiring harnesses;
- the following parts, provided that they are separated from electrical parts (other than insulated wires and cables) which under fault conditions are likely to produce a temperature that could cause ignition, by at least 13 mm of air or by a solid barrier of material of flammability class V-1:

- other small parts which would contribute negligible fuel to a fire, including, labels, mounting feet, key caps, knobs and the like;
- tubing for air or any fluid systems, containers for powders or liquids and foamed plastic parts, provided that they are of flammability class HB.

Compliance is checked by inspection of the equipment and material data sheets and, if necessary, by the appropriate test or tests of IEC series 60695.

9.1.3.4 Materials for air filter assemblies

Air filter assemblies shall be constructed of materials of flammability class V-2, or flammability class HF-2.

This requirement does not apply to the following constructions:

- air filter assemblies in air circulating systems, whether or not airtight, that are not intended to be vented outside the fire enclosure;
- air filter assemblies located inside or outside a fire enclosure, provided that the filter materials are separated by a metal screen from parts that could cause ignition. This screen may be perforated and shall meet the requirements of 9.1.4.3 for the bottoms of fire enclosures;
- air filter frames constructed of materials of flammability class HB, provided that they are separated from electrical parts (other than insulated wires and cables) which under fault conditions are likely to produce a temperature that could cause ignition, by at least 13 mm of air or by a solid barrier of material of flammability class V-1;
- air filter assemblies located externally to the fire enclosure, constructed of materials of flammability class HB.

Compliance is checked by inspection of the equipment and material data sheets and, if necessary, by the appropriate test or tests of IEC series 60695.

Table 20 – Summary of material flammability requirements

Part	Requirement
Large enclosure surface areas 9.1.3.1	Max. flame spread index of 100
Fire enclosures, 9.1.3.2	<ul style="list-style-type: none"> - 5VB - Test of IEC 60695-11-20 - Hot wire test of IEC 60695-2-20 (If <13 mm of air from parts at high temperatures which could cause ignition)
Components and parts, including mechanical and electrical enclosures, inside fire enclosures, 9.1.3.3	<ul style="list-style-type: none"> - V-2 or HF-2 - For components and exceptions see 9.1.3.3
Air filter assemblies 9.1.3.4	<ul style="list-style-type: none"> - V-2 or HF-2 - For exceptions see 9.1.3.4

9.1.4 Openings in fire enclosures

9.1.4.1 General

For equipment that is intended to be used or installed in more than one orientation as specified in the product documentation, the following requirements apply in each orientation.

These requirements are in addition to those in the following sections:

- 7.3.4, Protection against direct contact;

- 7.4, Protection against energy hazards;
- 13.5, Openings in enclosures.

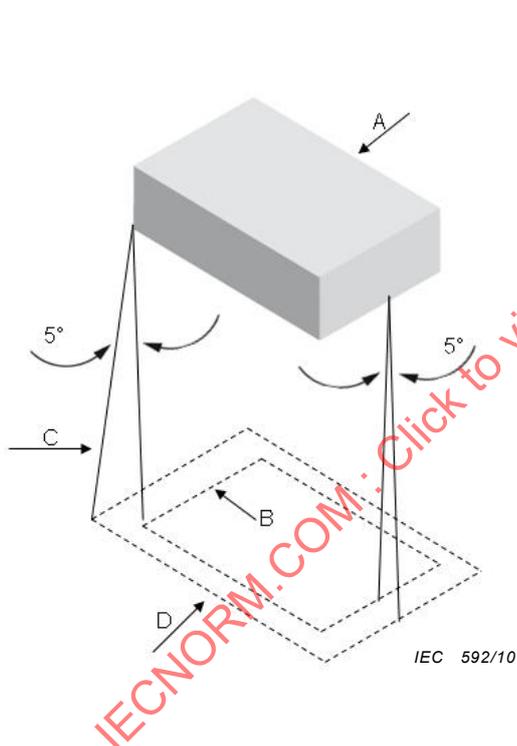
9.1.4.2 Side openings treated as bottom openings

Where a portion of the side of a fire enclosure falls within the area traced out by the 5° angle in Figure 14, the limitations in 9.1.4.3 regarding openings in bottoms of fire enclosures also apply to this portion of the side.

9.1.4.3 Openings in the bottom of a fire enclosure

The bottom of a fire enclosure or individual barriers, shall provide protection against emission of flaming or molten material under all internal parts, including partially enclosed components or assemblies, for which Method 2 of 9.1.1 has not been fully applied and complied with.

The location and size of the bottom or barrier shall cover area D in Figure 14 and shall be horizontal, lipped or otherwise shaped to provide equivalent protection. The area shall be free of openings, except for those protected by a baffle, screen or other means so that molten metal and burning material are unlikely to fall outside the fire enclosure.



Key

- A The component or subassembly under which a fire enclosure is required. If the component or subassembly does not have its own fire enclosure, the entire component is considered. If a component or subassembly has its own fire enclosure consideration needs to be given only to portions that are unenclosed or have openings through which flaming particles might be emitted.
- B The outline of the area A projected vertically downward onto horizontal plane of the lowest point of the fire enclosure.
- C Inclined line that traces an outline D on the same plane as B. Moving around the perimeter of the outline B, this line projects at a 5° angle from the vertical at every point round the perimeter of the component A, and is oriented to trace out the largest area.
- D Minimum outline of the bottom of the fire enclosure.

NOTE A portion of the side of a fire enclosure which is within the area traced out by the 5° angle is also considered to be part of the bottom of the fire enclosure.

Figure 14 – Fire enclosure bottom openings below an unenclosed or partially enclosed component

The following constructions are considered to satisfy the requirement without test:

- no opening in the bottom of a fire enclosure;
- openings in the bottom of any size under an internal barrier, screen or the like, which itself complies with the requirements for a fire enclosure;
- openings in the bottom, each not larger than 40 mm², under components and parts meeting the requirements for V-1 class material, or HF-1 class foamed material or under small components that pass the needle-flame test of IEC 60695-11-5 using a 30 s flame application;

- baffle plate construction as illustrated in Figure 15;
- metal bottoms of fire enclosures conforming to the dimensional limits of any line in Table 21;
- metal bottom screens having a mesh with nominal openings not greater than 2 mm between centre lines and with wire diameters of not less than 0,45 mm.

Constructions other than the above are acceptable if they comply with the hot flaming oil test below.

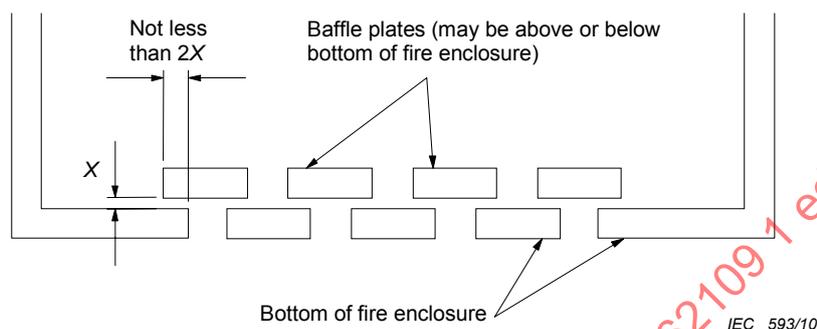


Figure 15 – Fire enclosure baffle construction

Table 21 – Allowable openings in fire enclosure bottoms

Applicable to circular holes			Applicable to other shaped openings	
Metal bottoms minimum thickness	Maximum diameter of holes	Minimum spacing of holes centre to centre	Maximum area	Minimum spacing of openings border to border
mm	mm	mm	mm ²	mm
0,66	1,1	1,7	1,1	0,56
0,66	1,2	2,3	1,2	1,1
0,76	1,1	1,7	1,1	0,55
0,76	1,2	2,3	1,2	1,1
0,81	1,9	3,1	2,9	1,1
0,89	1,9	3,1	2,9	1,2
0,91	1,6	2,7	2,1	1,1
0,91	2,0	3,1	3,1	1,2
1,0	1,6	2,7	2,1	1,1
1,0	2,0	3,0	3,2	1,0

Compliance is checked by inspection and, where necessary, by the flaming oil test as follows, during which the cheesecloth shall not ignite.

Mounting of samples: A sample of the complete finished bottom of the fire enclosure is securely supported in a horizontal position. Bleached cheesecloth of approximately 40 g/m² is placed in one layer over a shallow, flat-bottomed pan approximately 50 mm below the sample, and is of sufficient size to cover completely the pattern of openings in the sample, but not large enough to catch any of the oil that runs over the edge of the sample or otherwise does not pass through the openings.

NOTE Use of a metal screen or a wired-glass partition surrounding the test area is recommended.

Test procedure: A small metal ladle (preferably no more than 65 mm in diameter), with a pouring lip and a long handle whose longitudinal axis remains horizontal during pouring, is partially filled with 10 ml of a distillate fuel oil that is a medium volatile distillate having a mass per unit volume between 0,845 g/ml and 0,865 g/ml, a flash point between 43,5 °C and 93,5 °C and an average calorific value of 38 MJ/l. The ladle containing the oil is heated and the oil ignited and permitted to burn for 1 min, at which time all of the hot flaming oil is poured at the rate of approximately 1 ml/s in a steady stream onto the centre of the pattern of openings, from a position approximately 100 mm above the openings.

The test is repeated twice at 5 min intervals, using clean cheesecloth.

9.1.4.4 Equipment for use in a closed electrical operating area

The requirements of 9.1.4.3 do not apply to fixed equipment intended only for use in a closed electrical operating area and to be mounted on a concrete floor or other non-combustible surface. Such equipment shall be marked as follows:

WARNING: FIRE HAZARD. SUITABLE FOR MOUNTING ON CONCRETE OR OTHER
NON-COMBUSTIBLE SURFACE ONLY

9.1.4.5 Doors or covers in fire enclosures

If part of a fire enclosure consists of a door or cover leading to an operator access area, it shall comply with one of the following requirements:

- the door or cover shall be provided with a safety interlock; or
 - a door or cover, intended to be routinely opened by the user, shall comply with both of the following conditions:
 - it shall not be removable from other parts of the fire enclosure by the user;
- and
- it shall be provided with a means to keep it closed during normal operation.

A door or cover intended only for occasional use by an installer, such as for the installation of accessories, is permitted to be removable provided that the equipment instructions include directions for correct removal and reinstallation of the door or cover.

Compliance is checked by inspection.

9.1.4.6 Additional requirements for openings in transportable equipment

The risk of ignition caused by small metallic objects, moving around inside transportable equipment during transportation shall be reduced by measures to minimize the likelihood of such objects entering the equipment and bridging bare conductive parts between which the power is not limited in accordance with 9.2.

The bottom of the fire enclosure or individual barriers shall also provide protection against emission of flaming or molten material under all internal parts, including partially enclosed components or assemblies, for which Method 2 of 9.1.1 has not been fully applied and complied with.

The following measures provide acceptable protection against both the likelihood of objects entering the equipment, and the risk of emission of fire hazard from the enclosure:

- providing openings that do not exceed 1 mm in width regardless of length; or
- providing a screen having a mesh with nominal openings not greater than 2 mm between center lines and constructed with a thread or wire diameter of not less than 0,45 mm; or

- providing internal barriers.

Additionally, where metallized parts of a plastic barrier or enclosure are within 13 mm of parts of circuits where the available power is greater than 15 VA, one of the following requirements applies:

- access by a foreign metallic object shall be limited in accordance with the above acceptable measures even though the available power meets the limits of 9.2; or
- there shall be a barrier between the bare conductive parts and the enclosure; or
- fault testing shall be carried out to simulate bridging along a direct path between a bare conductive part and the nearest metallized part of a barrier or enclosure that is within 13 mm of the bare conductive part.

NOTE Examples of metallized plastic barriers or enclosures include those made of conductive composite materials or that are electroplated, vacuum-deposited, painted or foil lined.

Compliance is checked by inspection and measurement and, where appropriate, by test. All doors or covers are closed or in place and peripheral devices or assemblies, such as batteries, etc., are installed as intended during the inspection.

If simulated fault testing is carried out, no ignition of the metallized barrier or enclosure shall occur.

9.2 Limited power sources

9.2.1 General

This clause provides requirements for evaluating limited power sources, as referred to in clause 9.1. A limited power source shall comply with one of the following:

- the output is inherently limited in conformity with Table 22; or
- an impedance limits the output in conformity with Table 22. If a positive temperature coefficient device is used, it shall pass the tests specified in IEC 60730-1, clauses 15, 17, J.15 and J.17; or
- an overcurrent protective device is used and the output is limited in conformity with Table 23; or
- a regulating network limits the output in conformity with Table 22, both under normal operating conditions and after any single fault in the regulating network (open circuit or short circuit); or
- a regulating network limits the output in conformity with Table 22 under normal operating conditions, and one of the above protective means is used in addition to limit the output under single fault conditions.

Where an overcurrent protective device is used to meet the limits for a limited power source, it shall be a fuse or a non-adjustable, non-autoreset, electromechanical device.

Compliance is checked by the testing of clause 9.2.2.

9.2.2 Limited power source tests

Compliance with 9.2.1 is checked by inspection and measurement of the electrical quantities in Table 22 or Table 23 as applicable. Batteries shall be fully charged when conducting the measurements for U_{oc} and I_{sc} according to Table 22 and Table 23.

The load referenced in notes 2) and 3) of Table 22 and Table 23 is adjusted to develop maximum current and power transfer respectively. Single faults in a regulating network are applied under these maximum current and power conditions.

Table 22 – Limits for inherently limited power sources

Output voltage ¹⁾ U_{oc}		Output current ²⁾ I_{sc}	Apparent power ³⁾ S
V a.c.	V d.c.	A	VA
≤ 20	≤ 20	$\leq 8,0$	$\leq 5 \cdot U_{oc}$
$20 < U_{oc} \leq 30$	$20 < U_{oc} \leq 30$	$\leq 8,0$	≤ 100
-	$30 < U_{oc} \leq 60$	$\leq 150/U_{oc}$	≤ 100

1) U_{oc} : Output voltage measured with all load circuits disconnected. Voltages are for substantially sinusoidal a.c. and ripple free d.c. For non-sinusoidal a.c. and d.c. with ripple greater than 10 % of the peak, the peak voltage shall not exceed 42,4 V.

2) I_{sc} : Maximum output current with any non-capacitive load, including a short circuit, measured 60 s after application of the load.

3) S (VA): Maximum output VA with any non-capacitive load measured 60 s after application of the load.

Table 23 – Limits for power sources not inherently limited

Output voltage ¹⁾ U_{oc}		Output current ²⁾ I_{sc}	Apparent power ³⁾ S	Current rating of overcurrent protective device ⁴⁾
Vac	Vdc	A	VA	A
≤ 20	≤ 20	$\leq 1\,000/U_{oc}$	≤ 250	≤ 5
$20 < U_{oc} \leq 30$	$20 < U_{oc} \leq 30$			$\leq 100/U_{oc}$
-	$30 < U_{oc} \leq 60$			$\leq 100/U_{oc}$

1) U_{oc} : Output voltage measured in accordance with 7.3.2 with all load circuits disconnected. Voltages are for substantially sinusoidal a.c. and ripple free d.c. For non-sinusoidal a.c. and for d.c. with ripple greater than 10 % of the peak, the peak voltage shall not exceed 42,4 V.

2) I_{sc} : Maximum output current with any non-capacitive load, including a short circuit, measured 60 s after application of the load. Current limiting impedances in the equipment remain in the circuit during measurement, but overcurrent protective devices are bypassed.

3) S (VA): Maximum output VA with any non-capacitive load measured 60 s after application of the load. Current limiting impedances in equipment remain in the circuit during measurement, but overcurrent protective devices are bypassed.

NOTE The reason for making measurements with overcurrent protective devices bypassed is to determine the amount of energy that is available to cause possible overheating during the operating time of the overcurrent protective devices.

4) The current ratings of overcurrent protective devices are based on fuses and circuit breakers that break the circuit within 120 s with a current equal to 210 % of the current rating specified in the table.

9.3 Short-circuit and overcurrent protection

9.3.1 General

The *PCE* shall not present a hazard, under short-circuit or overcurrent conditions at any port, including phase-to-phase, phase-to-earth and phase-to-neutral, and adequate information shall be provided to allow proper selection of external wiring and external protective devices.

9.3.2 Number and location of overcurrent protective devices

Protection against short-circuits and overcurrents shall be provided for all input circuits, and for output circuits that do not comply with the requirements for limited power sources in 9.2, except for circuits in which no overcurrent hazard is presented by short-circuits and overloads.

NOTE In a PV circuit for which the conductors are selected based on the short-circuit rating of the array, there is typically no risk of overloading conductors in the array wiring. Typically, unless conductors are oversized, overcurrent protection is required in the equipment or as part of the installation, when 3 or more PV strings are in parallel, to prevent overcurrents in the wiring of one faulted string due to the total current available from the other two (or more) strings.

If a protective device interrupts a neutral conductor, it shall also simultaneously interrupt all ungrounded conductors of the same circuit.

Where a protective device or related set of devices require manual replacement or resetting and interrupt more than one conductor, the resetting means for all conductors protected by that device or set of devices shall be located together.

For pluggable equipment type B or fixed equipment, and for PV circuits, this protection may be provided by devices external to the equipment, in which case the installation instructions shall state the need for the protection to be provided in the installation and shall include the specifications for the required short-circuit and/or overcurrent protection (see 5.3.2).

For pluggable equipment type A, the PCE does not need to include or specify protection for mains input ports if all requirements of this standard are met when tested using the highest-rated overcurrent protective device that will be present in the installation upstream of the socket for the style of plug provided on the PCE.

Compliance is checked by inspection and by the tests of 4.4.4.5 and 4.4.4.7.

9.3.3 Short-circuit co-ordination (backup protection)

Protective devices provided or specified shall have adequate breaking capacity to interrupt the maximum short circuit current specified for the port to which they are connected. If protection that is provided integral to the PCE for an input port is not rated for the short-circuit current of the circuit in which it is used, the installation instructions shall specify that an upstream protective device, rated for the prospective short-circuit current of that port, shall be used to provide backup protection.

For pluggable equipment type A, the building installation is considered as providing short circuit backup protection.

Compliance is checked by inspection and by the test of 4.4.4.5.

10 Protection against sonic pressure hazards

10.1 General

The equipment shall provide protection against the effects of sonic pressure. Conformity tests are carried out if the equipment is likely to cause such hazards.

10.2 Sonic pressure and sound level

10.2.1 Hazardous noise levels

If equipment produces noise at a level that could cause a hazard, the noise shall be measured to determine the maximum sound pressure level that the equipment can produce (except that sound from alarms and from parts located remotely is not included). If the measured sound pressure exceeds 80 dBA above a reference sound pressure of 20 μ P, at a measurement distance of 1 m, the instructions shall include information regarding the sound pressure level and how to reduce the risk of hearing damage to safe levels, and the product shall be marked with symbol 22 of Annex C.

Compliance is checked by measurement and calculation of the maximum sound pressure level in accordance with ISO 3746, ISO 9614-1, ISO 9614-2, or ISO 9614-3 and by inspection of the information provided and the markings.

11 Protection against liquid hazards

NOTE Battery electrolyte hazards are addressed in 14.8.

11.1 Liquid containment, pressure and leakage

The liquid containment system components shall be compatible with the liquid to be used.

There shall be no leakage of liquid onto live parts as a result of:

- a) Normal operation, including condensation;
- b) Servicing of the equipment; or
- c) Inadvertent loosening or detachment of hoses or other cooling system parts over time.

The instruction manual for a PCE that includes a liquid containment system, shall include procedures to prevent the wetting live parts during servicing.

If a reservoir is part of the liquid containment system, a live part shall be located or protected so that it is not subject to dripping during the filling of the reservoir or if the reservoir fails.

Compliance is checked by overfilling the liquid reservoir, which shall not result in the wetting of live parts or electrical insulation that is likely to be adversely affected by the liquid. The intended liquid is to be poured into the reservoir. The reservoir is to be filled to the level recommended, if such level is plainly marked; otherwise, the reservoir is to be filled to maximum capacity. Additional intended liquid, equal to 50 % of the volume already filled, but not more than 2 l, is then to be poured into the reservoir. Determination of whether uninsulated live parts have become wet as a result of the overflow is to be made by means of visual inspection. If visual inspection is inconclusive, the unit shall be tested in accordance with the voltage test of 7.5.2.

11.2 Fluid pressure and leakage

NOTE Equipment meeting the requirements of this subclause will not necessarily be accepted as conforming to national requirements relating to high pressures.

11.2.1 Maximum pressure

The maximum pressure to which a part of the equipment can be subjected in normal use or single fault condition shall not exceed the rated maximum working pressure for the part.

The maximum pressure shall be considered to be the highest of the following:

- a) the rated maximum supply pressure specified for an external source;
- b) the pressure setting of an overpressure safety device provided as part of the assembly;
- c) the maximum pressure that can be developed by an air compressor that is part of the assembly, unless the pressure is limited by an overpressure safety device.

Compliance is checked by inspection of the ratings of the parts and, if necessary, by measuring pressures.

11.2.2 Leakage from parts

Leakage from liquid containing parts shall not cause a hazard.

Compliance is checked by inspection of the ratings of parts and, if necessary, by subjecting the parts to a liquid pressure of two times the maximum pressure in normal use. No leakage is to occur which could cause a hazard.

11.2.3 Overpressure safety device

A closed liquid containment system shall be provided with an overpressure safety device that shall not operate in normal use. The over pressure safety device shall:

- a) be connected as close as possible to the liquid-containing parts of the system that it is intended to protect;
- b) be installed so as to provide easy access for inspection, maintenance and repair;
- c) only be adjustable via the use of a tool;
- d) have its discharge opening so located and directed that the released material is not directed towards any person;
- e) have its discharge opening so located and directed that operation of the device will not deposit liquid on parts that may cause a hazard;
- f) have adequate discharge capacity to ensure that, in the event of a failure of the supply pressure control, the pressure does not exceed the rated maximum working pressure of the system;
- g) have no shut-off valve between it and the parts that it is intended to protect.

Compliance is checked by inspection and the test in 11.2.2.

11.3 Oil and grease

Where internal wiring, windings, commutators, slip-rings and the like, and insulation in general, are exposed to oil, grease or similar substances, the insulation shall have adequate properties to resist deterioration under these conditions.

Compliance is checked by inspection, and by evaluation of the data for the insulating material.

12 Chemical hazards

12.1 General

Means shall be provided to reduce the risk of injury resulting from contact with or exposure to hazardous chemicals or from inhalation of their vapours and fumes.

Examples of measures to reduce risks include:

- avoiding the use of constructional and consumable materials likely to cause injury by contact or inhalation during intended and normal conditions of use;
- avoiding conditions likely to cause leakage or vaporization;
- provision of markings to warn users about the hazards.

If a chemical is in liquid form, the requirements of Clause 11 are additionally to be applied.

Compliance is checked by inspection, and if necessary, by testing for accessibility, leakage, or vaporization under normal and fault conditions.

13 Physical requirements

13.1 Handles and manual controls

Handles, knobs, grips, levers and the like shall be reliably fixed so that they will not work loose in normal use, if this might result in a hazard. Sealing compounds and the like, other than self-hardening resins, shall not be used to prevent loosening. If handles, knobs and the like are used to indicate the position of switches or similar components, it shall not be possible to fix them in a wrong position if this might result in a hazard.

Compliance is checked by inspection, by manual test and by trying to remove the handle, knob, grip or lever by applying for 1 min an axial force as follows.

If the shape of these parts is such that an axial pull is unlikely to be applied in normal use, the force is:

- 15 N for the operating means of electrical components; and
- 20 N in other cases.

If the shape is such that an axial pull is likely to be applied, the force is:

- 30 N for the operating means of electrical components; and
- 50 N in other cases.

13.1.1 Adjustable controls

Equipment shall be so constructed that manual adjustment of a control device, such as a device for selection of different supply voltages, requires the use of a tool if incorrect setting or inadvertent adjustment might create a hazard.

Compliance is checked by analysis and by the test of 4.4.4.12.

13.2 Securing of parts

Screws, nuts, washers, springs or similar parts shall be secured so as to withstand mechanical stresses occurring in normal use if loosening would create a hazard, or if clearances or creepage distances over supplementary insulation or reinforced insulation would be reduced to less than the values specified in 7.3.7.4 and 7.3.7.5.

Compliance is checked by inspection, by measurement of clearance and creepage distances, and by manual test.

For the purpose of assessing conformity:

- it is assumed that two independent fixings will not become loose at the same time; and
- it is assumed that parts fixed by means of screws or nuts provided with self-locking washers or other means of locking are not liable to become loose.

NOTE Spring washers and the like can provide satisfactory locking.

13.3 Provisions for external connections

13.3.1 General

Provisions for external connections made during installation, shall comply with the following basic principles:

- connection means shall be of a type or so located as to comply with the requirements of this standard for protection against fire hazard, shock hazard, and energy hazard;

- wiring in DVC B and C circuits shall be separated from wiring and bare live parts in DVC A circuits if a shock hazard could result from insulation failure;
- wiring and flexible cables shall be securely terminated and provided with strain relief to prevent the transmission of stress to the connections;
- provisions for permanently connected wiring shall be rated for and suitable for the size and type of wiring that will be required to be used in the installation;
- disconnecting means shall be provided for each supply circuit in the equipment or be specified in the installation instructions, unless connectors are provided that are rated for disconnection under load; and
- wiring space shall be sufficient for connections to be made and inspected, and shall provide sufficient space for the required size and type of conductors to be installed without risk of damage or reduction of separation from other circuits.

Compliance is checked by inspection, and by applying the requirements of Clause 7, Clause 9 and the other applicable requirements in this clause.

13.3.2 Connection to an a.c. mains supply

13.3.2.1 General

For safe and reliable connection to a mains supply, equipment shall be provided with one of the following:

- terminals or leads or a non-detachable power supply cord for permanent connection to the supply; or
- a non-detachable power supply cord for connection to the supply by means of a plug; or
- an appliance inlet for connection of a detachable power supply cord; or
- a mains plug that is part of direct plug-in equipment as in 13.3.8.

NOTE In some countries it is required to fit a plug conforming to local standards to the power cord of certain equipment.

Compliance is checked by inspection.

13.3.2.2 Permanently connected equipment

Permanently connected equipment shall be provided with either:

- a set of terminals as specified in 13.3.3 for connection of supply wires; or
- a set of leads suitable for connection to supply wires using standard means such as wire nuts or splicing connectors, or
- a non-detachable power supply cord for permanent connection to the source.

Permanently connected equipment having a set of terminals or leads shall:

- permit the connection of the supply wires after the equipment has been fixed to its support; and
- be provided with cable entries, conduit entries, knock-outs or glands, which allow connection of the appropriate sizes and types of cables or conduits.

NOTE Sizes and types of cables and conduits are specified in national and local electrical installation codes. Dimensions for entries will vary based on size and type of cable or conduit, and are not given in this standard.

Conduit and cable entries and knock-outs for supply connections shall:

- not be located on covers that need to be removed to access or inspect wiring;

- be so designed or located that the introduction of the conduit and cable does not affect the protection against electric shock, or reduce clearances and creepage distances below the values specified in clause 7.3.7.4 and 7.3.7.5.

Leads provided for connection to supply wiring shall be sized according to Table 24 and shall be located in wiring space according to 13.3.4.

Compliance is checked by inspection, by a practical installation test, and by measurement of clearance and creepage distances.

13.3.2.3 Appliance inlets

Appliance inlets shall meet all of the following:

- be so located or enclosed that parts at hazardous voltage are not accessible during insertion or removal of the connector (appliance inlets complying with IEC 60309 or with the IEC 60320 series are considered to comply with this requirement); and
- be so located that the connector can be inserted without difficulty; and
- be so located that, after insertion of the connector, the equipment is not supported by the connector for any position of normal use on a flat surface.

Compliance is checked by inspection and, for accessibility, by means of the test finger specified in Figure D.1 in Annex D.

13.3.2.4 Power supply cords

A power supply cord for connection to the a.c. mains shall comply with all of the following, as appropriate:

- if rubber insulated, be of synthetic rubber and not of a lighter grade than ordinary tough rubber sheathed flexible cord according to IEC 60245-1 (designation 60245 IEC 53); and
- if PVC insulated:
 - for equipment provided with a non-detachable power supply cord and having a mass not exceeding 3 kg, be not of a lighter grade than light PVC sheathed flexible cord according to IEC 60227-1 (designation 60227 IEC 52);
 - for equipment provided with a non-detachable power supply cord and having a mass exceeding 3 kg, be not of a lighter grade than ordinary PVC sheathed flexible cord according to IEC 60227-1 (designation 60227 IEC 53);
 - for equipment provided with a detachable power supply cord, be not of a lighter grade than light PVC sheathed flexible cord according to IEC 60227-1 (designation 60227 IEC 52).

NOTE There is no limit on the mass of the equipment if the equipment is intended for use with a detachable power supply cord.

and

- include, for equipment required to have protective earthing, a protective earthing conductor having green-and-yellow insulation; and
- have conductors with cross-sectional areas not less than those specified in Table 24.

Compliance is checked by inspection.

Table 24 – Sizes of conductors

Rated current of equipment A	Minimum conductor sizes			
	Nominal cross-sectional area		AWG or kcmil [cross-sectional area in mm ²]	
	mm ²		see note 2	
Up to and including 6		0,75 ¹⁾	18	[0,8]
Over 6 up to and including 10	(0,75) ²⁾	1,00	16	[1,3]
Over 10 up to and including 13	(1,0) ³⁾	1,25	16	[1,3]
Over 13 up to and including 16	(1,0) ³⁾	1,5	14	[2]
Over 16 up to and including 25		2,5	12	[3]
Over 25 up to and including 32		4,0	10	[5]
Over 32 up to and including 40		6,0	8	[8]
Over 40 up to and including 63		10	6	[13]
Over 63 up to and including 80		16	4	[21]
Over 80 up to and including 100		25	2	[33]
Over 100 up to and including 125		35	1	[42]
Over 125 up to and including 160		50	0	[53]
Over 160 up to and including 190		70	000	[85]
Over 190 up to and including 230		95	0000	[107]
Over 230 up to and including 260		120	250 kcmil	[126]
Over 260 up to and including 300		150	300 kcmil	[152]
Over 300 up to and including 340		185	400 kcmil	[202]
Over 340 up to and including 400		240	500 kcmil	[253]
Over 400 up to and including 460		300	600 kcmil	[304]
1) For rated current up to 3 A, a nominal cross-sectional area of 0,5 mm ² is permitted in some countries provided the length of cord does not exceed 2 m.				
2) The value in parentheses applies to detachable power supply cords fitted with the connectors rated 10 A in accordance with IEC 60320 (types C13, C15, C15A, and C17) provided that the length of the cord does not exceed 2 m.				
3) The value in parentheses applies to detachable power supply cords fitted with the connectors rated 16 A in accordance with IEC 60320 (types C19, C21, and C23) provided that the length of the cord does not exceed 2 m.				
NOTE 1 IEC 60320 specifies acceptable combinations of appliance couplers and flexible cords, including those covered by items 1), 2), and 3). However, a number of countries have indicated that they do not accept all of the values listed in table 3B, particularly those covered by conditions 1), 2), and 3).				
NOTE 2 AWG and kcmil sizes are provided for information only. The associated cross-sectional areas, in square brackets, have been rounded to show significant figures only. AWG refers to the American Wire Gage and the term "cmil" refers to circular mils where one circular mil is equal to the area of a circle having a diameter of one mil (one thousandth of an inch). These terms are commonly used to designate wire sizes in North America.				

13.3.2.5 Cord anchorages and strain relief

For equipment with a non-detachable power supply cord, a cord anchorage shall be supplied such that:

- the connecting points of the cord conductors are relieved from strain; and
- the outer covering of the cord is protected from abrasion.

It shall not be possible to push the cord back into the equipment to such an extent that the cord or its conductors, or both, could be damaged or internal parts of the equipment could be displaced.

For non-detachable power supply cords containing a protective earthing conductor, the construction shall be such that if the cord should slip in its anchorage, placing a strain on conductors, the protective earthing conductor will be the last to take the strain.

The cord anchorage shall either be made of insulating material or have a lining of insulating material complying with the requirements for supplementary insulation. However, where the cord anchorage is a bushing that includes the electrical connection to the screen of a screened power cord, this requirement shall not apply.

The construction of the cord anchorage shall be such that:

- cord replacement does not impair the safety of the equipment; and
- for ordinary replacement cords, it is clear how relief from strain is to be obtained; and
- the cord is not clamped by a screw which bears directly on the cord, unless the cord anchorage, including the screw, is made of insulating material and the screw is of comparable size to the diameter of the cord being clamped; and
- methods such as tying the cord into a knot or tying the cord with a string are not used; and
- the cord cannot rotate in relation to the body of the equipment to such an extent that mechanical strain is imposed on the electrical connections.

Compliance is checked by inspection and by applying the following tests, which are made with the type of power supply cord supplied with the equipment.

The cord is subjected to a steady pull of the value shown in Table 25 applied in the most unfavourable direction. The test is conducted 25 times, each time for a duration of 1 s.

During the tests, the power supply cord shall not be damaged. This is checked by visual inspection, and by an electric strength test between the power cord conductors and accessible conductive parts, at the test voltage appropriate for reinforced insulation.

After the tests, the power supply cord shall not have been longitudinally displaced by more than 2 mm nor shall there be appreciable strain at the connections, and clearances and creepages shall not be reduced below the values specified in 7.3.7.4 and 7.3.7.5.

Table 25 – Physical tests on power supply cords

Mass (M) of the equipment kg	Pull N
$M \leq 1$	30
$1 < M \leq 4$	60
$M > 4$	100

13.3.2.6 Protection against mechanical damage

Power supply cords shall not be exposed to sharp points or cutting edges within or on the surface of the equipment, or at the inlet opening or inlet bushing.

The overall sheath of a non-detachable power supply cord shall continue into the equipment through any inlet bushing or cord guard and shall extend by at least half the cord diameter beyond the clamp of the cord anchorage.

Inlet bushings, where used, shall:

- be reliably fixed; and
- not be removable without the use of a tool.

A metallic inlet bushing shall not be used in a non-metallic enclosure.

An inlet bushing or cord guard secured to a conductive part that is not protectively earthed shall meet the requirements for supplementary insulation.

Compliance is checked by inspection.

13.3.3 Wiring terminals for connection of external conductors

13.3.3.1 Wiring terminals

Permanently connected equipment and equipment with non-detachable power supply cords shall be provided with terminals in which connection is made by means of screws, nuts or equally effective devices (see also 7.3.6.3.6).

Compliance is checked by inspection.

13.3.3.2 Screw terminals

Screws and nuts which clamp external supply conductors shall have a thread conforming to ISO 261 or ISO 262, or a thread comparable in pitch and mechanical strength (for example, unified threads). The screws and nuts shall not serve to fix any other component, except that they are permitted also to clamp internal conductors provided that the internal conductors are so arranged that they are unlikely to be displaced when fitting the supply conductors.

The terminals of a component (for example, a switch) built into the equipment are permitted for use as terminals for external mains supply conductors, provided that they comply with the requirements of this section.

Compliance is checked by inspection.

13.3.3.3 Wiring terminal sizes

Terminals shall be provided which accommodate the conductors specified in the installation documentation provided (see 5.3.1) and in the wiring rules applicable at the installation. The terminals shall meet the temperature rise test of 4.3 when connected using wire sizes as specified in the documentation or in Table 24, whichever is smaller.

Compliance is checked by inspection, by the temperature measurements of 4.3, and by trial installation of the smallest and largest conductors required.

13.3.3.4 Wiring terminal design

Wiring terminals shall be so designed that they clamp the conductor between metal surfaces with sufficient contact pressure and without damage to the conductor.

Terminals shall be so designed or located that the conductor cannot slip out when the clamping screws or nuts are tightened.

Terminals shall be provided with appropriate fixing hardware for the conductors (for example, nuts and washers).

Terminals shall be so fixed that, when the means of clamping the conductor is tightened or loosened:

- the terminal itself does not work loose; and
- internal wiring is not subjected to stress; and
- clearance and creepage distances are not reduced below the values specified in 7.3.7.4 and 7.3.7.5.

Compliance is checked by inspection and measurement of clearance and creepage distances.

13.3.3.5 Grouping of wiring terminals

Terminals associated with a particular input or output circuit shall be located in proximity to each other. In addition, terminals for connection to the mains supply circuit shall be located in proximity to the protective earthing terminal, if any.

Compliance is checked by inspection.

13.3.3.6 Stranded wire

Terminals shall be designed, located, guarded or insulated so that, should a strand of a stranded conductor escape when the conductor is fitted, there is no likelihood of accidental contact between such a strand and other parts if a shock, energy, or fire hazard could result.

Compliance is checked by inspection and, unless a special cord is prepared in such a way as to prevent the escape of strands, by the following test:

A piece of insulation approximately 8 mm long is removed from the end of a stranded conductor having the appropriate nominal cross-sectional area. One strand of the stranded conductor is left free and the other strands are fully inserted into, and clamped in the terminal. Without tearing the insulation back, the free strand is bent in every possible direction, but without making sharp bends around the guard.

If the conductor is in a circuit of DVC C, the free strand shall not touch any conductive part that is accessible or is connected to an accessible conductive part or, in the case of double insulated equipment, any conductive part that is separated from accessible conductive parts by supplementary insulation only.

If the conductor is connected to a DVC A circuit or to an earthing terminal, the free strand shall not touch any part at DVC B or C.

13.3.4 Supply wiring space

The supply wiring space provided inside, or as part of, the equipment for permanent connection or for connection of a non-detachable power supply cord shall be designed:

- to allow the conductors to be introduced and connected easily; and
- so that the uninsulated end of a conductor is unlikely to become free from its terminal, or, should it do so, cannot come into contact with:
 - an accessible conductive part that is not protectively earthed; or
 - an accessible conductive part of hand-held equipment; and
- to permit checking before fitting the cover, if any, that the conductors are correctly connected and positioned; and
- so that covers, if any, can be fitted without risk of damage to the supply conductors or their insulation; and
- so that covers, if any, giving access to the terminals can be removed with a commonly available tool.

Compliance is checked by inspection and by an installation test with wires or cables of the largest cross-sectional area required.

13.3.5 Wire bending space for wires 10 mm² and greater

The distance between a terminal for connection to external wiring and an obstruction toward which the wire is directed upon leaving the terminal shall be at least that specified in Table 26.

Table 26 – Wire bending space from terminals to obstructions

Size of wire mm ²	Minimum bending space, terminal to obstruction mm		
	Wires per terminal		
	1	2	3
10 – 16	40	-	-
25	50	-	-
35	65	-	-
50	80	125	180
70	90	150	190
95	105	180	205
120	205	205	230
150	255	255	280
185	305	305	330
240	305	305	380
300	355	405	455
350	355	405	510
400	455	485	560
450	455	485	610

13.3.6 Disconnection from supply sources

To enable servicing, a disconnect device or devices shall be provided to disconnect the equipment from each source of supply that has a hazardous live voltage or exceeds the values for hazardous energy or from which a hazardous live voltage or energy is derived. As an alternative, the installation instructions shall instruct that a disconnect device for each source of supply be provided as part of the installation, and shall indicate the required type and ratings for the device(s).

If the PCE is provided with a connector rated for disconnection under load, and the connector is accessible without requiring the use of a tool to allow emergency disconnection, no further disconnecting means is required.

Where a connector can be disconnected without tools, each of the disconnected or open connector ends, shall comply with the requirements in Clause 7 to prevent access to hazardous parts during or after disconnection.

Compliance is checked by inspection of the equipment and the installation instructions.

13.3.7 Connectors, plugs and sockets

Connectors, plugs and sockets shall not be employed in a manner likely to create a hazard due to misconnection.

Where connectors are used it shall not be possible to connect them misaligned or with reverse polarity if a hazard would result.

Use of a connector with a standardized purpose in a circuit type other than that for which it is intended (for example use of an a.c. mains socket for d.c. connections) shall not result in a hazard.

If connectors can be separated without the use of a tool, no hazard shall result from or be exposed, during and after separating the connector parts.

Compliance is checked by inspection, and if necessary by a test of connector misalignment or reverse polarity. Testing conditions and pass/fail criteria shall be as in 4.4 in general, and 4.4.4.11 and 4.4.4.13 for reverse polarity and miswiring testing.

13.3.8 Direct plug-in equipment

Direct plug-in equipment shall not impose undue stress on the socket-outlet. The mains plug part shall comply with the standard for the relevant mains plug.

Compliance is checked by inspection and, if necessary, by the following test.

The equipment is inserted, as in normal use, into a fixed socket-outlet of a configuration as intended by the manufacturer, which can be pivoted about a horizontal axis intersecting the centre lines of the contacts at a distance of 8 mm behind the engagement face of the socket outlet.

The additional torque which has to be applied to the socket-outlet to maintain the engagement face in the vertical plane shall not exceed 0,25 N·m.

13.4 Internal wiring and connections

13.4.1 General

The wiring and connections between parts of the equipment and within each part shall be protected from mechanical damage during installation. The insulation, conductors and routing of all wires of the equipment shall be suitable for the electrical, mechanical, thermal and environmental conditions of use. Conductors which are able to contact each other or bare live parts shall be provided with insulation rated for the highest possible working voltage present.

13.4.2 Routing

A hole through which insulated wires pass in a conductive wall within the enclosure of the equipment shall be provided with a smooth, well-rounded bushing or grommet or shall have smooth, well-rounded surfaces upon which the wires bear to reduce the risk of abrasion of the insulation.

Wires shall be routed away from sharp edges, screw threads, burrs, fins, moving parts, drawers, and similar parts, which could abrade the wire insulation.

The minimum bend radius specified by the wire manufacturer shall not be violated.

Clamps and guides, either metallic or non-metallic, used for routing internal wiring shall be provided with smooth, well-rounded edges. The clamping action and bearing surface shall be such that abrasion or cold flow of the insulation does not occur. If a metal clamp is used for conductors having thermoplastic insulation less than 0,8 mm thick, non-conducting mechanical protection shall be provided.

13.4.3 Colour coding

Insulated conductors, other than those which are integral to ribbon cable or multi-cord signal cable, identified by the colour green with or without one or more yellow stripes shall not be used other than for protective bonding.

13.4.4 Splices and connections

All splices and connections shall be mechanically secure and shall provide electrical continuity.

Electrical connections shall be soldered, welded, crimped, or otherwise securely connected. A soldered joint, other than a component on a PWB, shall additionally be mechanically secured.

When stranded internal wiring is connected to a wire-binding screw, the construction shall be such that loose strands of wire do not contact:

- other uninsulated live parts not always of the same potential as the wire; or
- de-energized metal parts.

When screw terminal connections are used, the resulting connections may require routine maintenance (tightening). Appropriate reference shall be made in the maintenance manual (see 5.3.4).

The end of a stranded conductor shall not be consolidated by soft soldering at places where the conductor is subject to contact pressure unless the method of clamping is designed so as to reduce the likelihood of a bad contact due to cold flow of the solder. Spring terminals that compensate for the cold flow are deemed to satisfy this requirement. Preventing the clamping screws from rotating is not considered to be adequate.

13.4.5 Interconnections between parts of the PCE

In addition to complying with the requirements given in 13.4.1 to 13.4.4, the means provided for the interconnection between parts of the PCE shall comply with the following requirements:

Cable assemblies and flexible cords provided for interconnection between sections of equipment or between units of a system shall be suitable for the service or use involved. Cables shall be protected from physical damage as they leave the enclosure and shall be provided with mechanical strain relief.

Misalignment of male and female connectors, insertion of a multipin connector in a connector other than the one intended to receive it, reverse polarity connection, and other manipulations of parts which are accessible without the use of a tool shall not result in mechanical damage or a risk of thermal hazards, electric shock, or injury to persons.

Compliance with 13.4.2 to 13.4.5 is shown by inspection.

13.5 Openings in enclosures

For equipment intended to be used in more than one orientation, the requirements of this clause apply in each orientation.

These requirements are in addition to those in the following sections:

- 7.3.4, Protection against direct contact;
- 7.4, Protection against energy hazards;
- 9.1.4, Openings in fire enclosures.

13.5.1 Top and side openings

Openings in the top and sides of enclosures shall be so located or constructed that it is unlikely that objects will enter the openings and create hazards by contacting bare conductive parts.

Openings, located behind doors, panels, covers, etc., that can be opened or removed by a user, are not required to comply provided that the equipment openings comply with the doors, panels and covers closed or in place.

Compliance is checked by inspection and measurement of the physical dimensions as specified below.

Except for that portion of the side of a fire enclosure that is subject to the requirements of 9.1.4, any one of the following is considered to satisfy the requirements (other constructions are not excluded):

- openings that do not exceed 5 mm in any dimension;
- openings that do not exceed 1 mm in width regardless of length;
- top openings in which vertical entry is prevented (see Figure 16 for examples);
- side openings provided with louvers that are shaped to deflect outwards an external vertically falling object (see Figure 17 for examples);
- top or side openings, as shown in Figure 18, that are not located vertically, or within a volume V bounded by a 5° vertical projection up to the size of opening L, above bare conductive parts:

NOTE The examples of Figure 16, Figure 17, and Figure 18 are not intended to be used as engineering drawings but are only shown to illustrate the intent of these requirements.

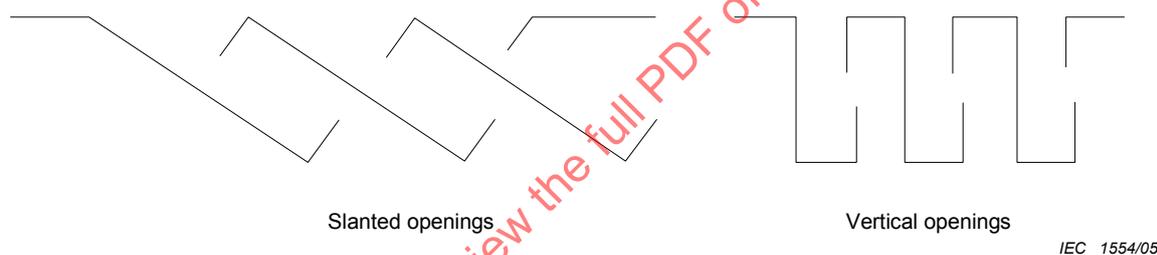


Figure 16 – Examples of cross-sections of designs of openings preventing vertical access

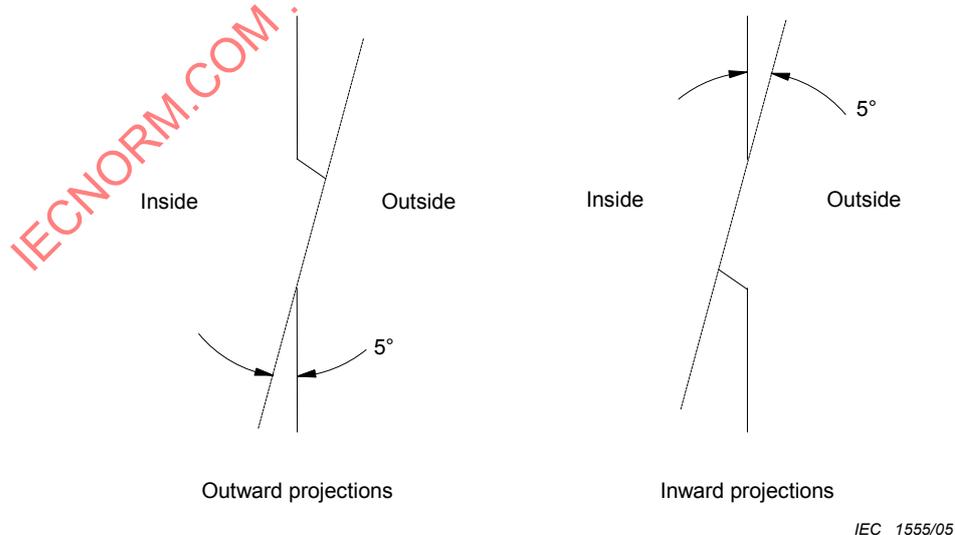
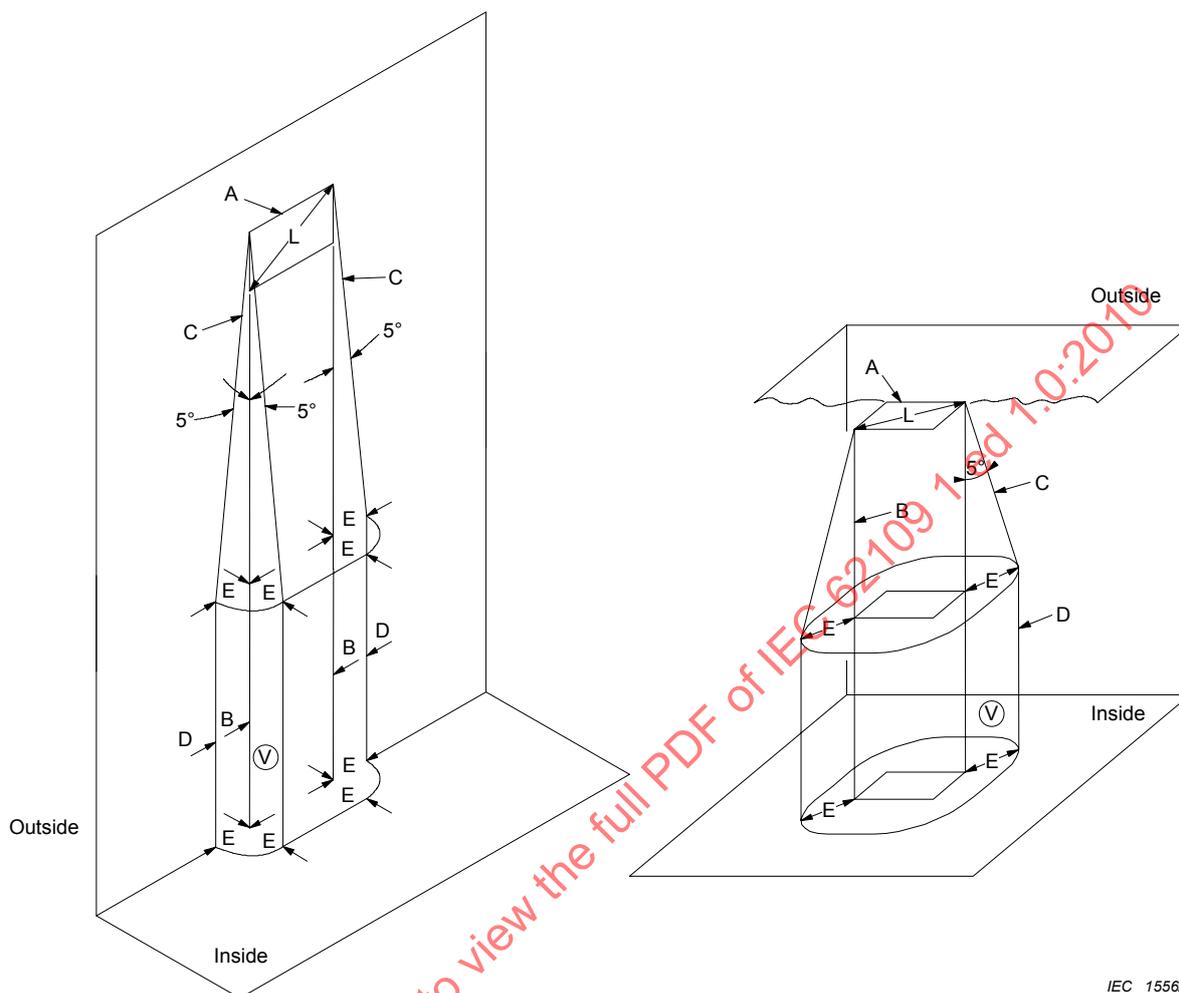


Figure 17 – Examples of louver design



IEC 1556/05

Key

- A Enclosure opening.
- B Vertical projection of the outer edges of the opening.
- C Inclined lines that project at a 5° angle from the edges of the opening to points located E distance from B.
- D Line which is projected straight downward in the same plane as the enclosure side wall.
- E Projection of the outer edge of the opening (B) and the inclined line (C) (not to be greater than L).
- L Maximum dimension of the enclosure opening.
- V Volume in which bare parts at hazardous voltage or hazardous energy are not located.

Figure 18 – Enclosure openings

13.6 Polymeric materials

13.6.1 General

Polymeric materials shall comply with 9.1.3 regarding materials selection for fire enclosures and for protection against fire hazard, with the thermal index or capability requirements in 13.6.1.1, and with the applicable requirements in 13.6.2, 13.6.3, and 13.6.4 as follows:

- section 13.6.2 for polymers serving as enclosures or barriers to provide protection against access to hazards (for example protection against direct contact according to 7.3.4.2 or protection against moving parts according to 8.2);
- section 13.6.3 for polymers serving as solid insulation;
- section 13.6.4 for resistance of polymeric parts to UV exposure.

A polymeric material or part that serves more than one of the above functions shall comply with all applicable requirements.

13.6.1.1 Thermal index or capability

All polymeric materials relied upon for compliance with this standard shall have a thermal index or capability (electrical and mechanical) at least as high as the maximum measured operating temperature of the material in the application, as measured during the temperature test of 4.3. The thermal index or capability shall be in accordance with at least one of the following: thermal index (TI), relative thermal index (RTI), relative thermal endurance index (RTE) or relative thermal capability (RTC) in accordance with at least one of the following standards; IEC 60216-1, IEC 60216-2, IEC 60216-3, IEC 60216-5, IEC 60216-6, ANSI UL 746B or UL ANSI UL 746C.

13.6.2 Polymers serving as enclosures or barriers preventing access to hazards

A polymeric material serving as an enclosure or barrier to prevent access to a hazard shall comply with the following requirements.

13.6.2.1 Stress relief test

Enclosures of moulded or formed thermoplastic materials shall be so constructed that any shrinkage or distortion of the material due to release of internal stresses caused by the moulding or forming operation does not result in the exposure of hazardous parts or in the reduction of creepage distances or clearances below the minimum required.

Compliance is checked by the test procedure described below or by the inspection of the construction and the available data where appropriate. One sample consisting of the complete equipment, or of the complete enclosure together with any supporting framework, is placed in a circulating air oven (according to IEC 60216-4-1) at a temperature 10 K higher than the maximum temperature observed on the enclosure during the test of 4.3, but not less than 70 °C, for a period of 7 h, then permitted to cool to room temperature.

With the concurrence of the manufacturer, it is permitted to increase the above time duration. For large equipment where it is impractical to condition a complete enclosure, it is permitted to use a portion of the enclosure representative of the complete assembly with regard to thickness and shape, including any mechanical support members.

NOTE Relative humidity need not be maintained at a specific value during this test.

There shall be no exposure of hazardous parts or reduction of creepage distances or clearances below the minimum required.

13.6.3 Polymers serving as solid insulation

A polymeric material serving as solid insulation shall comply with the requirements of 7.3.7.8, and the following.

13.6.3.1 Resistance to arcing

A polymeric material located inside the fire enclosure and closer than 13 mm from unenclosed parts that arc under normal conditions, such as switch contacts, shall have a high-ampere arc ignition (HAI) rating in accordance with ANSI UL 746C. The HAI rating shall

be 15 or better for material with a flammability rating of V-0 or better, and the HAI rating shall be 30 or better for material with a flammability rating of V-1 or better.

13.6.4 UV resistance

Polymeric parts of an outdoor enclosure required for compliance with this standard shall be sufficiently resistant to degradation by ultra-violet (UV) radiation.

Compliance is checked by examination of the construction and of available data regarding the UV resistance characteristics of the enclosure material and any associated protective coating. If such data is not available, the following tests are to be carried out.

Samples taken from the parts, or consisting of identical material, are prepared according to the standard for the test to be carried out. They are then UV conditioned according to Annex J.

After conditioning, the samples shall show no signs of significant deterioration, such as crazing or cracking. They are then kept at room ambient conditions for not less than 16 h and not more than 96 h, after which they are tested according to the standard for the relevant test.

In order to evaluate the percent retention of properties after test, samples that have not been conditioned according to Annex J are tested at the same time as the conditioned samples. The retention shall be as specified in Table 27.

Table 27 – Minimum property retention limits after UV exposure

Parts to be tested	Property	Standard for the test method	Minimum retention after test
Parts providing mechanical support	Tensile strength ^a	ISO 527	70 %
	or Flexural strength ^{a, b}	ISO 178	70 %
Parts providing impact resistance	Charpy impact ^c	ISO 179	70 %
	or Izod impact ^c	ISO 180	70 %
	or Tensile impact ^c	ISO 8256	70 %
All parts	Flammability classification	9.1.3	note ^d
^a Tensile strength and flexural strength tests are to be conducted on specimens no thicker than the actual thicknesses. ^b The side of the sample exposed to UV radiation is to be in contact with the two loading points when using the three-point loading method. ^c Tests conducted on 3,0 mm thick specimens for Izod impact and tensile impact tests, and 4,0 mm thick specimens for Charpy impact tests, are considered representative of other thicknesses, down to 0,8 mm. ^d The flammability classification may change as long as it does not fall below that specified in 9.1.3.			

13.7 Mechanical resistance to deflection, impact, or drop

13.7.1 General

The mechanical deflection, impact, or drop likely to occur in normal use shall not result in a hazard or reduction of protection provided in the PCE. Equipment shall have adequate mechanical strength, components shall be reliably secured, and electrical connections shall be secure.

Compliance is checked by the following tests, as applicable:

- the 250 N deflection test of 13.7.2 - applies to PCE with metal enclosures, except for direct plug-in, handheld, and transportable equipment;
- the 7 J impact test of 13.7.3 - applies to PCE with polymeric enclosures, except for direct plug-in, handheld, and transportable equipment;
- the drop test of 13.7.4 - applies to direct plug-in, handheld, and transportable equipment.

For impact and drop tests on polymeric parts, the test shall be performed after the part under test or the complete PCE is brought to the lowest temperature for which the PCE is rated for use. The PCE or part is not energized during this temperature conditioning, and the impact or drop test is performed immediately upon removal from the temperature chamber.

At the conclusion of the applicable test, the PCE shall pass the voltage test of 7.5.2 and shall be inspected to check that:

- live parts have not become accessible;
- enclosures show no cracks or openings which could cause a hazard;
- clearances are not less than their minimum permitted values and other insulation is undamaged; clearances are to be verified using the impulse test of 7.5.1 unless they can be inspected and determined not to have been reduced;
- barriers have not been damaged or loosened;
- no moving parts which could cause a hazard are exposed.

The PCE is not required to be operational after testing and the enclosure may be deformed to such an extent that its original IP classification is not maintained.

13.7.2 250 N deflection test for metal enclosures

The enclosure shall be held firmly against a rigid support and subjected to a steady force of 250 N applied for 5 s through the end of a rod having a 12,7 mm by 12,7 mm square, flat steel face.

13.7.3 7 J impact test for polymeric enclosures

A sample consisting of the enclosure or a portion thereof representing the largest non-reinforced area shall be supported in its normal position. A solid smooth steel sphere, approximately 50 mm in diameter and with a mass of 500 g ± 25 g, shall be permitted to fall freely from rest through a vertical distance of 1 300 mm onto the sample. Vertical surfaces are exempt from this test.

In addition, the steel sphere shall be suspended by a cord and swung as a pendulum in order to apply a horizontal impact, dropping through a vertical distance of 1 300 mm. Horizontal surfaces are exempt from this test.

If the pendulum test is inconvenient, it is permitted to simulate horizontal impacts on vertical or sloping surfaces by mounting the sample at 90° to its normal position and applying the vertical impact test instead of the pendulum test.

13.7.4 Drop test

The drop test applies to hand-held, direct plug-in, and transportable equipment.

A sample of the complete equipment is subjected to three drops onto a horizontal surface in positions likely to produce the most adverse results.

The height of the drops shall be 1 000 mm ± 10 mm.

The horizontal surface consists of hardwood at least 13 mm thick, mounted on two layers of plywood each 19 mm to 20 mm thick, all supported on a concrete or equivalent non-resilient floor.

13.8 Thickness requirements for metal enclosures

13.8.1 General

Metal enclosures shall have a thickness as specified in 13.8.2 or 13.8.3. This does not apply to enclosures that comply with the applicable tests of 13.7.

13.8.2 Cast metal

Die-cast metal, except at threaded holes for conduit, where a minimum of 6,4 mm is required, shall be:

- not less than 2,0 mm thick for an area larger than 155 cm² or having any dimension larger than 150 mm;
- not less than 1,2 mm thick for an area of 155 cm² or less and having no dimension larger than 150 mm.

The area under evaluation may be bounded by reinforcing ribs subdividing a larger area.

Malleable iron or permanent-mould cast aluminium, brass, bronze, or zinc shall be:

- at least 2,4 mm thick for an area greater than 155 cm² or having any dimension more than 150 mm; and
- at least 1,5 mm thick for an area of 155 cm² or less having no dimension more than 150 mm; and
- at least 6,4 mm thick at threaded holes for conduit.

A sand-cast metal enclosure shall be a minimum of 3,0 mm thick except at locations for threaded holes for conduit, where a minimum of 6,4 mm is required.

13.8.3 Sheet metal

The thickness of a sheet-metal enclosure at points to which a wiring system is to be connected shall be not less than 0,8 mm thick for uncoated steel, 0,9 mm thick for zinc-coated steel, and 1,2 mm thick for non-ferrous metal.

Enclosure thickness at points other than where a wiring system is to be connected shall be not less than that specified in Table 28 or Table 29.

With reference to Table 28 and Table 29, a supporting frame is a structure of angle or channel or folded section of sheet metal, which is attached to and has the same outside dimensions as the enclosure surface, and which has torsional rigidity to resist the bending moments that are applied by the enclosure surface when it is deflected.

A structure that is as rigid as one built with a frame of angles or channels has equivalent reinforcing. Constructions without supporting frame include:

- a single sheet with single formed flanges or edges;
- a single sheet which is corrugated or ribbed;
- an enclosure surface loosely attached to a frame, for example, with spring clips; and
- an enclosure surface having an unsupported edge.

**Table 28 – Thickness of sheet metal for enclosures:
Carbon steel or stainless steel**

Without supporting frame ^a		With supporting frame ^a		Minimum thickness mm
Maximum width mm ^b	Maximum length mm ^c	Maximum width mm ^b	Maximum length mm ^c	
100	Not limited	160	Not limited	0,6 ^d
120	150	170	210	
150	Not limited	240	Not limited	0,75 ^d
180	220	250	320	
200	Not limited	310	Not limited	0,9
230	290	330	410	
320	Not limited	500	Not limited	1,2
350	460	530	640	
460	Not limited	690	Not limited	1,4
510	640	740	910	
560	Not limited	840	Not limited	1,5
640	790	890	1 090	
640	Not limited	990	Not limited	1,8
740	910	1 040	1 300	
840	Not limited	1 300	Not limited	2,0
970	1 200	1 370	1 680	
1 070	Not limited	1 630	Not limited	2,5
1 200	1 500	1 730	2 130	
1 320	Not limited	2 030	Not limited	2,8
1 520	1 880	2 130	2 620	
1 600	Not limited	2 460	Not limited	3,0
1 850	2 290	2 620	3 230	

^a See 13.8.3.

^b The width is the smaller dimension of a rectangular piece of sheet metal which is part of an enclosure. Adjacent surfaces of an enclosure are able to have supports in common and be made of a single sheet.

^c Not limited applies only when the edge of the surface is flanged at least 12,7 mm or fastened to adjacent surfaces not normally removed in use.

^d Sheet steel for an enclosure intended for outdoor use shall be not less than 0,86 mm thick.