Adjustable speed electrical power drive systems —

Part 5-1: Safety requirements — Electrical, thermal and energy

The European Standard EN 61800-5-1:2007 has the status of a British Standard

ICS 29.130.01; 29.200

British Standards

National foreword

This British Standard is the UK implementation of EN 61800-5-1:2007. It is identical to IEC 61800-5-1:2007. It supersedes BS EN 61800-5-1:2003, which will be withdrawn on 1 August 2010.

The UK participation in its preparation was entrusted to Technical Committee PEL/22, Power electronics.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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Adjustable speed electrical power drive systems - Part 5-1: Safety requirements - Electrical, thermal and energy

(IEC 61800-5-1:2007)

Entraînements électriques de puissance à vitesse variable -
Partie 5-1: Exigences de sécurité -
Electrique, thermique et énergétique
(CEI 61800-5-1:2007)

Elektrische Leistungsantriebssysteme mit einstellbarer Drehzahl -
Teil 5-1: Anforderungen an die Sicherheit -
Elektrische, thermische und energetische Anforderungen
(IEC 61800-5-1:2007)

This European Standard was approved by CENELEC on 2007-08-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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CENELEC

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Foreword

The text of document 22G/178/FDIS, future edition 2 of IEC 61800-5-1, prepared by SC 22G, Adjustable speed electric drive systems incorporating semiconductor power converters, of IEC TC 22, Power electronic systems and equipment, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61800-5-1 on 2007-08-01.

This European Standard supersedes EN 61800-5-1:2003.

The major areas of change in EN 61800-5-1:2007 are the following:

– addition of alphabetical Table 1 in Clause 3;

– addition of Table 2 in 4.1 for relevance to PDS/CDM/BDM;

– addition of Table 4 summary of decisive voltage class requirements;

– expansion of subclause on protective bonding (4.3.5.3);

– clarification of distinction between touch current and protective conductor current;

– revision of section on insulation (now 4.3.6) to include solid insulation;

– addition of overvoltage categories I and II to HV insulation voltage;

– revision of section on Solid insulation (now 4.3.6.8);

– addition of high-frequency insulation requirements (4.3.6.9, Annex E);

– addition of requirements for liquid-cooled PDS (4.4.5);

– addition of climatic and vibration tests (5.2.6);

– clarification of voltage test procedure to avoid over-stress of basic insulation (5.2.3.2.3);

– revision of short-circuit test requirement for large, high-voltage and one-off PDS (now 5.2.3.6);

– addition of informative Annex B for overvoltage category reduction.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2008-05-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2010-08-01

Annex ZA has been added by CENELEC.

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Endorsement notice

The text of the International Standard IEC 61800-5-1:2007 was approved by CENELEC as a European Standard without any modification.

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CONTENTS

ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –

Part 5-1: Safety requirements – Electrical, thermal and energy

1 Scope

This part of IEC 61800 specifies requirements for adjustable speed *power drive systems*, or their elements, with respect to electrical, thermal and energy safety considerations. It does not cover the driven equipment except for interface requirements. It applies to adjustable speed electric drive systems which include the power conversion, drive control, and motor or motors. Excluded are traction and electric vehicle drives. It applies to d.c. drive systems connected to line voltages up to 1 kV a.c., 50 Hz or 60 Hz and a.c. drive systems with converter input voltages up to 35 kV, 50 Hz or 60 Hz and output voltages up to 35 kV.

Other parts of IEC 61800 cover rating specifications, EMC, functional safety, etc.

The scope of this part of IEC 61800 does not include devices used as component parts of a *PDS* if they comply with the safety requirements of a relevant product standard for the same environment. For example, motors used in *PDS* shall comply with the relevant parts of IEC 60034.

Unless specifically stated, the requirements of this International Standard apply to all parts of the *PDS*, including the *CDM/BDM* (see Figure 1).

NOTE In some cases, safety requirements of the *PDS* (for example, protection against direct contact) can necessitate the use of special components and/or additional measures.

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.

NOTE This does not mean that compliance is required with all clauses of the referenced documents, but rather that this international standard makes a reference that cannot be understood in the absence of the referenced document.

IEC 60034 (all parts), *Rotating electrical machines*

IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-5, *Rotating electrical machines – Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP code) - Classification*

IEC 60050-111, *International Electrotechnical Vocabulary (IEV) – Chapter 111: Physics and chemistry*

IEC 60050-151, *International Electrotechnical Vocabulary (IEV) – Part 151: Electrical and magnetic devices*

IEC 60050-161, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

IEC 60050-191, *International Electrotechnical Vocabulary (IEV) – Chapter 191: Dependability and quality of service*

IEC 60050-441, *International Electrotechnical Vocabulary (IEV) – Chapter 441: Switchgear, controlgear and fuses*

IEC 60050-442, *International Electrotechnical Vocabulary (IEV) – Part 442: Electrical accessories*

IEC 60050-551, *International Electrotechnical Vocabulary (IEV) – Part 551: Power electronics*

IEC 60050-601, *International Electrotechnical Vocabulary (IEV) – Chapter 601: Generation, transmission and distribution of electricity – General*

IEC 60060-1:1989, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60068-2-2:1974, *Environmental testing – Part 2: Tests. Tests B: Dry heat*

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

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

IEC 60112:2003, *Method for the determination of the proof and the comparative tracking indices of solid insulating materials*

IEC 60204-11, *Safety of machinery – Electrical equipment of machines – Part 11: Requirements for HV equipment for voltages above 1 000 V a.c. or 1 500 V d.c. and not exceeding 36 kV*

IEC 60309, *Plugs, socket-outlets and couplers for industrial purposes*

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

IEC 60364-5-54:2002, *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 60529:1989, *Degrees of protection provided by enclosures (IP code)*

IEC 60617, *Graphical symbols for diagrams*

IEC 60664-1:1992, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*[1)]
Amendment 1 (2000)
Amendment 2 (2002)

IEC 60664-3:2003, *Insulation coordination for equipment within low-voltage systems – Part 3: Use of coatings to achieve insulation coordination of printed board assemblies*

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

IEC 60695-2-10, *Fire hazard testing – Part 2-10: Glowing/hot-wire based test methods – Glow-wire apparatus and common test procedure*

IEC 60695-2-13, *Fire hazard testing – Part 2-13: Glowing/hot-wire based test methods – Glow-wire ignitability test method for materials*

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

IEC 60947-7-1:2002, *Low-voltage switchgear and control gear – Part 7-1: Ancillary equipment –Terminal blocks for copper conductors*

IEC 60947-7-2:2002, *Low-voltage switchgear and controlgear – Part 7-2: Ancillary equipment – Protective conductor terminal blocks for copper conductors*

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

IEC 61230, *Live working – Portable equipment for earthing or earthing and short-circuiting*

IEC 61800-1, *Adjustable speed electrical power drive systems – Part 1: General requirements – Rating specifications for low voltage adjustable speed d.c. power drive systems*

IEC 61800-2, *Adjustable speed electrical power drive systems – Part 2: General requirements – Rating specifications for low voltage adjustable frequency a.c. power drive systems*

IEC 61800-4, *Adjustable speed electrical power drive systems – Part 4: General requirements – Rating specifications for a.c. power drive systems above 1 000 V a.c. and not exceeding 35 kV*

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

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1 There exists a consolidated edition 1.2 (2002) including IEC 60664-1:1992 and its Amendments 1 and 2.

IEC 62271-102, *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

ISO 3864 (all parts), *Graphical symbols – Safety colours and safety signs*

ISO 7000:2004, *Graphical symbols for use on equipment – Index and synopsis*

3 Terms and definitions

For the purposes of this international standard, the terms and definitions given in IEC 60050-111, IEC 60050-151, IEC 60050-161, IEC 60050-191, IEC 60050-441, IEC 60050-442, IEC 60050-551, IEC 60050-601, IEC 60664-1, IEC 61800-1, IEC 61800-2, IEC 61800-3 and IEC 61800-4 (some of which are repeated below for convenience), and the following definitions apply.

Table 1 provides an alphabetical cross-reference listing of terms.

Table 1 – Alphabetical list of terms

Term	Term number	Term	Term number	Term	Term number
adjacent circuit	3.1	(earth) leakage current	3.16	protective screening	3.31
basic drive module (BDM)	3.2	live part	3.17	protective separation	3.32
basic insulation	3.3	low-voltage *PDS*	3.18	reinforced insulation	3.33
CDM (complete drive module)	3.4	open-type (product)	3.19	routine test	3.34
closed electrical operating area	3.5	power drive system (PDS)	3.20	safety *ELV* (SELV) circuit	3.35
commissioning test	3.6	protective *ELV* (PELV) circuit	3.21	sample test	3.36
decisive voltage class (DVC)	3.7	prospective short-circuit current	3.22	supplementary insulation	3.37
double insulation	3.8	protective bonding	3.23	system voltage	3.38
extra low voltage (ELV)	3.9	protective class 0	3.24	temporary overvoltage	3.39
electrical breakdown	3.10	protective class I	3.25	touch current	3.40
expected lifetime	3.11	protective class II	3.26	type test	3.41
functional insulation	3.12	protective class III	3.27	user terminal	3.42
high-voltage *PDS*	3.13	protective earthing (PE)	3.28	working voltage	3.43
installation	3.14	protective earthing conductor	3.29	zone of equipotential bonding	3.44
integrated *PDS*	3.15	protective impedance	3.30		

3.1
adjacent circuit
circuit having no galvanic connection to the circuit under consideration

NOTE A protective impedance is not considered to be a galvanic connection.

3.2
basic drive module (BDM)
drive module, consisting of a converter section and a control section for speed, torque, current or voltage, etc. (see Figure 1)

3.3
basic insulation
insulation applied to *live parts* to provide basic protection against electrical shock

[IEV 826-12-14, modified]

3.4
complete drive module
CDM
drive system, without the motor and the sensors which are mechanically coupled to the motor shaft, consisting of, but not limited to, the *BDM*, and extensions such as feeding section and auxiliaries (see Figure 1)

3.5
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

3.6
commissioning test
test on a device or equipment performed on site, to prove the correctness of installation and operation

[IEV 151-16-24, modified]

3.7
decisive voltage class
DVC
classification of voltage range used to determine the protective measures against electric shock

3.8
double insulation
insulation comprising both *basic insulation* and *supplementary insulation*

[IEV 826-12-16]

NOTE *Basic* and *supplementary insulation* are separate, each designed for basic protection against electric shock.

3.9
extra low voltage
ELV
any voltage not exceeding 50 V a.c. r.m.s. and 120 V d.c.

NOTE 1 R.M.S. ripple voltage of not more than 10 % of the d.c. component.

NOTE 2 In this international standard, protection against electric shock is dependent on the *decisive voltage classification. DVC* A and B are contained in the voltage range of *ELV*.

3.10
electrical breakdown
failure of insulation under electric stress when the discharge completely bridges the insulation, thus reducing the voltage between the electrodes almost to zero

[IEC 60664-1:1992, definition 1.3.20]

3.11
expected lifetime
minimum duration for which the safety performance characteristics are valid at rated conditions of operation

3.12
functional insulation
insulation between conductive parts within a circuit, which is necessary for the proper functioning of the circuit, but which does not provide protection against electric shock

3.13
high-voltage *PDS*
product with rated supply voltage between 1 kV and 35 kV a.c., 50 Hz or 60 Hz

NOTE These products fall into the scope of IEC 61800-4

3.14
installation
equipment or equipments including at least the *PDS* and the driven equipment (see Figure 1)

NOTE The word “installation” is also used in this international standard to denote the process of installing a *PDS/CDM/BDM*. In these cases, the word does not appear in italics.

3.15
integrated *PDS*
PDS where motor and *CDM/BDM* are mechanically integrated into a single unit

3.16
(earth) leakage current
current flowing from the *live parts* of the *installation* to earth, in the absence of an insulation fault

[IEV 442-01-24]

3.17
live part
conductor or conductive part intended to be energized in normal use, including a neutral conductor but not a protective earth neutral

3.18
low-voltage *PDS*
product with rated supply voltage up to 1 000 V a.c., 50 Hz or 60 Hz

NOTE These products fall into the scope of IEC 61800-1 or IEC 61800-2.

3.19
open type (product)
(product) intended for incorporation within enclosure or assembly which will provide access protection

3.20
power drive system
PDS
system for the speed control of an electric motor, including the *CDM* and motor but not the driven equipment (see Figure 1)

3.21
protective *ELV* (PELV) circuit
electrical circuit with the following characteristics:

- the voltage does not continuously exceed *ELV* under single fault as well as normal conditions;
- *protective separation* from circuits other than *PELV* or *SELV*;
- provisions for earthing of the *PELV circuit*, or its accessible conductive parts, or both

3.22
prospective short-circuit current
current which flows when the supply conductors to the circuit are short-circuited by a conductor of negligible impedance located as near as possible to the supply terminals of the *PDS*/*CDM*/*BDM*

3.23
protective bonding
electrical connection of conductive parts for safety purposes

3.24
protective class 0
equipment in which protection against electric shock relies only upon *basic insulation*

NOTE Equipment of this class becomes hazardous in the event of a failure of the *basic insulation*.

3.25
protective class I
equipment in which protection against electric shock does not rely on *basic insulation* only, but which includes an additional safety precaution in such a way that means are provided for the connection of accessible conductive parts to the *protective (earthing) conductor* in the fixed wiring of the *installation*, so that accessible conductive parts cannot become live in the event of a failure of the *basic insulation*

3.26
protective class II
equipment in which protection against electric shock does not rely on *basic insulation* only, but in which additional safety precautions such as *supplementary insulation* or *reinforced insulation* are provided, there being no provision for *protective earthing* or reliance upon installation conditions

3.27
protective class III
equipment in which protection against electric shock relies on supply at *ELV* and in which voltages higher than those of *ELV* are not generated and there is no provision for *protective earthing*

[see IEC 61140, subclause 7.4]

3.28
protective earthing (PE)
earthing of a point in a system, or equipment, for protection against electric shock in case of a fault

3.29
protective earthing conductor
protective conductor provided for *protective earthing*

[IEV 195-02-11]

3.30
protective impedance
impedance connected between *live parts* and accessible conductive parts, of such value that the current, in normal use and under likely fault conditions, is limited to a safe value, and which is so constructed that its reliability is maintained throughout the life of the equipment

[IEV 442-04-24, modified]

3.31
protective screening
separation of circuits from hazardous live-parts by means of an interposed conductive screen, connected to the means of connection for a *protective earthing conductor*

3.32
protective separation
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*)

3.33
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 in the relevant IEC standard

[IEC 60664-1: 1992, definition 1.3.17.5]

3.34
routine test
test to which each individual device is subjected during or after manufacture to ascertain whether it complies with certain criteria

[IEV 151-16-17]

3.35
Safety *ELV* (SELV) circuit
electrical circuit with the following characteristics:

- the voltage does not exceed *ELV*;
- *protective separation* from circuits other than *SELV* or *PELV*;
- no provisions for earthing of the *SELV circuit*, or its accessible conductive parts;
- *basic insulation* of the *SELV circuit* from earth and from *PELV circuits*

3.36
sample test
test on a number of devices taken at random from a batch

[IEV 151-16-20, modified]

3.37
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*

[IEC 60664-1: 1992, definition 1.3.17.3]

NOTE *Basic* and *supplementary insulation* are separate, each designed for basic protection against electric shock.

3.38
system voltage
voltage used to determine insulation requirements

NOTE See 4.3.6.2.1 for further consideration of *system voltage*.

3.39
temporary overvoltage
overvoltage at the supply frequency of relatively long duration

[IEC 60664-1:1992, definition 1.3.7.1, modified]

3.40
touch current
electric current passing through a human body or through an animal body when it touches one or more accessible parts of an electrical installation or electrical equipment

[IEV 826-11-12]

3.41
type test
test of one or more devices made to a certain design to show that the design meets certain specifications

[IEV 151-16-16, modified]

3.42
user terminal
terminal provided for external connection to the *PDS*/*CDM*/*BDM*

3.43
working voltage
voltage, at rated supply conditions (without tolerances) and worst case operating conditions, which occurs by design in a circuit or across insulation

NOTE The *working voltage* can be d.c. or a.c. Both the r.m.s. and recurring peak values are used.

3.44
zone of equipotential bonding
zone where all simultaneously accessible conductive parts are electrically connected to prevent hazardous voltages appearing between them

NOTE For equipotential bonding, it is not necessary for the parts to be earthed.

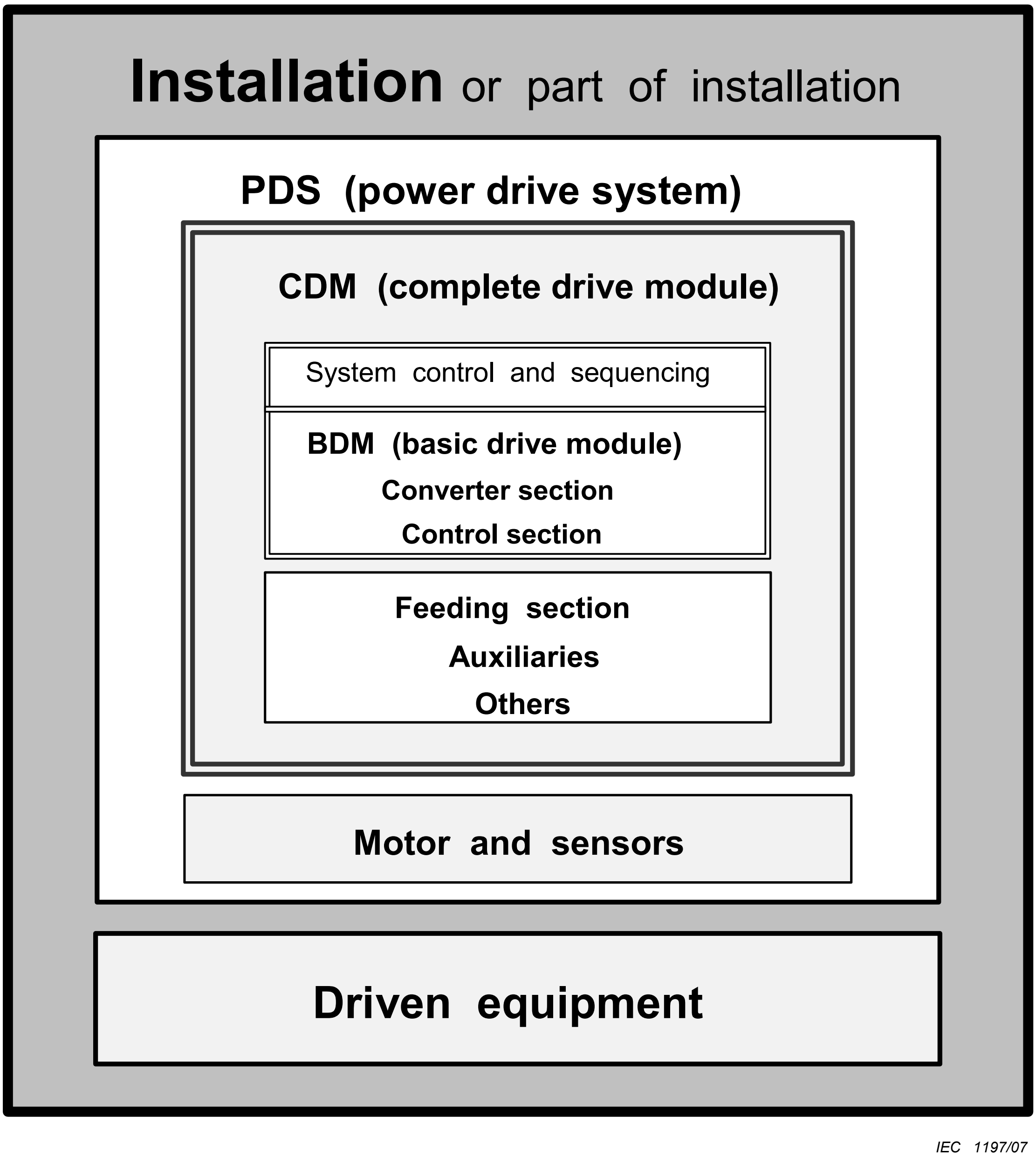


Figure 1 – *PDS* hardware configuration within an *installation*

4 Protection against electric shock, thermal, and energy hazards

4.1 General

This Clause 4 defines the minimum requirements for the design and construction of a *PDS*, to ensure its safety during installation, normal operating conditions and maintenance for the *expected lifetime* of the *PDS*. Consideration is also given to minimising hazards resulting from reasonably foreseeable misuse.

Table 2 shows the application of the requirements of this Clause 4 to *PDS, CDM* or *BDM*.

Table 2 – Relevance of requirements to *PDS/CDM/BDM*

Sub-clause	Title	*PDS* [a]	*CDM/BDM*
4.2	(Protection against electric shock, thermal, and energy hazards) - Fault conditions	A	A
4.3.1	*Decisive voltage classification*	A	A
4.3.2	*Protective separation*	A	A
4.3.3	Protection against direct contact	A	C
4.3.4	Protection in case of direct contact	A	C
4.3.5.1	(Protection against indirect contact) - General	A	A
4.3.5.2	Insulation between *live parts* and accessible conductive parts	A	C
4.3.5.3	**4.1.1.1 *Protective bonding* circuit**	A	C
4.3.5.4	*Protective earthing conductor*	A	A
4.3.5.5	Means of connection for the *protective earthing conductor*	A	A
4.3.5.6	Special features in equipment for *protective class II*	A	C
4.3.6	Insulation	A	A
4.3.7	Enclosures	A	C
4.3.8	Wiring and connections	A	A
4.3.9	Output short-circuit requirements	A	A
4.3.10	Residual current-operated protective (RCD) or monitoring (RCM) device compatibility	A	C
4.3.11	Capacitor discharge	A	A
4.3.12	Access conditions for *high-voltage PDS*	A	C
4.4	Protection against thermal hazards	A	A
4.4.3	Flammability of enclosure materials	A	C
4.4.5	Specific requirements for liquid cooled *PDS*	A	A
4.5	Protection against energy hazards	A	A
4.5.2	Mechanical energy hazards	A	C
4.6	Protection against environmental stresses	A	A

A Requirement always relevant.

C Requirement relevant unless *CDM* or *BDM* is incorporated into an assembly that provides the required protection.

[a] *Integrated PDS* shall meet the requirement for *PDS*.

4.2 Fault conditions

PDS shall be designed to avoid operating modes or sequences that can cause a fault condition or component failure leading to a hazard, unless other measures to prevent the hazard are provided by the *installation*.

Protection against thermal hazards and electric shock shall be maintained in single fault conditions as well as under normal conditions.

Circuit analysis shall be performed to identify components (including insulation systems) whose failure would result in a thermal or electric shock hazard. The analysis shall include the effect of short-circuit and open-circuit conditions of the component. The analysis need not include power semiconductor devices if equivalent testing is accomplished during short-circuit tests, or components which have been determined to have an insignificant probability of failure during the *expected lifetime* of the *PDS*. See 5.2.3.6.4 for test.

NOTE It is possible that no critical components will be revealed by the analysis. In this case, no component failure testing is required.

Consideration shall be given to potential safety hazards associated with major component parts of the *PDS*, such as motor rotating parts and flammability of transformer and capacitor oils.

4.3 Protection against electric shock

4.3.1 *Decisive voltage classification*

4.3.1.1 Use of *decisive voltage class (DVC)*

Protective measures against electric shock depend on the *decisive voltage classification* of the circuit according to Table 3, which correlates the limits of the *working voltage* within the circuit with the *DVC*. The *DVC* in turn determines the minimum required level of protection for the circuit.

4.3.1.2 Limits of *DVC*

Table 3 – Summary of the limits of the *decisive voltage classes*

DVC	**Limits of *working voltage* (V)**			**Subclause**
	a.c. voltage (r.m.s.) U_{ACL}	**a.c. voltage (peak)** U_{ACPL}	**d.c. voltage (mean)** U_{DCL}	
A [a]	25	35,4	60	4.3.4.2, 4.3.4.4
B	50	71	120	4.3.5.3.1 a), b)
C	1 000	4 500 [b]	1 500	
D	> 1 000	> 4 500	> 1 500	

[a] For equipment having only one *DVC* A circuit, the r.m.s. and peak voltage limits are 30 V and 42,4 V respectively.

[b] The value of 4 500 V allows all *low-voltage PDS* to be covered by Table 7 (possible reflections up to $3 \times \sqrt{2} \times 1\ 000$ V = 4 242 V).

4.3.1.3 Requirements for protection

Table 4 shows the requirements for the application of *basic insulation* or *protective separation*, dependent on the *DVC* of the circuit under consideration and of *adjacent circuits*.

Table 4 – Protection requirements for considered circuit

DVC of considered circuit	Protection required against direct contact	Insulation to earthed parts	Insulation to accessible conductive parts that are not earthed	Insulation to *adjacent circuit* of *DVC*:			
				A	**B**	**C**	**D**
A	No	a *	a	f *	b	p ‡	p
B	Yes	b	p		b	p ‡	p
C	Yes	b	p			b	p
D	Yes	b	p				b

a Insulation is not necessary for safety, but may be required for functional reasons.

* If the considered circuit is designated as a *SELV circuit*, *basic insulation* is required from earth and from *PELV circuits*.

f *Functional insulation* for circuit of higher voltage.

b *Basic insulation* for circuit of higher voltage.

p *Protective separation* for circuit of higher voltage.

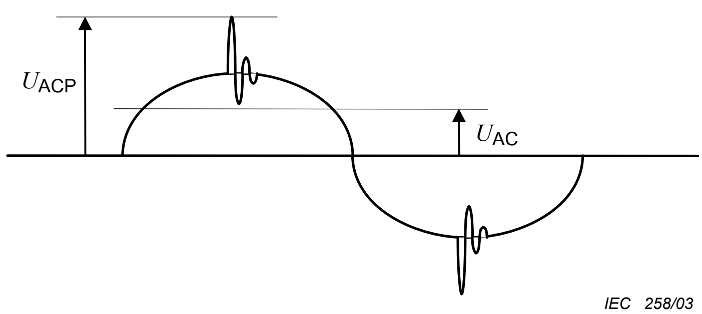
‡ It is permitted to use *basic insulation* for the circuit of higher voltage if protection against direct contact is applied to the considered circuit by *basic* or *supplementary insulation* for the circuit of higher voltage.

4.3.1.4 Circuit evaluation

4.3.1.4.1 General

The *DVC* of a given circuit is evaluated by the method set out below, three cases of waveforms being considered.

4.3.1.4.2 A.C. *working voltage* (see Figure 2)



Key

U_{AC} r.m.s. voltage

U_{ACP} recurring peak voltage

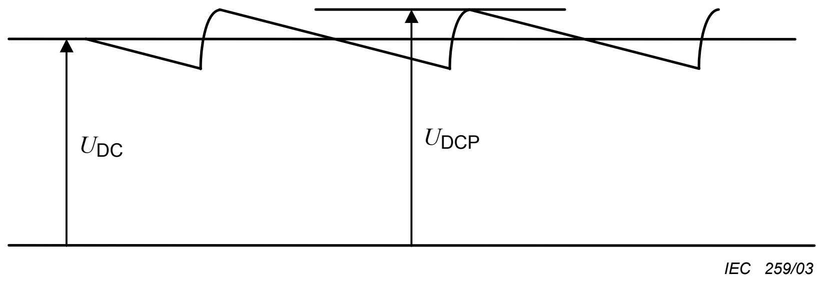
Figure 2 – Typical waveform for a.c. *working voltage*

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 3 for which both of the following conditions are satisfied.

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

4.3.1.4.3 D.C. *working voltage* (see Figure 3)



Key

U_{DC} mean voltage

U_{DCP} recurring peak voltage

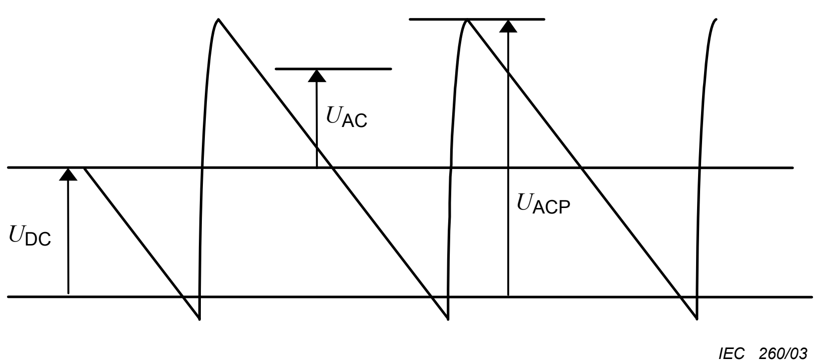
Figure 3 – Typical waveform for d.c. *working voltage*

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 3 for which both of the following conditions are satisfied.

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

4.3.1.4.4 Pulsating *working voltage* (see Figure 4)



Key

U_{DC} mean voltage

U_{DCP} recurring peak voltage

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 3 for which both of the following conditions are satisfied.

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

4.3.2 *Protective separation*

Protective separation shall be achieved by application of materials resistant to degradation, as well as by special constructive measures; and

- by *double* or *reinforced insulation*,

  or

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

  or

- by *protective impedance* according to 4.3.4.3 comprising limitation of discharge energy and of current, or by limitation of voltage according to 4.3.4.4.

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

4.3.3 Protection against direct contact

4.3.3.1 General

Protection against direct contact is employed to prevent persons from touching *live parts* which do not meet the requirements of 4.3.4. It shall be provided by one or more of the measures given in 4.3.3.2 and 4.3.3.3.

For *integrated PDS* the motor shall meet the requirements of IEC 60034-5. For the *BDM* the protection shall be provided by one or more of the measures given in 4.3.3.2 and 4.3.3.3.

4.3.3.2 Protection by means of insulation of *live parts*

Live parts shall be completely surrounded with insulation if their *working voltage* is greater than the maximum limit of *DVC* A or if they do not have *protective separation* from *adjacent circuits* of *DVC* C or D. The insulation shall be rated according to the impulse voltage, *temporary overvoltage* or *working voltage* (see 4.3.6.2.1), whichever gives the most severe requirement. It shall not be possible to remove the insulation without the use of a tool.

Any conductive part which is not separated from the *live 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 4.3.6.4, shown by L_1 and L_2 in Figure 5, may be provided.

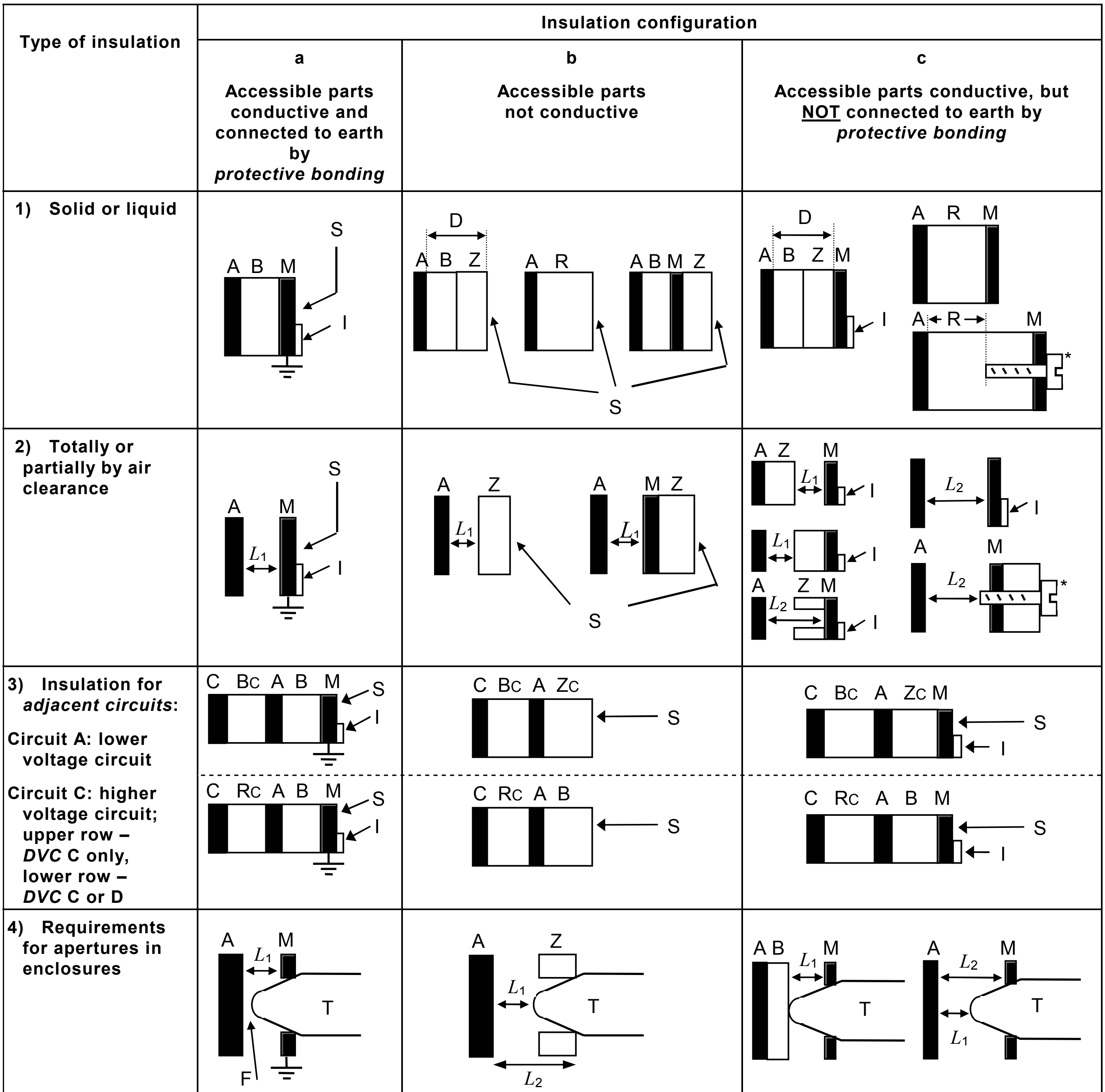
The grade of insulation – *basic*, *double* or *reinforced* – depends on:

- the *DVC* of the *live parts* or *adjacent circuits*,

  and

- the connection of conductive parts to earth by *protective bonding*.

Examples of insulation configurations are given in Figure 5, which also shows the requirements for apertures.



A	*live part*	L_1	clearance for *basic insulation*	T	test finger (Clause 12 of IEC 60529)
B	*basic insulation* for circuit A	L_2	clearance for *reinforced insulation*	Z	*supplementary insulation* for circuit A
Bc	*basic insulation* for circuit C	M	conductive part	Zc	*supplementary insulation* for circuit C
C	*adjacent circuit*	R	*reinforced insulation* for circuit A	*	also applies to plastic screws
D	*double insulation* for circuit A	Rc	*reinforced insulation* for circuit C	F	*functional insulation* for circuit A
I	insulation less than B	S	surface of equipment		

NOTE 1: In column c a plastic screw is treated like a metal screw because a user could replace it with a metal screw during the life of the equipment.

NOTE 2: In row 4), the insertion of the test finger is considered to represent the first fault.

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Figure 5 – Examples for protection against direct contact

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)).

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* C or D. The relevant voltage is that of the *live parts* (see Figure 5, cells 1)b), 1)c), 2)b), 2)c)).
- *supplementary insulation* between accessible parts and *live parts* of circuits of *DVC* A or B which are separated by *basic insulation* from *adjacent circuits* of *DVC* C. The relevant voltage is the highest voltage of the *adjacent circuits* (see Figure 5, upper cells 3)b), 3)c)).
- *basic insulation* between accessible parts and *live parts* of circuits of *DVC* B which have *protective separation* from *adjacent circuits* of *DVC* C or D. The relevant voltage is that of the *live parts* (see Figure 5, lower cells 3)b), 3)c)).

4.3.3.3 Protection by means of enclosures and barriers

Live parts of *DVC* B, C or D shall be arranged in enclosures or located behind enclosures or barriers, which meet at least the requirements of the Protective Type IPXXB according to 15.1 of IEC 60529. The top surfaces of enclosures or barriers which are accessible when the equipment is energized shall meet at least the requirements of the Protective Type IP3X with regard to vertical access only. See 5.2.2.3 for test. It shall only be possible to open enclosures or remove barriers with the use of a tool or after de-energization of these *live parts*.

Where the enclosure is required to be opened and the *PDS* energised during installation or maintenance:

a) accessible *live parts* of *DVC* B, C or D shall be protected to at least IPXXA;

b) *live parts* of *DVC* B, C or D that are likely to be touched when making adjustments shall be protected to at least IPXXB;

c) it shall be ensured that persons are aware that *live parts* of *DVC* B, C or D are accessible.

Open type sub-assemblies and devices do not require protective measures against direct contact.

Products containing circuits of *DVC* A, B or C, intended for installation in *closed electrical operating areas*, as defined in 3.5, need not have protective measures against direct contact.

Products containing circuits of *DVC* D, intended for installation within a *closed electrical operating area*, have additional requirements (see 4.3.12).

4.3.4 Protection in case of direct contact

4.3.4.1 General

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

The protection against direct contact according to 4.3.3 is not required if the circuit contacted is separated from all other circuits according to 4.3.1.3, and:

- is of *DVC* A and complies with 4.3.4.2,

  or
- is current limited via a *protective impedance* according to 4.3.4.3,

  or
- is limited in voltage according to 4.3.4.4.

See Annex A for examples of these measures.

NOTE The requirements of these subclauses apply to the entire circuit including power supplies and any associated peripheral devices.

Compliance with *protective separation* requirements shall be verified according to 5.2.1, 5.2.2, and 5.2.3 as appropriate.

4.3.4.2 Protection using *DVC* A

Unearthed circuits of *DVC* A, and earthed circuits of *DVC* A used within a *zone of equipotential bonding* (see 3.44), do not require protection in case of direct contact.

Earthed circuits of *DVC* A that are not within a *zone of equipotential bonding* require additional protection in case of direct contact, by one of the measures given in 4.3.4.3 or 4.3.4.4, in order to provide protection in cases where the earth reference potentials of the *DVC* A circuits are not the same. The instruction manual shall provide information concerning the use of these circuits (see 6.3.6.5).

4.3.4.3 Protection by means of *protective impedance*

The connection of accessible *live parts* to circuits of *DVC* B, C or D, or to earthed circuits of *DVC* A not used within a *zone of equipotential bonding*, shall only be made through *protective impedances* (unless 4.3.4.4 applies).

The same constructional provisions as those for *protective separation* shall be applied for the construction and arrangement of a *protective impedance*. The current value stated below shall not be exceeded in the event of failure of a single component. The stored charge available between simultaneously accessible parts protected by the *protective impedance* shall not exceed 50 μC.

The *protective impedances* shall be designed so that the current available through them to earth at the accessible *live part* does not exceed a value of 3,5 mA a.c. or 10 mA d.c. See 5.2.3.4 for test.

The *protective impedances* shall be designed and tested to withstand the impulse voltages and *temporary overvoltages* for the circuits to which they are connected. See 5.2.3.1 and 5.2.3.2 for tests.

4.3.4.4 Protection by means of limited voltages

This type of protection implies a voltage division technique from a circuit protected against direct contact, resulting in a voltage to earth not greater than that of *DVC* A.

This circuit shall be designed so that, even in the event of failure of a single component in the voltage division circuit, the voltage across output terminals as well as the voltage to earth will not become greater than that of *DVC* A. The same constructional measures as in *protective separation* shall be employed in this case.

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

4.3.5 Protection against indirect contact

4.3.5.1 General

Protection against indirect contact is required to prevent shock currents which can result from accessible conductive parts during an insulation failure. This protection shall comply with the requirements for *protective class I*, *class II* or *class III*.

That part of a *PDS* which meets the requirements of 4.3.5.2, 4.3.5.3 and 4.3.5.3.2 is defined as *protective class I*.

That part of a *PDS* which meets the requirements of 4.3.5.6 is defined as *protective class II*.

That part of a *PDS* which meets the requirements of *SELV* is defined as *protective class III*.

Protective class 0 is only acceptable for parts of the *PDS* when instructions are provided to meet the requirements of 4.3.3.3 (*closed electrical operating areas*) (see 6.3.6.5). In the case of *high-voltage PDS*, special requirements exist (see 4.3.12).

4.3.5.2 Insulation between *live parts* and accessible conductive parts

Accessible conductive parts of equipment shall be separated from *live parts* at least by *basic insulation* or by clearances as in 4.3.6.4.

4.3.5.3 *Protective bonding* circuit

4.3.5.3.1 General

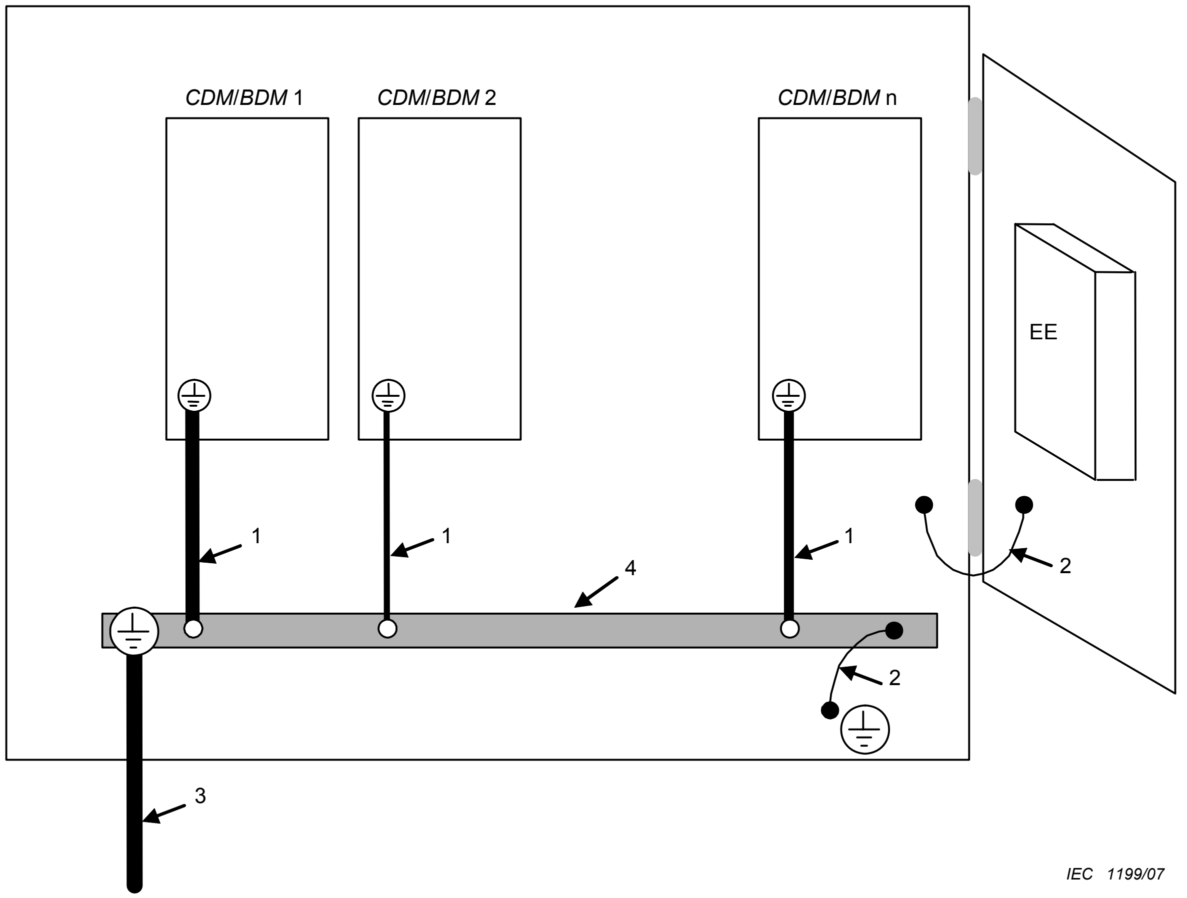
Other than in a) or b) below, *protective bonding* shall be provided between accessible conductive parts of equipment and the means of connection for the *protective earthing conductor*:

a) when accessible conductive parts are protected by one of the measures in 4.3.4.2 to 4.3.4.4;

b) when accessible conductive parts are separated from *live parts* using *double* or *reinforced insulation*.

NOTE Some examples of such parts are magnetic cores, screws, rivets, nameplates and cable clamps.

Figure 6 shows an example *CDM/BDM* assembly and its associated *protective bonding*.



1 *CDM/BDM protective earthing conductor* (dimensioned according to *CDM/BDM* requirements)

2 *Protective bonding*

3 *PDS protective earthing conductor* (dimensioned according to *PDS* requirements) to *installation* earthing point

4 *Earth* bar

EE other *electrical* equipment (bonded as relevant for that equipment)

Figure 6 – Example of *protective bonding*

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

- through direct metallic contact;
- through other accessible conductive parts which are not removed when the *PDS*/*CDM*/*BDM* is used as intended;
- through a dedicated *protective bonding* conductor;
- through other metallic components of the *PDS*/*CDM*/*BDM*.

NOTE When painted surfaces (in particular powder painted surfaces) are joined together, then a separate connection should be made for reliable contact.

Where electrical equipment is mounted on lids, doors, or cover plates, continuity of the *protective bonding* circuit shall be ensured and it is recommended that a dedicated conductor be used. Otherwise fastenings, hinges or sliding contacts designed and maintained to have a low resistance shall be used.

Metal ducts of flexible or rigid construction and metallic sheaths shall not be used as protective conductors.

For *high-voltage PDS*, metal ducts and metal sheathing of all connecting cables (e.g. cable armouring, lead sheath) shall be connected to earth by the *protective bonding* circuit. If only one end of such ducting or sheathing is so connected, it shall not be possible to touch the other end. This shall be connected to earth by the *protective bonding* circuit via an impedance to limit any induced voltage to a maximum of 50 V a.c.

The *protective bonding* circuit shall not incorporate a switching device, an overcurrent device (e.g. switch, fuse) or means of current detection for such devices.

4.3.5.3.2 Rating of protective bonding

Protective bonding shall withstand the highest thermal and dynamic stresses that can occur to the *PDS*/*CDM*/*BDM* item(s) concerned when they are subjected to a fault connecting 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.

These conditions will be satisfied if the cross-section of the *protective bonding* conductor is the same as that for the *protective earthing conductor* according to 4.3.5.4. For testing, see 5.2.3.9.

Alternatively, *protective bonding* may be designed to meet the impedance requirements of 4.3.5.3.3.

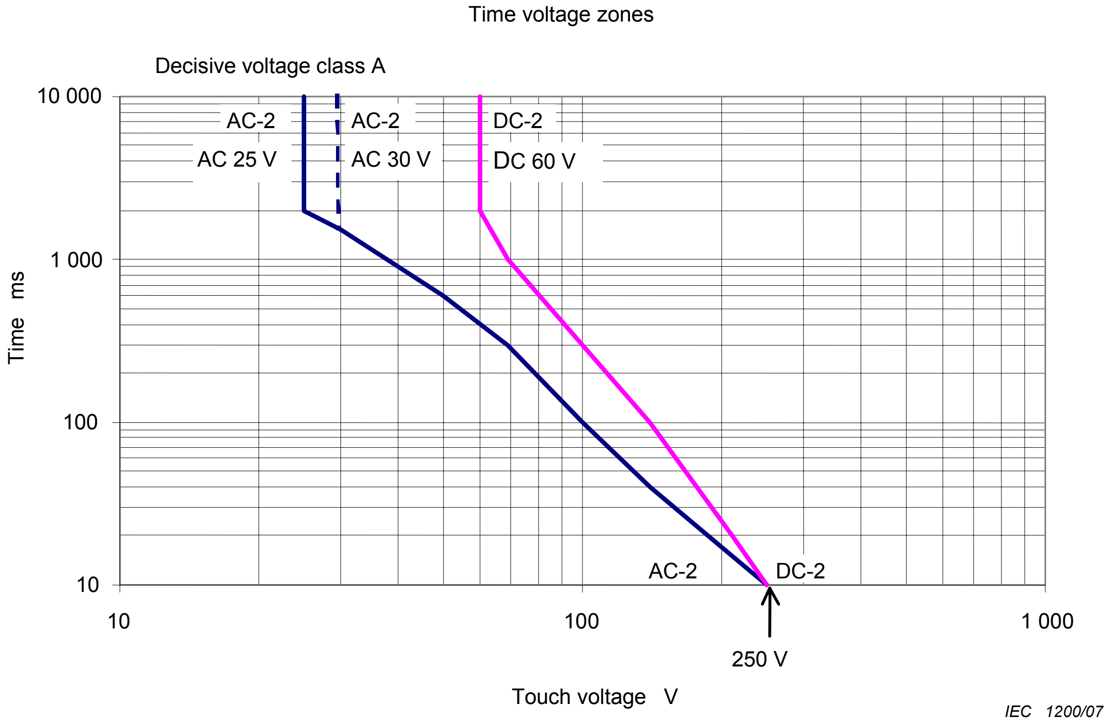
4.3.5.3.3 *Protective bonding* impedance

The impedance of the *protective bonding* shall be sufficiently low that:

- during normal operation, no voltage exceeding continuously 5 V a.c. or 12 V d.c. can persist between the accessible conductive parts and the means of connection for the *protective earthing conductor*,

  and

- under fault conditions, no voltage exceeding AC-2 or DC-2 in Figure 7 can persist between accessible conductive parts and the means of connection for the *protective earthing conductor* until an upstream protective device removes power from the part. The upstream protective device considered for this requirement shall have the characteristics required by the installation manual according to 6.3.7.



NOTE The dashed line of AC-2 applies if only a single *DVC* A circuit is present; the solid line applies if more than one *DVC* A circuit is present.

Figure 7 – Voltage limits under fault conditions

For testing, see 5.2.3.9.

4.3.5.4 *Protective earthing conductor*

A *protective earthing conductor* shall be connected at all times when power is supplied to the *PDS*/*CDM*/*BDM*, unless the *PDS*/*CDM*/*BDM* complies with the requirements of *protective class II* (see 4.3.5.6). Unless local wiring regulations state otherwise, the *protective earthing conductor* cross-sectional area shall be determined from Table 5 or by calculation according to 543.1 of IEC 60364-5-54.

If the *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 5 – *Protective earthing conductor* cross-section

Cross-sectional area of phase conductors of the *PDS*/*CDM*/*BDM* S (mm^2)	Minimum cross-sectional area of the corresponding *protective earthing conductor* S_p (mm^2)
$S \le 16$	S
$16 < S \le 35$	16
$35 < S$	$S/2$
The values in Table 5 are valid only if the *protective earthing conductor* is made of the same metal as the phase conductors. If this is not so, the cross-sectional area of the *protective earthing conductor* shall be determined in a manner which produces a conductance equivalent to that which results from the application of Table 5.	

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 mm^2 if mechanical protection is provided,

  or

- 4 mm^2 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.

For special system topologies, such as 6-phase motors, the *PDS* designer shall verify the *protective earthing conductor* cross-section required.

4.3.5.5 Means of connection for the *protective earthing conductor*

4.3.5.5.1 General

Every *PDS* or *PDS* element (motor, converter, transformer) requiring connection to earth by *protective bonding* shall have a means of connection for the *protective earthing conductor*, 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 Table 5 and of cables in accordance with the wiring rules applicable at the *installation*. 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 *protective earthing conductor*.

For *high-voltage PDS*, protective shields of high voltage cables shall have provision for connection to earth by *protective bonding* in accordance with IEC 60204-11 and IEC 61800-4. The *protective bonding* concept shall be by agreement between the supplier and user and consistent with local requirements in the area of *installation*.

Connection and bonding points shall be designed so 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.

See 6.3.6.6 for marking requirements.

4.3.5.5.2 *Touch current* in case of failure of *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 plug-connected single phase *PDS*/*CDM*/*BDM*, not using an industrial connector according to IEC 60309, the *touch current* (measured in accordance with 5.2.3.5) shall not exceed 3,5 mA a.c. or 10 mA d.c.

For all other *PDS*/*CDM*/*BDM*, one or more of the following measures shall be applied, unless the *touch current* (measured in accordance with 5.2.3.5) can be shown to be less than 3,5 mA a.c. or 10 mA d.c.

a) A fixed connection and:

   - a cross-section of the *protective earthing conductor* of at least 10 mm^2 Cu or 16 mm^2 Al,

     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*,

or

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

For marking requirements, see 6.3.6.7.

4.3.5.6 Special features in equipment for *protective class II*

If equipment is designed to use *double* or *reinforced insulation* between *live parts* and accessible surfaces in accordance with 4.3.3.2, then the design is considered to meet *protective class II*, if the following also apply.

- Equipment designed to *protective class II* shall not have means of connection for the *protective earthing conductor*. However this does not apply if a *protective earthing conductor* is passed through the equipment to equipment series-connected beyond it. In the latter event, the *protective earthing conductor* and its means for connection shall be insulated with *basic insulation* from the accessible surface of the equipment and from circuits which employ *protective separation*, extra-low voltage, *protective impedance* and limited discharging energy, according to 4.3.4. 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 of *protective class II* shall be marked according to 6.3.6.6.

4.3.6 Insulation

4.3.6.1 General

4.3.6.1.1 Influencing factors

This subclause gives minimum requirements for insulation, based on the principles of IEC 60664 and IEC 60071.

Manufacturing tolerances shall be taken into account during design and installation of the *PDS*.

For *integrated PDS* the motor insulation system shall meet the requirements of the relevant part of IEC 60034. The *CDM*/*BDM* shall comply with the requirements of 4.3.6.

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;

Verification of insulation shall be made according to 5.2.2.1, 5.2.3.1, 5.2.3.2, and 5.2.3.3.

4.3.6.1.2 Pollution degree

Insulation, especially when provided by clearances and creepage distances, is affected by pollution which occurs during the *expected lifetime* of the *PDS*. The micro-environmental conditions for insulation shall be applied according to Table 6.

Table 6 – Definitions of pollution degrees

Pollution degree	Description
1	No pollution or only dry, non-conductive pollution occurs. The pollution has no influence.
2	Normally, only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation is to be expected, when the *PD*S is out of operation.
3	Conductive pollution or dry non-conductive pollution occurs, which becomes conductive due to condensation, which is to be expected.
4	The pollution generates persistent conductivity caused, for example by conductive dust or rain or snow.

In accordance with IEC 61800-1, IEC 61800-2 and IEC 61800-4, a standard *PDS* shall be designed for pollution degree 2. For safety, pollution degree 3 shall be assumed in determining the insulation. Thereby the *PDS* is usable for pollution degree 1, 2 and 3 environments.

The insulation may be determined according to pollution degree 2 if one of the following applies:

a) instructions are provided with the *PDS* indicating that it shall be installed in a pollution degree 2 environment,

   or

b) the specific installation application of the *PDS* is known to be a pollution degree 2 environment,

   or

c) the *PDS* enclosure or coatings applied within the *PDS* according to 4.3.6.8.4.2 or 4.3.6.8.6 provide adequate protection against what is expected in pollution degree 3 and 4 (conductive pollution and condensation).

If operation in pollution degree 4 is required, protection shall be provided by means of a suitable enclosure.

4.3.6.1.3 Overvoltage category

The concept of overvoltage categories (based on IEC 60364-4-44 and IEC 60664-1) is used for equipment energized from the supply 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;

- category III applies to equipment permanently connected in fixed *installations* (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 fixed *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.

Annex B shows examples of overvoltage category considerations for insulation requirements.

NOTE For *PDS* not intended to be powered from the supply mains, the appropriate overvoltage category should be determined as required by the application.

4.3.6.1.4 Supply earthing systems

IEC 60364-1describes the three following basic types of earthing system.

- 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.

4.3.6.1.5 Insulation voltages

Table 7 and Table 8 use the *system voltage* of the circuit under consideration and overvoltage category to define the impulse voltage. The *system voltage* is also used to define the *temporary overvoltage*.

Table 7 – Insulation voltage for low voltage circuits

Column 1	2	3	4	5	6
System voltage (4.3.6.2.1) (V)	Impulse voltage (V) Overvoltage category				*Temporary overvoltage* (crest value / r.m.s.) [a] (V)
	I	II	III	IV	
≤ 50	330	500	800	1 500	1 770 / 1 250
100	500	800	1 500	2 500	1 840 / 1 300
150	800	1 500	2 500	4 000	1 910 / 1 350
300	1 500	2 500	4 000	6 000	2 120 / 1 500
600	2 500	4 000	6 000	8 000	2 550 / 1 800
1 000	4 000	6 000	8 000	12 000	3 110 / 2 200

NOTE 1 Interpolation is not permitted.

NOTE 2 The last row only applies to single-phase systems, or to the phase-to-phase voltage in three-phase systems.

[a] These values are derived using the formula (1 200 V + *system voltage*) from IEC 60664-1.

Table 8 – Insulation voltage for high voltage circuits

Column 1	2	3	4	5	6
System voltage (4.3.6.2.1) (V)	Impulse voltage (V) Overvoltage Category				*Temporary overvoltage* (crest value / r.m.s.) (V)
	I	II	III	IV	
> 1 000	4 000	6 000	8 000	12 000	4 250 / 3 000
3 600	9 000 [a]	16 000 [a]	20 000 [b]	40 000 [b]	14 150 / 10 000 [b]
7 200	17 500 [a]	29 000 [a]	40 000 [b]	60 000 [b]	28 300 / 20 000 [b]
12 000	29 000 [a]	42 500 [a]	60 000 [b]	75 000 [b]	39 600 / 28 000 [b]
17 500	40 000 [a]	55 000 [a]	75 000 [b]	95 000 [b]	53 750 / 38 000 [b]
24 000	52 000 [a]	75 000 [a]	95 000 [b]	125 000 [b]	70 700 / 50 000 [b]
36 000	75 000 [a]	95 000 [a]	125 000 [b]	145 000 [b]	99 000 / 70 000 [b]

NOTE 1 Interpolation is permitted.

[a] These values have been derived or extrapolated from Tables 4 and 5 of IEC 62103: 2003.

[b] These values have been derived or extrapolated from Table 2 of IEC 60071-1:2006.

[c] This value has been taken from IEC 60146-1-1, Ed.4 (in preparation).

4.3.6.2 Insulation to the surroundings

4.3.6.2.1 General

Insulation for *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.

NOTE 1 For creepage distances, the r.m.s. value of the *working voltage* is used. For clearance distances and solid insulation, the recurring peak value of the *working voltage* is used, as described in 4.3.6.2.2 to 4.3.6.2.4.

NOTE 2 Examples of *working voltage* with the combination of a.c., d.c. and recurring peaks are on the d.c. link of an indirect voltage source converter, or the damped oscillation of a thyristor snubber, or internal voltages of a switch-mode power supply.

The impulse voltage and *temporary overvoltage* depend on the *system voltage* of the circuit, and the impulse voltage also depends on the overvoltage category, as shown in Table 7 (for *low-voltage PDS*) and Table 8 (for *high-voltage PDS*).

The *system voltage* in column 1 of these tables is:

- For Table 7
  - in TN and TT systems: the r.m.s. value of the rated voltage between a phase and earth;

    NOTE 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 For most systems, this is equivalent to dividing the phase-to-phase voltage by $\sqrt{3}$.
    - 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 phases.
- For Table 8: the r.m.s. value of the rated voltage between phases.

NOTE 3 For both tables, when 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.

NOTE 4 Voltages generated within the *PDS* by the secondaries of transformers providing galvanic isolation from the supply mains are also considered to be *system voltages* for the determination of impulse voltages.

NOTE 5 For *PDS* having series-connected diode bridges (12-pulse, 18-pulse, etc.), the *system voltage* is the sum of the a.c. voltages at the diode bridges.

4.3.6.2.2 Circuits connected directly to the supply mains

Insulation between the surroundings and circuits which are connected directly to the supply mains shall be designed according to the impulse voltage, *temporary overvoltage*, or *working voltage*, whichever gives the most severe requirement.

This insulation is normally evaluated to withstand impulses of overvoltage category III, except that overvoltage category IV shall be used when the *PDS* is connected at the origin of the *installation*. Overvoltage category II may be used for plug-in equipment connected to a supply for non-industrial purposes without special requirements with regard to reliability.

If measures are provided which reduce impulses of overvoltage category IV to values of category III, or values of category III to values of category II, *basic* or *supplementary insulation* may be designed for the reduced values. If the devices used for this purpose 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. 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.

NOTE Circuits which are connected to the supply mains via *protective impedances*, according to 4.3.4.3, or via means of voltage limitation, according to 4.3.4.4, are not regarded as connected directly to the supply mains.

4.3.6.2.3 Circuits not connected directly to the supply mains

Insulation between the surroundings and circuits supplied by a transformer providing galvanic isolation from the supply mains shall be designed according to: a) the impulse voltage determined using the transformer secondary voltage as the *system voltage*; or b) the *working voltage*, whichever gives the more severe requirement.

This insulation is normally evaluated to withstand impulses of overvoltage category II, except that overvoltage category III shall be used when the *PDS* is connected at the origin of the *installation*.

If measures are provided which reduce impulses of overvoltage category III to values of category II, or, for *low-voltage PDS* only, values of category II to values of category I, *basic* or *supplementary insulation* may be designed for the reduced value. If the devices used for this purpose 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. 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.

Insulation between the surroundings and circuits of *DVC* A or B, supplied by a transformer at a frequency other than that of the supply mains, or supplied by other means providing galvanic isolation from the supply mains, shall be evaluated according to the *working voltage* (recurring peak) of the circuit.

4.3.6.2.4 Insulation between circuits

Insulation between two circuits shall be designed according to the circuit having the more severe requirement.

4.3.6.3 *Functional insulation*

For parts or circuits that are not significantly affected by external transients, *functional insulation* shall be designed according to the *working voltage* across the insulation.

For parts or circuits that are significantly affected by external transients, *functional insulation* shall be designed according to the impulse voltage of overvoltage category II, except that overvoltage category III shall be used when the *PDS* is connected at the origin of the *installation*.

Where measures are provided which reduce transient overvoltages within the circuit from category III to values of category II, or values of category II to values of category I, *functional insulation* may be designed for the reduced values.

Where the circuit characteristics can be shown by testing (see 5.2.3.1) to reduce impulse voltages, *functional insulation* may be designed for the highest impulse voltage occurring in the circuit during the tests.

4.3.6.4 Clearance distances

4.3.6.4.1 Determination

Table 9 defines the minimum clearance distances required to provide *functional*, *basic*, or *supplementary insulation* (see Annex C for examples of clearance distances).

Clearances for use in altitudes between 2 000 m and 20 000 m shall be calculated with a correction factor according to Table A.2 of IEC 60664-1, which is reproduced as Clearances in air are a function of the atmospheric pressure according to Paschen's Law. Clearance distances provided in Table 9 are valid up to 2000 m above sea level. Clearances above 2000 m must be multiplied by the factor provided in Table D.1.

Table D.1.

To determine clearances for *reinforced insulation* from Table 9:

- for *low-voltage PDS*, the value corresponding to the next higher impulse voltage, or 1,6 times the *temporary overvoltage*, or twice the *working voltage* shall be used;
- for *high-voltage PDS*, the value corresponding to 1,6 times the impulse voltage, *temporary overvoltage* or *working voltage* shall be used.

Clearances for *reinforced insulation* between circuits connected directly to the supply mains and other circuits shall not be reduced when measures to reduce transient overvoltages are provided.

The compliance of clearances shall be verified by visual inspection (see 5.2.2.1) and if necessary by performing the impulse voltage test of 5.2.3.1 and the a.c. or d.c voltage test of 5.2.3.2.

Figure E.1 and Table E.1 provide informative guidance for determination of clearances for frequencies above 30 kHz.

Table 9 – Clearance distances

Column 1	2	3	4	5	6
Impulse voltage (Table 7, Table 8, 4.3.6.3)	*Temporary overvoltage* (crest value) for determining insulation between surroundings and circuits or *Working voltage* (recurring peak) for determining *functional insulation*	*Working voltage* (recurring peak) for determining insulation between surroundings and circuits	Minimum clearance mm		
			Pollution degree		
(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		
20 000	12 000	7 600	25		
40 000	26 000	16 000	60		
60 000	37 000	23 000	90		
75 000	48 000	30 000	120		
95 000	61 000	38 000	160		
125 000	80 000	50 000	220		
145 000	99 000	60 000	270		

NOTE 1 Interpolation is permitted.

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

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

4.3.6.4.2 Electric field homogeneity

The dimensions in Table 9 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 supply mains or 4 000 V within a circuit, the clearance for *basic* or *supplementary insulation* may be reduced to not less than that required by Table 2 Case B of IEC 60664-1. In this case, however, the impulse voltage test of 5.2.3.1 shall be performed on the clearance.

Clearances for *reinforced insulation* shall not be reduced for homogeneous fields.

4.3.6.4.3 Clearance to conductive enclosures

The clearance between any non-insulated *live part* and the walls of a metal enclosure shall be in accordance with 4.3.6.4.1 following the deformation tests of 5.2.2.5.

If the design clearance is at least 12,7 mm and the clearance required by 4.3.6.4.1 does not exceed 8 mm, the deformation tests may be omitted.

4.3.6.5 Creepage distances

4.3.6.5.1 General

Creepage distances shall be large enough to prevent long-term degradation of the surface of solid insulators, according to Table 10.

For *functional*, *basic* and *supplementary insulation*, the values in Table 10 apply directly. For *reinforced insulation*, the distances in Table 10 shall be doubled.

When the creepage distance determined from Table 10 is less than the clearance required by 4.3.6.4.1 or the clearance determined by impulse testing (see 5.2.3.1), then it shall be increased to that clearance.

Creepage distances shall be verified by measurement or inspection (see 5.2.2.1) (see Annex C for examples of creepage distances).

Figure E.2 and Table E.2 provide informative guidance for determination of creepage distances for frequencies above 30 kHz.

4.3.6.5.2 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 ≥ 600;
- Insulating material group II 600 > CTI ≥ 400;
- Insulating material group IIIa 400 > CTI ≥ 175;
- Insulating material group IIIb 175 > CTI ≥ 100.

Creepage distances on printed wiring boards (PWBs) exposed to pollution degree 3 environmental conditions shall be determined based on Table 10 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 using insulating material of group II and the creepage distance of insulating material of group II may be applied 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 Table C.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 9

Table 10 – Creepage distances (mm)

Column 1	2	3	4	5	6	7	8	9	10	11	12
Working voltage (r.m.s.)	PWBs [a]		Other insulators								
	Pollution degree		Pollution degree								
	1	2	1	2				3			
				Insulating material group				Insulating material group			
(V)	[b]	[c]	[b]	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	[e]
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	[f]	[f]	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	
12 500			50	63	90	125		[d]	[d]	[d]	
16 000			63	80	110	150					
20 000			80	100	140	200					
25 000			100	125	180	250					
32 000			125	160	220	320					

NOTE Interpolation is permitted.

[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] Values for creepage distances are not determined for this range.

[e] Insulating materials of group IIIb are not normally recommended for pollution degree 3 above 630V.

[f] above 1 250 V use the values from columns 4 to 11, as appropriate.

4.3.6.6 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 4.3.6.8.4.2 and 4.3.6.8.6).

4.3.6.7 PWB spacings for *functional insulation*

Spacings for *functional insulation* on a PWB which do not comply with 4.3.6.4 and 4.3.6.5 are permitted when all the following are satisfied:

- the PWB has a flammability rating of V-0 (see IEC 60695-11-10);
- the PWB base material has a minimum CTI of 100;
- the equipment complies with the PWB short-circuit test (see 5.2.2.2).

On 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.

4.3.6.8 Solid insulation

4.3.6.8.1 General

Materials selected for solid insulation shall be able to withstand the stresses occurring. 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 *PDS*.

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 product standard which provides 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.

4.3.6.8.2 Requirements for electrical withstand capability

4.3.6.8.2.1 Basic or supplementary insulation:

- Test with impulse withstand voltage according to 5.2.3.1, column 2 or column 4 of Table 19, or Table 20, column 2 or 4, as appropriate;

  and

- Test with a.c. or d.c. voltage according to 5.2.3.2, column 2 ofTable 21, Table 22, orTable 23, as appropriate.

4.3.6.8.2.2 *Double* and *reinforced insulation*:

- Test with impulse withstand voltage according to 5.2.3.1 Table 19, column 3 or column 5, or Table 20, column 3 or 5 as appropriate;

  and

- test with a.c. or d.c. voltage according to 5.2.3.2, column 3 of Table 21, Table 22, orTable 23, as appropriate;

  and

- partial discharge test according to 5.2.3.3, if the recurring peak working voltage across the insulation is greater than 750 V and the voltage stress on the insulation is greater than 1 kV/mm.

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

  The partial discharge test shall be performed as a *type test* on all components, subassemblies and PWB. In addition, a *sample test* shall be performed if the insulation consists of a single layer of material.

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.

4.3.6.8.2.3 Functional insulation

Functional insulation shall comply with the requirements of 4.3.6.3. Testing is not required, except where the circuit analysis required by 4.2 shows that failure of the insulation could result in a hazard. In these cases, the insulation shall meet the requirements and tests for *basic insulation*.

4.3.6.8.3 Thin sheet or tape material

4.3.6.8.3.1 General

Subclause 4.3.6.8.3 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 0,75 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 1 One layer of insulation tape wound with more than 50 % overlap is considered to constitute two layers.

NOTE 2 *Basic*, *supplementary* and *double insulation* may be applied as a pre-assembled system of thin materials.

4.3.6.8.3.2 Material thickness not less than 0,2 mm

- *Basic* or *supplementary insulation* shall consist of at least one layer of material, which will meet the requirements of 4.3.6.8.1 and 4.3.6.8.2.1.
- *Double insulation* shall consist of at least two layers of material, each of which will meet the requirements of 4.3.6.8.1, 4.3.6.8.2.1, and the partial discharge requirements of 4.3.6.8.2.2, and both layers together will meet the impulse and a.c. or d.c. voltage requirements of 4.3.6.8.2.2.
- *Reinforced insulation* shall consist of a single layer of material, which will meet the requirements of 4.3.6.8.1 and 4.3.6.8.2.2.

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.

4.3.6.8.3.3 Material thickness less than 0,2 mm

- *Basic* or *supplementary insulation* shall consist of at least one layer of material, which will meet the requirements of 4.3.6.8.1 and 4.3.6.8.2.1.
- *Double insulation* shall consist of at least three layers of material. Each layer shall meet the requirements of 4.3.6.8.1 and 4.3.6.8.2.1, and any two layers together shall meet the requirements of 4.3.6.8.2.2.

- *Reinforced insulation* consisting of a single layer of material is not permitted.

4.3.6.8.3.4 Compliance

Compliance is checked by the tests described in 5.2.3.1 to 5.2.3.3.

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.

4.3.6.8.4 Printed wiring boards (PWBs)

4.3.6.8.4.1 General

Insulation between conductor layers in double-sided single-layer PWBs, multi-layer PWBs and metal core PWBs, shall meet the requirements of 4.3.6.8.1. *Basic*, *supplementary*, *double* and *reinforced insulation* shall meet the appropriate requirements of 4.3.6.8.2.1 or 4.3.6.8.2.2. *Functional insulation* in PWBs shall meet the requirements of 4.3.6.8.2.3.

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 Example C.14 of Annex C);

  or

- solid insulation, in which case it shall meet the requirements of 4.3.6.8.1 and 4.3.6.8.2.

4.3.6.8.4.2 Use of coating materials

A coating material used 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 of the parts under protection. The clearance and creepage distance of Table 9 and Table 10 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 4.3.6.8 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 9 and Table 10 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 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 *PDS*/*CDM*/*BDM*. A *type test* on representative PWBs shall be 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°C.

4.3.6.8.5 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 4.3.6.8.1 and 4.3.6.8.2.

The component itself shall pass the requirements given in 4.3.6.8.1 and 4.3.6.8.2. If the component has *reinforced* or *double insulation*, the voltage test of 5.2.3.2 shall be performed as a *routine test*.

4.3.6.8.6 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 4.3.6.8.1 and 4.3.6.8.2. If used to protect against pollution, the requirements for Type 1 protection in 4.3.6.8.4.2 apply.

4.3.6.9 Insulation requirements above 30 kHz

Where voltages across insulation have fundamental frequencies greater than 30 kHz, further considerations apply. For low-voltage circuits, guidance is provided in IEC 60664-4.

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

4.3.7 Enclosures

4.3.7.1 General

Metal enclosures shall comply with the deflection test of 5.2.2.5.2 or have a thickness as specified in 4.3.7.2 or 4.3.7.3.

Polymeric enclosures or polymeric parts, relied on to complete and maintain the integrity of an electrical enclosure, shall comply with the flammability requirements of 4.4.3 and the impact test in 5.2.2.5.3.

For *integrated PDS* the *CDM*/*BDM* enclosure shall comply with the above requirements. The motor enclosure shall meet the requirements of the relevant parts of IEC 60034.

Enclosures shall be suitable for use in their intended environments. The manufacturer shall specify the intended environment (see 6.3.3) and the IP rating of the enclosure (see 5.2.2.4 for test).

For *integrated PDS* the combination of motor and *CDM*/*BDM* shall be tested according to their intended environment. For external fans and drain holes of the motor part the requirements of IEC 60034-5 apply.

4.3.7.2 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 cm^2 or having any dimension larger than 150 mm;
- not less than 1,2 mm thick for an area of 155 cm^2 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, except at threaded holes for conduit, where a minimum of 6,4 mm is required, shall be:

- at least 2,4 mm thick for an area greater than 155 cm^2 or having any dimension more than 150 mm;

- at least 1,5 mm thick for an area of 155 cm^2 or less having no dimension more than 150 mm.

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.

4.3.7.3 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 11 or Table 12.

With reference to Table 11 and Table 12, 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 which 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 – formed 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 11 – 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) [c]	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 4.3.7.3

[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.

Table 12 – Thickness of sheet metal for enclosures: aluminium, copper or brass

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]	
75 90	Not limited 100	180 220	Not limited 240	0,6 [d]
100 125	Not limited 150	250 270	Not limited 340	0,75
150 165	Not limited 200	360 380	Not limited 460	0,9
200 240	Not limited 300	480 530	Not limited 640	1,2
300 350	Not limited 400	710 760	Not limited 950	1,5
450 510	Not limited 640	1 100 1 150	Not limited 1 400	2,0
640 740	Not limited 1 000	1 500 1 600	Not limited 2 000	2,4
940 1 100	Not limited 1 350	2 200 2 400	Not limited 2 900	3,0
1 300 1 500	Not limited 1 900	3 100 3 300	Not limited 4 100	3,9

[a] See 4.3.7.3

[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 aluminium, copper or brass for an enclosure intended for outdoor use shall be not less than 0,74 mm thick.

4.3.8 Wiring and connections

4.3.8.1 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 shall be provided with insulation rated for the *DVC* requirements of the relevant circuits.

The compliance with 4.3.8.2 to 4.3.8.8 shall be checked by visual inspection (see 5.2.1) of the overall construction and datasheets if applicable.

NOTE Electrical reflections in a motor cable fed from a pulse width modulated (PWM) source can cause high voltages to appear on the cable, which should be taken into consideration for *PDS* component selection.

4.3.8.2 Routing

A hole through which insulated wires pass in a sheet metal 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 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 stationary 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.

4.3.8.3 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*.

NOTE The choice of green or green/yellow for the *protective bonding* is covered by national regulations.

4.3.8.4 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;
- 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 6.5.1).

4.3.8.5 Accessible connections

In addition to measures given in 4.3.4.1 to 4.3.4.3 it shall be ensured that neither insertion error nor polarity reversal of connectors can lead to a voltage on an accessible connection higher than the maximum of *DVC* A. 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. This does not apply to equipment intended to be installed in *closed electrical operating areas*.

If relevant, non-interchangeability and protection against polarity reversal of connectors, plugs and socket outlets shall be confirmed by inspection and trial insertion.

4.3.8.6 Interconnections between parts of the *PDS*

In addition to complying with the requirements given in 4.3.8.1 to 4.3.8.5, the means provided for the interconnection between parts of the *PDS* shall comply with the following requirements or those of 4.3.8.7.

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 male connector in a female connector other than the one intended to receive it, and other manipulations of parts which are accessible to the operator shall not result in mechanical damage or a risk of thermal hazards, electric shock, or injury to persons.

When external interconnecting cables terminate in a plug which mates with a receptacle on the external surface of an enclosure, no risk of electric shock shall exist at accessible contacts of either the plug or receptacle when disconnected.

NOTE An interlock circuit in the cable to de-energize the accessible contacts whenever an end of the cable is disconnected meets the intent of these requirements.

4.3.8.7 Supply connections

A *PDS* intended for permanent connection to the power supply shall have provision for connection to the applicable wiring system in accordance with the requirements where it is being installed. The connection points provided shall be of appropriate construction to preclude the possibility of loose strands reducing the spacing between conductors when careful attention is paid to installation.

4.3.8.8 Terminals

4.3.8.8.1 Construction requirements

All parts of terminals which maintain contact and carry current shall be of metal having adequate mechanical strength.

Terminal connections shall be such that the conductors can be connected by means of screws, springs or other equivalent means so as to ensure that the necessary contact pressure is maintained.

Terminals shall be so constructed that the conductors can be clamped between suitable surfaces without any significant damage either to conductors or terminals.

Terminals shall not allow the conductors to be displaced or be displaced themselves in a manner detrimental to the operation of equipment and the insulation shall not be reduced below the rated values.

The requirements of this subclause are met by using terminals complying with IEC 60947-7-1 or IEC 60947-7-2, as appropriate.

4.3.8.8.2 Connecting capacity

Terminals shall be provided which accommodate the conductors specified in the installation and maintenance manuals (see 6.3.6.4) and cables in accordance with the wiring rules applicable at the *installation*. The terminals shall meet the temperature rise test of 5.2.3.8. The terminals shall also be suitable for conductors of the same type at least two sizes smaller, as given in the appropriate column of Table F.1.

Standard values of cross-section of round copper conductors are shown in Annex F, which also gives the approximate relationship between ISO metric and AWG/MCM sizes.

4.3.8.8.3 Connection

Terminals for connection to external conductors shall be readily accessible during installation.

Clamping screws and nuts shall not serve to fix any other component although they may hold the terminals in place or prevent them from turning.

4.3.8.8.4 Wire bending space for wires 10 mm^2 and greater

For *low-voltage PDS*, the distance between a terminal for connection to the main supply, or between major parts of the *PDS* (for example, motor, transformer, *CDM/BDM*), and an obstruction toward which the wire is directed upon leaving the terminal shall be at least that specified in Table 13.

Table 13 – Wire bending space from terminals to enclosure

Size of wire mm^2	**Minimum bending space, terminal to enclosure** mm		
	Wires per terminal		
	1	**2**	**3**
10 – 16	40	–	–
25	50	–	–
35	65	–	–
50	125	125	180
70	150	150	190
95	180	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

For *high-voltage PDS*, the minimum wire bending space for conductors for interconnection between parts of the *PDS* or to the main supply shall be:

- eight times the overall diameter for non-shielded conductors,

  or

- 12 times the overall diameter for shielded or lead-covered conductors.

4.3.9 Output short-circuit requirements

The *PDS* shall not present a thermal hazard, electric shock or energy hazard under short-circuit conditions at any output that is capable of providing power. In some cases, short-circuit protection may be provided by external measures, the characteristics of which shall be specified by the manufacturer.

For co-ordination with upstream protection devices, the manufacturer shall specify a maximum *prospective short-circuit current* rating corresponding to each power output of the *CDM/BDM*. If protection devices with particular characteristics are necessary, these shall also be specified.

NOTE The maximum *prospective short-circuit current* rating refers to the capability of the power source which supplies the *PDS*.

Short-circuit evaluation shall be performed according to 5.2.3.6 on all power outputs.

4.3.10 Residual current-operated protective (RCD) or monitoring (RCM) device compatibility

RCD and RCM are used to provide protection against insulation faults in some domestic and industrial *installations*, additional to that provided by the installed equipment.

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

Annex G gives guidelines to assist with the selection of the RCD or RCM type.

PDS shall satisfy one of the following conditions.

a) A plug-connected single-phase *PDS* with rated input current less than or equal to 16 A, not using an industrial connector according to IEC 60309, shall be designed so that, under normal and fault conditions, it does not reduce the ability of RCD and RCM of type A to provide protection for other equipment in the *installation*.
b) For plug-connected *PDS* other than a) with an industrial connector according to IEC 60309, and *PDS* having a fixed connection, if a d.c. current can be present in the *protective earthing conductor*, a caution notice and the symbol ISO 7000-0434 (2004-01) shall be provided in the user manual, and the symbol shall be placed on the *PDS* (see 6.3.6.7 and Annex H.

   See 6.3.6.7 for information and marking requirements.

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

4.3.11 Capacitor discharge

Capacitors within a *PDS* shall be discharged to a voltage less than 60 V, or to a residual charge less than 50 μC, within 5 s after the removal of power from the *PDS*. If this requirement is not achievable for functional or other reasons, the information and marking requirements of 6.5.2 apply. See 5.2.3.7 for test.

NOTE This requirement also applies to capacitors used for power factor correction, filtering, etc.

In the case of plugs 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 shall not exceed 1 s. Otherwise such conductors shall be protected against direct contact to at least IPXXB. If neither a discharge time of 1 s nor a protection of at least IPXXB can be achieved, additional disconnecting devices or an appropriate warning device shall be applied.

4.3.12 Access conditions for *high-voltage PDS*

The high voltage sections (transformer, converter, motor, etc.) shall be protected by an appropriate housing enclosure according to IEC 60204-11 with respect to personnel safety.

a) Operating conditions

   Interlocking doors shall prevent any access inside the enclosure of the high voltage converter section when main circuit breaker(s) providing the high voltage to the circuit are on, and if *live parts* have not been earthed (see 0).

b) Access for maintenance – earthing instructions

   The earthing operation is performed after the normal discharge time stated by the converter manufacturer. Care shall be taken to ensure that this operation is safe even in case of failure of the discharge circuit. Care shall also be taken that on the input and output side the stray capacitance of cables, motor and/or transformer shall be discharged before possible access to *live parts*. The requirements of 4.3.11 apply.

   Earthing devices (earthing switches and/or earthing cables) shall be provided in sufficient quantity to facilitate work being carried out in safety on the *live parts* of the HV equipment of the *PDS*. The earthing devices shall comply with the relevant requirements of IEC 62271-102 or IEC 61230. The earthing contacts, or an indication that the contacts of the switches are closed, shall be visible by the maintenance personnel before they access the equipment.

   NOTE In particular cases, (for example, load-commutated inverters), two earthing devices (one line side, one load side) can be required.

For parts which are not directly earthed by an earthing switch the component manufacturers shall provide safe instructions to perform earthing (see 6.3.6.6).

4.4 Protection against thermal hazards

4.4.1 Minimizing the risk of ignition

The risk of ignition due to high temperature shall be minimized by the appropriate selection and use of components and by suitable construction.

Electrical components shall be used in such a way that their maximum working temperature under normal load conditions is less than that necessary to cause ignition of the surrounding materials with which they are likely to come into contact. The limits in Table 15 shall not be exceeded for the surrounding material.

Where it is not practical to protect components against overheating under fault conditions, all materials in contact with such components shall be of flammability class V-1, according to IEC 60695-11-10, or better.

Compliance with 4.4.2 to 4.4.5 shall be confirmed by inspection of component and material data sheets and, where necessary, by test.

4.4.2 Insulating materials

4.4.2.1 General

A material which is used for the direct support of an uninsulated *live part* shall comply with the following requirements.

NOTE A material is typically considered to be in direct support of an uninsulated *live part* when:

a) it is in direct physical contact with the uninsulated *live part*, and

b) it physically supports or maintains the relative position of the uninsulated *live part*.

The insulating material shall be suitable for the maximum temperature it attains as determined by the temperature rise test of 5.2.3.8. Consideration shall be given as to whether or not the insulating material additionally provides mechanical strength and whether or not the part can be subject to impact during use.

4.4.2.2 Material requirements

The insulating material shall have a CTI of 100 or greater.

No further evaluation is required when generic materials are used according to Table 14.

Table 14 – Generic materials for the direct support of uninsulated *live parts*

Generic material	Minimum thickness (mm)	Maximum temperature (° C)
Any cold-moulded composition	No limit	No limit
Ceramic, porcelain	No limit	No limit
Diallyl phthalate	0,7	105
Epoxy	0,7	105
Melamine	0,7	130
Melamine-phenolic	0,7	130
Phenolic	0,7	150
Unfilled nylon	0,7	105
Unfilled polycarbonate	0,7	105
Urea formaldehyde	0,7	100

In other cases, the insulating material shall comply with the glow-wire test described in 5.2.5.2 at a test temperature of 850 °C. The alternative hot wire ignition test of 5.2.5.3 may be used.

Where an insulating material is used in a device that incorporates switching contacts, and is within 12,7 mm of the contacts, it shall comply with the high current arcing ignition test of 5.2.5.1.

The manufacturer may provide data from the insulating material supplier to demonstrate compliance with the above requirements. In this case, no further testing is required.

4.4.3 Flammability of enclosure materials

Materials used for enclosures of *PDS* shall meet the test requirements of 5.2.5.4.

Metals, ceramic materials, and glass which is heat-resistant tempered, wired or laminated, are considered to comply without test.

Materials are considered to comply without test if, in the minimum thickness used, the material is of flammability class 5VA, according to IEC 60695-11-20.

Components which fill an opening in an enclosure, and which are intended to be mounted in this way, need not be evaluated for compliance with the flammability requirements of 5.2.5.4, provided that the components comply with the flammability aspects of the relevant IEC component standard.

NOTE Examples of these components are fuse-holders, switches, pilot lights, connectors and appliance inlets.

Compliance is checked by visual inspection and, where necessary, by test.

The manufacturer may provide data from the insulating material supplier to demonstrate compliance with the above requirements. In this case, no further testing is required.

4.4.4 Temperature limits

4.4.4.1 Internal parts

Equipment and its component parts shall not attain temperatures in excess of those in Table 15 when tested in accordance with the ratings of the equipment.

Table 15 – Maximum measured temperatures for internal materials and components

Materials and components		Thermometer method (° C)	Resistance method (° C)
1	Rubber- or thermoplastic-insulated conductors [a]	75	
2	*User terminals* [b]	[c]	
3	Copper bus bars and connecting straps	[d]	
4	Insulation systems		
	Class A (105)	105	125
	Class E (120)	120	135
	Class B (130)	125	145
	Class F (155)	135	155
	Class H (180)	155	175
	Class N (220)	195	215
5	Phenolic composition [a]	165	
6	On bare resistor material	415	
7	Capacitor	[e]	
8	Power switching semiconductors	[f]	
9	PWBs	[g]	
10	Liquid cooling medium	[h]	

[a] The limitation on phenolic composition and on rubber and thermoplastic insulation does not apply to compounds which have been investigated and found to meet the requirements for a higher temperature.

[b] The temperature on a wiring terminal or lug is measured at the point most at risk of being contacted by the insulation of a conductor installed as in actual service.

[c] The maximum terminal temperature shall not exceed 15 °C more than the insulation temperature rating of the conductor or cable specified by the manufacturer (see 6.3.6.4).

[d] The maximum permitted temperature is determined by the temperature limit of support materials or insulation of connecting wires or other components. A maximum temperature of 140 ºC is recommended.

[e] For a capacitor, the maximum temperature specified by the manufacturer shall not be exceeded.

[f] The maximum temperature on the case shall be the maximum case temperature for the applied power dissipation specified by the semiconductor manufacturer.

[g] The maximum operating temperature of the PWB shall not be exceeded.

[h] The maximum temperature of the cooling medium, specified by the manufacturer of the medium or determined from the known characteristics of the medium, shall not be exceeded.

The resistance method for temperature measurement as specified in Table 15 consists of the calculation of the temperature rise of a winding using the equation:

$$\Delta t = \frac{r_2}{r_1}(k + t_1) - (k + t_2)$$

where:

- Δt is the temperature rise;
- r_2 is the resistance at the end of the test (Ω);
- r_1 is the resistance at the beginning of the test (Ω);.

- t_1 is the ambient temperature at the beginning of the test (° C);
- t_2 is the ambient temperature at the end of the test (° C);
- *k* is 234,5 for copper, 225,0 for electrical conductor grade (EC) aluminium; values of the constant for other conductors shall be determined.

4.4.4.2 External parts of *CDM*

The maximum temperature for accessible exterior parts of the *CDM* shall be in compliance with Table 16. It is permitted that parts have temperatures exceeding these values, but they shall then be marked with a warning statement as given in 6.4.3.4. Under no circumstances shall the temperature of accessible parts exceed 150 °C.

Table 16 – Maximum measured temperatures for external parts of the *CDM*

Part	Material	
	Metal (° C)	Thermoplastic or glass (° C)
User operated devices (knobs, handles, switches, displays, etc.).	55	65
Enclosure parts accessible to user by casual contact.	70	80
Enclosure parts where they contact building materials upon installation.	90	90

4.4.5 Specific requirements for liquid cooled *PDS*

NOTE Sealed heat-pipe cooling systems, used to transfer heat from a hot component to a heat sink, are not considered to be liquid cooling systems in this international standard. However, the possible failure of such components should be considered during the circuit analysis of 4.2.

4.4.5.1 Coolant

The specified coolant (see 6.2) shall be suitable for the anticipated ambient temperatures. Coolant temperature in operation shall not exceed the limit specified in Table 15.

4.4.5.2 Design requirements

4.4.5.2.1 Corrosion resistance

All cooling system components shall be suitable for use with the specified coolant. They shall be corrosion resistant and shall not corrode as a result of electrolytic action or prolonged exposure to the coolant and/or air.

4.4.5.2.2 Tubing, joints and seals

Cooling system tubing, joints and seals shall be designed to prevent leakage during excursions of pressure over the life of the equipment. The entire cooling system including tubing shall satisfy the requirements of the Hydrostatic pressure test of 5.2.7.

4.4.5.2.3 Provision for condensation

Where internal condensation occurs during normal operation or maintenance, measures shall be taken to prevent degradation of insulation. In those areas where such condensation is expected, clearance and creepage distances shall be evaluated at least for a pollution degree 3 environment (see Table 6), and provision shall be made to prevent accumulation of water (for example by providing a drain).

4.4.5.2.4 Leakage of coolant

Measures shall be taken to prevent leakage of coolant onto *live parts* as a result of normal operation, servicing, or loosening of hoses or other cooling system parts during the *expected lifetime*. If a pressure relief mechanism is provided, this shall be located so that there shall be no leakage of coolant onto live components when it is activated.

4.4.5.2.5 Loss of coolant

Loss of coolant from the cooling system shall not result in thermal hazards, explosion, or shock hazard. The requirements of the Loss of coolant test of 5.2.4.5.4 shall be satisfied.

4.4.5.2.6 Conductivity of coolant

When the coolant is intentionally in contact with *live parts* (for example non-earthed heatsinks), the conductivity of the coolant shall be continuously monitored and controlled, in order to avoid hazardous current flow through the coolant.

4.4.5.2.7 Insulation requirements for coolant hoses

When the coolant is intentionally in contact with *live parts* (for example non-earthed heatsinks), the coolant hoses form a part of the insulation system. Depending on the location of the hoses, the requirements of 4.3.6 for *functional* or *basic insulation* or *protective separation* shall be applied where relevant.

4.5 Protection against energy hazards

4.5.1 Electrical energy hazards

Failure of any component within the *PDS* shall not release sufficient energy to lead to a hazard, for example, expulsion of material into an area occupied by personnel.

Where appropriate, the possibility should be considered of energy transfer from the *PDS* motor to the *CDM*/*BDM* when the driven equipment over-runs the *CDM*/*BDM* control.

NOTE There are no tests in this part of IEC 61800 for this requirement.

4.5.2 Mechanical energy hazards

4.5.2.1 General

Mechanical failure due to critical speed considerations or torsional problems can create a hazard to operating personnel. These considerations are applicable to all *PDS*, although they are increasingly significant with increased equipment size, such as with *high-voltage PDS*. As these subjects are application-dependent, it is not possible to include specific requirements in this standard.

4.5.2.2 Critical torsional speed

Where appropriate, communication should be established between *PDS*/*CDM*/*BDM* supplier, driven equipment supplier, installer, and user with respect to any anticipated critical torsional speed considerations.

4.5.2.3 Transient torque analysis

Transient torque analysis is an important design tool for *PDS* to check torsional stresses in the whole mechanical string. For example, the following operating conditions are areas of concern.

- start-up;
- single-phase or three-phase short-circuit at the terminals of an a.c. motor;
- impact of possible commutation failure of an a.c. *CDM*;
- impact of the harmonic components of an a.c. *CDM*;
- field supply loss in a d.c. *CDM*;
- short-circuit at the armature terminals of a d.c. motor.

Where appropriate, communication should be established with the driven equipment supplier and the information required by 6.3.5.4 provided.

4.5.3 Acoustic noise emission

Under consideration. Requirements for acoustic noise emission are often present in local regulations. In the absence of such regulations, it is recommended that the limits of IEC 60034-9 should be applied.

4.6 Protection against environmental stresses

The *PDS/CDM/BDM* shall not present any hazards as a result of specified environmental stresses. As a minimum, the *PDS/CDM/BDM* shall satisfy the environmental endurance tests of 5.2.6. More demanding requirements may be specified by the manufacturer, in which case less demanding tests of this standard do not need to be performed.

5 Test requirements

5.1 General

5.1.1 Test objectives and classification

Testing, as defined in this Clause 5, is required to demonstrate that *PDS* is fully in accordance with the requirements of this part of IEC 61800. Testing may be waived if permitted by the relevant requirements subclause of Clause 4.

The subclauses in this Clause 5 describe the procedures to be adopted for the testing of *PDS*. The tests are classified as:

- *type tests*;
- *routine tests;*
- *sample tests*.

The manufacturer and/or test house shall ensure that the specified maximum and/or minimum environment (or test) values are imposed, taking tolerances and measurement uncertainties fully into account.

Warning ! These tests can result in hazardous situations. Suitable precautions shall be taken to avoid injury.

5.1.2 Selection of test samples

When testing a range or series of similar products, it may not be necessary to test all models in the range. Each test should be performed on a model or models having mechanical and electrical characteristics that adequately represent the entire range for that particular test.

5.1.3 Sequence of tests

In general, there is no requirement for tests to be performed in a set sequence, nor is it required that they are all performed on the same sample of equipment. However, the pass criteria for some of the tests require that they are followed by one or more further tests.

5.1.4 Earthing conditions

The manufacturer shall state the acceptable earthing systems (see 4.3.6.1.4) for the *PDS*. Test requirements shall be determined using the worst-case (most stressful) earthing system allowed by the manufacturer. Earthing systems may include:

- neutral to earth;
- line to earth;
- neutral to earth through high impedance;
- isolated (not earthed).

The unacceptable systems shall be indicated as

- forbidden;
- with modification of values and/or safety levels which shall be quantified through *type test.*

5.1.5 Compliance

Compliance with this part of IEC 61800 shall be verified by carrying out the appropriate tests specified in this Clause 5.

Compliance may only be claimed if all relevant tests have been passed.

Compliance with construction requirements and information to be provided by the manufacturer shall be verified by suitable examination, visual inspection, and/or measurement.

Whenever design or component changes have potential impact upon compliance, new *type testing* shall be performed to confirm compliance. It is desirable that the modified product should be identified, for example by using a suitable date code or serial number as described in 6.2.

5.1.6 Test overview

Table 17 provides an overview of the *type*, *routine* and *sample testing* of electronic components, devices and *PDS/CDM/BDM*.

Table 17 – Test overview

Test	*Type*	*Routine*	*Sample*	Requirement(s)	Specification
Visual inspection	X	X	X		5.2.1
Mechanical tests					5.2.2
Clearance and creepage distances	X			4.3.6.1, 4.3.6.4, 4.3.6.5	5.2.2.1
PWB short-circuit	X			4.3.6.7	5.2.2.2
Non-accessibility	X			4.3.3.3	5.2.2.3
Enclosure integrity	X			4.3.7.1	5.2.2.4
Deformation tests				4.3.6.4.3	5.2.2.5
Deflection	X			4.3.7.1	5.2.2.5.2
Impact	X			4.3.7.1	5.2.2.5.3
Electrical tests				4.3.4.1, 4.3.6.8.2	5.2.3
Impulse voltage	X		X	4.3.3.2, 4.3.4.3, 4.3.6.1, 4.3.6.8.2.1, 4.3.6.8.2.2, 4.3.6.8.3	5.2.3.1
a.c. or d.c. voltage	X	X		4.3.3.2, 4.3.4.3, 4.3.6.1, 4.3.6.8.2.1, 4.3.6.8.2.2, 4.3.6.8.4.2	5.2.3.2
Partial discharge	X		X	4.3.6.1, 4.3.6.8.2.2, 4.3.6.8.3	5.2.3.3
Protective impedance	X	X		4.3.4.3	5.2.3.4
Touch current measurement	X			4.3.5.5.2	5.2.3.5
Short-circuit test	X			4.3.9	5.2.3.6.3
Breakdown of components	X			4.2	5.2.3.6.4
Capacitor discharge	X			4.3.11	5.2.3.7
Temperature rise	X			4.3.8.8.2, 4.4.2.1	5.2.3.8
Protective bonding	X	X		4.3.5.3	5.2.3.9
Abnormal operation tests				4.2	5.2.4
Loss of phase	X			4.2	5.2.4.4
Inoperative blower	X			4.2	5.2.4.5.2
Clogged filter	X			4.2	5.2.4.5.3
Loss of coolant	X			4.4.5.2.5	5.2.4.5.4
Material tests					5.2.5
High current arcing ignition	X			4.4.2.2	5.2.5.1
Glow-wire	X			4.4.2.2	5.2.5.2
Hot wire ignition	X			4.4.2.2	5.2.5.3
Flammability	X			4.4.3	5.2.5.4

Table 17 – Test overview *(Continued)*

Test	*Type*	*Routine*	*Sample*	Requirement(s)	Specification
Environmental tests				4.6	5.2.6
Dry heat	X			4.6	5.2.6.3.1
Damp heat	X			4.6	5.2.6.3.2
Vibration test	X			4.6	5.2.6.4
Hydrostatic pressure	X	X		4.4.5.2.2	5.2.7

5.2 Test specifications

5.2.1 Visual inspections (*type test*, *sample test* and *routine test*)

Visual inspections shall be made:

- as *routine tests*, to check features such as adequacy of labelling, warnings and other safety aspects.
- as acceptance criteria of individual *type tests*, *sample tests* or *routine tests*, to verify that the requirements of this standard have been met;

Routine inspections may be part of the production or assembly process.

Before *type testing*, a check shall be made that the *PDS* delivered for the test is as expected with respect to supply voltage, input and output ranges, etc.

5.2.2 Mechanical tests

5.2.2.1 Clearances and creepage distances (*type test*)

It shall be verified by measurement or visual inspection that the clearance and creepage distances comply with Table 9 and Table 10. See Annex C for measurement examples. Where this verification is impossible to perform, an impulse voltage test (see 5.2.3.1) shall be performed between the considered circuits.

5.2.2.2 PWB short-circuit test (*type test*)

On PWBs, *functional insulation* provided by spacings which are less than those specified in Table 9 and Table 10 (see 4.3.6.7) shall be *type tested* as described below.

A sample of the equipment containing the PWB assembly shall be connected as intended to an electrical supply circuit sized and protected to simulate end-use conditions. In the case of a *PDS/CDM/BDM* supplied without an enclosure, a wire mesh cage which is 1,5 times the individual linear dimensions of the part under study may be used to simulate the intended enclosure.

Surgical cotton shall be placed at all openings, handles, flanges, joints and similar locations on the outside of the enclosure, and the wire mesh cage (if used), in a manner which will not significantly affect the cooling.

The decreased spacings shall be short-circuited one at a time, on representative samples, and the short-circuit shall be maintained until no further damage occurs.

As a result of the PWB short-circuit test, the *PDS*/*CDM/BDM* shall comply with the following:

- there shall be no emission of flame or molten metal;
- the surgical cotton indicator shall not have ignited;
- the earth connection shall not have opened;
- the door or cover shall not have blown open;
- during and after the test, accessible *SELV* and *PELV circuits* shall not exhibit voltages greater than the time dependent voltages of Figure 7;
- during and after the test, *live parts* at voltages greater than *decisive voltage class* A shall not become accessible.

The *PDS*/*CDM/BDM* is not required to be operational after testing and it is possible that the enclosure can become deformed. Overcurrent protection integral to the *PDS/CDM/BDM*, or required to be used with the *PDS/CDM/BDM*, is allowed to open.

5.2.2.3 Non-accessibility test (*type test*)

This test is intended to show that *live parts*, protected by means of enclosures and barriers in compliance with 4.3.3.3, are not accessible.

This test shall be performed as a *type test* of the enclosure of a *PDS* as specified in IEC 60529 for the enclosure classification for protection against access to hazardous parts. Exception:

- the test probe for IP3X shall not penetrate the top surface of the enclosure when probed from the vertical direction ± 5° only.

5.2.2.4 Enclosure integrity test (*type test*)

The claimed IP rating of the enclosure shall be verified. This test shall be performed as a *type test* of the enclosure of a *PDS* as specified in IEC 60529 for the enclosure classification.

5.2.2.5 Deformation tests

5.2.2.5.1 General

The Deflection and Impact tests apply to *PDS*, and to enclosed *CDM*/*BDM* where they are intended for operation without a further enclosure to which access is restricted to trained maintenance staff. After completion of the Deflection test (see 5.2.2.5.2) for metallic enclosures and the Impact test (see 5.2.2.5.3) for polymeric enclosures, the *PDS*/*CDM*/*BDM* shall pass the tests of 5.2.3.1 and 5.2.3.2 and shall be inspected to check that:

- *live parts* have not become accessible (see 4.3.3.3);
- 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;
- barriers have not been damaged or loosened;

- no moving parts which could cause a hazard are exposed.

The Deflection and Impact tests shall be performed at the worst case point on representative accessible face(s) of the enclosure.

The *PDS*/*CDM*/*BDM* 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.

5.2.2.5.2 Deflection test (*type test*)

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.

Damage to the finish, small dents and small chips which do not adversely affect the protection against electric shock or moisture, may be ignored.

5.2.2.5.3 Impact test (*type test*)

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.

5.2.3 Electrical tests

5.2.3.1 Impulse voltage test (*type test* and *sample test*)

The impulse voltage test is performed with a voltage having a 1,2/50 µs waveform (see Figure 6 of IEC 60060-1) and is intended to simulate overvoltages of atmospheric origin. It also covers overvoltages due to switching of equipment. See Table 18 for conditions of the impulse voltage test.

Tests on clearances smaller than required by Table 9 and on solid insulation are performed as *type tests* using appropriate voltages from Table 19 or Table 20.

Tests on components and devices for *protective separation* are performed as a *type test* and a *sample test* before they are assembled into the *PDS*, using the impulse withstand voltages listed in column 3 or column 5 of Table 19 or Table 20, as appropriate.

To ensure that limiting devices (see 4.3.6.2.2, 4.3.6.2.3, 4.3.6.3) are able to reduce the overvoltage, the values of column 2 or column 4 in Table 19 or Table 20, as appropriate, are applied to the *PDS* as a *type test*, and reduced values corresponding to the next lower voltage of the same column of that Table are verified.

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 9 in reverse.

Table 18 – Impulse voltage test

<table>
<tr><th>Subject</th><th colspan="2">Test conditions</th></tr>
<tr><td>Test reference</td><td colspan="2">Clause 19, 20.1.1 and Figure 6 of IEC 60060-1; 4.1.1.2.1 of IEC 60664-1</td></tr>
<tr><td>Requirement reference</td><td colspan="2">According to 4.3.3.2, 4.3.4.3 and 4.3.6</td></tr>
<tr><td>Preconditioning</td><td colspan="2">Live parts 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.</td></tr>
<tr><td>Initial measurement</td><td colspan="2">According to specification of PDS, component, or device</td></tr>
<tr><td>Test equipment</td><td colspan="2">Impulse generator 1,2/50 μs with an effective internal impedance not higher than: 2 Ω for testing clearances and limiting devices; and 500 Ω for testing solid insulation and components.</td></tr>
<tr><td>Measurement and verification</td><td>a)
Clearances smaller than required by Table 9
Clearances reduced by overvoltage limiting means or by circuit characteristics
Solid basic or supplementary insulation</td><td>b)
Solid reinforced insulation
Clearances, components and devices for protective separation</td></tr>
<tr><td></td><td colspan="2">Three pulses 1,2/50 μs of each polarity in ≥ 1 s interval, peak voltage (± 5 %) according to:</td></tr>
<tr><td>Test voltage</td><td>column 2 or column 4 of Table 19, column 2 or column 4 of Table 20, as appropriate</td><td>column 3 or column 5 of Table 19, column 3 or column 5 of Table 20, as appropriate</td></tr>
<tr><td></td><td colspan="2">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 5 (and 4.1.1.2.1.2) of IEC 60664-1, which is reproduced as Impulse tests performed below 2000 m altitude for the purpose of verifying air clearances must use test voltages which have been corrected for air pressure (altitude). Test voltages which have been corrected for three altitudes are provided in Table D.2. Altitude correction of test voltage is not required for impulse testing of solid insulation. The voltage values of Table D.2 apply for the verification of clearances only.

Table D.2 in this international standard.</td></tr>
</table>

The impulse voltage test is successfully passed if no puncture, flashover, or sparkover occurs. In the case of components and devices which use solid insulation for *protective separation*, a subsequent partial discharge test (see 5.2.3.3) shall also be passed.

Alternatively for *high-voltage PDS* the impulse test is successfully passed if

a) three consecutive impulses for each polarity have been applied and:

- no disruptive discharge occurs,

  or

- one discharge occurs in the self-restoring part of insulation, and then nine additional impulses have been applied with no disruptive discharge occurring;

or

b) 15 consecutive impulses for each polarity have been applied and:

- the number of disruptive discharges on self-restoring insulation does not exceed two for each series,

  and

- no disruptive discharge on non-self-restoring insulation occurs.

Table 19 – Impulse test voltage for *low-voltage PDS*

Column 1	2	3	4	5
System voltage **(see 4.3.6.2.1)**	**Impulse withstand voltage for insulation between circuits not connected directly to the supply mains and their surroundings according to overvoltage category II**		**Impulse withstand voltage for insulation between circuits connected directly to the supply mains and their surroundings according to overvoltage category III**	
	Basic* or *supplementary	***Reinforced***	***Basic* or *supplementary***	***Reinforced***
(V)	**(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 7.		NOTE Test voltages for overvoltage categories II and IV can be derived in a similar way from Table 7.	

Table 20 – Impulse test voltage for *high-voltage PDS*

Column 1	2	3	4	5
System voltage **(see 4.3.6.2.1)**	**Impulse withstand voltage for insulation between circuits and their surroundings according to overvoltage category III**		**Impulse withstand voltage for insulation between circuits and their surroundings according to overvoltage category IV**	
	Basic* or *supplementary	***Reinforced***	***Basic* or *supplementary***	***Reinforced***
(V)	**(V)**	**(V)**	**(V)**	**(V)**
>1 000	8 000	12 800	12 000	19 200
3 600	20 000	32 000	40 000	64 000
7 200	40 000	64 000	60 000	96 000
12 000	60 000	96 000	75 000	120 000
17 500	75 000	120 000	95 000	152 000
24 000	95 000	152 000	125 000	200 000
36 000	125 000	200 000	145 000	232 000
Interpolation is permitted NOTE Test voltages for overvoltage categories I and II can be derived in a similar way from Table 8.				

5.2.3.2 A.C. or d.c. voltage test (*type test* and *routine test*)

5.2.3.2.1 Purpose of test

The test is used to verify that the clearances and solid insulation of components and of assembled *PDS*/*CDM*/*BDM* has adequate dielectric strength to resist overvoltage conditions.

5.2.3.2.2 Value and type of test voltage

The values of the test voltage are determined from column 2 or 3 ofTable 21, Table 22, or Table 23, depending upon whether the circuit under test is connected to low voltage mains, high voltage mains, 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 by partial discharge.

The values of column 3 shall apply to *PDS* with protection against direct contact according to 4.3.3. The test is performed between circuits and accessible surfaces of *PDS*, 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.

Routine tests are performed to verify that clearances have not been reduced during the manufacturing operations. Protective devices designed to reduce impulse voltages on the circuits under test (see 4.3.6.2.2 and 4.3.6.2.3), 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.

Table 21 – A.C. or d.c. test voltage for circuits connected directly to low voltage mains

Column 1 ***System voltage*** **(see 4.3.6.2.1)**	**2** **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 4.3.5.6)**	
(V)	**a.c. r.m.s. [a]** **(V)**	**d.c.** **(V)**	**a.c. r.m.s.** **(V)**	**d.c.** **(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	2 550	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 22 – A.C. or d.c. test voltage for circuits connected directly to high voltage mains

Column 1 Line to line *System voltage* (see 4.3.6.2.1)	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 4.3.5.6)	
(V)	a.c. r.m.s. [a] (V)	d.c. (V)	a.c. r.m.s. (V)	d.c. (V)
>1 000	3 000	4 250	4 800	6 800
3 600	10 000	14 150	16 000	22 650
7 200	20 000	28 300	32 000	45 300
12 000	28 000	39 600	44 800	63 350
17 500	38 000	53 700	60 800	85 900
24 000	50 000	70 700	80 000	113 100
36 000	70 000	99 000	112 000	158 400

NOTE Interpolation is permitted.

[a] Values from Table 2 of IEC 60071-1

[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 23 – A.C. or d.c. test voltage for circuits not connected directly to the mains

Column 1 *Working voltage* (recurring peak) (see 4.3.6.2.1)	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 4.3.5.6)	
(V)	a.c. r.m.s. (V)	d.c. (V)	a.c. r.m.s. (V)	d.c. (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
2 300	2 600	3 700	4 200	5 900
3 000	3 400	4 800	5 400	7 700
4 600	5 200	7 400	8 300	11 800
7 600	8 500	12 000	14 000	19 000
16 000	18 000	26 000	29 000	42 000
23 000	26 000	37 000	42 000	59 000
30 000	34 000	48 000	54 000	77 000
38 000	43 000	61 000	69 000	98 000
50 000	57 000	80 000	91 000	130 000
60 000	70 000	99 000	109 000	154 000

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 9 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.

5.2.3.2.3 Performing the voltage test

The test shall be applied as follows, according to Figure 8.

a) Test (1) between accessible conductive part (connected to earth) and each circuit sequentially (except *DVC* A circuits). Test voltage according to, Table 22, or Table 23, 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 toTable 21, Table 22, or Table 23, 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 21, Table 22, or Table 23, 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 21, Table 22, or Table 23, 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. It is necessary to test *basic insulation* between *PELV* and *SELV circuits*, but it is not necessary to test *functional insulation* between *adjacent PELV* or *adjacent SELV circuits*.

Because *PELV / SELV circuits* and circuits of *DVC* C and D are typically separated from chassis (earth) by *basic insulation*, it is typically impossible to test *double* or *reinforced insulation* separating low-voltage circuits from high-voltage circuits in a fully-assembled *PDS* without overstressing the *basic insulation*. Because of this, it may be necessary to disassemble the *PDS*, or it may not be possible to perform *type tests* of protective insulation at voltages according to column 3 of Table 21 to Table 23. 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.

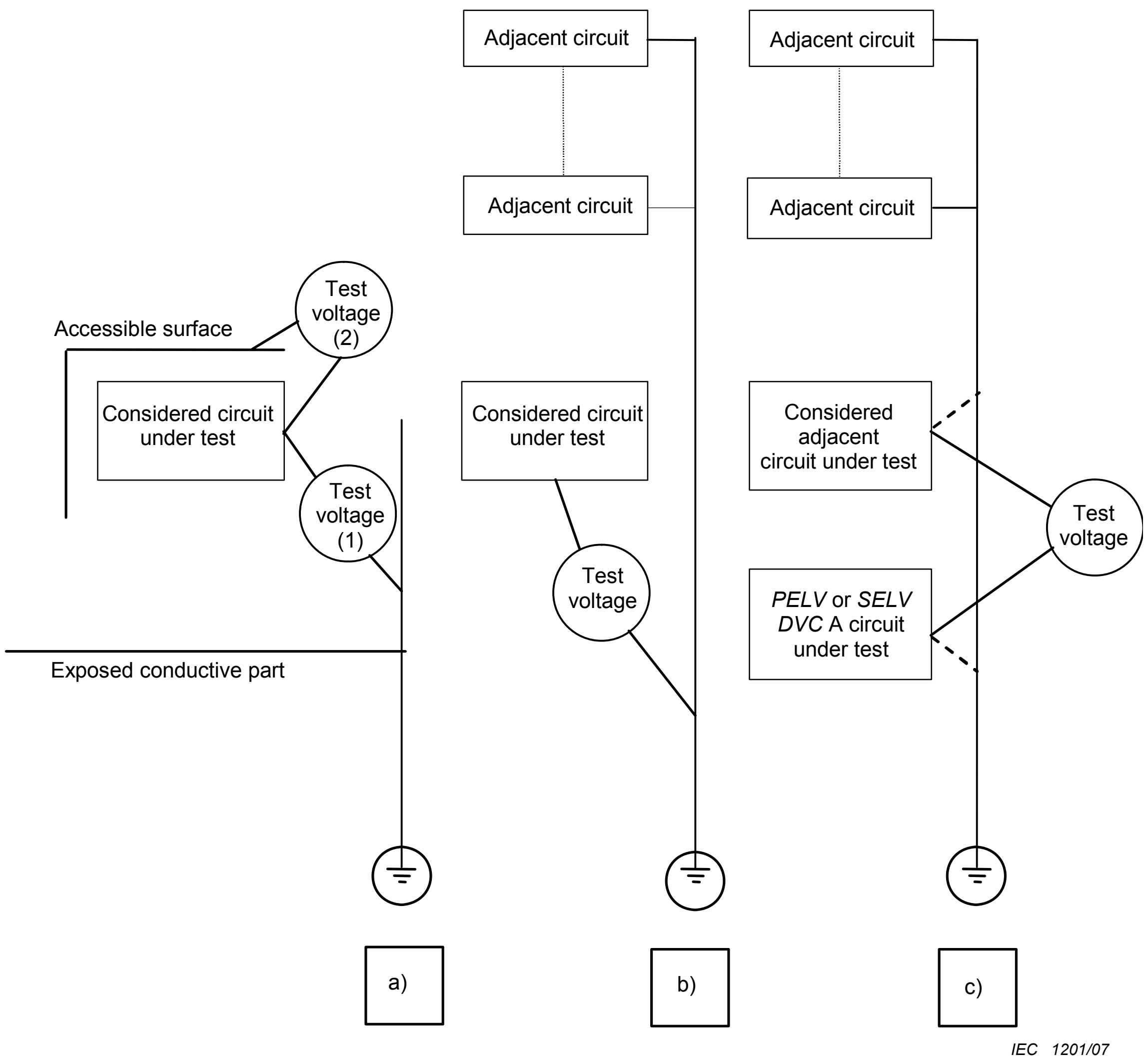


Figure 8 – Voltage test procedures

The tests shall be performed with the doors of the enclosure closed.

When the circuit is electrically connected to accessible conductive parts, the voltage test is not relevant, and may be omitted.

To create a continuous circuit for the voltage test on the *PDS*, 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.

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 5.2.3.2.2.

Where the *PDS* 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 *PDS* is not required if:

- *routine testing* of all subassemblies related to the insulation system of the *PDS* is performed;

  and

- it can be demonstrated that final assembly will not compromise the insulation system;

  and

- *type testing* of the fully-assembled *PDS* was performed successfully.

Protective impedances according to 4.3.4.3 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 4.3.2 shall remain connected to accessible conductive parts during the voltage test.

In the case of *high-voltage PDS*, the voltage shall be applied using a ramp of up to 5 s in duration. Also, for *high-voltage PDS*, if the test is required or requested to be repeated, the voltage shall be de-rated to 80 % of the original test voltage.

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

The duration of the test shall be at least 5 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 but the full voltage shall be maintained for 5 s and 1 s respectively for *type* and *routine tests*.

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

The test is successfully passed if no *electrical breakdown* occurs during the test.

5.2.3.3 Partial discharge test (*type test*, *sample test*)

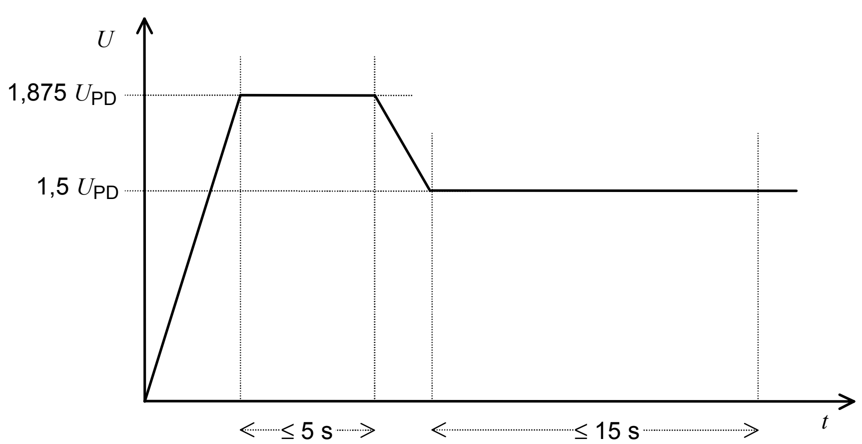
The partial discharge test (see Table 24) shall confirm that the solid insulation (see 4.3.6.8) used in components and subassemblies for *protective separation* of electrical circuits remains partial-discharge-free within the specified voltage range (see Table 24).

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 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*.

Table 24 – Partial discharge test

Subject	Test conditions
Test reference	4.1.2.4 of IEC 60664-1
Requirement reference	4.3.6.8
Preconditioning	Samples shall be pre-conditioned according to method b) of 4.1.2.1 of IEC 60664-1. *Live parts* belonging to the same circuit shall be connected together. It is recommended that the partial discharge test is performed after the impulse voltage test (see 5.2.3.1) in order that any damage caused by the impulse voltage test is apparent. 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.
Initial measurement	According to specification of component or device
Test equipment	Calibrated charge measuring device or radio interference meter without weighting filters
Test circuit	Clause C.1 of IEC 60664-1
Test voltage	The peak value of a.c. 50 Hz or 60 Hz
Test method	4.1.2.4 of IEC 60664-1: F_1 = 1,2; F_2, F_3 = 1,25. Test procedure 4.1.2.4.2 of IEC 60664-1
Calibration of test equipment	Clause C.4 of IEC 60664-1
Measurement	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 The voltage shall then be linearly decreased to 1,5 times U_{PD} (± 5 %) and held for a maximum time of 15 s, during which the partial discharge is measured
Verification	The test shall be considered to have been successfully passed if the partial discharge is less than 10 pC during the measurement period



IEC 263/03

[a] The rated discharge voltage is the sum of the recurring peak voltages in each of the circuits separated by the insulation.

5.2.3.4 Protective impedance (type test and routine test)

A *type test* shall be performed to verify that the current through a *protective impedance* under normal operating conditions does not exceed the values given in 4.3.4.3. The test shall be performed using the circuit of IEC 60990, Figure 4.

NOTE IEC 60990 states that the use of a single network for the measurement of a.c. combined with d.c. has not been investigated, but no suggestion is made for measurement in such cases.

The value of the *protective impedance* shall be verified as a *routine test*.

5.2.3.5 *Touch current* measurement (*type test*)

The touch current shall be measured to determine if the measures of protection need not be taken (see 4.3.5.5.2). The test may be used for a *BDM*, but in that case the *BDM* shall be connected to a motor. The motor may be unloaded, but the length and the type of the motor cable indicated by the manufacturer shall be used.

The *PDS* shall be set up in an insulated state without any connection to the earth and shall be operated at rated voltage. Under these conditions, the touch current shall be measured between the means of connection for the *protective earthing conductor* and the *protective earthing conductor* itself with the measuring network of Figure 4 of IEC 60990.

- For a *PDS* to be connected to an earthed neutral system, the neutral of the mains of the test site shall be directly connected to the *protective earthing conductor*.
- For a *PDS* to be connected to an isolated system or impedance system, the neutral shall be connected through a resistance of 1 kΩ to the *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 *PDS* to be connected to a corner earthed system, the *protective earthing conductor* shall be connected to each input phase in turn. The highest value will be taken as the definitive result.
- For a *PDS* with a particular earthing system, this system shall operate as intended during the test.
- If a *PDS* 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 *touch current* measurement.

This is performed as a *type test*.

5.2.3.6 Short-circuit test and Breakdown of components test (*type tests*)

5.2.3.6.1 General

Protection against risk of thermal, electric shock and energy hazards in case of short circuit or breakdown of a component for a *CDM/BDM* or for a *PDS* in combination with its *installation* shall be evaluated by:

a) tests defined in 5.2.3.6.3 and 5.2.3.6.4,

   or

b) calculation or simulation based on tests as defined in 5.2.3.6.3 and 5.2.3.6.4 on a representative model of *PDS*/*CDM*/*BDM*, where no damage other than opening of fuses or tripping of circuit breakers has occurred to the test sample, NOTE A representative model means a *PDS*/*CDM*/*BDM* with similar power elements (for example, power semiconductors, fuses, circuit breakers, capacitors, short circuit detection and output inductances) and circuit topologies as the *PDS*/*CDM*/*BDM* under consideration.

or

c) for *high-voltage PDS*:
calculation or simulation based on tests of elements that adequately represent those used in the *PDS*. The elements, tests and test conditions shall be selected so that there is sufficient confidence in the test results for them to be transferred (for example, by scaling from lower to higher power) to the *PDS*/*CDM*/*BDM* under consideration,

or

d) for custom *PDS*:
risk and hazard analysis of the intended application, and analysis of the construction characteristics. See 6.3.9 for commissioning information requirements.

NOTE Custom *PDS* rely on the construction characteristics of the installation to provide protection.

5.2.3.6.2 Test configuration

In the case of a *PDS*/*CDM/BDM* supplied without an enclosure, a wire mesh cage which is 1,5 times the individual linear dimensions of the *PDS*/*CDM/BDM* part under study shall be used to simulate the intended enclosure.

The *PDS*/*CDM/BDM*, and the wire mesh cage (if used), shall be earthed according to the requirements of 4.3.5.3.2.

Surgical cotton shall be placed at all openings, handles, flanges, joints, and similar locations on the outside of the enclosure or around the wire mesh cage (if used).

Where the *PDS* under test is specified in its installation manual to require external means of protection against faults, these specific means shall be provided for the test.

The voltages of accessible *SELV* and *PELV circuits* of *DVC* A shall be monitored.

5.2.3.6.2.1 Supply voltage and current

PDS rated for d.c. input shall be tested using a d.c. source. *PDS* rated for a.c input shall be tested at their rated input frequency.

The open-circuit voltage of the supply shall be 100 % - 105 % of the rated input voltage. The open-circuit voltage may exceed 105 % of the rated input voltage at the request of the manufacturer.

For the Short-circuit test, the supply shall be capable of delivering the specified *prospective short-circuit current* (see 4.3.9) at the connection to the *PDS*, unless circuit analysis demonstrates that a lesser value may be used.

For the Breakdown of components test, the supply shall be capable of delivering a *prospective short-circuit current* of between 1 kA and 5 kA, unless the analysis of 4.2 shows that a different value is required.

5.2.3.6.3 Short-circuit test

5.2.3.6.3.1 Load conditions

The short circuit test shall be performed with the *CDM*/*BDM* at full load or light load whichever creates the more severe condition.

5.2.3.6.3.2 Location of short-circuit

Power outputs shall be provided with cable of a cross-section appropriate to the rated current available at the output. The length of each loop shall be approximately 2 m, unless the size of the *PDS* requires a greater length, in which case the length shall be as short as practical to perform the test.

All output terminals of each power output tested shall be simultaneously connected together, using an appropriate switching device.

Each sample shall be subjected to only one short-circuit test.

5.2.3.6.4 Breakdown of components test

5.2.3.6.4.1 Load conditions

The breakdown of a component, identified as a result of the circuit analysis of 4.2, shall be tested with the *CDM*/*BDM* at full load or light load whichever creates the more severe condition.

5.2.3.6.4.2 Application of short-circuit or open-circuit

The short circuit or open circuit shall be applied with cable of a cross-section of minimum 2,5 mm^2 and an appropriate switching device. The length of the loop shall be as short as practical to perform the test.

Each identified component shall be subjected to only one Breakdown of components test.

5.2.3.6.5 Test sequence

The *PDS* shall be powered, with its output(s) operating.

- For the Short-circuit test, a short-circuit shall be introduced at the output under test.
- For the Breakdown of components test, identified components shall be short-circuited or open-circuited, whichever creates the worse hazard, one at a time.

The *PDS* shall be operated until one or more of the following ultimate results are obtained:

- the operation of electronic short-circuit protection circuitry, or
- the opening of a short-circuit protection device, or
- a steady state temperature is attained after a minimum of 10 min.

5.2.3.6.6 Pass criteria

As a result of the Short-circuit test and the Breakdown of components test, the *PDS*/*CDM*/*BDM* shall comply with the following:

- there shall be no emission of flame or molten metal;
- the surgical cotton indicator shall not have ignited;
- the earth connection shall not have opened;

- the door or cover shall not have blown open;
- during and after the test, accessible *SELV* and *PELV circuits* shall not exhibit voltages greater than the time dependent voltages of Figure 7;
- during and after the test, *live parts* at voltages greater than *decisive voltage class* A shall not become accessible.

The *PDS*/*CDM*/*BDM* is not required to be operational after testing and it is possible that the enclosure can become deformed.

5.2.3.7 Capacitor discharge (*type test*)

Verification of the capacitor discharge time as required by 4.3.11 may be done by a *type test* and/or by calculation.

5.2.3.8 Temperature rise test (*type test*)

The test is intended to ensure that parts and accessible surfaces of the *PDS* do not exceed the temperature limits specified in 4.4 and that the manufacturer's temperature limits of safety-relevant parts are not exceeded.

Where possible, the *PDS* shall be tested at worst-case conditions of rated power and *CDM*/*BDM* output current. For *integrated PDS* where the motor speed might affect the thermal condition in the *CDM*/*BDM* the test shall be conducted at worst case operating speed and load according to the manufacturer's specification.

If this is not possible, it is permitted to simulate the temperature rise, if the validity of the simulation can be demonstrated by tests at lower power levels.

The *PDS* shall be tested with at least 1,2 m of wire attached to each *user terminal*. The wire shall be of the smallest size intended to be connected to the *PDS* as specified by the manufacturer for installation. When there is only provision for the connection of bus bars to the *PDS*, they shall be of the minimum size intended to be connected to the *PDS* as specified by the manufacturer, and they shall be at least 1,2 m in length.

The test shall be maintained until thermal stabilization has been reached. That is, when three successive readings, taken at intervals of 10 percent of the previously elapsed duration of the test and not less than 10 minute intervals, indicate no change in temperature, defined as ± 1 °C between any of the three successive readings, with respect to the ambient temperature.

The maximum temperature of electrical insulation (other than that of windings), the failure of which could cause a hazard, is measured on the surface of the insulation at a point close to the heat source.

The maximum temperature attained shall be corrected to the rated ambient temperature of the *PDS* by adding the difference between the ambient temperature during the test and the maximum rated ambient temperature.

No corrected temperature shall exceed the rated temperature of the material or component measured.

During the test, thermal cutout, overload detection functions and devices shall not operate.

5.2.3.9 Protective bonding (type test and routine test)

The impedance of each *protective bonding* circuit between the *PE* terminal and relevant points that are part of each *protective bonding* circuit shall be measured with a current of at least 10 A derived from a supply source, the output of which is not earthed, having a maximum no-load voltage of 24 V.

When the *protective bonding* has been designed using the cross-section rules of 4.3.5.4, the impedance shall not exceed 0,02 Ω.

When the *protective bonding* has been designed using the rules of 4.3.5.3.3, the impedance shall not exceed the value required to meet the time dependent voltage limits of Figure 7.

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.

This test shall be performed as a *routine test* if the continuity of the *protective bonding* is achieved at any point by means of a single fastener.

5.2.4 Abnormal operation tests

5.2.4.1 General

Before all operation tests, the test sample shall be mounted, connected, and operated as described in the temperature rise test.

In the case of a *CDM*/*BDM* supplied without an enclosure, a wire mesh cage which is 1,5 times the individual linear dimensions of the *CDM*/*BDM* part under study shall be used to simulate the intended enclosure.

The *PDS*, and the wire mesh cage (if used), shall be earthed according to the requirements of 4.3.5.3.2.

Surgical cotton shall be placed at all openings, handles, flanges, joints and similar locations on the outside of the enclosure, and the wire mesh cage (if used), in a manner which will not significantly affect the cooling.

5.2.4.2 Test duration

The individual tests shall be performed until terminated by a protective device or mechanism (internal or external), a component failure occurs, or the temperature stabilizes.

5.2.4.3 Pass criteria

As a result of the Abnormal operation tests, the *PDS*/*CDM*/*BDM* shall comply with the following:

- there shall be no emission of flame or molten metal;
- the surgical cotton indicator shall not have ignited;
- the earth connection shall not have opened;
- the door or cover shall not have blown open;

- during and after the test, accessible *SELV* and *PELV circuits* shall not exhibit voltages greater than the time dependent voltages of Figure 7;
- during and after the test, *live parts* at voltages greater than *decisive voltage class* A shall not become accessible.

The *PDS*/*CDM*/*BDM* is not required to be operational after testing and it is possible that the enclosure can become deformed.

5.2.4.4 Loss of phase (*type test*)

A multi-phase *PDS* shall be operated with each line (including neutral, if used) disconnected in turn at the input. The test shall be performed by disconnecting one line with the power conversion equipment operating at its maximum normal load (this particular requirement does not apply to *high-voltage PDS* and may be simulated for *low-voltage PDS* with rated input current greater than 500 A) and shall be repeated by initially energizing the device with one lead disconnected.

5.2.4.5 Cooling failure tests (*type tests*)

5.2.4.5.1 General

For *PDS* having a combination of cooling mechanisms, all relevant tests shall be performed. It is not necessary to perform the tests simultaneously.

5.2.4.5.2 Inoperative blower motor

A *PDS* having forced ventilation shall be operated at rated load with blower motor or motors made inoperative, singly or in combination from a single fault, by physically preventing their rotation.

5.2.4.5.3 Clogged filter

Enclosed *PDS*/*CDM*/*BDM* having filtered ventilation openings shall be operated with the openings blocked to represent clogged filters. The test shall be performed initially with the ventilation openings blocked 50 %. The test shall be repeated under a full blocked condition.

5.2.4.5.4 Loss of coolant

A liquid cooled *PDS* shall be operated at rated load. Loss of coolant shall be simulated by blocking the flow or disabling the system coolant pump. The a.c. or d.c. voltage test 5.2.3.2 shall be performed after termination of the Loss of coolant test.

5.2.5 Material tests

5.2.5.1 High current arcing ignition test (*type test*)

Five samples of each insulating material (see 4.4.2) to be tested are used. The samples are 130 mm long minimum by 13 mm wide and of uniform thickness representing the thinnest section of the part. Edges shall be free from burrs, fins, etc.

Each test is made with a pair of test electrodes and a variable inductive impedance load connected in series to a source of 220 V to 240 V a.c., 50 Hz or 60 Hz (see Figure 9).

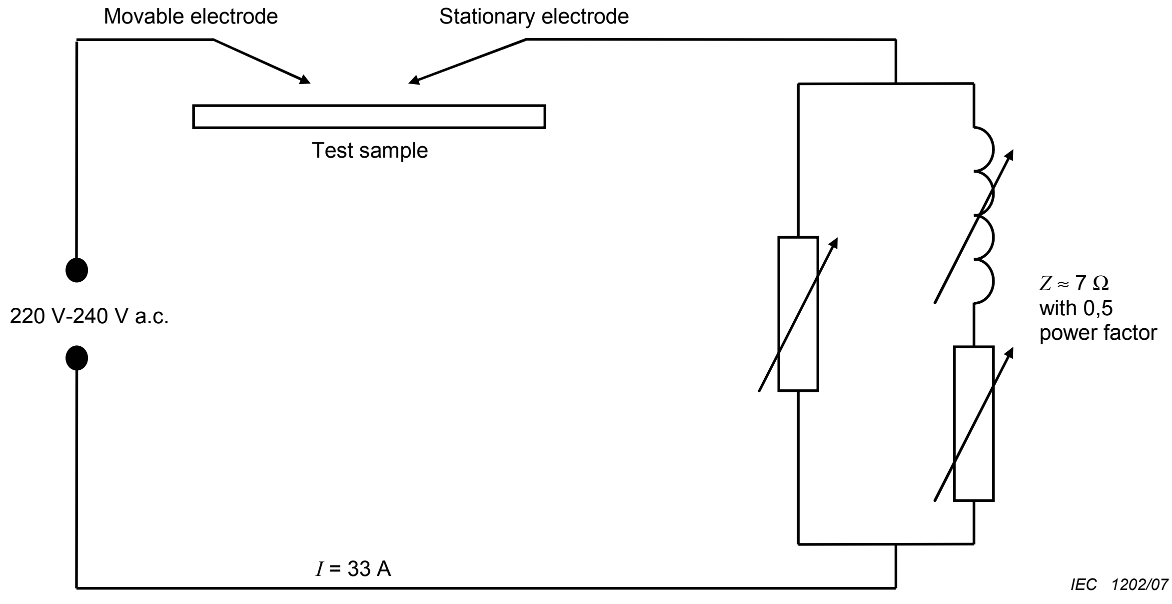


Figure 9 – Circuit for high-current arcing test

It is permitted to use an equivalent circuit.

One electrode is stationary and the second movable. The stationary electrode consists of a 3,5 mm diameter solid copper conductor having a 30° chisel point. The movable electrode is a 3 mm diameter stainless steel rod with a symmetrical conical point having a total angle of 60° and is capable of being moved along its own axis. The radius of curvature for the electrode tips does not exceed 0,1 mm at the start of a given test. The electrodes are located opposing each other, in the same plane, at an angle of 45° to the horizontal. With the electrodes short-circuited, the variable inductive impedance load is adjusted until the current is 33 A at a power factor of 0,5.

The sample under test is supported horizontally in air or on a non-conductive surface so that the electrodes, when touching each other, are in contact with the surface of the sample. The movable electrode is manually or otherwise controlled so that it can be withdrawn from contact with the stationary electrode to break the circuit and lowered to remake the circuit, so as to produce a series of arcs at a rate of approximately 40 arcs/min, with a separation speed of (250 ± 25) mm/s.

The test is continued until ignition of the sample occurs, a hole is burned through the sample or a total of 200 arcs have elapsed.

The average number of arcs to ignition of the specimens tested shall be not less than 15 for V-0 class materials and not less than 30 for other materials.

5.2.5.2 Glow-wire test (*type test*)

The glow-wire test shall be made under the conditions specified in 4.4.2 according to IEC 60695-2-10 and IEC 60695-2-13.

NOTE If the test has to be made at more than one place on the same sample, care should be taken to ensure that any deformation caused by previous tests does not affect the test to be made.

5.2.5.3 Hot wire ignition test (*type test* – alternative to Glow-wire test)

Five samples of each insulating material (see 4.4.2) are tested. The samples are 130 mm long minimum by 13 mm wide and of a uniform thickness representing the thinnest section of the part. Edges shall be free from burrs, fins, etc.

A 250 mm ± 5 mm length of nichrome wire (nominal composition 80 % nickel, 20 % chromium, iron-free) approximately 0,5 mm diameter and having a cold resistance of approximately 5 Ω/m is used. The wire is connected in a straight length to a variable source of power which is adjusted to generate 0,25 W/mm ± 0,01 W/mm in the wire for a period of 8 s to 12 s. After cooling, the wire is wrapped around a sample to form five complete turns spaced 6 mm apart.

The wrapped sample is supported in a horizontal position (see Figure 10) and the ends of the wire connected to the variable power source, which is again adjusted to generate (0,25 ± 0,01) W/mm in the wire.

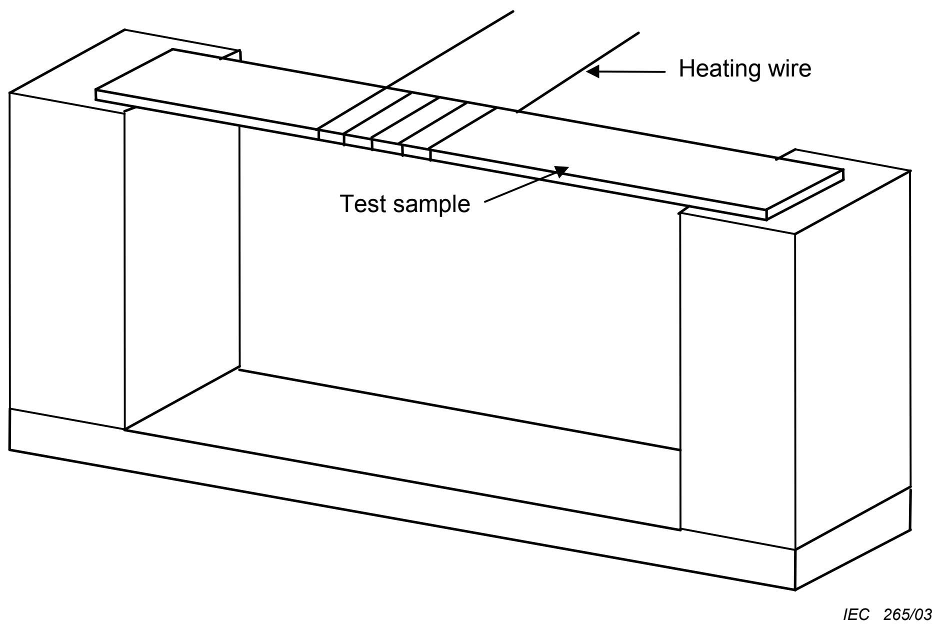


Figure 10 – Test fixture for hot-wire ignition test

The test is continued until the test specimen ignites or until 120 s have passed. When ignition occurs or 120 s have passed, the test is discontinued and the test time recorded. For specimens which melt through the wire without ignition, the test is discontinued when the specimen is no longer in intimate contact with all five turns of the heater wire.

The test is repeated on the remaining samples.

The average ignition time of the specimens tested shall not be less than 15 s.

5.2.5.4 Flammability test (*type test*)

Three samples of the complete equipment or three test specimens of the enclosure thereof (see 4.4.3) shall be subjected to this test. Consideration shall be given to leaving in place components and other parts that might influence the performance. The test samples shall be conditioned in a full draft circulating air oven for seven days at 10 °C greater than the maximum use temperature but not less than 70 °C in any case. Prior to testing, the samples shall be conditioned for a minimum of 4 h at 23 °C ± 2 °C and 50 % ± 5 % relative humidity. The flame shall be applied to an inside surface of the sample at a location judged to be likely to become ignited because of its proximity to a source of ignition including surfaces provided with ventilation holes. If more than one part is near a source of ignition, each sample shall be tested with the flame applied to a different location.

The three test samples shall result in the acceptable performance described below. If one sample does not comply, the test shall be repeated on a set of three new samples with the flame applied under the same conditions as for the unsuccessful sample. If all the new specimens comply with the requirements described below the material is acceptable.

The laboratory burner, adjustment and calibration shall be identical to that described in IEC 60695-11-10 and IEC 60695-11-20.

When a complete enclosure is used to conduct the flame test, the sample shall be mounted as intended in service, if it does not impair the flame testing, in a draft-free test chamber, enclosure, or laboratory hood. A layer of absorbent 100 % cotton shall be located 305 mm below the point of application of the test flame. The 127 mm flame shall be applied to any portion of the interior of the part judged as likely to be ignited (by its proximity to live or arcing parts, coils, wiring, and the like) at an angle of approximately 20° insofar as possible from the vertical so that the tip of the blue cone touches the specimen. The test flame shall be applied to three different locations on each of the three samples tested. A supply of technical-grade methane gas shall be used with a regulator and meter for uniform gas flow. Natural gas having a heat content of approximately 37 MJ/m^3 at 23 °C has been found to provide similar results and may be used.

The flame shall be applied for 5 s and removed for 5 s. The operation shall be repeated until the specimen has been subjected to five applications of the test flame.

The following conditions shall be met as a result of this test:

- the material shall not continue to burn for more than 1 min after the fifth 5 s application of the test flame, with an interval of 5 s between applications of the flame;

  and

- flaming drops or flaming or glowing particles that ignite surgical cotton 305 mm below the test specimen shall not be emitted by the test sample at any time during the test;

5.2.6 Environmental tests (*type tests*)

5.2.6.1 General

Environmental testing is required to establish the safety of the *PDS* at the extremes of the environmental classification to which it will be subjected.

If size or power considerations prevent the performance of these tests on the complete *PDS*, it is permitted to test individual parts that are considered to be relevant to the safety of the *PDS*.

5.2.6.2 Acceptance criteria

The following acceptance criteria shall be satisfied:

- no degradation of any safety-relevant component of the *PDSICDMIBDM;*
- no potentially hazardous behaviour of the *PDSICDMIBDM* during the test;
- no sign of component overheating;
- no *live part* shall become accessible;
- no cracks in the enclosure and no damaged or loose insulators;
- pass routine a.c. or d.c. voltage test 5.2.3.2;
- pass *Protective bonding* test 5.2.3.9;
- no potentially hazardous behaviour when the *PDSICDMIBDM* is operated following the test.

5.2.6.3 Climatic tests

5.2.6.3.1 Dry heat test (steady state)

The Dry heat (steady state) test shall be performed according to Table 25.

Table 25 – Dry heat test (steady state)

Subject	Test conditions
Test reference	Test Bd of IEC 60068-2-2
Requirement reference	4.6
Preconditioning	According to 5.1.2 and 5.2.1
Operating conditions Temperature Accuracy Humidity Duration of exposure	Operating at rated conditions 40 °C or manufacturer’s specified maximum temperature, whichever is higher ± 2 °C (see 37.1 of IEC 60068-2-2) According to IEC 60068-2-2, Test Bd (16 ± 1) h
Recovery procedure - time - climatic conditions - Temperature - Relative humidity - Barometric pressure - power supply	 1 h minimum 15 °C to 35 °C 25 % to 75 % 86 kPa to 106 kPa Power supply unconnected

5.2.6.3.2 Damp heat test (steady state)

To prove the resistance to humidity, the *CDM* shall be subjected to a Damp heat test (steady state) according to Table 26.

Table 26 – Damp heat test (steady state)

Subject	Test conditions
Test reference	Test Cab of IEC 60068-2-78
Requirement reference	4.6
Preconditioning	According to 5.1.2 and 5.2.1
Operating conditions Special precautions Temperature Humidity Duration of exposure	Power supply disconnected Internal voltage sources may remain connected if the heat produced by them in the specimen is negligible (40 ± 2) °C (according to IEC 60068-2-78) $(93\ ^{+2}_{-3})$ % non-condensing 4 Days
Recovery procedure - time - climatic conditions - Temperature - Relative humidity - Barometric pressure - power supply - condensation	 1 h minimum 15°C to 35°C 25% to 75% 86 kPa to 106 kPa Power supply disconnected All external and internal condensation shall be removed by air flow prior to performing the a.c. or d.c. voltage test or re-connecting the CDM to a power supply

5.2.6.4 Vibration test (*type test*)

To verify the mechanical strength, a vibration test shall be performed according to Table 27 as a *type test* using a sliding frequency.

For *PDS*/*CDM*/*BDM* with a mass more than 100 kg, this test may be performed on sub-assemblies.

NOTE For large equipment, the possibility of using a shock test as an alternative to a vibration test is under consideration.

Table 27 – Vibration test

Subject	Test conditions
Test reference	Test Fc of IEC 60068-2-6
Requirement reference	4.6
Preconditioning	According to 5.1.2 and 5.2.1
Conditions Motion Vibration amplitude/acceleration 10 Hz ≤ f ≤ 57 Hz 57 Hz < f ≤ 150 Hz Vibration duration Detail of mounting	Power supply unconnected Sinusoidal 0,075 mm amplitude 1 g 10 sweep cycles per axis on each of three mutually perpendicular axes According to manufacturer's specification
Where the manufacturer specifies vibration levels that are greater than those above, the higher levels shall be used for the test. The acceptance criteria shall not be changed.	

5.2.7 Hydrostatic pressure (*type test* and *routine test*)

For *type tests*, the pressure inside the cooling system of a liquid cooled *PDS* (see 4.4.5.2.2) shall be increased at a gradual rate until a pressure relief mechanism (if provided) operates, or until a pressure of twice the operating value or 1,5 times the maximum pressure rating of the system is achieved, whichever is the greater.

For *routine tests*, the pressure shall be increased to its operating value.

The pressure shall be maintained for at least 1 min.

There shall be no thermal, shock, or other hazard resulting from the test. There shall be no significant leakage of coolant or loss of pressure during the test, other than from a pressure relief mechanism during a *type test*.

6 Information and marking requirements

6.1 General

The purpose of this Clause 6 is to define the information necessary for the safe selection, installation and commissioning, operation, and maintenance of *PDS*/*CDM*/*BDM*. It is presented as Table 28, showing where the information shall be provided, followed by explanatory subclauses.

The requirements of this Clause 6 apply to all *PDS*/*CDM*/*BDM*, unless otherwise stated.

Since any electrical equipment can be installed or operated in such a manner that hazardous conditions can occur, compliance with the design requirements of this part of IEC 61800 does not by itself assure a safe *installation*. However, when equipment complying with those requirements is properly selected and correctly installed and operated, the hazards will be minimized.

All information shall be in an appropriate language, and documents shall have identification references. Drawing symbols shall conform to IEC 60417 or IEC 60617 as appropriate. Symbols not shown in IEC 60417 or IEC 60617 shall be identified where used.

NOTE Further guidance for the preparation of documentation is provided in IEC 61082, and for the preparation of instructions and manuals in IEC 62079.

Table 28 – Information requirements

Information	Subclause reference	Location [a, b, c]					Technical subclause reference
		1	2	3	4	5	
For selection	**6.2**						
Manufacturer's name and catalogue number	6.2	X	X	X	X	X	
Voltage rating	6.2	X		X	X	X	
Current rating	6.2	X		X		X	
Power rating	6.2	X		X		X	
Short-circuit ratings	6.2			X			4.3.9
IP rating	6.2	X		X		X	4.3.3.3, 4.3.7.1
Reference to standards	6.2			X			
Date code or serial number	6.2	X					
Reference to instructions	6.2			X	X	X	
For installation and commissioning	**6.3**						
Dimensions (SI units)	6.3.2			X		X	
Mass (SI units)	6.3.2		X	X		X	
Mounting details (SI units)	6.3.2			X		X	
Operating and storage environments	6.3.3			X		X	
Enclosure details	6.3.3			X		X	4.3.3.3, 4.3.7.1, 4.4.3
Handling requirements	6.3.4		X	X		X	
Motor requirements	6.3.5			X	X	X	
Interconnection and wiring diagrams	6.3.6.2			X		X	
Cable requirements	6.3.6.3			X		X	4.3.8
Terminal details	6.3.6.4	X		X		X	4.3.8.8.2
Protection requirements	6.3.6.5			X		X	4.3
Earthing	6.3.6.6	X		X		X	4.3.5.3, 4.3.5.3.2, 4.3.12
Protective earthing conductor current	6.3.6.7	X		X		X	4.3.5.5.2, 4.3.10
Special requirements	6.3.6.8			X		X	
Supply overload protection	6.3.7	X		X		X	
Motor overload protection	6.3.8			X		X	
Commissioning information	6.3.9			X			
For use	**6.4**						
General	6.4.1			X		X	
Adjustment	6.4.2			X	X	X	
Labels, signs, and signals	6.4.3	X		X	X	X	
For maintenance	**6.5**						
Maintenance procedures	6.5.1					X	4.3.3.3
Maintenance schedules	6.5.1				X	X	
Subassembly and component locations	6.5.1					X	
Repair and replacement procedures	6.5.1					X	
Adjustment procedures	6.5.1			X	X	X	
Special tools list	6.5.1				X	X	
Capacitor discharge	6.5.2	X		X		X	4.3.11
Auto restart/bypass	6.5.3			X	X	X	
PT/CT connection	6.5.4	X		X		X	
Other hazards	6.5.5	X				X	

[a] Location: 1. On product (see 6.4.3); 2. On packaging; 3. In installation manual; 4. In user's manual; 5. In maintenance manual.

[b] The installation, user's and maintenance manuals may be combined as appropriate and, if acceptable to the customer, may be supplied in electronic format. When more than one of any product is supplied to a single customer, it is not necessary to supply a manual with each unit, if acceptable to the customer.

[c] For *integrated PDS* the information required for location 1 may be combined with the motor nameplate information required by IEC 60034-1.

6.2 Information for selection

Each part of a *PDS* that is supplied as a separate product shall be provided with information relating to its function, electrical characteristics, and intended environment, so that its fitness for purpose and compatibility with other parts of the *PDS* can be determined. For *CDM*/*BDM*, this information includes, but is not limited to:

- the name or trademark of the manufacturer, supplier or importer;
- catalogue number or equivalent;
- input and output voltage range, current, and power rating information, including:
  – number of phases;
  – frequency range;
- *protective class*;
- the type of electrical supply system (e.g. TN, IT, etc.) to which the *PDS*/*CDM*/*BDM* may be connected;
- *prospective short-circuit current* rating(s) and protective device characteristics
- field supply requirements (if any);
- coolant type and design pressure for liquid cooled product;
- IP rating;
- operating and storage environment;
- reference(s) to relevant international standard(s) for manufacture, test, or use;
- date code, or serial number from which the date of manufacture can be determined;
- reference to instructions for installation, use and maintenance.

The information shall be limited to that which is essential for correct selection to be made, and should relate to specific equipment. If information covers a number of product variants, it shall be readily possible to distinguish between them.

6.3 Information for installation and commissioning

6.3.1 General

Safe and reliable installation is the responsibility of the installer, machine builder, and/or user. The manufacturer of any part of the *PDS* shall provide information to support this task. This information shall be unambiguous, and may be in diagrammatic form.

6.3.2 Mechanical considerations

The following drawings shall be prepared by the manufacturer:

- dimensional drawing, including mass information;
- mounting drawing.

Dimensions, mass, etc., shall be in SI units.

6.3.3 Environment

The following environmental conditions shall be specified, for operation, transportation and storage:

- climatic (temperature, humidity, altitude, pollution, ultra-violet light, etc.);
- mechanical;
- electrical.

NOTE Environmental categories as specified in IEC 60721 may be used where appropriate.

6.3.4 Handling and mounting

In order to prevent injury or damage, the installation documents shall include warnings of any hazards which can be experienced during installation. Where necessary, instructions shall be provided for:

- packing and unpacking;
- moving;
- lifting;
- strength and rigidity of mounting surface;
- fastening;
- provision of adequate access for operation, adjustment and maintenance.

When *PDS* surfaces at temperatures exceeding 90 ºC are close to mounting surfaces, the installation manual shall contain a warning to consider the combustibility of the mounting surface.

6.3.5 Motor and driven equipment

6.3.5.1 Motor selection

Where necessary for *CDM*/*BDM*, information on suitable motor specifications (for example, based on IEC 60034-1) shall be provided. The possible influence on motor insulation of reflections of the PWM output waveform shall be taken into consideration.

6.3.5.2 Motor integrated sensors

Insulation requirements shall be identified (see 4.3.5 and 4.3.6).

6.3.5.3 Critical torsional speeds

When required, the *PDS* supplier shall provide all relevant motor information to enable critical torsional speeds to be identified (see 4.5.2.2).

6.3.5.4 Transient torque analysis

When required, the *PDS* supplier shall provide all relevant electrical and mechanical information to enable transient torque analysis to be performed (see 4.5.2.3).

6.3.6 Connections

6.3.6.1 General

Information shall be provided to enable the installer to make safe electrical connection to the *PDS*. This shall include information for protection against hazards (for example, electric shock or availability of energy) that may be encountered during installation, operation or maintenance.

6.3.6.2 Interconnection and wiring diagrams

The installation and maintenance manuals shall include details of all necessary connections, together with a suggested interconnection diagram.

6.3.6.3 Conductor (cable) selection

The Installation manual shall define the voltage and current levels for all connections to the *PDS*/*CDM*/*BDM*, together with cable insulation requirements. These shall be worst-case values, taking into account overcurrent and overload conditions and the possible effects of non-sinusoidal currents.

6.3.6.4 Terminal capacity and identification

The installation and maintenance manuals shall indicate the range of acceptable conductor sizes and types (solid or stranded) for all terminals, and also the maximum number of conductors which can simultaneously be connected. For *user terminals*, the manuals shall specify the requirements for tightening torque values and also the insulation temperature rating requirements for the conductor or cable.

The identification of all *user terminals* shall be marked on the *PDS*/*CDM*/*BDM*, either directly or by a label attached close to the terminals.

6.3.6.5 Protection requirements

The installation, users and maintenance manuals shall identify any accessible parts at voltages greater than *ELV*, and shall describe the insulation and separation provisions required for protection. Accessible *ELV* parts of a *PDS*/*CDM*/*BDM* which are of *protective class 0* shall be clearly identified, and instructions provided in the installation manual to increase the protection against indirect contact.

The manuals shall also indicate the precautions to be taken to ensure that the safety of *ELV* connections is maintained during installation.

The manuals shall provide instructions for the use of *PELV circuits* within a *zone of equipotential bonding*.

The installation, users, and maintenance manuals shall identify all external terminals relating to circuits protected by one of the methods of 4.3.4.2 to 4.3.4.4.

6.3.6.6 Earthing

The installation manual shall specify requirements for safe earthing of the *PDS*/*CDM*/*BDM*.

The installation and maintenance manuals for *high-voltage PDS* shall provide instructions for the use of an earthing switch to ensure safe access during maintenance.

Terminals for connection of the *protective earthing conductor* shall be clearly and indelibly marked with the symbol IEC 60417-5019 (2006-08) (see Annex H), or with the letters PE, or by the colour coding green or green-yellow. The indication shall not be placed on or fixed by screws, washers or other parts which might be removed when conductors are being connected.

Equipment of *protective class II* shall be marked with symbol IEC 60417-5172 (2003-02) (see Annex H). Where such equipment has provision for the connection of an earthing conductor for functional reasons (see 4.3.5.6) it shall be marked with symbol IEC 60417-5018 (2006-10) (see Annex H).

6.3.6.7 *Protective earthing conductor* current

Where the *touch current* in the *protective earthing conductor* (see 4.3.5.5.2) exceeds 3,5 mA a.c. or 10 mA d.c., this shall be stated in the installation and maintenance manuals. In addition, a caution symbol ISO 7000-0434 (2004-01) (see Annex H) shall be placed on the product, and a notice shall be provided in the installation manual to instruct the user that the minimum size of the *protective earthing conductor* shall comply with the local safety regulations for high *protective earthing conductor* current equipment.

The installation and maintenance manuals shall indicate compatibility with RCDs (see 4.3.10).

When 4.3.10 b) applies, a caution notice and the symbol ISO 7000-0434 (2004-01) (see Annex H) shall be provided in the user manual, and the symbol shall be placed on the product. The caution notice shall be: *"This product can cause a d.c. current in the protective earthing conductor. 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.."* (See 6.4.3 for general requirements for labels, signs and signals.)

6.3.6.8 Special requirements

Any particular cable and connection requirements shall be identified in the installation and maintenance manuals.

6.3.7 Overcurrent or short-circuit protection

Where external devices are necessary to protect against overcurrent or short-circuit, the installation manual shall specify the required characteristics (see also 5.2.2.2, 5.2.3.6.2, 5.2.4.2).

6.3.8 Motor overload protection

The installation and maintenance manuals of *CDM*/*BDM* incorporating internal overload protection for the motor shall indicate the overload protection provided in percent of full-load current and duration. If the protection is adjustable, the manuals shall include instructions for adjustment.

The manuals for *CDM*/*BDM* not incorporating internal overload protection for the motor and intended to be used with external or remote overload protection shall indicate that such protection shall be provided.

Where *CDM*/*BDM* have inputs that can be used with motors which have thermal sensors, the manuals shall contain instructions for the proper connection to these inputs.

6.3.9 Commissioning

If *commissioning tests* are necessary to ensure the electrical and thermal safety of a *PDS*, information to support these tests shall be provided for each part of the *PDS*. This information can depend on the specific *installation*, and close cooperation between manufacturer, installer, and user can be required.

Commissioning information shall include references to hazards that might be encountered during commissioning, for example those mentioned in 6.4 and 6.5.

6.4 Information for use

6.4.1 General

The user's manual shall include all information regarding the safe operation of the *PDS*/*CDM*/*BDM*. In particular, it shall identify any hazardous materials and risks of electrical shock, overheating, explosion, excessive acoustic noise, etc.

The manual should also indicate any hazards which can result from reasonably foreseeable misuse of the *PDS*.

6.4.2 Adjustment

The user's manual shall give details of all safety-relevant adjustments intended for the user. The identification or function of each control or indicating device and fuse shall be marked adjacent to the item. Where it is not possible to do this on the product, the information shall be provided pictorially in the manual.

Maintenance adjustments may also be described in this manual, but it shall be made clear that they should only be made by qualified personnel.

Clear warnings shall be provided where excessive adjustment could lead to a hazardous state of the *PDS*/*CDM*/*BDM*.

Any special equipment necessary for making adjustments shall be specified and described.

6.4.3 Labels, signs and signals

6.4.3.1 General

Labelling shall be in accordance with good ergonomic principles so that notices, controls, indications, test facilities, fuses, etc., are sensibly placed and logically grouped to facilitate correct and unambiguous identification.

All safety related equipment labels shall be located so as to be visible after installation or readily visible by opening a door or removing a cover.

Where a hazard is present after the removal of a cover, a warning label shall be placed on the equipment. The label shall be visible before the cover is removed.

Labels shall:

- wherever possible, use international symbols as given by ISO 3864, ISO 7000 or IEC 60417;
- if no international symbol is available, be worded in an appropriate language or in a language associated with a particular technical field;
- be conspicuous, legible and durable;
- be concise and unambiguous;
- state the hazards involved and give ways in which risks can be reduced.

When instructing the person(s) concerned as to

- **what to avoid**: the wording should include “no”, “do not”, or “prohibited”;
- **what to do**: the wording should include “shall”, or “must”;
- **the nature of the hazard**: the wording should include “caution”, “warning”, or “danger”, as appropriate;
- **the nature of safe conditions**: the wording should include the noun appropriate to the safety device.

Safety signs shall comply with ISO 3864.

The signal words indicated hereinafter shall be used and the following hierarchy respected:

- **DANGER** to call attention to a high risk, for example: “High voltage”
- **WARNING** to call attention to a medium risk, for example: “This surface can be hot.”
- **CAUTION** to call attention to a low risk, for example; “Some of the tests specified in this standard involve the use of processes imposing risks on persons concerned.”

Danger, warning and caution markings on the *PDS* shall be prefixed with the word “DANGER”, “WARNING”, or “CAUTION” as appropriate in letters not less than 3,2 mm high. The remaining letters of such markings shall be not less than 1,6 mm high.

6.4.3.2 Isolators

Where an isolating device is not intended to interrupt load current, a warning shall state:

DO NOT OPEN UNDER LOAD.

The following requirements apply to any supply isolating device which does not disconnect all sources of power to the *PDS*.

- If the isolating device is mounted in an equipment enclosure with the operating handle externally operable, a warning label shall be provided adjacent to the operating handle stating that it does not disconnect all power to the *PDS*.
- Where a control circuit disconnector can be confused with power circuit disconnectors due to size or location, a warning label shall be provided adjacent to the operating handle of the control circuit disconnector stating that it does not disconnect all power to the *PDS*.

6.4.3.3 Visual and audible signals

Visual signals such as flashing lights, and audible signals such as sirens, may be used to warn of an impending hazardous event such as the driven equipment start-up and shall be identified.

It is essential that these signals:

- are unambiguous;
- can be clearly perceived and differentiated from all other signals used;
- can be clearly recognized by the user;
- are emitted before the occurrence of the hazardous event.

It is recommended that higher frequency flashing lights be used for higher priority information.

NOTE IEC 60073 provides guidance on recommended flashing rates and on/off ratios.

6.4.3.4 Hot surfaces

Surfaces which can exceed the temperature limits of Table 16 shall be marked with the warning symbol IEC 60417-5041 (2002-10) (see Annex H). The user's manual shall also contain this information.

6.4.3.5 Equipment marking

The identification of each control or indicating device and fuse shall be marked adjacent to the item. Replaceable fuses shall be marked with their rating and time characteristics. Where it is not possible to do this on the product, the information shall be provided pictorially in the manual.

Appropriate identification shall be marked on or adjacent to each movable connector.

Test points shall be individually marked with the circuit diagram reference.

The polarity of any polarized devices shall be marked adjacent to the device.

The diagram reference and if possible the function shall be marked adjacent to each pre-set control in a position where it is clearly visible while the adjustment is being made.

6.5 Information for maintenance

6.5.1 General

Safety information shall be provided in the maintenance manual including, as appropriate, the following:

- preventive maintenance procedures and schedules;
- safety precautions during maintenance (for example, the use of earthing switches for *high-voltage PDS*);
- location of *live parts* that can be accessible during maintenance (for example, when covers are removed);
- adjustment procedures;

- subassembly and component repair and replacement procedures;
- any other relevant information.

NOTE 1 These may best be presented as diagrams.

NOTE 2 A list of special tools should be provided, when appropriate.

6.5.2 Capacitor discharge

When the requirements of the first sentence of 4.3.11 are not met, the warning symbol IEC 6041-5036 (2002-10) 7 (see Annex H) and an indication of the discharge time (for example, 45 s, 5 min) 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). The symbol shall be explained and the time required for the capacitors to discharge after the removal of power from the *PDS* shall be stated in the installation and maintenance manuals.

6.5.3 Auto restart/bypass connection

If a *CDM*/*BDM* can be configured to provide automatic restart or bypass connection, the installation, user and maintenance manuals shall contain appropriate warning statements.

A *PDS* which is set to provide automatic restart or bypass connection after the removal of power shall be clearly identified at the *installation*.

6.5.4 PT/CT connection

A *PDS* which has monitoring or control functions using a potential transformer (PT) supplied from high voltage, or a current transformer (CT) supplied from a high current connection, shall be clearly marked to show the possible hazards of voltage transients upon disconnection of the secondary circuit. The hazards shall also be described in the installation and maintenance manuals.

6.5.5 Other hazards

The manufacturer shall identify any components and materials of a *PDS* which require special procedures to prevent hazards.

Annex A
(informative)

Examples of protection in case of direct contact

A.1 General

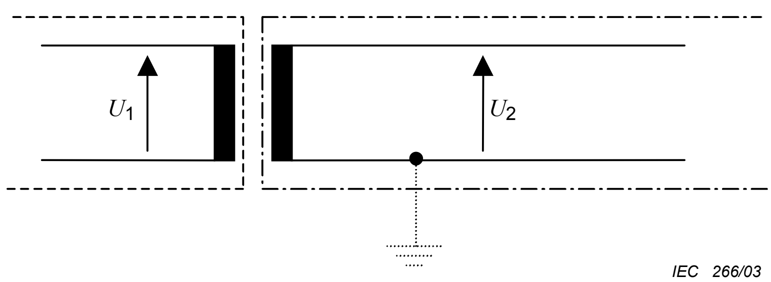
Figures A.1 to A.3 show examples of the methods used for protection in case of direct contact (see 4.3.4).

- - - - - - - - - - - - - - - - - - - Protection against direct contact

–·–·–·–·–·–·–·–·–·– *Protective separation* from circuits requiring protection against direct contact

A.2 Protection by means of *DVC* A

(See 4.3.4.2.)



Key

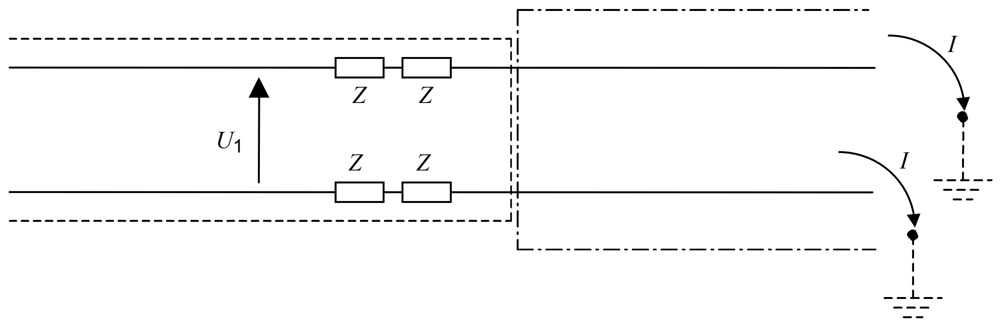
U_1: hazardous voltage, earthed or unearthed.

U_2: ≤ 30 V a.c.

Figure A.1 – Protection by *DVC* A, with *protective separation*

A.3 Protection by means of *protective impedance*

(See 4.3.4.3.)



Key

U_1: hazardous voltage, earthed or unearthed.

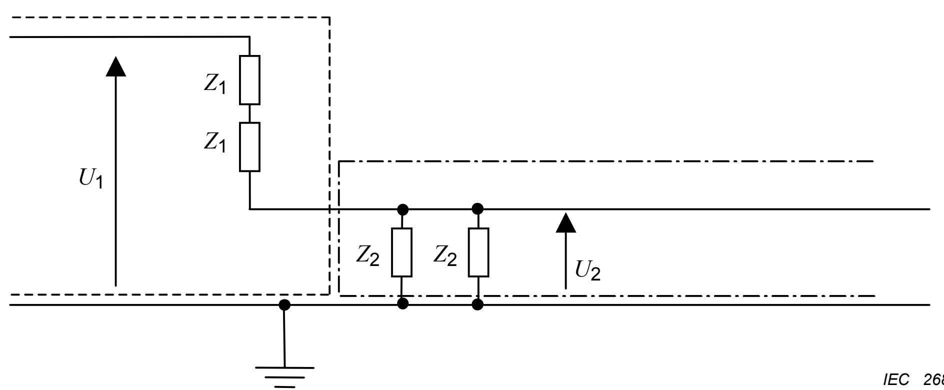
$I \leq$ 3,5 mA a.c., 10 mA d.c.

NOTE To provide protection in single-fault conditions, $I = U_1/Z$

Figure A.2 – Protection by means of *protective impedance*

A.4 Protection by using limited voltages

(See 4.3.4.4.)



Key

U_1: hazardous voltage, earthed.

U_2: ≤ 30 V a.c., 60 V d.c.

NOTE To provide protection in single-fault conditions, $U_2 = U_1Z_2/(2Z_1 + Z_2)$ or $U_2 = U_1Z_2/2(Z_1 + Z_2/2)$.

Figure A.3 – Protection by using limited voltages

Annex B
(informative)

Examples of overvoltage category reduction

B.1 General

The following Figures B.1 to B.13 are intended as illustrations of the requirements in Table 4, 4.3.6.2 and 4.3.6.3. They are not intended as indications of good design practice.

- - - - - - - - -	Protection against direct contact
▬ ▬ ▬	Conductive accessible parts
—·—·—·—	Protective separation
SPD	Surge protection device (example of measure to reduce transient overvoltages)
OVC	Overvoltage category

B.2 Insulation to the surroundings (see 4.3.6.2)

B.2.1 Circuits connected directly to the supply mains (see 4.3.6.2.2)

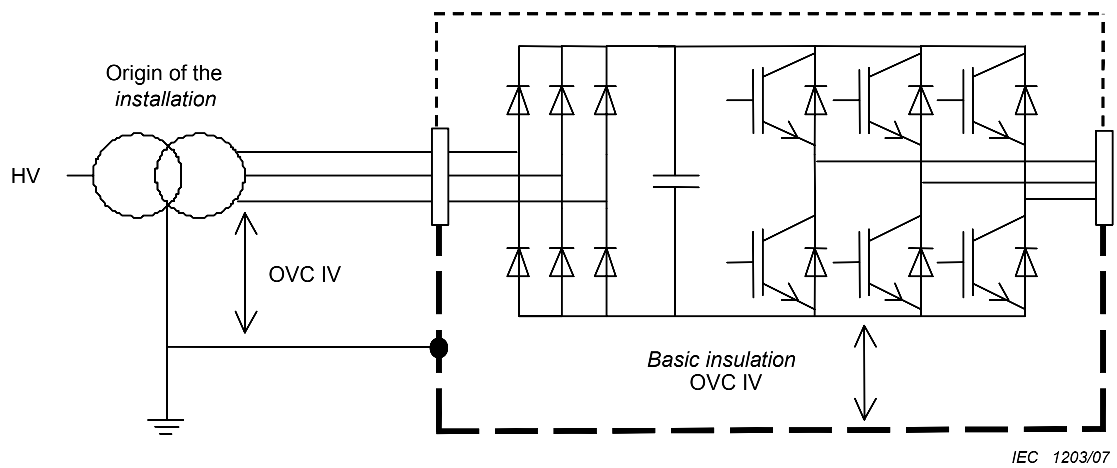


Figure B.1 – *Basic insulation* evaluation for circuits connected directly to the origin of the *installation* supply mains

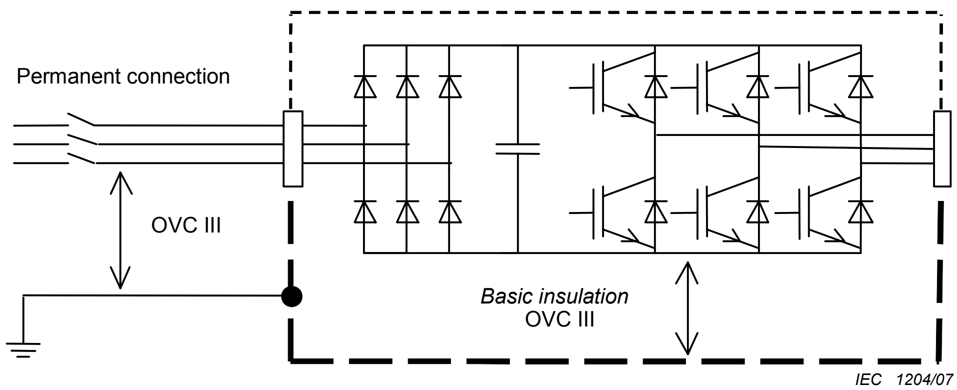


Figure B.2 – *Basic insulation* evaluation for circuits connected directly to the supply mains

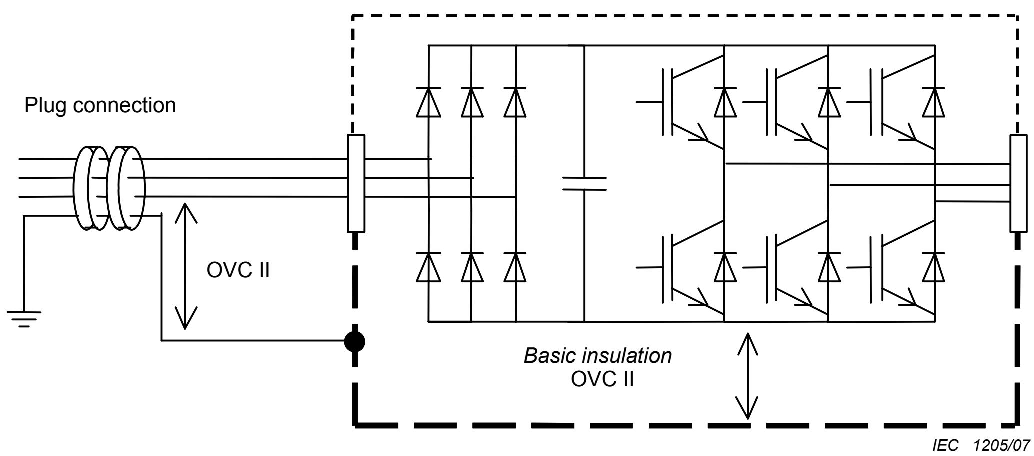


Figure B.3 – *Basic insulation* evaluation for equipment not permanently connected to the supply mains

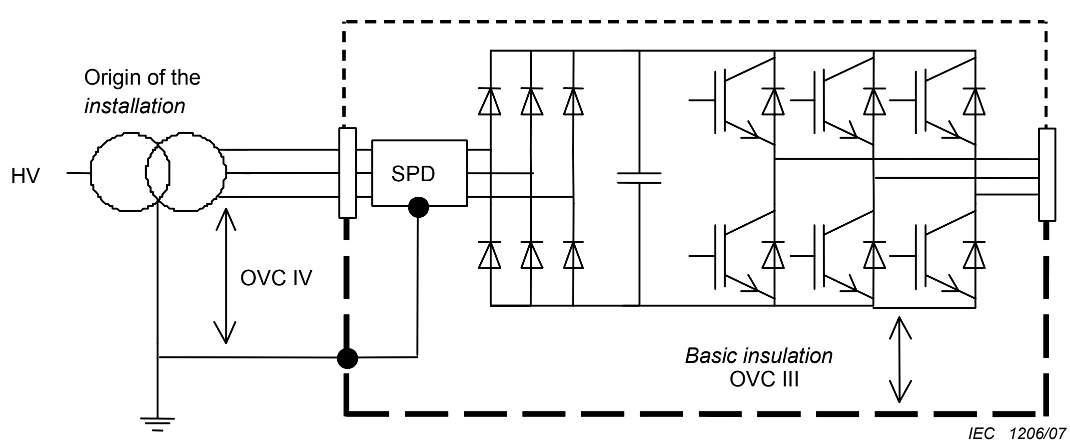


Figure B.4 – *Basic insulation* evaluation for circuits connected directly to the origin of the *installation* supply mains where internal SPDs are used

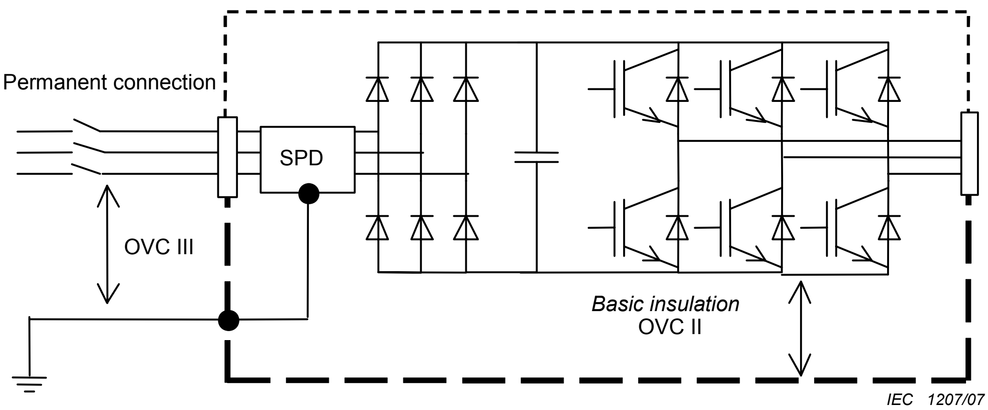


Figure B.5 - *Basic insulation* evaluation for circuits connected directly to the supply mains where internal SPDs are used

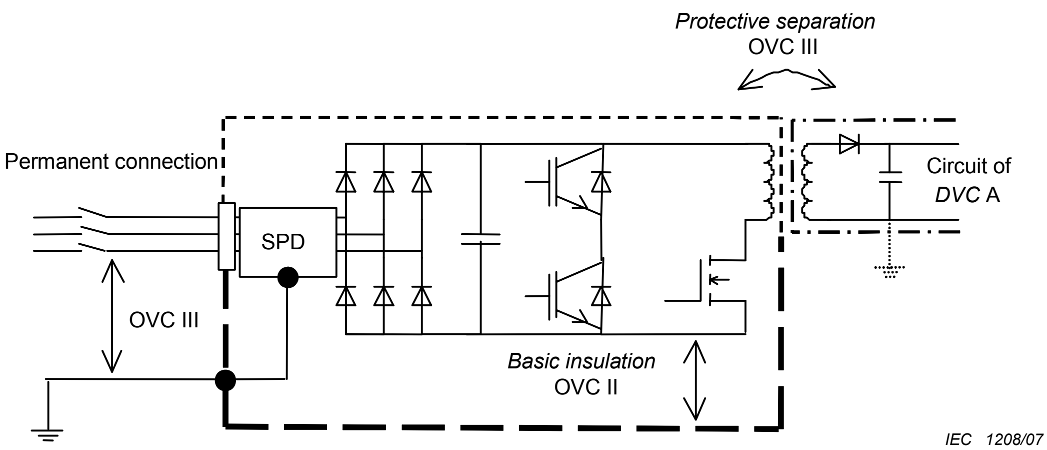


Figure B.6 – Example of *protective separation* evaluation for circuits connected directly to the supply mains where internal SPDs are used

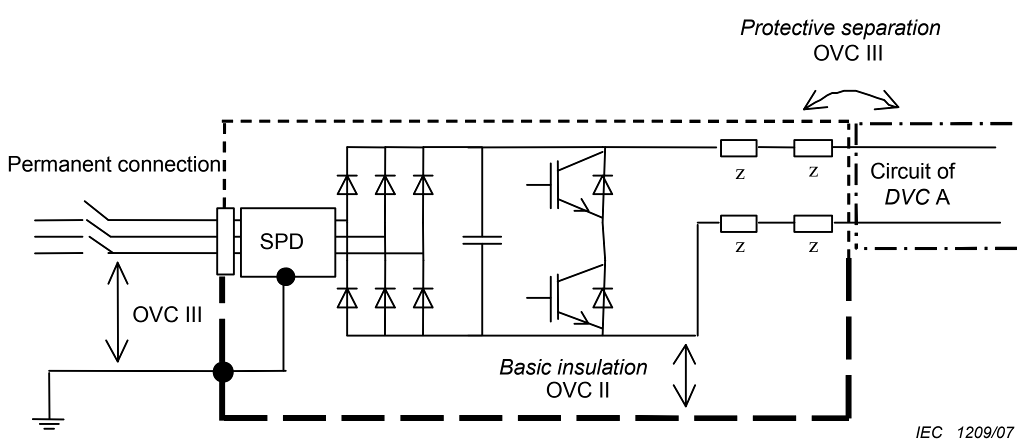


Figure B.7 – Example of *protective separation* evaluation for circuits connected directly to the supply mains where internal SPDs are used

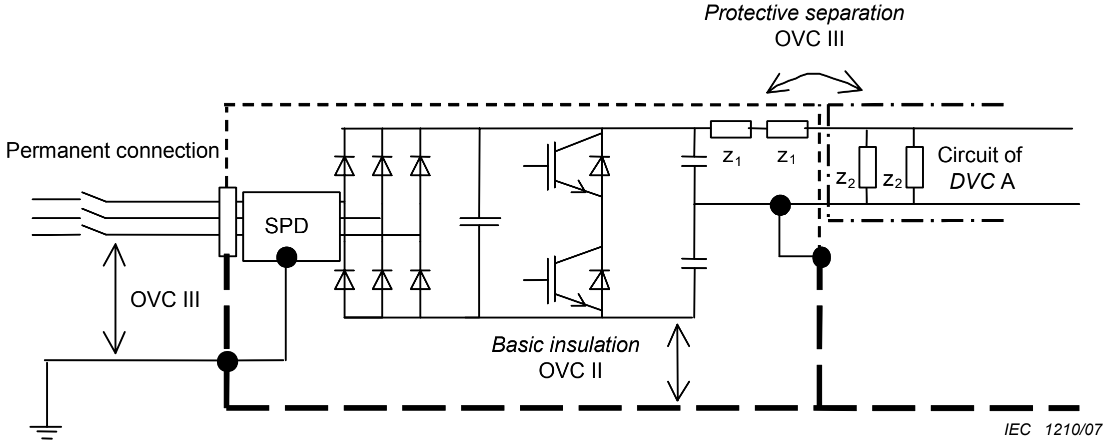


Figure B.8 Example of *protective separation* evaluation for circuits connected directly to the supply mains where internal SPDs are used

NOTE The requirements for *protective separation* in 5.2.3.1 to 5.2.3.3 are not reduced by the use of the SPD (see 4.3.6.2.2 and 4.3.6.2.3).

B.2.2 Circuits not connected directly to the supply mains (see 4.3.6.2.3)

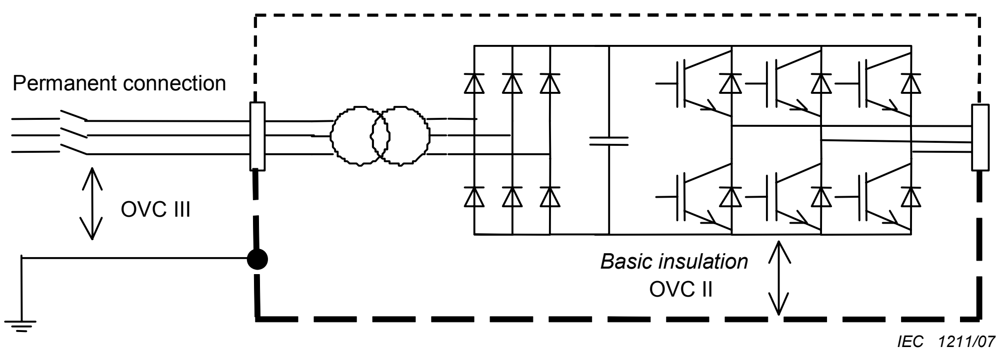


Figure B.9 – *Basic insulation* evaluation for circuits not connected directly to the supply mains

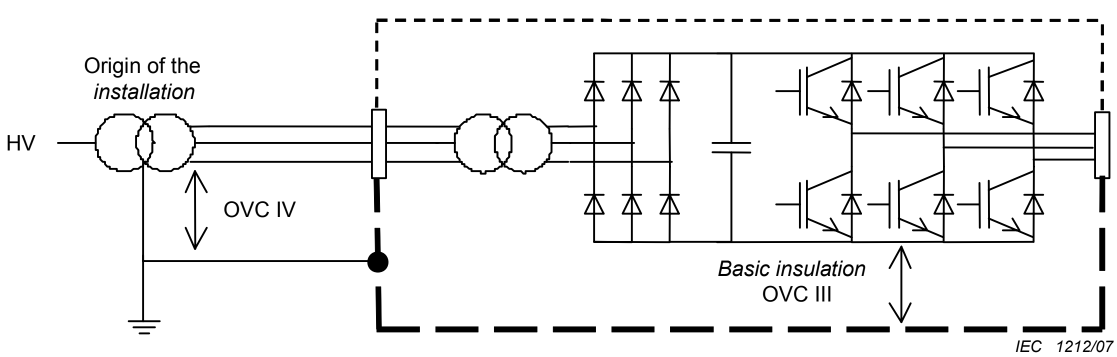
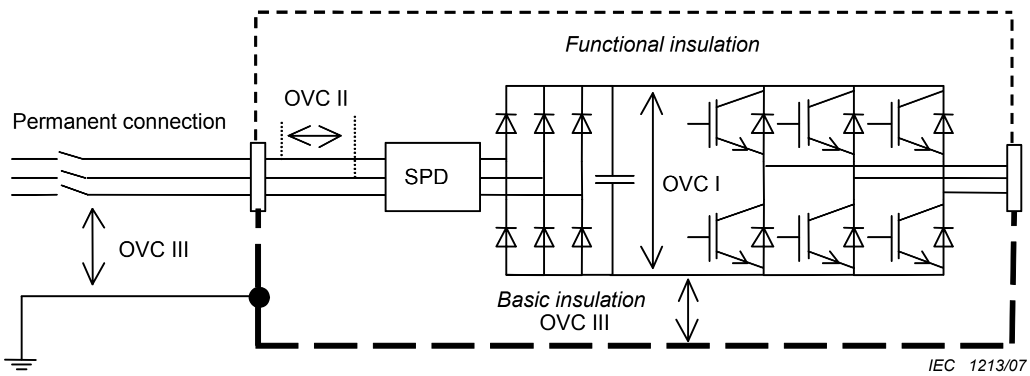


Figure B.10 – *Basic insulation* evaluation for circuits not connected directly to the supply mains

B.2.3 Insulation between circuits (see 4.3.6.2.4)

Insulation between two circuits shall be designed according to the circuit having the more severe requirement (see also Figure B.12).

B.3 *Functional insulation* (see 4.3.6.3)



NOTE 1 The SPD is not connected to earth, and so has no effect on the overvoltage catgory to earth.

NOTE 2 The requirements for functional insulation may be further reduced by the circuit characteristics (see 4.3.6.3).

Figure B.11 – *Functional insulation* evaluation within circuits affected by external transients

B.4 Further examples

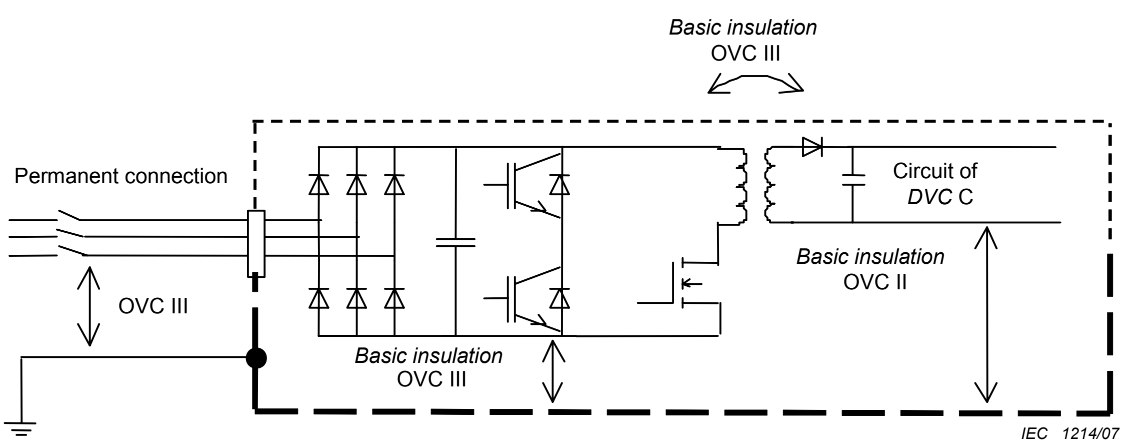


Figure B.12 – *Basic insulation* evaluation for circuits both connected and not connected directly to the supply mains

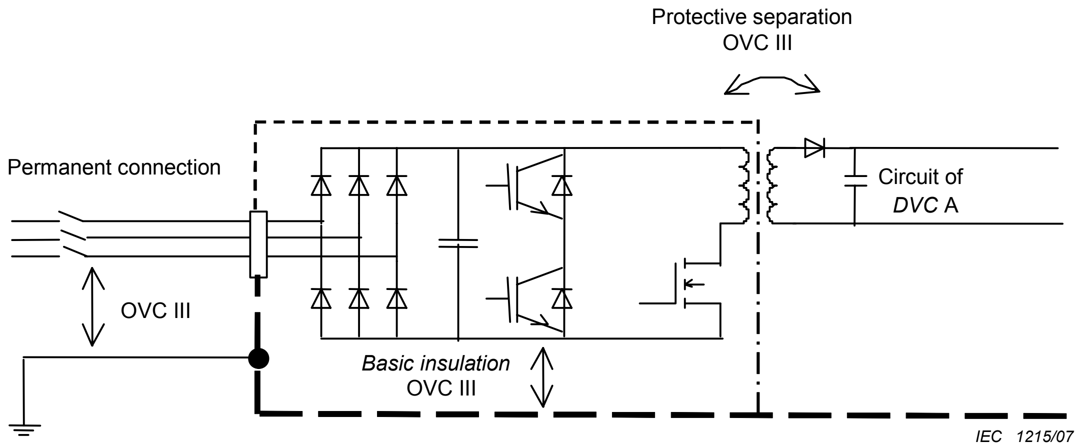


Figure B.13 – Insulation evaluation for accessible circuit of *DVC* A

Annex C
(normative)

Measurement of clearance and creepage distances

C.1 Measurement

Clearance and creepage distances shall be measured as illustrated in the examples contained in Examples C.1 to C.14.

C.2 Relationship of measurement to pollution degree

The "X" values are a function of pollution degree and shall be as specified in Table C.1. If the associated permitted clearance is less than 3 mm, the X value is one-third of the clearance.

Table C.1 – Width of grooves by pollution degree

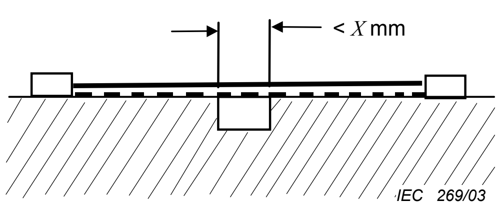
Pollution degree	X value mm
1	0,25
2	1,0
3	1,5

C.3 Examples

In the Examples C.1 to C.14 below, clearance and creepage distances are denoted as follows:

Clearance ———

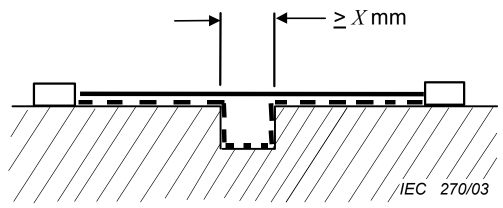
Creepage distance – – –



Example C.1

Condition: the path under consideration includes a parallel, diverging or converging-sided groove of any depth with a width less than X mm.

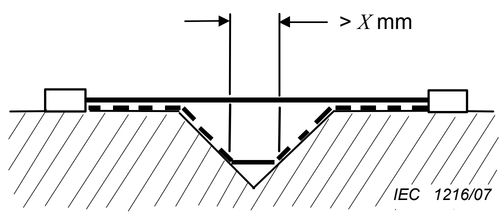
Rule: creepage distance and clearance are measured directly across the groove as shown.



Example C.2

Condition: Path under consideration includes a parallel or diverging-sided groove of any depth with a width equal to or more than X mm.

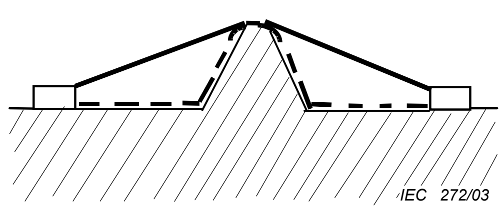
Rule: Clearance is the “line of sight” distance. Creepage path follows the contour of the groove.



Example C.3

Condition: Path under consideration includes a V-shaped groove with a width greater than X mm.

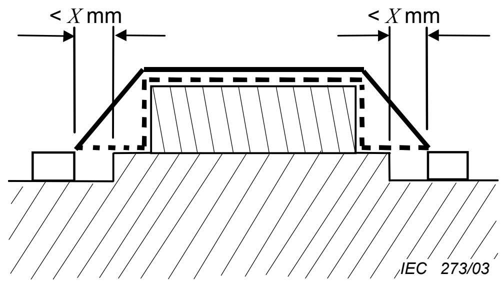
Rule: Clearance is the “line of sight” distance. Creepage path follows the contour of the groove but “short-circuits” the bottom of the groove by X mm link.



Example C.4

Condition: Path under consideration includes a rib.

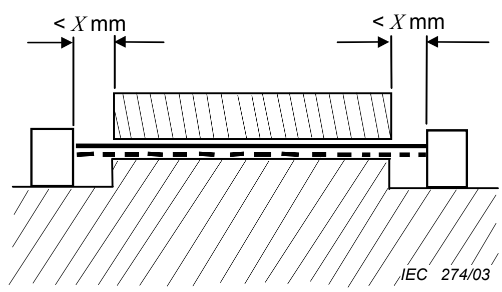
Rule: Clearance is the shortest air path over the top of the rib. Creepage path follows the contour of the rib.



Example C.5

Condition: Path under consideration includes a cemented joint with grooves less than *X* mm wide on each side.

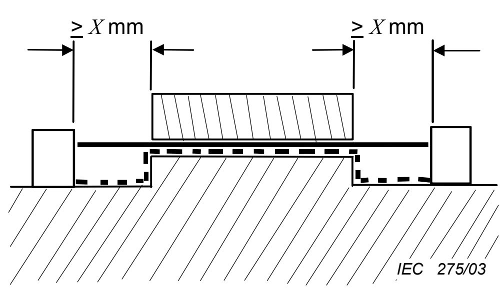
Rule: Clearance is the shortest air path over the top of the joint. Creepage distance is measured directly across the grooves and follows the contour of the joint.



Example C.6

Condition: Path under consideration includes an uncemented joint with grooves less than *X* mm wide on each side.

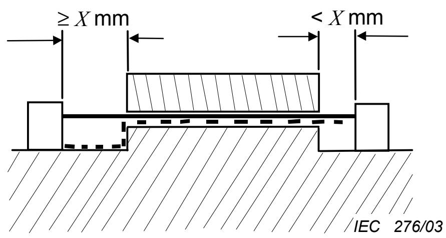
Rule: Creepage and clearance path is the “line of sight” distance shown.



Example C.7

Condition: Path under consideration includes an uncemented joint with grooves equal to or more than *X* mm wide on each side.

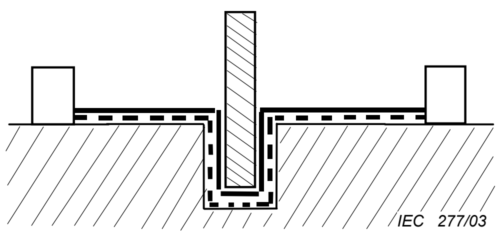
Rule: Clearance is the “line of sight” distance. Creepage path follows the contour of the grooves.



Example C.8

Condition: Path under consideration includes an uncemented joint with a groove on one side less than X mm wide and the groove on the other side equal to or more than X mm wide.

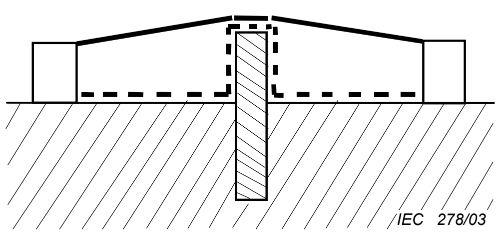
Rule: Clearance and creepage paths are as shown.



Example C.9

Condition: Path under consideration includes an uncemented barrier when path under the barrier is less than the path over the barrier.

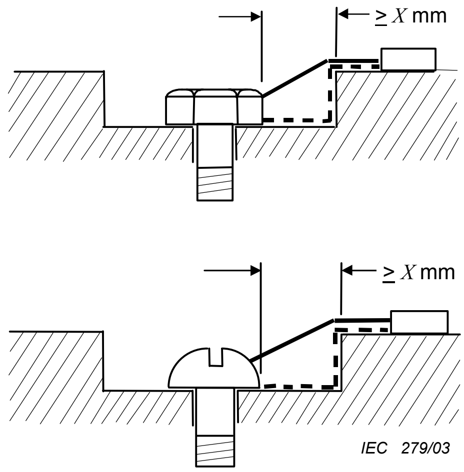
Rule: Clearance and creepage paths follow the contour under the barrier.



Example C.10

Condition: Path under consideration includes an uncemented barrier when path over the barrier is less than the path under the barrier.

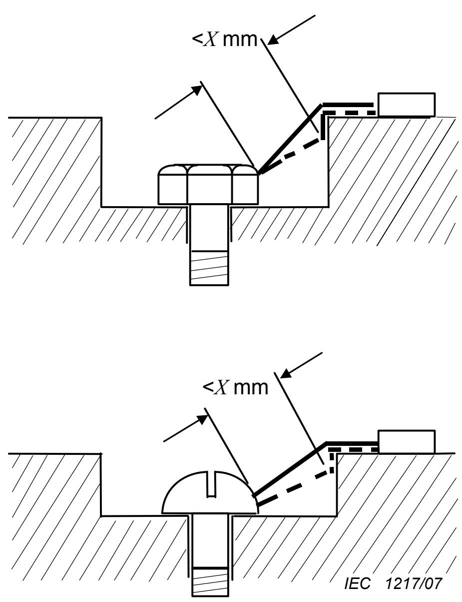
Rule: Clearance is the shortest air path over the top of the barrier. Creepage path follows the contour of the barrier.



Example C.11

Condition: Path under consideration includes a gap between head of screw and wall of recess which is equal to or more than X mm wide.

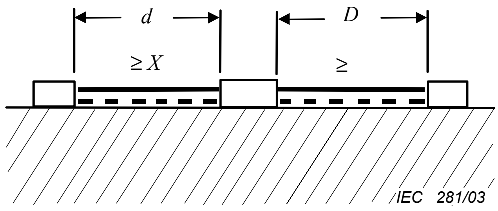
Rule: Clearance is the shortest air path through the gap and over the top surface. Creepage path follows the contour of the surfaces.



Example C.12

Condition: Path under consideration includes a gap between head of screw and wall of recess which is less than X mm wide.

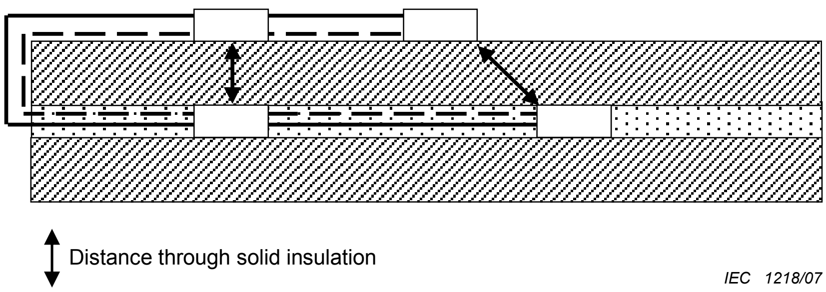
Rule: Clearance is the shortest air path through the gap and over the top surface. Creepage path follows the contour of the surfaces but “short-circuits” the bottom of the recess by X mm link.



Example C.13

Condition: Path under consideration includes an isolated part of conductive material.

Rule: Clearance and creepage paths are the sum of d plus D.



Example C.14

Condition: Path under consideration includes inner layer of PWB.

Rule: For the inner layer(s), the distance between adjacent tracks on the same layer is treated as creepage distance for pollution degree 1 and clearance as in air (see 4.3.6.8.4.1).

Annex D
(informative)

Altitude correction for clearances

Clearances in air are a function of the atmospheric pressure according to Paschen's Law. Clearance distances provided in Table 9 are valid up to 2000 m above sea level. Clearances above 2000 m must be multiplied by the factor provided in Table D.1.

Table D.1 – Correction factor for clearances at altitudes between 2 000 m and 20 000 m (see 4.3.6.4.1)

Altitude m	Normal barometric pressure kPa	Multiplication factor for clearances
2 000	80,0	1,00
3 000	70,0	1,14
4 000	62,0	1,29
5 000	54,0	1,48
6 000	47,0	1,70
7 000	41,0	1,95
8 000	35,5	2,25
9 000	30,5	2,62
10 000	26,5	3,02
15 000	12,0	6,67
20 000	5,5	14,50

Impulse tests performed below 2000 m altitude for the purpose of verifying air clearances must use test voltages which have been corrected for air pressure (altitude). Test voltages which have been corrected for three altitudes are provided in Table D.2. Altitude correction of test voltage is not required for impulse testing of solid insulation. The voltage values of Table D.2 apply for the verification of clearances only.

Table D.2 – Test voltages for verifying clearances at different altitudes

Impulse voltage (from Table 7) kV	Impulse test voltage at sea level kV	Impulse test voltage at 200 m altitude kV	Impulse test voltage at 500 m altitude kV
0,33	0,36	0,36	0,35
0,50	0,54	0,54	0,53
0,80	0,93	0,92	0,90
1,50	1,8	1,7	1,7
2,50	2,9	2,9	2,8
4,00	4,9	4,8	4,7
6,00	7,4	7,2	7,0
8,00	9,8	9,6	9,4
12,00	15	14	14

NOTE 1 Explanations concerning the influencing factors (air pressure, altitude, temperature, humidity) with respect to electric strength of clearances are given in 4.1.1.2.1.2 of IEC 60664-1.

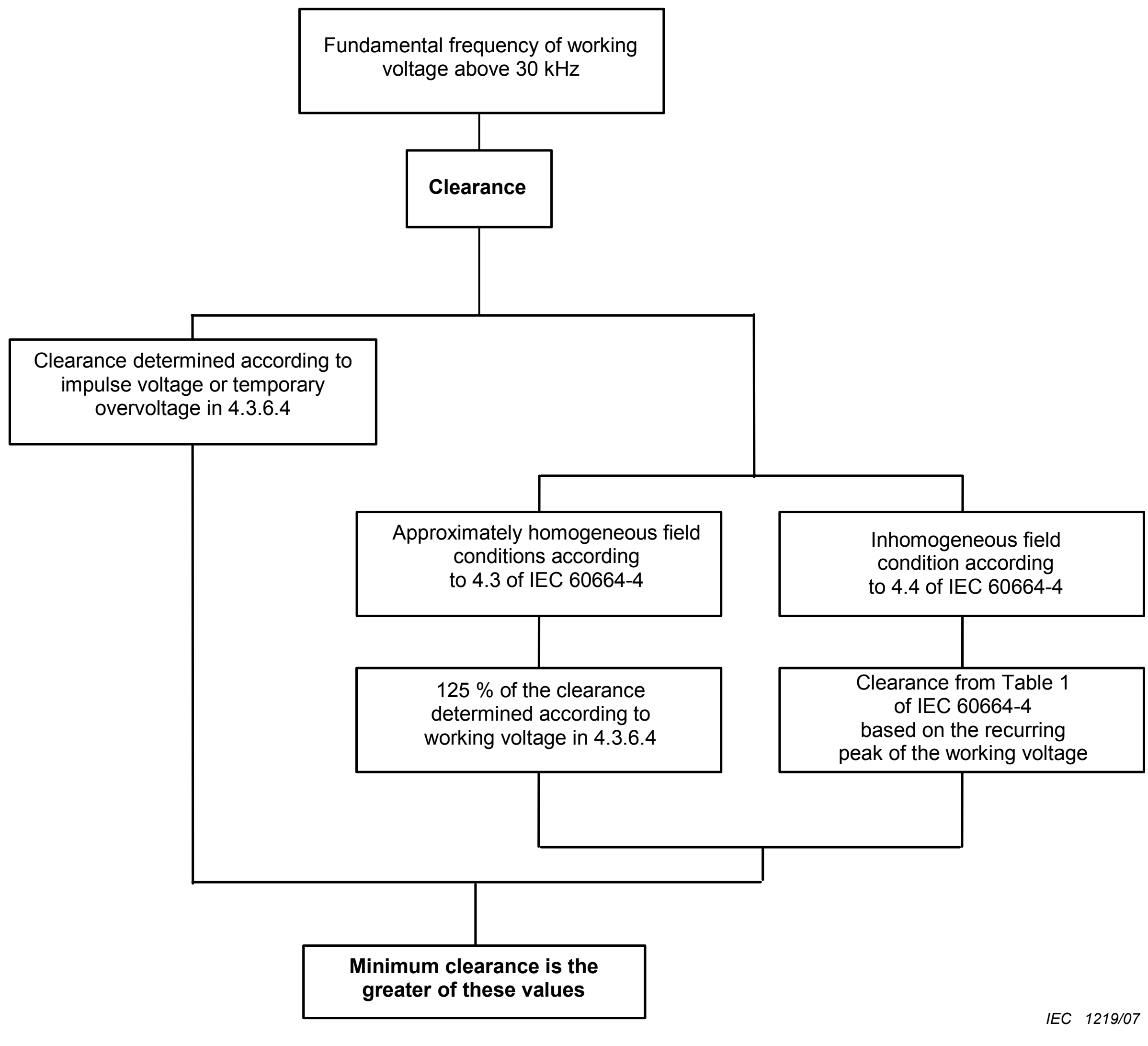
NOTE 2 When testing clearances, associated solid insulation will be subjected to the test voltage. As the impulse test voltage is increased with respect to the rated impulse voltage, solid insulation will be designed accordingly. This results in an increased impulse withstand capability of the solid insulation.

NOTE 3 Values given above have been rounded from the calculation in subclause 4.1.1.2.1.2 of IEC 60664-1.

Annex E
(informative)

Clearance and creepage distance determination for frequencies greater than 30 kHz

E.1 Clearance



NOTE For frequencies exceeding 30 kHz, an approximately homogeneous field is considered to exist when the radius of curvature *r* of the conductive parts is equal or greater than 20 % of the clearance. The necessary radius of curvature can only be specified at the end of the dimensioning procedure.

Figure E.1 – Determination of clearance for frequencies greater than 30 kHz

E.2 Creepage distance

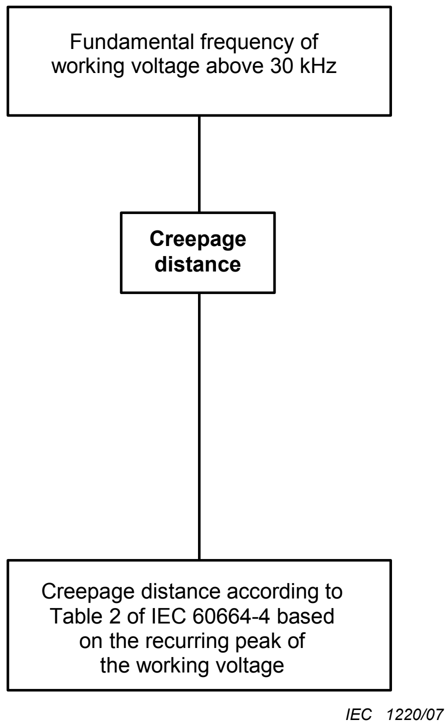


Figure E.2 – Determination of creepage for frequencies greater than 30 kHz

Table E.1 – Minimum values of clearances in air at atmospheric pressure for inhomogeneous field conditions (Table 1 of IEC 60664-4)

Peak voltage [a] kV	**Clearance** mm
≤ 0,6 [b]	0,065
0,8	0,18
1,0	0,5
1,2	1,4
1,4	2,35
1,6	4,0
1,8	6,7
2,0	11,0

[a] For voltages between the values stated in this table, interpolation is permitted.

[b] No data is available for peak voltages less than 0,6 kV.

Table E.2 – Minimum values of creepage distances for different frequency ranges (Table 2 of IEC 60664-4)

Peak voltage	Creepage distance [a] [b] (mm)						
kV	30 kHz < f ≤ 100 kHz	f ≤ 0,2 MHz	f ≤ 0,4 MHz	f ≤ 0,7 MHz	f ≤ 1 MHz	f ≤ 2 MHz	f ≤ 3 MHz
0,1	0,0167						0,3
0,2	0,042					0,15	2,8
0,3	0,083	0,09	0,09	0,09	0,09	0,8	20
0,4	0,125	0,13	0,15	0,19	0,35	4,5	
0,5	0,183	0,19	0,25	0,4	1,5	20	
0,6	0,267	0,27	0,4	0,85	5		
0,7	0,358	0,38	0,68	1,9	20		
0,8	0,45	0,55	1,1	3,8			
0,9	0,525	0,82	1,9	8,7			
1	0,6	1,15	3	18			
1,1	0,683	1,7	5				
1,2	0,85	2,4	8,2				
1,3	1,2	3,5					
1,4	1,65	5					
1,5	2,3	7,3					
1,6	3,15						
1,7	4,4						
1,8	6,1						

[a] The values for the creepage distances in the table apply for pollution degree 1. For pollution degree 2 a multiplication factor of 1,2 and for pollution degree 3 a multiplication factor 1,4 shall be used.

[b] Interpolation between columns is permitted.

Annex F
(informative)

Cross-sections of round conductors

Standard values of cross-section of round copper conductors are shown in Table F.1, which also gives the approximate relationship between ISO metric and AWG/MCM sizes.

Table F.1 – Standard cross-sections of round conductors

	AWG/MCM	
ISO cross-section mm^2	**Size**	**Equivalent cross-section** mm^2
0,2	24	0,205
–	22	0,324
0,5	20	0,519
0,75	18	0,82
1,0	–	–
1,5	16	1,3
2,5	14	2,1
4,0	12	3,3
6,0	10	5,3
10	8	8,4
16	6	13,3
25	4	21,2
35	2	33,6
50	0	53,5
70	00	67,4
95	000	85,0
–	0000	107,2
120	250 MCM	127
150	300 MCM	152
185	350 MCM	177
240	500 MCM	253
300	600 MCM	304
NOTE The dash, when it appears, counts as a size when considering connecting capacity (see 4.3.8.8.2)		

Annex G
(informative)

Guidelines for RCD compatibility

G.1 Selection of RCD type

Depending on the supply circuitry and the type of RCD (type A, AC or B – see IEC 60755), *PD*S and RCD/RCM can be compatible or incompatible (see 4.3.10). If circuits which can cause current with a d.c. component to flow in the *protective earthing conductor* during normal operation or during failure are not separated from the environment by *double* or *reinforced insulation*, it is considered that the *PDS* itself can cause smooth d.c. current and is therefore incompatible with RCDs of type A and AC.

The flow chart of Figure G.1 will help with the selection of the RCD type when using a *PDS* downstream of the RCD.

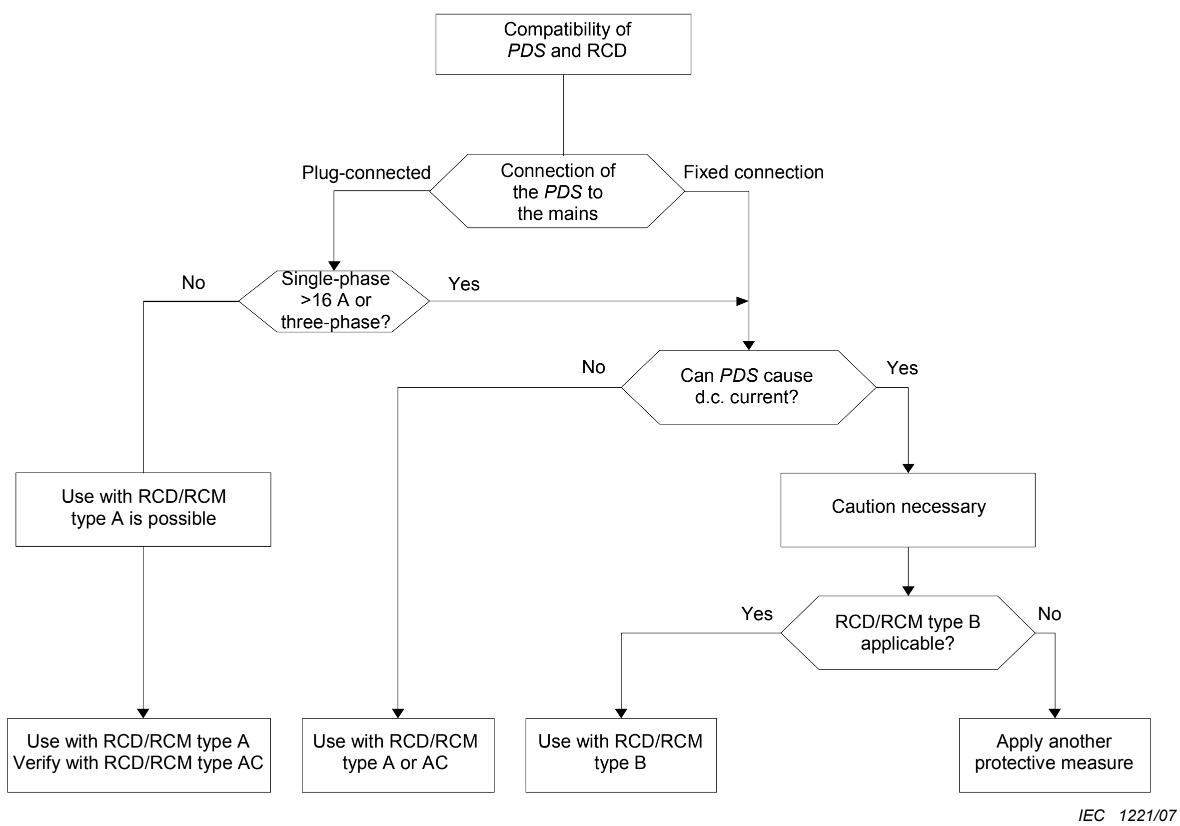
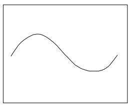


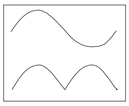
Figure G.1 – Flow chart leading to selection of the RCD/RCM type upstream of a *PDS*

RCDs suitable to be triggered by differing waveforms of residual current are marked with the following symbols, as defined in IEC 60755:

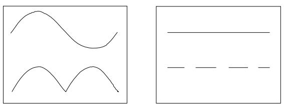
Type AC: – a.c. current sensitive (suitable for circuits 8 and 9 of Figure G.2)



Type AC: – a.c. current sensitive (suitable for circuits 8 and 9 of Figure G.2)



Type A: – a.c. current sensitive and pulse current sensitive (suitable for circuits 1, 4, 5, 8, 9 of Figure G.2)



Type B: – universal current sensitive (suitable for all circuits of Figure G.2)

G.2 Fault current waveforms

Figure G.2 shows typical fault current waveforms for different *PDS* circuit configurations, used to determine RCD compatibility.

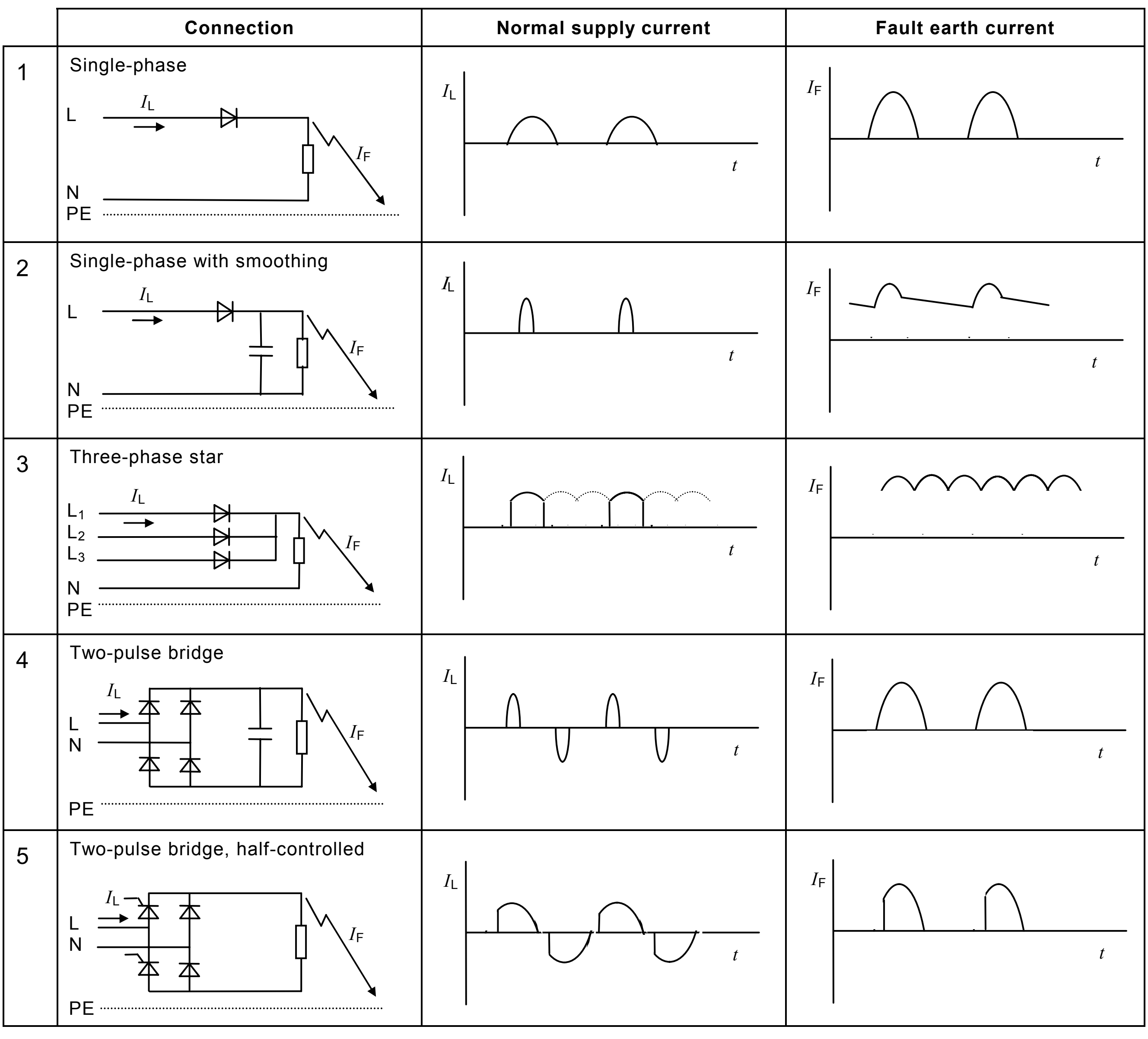


Figure G.2 – Fault current waveforms in connections with semiconductor devices

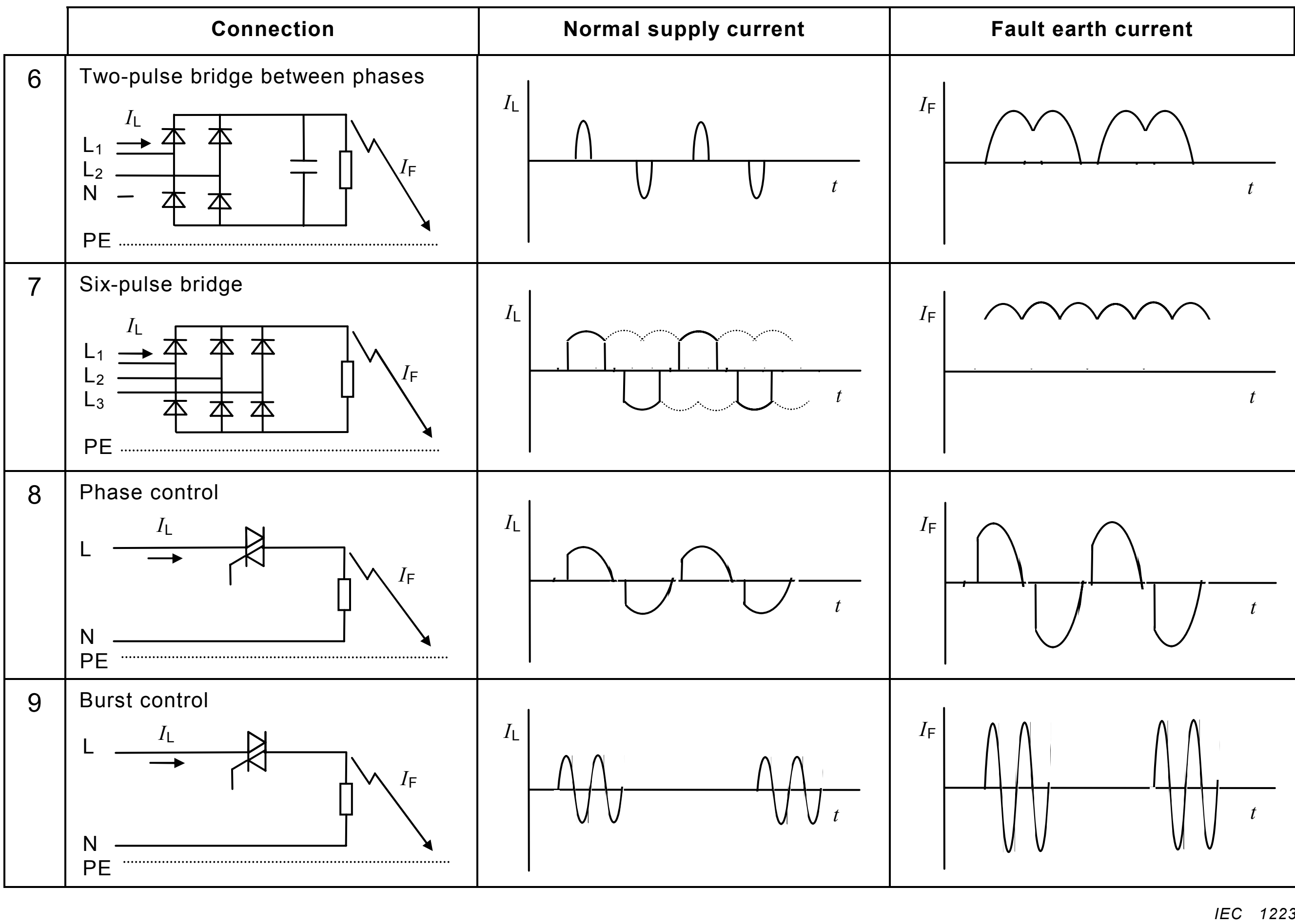


Figure G.2 – Fault current waveforms in connections with semiconductor devices
(continued)

Annex H
(informative)

Symbols referred to in this part of IEC 61800

Table H.1 – Symbols used

Symbol	Standard reference	Description	Subclauses
	IEC 60417–5019 (2006-08)	Protective earth; protective ground	6.3.6.6
	IEC 60417–5172 (2003-02)	Class II (double insulated) equipment	6.3.6.6
	IEC 60417-5018 (2006-10)	Functional earthing; functional grounding	6.3.6.6
	ISO 7000-0434 (2004-01)	Caution	6.3.6.7
	IEC 60417-5041 (2000-10)	Caution, hot surface	6.4.3.4
	IEC 60417-5036 (2002-10)	Dangerous voltage	6.5.2

Bibliography

IEC 60034-9, *Rotating electrical machines – Part 9: Noise limits*

NOTE Harmonized as EN 60034-9:2005 (modified).

IEC 60050-195:1998, *International Electrotechnical Vocabulary (IEV) – Part 195: Earthing and protection against electroshock*

IEC 60050-826:2004, *International Electrotechnical Vocabulary (IEV) – Part 826: Electrical installations*

IEC 60071 (all parts), *Insulation co-ordination*

NOTE Harmonized in EN 60071 series (not modified).

IEC 60071-1:2006, *Insulation co-ordination – Part 1: Definitions, principles and rules*

NOTE Harmonized as EN 60071-1:2006 (not modified).

IEC 60071-2:1996, *Insulation co-ordination – Part 2: Application guide*

NOTE Harmonized as EN 60071-2:1997 (not modified).

IEC 60146-1-1, *Semiconductor convertors – General requirements and line commutated convertors – Part 1-1: Specifications of basic requirements*

NOTE Harmonized as EN 60146-1-1:1993 (not modified).

IEC 60309-1, *Plugs, socket-outlets and couplers for industrial purposes – Part 1: General requirements*

NOTE Harmonized as EN 60309-1:1999 (not modified).

IEC 60364-4-44, *Electrical installations of buildings – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

NOTE Amendment 1:2003 to IEC 60364-4-44:2001 is harmonized as HD 60364-4-443:2006 (modified)

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

NOTE Harmonized in EN 60664 series (not modified).

IEC 60695-2-11:2000, *Fire hazard testing – Part 2-11: Glowing/hot-wire based test methods – Glow-wire flammabiliy test method for end-products*

NOTE Harmonized as EN 60695-2-11:2001 (not modified).

IEC 60695-2-12:2000, *Fire hazard testing – Part 2-12: Glowing/hot-wire based test methods – Glow-wire flammability test method for materials*

NOTE Harmonized as EN 60695-2-12:2001 (not modified).

IEC 60721 (all parts), *Classification of environmental conditions*

NOTE Harmonized in EN 60721 series (not modified).

IEC 61082 (all parts), *Preparation of documents used in electrotechnology*

NOTE Harmonized in EN 61082 series (not modified).

IEC 61140:2001, *Protection against electric shock – Common aspects for installation and equipment*

NOTE Harmonized as EN 61140:2002 (not modified).

IEC 61180-1:1992, *High-voltage test techniques for low-voltage equipment – Part 1: Definitions, test and procedure requirements*

NOTE Harmonized as EN 61180-1:1994 (not modified).

IEC 61189-2, *Test methods for electrical materials, printed boards and other interconnection structures and assemblies – Part 2: Test methods for materials for interconnection structures*

NOTE Harmonized as EN 61189-2:2006 (not modified).

IEC 61643-12:2002, *Low-voltage surge protective devices – Part 12: Surge protective devices connected to low-voltage power distribution systems – Selection and application principles*

NOTE Harmonized as CLC/TS 61643-12:2006 (modified).

IEC 61800-3:2004, *Adjustable speed electrical power drive systems – Part 3: EMC requirements and specific test methods*

NOTE Harmonized as EN 61800-3:2004 (not modified).

IEC 62079:2001, *Preparation of instructions – Structuring, content and presentation*

NOTE Harmonized as EN 62079:2001 (not modified).

IEC 62103:2003, *Electronic equipment for use in power installations*

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60034	Series	Rotating electrical machines	EN 60034	Series
IEC 60034-1	-[1]	Rotating electrical machines - Part 1: Rating and performance	EN 60034-1	2004[2]
IEC 60034-5	-[1]	Rotating electrical machines - Part 5: Degrees of protection provided by the integral design of rotating electrical machines (IP code) - Classification	EN 60034-5	2001[2]
IEC 60050-111	-[1]	International Electrotechnical Vocabulary (IEV) - Chapter 111: Physics and chemistry	-	-
IEC 60050-151	-[1]	International Electrotechnical Vocabulary (IEV) - Part 151: Electrical and magnetic devices	-	-
IEC 60050-161	-[1]	International Electrotechnical Vocabulary (IEV) - Chapter 161: Electromagnetic compatibility	-	-
IEC 60050-191	-[1]	International Electrotechnical Vocabulary (IEV) - Chapter 191: Dependability and quality of service	-	-
IEC 60050-441	-[1]	International Electrotechnical Vocabulary (IEV) - Chapter 441: Switchgear, controlgear and fuses	-	-
IEC 60050-442	-[1]	International Electrotechnical Vocabulary (IEV) - Part 442: Electrical accessories	-	-
IEC 60050-551	-[1]	International Electrotechnical Vocabulary (IEV) - Part 551: Power electronics	-	-
IEC 60050-601	-[1]	International Electrotechnical Vocabulary (IEV) - Chapter 601: Generation, transmission and distribution of electricity - General	-	-

[1] Undated reference.

[2] Valid edition at date of issue.

Publication	Year	Title	EN/HD	Year
IEC 60060-1	1989	High-voltage test techniques - Part 1: General definitions and test requirements	HD 588.1 S1	1991
IEC 60068-2-2	1974	Environmental testing - Part 2: Tests - Tests B: Dry heat	EN 60068-2-2[3)]	1993
IEC 60068-2-6	-[1)]	Environmental testing - Part 2: Tests - Test Fc: Vibration (sinusoidal)	EN 60068-2-6	1995[2)]
IEC 60068-2-78	-[1)]	Environmental testing - Part 2-78: Tests - Test Cab: Damp heat, steady state	EN 60068-2-78	2001[2)]
IEC 60112	2003	Method for the determination of the proof and the comparative tracking indices of solid insulating materials	EN 60112	2003
IEC 60204-11	-[1)]	Safety of machinery - Electrical equipment of machines - Part 11: Requirements for HV equipment for voltages above 1 000 V a.c. or 1 500 V d.c. and not exceeding 36 kV	EN 60204-11	2000
IEC 60309 (mod)	Series	Plugs, socket-outlets and couplers for industrial purposes	EN 60309	Series
IEC 60364-1 (mod)	-[1)]	Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, definitions	-[4)]	-
IEC 60364-5-54 (mod)	2002	Electrical installations of buildings - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements, protective conductors and protective bonding conductors	HD 60364-5-54	2007
IEC 60417	Data-base	Graphical symbols for use on equipment	-	-
IEC 60529	1989	Degrees of protection provided by enclosures (IP Code)	EN 60529 + corr. May	1991 1993
IEC 60617	Data-base	Graphical symbols for diagrams	-	-
IEC 60664-1 + A1 + A2	1992 2000 2002	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests	EN 60664-1 [5)]	2003
IEC 60664-3	2003	Insulation coordination for equipment within low-voltage systems - Part 3: Use of coating, potting or moulding for protection against pollution	EN 60664-3	2003

[3)] EN 60068-2-2 includes supplement A:1976 to IEC 60068-2-2.

[4)] IEC 60364-1:2005 (modified) will be submitted to formal vote for acceptance as HD 60364-1.

[5)] EN 60664-1 is superseded by EN 60664-1:2007, which is based on IEC 60664-1:2007.

Publication	Year	Title	EN/HD	Year
IEC 60664-4	2005	Insulation coordination for equipment within low-voltage systems - Part 4: Consideration of high-frequency voltage stress	EN 60664-4 + corr. October	2006 2006
IEC 60695-2-10	-[1)]	Fire hazard testing - Part 2-10: Glowing/hot-wire based test methods - Glow-wire apparatus and common test procedure	EN 60695-2-10	2001[2)]
IEC 60695-2-13	-[1)]	Fire hazard testing - Part 2-13: Glowing/hot-wire based test methods - Glow-wire ignitability test method for materials	EN 60695-2-13	2001[2)]
IEC 60695-11-10	-[1)]	Fire hazard testing - Part 11-10: Test flames - 50 W horizontal and vertical flame test methods	EN 60695-11-10	1999[2)]
IEC 60695-11-20	-[1)]	Fire hazard testing - Part 11-20: Test flames - 500 W flame test methods	EN 60695-11-20	1999[2)]
IEC/TR 60755	-[1)]	General requirements for residual current operated protective devices	-	-
IEC 60947-7-1	2002	Low-voltage switchgear and controlgear - Part 7-1: Ancillary equipment - Terminal blocks for copper conductors	EN 60947-7-1	2002
IEC 60947-7-2	2002	Low-voltage switchgear and controlgear - Part 7-2: Ancillary equipment - Protective conductor terminal blocks for copper conductors	EN 60947-7-2	2002
IEC 60990	1999	Methods of measurement of touch current and protective conductor current	EN 60990	1999
IEC 61230 (mod)	-[1)]	Live working - Portable equipment for earthing or earthing and short-circuiting	EN 61230 +A11	1995[2)] 1999
IEC 61800-1	-[1)]	Adjustable speed electrical power drive systems - Part 1: General requirements - Rating specifications for low voltage adjustable speed d.c. power drive systems	EN 61800-1	1998[2)]
IEC 61800-2	-[1)]	Adjustable speed electrical power drive systems - Part 2: General requirements - Rating specifications for low voltage adjustable frequency a.c. power drive systems	EN 61800-2	1998[2)]
IEC 61800-4	-[1)]	Adjustable speed electrical power drive systems - Part 4: General requirements - Rating specifications for a.c. power drive systems above 1 000 V a.c. and not exceeding 35 kV	EN 61800-4	2003[2)]
IEC 62020	-[1)]	Electrical accessories - Residual current monitors for household and similar uses (RCMs)	-	-

Publication	Year	Title	EN/HD	Year
IEC 62271-102	-[1)]	High-voltage switchgear and controlgear - Part 102: Alternating current disconnectors and earthing switches	EN 62271-102 + corr. March	2002[2)] 2005
ISO 3864	Series	Graphical symbols - Safety colours and safety signs	-	-
ISO 7000	2004	Graphical symbols for use on equipment - Index and synopsis	-	-

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