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**IEC
CEI**

**NORME
INTERNATIONALE**

61800-5-1

Second edition
Deuxième édition
2007-07

**Adjustable speed electrical
power drive systems –**

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

**Entraînements électriques de
puissance à vitesse variable –**

**Partie 5-1:
Exigences de sécurité –
Electrique, thermique et énergétique**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ADJUSTABLE SPEED ELECTRICAL POWER DRIVE SYSTEMS –**Part 5-1: Safety requirements –
Electrical, thermal and energy**

FOREWORD

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International Standard IEC 61800-5-1 has been prepared by subcommittee 22G: Semiconductor power converters for adjustable speed electric drive systems, of IEC technical committee 22: Power electronic systems and equipment.

This second edition cancels and replaces the first edition published in 2003. It constitutes a technical revision.

The major areas of change in this edition are the following:

- a) addition of alphabetical Table 1 in Clause 3;
- b) addition of Table 2 in 4.1 for relevance to PDS/CDM/BDM;
- c) addition of Table 4 summary of decisive voltage class requirements;
- d) expansion of subclause on protective bonding (4.3.5.3);

- e) clarification of distinction between touch current and protective conductor current;
- f) revision of section on insulation (now 4.3.6) to include solid insulation;
- g) addition of overvoltage categories I and II to HV insulation voltage;
- h) revision of section on Solid insulation (now 4.3.6.8)
- i) addition of high-frequency insulation requirements (4.3.6.9, Annex E);
- j) addition of requirements for liquid-cooled PDS (4.4.5);
- k) addition of climatic and vibration tests (5.2.6);
- l) clarification of voltage test procedure to avoid over-stress of basic insulation (5.2.3.2.3);
- m) revision of short-circuit test requirement for large, high-voltage and one-off PDS (now 5.2.3.6);
- n) addition of informative Annex B for overvoltage category reduction.

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

FDIS	Report on voting
22G/178/FDIS	22G/181/RVD

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

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 61800 series, published under the general title *Adjustable speed electrical power drive systems*, can be found on the IEC website.

Terms in *italics* in the text are defined in Clause 3.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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 coating, potting or moulding for protection against pollution*

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

IEC 60695-2-10, *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)*

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 <i>PDS</i>	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 <i>ELV</i> (SELV) circuit	3.35
commissioning test	3.6	protective <i>ELV</i> (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 <i>PDS</i>	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 <i>PDS</i>	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**

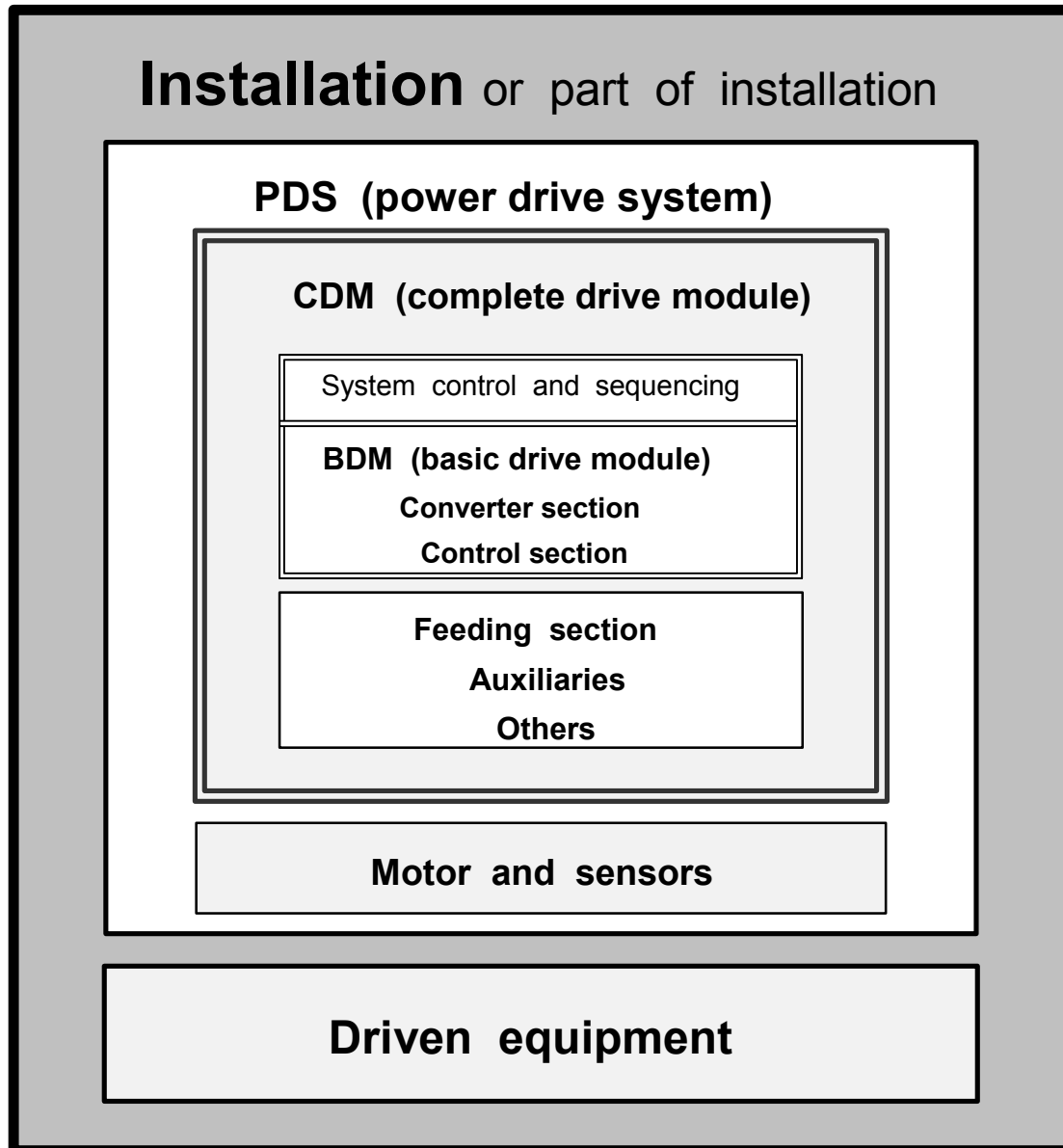
voltage, at rated supply conditions (without tolerances) and worst case operating conditions, which occurs by design in a circuit or across insulation

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.



IEC 1197/07

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	<i>PDS</i> ^a	<i>CDM/BDM</i>
4.2	(Protection against electric shock, thermal, and energy hazards) - Fault conditions	A	A
4.3.1	<i>Decisive voltage classification</i>	A	A
4.3.2	<i>Protective separation</i>	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 <i>live parts</i> and accessible conductive parts	A	C
4.3.5.3	4.1.1.1 <i>Protective bonding circuit</i>	A	C
4.3.5.4	<i>Protective earthing conductor</i>	A	A
4.3.5.5	Means of connection for the <i>protective earthing conductor</i>	A	A
4.3.5.6	Special features in equipment for <i>protective class II</i>	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 <i>high-voltage PDS</i>	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 <i>PDS</i>	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 <i>CDM</i> or <i>BDM</i> is incorporated into an assembly that provides the required protection.			
^a <i>Integrated PDS</i> shall meet the requirement for <i>PDS</i> .			

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 <i>working voltage</i> (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 $3 \times \sqrt{2} \times 1\,000\text{ V} = 4\,242\text{ V}$).

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 <i>adjacent circuit</i> 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.

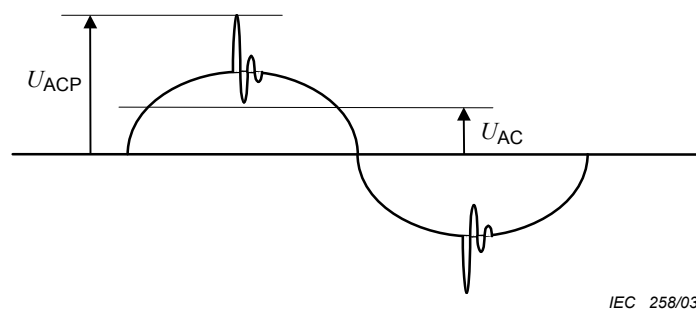
‡ It is permitted to use *basic insulation* for the circuit of higher voltage if protection against direct contact is applied to the considered circuit by *basic* or *supplementary insulation* for the circuit of higher voltage.

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

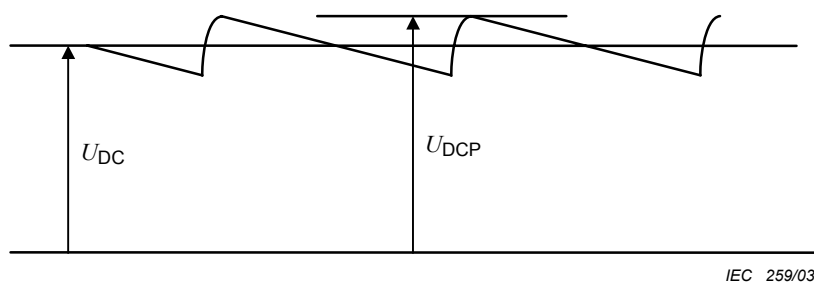
Figure 2 – Typical waveform for a.c. working voltage

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

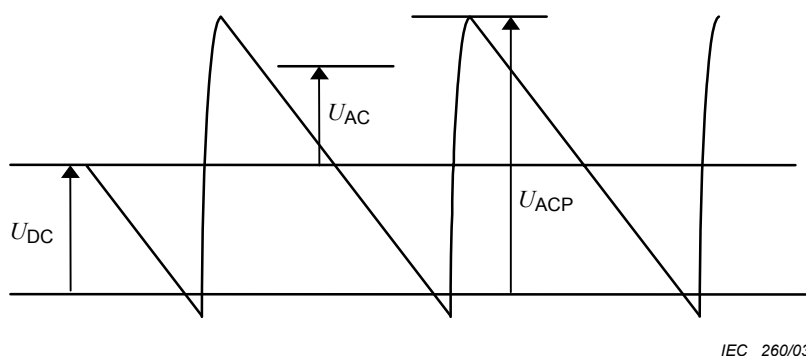
Figure 3 – Typical waveform for d.c. working voltage

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.

Type of insulation	Insulation configuration		
	a Accessible parts conductive and connected to earth by <i>protective bonding</i>	b Accessible parts not conductive	c Accessible parts conductive, but NOT connected to earth by <i>protective bonding</i>
1) Solid or liquid			
2) Totally or partially by air clearance			
3) Insulation for adjacent circuits:			
Circuit A: lower voltage circuit			
Circuit C: higher voltage circuit; upper row – DVC C only, lower row – DVC C or D			
4) Requirements for apertures in enclosures			
A live part	L ₁ clearance for <i>basic insulation</i>	T test finger (Clause 12 of IEC 60529)	
B basic insulation for circuit A	L ₂ clearance for <i>reinforced insulation</i>	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.			

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

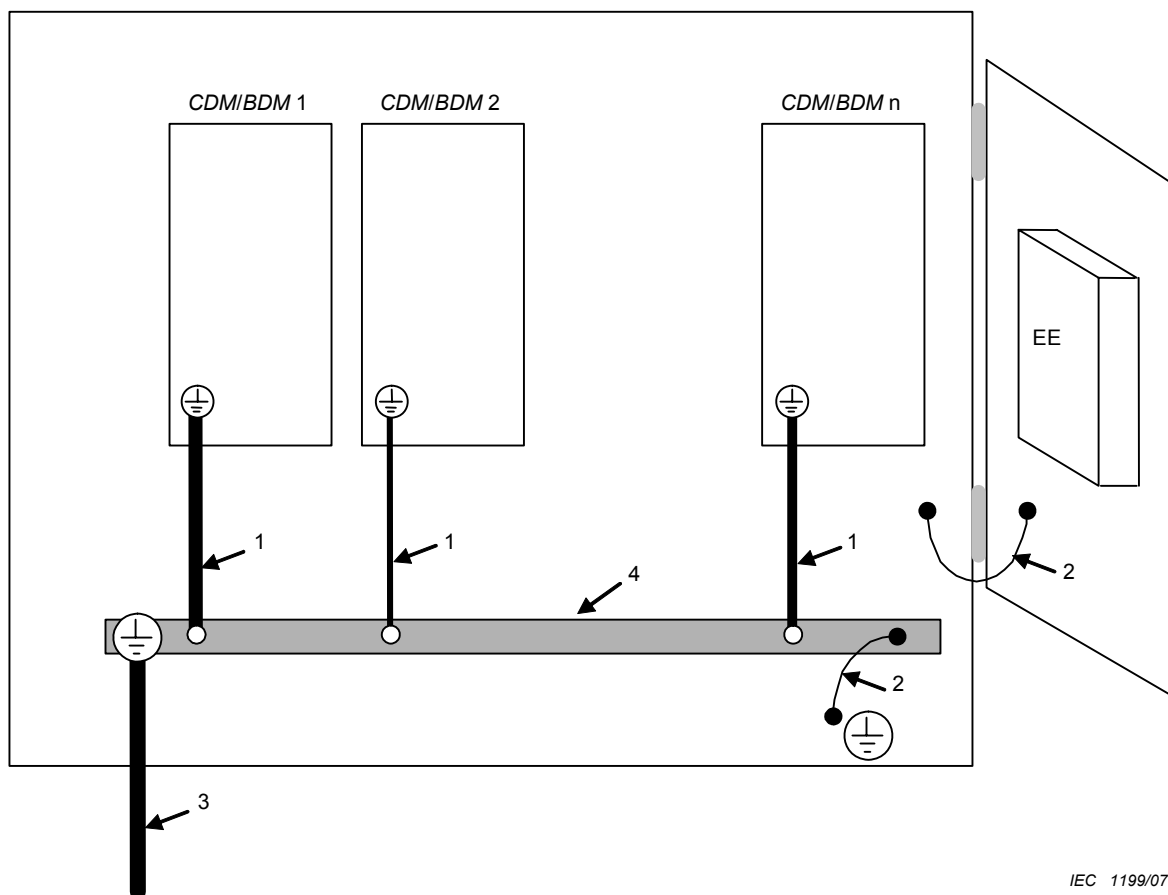
4.3.5.3.1 General

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*.



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- 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.

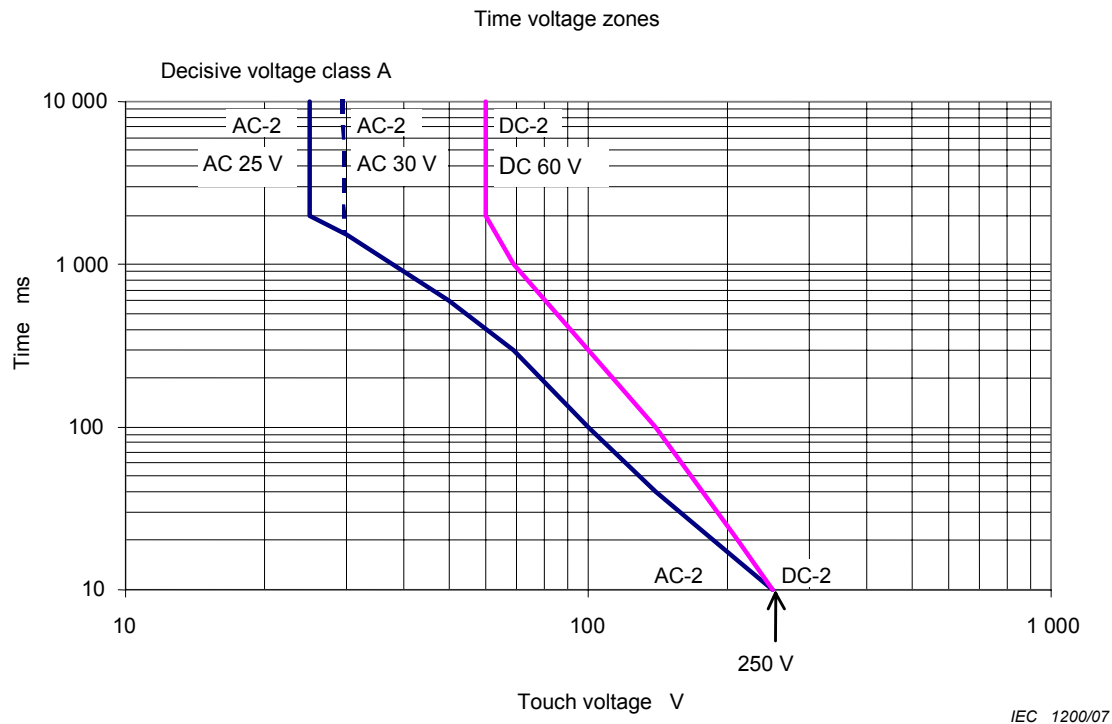
These conditions will be satisfied if the cross-section of the *protective bonding* conductor is the same as that for the *protective earthing conductor* according to 4.3.5.4. For testing, see 5.2.3.9.

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 <i>PDS/CDM/BDM</i> S (mm ²)	Minimum cross-sectional area of the corresponding <i>protective earthing conductor</i> S_p (mm ²)
$S \leq 16$	S
$16 < S \leq 35$	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 mm² if mechanical protection is provided,
or
- 4 mm² if mechanical protection is not provided. For cord-connected equipment, provisions shall be made so that the *protective earthing conductor* in the cord shall, in the case of failure of the strain-relief mechanism, be the last conductor to be interrupted.

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 mm² Cu or 16 mm² 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 mm² 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 <i>PDS</i> 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:

- instructions are provided with the *PDS* indicating that it shall be installed in a pollution degree 2 environment,
or
- the specific installation application of the *PDS* is known to be a pollution degree 2 environment,
or
- 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 60364-1 describes 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)				Temporary overvoltage (crest value / r.m.s.) ^a (V)
	Overvoltage category				
	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 + <i>system voltage</i>) 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	
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 <i>temporary overvoltage</i> and <i>working voltage</i> 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 $CTI \geq 600$;
- Insulating material group II $600 > CTI \geq 400$;
- Insulating material group IIIa $400 > CTI \geq 175$;
- Insulating material group IIIb $175 > CTI \geq 100$.

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.) (V)	PWBs ^a		Other insulators								
	Pollution degree		Pollution degree								
	1	2	1	2				3			
	b	c	b	Insulating material group				Insulating material group			
				I	II	IIIa	IIIb	I	II	IIIa	IIIb
≤ 2	0,025	0,04	0,056	0,35	0,35	0,35		0,87	0,87	0,87	
5	0,025	0,04	0,065	0,37	0,37	0,37		0,92	0,92	0,92	
10	0,025	0,04	0,08	0,40	0,40	0,40		1,0	1,0	1,0	
25	0,025	0,04	0,125	0,50	0,50	0,50		1,25	1,25	1,25	
32	0,025	0,04	0,14	0,53	0,53	0,53		1,3	1,3	1,3	
40	0,025	0,04	0,16	0,56	0,80	1,1		1,4	1,6	1,8	
50	0,025	0,04	0,18	0,60	0,85	1,20		1,5	1,7	1,9	
63	0,04	0,063	0,20	0,63	0,90	1,25		1,6	1,8	2,0	
80	0,063	0,10	0,22	0,67	0,95	1,3		1,7	1,9	2,1	
100	0,10	0,16	0,25	0,71	1,0	1,4		1,8	2,0	2,2	
125	0,16	0,25	0,28	0,75	1,05	1,5		1,9	2,1	2,4	
160	0,25	0,40	0,32	0,80	1,1	1,6		2,0	2,2	2,5	
200	0,40	0,63	0,42	1,0	1,4	2,0		2,5	2,8	3,2	
250	0,56	1,0	0,56	1,25	1,8	2,5		3,2	3,6	4,0	
320	0,75	1,6	0,75	1,6	2,2	3,2		4,0	4,5	5,0	
400	1,0	2,0	1,0	2,0	2,8	4,0		5,0	5,6	6,3	
500	1,3	2,5	1,3	2,5	3,6	5,0		6,3	7,1	8,0	
630	1,8	3,2	1,8	3,2	4,5	6,3		8,0	9,0	10,0	
800	2,4	4,0	2,4	4,0	5,6	8,0		10,0	11	12,5	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 of Table 21, Table 22, or Table 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, or Table 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 cm² or having any dimension larger than 150 mm;
- not less than 1,2 mm thick for an area of 155 cm² or less and having no dimension larger than 150 mm.

The area under evaluation may be bounded by reinforcing ribs subdividing a larger area.

Malleable iron or permanent-mould cast aluminium, brass, bronze, or zinc, 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 cm² or having any dimension more than 150 mm;

- at least 1,5 mm thick for an area of 155 cm² 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	
100 120	Not limited 150	160 170	Not limited 210	0,6 ^d
150 180	Not limited 220	240 250	Not limited 320	0,75 ^d
200 230	Not limited 290	310 330	Not limited 410	0,9
320 350	Not limited 460	500 530	Not limited 640	1,2
460 510	Not limited 640	690 740	Not limited 910	1,4
560 640	Not limited 790	840 890	Not limited 1 090	1,5
640 740	Not limited 910	990 1 040	Not limited 1 300	1,8
840 970	Not limited 1 200	1 300 1 370	Not limited 1 680	2,0
1 070 1 200	Not limited 1 500	1 630 1 730	Not limited 2 130	2,5
1 320 1 520	Not limited 1 880	2 030 2 130	Not limited 2 620	2,8
1 600 1 850	Not limited 2 290	2 460 2 620	Not limited 3 230	3,0
^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.