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IEC TC 109 : INSULATION CO-ORDINATION FOR LOW-VOLTAGE EQUIPMENT

SECRETARIAT: Germany	SECRETARY: Mr Toni Hoffmann
OF INTEREST TO THE FOLLOWING COMMITTEES: TC 2,TC 8,TC 9,TC 13,SC 17A,SC 17C,TC 22,TC 23,SC 23B,SC 23E,SC 23H,TC 28,TC 31,SC 37A,TC 38,TC 42,SC 48B,TC 61,TC 64,TC 66,TC 69,TC 70,TC 72,TC 82,TC 88,TC 91,TC 96,TC 99,TC 105,TC 108,TC 120,TC 121,SC 121A,SC 121B	PROPOSED HORIZONTAL STANDARD: ☒ Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.

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TITLE:

Insulation coordination for equipment within low-voltage supply systems - Part 1: Principles, requirements and tests (Proposed horizontal standard)

NOTE FROM TC/SC OFFICERS:

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INSULATION COORDINATION FOR EQUIPMENT WITHIN LOW-VOLTAGE SUPPLY SYSTEMS –

Part 1: Principles, requirements and tests

FOREWORD

International Standard IEC 60664 has been prepared by IEC technical committee 109: Insulation co-ordination for low-voltage equipment.

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

FDIS	Report on voting
XX/XX/FDIS	XX/XX/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.

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

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- withdrawn,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

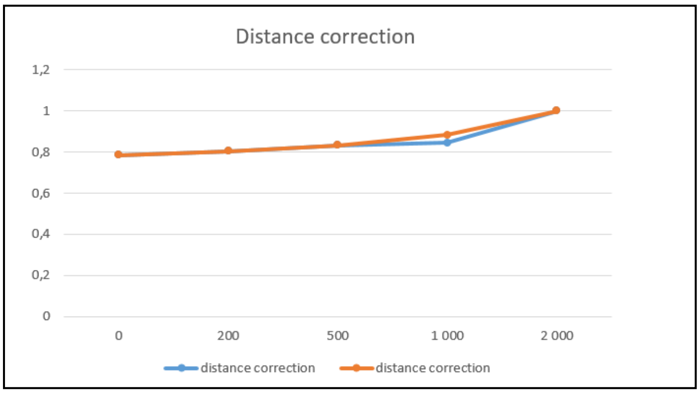
The National Committees are requested to note that for this publication the stability date is .... THIS TEXT IS INCLUDED FOR THE INFORMATION OF THE NATIONAL COMMITTEES AND WILL BE DELETED AT THE PUBLICATION STAGE.

IMPORTANT – The "colour inside" logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this publication using a colour printer.

Informations regarding this working document:

– No major technical change compares to the previous edition IEC 60664-1 Ed2,
– Scope, Clauses 2 and 3 have been updated from IEC 60664-1 Ed2,
– Addition of 1 500 V DC into tables,
– Clauses 4 and 5 are based on a new structure,
– Annex G for clearances is added,
– Annex H for creepage distances is added,
– Automatic cross references added,
– Defined terms written in bold letters throughout the document,
– Technical countries committees are invited to have a view to try to valid values to Table F.9. Value 0,884 seems to be in line with other standards and more logical if you have a look to the curve below:

Altitude m	**Factor k_d for distance correction**	**Factor k_d for distance correction**
0	0,784	0,784
200	0,803	0,803
500	0,833	0,833
1 000	0,844	**0,884**
2 000	1	1



1 Scope

This part of IEC 60664 deals with **insulation coordination** for equipment having a **rated voltage** up to AC 1 000 V or a **rated voltage** up to DC 1 500 V connected to **low-voltage supply systems**.

Thisdocument applies to frequencies up to 30 kHz.

NOTE 1 **Insulation coordination** for equipment within low-voltage supply systems with rated frequencies above 30 kHz is given in IEC 60664-4.

NOTE 2 Higher voltages can exist in internal circuits of the equipment.

It applies to equipment for use up to 2 000 m above sea level, and provides guidance for use at higher altitudes.

It provides requirements for technical committees to determine **clearances**, **creepage distances** and criteria for **solid insulation**. It includes methods of electric **testing** with respect to **insulation coordination**.

The minimum **clearances** specified in this document do not apply where ionized gases occur. Special requirements for such situations can be specified at the discretion of the relevant technical committee.

This document does not deal with distances:

– through liquid **insulation**;

– through gases other than air;

– through compressed air.

This document is primarily intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC Guide 104 and ISO/IEC Guide 51. However, in case of missing specified values for clearances, creepage distances and requirements for solid insulation in the relevant product standards, or even missing standards, this document can be used.

One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications. The requirements, **test** methods or **test** conditions of this basic safety publication will not apply unless specifically referred to or included in the relevant publications.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60038:2009, *IEC standard voltages*

IEC 60068-1:2013, *Environmental testing – Part 1: General and guidance*

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

IEC 60068-2-14:2009, *Environmental testing – Part 2-14: Tests – Test N: Change of temperature*

IEC 60068-2-78:2012, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state*

IEC 60085:2007, *Electrical insulation – Thermal evaluation and designation*

IEC 60099-1:1991[1], *Surge arresters – Part 1: Non-linear resistor type gapped surge arresters for a.c. systems*

[1] IEC 60099-1 has been withdrawn

IEC 60112:2003, Method for the determination of the proof and the comparative tracking indices of solid insulating materials
IEC 60112:2003/AMD1:2009

IEC 60216, (all parts) *Electrical insulating materials – Thermal endurance properties*

IEC 60270:2000, *High-voltage test techniques – Partial discharge measurements*

IEC 60664-3:2016, *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 60364-4-44:2007, *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

IEC 61000-4-5:2014, *Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test*

IEC 61140:2016, *Protection against electric shock – Common aspects for installation and equipment*

IEC 61180:2016, *High-voltage test techniques for low-voltage equipment –Definitions, test and procedure requirements*

IEC Guide 104:2010, *The preparation of safety publications and the use of basic safety publications and group safety publications*

ISO/IEC Guide 51:2014, *Safety aspects — Guidelines for their inclusion in standards*

3 Terms, definitions and abbreviations

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

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

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

3.1 Terms and definitions

3.1.1
low-voltage supply system
all installations and plant provided for the purpose of generating, transmitting and distributing electricity

[SOURCE: IEC 60050-601:1985, 601-01-01, modified – Title “low-voltage supply system” instead of “electric power system – electricity supply system”]

3.1.2
insulation coordination
mutual correlation of **insulation** characteristics of electrical equipment taking into account the expected **micro-environment** and other influencing stresses

Note 1 to entry: Expected voltage stresses are characterized in terms of the characteristics defined in 3.1.6 to 3.1.17.

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-09-01, modified – “electrical” instead of “electric” and Note 1 to entry has been added]

3.1.3
clearance
shortest distance in air between two conductive parts

Note 1 to entry: This distance can be measured along a string stretched the shortest way between these conductive parts.

[SOURCE: IEC 60050-581:2008, 581-27-76, modified – Note 1 to entry has been added.]

3.1.4
creepage distance
shortest distance along the surface of a solid insulating material between two conductive parts

[SOURCE: IEC 60050-151:2001, 151-15-50]

3.1.5
solid insulation
solid insulating material or a combination of solid insulating materials, placed between two conductive parts or between a conductive part and a body part

[SOURCE: IEC 60050-903:2015, 903-04-14, modified – without the example]

3.1.6
working voltage
highest r.m.s. value of the AC or DC voltage across any particular **insulation** which can occur when the equipment is supplied at **rated voltage**

Note 1 to entry: **Transient overvoltage**s are disregarded.

Note 2 to entry: Both open-circuit conditions and normal operating conditions are taken into account.

[SOURCE: IEC 60050-851:2008, 851-12-31]

3.1.7
steady-state working voltage
working voltage after the transient voltage phenomena have subsided

3.1.8
steady-state peak voltage
peak value of the **steady-state voltage**

3.1.9
recurring peak voltage
U_{rp}
maximum peak value of periodic excursions of the voltage waveform resulting from distortions of an AC voltage or from AC components superimposed on a DC voltage

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-09-15, modified – Note 1 to entry has been deleted]

3.1.10
overvoltage
any voltage having a peak value exceeding the corresponding peak value of maximum **steady-state voltage** at normal operating conditions

3.1.11
temporary overvoltage
overvoltage at power frequency of relatively long duration

[SOURCE: IEC 60050-614:2016, 614-03-13, modified – “overvoltage at power frequency” instead of “power frequency overvoltage” and Note 1 to entry has been deleted]

3.1.12
transient overvoltage
short duration **overvoltage** of a few milliseconds or less, oscillatory or non-oscillatory, usually highly damped

[SOURCE: IEC 60050-614:2016, 614-03-14, modified – “short duration overvoltage” instead of “overvoltage with a duration” and Note 1 to entry and Note 2 to entry have been deleted]

3.1.13
withstand voltage
voltage to be applied to a specimen under prescribed **test** conditions which does not cause breakdown and/or **flashover** of a satisfactory specimen

3.1.14
impulse withstand voltage
highest peak value of impulse voltage of prescribed form and polarity which does not cause breakdown of **insulation** under specified conditions

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-09-18]

3.1.15
r.m.s. withstand voltage
r.m.s. value of sinusoidal power frequency voltage that the equipment can withstand during tests made under specified conditions and for a specified duration

[SOURCE: IEC 60050-581:2008, 581-21-21]

3.1.16
recurring peak withstand voltage
highest peak value of a recurring voltage which does not cause breakdown of **insulation** under specified conditions

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-09-20]

3.1.17
temporary withstand overvoltage
highest r.m.s value of a temporary **overvoltage** which does not cause breakdown of **insulation** under specified conditions

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-09-19]

3.1.18
rated voltage
U_n
value of voltage assigned by the manufacturer, to a component, device or equipment and to which operation and performance characteristics are referred

Note 1 to entry: Equipment may have more than one **rated voltage** value or may have a **rated voltage** range.

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-09-10, modified – “value of voltage” instead of “rated value of the voltage” and Note 2 to entry has been deleted]

3.1.19
rated insulation voltage
U_i
value of the rms withstand voltage assigned by the manufacturer to the equipment or to a part of it, characterizing the specified (long-term) withstand capability of its **insulation**

Note 1 to entry: The **rated insulation voltage** is equal to or greater than the **rated voltage** of equipment which is primarily related to functional performance.

[SOURCE: IEC 60050-312:2015, 312-06-02, modified – "rated value" has been replaced by "value"]

3.1.20
rated impulse withstand voltage
U_{imp}
impulse withstand voltage value assigned by the manufacturer to the equipment or to a part of it, characterizing the specified withstand capability of its **insulation** against **transient overvoltages**

3.1.21
rated temporary withstand overvoltage
temporary withstand overvoltage value assigned by the manufacturer to the equipment, or to a part of it, characterizing the specified short-term withstand capability of its **insulation** against AC voltages

3.1.22
overvoltage category
numeral defining a **transient overvoltage** condition

Note 1 to entry: **Overvoltage categories** I, II, III and IV are used, see 4.3.2.

[SOURCE: IEC 60050-581:2008, 581-21-02, modified – Note 1 to entry has been added]

3.1.23
environment
surrounding which may affect performance of a device or system

Note 1 to entry: Examples are pressure, temperature, humidity, **pollution**, radiation and vibration.

3.1.24
macro-environment
environment of the room or other location in which the equipment is installed or used

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-01-55]

3.1.25
micro-environment
immediate **environment** of the **insulation** which particularly influences the dimensioning of the **creepage distances**

[SOURCE: IEC 60050-851:2008, 851-15-16]

3.1.26
pollution
any condition of foreign matter, solid, liquid or gaseous (ionized gases), that may affect dielectric strength or surface resistivity

3.1.27
pollution degree
numeral characterizing the expected **pollution** of the **micro-environment**

[SOURCE: IEC 60050-581:2008, 581-21-07, modified – Note 1 to entry has been deleted]

3.1.28
homogeneous field
electric field which has an essentially constant voltage gradient between electrodes

Note 1 to entry: The **homogeneous field** condition is referred to as case B in Table F.2 and Table F.8a.

3.1.29
inhomogeneous field
electric field which does not have an essentially constant voltage gradient between electrodes (non-uniform field)

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-09-03, modified – "inhomogeneous field" instead of "inhomogeneous electric field" and Note 1 to entry and Note 2 to entry have been deleted]

3.1.30
Insulation
that part of an electrotechnical product which separates the conducting parts at different electrical potentials during operation or insulates such parts from the surroundings

[SOURCE: IEC 60050-212:2010, 212-11-07, modified – title without "electric" and "that part" instead of "part"]

3.1.31
functional insulation
insulation between conductive parts which is necessary only for the proper functioning of the equipment

3.1.32
basic insulation
insulation of hazardous-live-parts which provides basic protection

Note 1 to entry: This concept does not apply to insulation used exclusively for functional purposes.

[SOURCE: IEC 60050-826:2004, 826-12-14]

3.1.33
supplementary insulation
independent **insulation** applied in addition to **basic insulation** for fault protection

[SOURCE: IEC 60050-826:2004, 826-12-15]

3.1.34
double insulation
insulation comprising both **basic insulation** and **supplementary insulation**

[SOURCE: IEC 60050-826:2004, 826-12-16]

3.1.35
reinforced insulation
insulation of hazardous-live-parts which provides a degree of protection against electric shock equivalent to **double insulation**

Note 1 to entry: **Reinforced insulation** may comprise several layers which cannot be tested singly as **basic insulation** or **supplementary insulation**.

[SOURCE: IEC 60050-826:2004, 826-12-17]

3.1.36
partial discharge
PD
electric discharge that partially bridges the **insulation**

Note 1 to entry: A **partial discharge** may occur inside the **insulation** or adjacent to a conductor.

Note 2 to entry: Scintillations of low energy on the surface of insulating materials are often described as **partial discharges** but should rather be considered as disruptive discharges of low energy, since they are the result of local dielectric breakdowns of high ionization density, or small arcs, according to the conventions of physics.

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-09-05, modified – Notes 1 to entry and Note 2 to entry have been added]

3.1.37
apparent charge
q_{app}
electric charge which can be measured at the terminals of the specimen under **test**

Note 1 to entry: The **apparent charge** is smaller than the **partial discharge**.

Note 2 to entry: The measurement of the **apparent charge** requires a short-circuit condition at the terminals of the specimen (see Clause D.2) under **test**.

[SOURCE: IEC 60050-442:1998/AMD1:2015, 442-09-06, modified – In the Note 2 to entry, “(see Clause D.2)” has been added]

3.1.38
specified discharge magnitude
magnitude of the **apparent charge** which is regarded as the limiting value according to the objective of this document

Note 1 to entry: The pulse with the maximum amplitude should be evaluated.

Note 2 to entry: Adapted to be in accordance with the objective of this document.

[SOURCE: IEC 60050-442:1998/AMD1;2015, 442-09-07, modified – “which” instead of “when this”, introduction of “according to the objective of this document” and Note 2 to entry has been added]

3.1.39
pulse repetition rate
average number of pulses per second with an **apparent charge** higher than the detection level

Note 1 to entry: Within the scope of this document, it is not permitted to weigh discharge magnitudes according to the **pulse repetition rate**.

3.1.40
partial discharge inception voltage
PDU_i
lowest peak value of the **test** voltage at which the **apparent charge** becomes greater than the **specified discharge magnitude** when the **test** voltage is increased above a low value for which no discharge occurs

Note 1 to entry: For AC **tests** the r.m.s. value may be used.

[SOURCE: IEC 60050-212 2015/AMD1, 212-11-41]

3.1.41
partial discharge extinction voltage
PDU_e
lowest peak value of the **test** voltage at which the **apparent charge** becomes less than the **specified discharge magnitude** when the **test** voltage is reduced below a high level where such discharges have occurred

Note 1 to entry: For AC **tests** the r.m.s. value may be used.

3.1.42
partial discharge test voltage
PDU_t
peak value of the voltage in a partial discharge test, where the **apparent charge** is less than the **specified discharge magnitude**

Note 1 to entry: For AC **tests** the r.m.s. value may be used.

[SOURCE: IEC 60050-212:2014, 212-11-62, modified – Note 1 to entry has been deleted, Note 2 to entry is renumbered as Note 1 to entry]

3.1.43
test
technical operation that consists of the determination of one or more characteristics of a given product, process or service according to a specified procedure

Note 1 to entry: A **test** is carried out to measure or classify a characteristic or a property of an item by applying to the item a set of environmental and operating conditions and/or requirements.

[SOURCE: IEC 60050-151:2001, 151-16-13]

3.1.44
type test
test made on one or more devices representative to a certain design to check the conformity to the specifications

3.1.45
routine test
conformity **test** made on each individual item during or after manufacture

[SOURCE: IEC 60050-151:2001, 151-16-17]"

3.1.46
sampling test
test on a number of devices taken at random from a batch

[SOURCE: IEC 60050-811:1991, 811-10-06]

3.1.47
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

3.1.48
sparkover
electrical breakdown in a gaseous or liquid medium

3.1.49
flashover
electric breakdown between conductors in a gas or a liquid or in vacuum, at least partly along the surface of **solid insulation**

3.1.50
puncture
electrical breakdown through **solid insulation**

[SOURCE: IEC 60050-614:2016, 614-03-17, modified – “electrical breakdown” instead of “disruptive discharge” and “insulation” instead of “dielectric”]

3.2 Abbreviations

Alphabetical list of terms with abbreviations together with the subclause where they are first used:

Abbreviations	Term	Subclause
U_n	**rated voltage**	3.1.18
U_i	**rated insulation voltage**	3.1.19
U_{imp}	**rated impulse withstand voltage**	3.1.20
U_{rp}	**recurring peak voltage**	3.1.9
q_{app}	**apparente charge**	3.1.37
PD	**partial discharge**	3.1.36
PDU_i	**partial discharge inception voltage**	3.1.40
PDU_e	**partial discharge extinction voltage**	3.1.41
PDU_t	**partial discharge test voltage**	3.1.42

4 Basic technical characteristics for insulation coordination

4.1 General

Insulation coordination requires the selection of the electric **insulation** technical characteristics of the equipment with regard to its application and in relation to its surroundings. It represents one aspect of the safety of persons, livestock and property, so that the probability of undesired incidents due to voltage stresses does not lead to an unacceptable risk of harm.

NOTE See ISO/IEC Guide 51 and IEC Guide 116 for further details about risk assessment and unacceptable risk of harm.

Electric **insulation** technical characteristics cover:

– voltages across the **insulation** according to 4.2
– **overvoltage categories** according to 4.3;
– frequency according to 4.4;
– **pollution degree** according to 4.5;
– **insulation** materials according to 4.6; and
– environmental aspects according to 4.7 (e.g. temperature, altitude, vibrations, humidity, duration);
– field distribution according to 4.8.

Insulation coordination can only be achieved if the design of the equipment is based on the stresses to which it is likely to be subjected during its intended life.

4.2 Voltages

4.2.1 General aspects

When considering **insulation** performances, the following aspects are relevant:

– the voltages which can appear within the system:
  - **transient overvoltages** and **overvoltage category** according to 4.2.2;
  - **temporary overvoltages** according to 4.2.3.

– the voltages generated by the equipment (which could adversely affect other equipment in the system):
  - **recurring peak voltage** according to 4.2.4;
  - **steady-state working voltage** according to 4.2.5;
  - **steady-state peak voltage** according to 4.2.6.

4.2.2 Transient overvoltages

4.2.2.1 General

To apply the concept of **insulation coordination**, **transient overvoltage** shall be taken into consideration. The **transient overvoltages** that shall be considered are:

– **transient overvoltages** generated by atmospheric disturbances (for example indirect lightning strikes) and transmitted by the supply distribution system;

– **transient overvoltages** generated due to switching of loads in the supply system;

– **transient overvoltages** generated by external circuits; and

– **transient overvoltages** generated internally in the equipment.

Insulation coordination uses a preferred series of values of impulse voltages. The preferred values of rated impulse withstand voltage are:

330 V, 500 V, 800 V, 1 500 V, 2 500 V, 4 000 V, 6 000 V, 8 000 V, 12 000 V.

4.2.2.2 Transient overvoltages entering through the mains

To determine the expected transients generated by atmospheric disturbances or due to switching of loads in the supply system, the **rated voltage** (U_n) and the **overvoltage category** are normally used as the basis to determine the required impulse withstand voltage.

For equipment that is likely, when installed, to be subjected to transient voltages that exceed those of the **overvoltage category** typically defined for such kind of equipment, these transient voltages shall be taken into account.

4.2.2.3 Transient overvoltages generated by external circuits

The applicable value of the transient voltage that may occur on any external circuit (for example coax or twisted pair networks) shall be determined. Where more than one external circuit is present, the highest transient voltage applies.

If the external circuit transient voltages are known to be higher than the one from the **overvoltage category** typically defined for such kind of equipment, the highest value of these know transient voltages shall be used.

4.2.2.4 Transient overvoltages generated internally in the equipment

For the equipment capable of generating an **overvoltage** that is higher than the transients expected to come in to the equipment, for example due to switching devices, the required impulse voltage shall take into account the transient generated in the equipment.

4.2.2.5 Attenuation of transient voltage levels

Equipment or parts of equipment may be used under conditions where the transients are reduced. For example, attenuation of the transient can occur due to:

– an **overvoltage** protective device;

NOTE SPD, is some applications, can allow voltage coordination between devices installed and using different performances regarding their overvoltage category.

– a transformer with isolated windings, where the secondary winding is earthed, or a transformer employing an earth screen between primary and secondary or any kind of attenuation system coupling with transformer;

– a distribution system with a multiplicity of branch circuits capable of diverting energy of surges;

– a capacitance capable of absorbing energy of surges; or

– a resistance or similar damping device capable of dissipating the energy of surges.

Attention is drawn to the fact that an **overvoltage** protective device within the installation or within equipment may have to dissipate more energy than an **overvoltage** protective device at the origin of the installation having a higher protection level (clamping voltage). This applies particularly to the **overvoltage** protective device with the lowest protection level (clamping voltage).

In case attenuation of the transient is expected, the transient voltage across the **insulation** may be measured by applying the required impulse **test** to the equipment and measuring the actual remaining transient over the **insulation**. The measured value may be used as the expected transient voltage. While performing the **test**, transients of both polarities shall be considered.

4.2.3 Temporary overvoltages

Due to faults on the public mains distribution system **temporary overvoltages** between lines and earth/neutral of several seconds will be generated and shall be considered when applying the concept of **insulation coordination**.

Insulation coordination with regard to **temporary overvoltages** is based on the **temporary overvoltage** specified in Clause 442 of IEC 60364-4-44: 2007. The values of **temporary overvoltage** in low-voltage equipment due to an earth fault in the high-voltage system are given in 5.4.3.2.

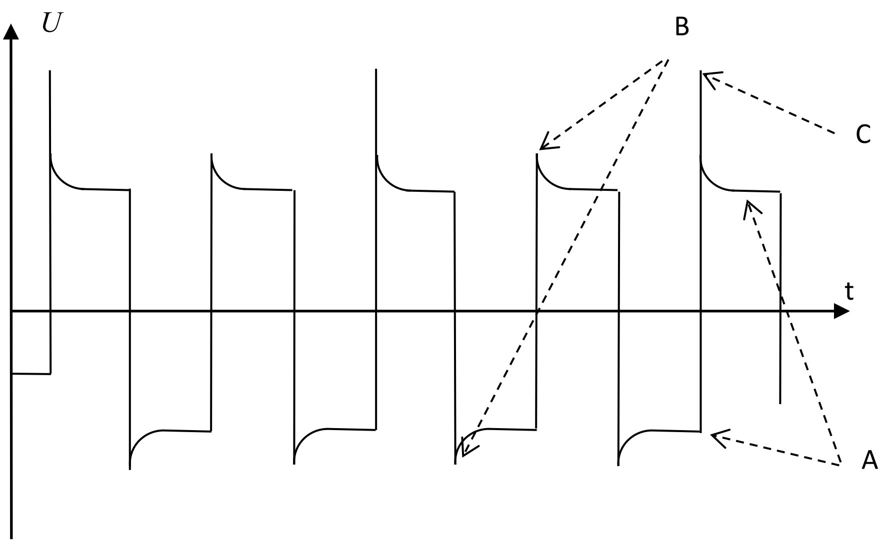
4.2.4 Recurring peak voltage

Due to the intended operation modes of specific products, internally generated voltages may also include recurring peaks superimposed to the **working voltage**. These recurring peaks voltages shall be considered when applying the concept of **insulation coordination**.

Insulation coordination with regard to **recurring peak voltage** shall consider that **partial discharges** can occur in **solid insulation** (see 4.6.2.3) or along surfaces of **insulation** (see Table F.8b).

NOTE See 4.4.2 and Table 1 of IEC/TS 61934:2011 for an example of parameter values of characteristics of **partial discharge** measurment.

Recurring peak voltage has a waveshape which is measured by an oscilloscope of sufficient bandwidth, from which the peak amplitude is determined according to Figure 1.



Key

A Steady-state working voltage value, (e.g as normal working voltage)

B Peak of the working value

C Recurring peak voltage

Figure 1 – Recurring peak voltage

4.2.5 Steady-state working voltage

The highest **steady-state working voltage** (RMS value of the AC or DC.value) across the insulation with the equipment supplied at the **rated voltage** shall be considered. This kind of **steady-state voltage** can be lower, equal or higher than the **rated voltage** of the equipment. The **steady-state working voltage** of internal circuits is a direct consequence of the design of products.

4.2.6 Steady-state peak voltage

The highest continuous **peak voltage** across the insulation with the equipment supplied at the **rated voltage** shall be considered. The **steady-state peak voltage** of internal circuits is a direct consequence of the design of products.

4.3 Overvoltage categories

4.3.1 General

The concept of **overvoltage categories** is used for equipment energized directly from the low-voltage mains.

The **overvoltage categories** have a probabilistic implication rather than the meaning of physical attenuation of the **transient overvoltage** downstream in the installation.

NOTE This concept of **overvoltage categories** is used in Clause 443 of IEC 60364-4-44:2007.

A similar concept can also be used for equipment connected to other systems, for example telecommunication and data systems.

4.3.2 Equipment energized directly from the supply mains

Technical committees shall specify the **overvoltage category** as based on the following general explanation of **overvoltage categories**:

– Equipment with an impulse withstand voltage corresponding to overvoltage category IV is suitable for use at, or in the proximity of, the origin of the installation, for example upstream of the main distribution board. Equipment of category IV has a very high impulse withstand capability providing the required high degree of reliability.

NOTE 1 Examples of such equipment are electricity meters, primary overcurrent protection devices and ripple control units.

– Equipment with an impulse withstand voltage corresponding to overvoltage category III is for use in the fixed installation downstream of, and including the main distribution board, providing a high degree of availability.

NOTE 2 Examples of such equipment are distribution boards, circuit-breakers, wiring systems (see IEC 60050-826, definition 826-15-01), including cables, bus-bars, junction boxes, switches, socket-outlets) in the fixed installation, and equipment for industrial use and some other equipment, e.g. stationary motors with permanent connection to the fixed installation.

– Equipment with an impulse withstand voltage corresponding to overvoltage category II is suitable for connection to the fixed electrical installation, providing a normal degree of availability normally required for current-using equipment.

NOTE 3 Examples of such equipment are household appliances and similar loads.

– Equipment with an impulse withstand voltage corresponding to overvoltage category I is only suitable for use in the fixed installation of buildings where protective means are applied outside the equipment – to limit transient overvoltages to the specified level.

NOTE 4 Examples of such equipment are those containing electronic circuits like computers, appliances with electronic programmes, etc.

– Equipment with an impulse withstand voltage corresponding to overvoltage category I shall not have direct connection to a public supply system.

4.3.3 Systems and equipment not energized directly from the low-voltage mains

It is recommended that technical committees specify **overvoltage categories** or **rated impulse withstand voltage** as appropriate. Application of the preferred series of 4.2.2.1is recommended.

NOTE Telecommunication or industrial control systems or independent systems on vehicles are examples of such systems.

4.4 Frequency

For frequencies above 1 kHz additional or alternative AC voltage **tests** according to 6.3.5 or **partial discharge tests** according to 6.3.6 may be necessary. For high frequencies voltage test, see also 6.3.8.

4.5 Pollution

4.5.1 General

The **micro-environment** determines the effect of **pollution** on the **insulation**. The **macro-environment**, however, has to be taken into account when considering the **micro-environment**.

Means may be provided to reduce **pollution** at the **insulation** under consideration by effective use of enclosures, encapsulation or hermetic sealing. Such means to reduce **pollution** may not be effective when the equipment is subject to condensation or if, in normal operation, it generates pollutants itself.

Degrees of protection provided by enclosures (IP), according to the classes specified in IEC 60529, do not necessarily improve the **micro-environment** with regard to **pollution**.

Small **clearances** can be bridged completely by solid particles, dust and water and therefore minimum **clearances** are specified where **pollution** may be present in the **micro-environment**.

4.5.2 Degrees of pollution in the micro-environment

For the purpose of evaluating **creepage distances** and **clearances**, the following four degrees of **pollution** in the **micro-environment** are established:

– ***Pollution degree 1***

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

– ***Pollution degree 2***

  Only non-conductive **pollution** occurs except that occasionally a temporary conductivity caused by condensation is to be expected. This condensation may occur during periods of on-off load cycles of the equipment.

– ***Pollution degree 3***

  Conductive **pollution** occurs or dry non-conductive **pollution** occurs which becomes conductive due to condensation which is to be expected.

– ***Pollution degree 4***

  Continuous conductivity occurs due to conductive dust, rain or other wet conditions.

4.5.3 Conditions of conductive pollution

The dimensions for **creepage distance** cannot be specified where permanently conductive **pollution** is present (**pollution degree 4**). For temporarily conductive **pollution** (**pollution degree 3**), the surface of the **insulation** may be designed to avoid a continuous path of conductive **pollution**, e.g. by means of ribs and grooves (see 5.3.3.7).

4.6 Insulating material

4.6.1 Solid insulation, general

The concept of **insulation coordination** may be realized by an appropriate **insulation** material. The **insulation** behaviour of the **solid insulation** is affected by its material characteristics. Electrical, mechanical and other stresses which might affect the **insulation** behaviour over the life time of the product shall be considered.

As the electric strength of **solid insulation** is considerably greater than that of air, it may receive little attention during the design of low-voltage **insulation** systems. On the other hand, the insulating distances through solid insulating material are, as a rule, much smaller than the **clearances** so that high electric stresses result. Another point to be considered is that the high electric strength of material is seldom made use of in practice. In **insulation** systems, gaps may occur between electrodes and **insulation** and between different layers of **insulation**, or voids may be present in the **insulation**. **Partial discharges** can occur in these gaps or voids at voltages far below the level of **puncture** and this may influence decisively the service life of the **solid insulation**. However, **partial discharges** are unlikely to occur below a peak voltage of 500 V.

Of equally fundamental importance is the fact that **solid insulation**, as compared with gases, is not a renewable insulating medium so that, for example, high voltage peaks which may occur infrequently can have a very damaging effect on **solid insulation**. This situation can occur while in service and during routine high-voltage **testing**.

A number of detrimental influences accumulate over the service life of **solid insulation**. These follow complex patterns and result in ageing. Therefore, electrical and other stresses (e.g. thermal, environmental) are superimposed and contribute to ageing.

The long-term performance of **solid insulation** can be simulated by a short-term **test** in combination with suitable conditioning (see 6.3.3).

If **solid insulation** is subjected to high frequencies, the dielectric losses of **solid insulation** and **partial discharges** become increasingly important. This condition has been observed in switched-mode power supplies where the **insulation** is subjected to repetitive voltage peaks at frequencies up to 500 kHz.

There is a general relationship between the thickness of **solid insulation** and the aforesaid failure mechanisms. By a reduction of the thickness of **solid insulation** the field strength is increased and leads to a higher risk of failure. As it is not possible to calculate the required thickness of **solid insulation** the performance can only be verified by **testing**.

4.6.2 Stresses

4.6.2.1 Frequency of the voltage

The frequency of the voltage influences the electric strength of the **solid insulation**. Dielectric heating and the probability of thermal instability increase approximately in proportion to the frequency. Increasing the frequency will reduce the electric strength of most insulating materials.

4.6.2.2 Mechanical shock

In the case of inadequate impact strength, mechanical shock may cause **insulation** failure. Failure from mechanical shock could also occur due to reduced impact strength of materials:

– due to material becoming brittle when the temperature falls below its glass transition temperature;

– after prolonged exposure to high temperature that has caused loss of plasticiser or degradation of the base polymer.

Technical committees shall consider this when specifying environmental conditions for transportation, storage, installation and use.

4.6.2.3 Partial discharges (PD)

Some types of **solid insulation** can withstand discharges, while others cannot. Voltage, repetition rate of discharges and discharge magnitude are important parameters.

NOTE Ceramic insulators are usually able to withstand **partial discharges**.

The PD behaviour is influenced by the frequency of the applied voltage. It is established from accelerated life **tests** at increased frequency that the time to failure is approximately inversely proportional to the frequency of the applied voltage. However, practical experience only covers frequencies up to 5 kHz since, at higher frequencies, other failure mechanisms may also be present, for example dielectric heating.

4.6.2.4 Other stresses

Many other stresses can damage **insulation** and their consequences need to be considered by technical committees.

Examples of such stresses include:

– radiation, both ultraviolet and ionizing;
– stress-crazing or stress-cracking caused by exposure to solvents or active chemicals;
– migration of plasticizers;
– the effect of bacteria, moulds or fungi;
– mechanical creep.

4.6.3 Comparative tracking index (CTI)

4.6.3.1 Behaviour of insulating material in the presence of scintillations

With regard to tracking, an insulating material can be roughly characterized according to the damage it suffers from the concentrated release of energy during scintillations when a surface leakage current is interrupted due to the drying-out of the contaminated surface. The following behaviour of an insulating material in the presence of scintillations can occur:

– no decomposition of the insulating material;
– the wearing away of insulating material by the action of electrical discharges (electrical erosion);
– the progressive formation of conductive paths which are produced on the surface of insulating material due to the combined effects of electric stress and electrolytically conductive contamination on the surface (tracking).

NOTE Tracking or erosion will occur when:

– a liquid film carrying the surface leakage current breaks; and
– the applied voltage is sufficient to break down the small gap formed when the film breaks; and
– the current is above a limiting value which is necessary to provide sufficient energy locally to thermally decompose the insulating material beneath the film.

Deterioration increases with the time for which the current flows.

4.6.3.2 CTI values to categorize insulating materials

A method of classification for insulating materials according to 4.6.3.1 does not exist. The behaviour of the insulating material under various contaminants and voltages is extremely complex. Under these conditions, many materials may exhibit two or even all three of the characteristics stated. A direct correlation with the material groups of 5.3.2.4 is not practical. However, it has been found by experience and **tests** that insulating materials having a higher relative performance also have approximately the same relative ranking according to the comparative tracking index (CTI). Therefore, this document uses the CTI values to categorize insulating materials.

4.6.3.3 Test for comparative tracking index (CTI)

The **test** for comparative tracking index (CTI) in accordance with IEC 60112 is designed to compare the performance of various insulating materials under **test** conditions. It gives a qualitative comparison and in the case of insulating materials having a tendency to form tracks, it also gives a quantitative comparison.

4.6.3.4 Non- tracking materials

For glass, ceramics or other inorganic insulating materials which do not track, creepage distances need not be greater than their associated clearance for the purpose of insulation coordination.

4.7 Environmental aspects

4.7.1 General

The physical and geographical location of the equipment can affect the **insulation** system significantly. Environmental factors as altitude, temperature, vibrations and humidity require consideration to ensure that the **insulation coordination** remains reliable over the life time of the equipment.

4.7.2 Altitude

The breakdown voltage of a clearance in air is, according to Paschen's Law, proportional to the product of the distance between electrodes and the atmospheric pressure. The required distances for clearance in this standard is corrected according to the difference in atmospheric pressure between 2 000 m and sea level for homogeneous inhomogeneous fields.

See 5.2.3.4 for dimensioning of clearance for altitude above 2 000 m and 6.2.2.1.4 for altitude consideration when verifying clearance at altitude different from 2 000 m.

4.7.3 Temperature

Temperature can cause:

- mechanical distortion due to the release of locked-in stress;
- softening of thermoplastics;
- embrittlement of some materials due to loss of plasticiser;
- softening of some cross-linked materials particularly if the glass transition temperature of the material is exceeded;
- increased dielectric losses leading to thermal instability and failure.

High temperature gradients, for example during short-circuits, may cause mechanical failure.

4.7.4 Vibrations, transportation

Mechanical stresses caused by vibration or shock during operation, storage or transportation may cause delamination, cracking or breaking-up of the insulating material (see 5.4.4.2).

4.7.5 Humidity

The presence of water vapour can influence the **insulation** resistance and the discharge extinction voltage, aggravate the effect of surface contamination, produce corrosion and dimensional changes. For some materials, high humidity will significantly reduce the electric strength. Low humidity can be unfavourable in some circumstances, for example by increasing the retention of electrostatic charge and by decreasing the mechanical strength of some materials, such as polyamide.

4.7.6 Duration of voltage stress

With regard to **creepage distances**, the time under voltage stress influences the number of occasions when drying out can result in surface scintillations with energy high enough to entail tracking. The number of such occasions is considered to be sufficiently large to cause tracking:

- in equipment intended for continuous use but not generating sufficient heat to keep the surface of the **insulation** dry;
- in equipment subjected to condensation for extended periods during which it is frequently switched ON and OFF;
- on the input side of a switching device, and between its line and load terminals, that is connected directly to the supply mains.

The **creepage distances** shown in Table F.5 have been determined for **insulation** intended to be under voltage stress during a long period of time (see 5.3.3.4).

4.8 Field distribution

The electrical field influences the electric strength of insulation.

- The **homogenous field** distribution is the most favourable and theoretical case where the electrical field is completely homogeneous between two spheres (see 3.1.28). Typically, to achieve a **homogeneous field** conditions between two spheres, the radius of each sphere shall be greater than the distance between them. This case can never be reached in real design.
- The **inhomogeneous field** condition of a point-plane electrode configuration is the worst case with regard to voltage withstand capability and is referred to as case A. It is represented by a point electrode having a 30 μm radius and a plane of 1 m $\times$ 1 m.

In fact, the field distribution will normally be in between homogenous and inhomogenous field.

5 Design of insulation coordination

5.1 General

5.1.1 Design of the insulation coordination

The design of the **insulation coordination** shall be realized by means of:

– **clearances** (5.2);

– **creepage distances** (5.3); and

– **solid insulation** (5.4)

and applies to each individual **insulation** under consideration.

5.1.2 Frequency >30 kHz

Requirements to **insulation coordination** for equipment within **low-voltage systems** with rated frequencies above 30 kHz are given in IEC 60664-4.

5.1.3 Reduced distances due to coating or potting

Requirements to **insulation coordination** for equipment within **low-voltage systems** using coating, potting or moulding for protection against **pollution**, allowing a reduction of **clearance** and **creepage distances** are given in IEC 60664-3.

5.2 Dimensioning of clearances

5.2.1 General

Clearance dimensions shall be selected, taking into account the following influencing factors:

– **impulse withstand voltage** according to 5.2.2.2 for functional insulation, for **basic insulation**, **supplementary insulation** and **reinforced insulation**;

– **temporary withstand overvoltages** (see 5.2.2.4);

– **steady-state peak voltage and recurring peak voltages** (see 5.2.2.4);

– electric field conditions (see 5.2.3.2 and 5.2.3.3);

– altitude: (see 5.2.3.4);

– degrees of **pollution** in the **micro-environment** (see 4.5.2).

Larger **clearances** may be required due to mechanical influences such as vibration or applied forces.

5.2.2 Dimensioning criteria for clearances

5.2.2.1 General

Clearances shall be dimensioned to withstand the largest of the following:

- For circuits directly connected to the low-voltage mains, the **rated impulse withstand voltage** determined on the basis of 5.2.2.2 and 5.2.2.3.

- If a **steady-state peak voltage**, a **temporary overvoltage** or a **recurring peak voltage** is present determined on the basis of 5.2.2.4.

See Annex G for guidedance how to determine clearance based on the requirement of 5.2.

5.2.2.2 Selection of rated impulse withstand voltage for equipment

The **rated impulse withstand voltage** of the equipment shall be selected from Table F.1 corresponding to the **overvoltage category** specified and to the **rated voltage** U_n of the equipment.

NOTE 1 Equipment with a particular **rated impulse withstand voltage** and having more than one **rated voltage** can be suitable for use in different **overvoltage categories**.

NOTE 2 For consideration of the **switching overvoltage** aspect, see 4.2.2.4.

5.2.2.3 Dimensioning to withstand transient overvoltages

Clearances shall be dimensioned to withstand the required **impulse withstand voltage**, according to Table F.2. For circuits directly connected to the supply mains, the required

impulse withstand voltage is the **rated impulse withstand voltage** established on the basis of 5.2.2.2.

5.2.2.4 Dimensioning to withstand steady-state peak voltages, temporary overvoltages or recurring peak voltages

Clearances shall be dimensioned according to Table F.8a to withstand the **steady-state peak voltages**, the **temporary overvoltages** or the **recurring peak voltages**.

5.2.3 Other factors involving clearances

5.2.3.1 General

The shape and arrangement of the conductive parts (electrodes) influence the homogeneity of the field (see 4.8) and consequently the **clearance** needed to withstand a given voltage (see Table F.2, Table F.8a and Table A.1).

It is recommended to design for inhomogeneous field condition according to 5.2.3.2 (case A) during design. If designed for homogeneous field conditions according to 5.2.3.3 (case B), 5.2.3.3 applies (see also 6.2.2.1).

5.2.3.2 Inhomogeneous field conditions (case A of Table F.2)

Clearances not less than those specified in Table F.2 for **inhomogeneous field** conditions can be used irrespective of the shape and arrangement of the conductive parts and without verification by a voltage withstand **test**.

Clearances through openings in enclosures of insulating material shall not be less than those specified for **inhomogeneous field** conditions since the configuration is not controlled, which may have an adverse effect on the homogeneity of the electric field.

5.2.3.3 Homogeneous field conditions (case B of Table F.2)

Values for **clearances** in Table F.2 for case B are only applicable for **homogeneous fields**. They can only be used where the shape and arrangement of the conductive parts is designed to achieve an electric field having an essentially constant voltage gradient.

Clearances smaller than those for **inhomogeneous field** conditions require verification by a voltage withstand **test** (see 6.2.2.1). For small values of **clearances**, the uniformity of the electric field can deteriorate in the presence of **pollution**, making it necessary to increase the **clearances** above the values of case B.

5.2.3.4 Altitude correction

The **clearance** given in this document is valid up to 2 000 m.

For altitude above 2 000 m, Table A.2 is a reference to determine the altitude correction factors for clearance correction. See also 4.7.2 for the calculation procedure with respect to altitude correction for clearances correction.

Linear interpolation between two altitude values is not allowed.

5.2.4 Dimensioning of clearance of functional insulation

For a clearance of **functional insulation**, the required withstand voltage is the maximum impulse voltage or **steady-state peak voltage** (with reference to Table F.8) or **recurring peak voltage** (with reference to Table F.8) expected to occur across it, under rated conditions of the equipment, and in particular the **rated voltage** and rated impulse voltage (refer to Table F.2).

5.2.5 Dimensioning of clearances of basic insulation, supplementary insulation and reinforced insulation

Clearances of **basic** insulation and **supplementary insulation** shall each be dimensioned as specified in Table F.2 corresponding to:

– the **rated impulse withstand voltage**, according to 4.2.2 or 5.2.2.2; or

– the internally generated transient over **withstand voltage** requirements according to 4.2.2.4;

and as specified in Table F 8a corresponding to:

– the **steady-state peak voltage** according to 4.2.6;

– the **recurring peak voltage** according to 4.2.4; and

– the **temporary overvoltage** according to 4.2.3.

With respect to **impulse withstand voltages**, **clearances** of **reinforced insulation** shall be dimensioned as specified in Table F.2 corresponding to the **rated impulse withstand voltage** but one step higher in the preferred series of values in 4.2.2.1 than that specified for **basic insulation**. If the **impulse withstand voltage** required for **basic insulation** according to 4.2.2.1, is other than a value taken from the preferred series, **reinforced insulation** shall be dimensioned to withstand 160 % of the **impulse withstand voltage** required for **basic insulation**.

NOTE 1 In a coordinated system, **clearances** above the minimum required are unnecessary for a required **impulse withstand voltage**. However, it can be necessary, for reasons other than **insulation coordination**, to increase **clearances** (for example due to mechanical influences). In such instances, the **test** voltage is to remain based on the **rated impulse withstand voltage** of the equipment, otherwise undue stress of associated **solid insulation** can occur.

With respect to **steady-state peak voltages**, **recurring peak voltages** and **temporary overvoltages clearances** of **reinforced insulation** shall be dimensioned as specified in Table F.8a to withstand 160 % of the **withstand voltage** required for **basic insulation**.

For equipment provided with **double insulation** where **basic insulation** and **supplementary insulation** cannot be tested separately, the **insulation** system is considered as **reinforced insulation**.

NOTE 2 When dimensioning **clearances** to accessible surfaces of insulating material, such surfaces are assumed to be covered by metal foil. Further details can be specified by technical committees.

5.2.6 Isolating devices

Devices suitable for isolation are intended to disconnect and maintain for reasons of safety adequate **clearance** from every source of electric energy. **Clearances** between lines and loads terminals shall withstand the minimum impulse **withstand voltage** defined in 8.4.2 of IEC 61140:2016.

5.3 Dimensioning of creepage distances

5.3.1 General

To determine the required **creepage distances**, the following influencing factors must be taken into account:

- voltage (see 5.3.2.2);
- **pollution degree** (see 5.3.2.3);
- material group (see 5.3.2.4);
- orientation and location of the **creepage distance** (see 5.3.3.2);
- shape of insulating surface (see 5.3.3.3);
- duration of the voltage stress (see 5.3.3.4);
- components mounted on PWB (see 5.3.3.8).

See Annex H for guidance how to determine creepage based on the requirement of 5.3.

NOTE The values of Table F.5 are based upon existing empirical data and are suitable for the majority of applications. However, for functional insulation, values of creepage distances other than those of Table F.5 can be appropriate.

5.3.2 Dimensioning criteria of creepage distances

5.3.2.1 General

Creepage distances shall be dimensioned to withstand the long term rms voltage stress across the considered **insulation** and taking to account the **pollution degree** and the material group over which the **creepage distance** is considered (see 5.3.2.2 to 5.3.2.4). Other factors considering mechanical shape, material parameters and time under voltage stress shall also be taken into account (see 5.3.3).

5.3.2.2 Determination of the voltage

The voltage to be used for the selection of the minimum **creepage distances** in Table F.5 shall be in accordance with the rationalized voltages of Table F.3 and Table F.4. They may also be used for the selection of **rated insulation voltages**.

For equipment having several **rated voltages** so that it may be used at different nominal voltages of the low-voltage mains, the voltage selected shall be appropriate for the highest **rated voltage** of the equipment.

The highest **steady-state working voltage** which can occur in the system, equipment or internal circuits shall be used. The voltage is determined for supply at **rated voltage** and under the worst case operating conditions within the rating of the equipment.

Fault conditions are not taken into account.

The basis for the determination of a **creepage distance** is the long-term r.m.s. value of the voltage existing across it. This voltage is the **steady-state working voltage** (see4.2.5), the **rated insulation voltage** (see 5.3.4) or the **rated voltage** (see 5.3.4).

Transient overvoltages are neglected since they will normally not influence the tracking phenomenon. However, **temporary overvoltages** should be considered if their duration and frequency of occurrence can influence tracking (see 5.3.3.4).

5.3.2.3 Determination of the pollution degree

The influence of the **pollution degree,** considering the combination of **pollution** and humidity in the **micro-environment** (see 4.5.2), shall be taken into account when dimensioning **creepage distances** according to Table F.5

NOTE In an equipment, different micro-environmental conditions can exist.

5.3.2.4 Determination of the material group

For the purposes of this document, materials are classified into four groups according to their CTI values. These values are determined in accordance with IEC 60112 using solution A. The groups are as follows:

– material group I: 600 ≤ CTI;

– material group II: 400 ≤ CTI < 600;

– material group IIIa: 175 ≤ CTI < 400;

– material group IIIb: 100 ≤ CTI < 175.

5.3.2.5 Relationship of creepage distance to clearance

A **creepage distance** cannot be less than the associated clearance so that the shortest **creepage distance** possible is equal to the required clearance. However, there is no physical relationship, other than this dimensional limitation, between the minimum clearance in air and the minimum acceptable **creepage distance**.

Creepage distances less than the **clearances** required in case A of Table F.2 may only be used under conditions of **pollution degrees** 1 and 2 when the **creepage distance** can withstand the voltage required for the associated clearance (Table F.2). For testing, see 6.2.1.

5.3.3 Other factors involving creepage distances

5.3.3.1 General

Technical committees shall take into account other factors influencing creepage distance as example orientation, shape of insulating surface. In case of specificity can influence creepage distances, those criterias shall be specified to inform the user of that case.

5.3.3.2 Orientation of a creepage distances

If necessary, the manufacturer shall indicate the intended orientation of the equipment or component in order that **creepage distances** are not adversely affected by the accumulation of pollution for which they were not designed.

5.3.3.3 Shape of insulating surface

Shaping of insulating surfaces is effective for dimensioning of **creepage distances** under **pollution degree** 3 only. Preferably, the surface of **solid insulation** should include transverse ribs and grooves that break the continuity of the leakage path caused by **pollution**. Likewise, ribs and grooves may be used to divert any water away from **insulation** which is electrically stressed. Joints or grooves joining conductive parts should be avoided since they can collect **pollution** or retain water.

5.3.3.4 Duration of the voltage stress

The duration of the voltage stress influences the number of occasions when drying out can result in surface scintillations with energy high enough to entail tracking. The number of such occasions is considered to be sufficiently large to cause tracking:

– in equipment intended for continuous use but not generating sufficient heat to keep the surface of the **insulation** dry;

– in equipment subjected to condensation for extended periods during which it is frequently switched ON and OFF;

– on the input side of a switching device, and between its line and load terminals, that is connected directly to the supply mains.

The **creepage distances** shown in Table F.5 have been determined for **insulation** intended to be under voltage stress during a long period of time.

5.3.3.5 Creepage distances where more than one material is used or more than one pollution degree occurs

A **creepage distance** may be split in several portions of different materials and/or have different **pollution degrees** if one of the **creepage distances** is dimensioned to withstand the total voltage or if the total distance is dimensioned according to the material having the lowest CTI and the highest **pollution degree**.

5.3.3.6 Creepage distances split by floating conductive part

A **creepage distance** may be split into several parts, made with the same **insulation** material, including or separated by floating conductors as long as the sum of the distances across each individual part is equal or greater than the **creepage distance** required if the floating part did not exist.

The minimum distance X for each individual part of the **creepage distance** is given in Table 1 (see also Example 11).

5.3.3.7 Reduction of creepage distances with the use of a rib (ribs)

Required **creepage distances** equal to or larger than 8 mm under **pollution degree** 3, may be reduced by the use of a rib. The values of these reduced **creepage distances** are those values listed in Table F.5 in brackets (see Note 4 of Table F.5). The rib shall have a minimum width (W) of 20 % and a minimum height (H) of 25 % of the required **creepage distance** including the rib as measured in Figure 2.

Where more than one rib is used, the required **creepage distance** shall be divided into sections equal to the number of wanted ribs. For each section the requirements of the above paragraph shall apply. The minimum distance between the multiple ribs shall be equal to the minimum width of the rib applicable for each section, measured from the base of the rib.

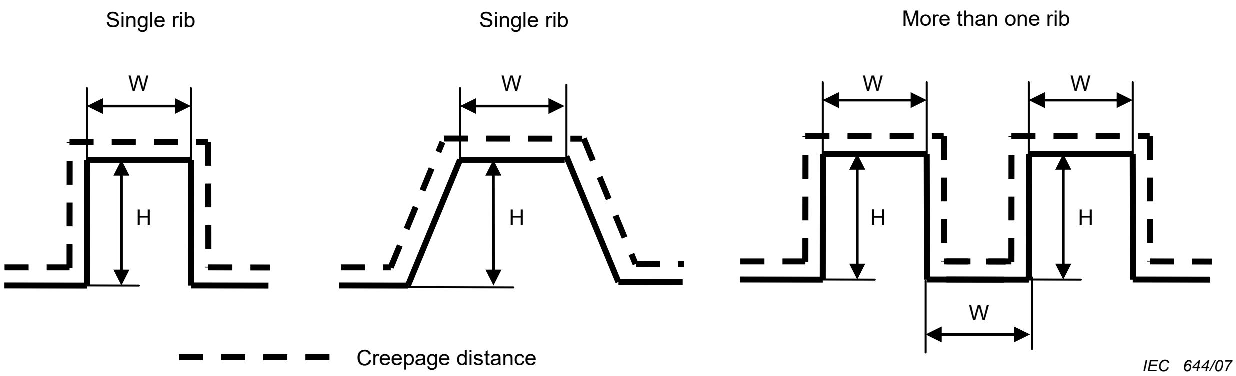


Figure 2 – Determination of the width (W) and height (H) of a rib

5.3.3.8 Creepage across component mounted on PWB

For **creepage distances** on printed wiring material only used under pollution degree 1, a reduced dimensioning is applicable and shall be selected from Table F.5. Attention is drawn on the possible reduction or other path of **creepage distances** due to the components.

5.3.4 Dimensioning of creepage distances of functional insulation

Creepage distances of **functional insulation** shall be dimensioned as specified in Table F.5 corresponding to the **steady-state working voltage** across the **creepage distance** considered.

When the **steady-state working voltage** is used for dimensioning, it is allowed to interpolate values for intermediate voltages. When interpolating, linear interpolation shall be used and values shall be rounded to the same number of digits as the values picked up from the tables.

5.3.5 Dimensioning of creepage distances of basic insulation, supplementary insulation and reinforced insulation

Creepage distances of **basic insulation** and **supplementary insulation** shall be selected from Table F.5 for:

– the rationalized voltages given in columns 2 and 3 of Table F.3 and columns 2, 3 and 4 of Table F.4b, corresponding to the nominal voltage of the supply low-voltage mains;

– the **rated insulation voltage** according to 4.3.2;

– the voltage specified in 4.3.3.

Technical committees responsible for equipment in which **insulation** is under voltage stress for only a short time may consider allowing reduced **creepage distances** (see 5.3.3.4).

When Table F.5 is used, it is allowed to interpolate values for intermediate voltages. When interpolating, linear interpolation shall be used and values shall be rounded to the same number of digits as the values picked up from the tables.

Creepage distances of **double insulation** are the sum of the values of the **basic insulation** and **supplementary insulation** which make up the **double insulation** system.

Creepage distances for **reinforced insulation** shall be twice the **creepage distance** for **basic insulation**.

NOTE 1 For **supplementary insulation**, the **pollution degree**, insulating material, mechanical stresses and environmental conditions of use can be different from those for **basic insulation**.

NOTE 2 For the purpose of the safety of persons and in order to reduce the risk of fire, the following restriction in the use of the reduced values for creepage distances on printed wiring material under pollution degree 2 (column 3 in Table F.5) is required: The use of the reduced dimensioning values for creepage distances on printed wiring material requires an additional protection against pollution. A solder resist of high quality is the minimum requirement for this purpose.

NOTE 3 When dimensioning **creepage distances** to accessible surfaces of insulating material, such surfaces are assumed to be covered by metal foil. Further details can be specified by technical committees.

Comparison of the minimum **clearances** and **creepage distances** specified in this document is described in Annex E.

5.4 Requirements for design of solid insulation

5.4.1 General

Solid insulation of **basic insulation**, **supplementary insulation** and **reinforced insulation** shall be capable of durably withstanding electrical and mechanical stresses as well as thermal and environmental influences which may occur during the intended life of the equipment.

Technical committees shall consider these stresses when specifying conditions for **testing**.

5.4.2 Voltage stress

Solid insulation shall withstand the voltage stress considering:

– **Transient overvoltages** according to 4.2.2;

– **Temporary overvoltages** according to 4.2.3;

– **Recurring peak voltage** according to 4.2.4;

– **Steady-state working voltage** according to4.2.6.

5.4.3 Withstand of voltage stresses

5.4.3.1 Transient overvoltages

Basic insulation and **supplementary insulation** shall have:

– an **impulse withstand voltage** requirement corresponding to the nominal of the mains voltage (see 4.2.2.3), and the relevant **overvoltage category** according to Table F.1; or

– an **impulse withstand voltage** of an internal circuit of an equipment which has been specified according to the **transient overvoltages** to be expected in the circuit (see 4.2.2.4).

Reinforced insulation shall have an **impulse withstand voltage** corresponding to the **rated impulse withstand voltage** but one step higher in the preferred series of values in 4.2.2.3 than that specified for **basic insulation**. If, according to 4.2.2.4, the **impulse withstand voltage** required for **basic insulation** is other than a value taken from the preferred series, **reinforced insulation** shall be dimensioned to withstand 160 % of the value required for **basic insulation**.

For verification by **testing**, see 6.3.4.

5.4.3.2 Temporary withstand overvoltages

Basic insulation and **supplementary insulation** of **solid insulation** shall be designed to withstand the following **temporary withstand overvoltages**:

– short-term **temporary overvoltages** of U_n + 1 200 V with durations up to 5 s;

– long-term **temporary overvoltages** of U_n + 250 V with durations longer than 5 s;

where U_n is the nominal line-to-neutral voltage of the neutral-earthed supply system.

The performance validated can be declared by the manufacturer as a rated temporary overvoltages value.

Reinforced insulation shall withstand twice the **temporary withstand overvoltages** specified for **basic insulation**.

For verification by **testing,** see 6.3.5.

NOTE 1 These values are from Clause 442 of IEC 60364-4-44:2007, where U_n is called U_o.

NOTE 2 The values are r.m.s. values.

5.4.3.3 Recurring peak voltages

The maximum **recurring peak voltages** occurring on the low-voltage mains can be assumed provisionally to be $F_4 \times \sqrt{2}\, U_n$, i.e. 1,1 times the peak value at U_n. Where **recurring peak voltages** are present, the partial discharge extinction voltage shall be at least:

– $F_1 \times F_4 \times \sqrt{2}\, U_n$, i.e. 1,32 $\sqrt{2}\, U_n$ for each **basic insulation** and **supplementary insulation**, and

– $F_1 \times F_3 \times F_4 \times \sqrt{2}\, U_n$, i.e. 1,65 $\sqrt{2}\, U_n$ for **reinforced insulation**.

NOTE $\sqrt{2}\, U_n$ is in neutral-earthed systems the peak value of the line-to neutral fundamental (undistorted) voltage at nominal voltage of mains. The application of the multiplying factors used in this subclause is described in Annex D.

For an explanation of factors *F*, see 6.3.6.1.

In internal circuits, the highest **recurring peak voltages** have to be evaluated in place of $F_4 \times \sqrt{2}\, U_n$ and **solid insulation** shall meet the requirements correspondingly.

For verification by **testing**, see 6.3.6.

5.4.3.4 Steady-state working voltages

The **steady-state working voltage** is a long-term voltage stress applied on **solid insulation**.

In those instances where **steady-state working voltages** are non-sinusoidal with periodically recurring peaks, special consideration shall be given to possible occurrence of **partial discharges**. Similarly, where **insulation** layers may exist and where voids in moulded **insulation** may exist, consideration shall be given to possible occurrence of **partial discharges** with resultant degradation of **solid insulation**.

For verification by **testing**, see 6.3.6.

5.4.4 Withstand on environmental stresses

5.4.4.1 Withstand of short-term heating stresses

Solid insulation shall not be impaired by short-term heating stresses which may occur in normal and, where appropriate, abnormal use. Technical committees shall specify severity levels.

NOTE Standard severity levels are specified by the IEC 60068 Technical Committee.

5.4.4.2 Withstand of mechanical stresses

Solid insulation shall not be impaired by mechanical vibration or shock which can be expected in use. Technical committees shall specify severity levels.

NOTE Standard severity levels are specified by the IEC 60068 Technical Committee.

5.4.4.3 Withstand of long-term heating stresses

Thermal degradation of **solid insulation** shall not impair **insulation coordination** during the intended life of the equipment. Technical committees shall specify whether a **test** is necessary (see also IEC 60085 and IEC 60216 series).

5.4.4.4 Withstand of the effects of humidity

Insulation coordination shall be maintained under the humidity conditions as specified for the equipment (see also 6.3.3).

5.4.4.5 Other factors impacting solid insulation

Equipment may be subjected to other stresses, for example as indicated in 4.6.2.4 which may adversely affect **solid insulation**. Technical committees shall state such stresses and specify **test** methods.

6 Tests and measurements

6.1 General

The following **test** procedures apply to **type testing**, so that a possible deterioration of the **test** specimen may be tolerated. It is assumed that further use of the **test** specimen is not intended.

Test procedures are specified for:

- the verification of **clearances** (see 6.2);
- the verification of **solid insulation** (see 6.3);
- dielectric **tests** on complete equipment (see 6.4); and
- other **tests** (see 6.5).

6.2 Test for verification of clearances

6.2.1 General

The stresses for **clearances** caused by **transient overvoltages** are assessed by the impulse voltage **test**, which may be substituted by an AC voltage **test** or a DC voltage **test**. See 6.2.2.1.3.

When electrical equipment is subjected to electric **tests** for verifying **clearances**, the **test** shall be in accordance with **withstand voltage** requirements specified in 5.2.2. The appropriate **test** for the verification of **clearances** is the impulse voltage **test**, but as stated in 5.2.3.3, the **test** is only required for **clearances** smaller than case A values of Table F.2.

If the withstand against **steady-state voltages**, **recurring peak voltages** or **temporary overvoltages** according to 5.2.2 is decisive for the dimensioning of **clearances** and if those **clearances** are smaller than the case A values of Table F.8a, an AC **test** voltage according to 6.2.2.1.3.2 **test** is required.

When verifying **clearances** within equipment by an impulse voltage **test**, it is necessary to ensure that the specified impulse voltage appears at the clearance under **test**.

NOTE 1 The electric **testing** of **clearances** will also stress the associated **solid insulation**.

NOTE 2 For some cases, these **tests** also have to be applied to **creepage distances**, see 5.3.2.5.

NOTE 3 For **testing** complete equipment, see 6.4.

6.2.2 Test voltages

6.2.2.1 Impulse voltage dielectric test

6.2.2.1.1 General

The purpose of this **test** is to verify that **clearances** will withstand specified **transient overvoltages**. The impulse withstand **test** is carried out with a voltage having a 1,2/50 µs waveform with the values specified in Table F.6. For the waveform, 7.1 of IEC 61180:2016 applies. It is intended to simulate overvoltages of atmospheric origin and covers overvoltages due to switching of low-voltage equipment.

Due to the scatter of the **test** results of any impulse voltage **test**, the **test** shall be conducted for a minimum of three impulses of each polarity with an interval of at least 1 s between pulses.

NOTE 1 The output impedance of the impulse generator cannot be higher than 500 Ω. When carrying out **tests** on equipment incorporating components across the **test** circuit, a much lower virtual impulse generator impedance can be specified (see 9.2 in IEC 61180:2016). In such cases, possible resonance effects, which can increase the peak value of the **test** voltage, can be taken into account when specifying **test** voltage values.

Technical committees may specify alternative dielectric **tests** according to 6.2.2.1.3.

NOTE 2 Values given in Table F.6 are derived from the calculation in 4.7.2. For accuracy of information, they are given with a high level of precision. For practical application, technical committees can choose to round the values.

6.2.2.1.2 Selection of impulse test voltage

If an electric **test** for **insulation coordination** of equipment with respect to **clearances** is required, for **clearances** smaller than case A as specified in Table F.2, the equipment shall be tested with the impulse **test** voltage corresponding to the **rated impulse withstand voltage** specified in accordance with 5.2.2.3. The impulse **test** voltages of Table F.6 apply.

For the **test** conditions, technical committees shall specify temperature and humidity values.

Technical committees shall consider whether **sampling tests** or **routine tests** have to be carried out in addition to **type tests**.

6.2.2.1.3 Alternatives to impulse voltage dielectric tests

6.2.2.1.3.1 General

Technical committees may specify an AC or DC voltage **test** for particular equipment as an alternative method.

While **tests** with AC and DC voltages of the same peak value as the impulse **test** voltage specified in Table F.6 verify the withstand capability of **clearances**, they more highly stress **solid insulation** because the voltage is applied for longer duration. They can overload and damage certain **solid insulations**. Technical committees should therefore consider this when specifying **tests** with AC or DC voltages as an alternative to the impulse voltage **test** given in 6.3.5.

While it is possible to substitute an impulse voltage **test** for **clearances** by an AC voltage **test** or by a DC voltage **test**, it is in principle not possible to substitute an AC voltage **test** for **solid insulation** by an impulse voltage **test**. The main reasons for this are the different propagation of the impulse voltages compared to power frequency voltages, especially in complex circuits, and the dependency of the withstand characteristics of **solid insulation** on the shape and the duration of the voltage stress.

6.2.2.1.3.2 Dielectric test with AC voltage

The waveshape of the sinusoidal power frequency **test** voltage shall be substantially sinusoidal. This requirement is fulfilled if the ratio between the peak value and the r.m.s. value is $\sqrt{2}$ ±5 %. The peak value shall be equal to the impulse **test** voltage of Table F.6 and applied for three cycles of the AC **test** voltage.

6.2.2.1.3.3 Dielectric test with DC voltage

The DC **test** voltage shall be substantially free of ripple. This requirement is fulfilled if the ratio between the peak values of the voltage and the average value is 1,0 ±3 %. The average value of the DC **test** voltage shall be equal to the impulse **test** voltage of Table F.6 and applied three times for 10 ms in each polarity.

6.2.2.1.4 Altitude correction for testing at altitude lower than 2 000 m

According to 5.2.3.4, the clearance is valid for equipment used up to 2 000 m above sea level. At 2 000 m, the normal barometric pressure is 80 kPa, while at sea level the value is 101,3 kPa. See also 4.7.2.

Due to the airs barometric pressure dependency, clearances tested according to 6.2.2.1, is tested using higher impulse test voltages at locations lower than 2 000 m. Table F.6 gives the impulse test voltage value for verifying clearances at altitudes below 2 000 m.

For the purpose of testing, the factors of temperature, humidity and climatic variations of air pressure are not taken into account provided that normal laboratory conditions exist.

Normal laboratory conditions are specified in IEC 60068-1:

– Temperature: 15 °C to 35 °C;

– Air pressure: 86 kPa to 106 kPa at sea level;

– Relative humidity: 25 % to 75 %.

The basis for the calculation of the sea level values and data for determining test values for other test locations is as follows:

The altitude correction factors given in Table A.2 are considered in relation to the curve of Figure A.1 The relationship is as follows:

$$k_{\mathrm{u}} = \left(\frac{1}{k_{\mathrm{d}}}\right)^{m}$$

where

d is the **clearance** under consideration in millimetres;

k_u is the altitude correction for withstand voltage correction;

k_d is the altitude correction for clearance correction (see Table F.9);

m is the gradient of the relevant straight line in curve 1 in Figure A.1 (logarithmic scales on the two co-ordinate axes) and has the value.

$m = 0{,}9163$ for $0{,}001 < d \leq 0{,}01$ mm;

$m = 0{,}3305$ for $0{,}01 < d \leq 0{,}062\ 5$ mm;

$m = 0{,}6361$ for $0{,}0625 < d \leq 1$ mm;

$m = 0{,}8539$ for $1 < d \leq 10$ mm;

$m = 0{,}9243$ for $10 < d \leq 100$ mm.

Applying altitude correction for clearance correction results in curve 1 of Figure A.1, the voltages will be changed with five different steps at only one shifting step for distance. The mathematical formula for this operation is shown above. Table F.6 includes this calculation as described.

In other words, each value of k_d (altitude correction factor for clearance correction) will produce five different values of k_u (altitude correction factor for withstand voltage correction) based on the five different gradients (*m*) of withstand voltage as a function of clearance (*m* having a different value for each of the five ranges of clearance, as laid out above).

6.3 Tests for the verification of solid insulation

6.3.1 General

The ability of **solid insulation** to withstand the voltage stresses has to be verified by a voltage **test** in any case. The stresses caused by **transient overvoltages** are assessed by the impulse voltage **test**, which may be substituted by an AC voltage **test** or a DC voltage **test**. The stresses caused by an AC **steady-state voltage** stress can only be assessed by an AC voltage **test**. The DC voltage **test** with a **test** voltage equal to the peak value of the AC voltage is not fully equivalent to the AC. voltage **test** due to the different withstand characteristics of **solid insulation** for these types of voltages. However, in case of a pure DC voltage stress, the DC voltage **test** is appropriate.

6.3.2 Selection of tests

Solid insulation that may be subjected to mechanical stresses during operation, storage, transportation or installation shall be **test**ed with respect to vibration and mechanical shock before the dielectric **testing**. Technical committees may specify **test** methods.

The **tests** for **insulation coordination** are **type tests**. Technical committees shall specify which **type tests** are required for the respective stresses occurring in the equipment.

NOTE Standard **test** methods are specified in the relevant part of IEC 60068 by the Technical Committee.

They have the following objectives:

a) The impulse voltage withstand **test** is to verify the capability of the **solid insulation** to withstand the **rated impulse withstand voltage** (see 5.4.3.1);

b) The AC voltage **test** is to verify the capability of the **solid insulation** to withstand:

- the short-term **temporary overvoltage** (see 5.4.3.2);
- the **steady-state working voltage** (see 5.4.3.4);
- the **recurring peak voltage** (see 5.4.3.3).

If the peak value of the AC **test** voltage is equal to or higher than the **rated impulse withstand voltage**, the impulse voltage **test** is covered by the AC voltage **test**.

Solid insulation has a different withstand characteristic compared to **clearances**, if the time of stress is being increased the withstand capability will be decreased significantly. Therefore, the AC voltage **test**, which is specified for the verification of the withstand capability of **solid insulation**, is not allowed to be replaced by an impulse voltage **test**.

c) The **partial discharge test**, generally used as a **routine test**, is to verify that no **partial discharges** are maintained in the **solid insulation**:

  – at the **steady-state working voltage** (see 5.4.3.4);
  – at the long-term **temporary overvoltage** (see 5.4.3.2);
  – at the **recurring peak voltage** (see 5.4.3.3).

d) The high-frequency voltage **test** is to verify the absence of failure due to dielectric heating according to 6.3.8

Partial discharge tests for **solid insulation** shall be specified if the peak value of the voltages listed under c) exceeds 700 V and if the average field strength is higher than 1 kV/mm. The average field strength is the peak voltage divided by the distance between two parts of different potential.

The above **tests** may also be suitable as sample or **routine tests**. It is, however, the responsibility of the technical committees to specify which **tests** shall be performed as sample and **routine tests** in order to ensure the quality of the **insulation** during production. The **tests** and conditioning, as appropriate, shall be specified with **test** parameters adequate to detect faults without causing damage to the **insulation** (see 6.5.2).

When performing **tests** on complete equipment, the procedure of 6.4 applies.

6.3.3 Conditioning

If not otherwise specified, the **test** shall be performed with a new **test** specimen. Conditioning of the specimen by temperature and humidity treatment is intended to:

– represent the most onerous normal service conditions;
– expose possible weaknesses which are not present in the new condition.

Technical committees shall specify the appropriate conditioning method from the following recommended methods:

a) dry heat (IEC 60068-2-2), in order to achieve a stable condition which may not exist immediately after manufacture;
b) dry heat cycle (IEC 60068-2-14), in order to induce the creation of voids which could develop in storage, transportation and normal use;
c) thermal shock (IEC 60068-2-14), in order to induce delamination within the **insulation** system which may develop in storage, transportation and normal use;
d) damp heat (IEC 60068-2-78), in order to evaluate the effect of water absorption on the electric properties of the **solid insulation**.

For **impulse withstand voltage**, AC power frequency voltage and high frequency voltage **tests**, the most significant conditioning methods are those in a) and d). For **partial discharge testing**, the conditioning methods b) and c) are most relevant.

If conditioning of **solid insulation** is required, it shall be performed prior to **type testing**. The values of temperature, humidity and time shall be selected from Table F.7.

It may be appropriate to subject components, for example electrical parts, sub-assemblies, insulating parts and materials, to conditioning before electric testing. When components have already been **type tested** according to this subclause, such conditioning is not required.

6.3.4 Impulse voltage test

6.3.4.1 Test method

The methods for impulse voltage testing of 6.2.2.1 apply also to **solid insulation**, except that the altitude correction factors as listed in Table F.6 are not applicable. The **test** shall be conducted for five impulses of each polarity with an interval of at least 1 s between impulses. The waveshape of each impulse shall be recorded (see 6.3.4.2).

6.3.4.2 Acceptance criteria

No **puncture** or partial breakdown of **solid insulation** shall occur during the **test**, but **partial discharges** are allowed. Partial breakdown will be indicated by a step in the resulting waveshape which will occur earlier in successive impulses.

NOTE **Partial discharges** in voids can lead to partial notches of extremely short durations which can be repeated in the course of an impulse.

6.3.5 AC power frequency voltage test

6.3.5.1 Test method

The waveshape of the sinusoidal power frequency **test** voltage shall be substantially sinusoidal. This requirement is fulfilled if the ratio between the peak value and the r.m.s. value is $\sqrt{2}$ ± 3 %. The peak value shall be equal to the highest of the voltages mentioned in 6.3.2 b).

For **basic insulation** and **supplementary insulation**, the **test** voltage has the same value as the voltages mentioned in 6.3.2 b). For **reinforced insulation**, the **test** voltage is twice the value used for **basic insulation**.

The AC **test** voltage shall be raised uniformly from 0 V to the value specified in 5.4.3.2 within not more than 5 s and held at that value for at least 60 s.

In those cases where the short term **temporary overvoltage** leads to the most stringent requirements with respect to the amplitude of the **test** voltage, a reduction of the duration of the **test** to a minimum value of 5 s can be considered by technical committees.

NOTE 1 For particular types of **insulation**, longer periods of **testing** can be required to detect weakness within the **solid insulation**.

NOTE 2 In case of **testing** with respect to high, steady-state stresses including high **recurring peak voltage**, technical committees can consider introducing a safety margin on the **test** voltage.

In some cases, the AC **test** voltage needs to be substituted by a DC **test** voltage of a value equal to the peak value of the AC voltage, however this **test** will be less stringent than the AC voltage **test**. Technical committees shall consider this situation (see 6.3.7).

Test equipment is specified in IEC 61180. It is recommended that the short-circuit output current of the generator is not less than 200 mA.

NOTE 3 For **test** voltages exceeding 3 kV, it is sufficient that the rated power of the **test** equipment is equal to or greater than 600 VA.

The tripping current of the generator shall be adjusted to a tripping current of 100 mA or for **test** voltages above 6 kV to the highest possible value.

NOTE 4 For **routine testing**, the tripping current can be adjusted to lower levels but not less than 3,5 mA.

6.3.5.2 Acceptance criteria

No breakdown of **solid insulation** shall occur.

6.3.6 Partial discharge test

6.3.6.1 General

The waveshape of the sinusoidal power frequency **test** voltage shall be substantially sinusoidal. This requirement is fulfilled if the ratio between the peak value and the r.m.s. value is $\sqrt{2}$ ±5 %. The peak value of U_t (see Figure 3) shall be equal to the highest of the voltages mentioned in 6.3.2 c) taking into account the multiplying factors F_1, F_3 and F_4 as far as applicable.

Partial discharge test methods are described in Annex C. When performing the **test**, the following multiplying factors apply. These examples are given for the **recurring peak voltage** U_{rp}, the factors similarly apply to the **steady-state peak voltage** and to the long-term **temporary overvoltage**.

F_1 Basic safety factor for PD **testing** and dimensioning **basic insulation** and **supplementary insulation**.

The PD extinction voltage may be influenced by environmental conditions, such as temperature. These influences are taken into account by a basic safety factor F_1 of 1,2. The PD extinction voltage for **basic insulation** or **supplementary insulation** is therefore at least 1,2 U_{rp}.

F_2 PD hysteresis factor.

Hysteresis occurs between the PD inception voltage U_i and the PD extinction voltage U_e. Practical experience shows that F_2 is not greater than 1,25. For **basic insulation** and **supplementary insulation**, the initial value of the **test** voltage is therefore $F_1 \times F_2 \times U_{rp}$, i.e. 1,2 × 1,25 U_{rp} = 1,5 U_{rp}.

NOTE This takes into account that PD can be initiated by **transient overvoltages** exceeding U_i and can be maintained, for example, by values of the **recurring peak voltage** exceeding U_e. This situation can require the combination of impulse and AC voltages for the **test**, which is impractical. Therefore, an AC **test** is performed with an initially increased voltage.

F_3 Additional safety factor for PD **testing** and dimensioning **reinforced insulation**.

For **reinforced insulation** a more stringent risk assessment is required. Therefore, an additional safety factor F_3 = 1,25 is required. The initial value of the **test** voltage is $F_1 \times F_2 \times F_3 \times U_{rp}$, i.e. 1,2 × 1,25 × 1,25 U_{rp} = 1,875 U_{rp}.

F_4 Factor covering the deviation from the nominal voltage U_n of the low-voltage mains.

For circuits connected to the low-voltage mains, this factor takes into account the maximum deviation of the mains voltage from its nominal value. Therefore, the crest voltage at nominal voltage U_n shall be multiplied by F_4 = 1,1.

6.3.6.2 Verification

The **test** is to verify that no **partial discharges** are maintained at the highest of the following values:

– the peak value of the **working voltage** (see 5.4.3.4);

– the peak value of the long-term **temporary overvoltage** (see 5.4.3.2);

– the **recurring peak voltage** (see 5.4.3.3).

NOTE For cases where, additionally, the actual values of PD inception and extinction voltage are of interest, the measuring procedure is described in D.1.

When **testing**, the PD **test** is generally applied to components, small equipment and one part of the equipment.

The minimum required discharge extinction voltage shall be higher, by factor F_1, than the highest of the voltages listed above.

According to the kind of **test** specimen, technical committees shall specify:

– the **test** circuit (see C.1);

– the measuring equipment (see C.3 and D.2);

– the measuring frequency (see C.3.1 and D.3.3);

– the **test** procedure (see 6.3.6.3).

6.3.6.3 Test procedure

The value of the **test** voltage U_t is 1,2 times the required **partial discharge extinction voltage** U_e. According to the **partial discharge** hysteresis (see 6.3.6.1), an initial value of 1,25 times the **test** voltage shall be applied.

The voltage shall be raised uniformly from 0 V up to the initial **test** voltage $F_2 \times U_t$, i.e. $F_1 \times F_2$ = 1,2 × 1,25 = 1,5 times the highest of the voltages listed under 6.3.6.2. It is then kept constant for a specified time t_1 not exceeding 5 s. If no **partial discharges** have occurred, the **test** voltage is reduced to zero after t_1. If a **partial discharge** has occurred, the voltage is decreased to the **test** voltage U_t, which is kept constant for a specified time t_2 until the **partial discharge** magnitude is measured.

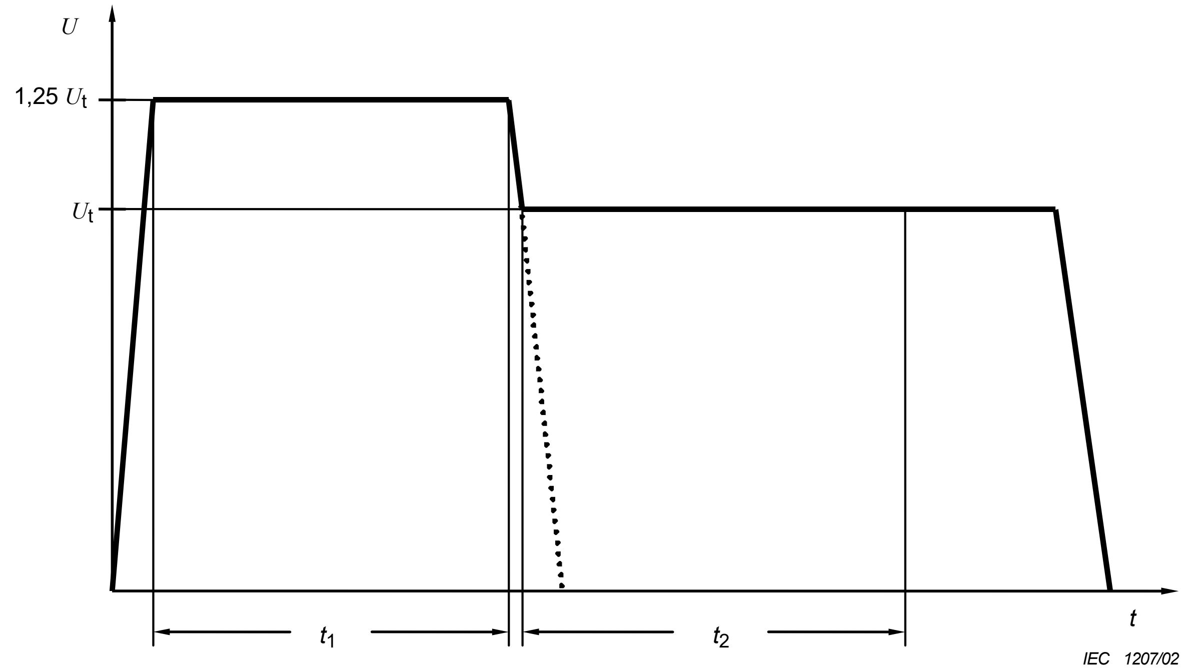


Figure 3 – Test voltages

6.3.6.4 Acceptance criteria

6.3.6.4.1 Specified discharge magnitude

As the objective is to have no continuous **partial discharges** under normal service conditions, the lowest practicable value shall be specified (see C.3).

NOTE 1 Except for discharges caused by corona discharges in air (e.g. in non-moulded transformers), values in excess of 10 pC are not suitable.

NOTE 2 Values as small as 2 pC are possible with currently available apparatus.

The noise level shall not be subtracted from the reading of the **partial discharge** meter.

6.3.6.4.2 Test result

The **solid insulation** complies if:

– no **insulation** breakdown has occurred; and

– during the application of the **test** voltage, **partial discharges** have not occurred, or after t_2 the magnitude of the discharge is not higher than specified.

6.3.7 DC voltage test

The DC voltage **test** with a **test** voltage equal to the peak value of the AC voltage is not fully equivalent to the AC voltage **test** due to the different withstand characteristics of **solid insulation** for these types of voltages. However, in case of a pure DC voltage stress, the DC voltage **test** is well appropriate.

The DC **test** voltage shall be substantially free of ripple. This requirement is fulfilled if the ratio between the peak values of the voltage and the average value is 1,0 ±3 %. The average value of the DC **test** voltage shall be equal to the peak value of the AC **test** voltage mentioned in 6.3.2 b).

For **basic insulation** and **supplementary insulation**, the **test** voltage has the same value as the voltages mentioned in 6.3.2 b). For **reinforced insulation**, the **test** voltage is twice the value used for **basic insulation**.

The DC **test** voltage shall be raised uniformly from 0 V to the value specified in 5.4.3.2 within not more than 5 s and held at that value for at least 60 s.

NOTE 1 In certain cases, the charging current due to capacitances can be too high and a longer rise time can be necessary.

Test equipment is specified in IEC 61180. It is recommended that the short-circuit output current of the generator is not less than 200 mA.

NOTE 2 For **test** voltages exceeding 3 kV, it is sufficient that the rated power of the **test** equipment is equal or greater than 600 VA.

The tripping current of the generator shall be adjusted to a tripping current of 100 mA or for **test** voltages above 6 kV to the highest possible value.

NOTE 3 For **routine testing**, the tripping current can be adjusted to lower levels but not less than 10 mA.

6.3.8 High-frequency voltage test

For high-frequency voltages according to 6.3.2 d), additional or alternative AC voltage **tests** according to 6.3.5 or **partial discharge tests** according to 6.3.6 may be necessary.

NOTE Information about the withstand characteristics of **insulation** at high frequency and methods of **testing** is given in IEC 60664-4.

6.4 Performing dielectric tests on complete equipment

6.4.1 General

When performing the impulse voltage **test** on complete equipment, the attenuation or amplification of the **test** voltage shall be taken into account. It needs to be assured that the required value of the **test** voltage is applied across the terminals of the equipment under **test**.

Surge protective devices (SPDs) shall be disconnected before dielectric **testing**.

NOTE If capacitors with high capacitance are parallel to the parts between which the **test** voltage needs to be applied, it can be difficult, or even impossible, to perform the AC voltage **test** because the charging current could exceed the capacity of the high voltage tester (200 mA). In the latter case, those parallel capacitors can be disconnected before **testing**. If this is also impossible, DC **testing** can be taken into consideration.

6.4.2 Parts to be tested

The **test** voltage shall be applied between parts of the equipment which are electrically separate from each other.

Examples of such parts include:

- live parts;
- separate circuits;
- earthed circuits;
- accessible surfaces.

Non-conductive parts of accessible surfaces shall be covered with metal foil. If a complete covering of large enclosures with metal foil is not practicable, a partial covering is sufficient if applied to those parts which provide protection against electric shock.

6.4.3 Preparation of equipment circuits

For the **test**, each circuit of the equipment shall be prepared as follows:

- external terminals of the circuit, if any, shall be connected together;
- switchgear and controlgear within equipment shall be in the closed position or bypassed;
- the terminals of voltage blocking components (such as rectifier diodes) shall be connected together;
- components such as RFI filters shall be included in the impulse **test** but it may be necessary to disconnect them during AC **tests**.

For the **test**, to include some specific components as follows:

- voltage sensitive components within any circuit of the equipment, which do not bridge **basic insulation** or **reinforced insulation**, may be bypassed by shorting the terminals;
- pre-tested plug-in printed circuit boards and pre-tested modules with multipoint connectors may be withdrawn, disconnected or replaced by dummy samples to ensure that the **test** voltage is propagated inside the equipment to the extent necessary for the **insulation tests**.

6.4.4 Test voltage values

Circuits connected to the low-voltage mains are **test**ed according to 6.2 and 6.3.

The **test** voltage between two circuits of the equipment shall have the value corresponding to the highest voltage that actually can occur between these circuits.

6.4.5 Test criteria

There shall be no disruptive discharge (**sparkover**, **flashover** or **puncture**) during the **test**. **Partial discharges** in **clearances** which do not result in breakdown are disregarded, unless otherwise specified by the technical committees.

NOTE It is recommended that an oscilloscope be used to observe the impulse voltage in order to detect disruptive discharge.

6.5 Other tests

6.5.1 Test for purposes other than insulation coordination

Technical committees specifying electric **tests** for purposes other than verification of **insulation coordination** shall not specify **test** voltages higher than those required for **insulation coordination**.

6.5.2 Sampling and routine tests

Sampling **tests** and **routine tests** are intended to ensure production quality. It is the responsibility of the relevant technical committee, and in particular of the manufacturer, to specify these **tests**. They shall be carried out with the waveforms and voltage levels such that faults are detected without causing damage to the equipment (**solid insulation** or components).

Technical committees specifying **sampling** and **routine tests** shall in no case specify **test** voltages higher than those required for **type testing**.

6.5.3 Measurement accuracy of test parameters

All important **test** parameters shall be measured with high accuracy in order to provide well defined and comparable **test** results. For the purpose of harmonization, the accuracy of measurement of the measuring devices used for the following **test** parameters is given in this document as follows:

a) **test** voltage (AC/DC): ±3 %;
   test voltage (impulse): ±5 %;

b) current: ±1,5 %;

c) frequency: ±0,2 %;

d) temperature:
   – below 100 °C ±2 K;
   – 100 °C up to 500 °C ±3 %;

e) relative humidity: ±3 % r.h.

NOTE The given accuracy refers to that of the humidity measuring device. It does not include the humidity uniformity within the chamber and/or the influence of the **test** sample on the humidity uniformity. The humidity in the chamber is measured only at one place before **testing** the sample.

f) **partial discharge** magnitude: ±10 % or ±1 pC (the greater values applies);

g) time (impulse voltage) ±20 %;
   time (**test** duration) ±1 %.

6.6 Measurement of reducing the transient voltages attenuation

The proposed measurement (see 4.2.2.5) of the attenuation of transients is only possible by use of a suitable impulse generator with very low output impedance.

Such measurement may be performed by the use of the so called “Hybrid generator” or “Combination wave generator” according to IEC 61000-4-5 with 2 Ω output impedance.

6.7 Measurement of clearances and creepage distances

The methods of measuring **clearances** and **creepage distances** are indicated in the following Examples 1 to 11. These cases do not differentiate between gaps and grooves or between types of **insulation**.

The following assumptions are made:

- where the distance across a groove is equal to or larger than the specified width *X* (see Table 1), the creepage distance is measured along the contours of the groove (see Example 2);
- any recess is assumed to be bridged with an insulating link having a length equal to the specified width *X* and being placed in the most unfavourable position (see Example 3);
- **clearances** and **creepage distances** measured between parts which can assume different positions in relation to each other, are measured when these parts are in their most unfavourable position.

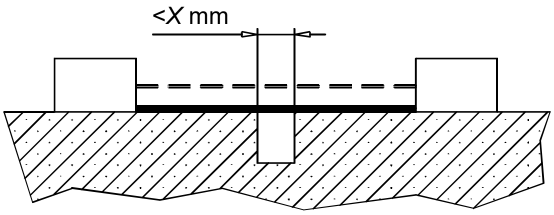
The dimension *X*, specified in the following examples, has a minimum value depending on the **pollution degree** as follows:

Table 1 – Dimensioning of grooves

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

If the associated **clearance** is less than 3 mm, the minimum dimension *X* may be reduced to one-third of the associated **clearance**.

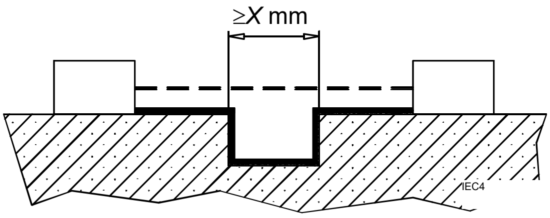
Example 1



Condition: Path under consideration includes a parallel- or converging-sided groove of any depth with a width less than *X* mm.

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

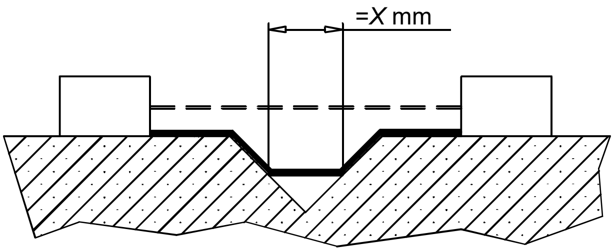
Example 2



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

Rule: **Clearance** is the "line of sight" distance. **Creepage** path follows the contour of the groove.

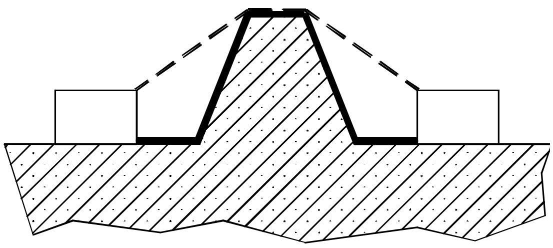
Example 3



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

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

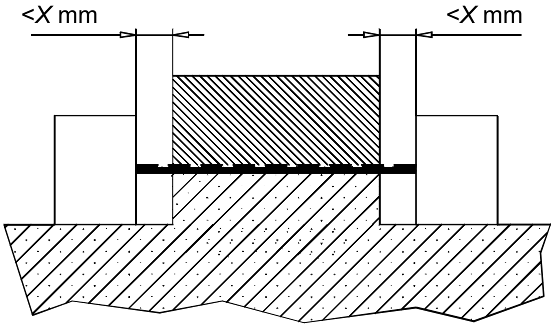
Example 4



Condition: Path under consideration includes a rib.

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

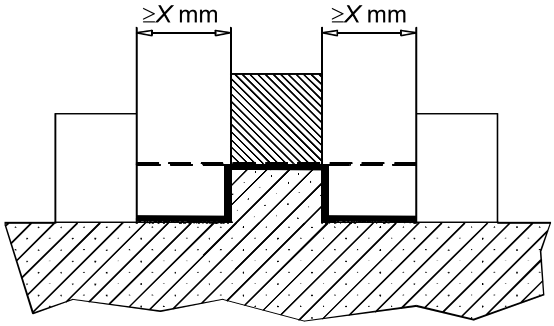
Example 5



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

Rule: **Clearance** and **creepage** path is the "line of sight" distance shown.

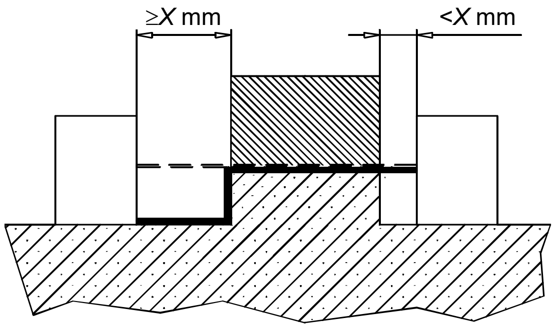
Example 6



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

Rule: **Clearance** is the "line of sight" distance. **Creepage** path follows the contour of the grooves.

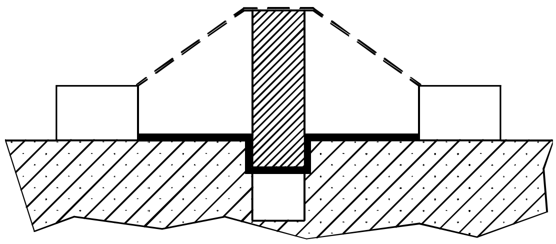
Example 7



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

Rule: **Clearance** and **creepage** paths area as shown.

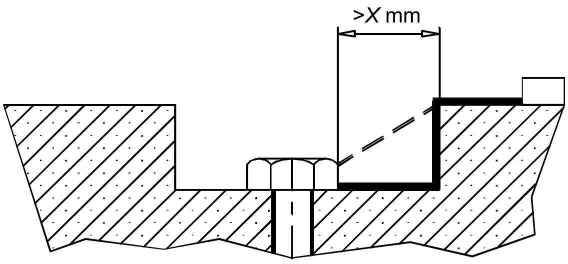
Example 8



Condition: **Creepage distance** through uncemented joint is less than creepage distance over barrier but more than **clearance** over the top of the barrier.

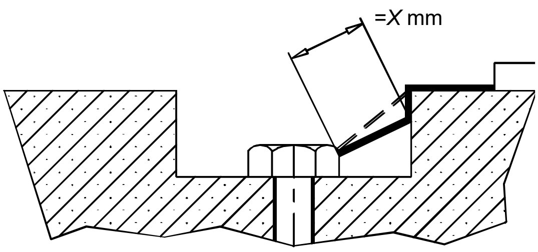
Rule: **Clearance** is the shortest direct air path over the top of the barrier.

Example 9



Gap between head of screw and wall of recess wide enough to be taken into account.

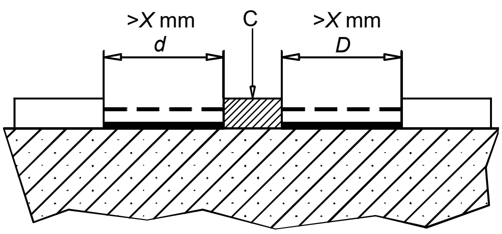
Example 10



Gap between head of screw and wall of recess too narrow to be taken into account.

Measurement of **creepage distance** is from screw to wall when the distance is equal to *X* mm.

Example 11



C conductive floating part

Clearance is the distance = *d* + *D*

Creepage distance is also = *d* + *D*

Clearance **Creepage distance**

Annex A
(informative)

Basic data on withstand characteristics of clearances

Table A.1 – Withstand voltages in kilovolts for an altitude of 2 000 m above sea level

Clearance	Case A Inhomogeneous field			Case B Homogeneous field	
	AC (50/60 Hz)		Impulse (1,2/50)	AC (50/60 Hz)	AC (50/60 Hz) and impulse (1,2/50)
mm	U r.m.s.	$\hat{U}$	$\hat{U}$	U r.m.s.	$\hat{U}$
0,001	0,028	0,040	0,040	0,028	0,040
0,002	0,053	0,075	0,075	0,053	0,075
0,003	0,078	0,110	0,110	0,078	0,110
0,004	0,102	0,145	0,145	0,102	0,145
0,005	0,124	0,175	0,175	0,124	0,175
0,00625	0,152	0,215	0,215	0,152	0,215
0,008	0,191	0,270	0,270	0,191	0,270
0,010	0,23	0,33+	0,33+	0,23	0,33+
0,012	0,25	0,35	0,35	0,25	0,35
0,015	0,26	0,37	0,37	0,26	0,37
0,020	0,28	0,40	0,40	0,28	0,40
0,025	0,31	0,44	0,44	0,31	0,44
0,030	0,33	0,47	0,47	0,33	0,47
0,040	0,37	0,52	0,52	0,37	0,52
0,050	0,40	0,56	0,56	0,40	0,56
0,0625	0,42	0,60+	0,60+	0,42	0,60+
0,080	0,46	0,65	0,70	0,50	0,70
0,10	0,50	0,70	0,81	0,57	0,81
0,12	0,52	0,74	0,91	0,64	0,91
0,15	0,57	0,80	1,04+	0,74	1,04
0,20	0,62	0,88	1,15	0,89	1,26
0,25	0,67	0,95	1,23	1,03	1,45
0,30	0,71	1,01	1,31	1,15	1,62
0,40	0,78	1,11	1,44	1,38	1,95
0,50	0,84	1,19	1,55	1,59	2,25
0,60	0,90	1,27	1,65	1,79	2,53
0,80	0,98	1,39	1,81	2,15	3,04
1,0	1,06	1,50+	1,95	2,47	3,50+
1,2	1,20	1,70	2,20	2,89	4,09
1,5	1,39	1,97	2,56	3,50	4,95
2,0	1,68	2,38	3,09	4,48	6,33
2,5	1,96	2,77	3,60	5,41	7,65
3,0	2,21	3,13	4,07	6,32	8,94
4,0	2,68	3,79	4,93	8,06	11,4
5,0	3,11	4,40	5,72	9,76	13,8
6,0	3,51	4,97	6,46	11,5	16,2
8,0	4,26	6,03	7,84	14,6	20,7
10,0	4,95	7,00+	9,10	17,7	25,0+
12,0	5,78	8,18	10,6	20,9	29,6
15,0	7,00	9,90	12,9	25,7	36,4
20,0	8,98	12,7	16,4	33,5	47,4
25,0	10,8	15,3	19,9	41,2	58,3
30,0	12,7	17,9	23,3	48,8	69,0
40,0	16,2	22,9	29,8	63,6	90,0
50,0	19,6	27,7	36,0	78,5	111,0
60,0	22,8	32,3	42,0	92,6	131,0
80,0	29,2	41,3	53,7	120,9	171,0

Table A.1 *(continued)*

Clearance	Case A Inhomogeneous field			Case B Homogeneous field	
	AC (50/60 Hz)		Impulse (1,2/50)	AC (50/60 Hz)	AC (50/60 Hz) and impulse (1,2/50)
mm	U r.m.s.	$\hat{U}$	$\hat{U}$	U r.m.s.	$\hat{U}$
100,0	35,4	50,0+	65,0	148,5	210,0+

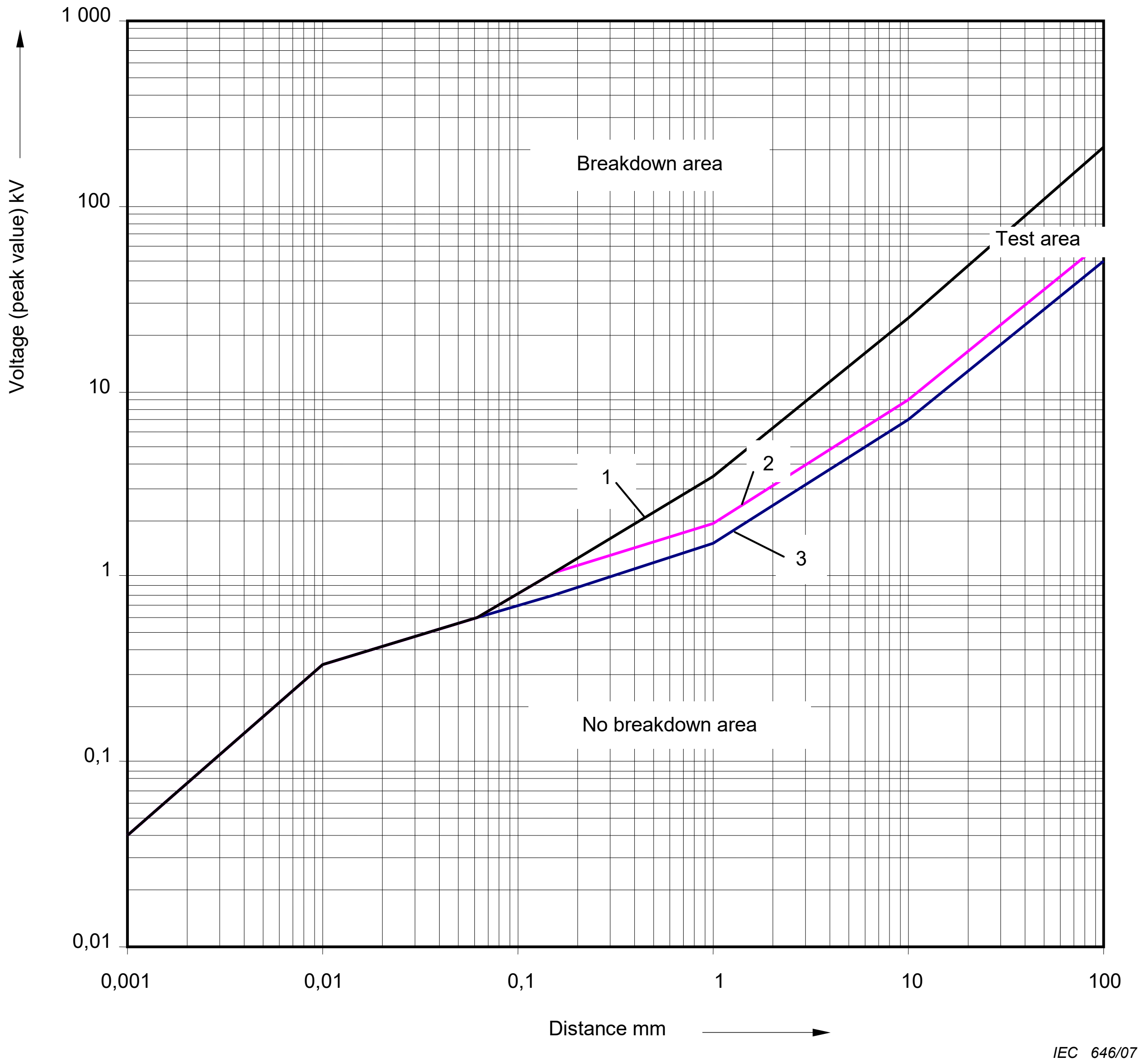
NOTE The information for **clearances** from 0,001 mm to 0,008 mm, is issued from document "Electrical breakdown experiments in air for micrometer gaps under various pressures" from P. Hartherz, K. en Yahia, L. Müller, R. Pfendtner and W. Pfeiffer and issued during the 9th International Symposium on Gaseous Dielectrics, Ellicot City, Maryland, USA 2001, pp333-338.

More details can be found in the thesis of P. Hartherz "Anwendung der Teilentladungsmeßtechnik zur Fehleranalyse in festen Isolierungen unter periodischer Impulsspannungsbelastung". Dissertation TU Darmstadt; Shaker Verlag, 2002.

For simplification, the statistical measured values according to Table A.1 above are replaced by straight lines between the values marked "+" in a double logarithmic diagram taking into account the correction factors from 0 m to 2 000 m altitude. The intermediate values are taken from that diagram (see Figure A.1) so that they enclose the measured values with a small safety margin. The values of U r.m.s. are found by dividing the values of $\hat{U}$ by $\sqrt{2}$.

Table A.2 – Altitude correction factors for clearance correction

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



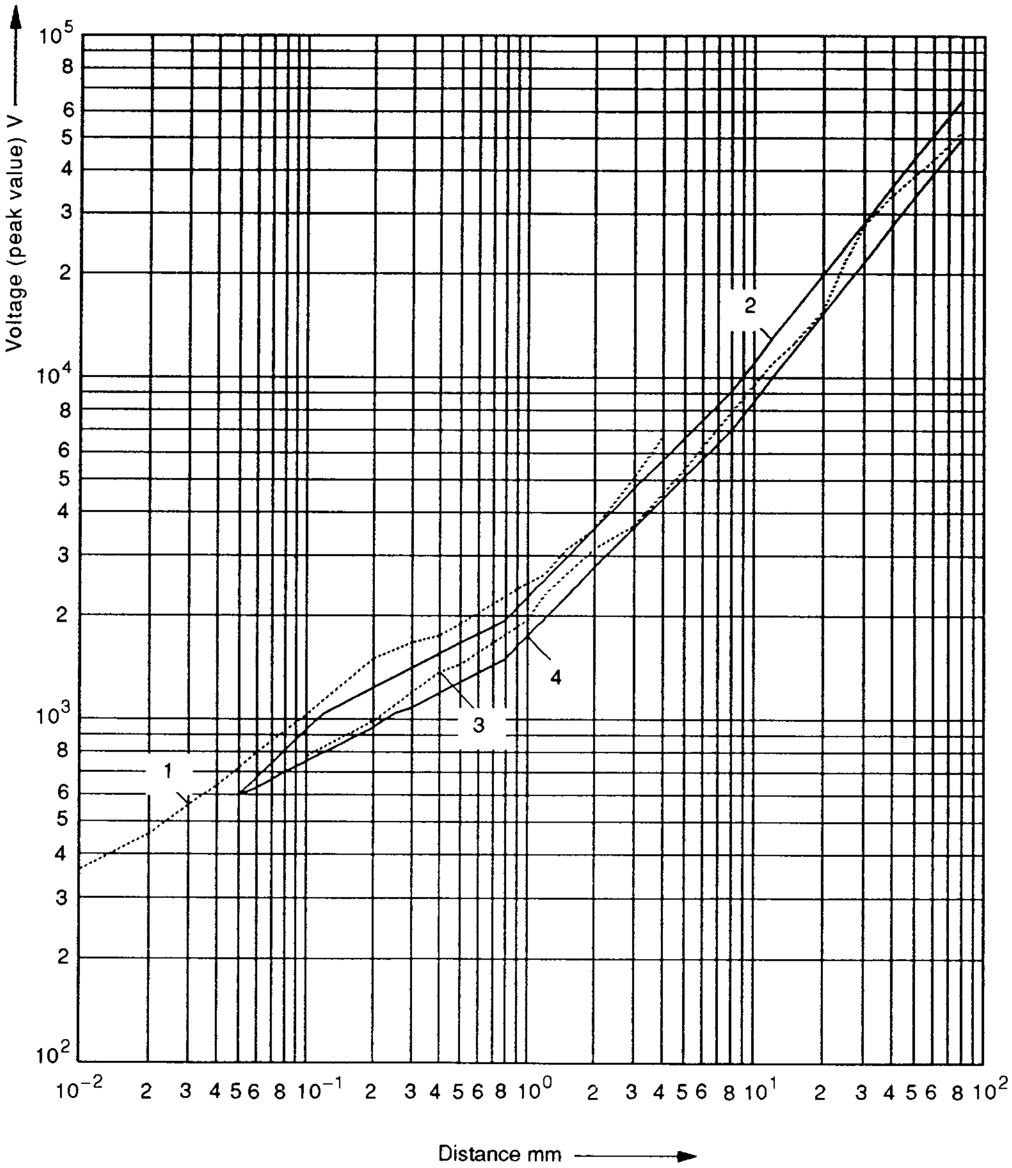
Key

1 case B; $\hat{U}$ 1,2/50 and $\hat{U}$ 50/60 Hz

2 case A; $\hat{U}$ 1,2/50

3 case A; $\hat{U}$ 50/60 Hz

Figure A.1 – Withstand voltage at 2 000 m above sea level



Key

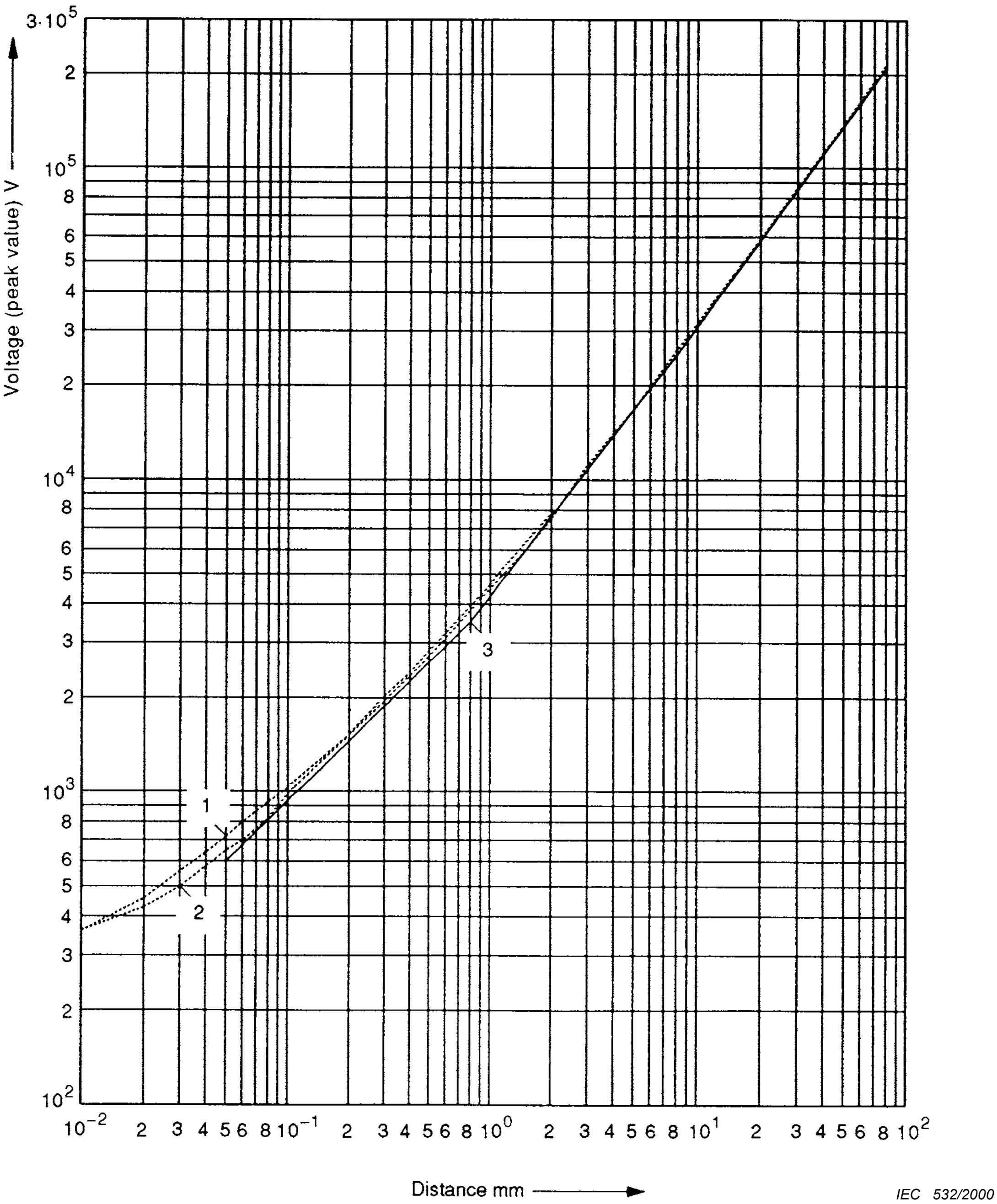
1 $\hat{U}$ 1,2/50 according to ETZ-B, 1976 pp300-302 [1]

2 Low limits for $\hat{U}$ 1,2/50

3 $\hat{U}$ 50 Hz according to ETZ-A, 1969 pp251-255 [2]

4 Low limits for $\hat{U}$ 50 Hz

Figure A.2 – Experimental data measured at approximately sea level and their low limits for inhomogeneous field



Key

1 Û 1,2/50 according to ETZ-B, 1976 pp300-302 [1]

2 Û 50 Hz according to Electra, 1974 pp61-82 [3]

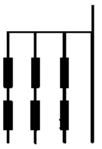
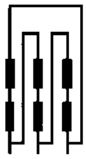
3 Low limits for Û 1,2/50 and Û 50 Hz

Figure A.3 – Experimental data measured at approximately sea level and their low limits for homogeneous field

Annex B
(informative)

Nominal voltages of supply systems for different modes of overvoltage control

Table B.1 – Inherent control or equivalent protective control

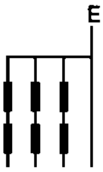
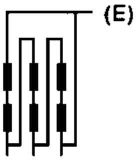
Voltage line-to-neutral derived from nominal voltages AC or DC up to and including 1)	Nominal voltages presently used in the world				Rated impulse withstand voltage for equipment 1)			
	Three-phase four-wire systems with earthed neutral  	Three-phase three-wire systems unearthed 	Single-phase two-wire systems AC or DC 	Single-phase three-wire systems AC or DC 	V			
					Overvoltage category			
V	V	V	V	V	I	II	III	IV
50			12,5 24 25 30 42 48	30-60	330	500	800	1 500
100	66/115	66	60		500	800	1 500	2 500
150	120/208* 127/220	115, 120, 127	100**, 110, 120	100-200** 110-220 120-240	800	1 500	2 500	4 000
300	220/380, 230/400 240/415, 260/440 277/480	200 **, 220, 230, 240, 260, 277, 347 380, 400, 415 440, 480	220	220-440	1 500	2 500	4 000	6 000
600	347/600, 380/660 400/690, 417/720 480/830	500, 577, 600	480	480-960	2 500	4 000	6 000	8 000
1 000		660 690, 720 830, 1 000	1 000		4 000	6 000	8 000	12 000
1 500.			1 500	1 500	6 000	8 000	10 000	15 000

1) These columns are taken from Table F.1 in which the **rated impulse withstand voltage** values are specified.

* Practice in the United States of America and in Canada.

** Practice in Japan.

Table B.2 – Cases where protective control is necessary and control is provided by surge protective device having a ratio of voltage protection level to rated voltage not smaller than that specified by IEC 61643 series

Voltage line-to-neutral derived from nominal voltages AC or DC up to and including 1)	Nominal voltages presently used in the world				Rated impulse withstand voltage for equipment 1) V			
	Three-phase four-wire systems with earthed neutral 	Three-phase three-wire systems earthed or unearthed 	Single-phase two-wire systems AC or DC 	Single-phase three-wire systems AC or DC. 	Overvoltage category			
V	**V**	**V**	**V**	**V**	**I**	**II**	**III**	**IV**
50			12,5 24 25 30 42 48	30-60	330	500	800	1 500
100	66/115	66	60		500	800	1 500	2 500
150	120/208 * 127/220	115, 120, 127	100 ** 110, 120	100-200 ** 110-220 120-240	800	1 500	2 500	4 000
300	220/380, 230/400 240/415, 260/440 277/480	200 **, 220, 230, 240 260, 277	220	220-440	1 500	2 500	4 000	6 000
600	347/600, 380/660 400/690, 417/720 480/830	347, 380, 400 415, 440, 480 500, 577, 600	480	480-960	2 500	4 000	6 000	8 000
1 000		660 690, 720 830, 1 000	1 000		4 000	6 000	8 000	12 000

1) These columns are taken from Table F.1 in which the **rated impulse voltage** values are specified.

* Practice in the United States of America and in Canada.

** Practice in Japan.

Annex C
(normative)

Partial discharge test methods

C.1 Test circuits

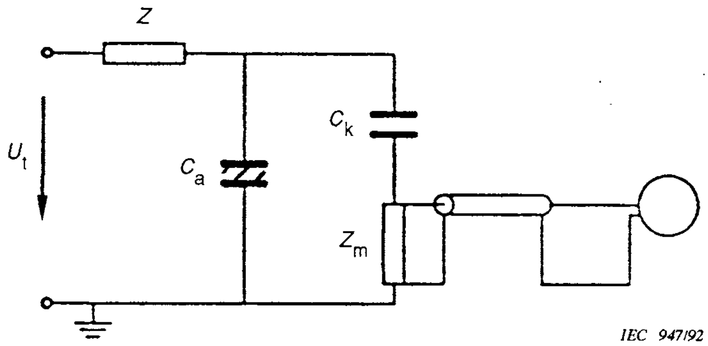
C.1.1 General

Test circuits shall perform as described in IEC 60270. The following circuits given in this annex meet those requirements and are given as examples.

NOTE 1 In the majority of cases, **testing** equipment designed in accordance with the examples given in this Annex will be sufficient. In special cases, for example in presence of extremely high ambient noise, it can be necessary to refer to IEC 60270.

NOTE 2 For an explanation of the basic operation, see Clause D.2.

C.1.2 Test circuit for earthed test specimen (Figure C.1)



Key

U_t **test** voltage

Z filter

C_a **test** specimen (usually it can be regarded as a capacitance)

C_k coupling capacitor

Z_m measuring impedance

Figure C.1 – Earthed test specimen

C.1.3 Test circuit for unearthed test specimen (Figure C.2)

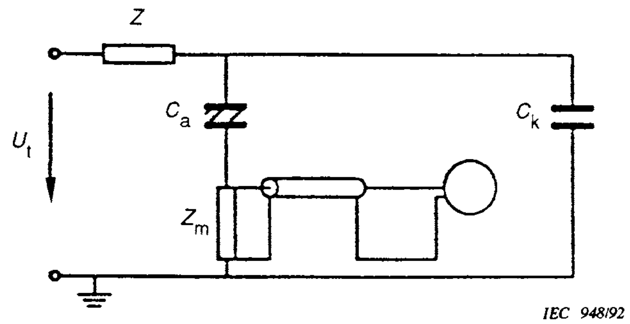


Figure C.2 – Unearthed test specimen

C.1.4 Selection criteria

Basically, both circuits are equivalent. However, the stray capacitances of the **test** specimen have a different influence upon sensitivity. The earth capacitance of the high-voltage terminal of the **test** specimen tends to reduce the sensitivity of the circuit according to C.1.2 and tends to increase the sensitivity of the circuit according to C.1.3 which therefore should be preferred.

C.1.5 Measuring impedance

The measuring impedance shall provide a negligibly low-voltage drop at **test** frequency. The impedance for the measuring frequency shall be selected in order to provide a reasonable sensitivity according to Clause D.2.

If voltage limiting components are used, they shall not be effective within the measuring range.

C.1.6 Coupling capacitor C_k

This capacitor shall be of low inductance type with a resonant frequency in excess of 3 f_2 (see Clause C.3). It shall be free of **partial discharges** up to the highest **test** voltage used.

C.1.7 Filter

The use of a filter is not mandatory. If used, its impedance shall be high for the measuring frequency.

C.2 Test parameters

C.2.1 General

Technical committees shall specify:

– the frequency f_t of the **test** voltage (C.2.2);

– the **specified discharge magnitude** (6.3.6.4.1);

– the climatic conditions for the PD **test** (C.2.3).

NOTE It can be necessary to have different specifications for the **type test** and the **routine test.**

C.2.2 Requirements for the test voltage

Normally AC voltages are used. The total harmonic distortion shall be less than 3 %.

NOTE 1 Low distortion of the sine wave allows the use of standard voltmeters and the calculation of the peak value from the r.m.s. reading. In the case of higher distortion, peak voltmeters can be used.

Tests are normally made at power frequency. If other frequencies are present in the equipment, technical committees shall consider the possible effect of frequency on discharge magnitude.

NOTE 2 PD **testing** with DC voltage is not recommended because of the difficulty of achieving an **environment** which is completely free of electrical noise. In addition it can be noted that the voltage distribution is greatly different for AC and DC.

C.2.3 Climatic conditions

It is recommended to perform the **test** at room temperature and average humidity (23 °C, 50 % r.h., see 4.3 of IEC 60068-1:2013).

C.3 Requirements for measuring instruments

C.3.1 General

Both wideband and narrowband charge measuring instruments may be used (see C.3.3). Radio interference voltmeters may only be used according to the precautions given in C.3.2.

The lower limit of the measuring frequency is determined by the frequency f_t of the **test** voltage and the frequency characteristic of the measuring impedance Z_m (see C.1.5). It should not be lower than 10 f_t.

The upper limit of the measuring frequency is determined by the shape of the PD pulses and the frequency response of the **test** circuit. It does not need to be higher than 2 MHz. For narrowband PD meters the measuring frequency shall be selected with regard to narrowband noise sources (see D.3.3).

NOTE Narrowband PD meters are recommended.

C.3.2 Classification of PD meters

The current through the measuring impedance Z_m is integrated to provide a reading proportional to q_m (see Figure D.1).

The integration can be affected by the measuring impedance. In this case, it shall represent a capacitance for all frequencies above the lower limit of the measuring frequency. The voltage across the capacitance, which is proportional to q_m, is amplified by a pulse amplifier. Periodic discharging shall also be provided.

If the measuring impedance is resistive for all frequencies above the lower limit of the measuring frequency, the integration shall be done within the pulse amplifier.

Single pulses shall be measured and the pulse with the maximum amplitude shall be evaluated. In order to limit errors due to pulse overlap, the pulse resolution time shall be less than 100 μs.

Radio interference meters are narrowband peak voltage meters. They are used to measure interference of radio signals. They incorporate a special filter circuit which creates dependency of the reading on the **pulse repetition rate** according to the subjective effect of noise to the human ear.

For measuring **partial discharges**, radio interference meters may only be used if the filter circuit is disconnected. Also, a suitable measuring impedance is required.

C.3.3 Bandwidth of the test circuit

Usually, the PD meter limits the bandwidth of the **test** circuit. PD meters are classified according to their bandwidth as wideband or narrowband.

a) The lower and the upper cut-off frequencies f_1 and f_2 are those where the frequency response has dropped by 3 dB of the constant value in the case of a wideband meter and by 6 dB from the peak value in the case of a narrowband meter.

b) For narrowband meters, the measuring frequency f_0 is identical with the resonance peak in the frequency response.

c) The bandwidth Δf is:

$$\Delta f = f_2 - f_1$$

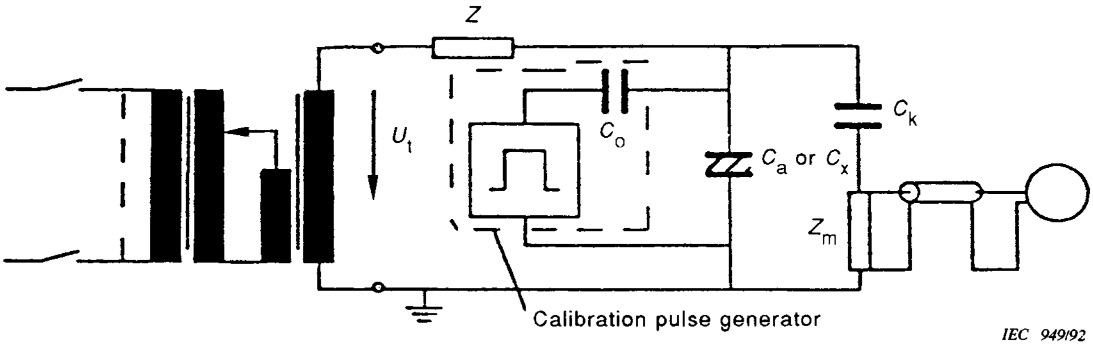
For wideband meters, Δf is in the same order of magnitude as f_2. For narrowband meters, Δf is much less than f_0.

C.4 Calibration

C.4.1 Calibration of discharge magnitude before the noise level measurement

The calibration of the **test** circuit (Figure C.3 or Figure C.4) shall be carried out at the **specified discharge magnitude** replacing the **test** specimen C_a by a capacitor C_x which exhibits no **partial discharge**. The impedance of the capacitor C_x shall be similar to that of the **test** specimen C_a.

The transformers shall be adjusted according to the specified PD **test** voltage but not energized and their primary windings shall be short-circuited. The **specified discharge magnitude** shall be applied to the terminals of the capacitor by means of the calibration pulse generator. The indication of the discharge magnitude on the discharge detector shall be adjusted to correspond with the calibration signal.



Key

U_t	**test** voltage
Z	filter
C_0	capacitance of the calibration impulse generator
C_a or C_x	**test** specimen (usually it can be regarded as a capacitance)
C_k	coupling capacitor
Z_m	measuring impedance

Figure C.3 – Calibration for earthed test specimen

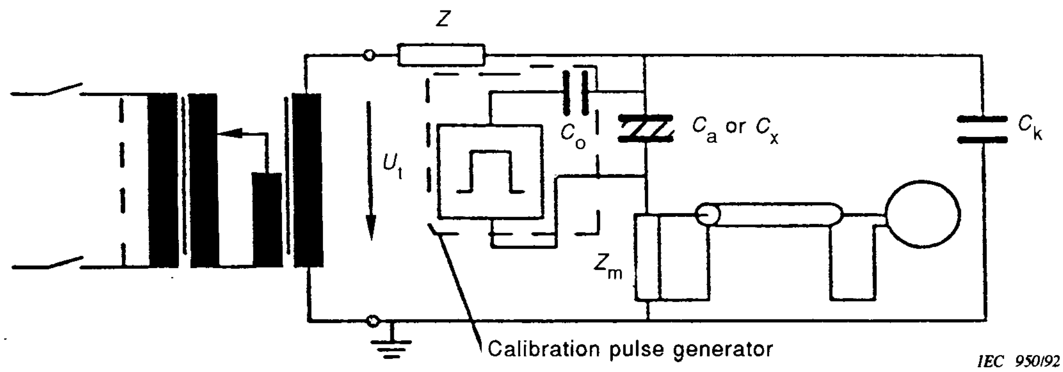


Figure C.4 – Calibration for unearthed test specimen

C.4.2 Verification of the noise level

With the arrangement used in C.4.1, the PD **test** voltage shall be raised up to the highest **test** voltage. The maximum noise level shall be less than 50 % of the **specified discharge magnitude**. Otherwise measures according to Clause D.3 are required.

C.4.3 Calibration for the PD test

With the **test** specimen in circuit, the procedure of C.4.1 shall be repeated.

Changes in **test** circuit or **test** specimen require recalibration. In the case of many similar **test** specimens, occasional recalibration may be sufficient if:

- the impedance of the coupling capacitor is less than 1/10 of that of the **test** specimen; or
- the impedance of the **test** specimen does not deviate from the value during calibration by more than ±10 %.

NOTE When specifying time intervals for recalibration, technical committees can bear in mind that, in case of insufficient sensitivity at the PD meter, potentially harmful discharges cannot be detected.

C.4.4 Calibration pulse generator

Basically, it consists of a small capacitance C_0 which has been charged to U_0.

The current pulses caused by the pulse generator should have a rise time of less than 0,03 / f_2. C_o shall have no higher value than 0,1 C_k. The tail time of the pulse should be greater than 100 µs.

To verify the performance of the PD meter, it shall be calibrated in all measuring ranges. The measuring impedance and the connecting cables shall be included in the procedure.

The following characteristics shall be checked:

– the precision and the stability of the calibration pulse generator;
– the reading for pulses of different amplitudes at a **pulse repetition rate** of 100 Hz;
– the pulse resolution time by using pulses of constant amplitude and increasing repetition rate;
– the lower and upper cut-off frequencies f_1 and f_2.

This procedure shall follow each time repairs are carried out on the PD meter but it shall in any case take place at least once a year.

Annex D
(informative)

Additional information on partial discharge test methods

D.1 Measurement of PD inception and extinction voltage

The **test** voltage is increased from a value below the **partial discharge inception voltage** until **partial discharges** occur (PD inception voltage U_i). After further increase of the **test** voltage by 10 %, the voltage is decreased until PD is smaller than the **specified discharge magnitude** (PD extinction voltage U_e). Thereby the insulation **test** voltage specified for the **test** specimen may not be exceeded.

NOTE It can occur that the **partial discharge extinction voltage** is influenced by the time of the voltage stress with values exceeding the **partial discharge inception voltage**. During successive measurements, both U_i and U_e can be influenced.

This procedure is appropriate for investigation measurements.

D.2 Description of PD test circuits (Figure D.1)

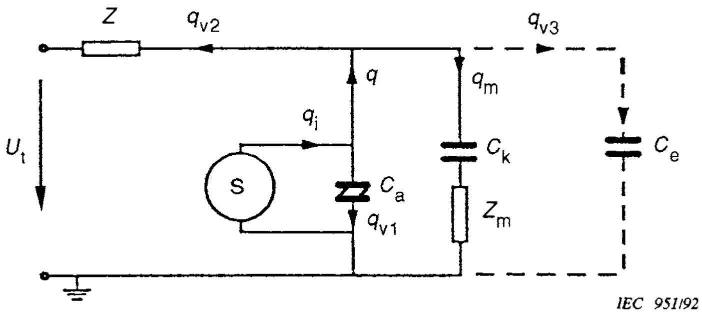
Each circuit consists of the following devices:

– the **test** specimen C_a (in special cases it may also be an impedance Z_a);

– the coupling capacitor C_k;

– the measuring circuit consisting of measuring impedance Z_m, the connecting cable and the PD meter;

– optionally a filter Z to reduce charge being bypassed by the **test** voltage source.



Key

U_t	**test** voltage	q_i	internal charge (not measurable)
Z	filter	q	**apparent charge**
S	PD current source	q_m	measurable charge
C_a	capacitance of the **test** specimen	q_{v1}	charge loss across the **test** specimen
C_k	coupling capacitor	q_{v2}	charge loss across the **test** voltage source
Z_m	measuring impedance	q_{v3}	charge loss across the earth stray capacitance
C_e	earth stray capacitance		

Figure D.1 – Partial discharge test circuits

The direct measurement of the **apparent charge** q would require a short-circuit at the terminals of the **test** specimen for the measuring frequency. This condition can be approximated as follows:

– $C_k > (C_a + C_e)$;

– high impedance Z;

– low measuring impedance Z_m.

Otherwise significant charge losses q_{v2} and q_{v3} may occur. These charge losses are taken into account by the calibration but they will limit the sensitivity. The situation is aggravated if the **test** specimen has a high capacitance.

D.3 Precautions for reduction of noise

D.3.1 General

The results of PD measurements may be greatly influenced by noise. Such noise may be introduced by conductive coupling or by electromagnetic interference. In unscreened industrial **test** sites, single charge pulses as high as 100 pC may occur due to noise. Even under favourable conditions, not less than 20 pC may be expected.

A noise level as low as 1 pC may be achieved, but this will require screening of the **test** circuit, careful earthing measures and filtering of the low-voltage mains input.

D.3.2 Sources of noise

Basically, there are two different kinds of noise sources.

D.3.2.1 Sources in the non-energized test circuit

These are caused for instance by switching in adjacent circuits. In case of conductive coupling they only occur if connection to the low-voltage mains supply is provided. In case of electromagnetic coupling they also occur if the mains supply is switched off (including the protective conductor).

D.3.2.2 Sources in the energized test circuit

Usually, noise increases with the **test** voltage and is caused by **partial discharges** outside the **test** specimen. PD may occur in the **test** transformer, the high-voltage connecting leads, bushings and points of poor contact. Harmonics of the **test** voltage may also contribute to the noise level.

D.3.3 Measures for reduction of noise

Noise caused by conductive coupling can be reduced by use of line filters in the central feeding of the **test** circuit. No earth loops should be present.

Electromagnetic interference, for instance by radio signals, can be excluded in a simple manner by variation of the measuring frequency f_0 for narrowband PD meters. For wideband PD meters, band-stop-filters may be required, wideband signals can only be suppressed by screening. The highest efficiency is provided by a fully enclosed screen with high electrical conductivity.

D.4 Application of multiplying factors for test voltages

D.4.1 General

The values of the multiplying factors defined in 6.3.6.1 and used in 5.4.3.3 and 6.3.6.1 are calculated as follows.

NOTE These examples are given for the **recurring peak voltage** U_{rp}. The factors similarly apply to the **steady-state peak voltage** and to the long-term **temporary overvoltage**.

D.4.2 Example 1

Circuit connected to the low-voltage mains.

D.4.2.1 Maximum recurring peak voltage U_{rp}

$$U_{\text{rp}} = \sqrt{2}\,U_{\text{n}} \times F_4 = 1{,}1\sqrt{2}\,U_{\text{n}}$$

D.4.2.2 PD extinction voltage U_{e} (basic insulation)

$$U_{\text{e}} = \sqrt{2}\,U_{\text{n}} \times F_4 \times F_1$$

$$U_e = \sqrt{2}\,U_n \times 1{,}1 \times 1{,}2 = 1{,}32\sqrt{2}\,U_n$$

D.4.2.3 Initial value of the PD test voltage U_1 (basic insulation)

$$U_1 = \sqrt{2}\,U_n \times F_4 \times F_1 \times F_2$$

$$U_1 = \sqrt{2}\,U_n \times 1{,}32 \times 1{,}25 = 1{,}65\sqrt{2}\,U_n$$

D.4.3 Example 2

Internal circuit with maximum **recurring peak voltage** U_{rp}.

D.4.3.1 PD extinction voltage U_e (basic insulation)

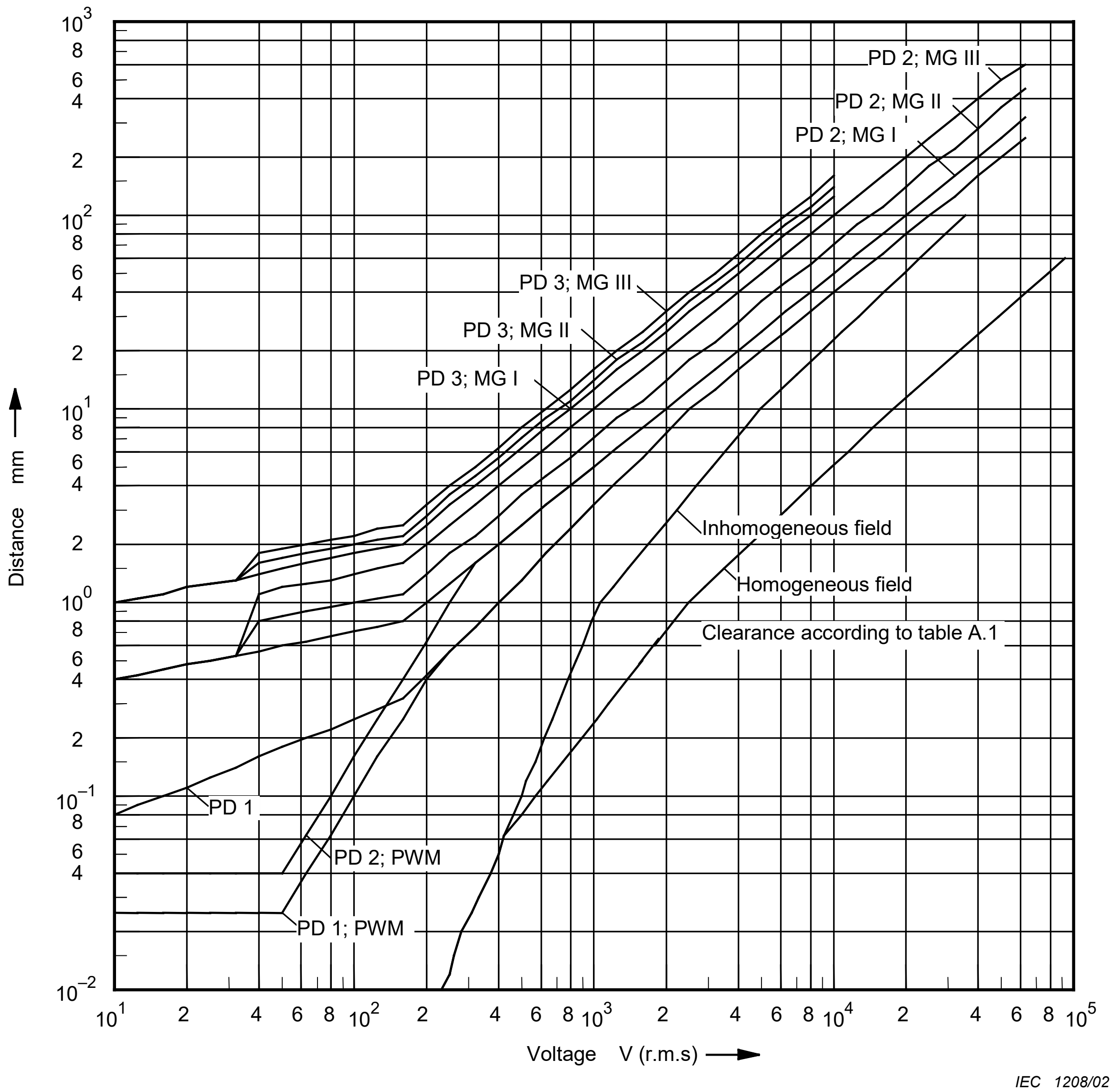
$$U_e = U_{rp} \times F_1 = U_{rp} \times 1{,}2$$

D.4.3.2 Initial value of the PD test voltage (basic insulation)

$$U_1 = U_{rp} \times F_1 \times F_2 = U_{rp} \times 1{,}5$$

Annex E
(informative)

Comparison of creepage distances specified in Table F.5 and clearances in Table A.1



Key

PD pollution degree

MG material group

PWM printed wiring material

Figure E.1 – Comparison between creepage distances specified in Table F.5 and clearances in Table A.1

Annex F
(normative)

Tables

Table F.1 – Rated impulse withstand voltage for equipment energized directly from the low-voltage mains

Nominal voltage of the supply system [1] based on IEC 60038 [3]		Voltage line to neutral derived from nominal voltages AC or DC up to and including	Rated impulse withstand voltage [2]			
			Overvoltage category [4]			
Three-phase V	Single phase V	V	I V	II V	III V	IV V
		50	330	500	800	1 500
		100	500	800	1 500	2 500
	120-240	150 [5]	800	1 500	2 500	4 000
230/400 277/480		300	1 500	2 500	4 000	6 000
400/690		600	2 500	4 000	6 000	8 000
1 000		1 000	4 000	6 000	8 000	12 000
	1 500 [6]	1 500 [6]	6 000	8 000	10 000	15 000

1) See Annex B for application to existing different low-voltage mains and their nominal voltages.

2) Equipment with this **rated impulse withstand voltage** can be used in installations in accordance with IEC 60364-4-44.

3) The / mark indicates a four-wire three-phase distribution system. The lower value is the voltage line-to-neutral, while the higher value is the voltage line-to-line. Where only one value is indicated, it refers to three-wire, three-phase systems and specifies the value line-to-line.

4) See 4.3for an explanation of the **overvoltage categories**.

5) Nominal voltages for single-phase systems in Japan are 100 V or 100-200 V. However, the value of the **rated impulse withstand voltage** for the voltages is determined from columns applicable to the voltage line to neutral of 150 V (see Annex B).

6) For DC values only.

Table F.2 – Clearances to withstand transient overvoltages

<table>
<tr><th rowspan="4">Required impulse withstand voltage [1] [5]

kV</th><th colspan="6">Minimum clearances in air up to 2 000 m above sea level</th></tr>
<tr><th colspan="3">Case A
Inhomogeneous field
(see 3.1.29)</th><th colspan="3">Case B
Homogeneous field
(see 3.1.28)</th></tr>
<tr><th colspan="3">Pollution degree [6]</th><th colspan="3">Pollution degree [6]</th></tr>
<tr><th>1
mm</th><th>2
mm</th><th>3
mm</th><th>1
mm</th><th>2
mm</th><th>3
mm</th></tr>
<tr><td>0,33 [2]</td><td>0,01</td><td rowspan="6">0,2 [3] [4]</td><td rowspan="8">0,8 [4]</td><td>0,01</td><td rowspan="7">0,2 [3] [4]</td><td rowspan="11">0,8 [4]</td></tr>
<tr><td>0,40</td><td>0,02</td><td>0,02</td></tr>
<tr><td>0,50 [2]</td><td>0,04</td><td>0,04</td></tr>
<tr><td>0,60</td><td>0,06</td><td>0,06</td></tr>
<tr><td>0,80 [2]</td><td>0,10</td><td>0,10</td></tr>
<tr><td>1,0</td><td>0,15</td><td>0,15</td></tr>
<tr><td>1,2</td><td>0,25</td><td>0,25</td><td>0,2</td></tr>
<tr><td>1,5 [2]</td><td>0,5</td><td>0,5</td><td>0,3</td><td>0,3</td></tr>
<tr><td>2,0</td><td>1,0</td><td>1,0</td><td>1,0</td><td>0,45</td><td>0,45</td></tr>
<tr><td>2,5 [2]</td><td>1,5</td><td>1,5</td><td>1,5</td><td>0,60</td><td>0,60</td></tr>
<tr><td>3,0</td><td>2,0</td><td>2,0</td><td>2,0</td><td>0,80</td><td>0,80</td></tr>
<tr><td>4,0 [2]</td><td>3,0</td><td>3,0</td><td>3,0</td><td>1,2</td><td>1,2</td><td>1,2</td></tr>
<tr><td>5,0</td><td>4,0</td><td>4,0</td><td>4,0</td><td>1,5</td><td>1,5</td><td>1,5</td></tr>
<tr><td>6,0 [2]</td><td>5,5</td><td>5,5</td><td>5,5</td><td>2,0</td><td>2,0</td><td>2,0</td></tr>
<tr><td>8,0 [2]</td><td>8,0</td><td>8,0</td><td>8,0</td><td>3,0</td><td>3,0</td><td>3,0</td></tr>
<tr><td>10</td><td>11</td><td>11</td><td>11</td><td>3,5</td><td>3,5</td><td>3,5</td></tr>
<tr><td>12 [2]</td><td>14</td><td>14</td><td>14</td><td>4,5</td><td>4,5</td><td>4,5</td></tr>
<tr><td>15</td><td>18</td><td>18</td><td>18</td><td>5,5</td><td>5,5</td><td>5,5</td></tr>
<tr><td>20</td><td>25</td><td>25</td><td>25</td><td>8,0</td><td>8,0</td><td>8,0</td></tr>
<tr><td>25</td><td>33</td><td>33</td><td>33</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>30</td><td>40</td><td>40</td><td>40</td><td>12,5</td><td>12,5</td><td>12,5</td></tr>
<tr><td>40</td><td>60</td><td>60</td><td>60</td><td>17</td><td>17</td><td>17</td></tr>
<tr><td>50</td><td>75</td><td>75</td><td>75</td><td>22</td><td>22</td><td>22</td></tr>
<tr><td>60</td><td>90</td><td>90</td><td>90</td><td>27</td><td>27</td><td>27</td></tr>
<tr><td>80</td><td>130</td><td>130</td><td>130</td><td>35</td><td>35</td><td>35</td></tr>
<tr><td>100</td><td>170</td><td>170</td><td>170</td><td>45</td><td>45</td><td>45</td></tr>
</table>

1) This voltage is:

– for functional insulation, for basic insulation directly exposed to or significantly influenced by **transient overvoltage**s from the low-voltage mains (see 4.2.2, 5.2.2.3 and 5.4.3.1), the r**ated impulse withstand voltage** of the equipment,

– for other **basic insulation** (see 5.4.3), the highest impulse voltage that can occur in the circuit.

For **reinforced insulation,** see 5.4.3.

2) Preferred values as specified in 4.2.2.

3) For printed wiring material, the values for **pollution degree** 1 apply except that the value shall not be less than 0,04 mm, as specified in Table F.5.

4) The minimum **clearances** given for **pollution degrees** 2 and 3 are based on the reduced withstand characteristics of the associated creepage distance under humidity conditions

5) For parts or circuits within equipment subject to **impulse withstand voltages** according to 5.4.3, interpolation of values is allowed. However, standardization is achieved by using the preferred series of impulse voltage values in 4.2.2.

6) The dimensions for **pollution degree** 4 are as specified for **pollution degree** 3, except that the minimum **clearance** is 1,6 mm.

Table F.3 – Single-phase three or two-wire AC. or DC systems

Nominal voltage of the supply system *	Voltages rationalized for Table F.4	
	For insulation line-to-line 1)	For insulation line-to-earth 1)
	All systems	Three-wire systems mid-point earthed
V	V	V
12,5	12,5	
24 25	25	
30	32	
42 48 50 **	50	
60	63	
30-60	63	32
100 **	100	
110 120	125	
150 **	160	
200	200	
100-200	200	100
220	250	
110-220 120-240	250	125
300 **	320	
220-440	500	250
600 **	630	
480-960	1 000	500
1 000 **	1 000	
1 500 ***	1 500	

1) Line-to-earth **insulation** level for unearthed or impedance-earthed systems equals that for line-to-line because the operating voltage to earth of any line can, in practice, approach full line-to-line voltage. This is because the actual voltage to earth is determined by the **insulation** resistance and capacitive reactance of each line to earth; thus, low (but acceptable) **insulation** resistance of one line can in effect earth it and raise the other two to full line-to-line voltage to earth.

* For relationship to **rated voltage** see 5.3.2.2

** These values correspond to the values given in Table F.1.

*** For DC values only.

Table F.4 – Three-phase four or three-wire AC systems

Nominal voltage of the supply system *	**Voltages rationalized for Table F.5**		
	For insulation line-to-line	**For insulation line-to-earth**	
	All systems	**Three-phase four-wire systems neutral-earthed** 2)	**Three-phase three-wire systems unearthed** 1) **or corner-earthed**
V	V	V	V
60	63	32	63
110 120 127	125	80	125
150 **	160	–	160
200	200		200
208	200	125	200
220 230 240	250	160	250
300 **	320	–	320
380 400 415	400	250	400
440	500	250	500
480 500	500	320	500
575	630	400	630
600 **	630	–	630
660 690	630	400	630
720 830	800	500	800
960	1 000	630	1 000
1 000 **	1 000	–	1 000

1) Line-to-earth **insulation** level for unearthed or impedance-earthed systems equals that for line-to-line because the operating voltage to earth of any line can, in practice, approach full line-to-line voltage. This is because the actual voltage to earth is determined by the **insulation** resistance and capacitive reactance of each line to earth; thus, low (but acceptable) **insulation** resistance of one line can in effect earth it and raise the other two to full line-to-line voltage to earth.

2) For equipment for use on both three-phase four-wire and three-phase three-wire supplies, earthed and unearthed, use the values for three-wire systems only.

* For relationship to **rated voltage** see 5.3.2.2.

** These values correspond to the values given in Table F.1.

Table F.5 – Creepage distances to avoid failure due to tracking

Voltage r.m.s. [1)]	Minimum creepage distances								
	Printed wiring material								
	Pollution degree								
	1	2	1	2			3		
	All material groups	All material groups, except IIIb	All material groups	Material group I	Material group II	Material group III	Material group I	Material group II	Material group III [2)]
V	mm	mm	mm	mm	mm	mm	mm	mm	mm
10	0,025	0,040	0,080	0,400	0,400	0,400	1,000	1,000	1,000
12,5	0,025	0,040	0,090	0,420	0,420	0,420	1,050	1,050	1,050
16	0,025	0,040	0,100	0,450	0,450	0,450	1,100	1,100	1,100
20	0,025	0,040	0,110	0,480	0,480	0,480	1,200	1,200	1,200
25	0,025	0,040	0,125	0,500	0,500	0,500	1,250	1,250	1,250
32	0,025	0,040	0,14	0,53	0,53	0,53	1,30	1,30	1,30
40	0,025	0,040	0,16	0,56	0,80	1,10	1,40	1,60	1,80
50	0,025	0,040	0,18	0,60	0,85	1,20	1,50	1,70	1,90
63	0,040	0,063	0,20	0,63	0,90	1,25	1,60	1,80	2,00
80	0,063	0,100	0,22	0,67	0,95	1,30	1,70	1,90	2,10
100	0,100	0,160	0,25	0,71	1,00	1,40	1,80	2,00	2,20
125	0,160	0,250	0,28	0,75	1,05	1,50	1,90	2,10	2,40
160	0,250	0,400	0,32	0,80	1,10	1,60	2,00	2,20	2,50
200	0,400	0,630	0,42	1,00	1,40	2,00	2,50	2,80	3,20
250	0,560	1,000	0,56	1,25	1,80	2,50	3,20	3,60	4,00
320	0,75	1,60	0,75	1,60	2,20	3,20	4,00	4,50	5,00
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 (7,9) [4)]
630	1,8	3,2	1,8	3,2	4,5	6,3	8,0 (7,9) [4)]	9,0 (8,4) [4)]	10,0 (9,0) [4)]
800	2,4	4,0	2,4	4,0	5,6	8,0	10,0 (9,0) [4)]	11,0 (9,6) [4)]	12,5 (10,2) [4)]
1 000	3,2	5,0	3,2	5,0	7,1	10,0	12,5 (10,2) [4)]	14,0 (11,2) [4)]	16,0 (12,8) [4)]
1 250			4,2	6,3	9,0	12,5	16,0 (12,8) [4)]	18,0 (14,4) [4)]	20,0 (16,0) [4)]
1 600			5,6	8,0	11,0	16,0	20,0 (16,0) [4)]	22,0 (17,6) [4)]	25,0 (20 0) [4)]
2 000			7,5	10,0	14,0	20,0	25,0 (20,0) [4)]	28,0 (22,4) [4)]	32,0 (25,6) [4)]
2 500			10,0	12,5	18,0	25,0	32,0 (25,6) [4)]	36,0 (28,8) [4)]	40,0 (32 0) [4)]
3 200			12,5	16,0	22,0	32,0	40,0 (32,0) [4)]	45,0 (36,0) [4)]	50,0 (40,0) [4)]

2154 **Table F.5** *(continued)*

Voltage r.m.s. [1)]	Minimum creepage distances									
	Printed wiring material									
	Pollution degree									
	1	2	1	2			3			
	All material groups	All material groups, except IIIb	All material groups	Material group I	Material group II	Material group III	Material group I	Material group II	Material group III [2)]
V	mm	mm	mm	mm	mm	mm	mm	mm	mm
4 000			16,0	20,0	28,0	40,0	50,0 (40,0) [4)]	56,0 (44,8) [4)]	63,0 (50,4) [4)]
5 000			20,0	25,0	36,0	50,0	63,0 (50,4) [4)]	71,0 (56,8) [4)]	80,0 (64,0) [4)]
6 300			25,0	32,0	45,0	63,0	80,0 (64,0) [4)]	90,0 (72,0) [4)]	100,0 (80,0) [4)]
8 000			32,0	40,0	56,0	80,0	100,0 (80,0) [4)]	110,0 (88,0) [4)]	125,0 (100,0) [4)]
10 000			40,0	50,0	71,0	100,0	125,0 (100,0) [4)]	140,0 (112,0) [4)]	160,0 (128,0) [4)]
12 500			50,0 [3)]	63,0 [3)]	90,0 [3)]	125,0 [3)]			
16 000			63,0 [3)]	80,0 [3)]	110,0 [3)]	160,0 [3)]			
20 000			80,0 [3)]	100,0 [3)]	140,0 [3)]	200,0 [3)]			
25 000			100,0 [3)]	125,0 [3)]	180,0 [3)]	250,0 [3)]			
32 000			125,0 [3)]	160,0 [3)]	220,0 [3)]	320,0 [3)]			
40 000			160,0 [3)]	200,0 [3)]	280,0 [3)]	400,0 [3)]			
50 000			200,0 [3)]	250,0 [3)]	360,0 [3)]	500,0 [3)]			
63 000			250,0 [3)]	320,0 [3)]	450,0 [3)]	600,0 [3)]			

1) This voltage is

– for functional insulation, for basic insulation and supplementary insulation of the circuit energized directly from the supply mains (see 4.3.1), the voltage rationalized through Table F.3 or Table F.4, based on the rated voltage of the equipment, or the rated insulation voltage,

– for **basic** insulation and **supplementary insulation** of systems, equipment and internal circuits not energized directly from the mains (see 4.3.2), the highest r.m.s. voltage which can occur in the system, equipment or internal circuit when supplied at **rated voltage** and under the most onerous combination of conditions of operation within equipment rating.

2) Material group IIIb is not recommended for application in **pollution degree** 3 above 630 V.

3) Provisional data based on extrapolation. Technical committees who have other information based on experience may use their dimensions.

4) The values given in brackets may be applied to reduce the creepage distance in case of using a rib (see 5.3.3.7).

NOTE The high precision for **creepage distances** given in this table does not mean that the uncertainty of measurement has to be in the same order of magnitude.

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Table F.6 – Test voltages for verifying clearances at different altitudes

The voltage values of Table F.6 apply for the verification of **clearances** only.

Rated impulse withstand voltage $\hat{U}$ kV	**Impulse test voltage at sea level** $\hat{U}$ kV	**Impulse test voltage at 200 m altitude** $\hat{U}$ kV	**Impulse test voltage at 500 m altitude** $\hat{U}$ kV
0,33	0,357	0,355	0,350
0,5	0,541	0,537	0,531
0,8	0,934	0,920	0,899
1,5	1,751	1,725	1,685
2,5	2,920	2,874	2,808
4,0	4,923	4,824	4,675
6,0	7,385	7,236	7,013
8,0	9,847	9,648	9,350
12,0	14,770	14,471	14,025

NOTE 1 Explanations concerning the influencing factors (air pressure, altitude, temperature, humidity) with respect to electric strength of **clearances** are given in 4.6.5.

NOTE 2 When **testing clearances**, associated **solid insulation** will be subjected to the **test** voltage. As the impulse **test** voltage of Table F.6 is increased with respect to the **rated impulse withstand voltage**, **solid insulation** will have to be designed accordingly. This results in an increased impulse withstand capability of the **solid insulation**.

Table F.7 – Severities for conditioning of solid insulation

Test	**Temperature** °C	**Relative humidity** %	**Time** h	**Number of cycles**
a) Dry heat	+55	–	48	1
b) Dry heat cycle	–10 to +55	–	Cycle duration 24	3
c) Thermal shock (rapid change of temperature)	–10 to +55	–	[2]	
d) Damp heat	30/40 [1]	93	96	1

[1] Standard temperature of damp heat **test** appears in IEC 60068-2-78.

[2] Duration of the temperature change depends on the thermal time constant of the **test** specimen, see IEC 60068-2-14.

NOTE For the damp heat **test** 25 °C is still used in some product standards.

Table F.8 – Clearances to withstand steady-state peak voltages, temporary overvoltages or recurring peak voltages

Table F.8a – Dimensioning of clearances to withstand steady-state peak voltages, temporary overvoltages or recurring peak voltages

Voltage 1) (peak value) 2)	Minimum clearances in air up to 2 000 m above sea level	
	Case A Inhomogeneous field conditions (see 3.1.29)	Case B Homogeneous field conditions (see 3.1.28)
kV	mm	mm
0,04	0,001 3)	0,001 3)
0,06	0,002 3)	0,002 3)
0,1	0,003 3)	0,003 3)
0,12	0,004 3)	0,004 3)
0,15	0,005 3)	0,005 3)
0,20	0,006 3)	0,006 3)
0,25	0,008 3)	0,008 3)
0,33	0,01	0,01
0,4	0,02	0,02
0,5	0,04	0,04
0,6	0,06	0,06
0,8	0,13	0,1
1,0	0,26	0,15
1,2	0,42	0,2
1,5	0,76	0,3
2,0	1,27	0,45
2,5	1,8	0,6
3,0	2,4	0,8
4,0	3,8	1,2
5,0	5,7	1,5
6,0	7,9	2
8,0	11,0	3
10	15,2	3,5
12	19	4,5
15	25	5,5
20	34	8
25	44	10
30	55	12,5
40	77	17
50	100	22
60		27
80		35
100		45

1) The **clearances** for other voltages are obtained by interpolation.

2) See Figure 1 for **recurring peak voltage**.

3) These values are based on experimental data obtained at atmospheric pressure.

Table F.8b – Additional information concerning the dimensioning of clearances to avoid partial discharge

Voltage 1) (peak value) 2)	Minimum clearances in air up to 2 000 m above sea level
	Case A Inhomogeneous field conditions (see 3.1.29)
kV	mm
0,04	As specified for Case A in Table F.8a
0,06	
0,1	
0,12	
0,15	
0,2	
0,25	
0,33	
0,4	
0,5	
0,6	
0,8	
1,0	
1,2	
1,5	
2,0	
2,5	2,0
3,0	3,2
4,0	11
5,0	24
6,0	64
8,0	184
10	290
12	320
15	3)
20	
25	
30	
40	
50	
60	
80	
100	

1) The **clearances** for other voltages are obtained by interpolation.

2) See Figure 1 for **recurring peak voltage**.

3) Dimensioning without **partial discharge** is not possible under **inhomogeneous field** conditions.

NOTE If clearances are stressed with **steady-state peak voltages** of 2,5 kV and above, dimensioning according to the breakdown values in Table F.8a cannot provide operation without corona (**partial discharges**), especially for **inhomogeneous field**s. In order to provide corona-free operation, it is either necessary to use larger **clearances**, as given in Table F.8b, or to improve the field distribution.

Table F.9 – Altitude correction factors

Altitude m	**Factor k_d for distance correction**
0	0,784
200	0,803
500	0,833
1 000	0,844
2 000	1

Annex G
(informative)

Determination of clearance distances according to 5.2

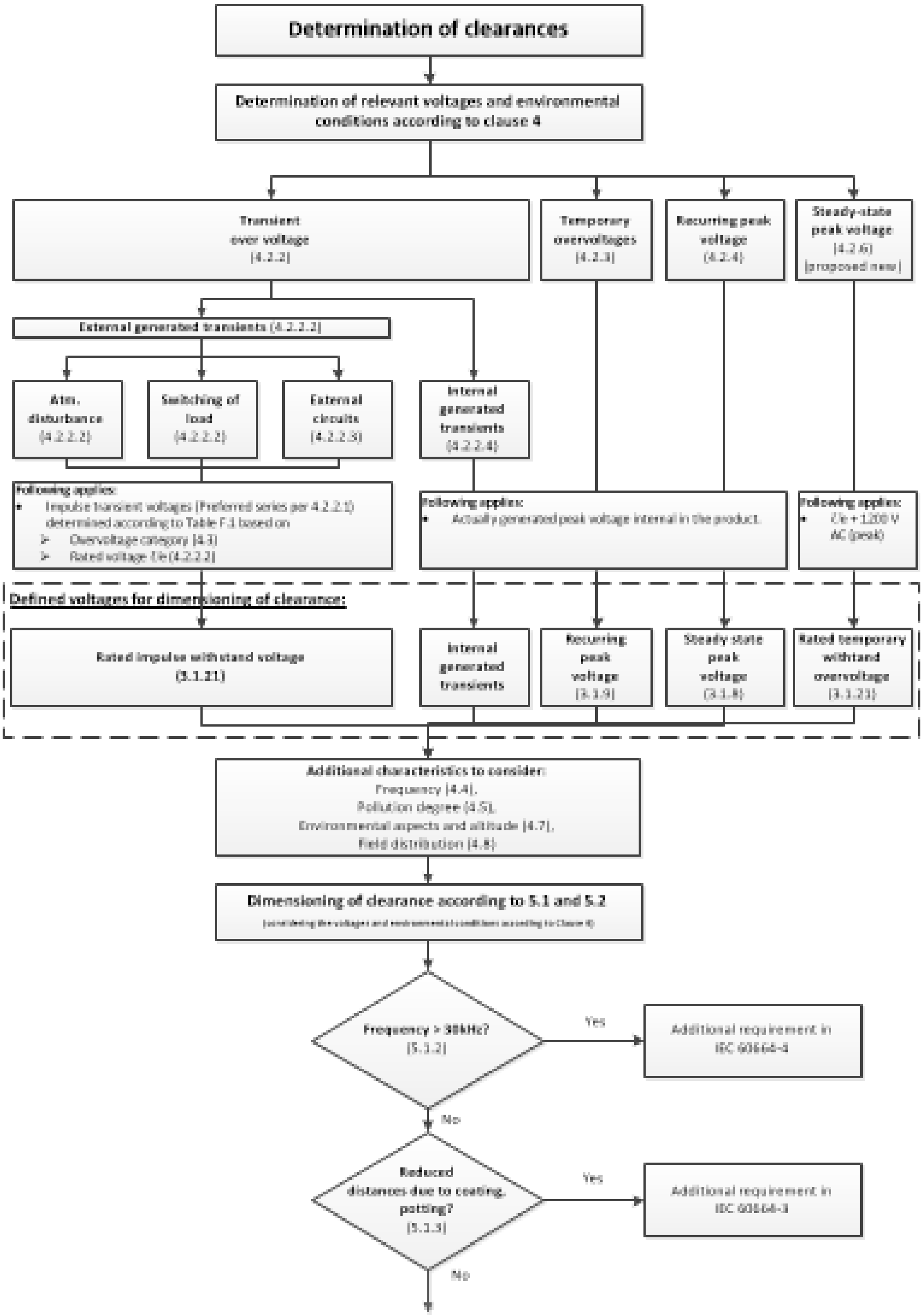


Figure G.1 – Determination of clearance distances according to 5.2
(continuation below)

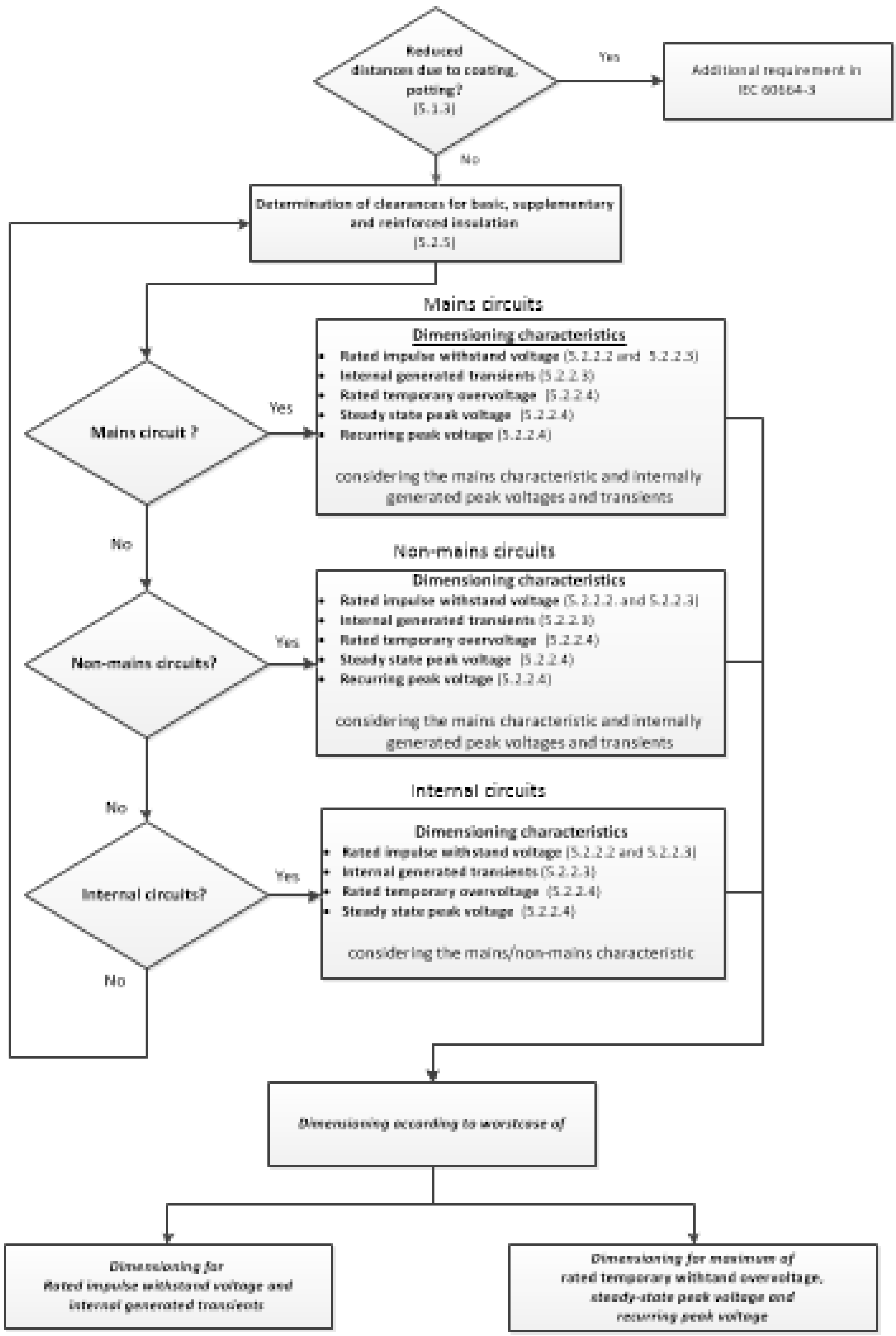


Figure G.1 – Determination of clearance distances according to 5.2
(continuation below)

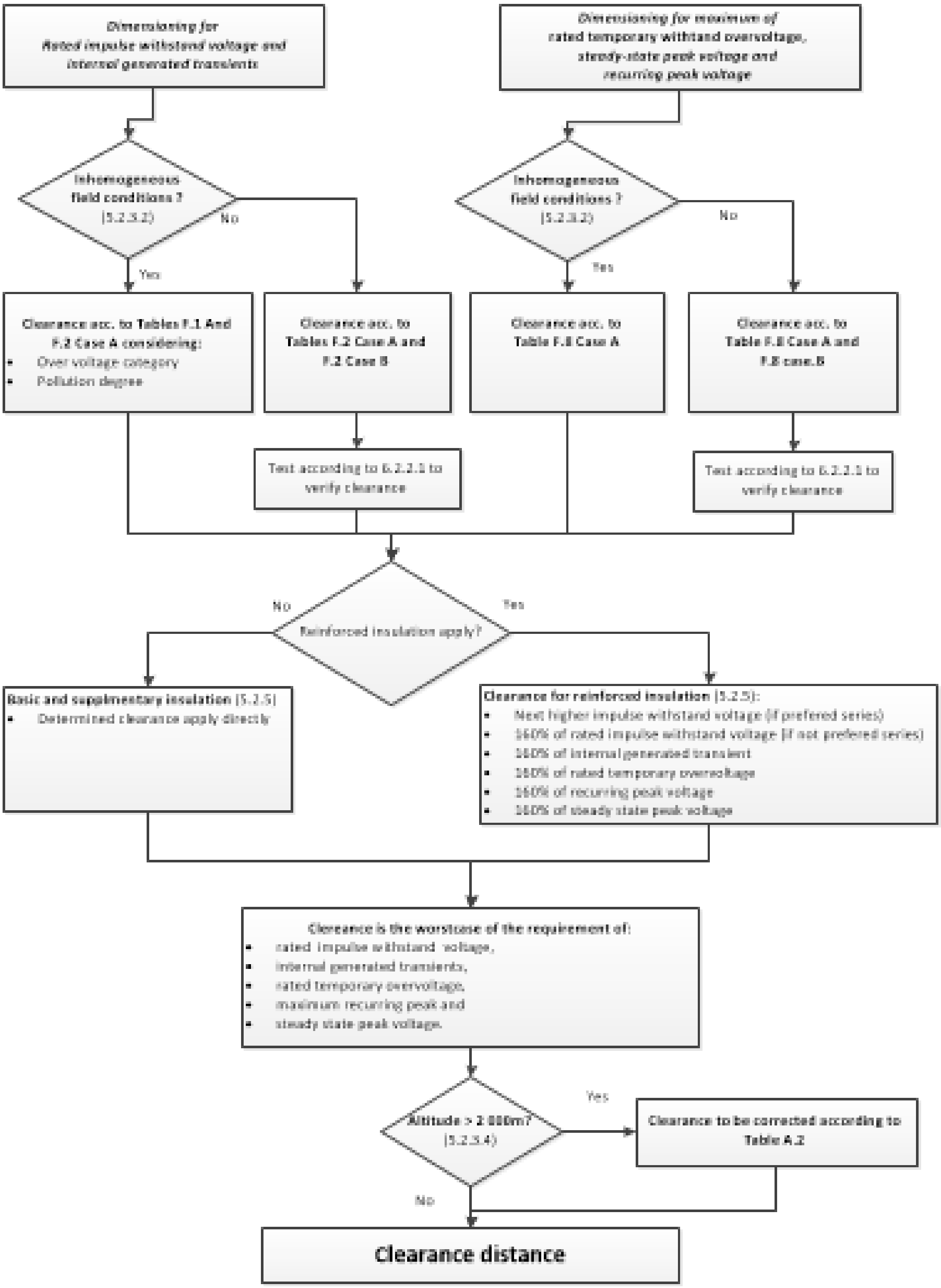


Figure G.1 – Determination of clearance distances according to 5.2
(end)

Annex H
(informative)

Determination of creepage distances according to 5.3

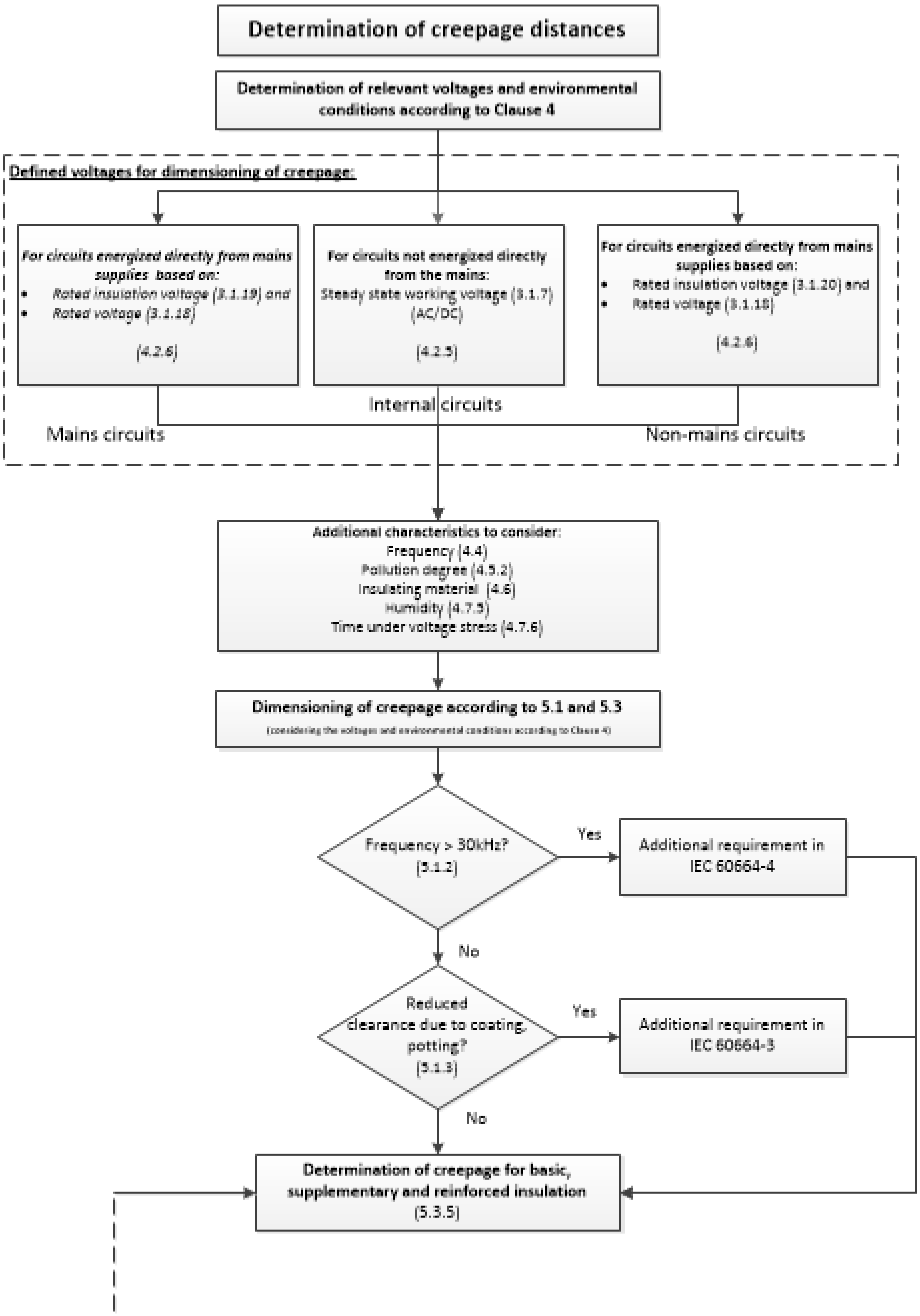


Figure H.1 – Determination of creepage distances according to 5.3
(continuation below)

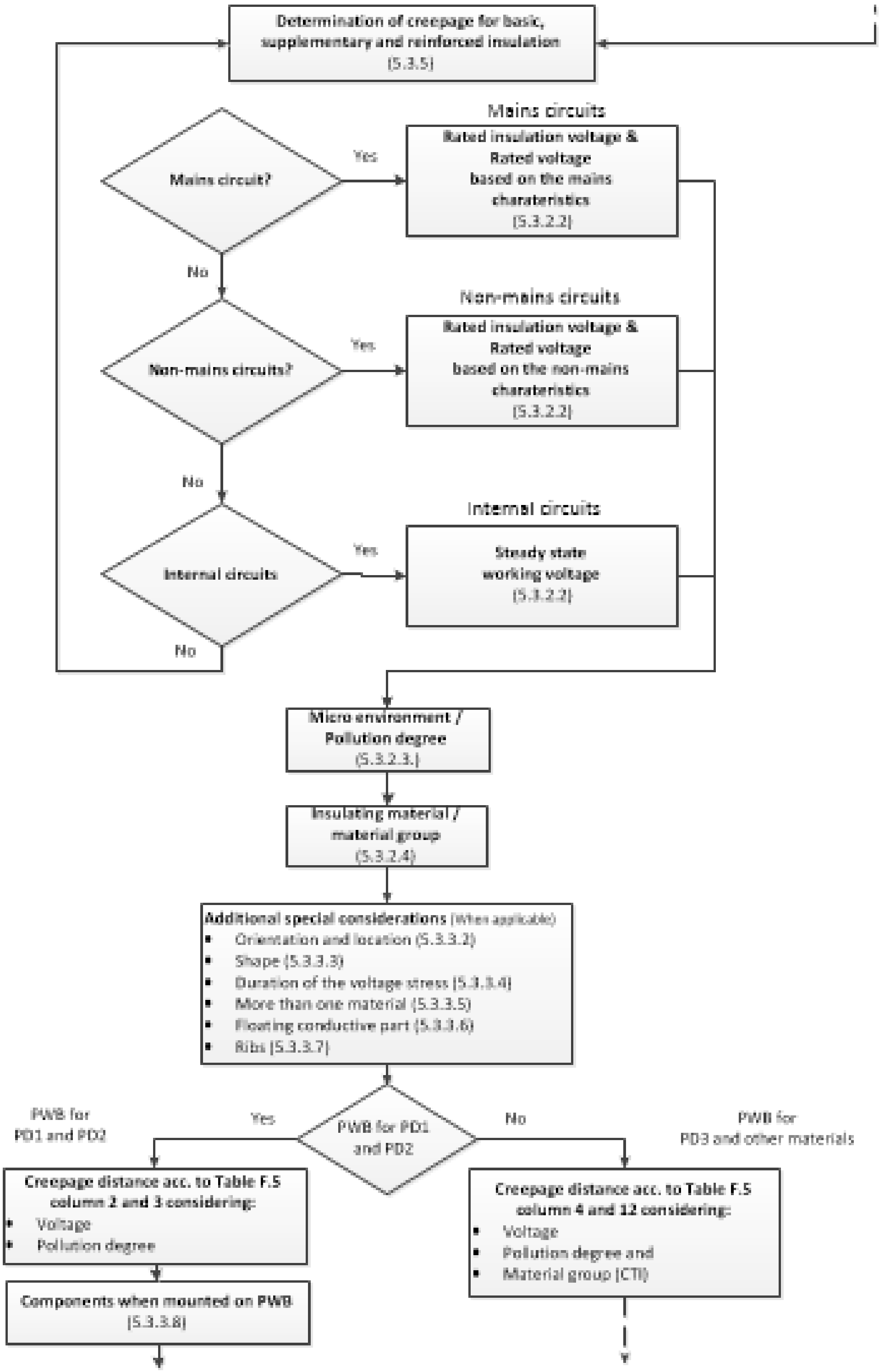
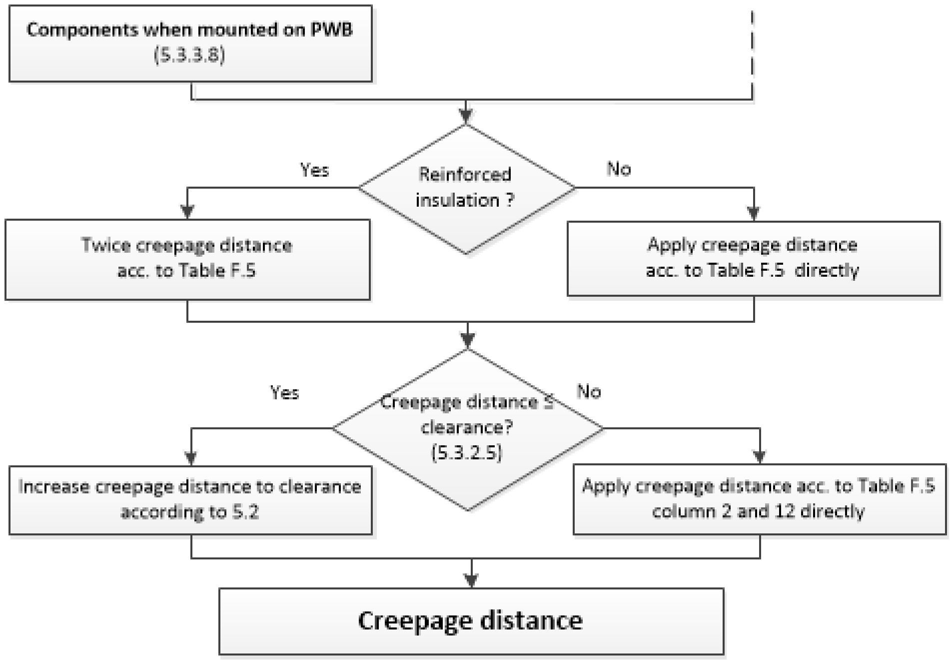


Figure H.1 – Determination of creepage distances according to 5.3
(continuation)



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2205 **Figure H.1 – Determination of creepage distances according to 5.3**
2206 *(end)*

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