भारतीय मानक
Indian Standard

IS 15382 (Part 1) : 2022
IEC 60664-1 : 2020

[*Superseding* IS 2165 (Part 1) : 1977]

निम्न-वोल्टता तंत्र में उपकरणों का विद्युतरोधी समन्वय

भाग 1 सिद्धांत, अपेक्षाएं और परीक्षण

(दूसरा पुनरीक्षण)

Insulation Coordination for Equipment within Low-Voltage Systems

Part 1 Principles, Requirements and Tests

(Second Revision)

ICS 29.080.30

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High Voltage Engineering Sectional Committee, ETD 19

NATIONAL FOREWORD

This Indian Standard (Part 1) (Second Revision) which is identical with IEC 60664-1 : 2020 'Insulation coordination for equipment within low-voltage systems — Part 1: Principles, requirements and tests' was adopted by the Bureau of Indian Standards on recommendation of the High Voltage Engineering Sectional Committee and approval of the Electrotechnical Division Council.

After the publication of this standard, IS 2165 (Part 1) : 1977 shall be treated as withdrawn since the requirements given in IS 2165 (Part 1) : 1977 has been covered in this standard.

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

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker, while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

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

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60068-2-78 Environmental testing — Part 2-78: Tests — Test Cab: Damp heat, steady state	IS 9000 (Part 4) : 2020 Environmental testing: Part 4 Tests — Test Cab: Damp heat, steady state (*second revision*)	Identical
IEC 60270 High-voltage test techniques — Partial discharge measurements	IS/IEC 60270 : 2000 High-voltage test techniques — Partial discharge measurements	Identical
IEC 61180 : 2016 High-voltage test techniques for low-voltage equipment — Definitions, test and procedure requirements, test equipment	IS 16826 : 2018 High-voltage test techniques for low-voltage equipment — Definitions, test and procedure requirements, test equipment	Identical

The technical committee has reviewed the provisions of the following International Standards referred to in this adopted standard and has decided that they are acceptable for use in conjunction with this standard:

International Standard	*Title*
IEC 60068-2-2	Environmental testing — Part 2-2: Tests — Tests B: Dry heat
IEC 60068-2-14 : 2009	Environmental testing — Part 2-14: Tests — Test N: Change of temperature
IEC 61140 : 2016	Protection against electric shock — Common aspects forinstallation and equipment

Only the English language text has been retained while adopting it in this Indian Standard, and as such, the page numbers given here are not the same as in the IEC Publication.

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

CONTENTS

Indian Standard

INSULATION COORDINATION FOR EQUIPMENT WITHIN LOW-VOLTAGE SYSTEMS

PART 1 PRINCIPLES, REQUIREMENTS AND TESTS

(Second Revision)

1 Scope

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

This document applies to frequencies up to 30 kHz.

NOTE 1 Requirements for **insulation coordination** for equipment within **low-voltage supply systems** with rated frequencies above 30 kHz are 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 (See 5.2.3.4).

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

The minimum **clearances** specified in this document do not apply where ionized gases are present. 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 basic safety publication focusing on safety essential requirements 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.

One of the responsibilities of a technical committee is, wherever applicable, to make use of basic safety publications in the preparation of its publications.

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 applies.

2 Normative references

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

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

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

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, test equipment*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the following terms and 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 – The term " electric power system" has been replaced with “low-voltage supply system”.]

3.1.2
mains supply
AC or DC power distribution system (external to the equipment) that supplies operating power to the equipment

Note 1 to entry: **Mains supply** includes public or private utilities and, unless otherwise specified in this document, equivalent sources such as motor-driven generators and uninterruptible power supplies.

3.1.3
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 3.1.7 to 3.1.16.

[SOURCE: IEC 60050-442:2014, 442-09-01, modified – “electrical” replaces “electric” and Note 1 to entry has been added.]

3.1.4
clearance
shortest distance in air between two conductive parts

[SOURCE: IEC 60050-581:2008, 581-27-76]

3.1.5
creepage distance
shortest distance along the surface of a solid insulating material between two conductive parts

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

3.1.6
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 – The example has been deleted.]

3.1.7
working voltage
highest RMS 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 overvoltages** 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]

3.1.8
steady-state working voltage
working voltage after the **transient overvoltage** phenomena have subsided and not taking into account short-term voltage variations

3.1.9
steady-state peak voltage
peak value of the **steady-state working voltage**

3.1.10
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

Note 1 to entry: Random **overvoltages**, for example due to occasional switching, are not considered to be recurring peak voltages.

[SOURCE: IEC 60050-442:2014, 442-09-15]

3.1.11
overvoltage
<electrical system> any voltage having a peak value exceeding the corresponding peak value of maximum **steady-state working voltage** at normal operating conditions

3.1.12
temporary overvoltage
overvoltage at power frequency of relatively long duration

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

3.1.13
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 – "overvoltage with a duration" has been replaced with "short duration overvoltage" and the notes have been deleted.]

3.1.14
withstand voltage
<in an electrical system> voltage to be applied to a specimen under specified test conditions which does not cause breakdown of insulation and/or **flashover** of a satisfactory specimen

3.1.15
impulse withstand voltage
highest peak value of impulse voltage of specified form and polarity which does not cause breakdown of insulation under specified conditions

[SOURCE: IEC 60050-442:2014, 442-09-18, modified – "prescribed" has been replaced with "specified".]

3.1.16
temporary withstand overvoltage
highest RMS value of a **temporary overvoltage** which does not cause breakdown of insulation under specified conditions

[SOURCE: IEC 60050-442:2014, 442-09-19]

3.1.17
rated voltage
U_{n}
<of equipment> 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 60050-442:2014, 442-09-10, modified – "rated value of the voltage" has been replaced with "value of voltage" and Note 2 to entry has been deleted.]

3.1.18
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 60050-312:2014, 312-06-02, modified – symbol has been added, in the definition "rated value" has been replaced by "value" and in the note "not necessarily equal to" has been replaced by "equal to or greater than".]

3.1.19
rated impulse withstand voltage
U_{imp}
value of the **impulse withstand voltage** assigned by the manufacturer to the equipment or to a part of it, characterizing the specified withstand capability of its insulation against **transient overvoltages**

3.1.20
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.]

3.1.21
environment
<of an electrical system> surrounding which can affect performance of a device or system

EXAMPLE Pressure, temperature, humidity, **pollution**, radiation and vibration.

3.1.22
macro-environment
environment of the room or other location in which the equipment is installed or used

[SOURCE: IEC 60050-442:2014, 442-01-55]

3.1.23
micro-environment
<of an electrical system> ambient conditions which immediately influences the dimensioning of the **clearance** and **creepage distances**

3.1.24
pollution
<of an electrical system> any condition of foreign matter, solid, liquid or gaseous (ionized gases), that can affect dielectric strength or surface resistivity

3.1.25
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.]

3.1.26
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.8. See also4.9.

3.1.27
inhomogeneous field
non-uniform field
electric field which does not have an essentially constant voltage gradient between electrodes

Note 1 to entry: See also 4.9.

[SOURCE: IEC 60050-442:2014, 442-09-03, modified – "inhomogeneous electric field" has been replaced with "inhomogeneous field", Note 1 to entry has been replaced with a new Note 1 and Note 2 to entry has been deleted.]

3.1.28
electric insulation
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 –"electric" has been replaced with "electrical".]

3.1.29
functional insulation
insulation between conductive parts which is necessary only for the proper functioning of the equipment

[SOURCE: IEC 60050-195:1998, 195-02-41, modified – "necessary" has been replaced with "which is necessary only".]

3.1.30
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]

3.1.31
supplementary insulation
independent insulation applied in addition to **basic insulation** for fault protection

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

3.1.32
double insulation
insulation comprising both **basic insulation** and **supplementary insulation**

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

3.1.33
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]

3.1.34
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 60050-442:2014, 442-09-05, modified – Notes 1 and 2 to entry have been added.]

3.1.35
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 60050-442:2014, 442-09-06, modified – In the Note 2 to entry, "(see Clause D.2)" has been added.]

3.1.36
specified discharge magnitude
magnitude of the **apparent charge** when this is regarded as the limiting value

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

[SOURCE: IEC 60050-442:2014, 442-09-07]

3.1.37
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**.

3.1.38
partial discharge inception voltage
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 RMS value may be used.

[SOURCE: IEC 60050-212:2014, 212-11-41]

3.1.39
partial discharge extinction voltage
<of an electrical system> 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 RMS value may be used.

3.1.40
partial discharge test voltage
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 RMS 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.]

3.1.41
type test
<of an electrical system> test made on one or more devices representative to a certain design to check the conformity to the specifications

3.1.42
routine test
conformity test made on each individual item during or after manufacture

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

3.1.43
sampling test
test on a number of devices taken at random from a batch

[SOURCE: IEC 60050-411:1996, 411-53-05, modified – "machine" has been replaced with "device".]

3.1.44
electric breakdown
failure of insulation under electric stress when the discharge completely bridges the insulation, thus reducing the voltage between the electrodes almost to zero

3.1.45
sparkover
<of an electrical system> **electric breakdown** in a gaseous or liquid medium

3.1.46
flashover
electric breakdown between conductors in a gas or a liquid or in vacuum, at least partly along the surface of **solid insulation**

[SOURCE: IEC 60050-212:2010, 212-11-47]

3.1.47
puncture
electric breakdown through **solid insulation**

[SOURCE: IEC 60050-614:2016, 614-03-17, modified – “disruptive discharge” has been replaced with “electric breakdown” and “dielectric” has been replaced with “insulation”.]

3.2 Abbreviated terms

List of terms with abbreviated terms and symbols together with the corresponding terminological entry:

Abbreviated term/Symbol	Term	Terminological entry
U_{n}	**rated voltage**	3.1.17
U_{i}	**rated insulation voltage**	3.1.18
U_{imp}	**rated impulse withstand voltage**	3.1.19
U_{rp}	**recurring peak voltage**	3.1.10
q_{app}	**apparent charge**	3.1.35
PD	**partial discharge**	3.1.34

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 and environmental conditions.

Insulation coordination represents one aspect of the safety of persons, livestock and property, so that the probability of risk of incidents due to voltage stresses does not lead to an unacceptable risk of harm.

This document addresses **insulation coordination** for any kind of hazard. Technical committees shall take into account the concepts of **clearance, creepage distance** and **solid insulation** as well as the concepts of **functional insulation, basic insulation, supplementary insulation**, **double insulation** and **reinforced insulation** for the specific hazard considering the nature of the hazard.

The technical committee shall make a risk assessment to identify the hazard in case of fault of **functional insulation**. In case a failure of **functional insulation** could create an unacceptable risk of harm (for example, due to mechanical conditions, ageing behaviour), **functional insulation** shall at a minimum be designed according to the requirements of **basic insulation**, after which another risk assessment is performed to assess the residual risk. See 5.2 to 5.4. In case a fault of **functional insulation** does not create any hazard, the technical committee may choose not to apply the requirements of this basic safety publication.

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;
- environmental aspects according to 4.7 (e.g. altitude see 4.7.2, temperature see 4.7.3, vibrations see 4.7.4, humidity see 4.7.5, duration see 4.8);
- field distribution according to 4.9.

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** according to 4.2.2 and **overvoltage category** according to 4.3;
  - **temporary overvoltages** according to 4.2.3.
- the voltages generated by the equipment (which could adversely affect other equipment in the system):
  - **transient overvoltage** according to 4.2.2;
  - **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 **mains supply** distribution system;
- **transient overvoltages** generated due to switching of loads in the **mains supply**;
- **transient overvoltages** generated by external circuits;
- **transient overvoltages** generated internally in the equipment.

Insulation coordination uses a preferred series of values of impulse voltages. The preferred impulse voltages 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.

Insulation coordination with regard to **transient overvoltage** is based on controlled **overvoltage** conditions. There are two kinds of control:

- inherent control: the condition within an electrical system wherein the characteristics of the system can be expected to limit the prospective **transient overvoltages** to a defined level;
- protective control: the condition within an electrical system wherein specific **overvoltage** attenuating means can be expected to limit the prospective **transient overvoltages** to a defined level.

See also Table B.1 and Table B.2.

4.2.2.2 Transient overvoltages entering through the mains supply

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

For equipment subjected to **transient overvoltages** that exceed the **impulse withstand voltage** these **transient overvoltages** shall be taken into account.

4.2.2.3 Transient overvoltages generated by external circuits

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

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

4.2.2.4 Transient overvoltages generated internally in the equipment

For the equipment likely to generate an **overvoltage** that is higher than the transients expected to come into the equipment, for example due to switching devices, the required impulse voltage shall take into account the transient generated in the equipment. The value of these **transient overvoltages** generated internally in the equipment shall be used without considering the preferred list in 4.2.2.1.

4.2.2.5 Attenuation of transient overvoltage levels

Equipment or parts of equipment may be used under conditions where the transients are reduced. Various technology of component exists such as surge protective device (SPD), transformer, capacitance, resistance, and can have different behaviour regarding the **transient overvoltage** attenuation. These various technologies shall be verified and the method of propagation measurement shall be defined based on their relevant product standard.

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

In case attenuation of the transient is expected, the **transient overvoltage** across the insulation may be measured by applying the required impulse test to the equipment and measuring the actual remaining transient over the insulation, see 6.7. The measured value may be used as the expected **transient overvoltage**. While performing the test, the equipment is energized at **rated voltage** and transients of both polarities shall be considered.

4.2.3 Temporary overvoltages

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

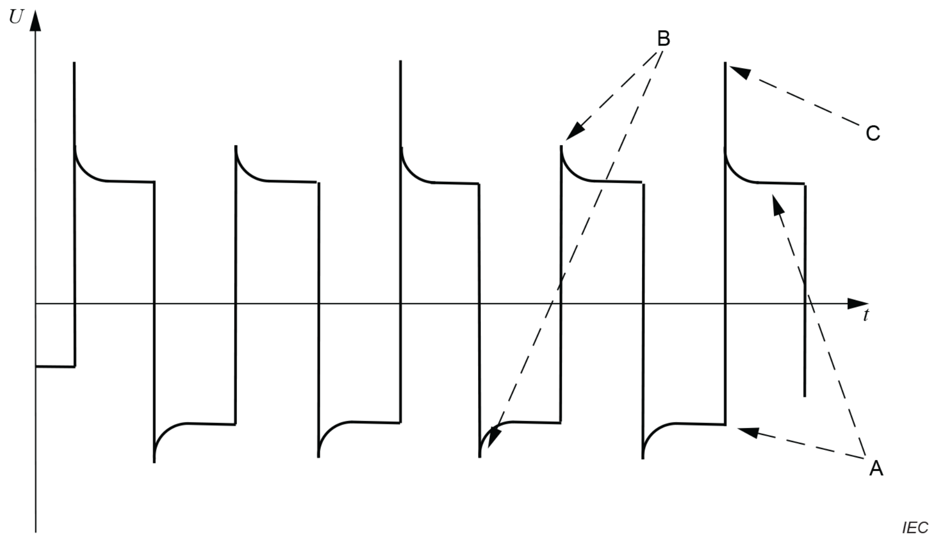
Insulation coordination with regard to **temporary overvoltages** is based on the **temporary overvoltage** specified in IEC 60364-4-44:2007, Clause 442. The values of **temporary overvoltage** in low-voltage equipment due to an earth fault in the high-voltage system are given in 5.4.3.2.

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.9).

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 voltage value

B **Steady-state peak voltage**

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 working 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 and might be significantly higher than the value of **rated voltage**.

4.2.6 Steady-state peak voltage

The peak value of **steady-state working 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 **mains supply**.

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 and IEC 60364-4-44:2007/AMD1:2015.

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 mains supply

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

– Equipment of **overvoltage category** IV is for use at the origin of the installation.

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

– Equipment of **overvoltage category** III is equipment in fixed installations and for cases where the reliability and the availability of the equipment is subject to special requirements.

NOTE 2 Examples of such equipment are switches in the fixed installation and equipment for industrial use with permanent connection to the fixed installation.

– Equipment of **overvoltage category** II is energy-consuming equipment to be supplied from the fixed installation. If such equipment is subjected to special requirements with regard to reliability and availability, **overvoltage category** III applies.

NOTE 3 Examples of such equipment are appliances, portable tools and other household and similar loads.

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

Measures shall be taken to ensure that the **temporary overvoltages** that could occur are sufficiently limited so that their peak value does not exceed the relevant rated impulse voltage of Table F.1.

NOTE 4 Unless the circuits are designed to take the **temporary overvoltages** into account, equipment of **overvoltage category** I cannot be directly connected to the **mains supply**.

4.3.3 Systems and equipment not energized directly from the mains supply

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

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

4.4 Frequency

4.4.1 General

The voltage withstand capability of **clearances**, **creepage distances** and **solid insulation** will be reduced with increased frequency. This effect can be observed from 1 kHz. The design of **clearances**, **creepage distances** and **solid insulation** according to this document cover the effect of high-frequencies up to 30 kHz. For frequencies above 30 kHz, see 5.1.2.

4.4.2 Solid insulation

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.

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.

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. Enclosures for outdoor and indoor installation, intended for use in locations with high humidity and temperatures varying within wide limits, shall be provided with suitable arrangements (natural ventilation, forced ventilation, internal heating, drain holes, etc.) to prevent harmful condensation within the enclosure. Degrees of protection provided by enclosures (IP code), according to the classes specified in IEC 60529, do not necessarily improve the **micro-environment** with regard to **pollution**.

The technical committee shall provide information to verify, according to their standards, the performance of the enclosed system.

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**, for example by means of ribs and grooves (see 5.3.3.7).

4.6 Insulating material

4.6.1 Solid insulation

The concept of **insulation coordination** may be realized by an appropriate insulation material. The insulation behaviour of the **solid insulation** is directly affected by its intrinsic 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, less attention may be paid to the design of 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 and irreversible effect on **solid insulation**. This situation can occur while in service and during routine high-voltage testing.

4.6.2 Stresses

4.6.2.1 General

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 6.4.3).

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. Due to the individual electrical characteristics of the materials it is not possible to calculate the required thickness of **solid insulation**. The performance can only be verified by testing.

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 the reduced impact strength of materials:

– due to material becoming brittle when the temperature falls below its glass transition temperature;
– after prolonged exposure to a high temperature that has caused loss of plasticizer 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:

- 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 Comparative tracking index (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 comparative tracking index (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 such 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 **clearances** in this document is corrected according to the difference in atmospheric pressure between 2 000 m and sea level for **homogeneous field** and **inhomogeneous field**. See 5.2.3.4 for dimensioning of **clearance** for altitudes above 2 000 m and 6.2.2.1.4 for altitude consideration when verifying **clearance** at altitudes 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

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 **partial 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.

4.8 Duration of voltage stress

The duration of voltage stress especially influences the long-term insulation behaviour of **creepage distance** and **solid insulation**. See 5.3.3.4 for **creepage distances**.

For **clearance**, where the voltage will create a breakdown of the insulation instantaneously, the duration in general does not influence the **clearance**.

4.9 Electrical field distribution

The electrical field distribution influences the electric strength of insulation.

– The **inhomogeneous field** condition of a point-plane electrode configuration is the worst case with regard to voltage withstand capability. It is represented by a point electrode having a 30 μm radius and a plane of 1 m × 1 m (see 3.1.27).
– The **homogeneous field** distribution is the most favourable and theoretical case where the electrical field is completely homogeneous between two spheres (see 3.1.26). Typically, to achieve a **homogeneous field** condition between two spheres, the radius of each sphere shall be greater than the distance between them. **Homogeneous field** conditions in real design are very difficult to achieve.

In fact, the electrical field distribution will normally be between **homogeneous field** and **inhomogeneous field**.

5 Design for insulation coordination

5.1 General

5.1.1 Means of insulation coordination

The design for **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.

The design requirements of **clearances** and **creepage distances** in 5.2 and 5.3 are minimum distances based on empirical test data as presented in Annex A and Annex F. During the design, production tolerances shall be taken into account.

NOTE IEC 61140 considers that isolating device requirements are applicable to **overvoltage category** III and category IV and not applicable to category I and category II.

5.1.2 Frequency above 30 kHz

Requirements for **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 for **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.

5.1.4 Equipment which are not connected to public low-voltage systems.

Insulation coordination applies to equipment which is connected to the public low-voltage systems. However, it is recommended to use the same principles for all other low-voltage systems which have no connection to the public low-voltage system (IEC TR 60664-2-1).

5.2 Dimensioning of clearances

5.2.1 General

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

– **impulse withstand voltage** (see 5.2.2.2 and 5.2.2.3);
– **temporary overvoltages**, peak voltage value (see 5.2.2.4);
– **steady-state peak voltage** or **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);
– **pollution degree** in the **micro-environment** (see 5.2.3.5).

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

See Annex G (Figure G.1) for guidance on how to determine **clearance** based on the requirement of 5.2.1.

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 **mains supply**, the **rated impulse withstand voltage** determined on the basis of 5.2.2.2 and 5.2.2.3.
– For a **steady-state peak voltage**, a peak value of **temporary overvoltage** (see 5.2.1) or a **recurring peak voltage** determined on the basis of 5.2.2.4.

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** 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 **mains supply**, 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.8 to withstand the **steady-state peak voltages**, the peak value of **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 4.9) and consequently the **clearance** needed to withstand a given voltage (see Table F.2, Table F.8 and Table A.1).

It is recommended to design for **inhomogeneous field** conditions according to 5.2.3.2 (case A). If designed for **homogeneous field** conditions (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 design 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 field** conditions. They can only be used where the shape and arrangement of the conductive parts are 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 (see also Figure A.2 and Figure A.3).

5.2.3.4 Altitude correction

The **clearances** given in this document are valid up to 2 000 m.

For altitudes above 2 000 m, Table A.2 should be used to determine the altitude correction factors for **clearance** correction. See also 6.2.2.1.4 for the calculation procedure with respect to altitude correction for **clearances** correction. Linear interpolation is acceptable between two adjacent values of Table A.2.

NOTE The phenomenon is nonlinear, it is the responsibility of technical committees to interpolate the value between two altitudes.

5.2.3.5 Pollution degree in micro-environment

Clearances shall be selected from Table F.2 under a **pollution degree** in the **micro-environment** according to 4.5.2. The **pollution degree** does not have a strong influence on the dimensioning of **clearance**. However, it cannot be ignored for small **clearances** where pollution such as solid particles, dust and condensation could bridge the air gap.

The minimum **clearance** values in **pollution degree** 2 and **pollution degree** 3 are specified in Table F.2.

5.2.4 Dimensioning of clearances 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 withstand voltage** (refer to Table F.2).

NOTE For distances equal to or less than 2 mm, IEC TR 63040 gives tests, research on influencing parameters to provide distances for insulation. The usage of this document is under the responsibility of the technical committees.

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 **withstand voltage** requirements with respect to **transient overvoltages** generated internally in the equipment according to 4.2.2.4;

and as specified in Table F.8 corresponding to:

– the peak value of **temporary overvoltage** according to 4.2.3;
– the **recurring peak voltage** according to 4.2.4;
– the **steady-state peak voltage** according to 4.2.6.

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 has 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.8 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.

5.3 Dimensioning of creepage distances

5.3.1 General

To determine the required **creepage distances**, the following influencing factors shall 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);
– more than one material or **pollution degree** (see 5.3.3.5);
– floating conductive part (see 5.3.3.6);
– use of ribs (see 5.3.3.7);
– components mounted on printed wiring material (see 5.3.3.8).

See Annex H (Figure H.1) for guidance on 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 into 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 basis for the determination of a **creepage distance** is the long-term RMS value of the voltage existing across it. This voltage is the highest value of the **steady-state working voltage** (see 4.2.5), the **rated insulation voltage** or the **rated voltage**. For the determination of the **rated insulation voltages** Table F.3 and Table F.4 may be used.

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

For equipment having several **rated voltages** so that it may be used at different nominal voltages of the **mains supply**, 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 while operating at **rated voltage** and under the worst case operating conditions within the rating of the equipment. Fault conditions are not taken into account.

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 comparative tracking index (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.

5.3.3 Other factors involving creepage distances

5.3.3.1 General

Technical committees shall take into account other factors influencing **creepage distance,** for example the orientation and shape of the insulating surface. In case of specific influencing factors for the **creepage distances**, those factors shall be taken into account.

5.3.3.2 Orientation of 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 direct 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 **mains supply**.

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.

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

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 into 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 comparative tracking index (CTI) and the highest **pollution degree**.

5.3.3.6 Creepage distances split by floating conductive parts

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. See Figure 14.

5.3.3.7 Reduction of required creepage distances by using 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 footnote d) 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.

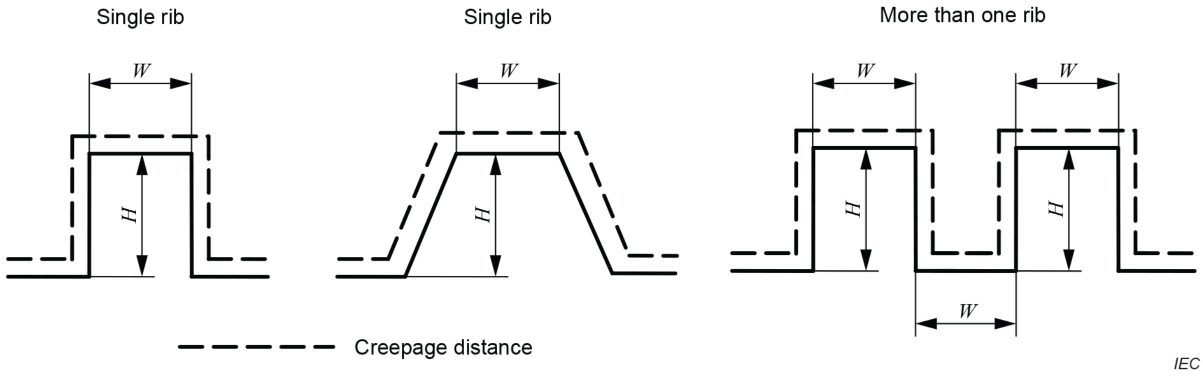


Figure 2 – Determination of the width (*W*) and height (*H*) of a rib

5.3.3.8 Creepage across component mounted on printed wiring material

For **creepage distances** on printed wiring material only used under **pollution degree** 1 and 2, a reduced dimensioning is allowed and may be selected from Table F.5. Attention is drawn on the possible reduction or other path of **creepage distances** due to the components.

The use of the reduced dimensioning values on printed wiring material under **pollution degree** 2 (column 3 in Table F.5) for **creepage distances** may require an additional protection against **pollution**.

5.3.4 Dimensioning of creepage distances of functional insulation

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

NOTE 1 The values of Table F.5 can be used for **functional insulation** however different values of **creepage distances** can be appropriate.

NOTE 2 For distances equal to or less than 2 mm, IEC TR 63040 gives tests, research on influencing parameters to provide distances for insulation. The usage of this document is under the responsibility of the technical committees.

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.4, corresponding to the nominal voltage of the **mains supply**;
– the **rated insulation voltage**;
– the voltage specified in 4.2.5.

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.

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**.

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

NOTE 2 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 (see Figure E.1).

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.

NOTE Subclause 5.4 does not provide any requirements for **solid insulation** used as **functional insulation**.

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 5.4.3.1;
– **temporary withstand overvoltages** according to 5.4.3.2;
– **recurring peak voltages** according to 5.4.3.3;
– **steady-state working voltages** according to 5.4.3.4.

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 voltage of the **mains supply** (see 4.2.2.2), 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 4.2.2.1

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 withstand 160 % of the value required for **basic insulation**.

For verification by testing, see 6.4.4.

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_0 + 1 200 V with durations up to 5 s;

– long-term **temporary overvoltages** of U_0 + 250 V with durations longer than 5 s;

where U_0 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 withstand overvoltage** value.

Reinforced insulation shall withstand twice the **temporary withstand overvoltages** specified for **basic insulation** except when the **partial discharge** test is used. For the **partial discharge** test, the factors given in 6.4.6.1 apply.

For verification by testing**,** see 6.4.5.

NOTE 1 The values are according to IEC 60364-4-44:2007, Clause 442.

NOTE 2 The values are RMS values.

5.4.3.3 Recurring peak voltages

The maximum **recurring peak voltages** occurring on the **mains supply** can be assumed provisionally to be $F_4 \times \sqrt{2}\, U_0$, i.e. 1,1 times the peak value at U_0. Where **recurring peak voltages** are present, the **partial discharge extinction voltage** shall be at least:

– $F_1 \times F_4 \times \sqrt{2}\, U_0$, i.e. 1,32 $\sqrt{2}\, U_0$ for each **basic insulation** and **supplementary insulation**, and

– $F_1 \times F_3 \times F_4 \times \sqrt{2}\, U_0$, i.e. 1,65 $\sqrt{2}\, U_0$ for **reinforced insulation**.

NOTE $\sqrt{2}\, U_0$ is in neutral-earthed systems the peak value of the line-to neutral fundamental (undistorted) voltage at the nominal voltage of the **mains supply**. The application of the multiplying factors used in this subclause is described in Annex D.

For an explanation of factors F, see 6.4.6.1.

In internal circuits, the highest **recurring peak voltages** shall be evaluated in place of $F_4 \times \sqrt{2}\, U_0$ and **solid insulation** shall meet the corresponding requirements.

For verification by testing, see 6.4.6.

5.4.3.4 Steady-state voltages

The **steady-state working voltage** and the **steady-state peak voltage** are a long-term voltage stress applied on **solid insulation**.

In those instances where **steady-state working voltages** are non-sinusoidal with **recurring peak voltages** or **steady state peak voltages**, see Figure 1, 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 6.4.6.

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 in IEC 60068 (all parts).

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 in IEC 60068 (all parts).

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.

NOTE See also IEC 60085 and IEC 60216 (all parts).

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 6.4.3).

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.

The verification procedures are specified for:

– the verification of **clearances** (see 6.2);
– the verification of **creepage distances** (see 6.3);
– the verification of **solid insulation** (see 6.4);
– dielectric tests on complete equipment (see 6.5);
– other tests (see 6.6).

Technical committees shall consider whether **sampling tests** or **routine tests** shall be carried out in addition to **type tests** and to specify the necessary tests to be performed as sample and **routine tests** in order to ensure the quality of the insulation system 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 6.6.2).

6.2 Verification of clearances

6.2.1 General

For the verification of **clearances** two cases shall be considered:

– for values according to case A of Table F.2, verification according to 6.8 is required and no further verification by voltage test is needed;

– the values smaller than the values of case A and larger than the values of case B of Table F.2, shall be verified by the impulse voltage test according to 6.2.2.1.

The stresses for **clearances** caused by **transient overvoltages** are assessed by the impulse voltage test, which may be substituted by an AC or a DC voltage test. See 6.2.2.1.3. If the withstand against **steady-state working voltages**, **recurring peak voltages** or peak value of **temporary overvoltages** according to 5.2.2.4 is decisive for the dimensioning of **clearances** and if those **clearances** are smaller than the case A values of Table F.8, an AC test voltage according to 6.2.2.1.3.2 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 electrical testing of **clearances** will also stress the associated **solid insulation**.

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

NOTE 3 For testing complete equipment, see 6.5.

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, IEC 61180:2016, 7.1 applies. It is intended to simulate **overvoltages** of atmospheric origin and covers **overvoltages** due to switching in the **mains supply**.

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.

The output impedance of the impulse generator shall not be higher than 500 Ω. When carrying out tests on equipment incorporating components across the test circuit, a much lower virtual impulse generator impedance may be specified (see IEC 61000-4-5:2014). In such cases, possible resonance effects, which can increase the peak value of the test voltage, shall be taken into account when specifying test voltage values.

Technical committees may specify alternative dielectric tests according to 6.2.2.1.3.

NOTE Values given in Table F.6 are derived from the calculation in 6.2.2.1.4. 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 electrical 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. See 6.2.2.1.4 for impulse testing at altitudes different than 2 000 m.

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

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 a 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 6.4.5.

While it is possible to substitute an impulse voltage test for **clearances** by an AC or 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 RMS value is $\sqrt{2}$ with a tolerance of ±3 %. 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 with a tolerance of ±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 altitudes different 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 air barometric pressure dependency, **clearances** tested according to 6.2.2.1, are 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

k_{u} is the altitude correction for **withstand voltage** correction;

k_{d} is the altitude correction for **clearance** correction (see Table F.10);

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 = 0,916 3 for 0,001 < d < 0,01 mm;

m = 0,330 5 for 0,01 ≤ d ≤ 0,062 5 mm;

m = 0,636 1 for 0,062 5 < d ≤ 1 mm;

m = 0,853 9 for 1 < d ≤ 10 mm;

m = 0,924 3 for 10 < d ≤ 100 mm.

and d is the **clearance** under consideration in millimetres.

Applying altitude correction factor 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 Verification of creepage distances

Creepage distances shall be verified following 6.8.

For some cases, tests shall also be applied to **creepage distances**, see 5.3.2.5.

6.4 Verification of solid insulation

6.4.1 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 in 6.4.4. The stresses caused by an AC **steady-state working voltage** stress can only be assessed by an AC voltage test (6.4.5). The DC voltage test in 6.4.7 with a test voltage equal to the peak value of the AC voltage is not fully equivalent to the AC voltage test in 6.4.5 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 in 6.4.7 is appropriate.

6.4.2 Selection of tests

Solid insulation that may be subjected to mechanical stresses during operation, storage, transportation or installation shall be tested 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 1 Standard severity levels are specified in IEC 60068 (all parts).

For the **double insulation** test on sample:

– when the two insulations can be tested separately, two test measurements shall be performed to verify the **basic insulation** and then the **supplementary insulation**;
– when the two insulations cannot be tested separately, one test measurement shall be performed to verify the two insulations in series with the test voltage of the **reinforced insulation**.

NOTE 2 In case of a high difference in value between the two capacitances across each insulation, the constraint of this test can be more than the voltage of a **basic insulation** on one of the two insulations. It can oblige to either oversize one insulation, or to equilibrate the capacitances across each insulation.

They have the following objectives:

a) The **impulse withstand voltage** 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 **recurring peak voltage** (see 5.4.3.3);
   – the **steady-state working voltage** (see 5.4.3.4);
   – the **steady-state peak voltage** (see 5.4.3.4).

   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** is to verify that no **partial discharges** are maintained in the **solid insulation** at:
   – the peak value of the long-term **temporary overvoltage** (see 5.4.3.2);
   – the **recurring peak voltage** (see 5.4.3.3);
   – the **steady-state working voltage** (see 5.4.3.4);
   – the **steady-state peak voltage** (see 5.4.3.4).
d) The high-frequency voltage tests for frequencies above 30 kHz is to verify the absence of failure due to dielectric heating and **partial discharge** according to 6.4.8.

NOTE 3 Information about the withstand characteristics of insulation at high frequency above 30 kHz and methods of testing is given in IEC 60664-4.

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.

When performing tests on complete equipment, the procedure of 6.5 applies.

Technical committees shall state whether the impulse test of **solid insulation** is covered by the AC voltage test of **solid insulation** or if a separate impulse voltage test of **solid insulation** is required.

6.4.3 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) change of temperature with specified rate of change (test Nb of IEC 60068-2-14:2009), in order to induce the creation of voids which could develop in storage, transportation and normal use;
c) thermal shock (rapid change of temperature with specified time of transfer, test Na of IEC 60068-2-14:2009), in order to induce delamination within the insulation system which may develop in storage, transportation and normal use;
d) damp heat, steady state (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. If needed, technical committees may specify higher severity values.

It may be appropriate to subject components, for example electrical parts, sub-assemblies, insulating parts and materials, to conditioning before electrical testing. When components have already been **type tested** according to 6.4.3, such conditioning is not required.

6.4.4 Impulse voltage test

6.4.4.1 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 6.4.4.2).

6.4.4.2 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.

6.4.5 AC power frequency voltage test

6.4.5.1 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 RMS value is $\sqrt{2}$ with a tolerance of ±3 %. The peak value shall be equal to the highest of the voltages mentioned in 6.4.2 b).

For **basic insulation** and **supplementary insulation**, the test voltage has the same value as the voltages mentioned in 6.4.2 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 6.4.7).

The test equipment shall comply with IEC 61180:2016.

6.4.5.2 Acceptance criteria

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

6.4.6 Partial discharge test

6.4.6.1 General

The test equipment shall comply with IEC 61180 and the voltage waveshape as defined in 6.1.1.1 of IEC 61180:2016. The **partial discharge test voltage** shall be equal to the highest of the voltages mentioned in 6.4.2 c) taking into account the multiplying factors F_1, F_3 and F_4 as far as applicable. The resulting value is shown in Figure 3 as $U_{\text{test voltage}}$.

Partial discharge test methods are described in Annex C. When performing the test, the following multiplying factors F_1 to F_4 apply. The use of these factors are given as an example for the **recurring peak voltage** U_{rp}, see also Annex D. The factors shall be applied to the **steady-state peak voltage** and to the peak value of long-term **temporary overvoltage** in the same way.

In the **partial discharge** test, the peak value is relevant, converting the RMS value of the **temporary overvoltage** to peak value should be done.

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

The **partial discharge 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 **partial discharge 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 **partial discharge inception voltage** and the **partial discharge extinction voltage**. 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 **partial discharge inception voltage** and can be maintained, for example, by values of the **recurring peak voltage** exceeding **partial discharge extinction voltage**. 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_0 of the **mains supply**.

For circuits connected to the **mains supply**, this factor takes into account the maximum deviation of the **mains supply** voltage from its nominal value. Therefore, the peak voltage at nominal voltage U_0 shall be multiplied by F_4 = 1,1.

6.4.6.2 Verification

The test is to verify that no **partial discharges** are maintained at the highest of the values in 6.4.2 c):

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

When testing, the PD test is generally applied to components, small assemblies and small equipment.

The minimum required discharge extinction voltage shall be higher, by factor F_1, than the highest of the voltages listed in 6.4.2 c).

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

– the test circuit (see Clause C.1);
– the measuring equipment (see Clauses C.3 and D.2);
– the measuring frequency (see C.3.1 and D.3.4);
– the test procedure (see 6.4.6.3).

6.4.6.3 Test procedure

The value of the test voltages and the application of the different factors are explained in 6.4.6.1. The voltage shall be raised uniformly from 0 V up to the initial test voltage. 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, see Figure 3.

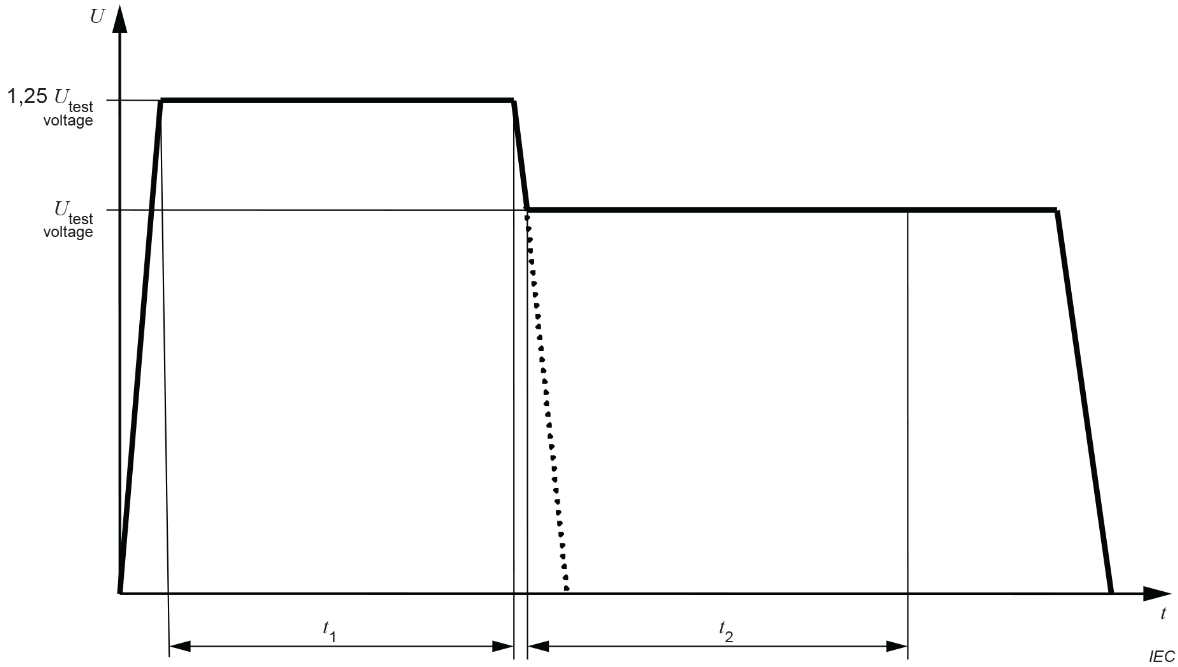


Figure 3 – Test voltages

6.4.6.4 Acceptance criteria

6.4.6.4.1 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 Annex D).

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.

6.4.6.4.2 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.

6.4.7 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 (see 6.4.5.1). However, in case of a pure DC voltage stress, the DC voltage test is 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 with a tolerance of ±3 %. The average value of the DC test voltage shall be equal to the peak value of the AC test voltage mentioned in 6.4.2 b).

For **basic insulation** and **supplementary insulation**, the test voltage has the same value as the voltages mentioned in 6.4.2 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 tests**, the tripping current can be adjusted to lower levels but not less than 10 mA.

6.4.8 High-frequency voltage test

For high-frequency voltages above 30 kHz according to 6.4.2 d), additional or alternative AC voltage tests according to 6.4.5 or **partial discharge** tests according to 6.4.6 may be necessary.

NOTE Information about the withstand characteristics of insulation at high frequency above 30 kHz and methods of testing is given in IEC 60664-4.

6.5 Performing dielectric tests on complete equipment

6.5.1 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 ensured 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.

6.5.2 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.

6.5.3 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**, **supplementary 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.

6.5.4 Test voltage values

Circuits connected to the **mains supply** are tested according to 6.2 and 6.4.

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.

6.5.5 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 An oscilloscope can be used to observe the impulse voltage in order to detect disruptive discharge.

6.6 Other tests

6.6.1 Test for purposes other than insulation coordination

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

6.6.2 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 tests** and **routine tests** shall in no case specify test voltages higher than those required for **type testing**.

6.6.3 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 % RH;

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 %.

6.7 Measurement of the attenuation of the transient overvoltages

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 "1,2/50 µs combination wave generator" according to IEC 61000-4-5 with an effective output impedance of 2 Ω .

NOTE The output impedance of 2 Ω is the worst case, see also IEC 61000-4-5:2014, Clause C.1 to the different source impedance to each coupling mode.

6.8 Measurement of clearances and creepage distances

Clearances and **creepage distances** are verified as a minimum by:

– physical measurement or,
– inspection of design board, drawings or,
– (CAD 2D or 3D) computer-aided design.

The methods of measuring **clearances** and **creepage distances** are indicated in Figure 4 to Figure 14. These cases do not differentiate between gaps and grooves or between types of insulation. Also, where the example is shown to form an angle, these cases may apply to any angle.

The following assumptions are made:

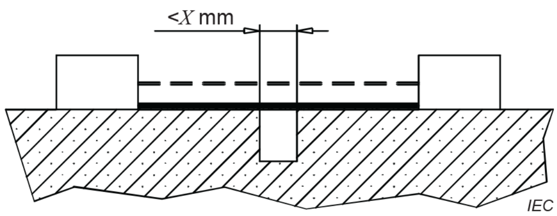
– Where the distance across a groove is less than the specified width X (see Table 1), the **creepage distance** is measured directly across the groove and do not take into account the contour of the groove (see Figure 4).
– where the distance across a groove is equal to or larger than the specified width X (see Table 1), the **creepage distance** is measured along the contours of the groove (see Figure 5);
– 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 Figure 6);
– **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 given in Table 1.

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

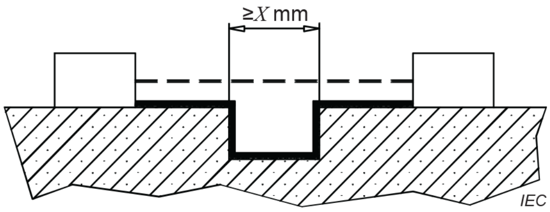


Condition: Path under consideration includes a parallel- or converging-sided groove of any depth with a width less than X mm.

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

– – – – Clearance ▬▬ Creepage distance

Figure 4 – Across the groove

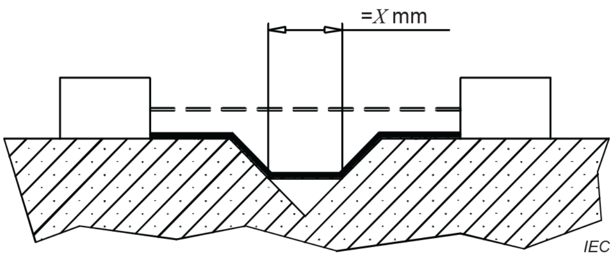


Condition: Path under consideration includes a parallel-sided groove of any depth and equal to or more than X mm.

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

Clearance **Creepage distance**

Figure 5 – Contour of the groove

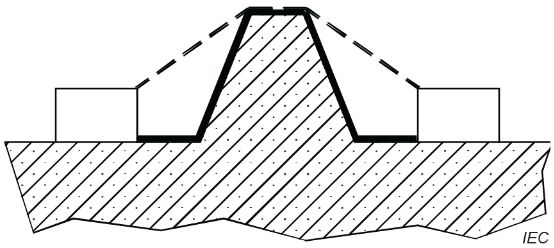


Condition: Path under consideration includes a V-shaped groove with a width greater than X mm.

Rule: **Clearance** is the "line of sight" distance. **Creepage** path follows the contour of the groove but covers the bottom of the groove by an X mm insulating link.

Clearance **Creepage distance**

Figure 6 – Contour of the groove with angle

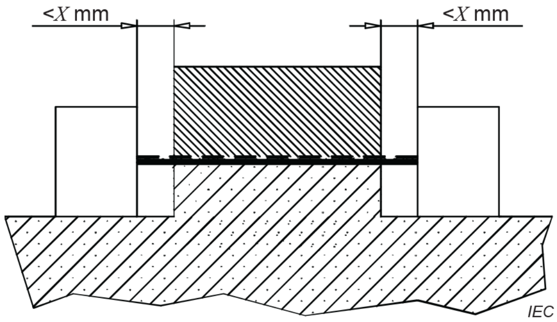


Condition: Path under consideration includes a rib.

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

Clearance **Creepage distance**

Figure 7 – Contour of rib

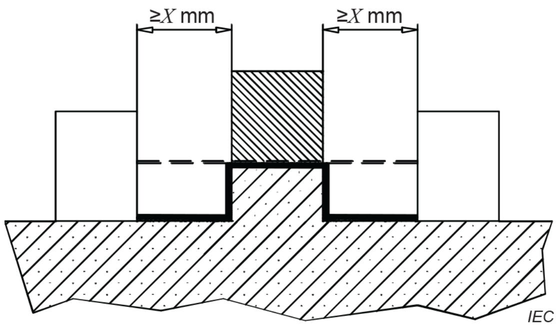


Condition: Path under consideration includes an uncemented joint with grooves less than *X* mm wide on each side.

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

— — — — — **Clearance** ▬▬▬ **Creepage distance**

Figure 8 – Uncemented joint with grooves less than *X*

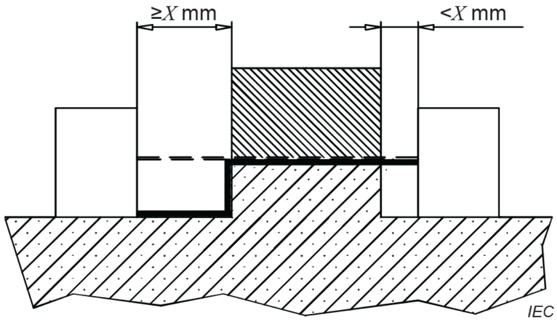


Condition: Path under consideration includes an uncemented joint with grooves equal to or more than *X* mm wide on each side.

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

— — — — — **Clearance** ▬▬▬ **Creepage distance**

Figure 9 – Uncemented joint with grooves equal to or more than *X*

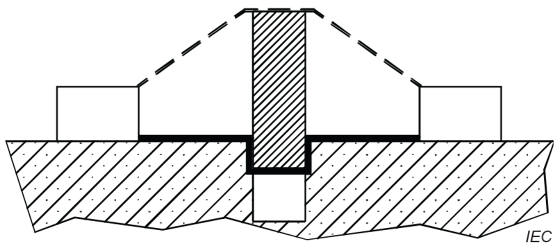


Condition: Path under consideration includes an uncemented joint with a groove on one side less than *X* mm wide and the groove on the other side equal to or more than *X* mm wide.

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

– – – – – **Clearance** ▬▬▬ **Creepage distance**

Figure 10 – Uncemented joint with a groove on one side less than *X*

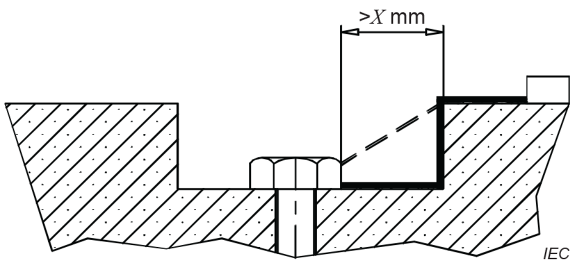


Condition: **Creepage distance** through the uncemented joint is less than the **creepage distance** over the barrier but more than the **clearance** over the top of the barrier.

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

– – – – – **Clearance** ▬▬▬ **Creepage distance**

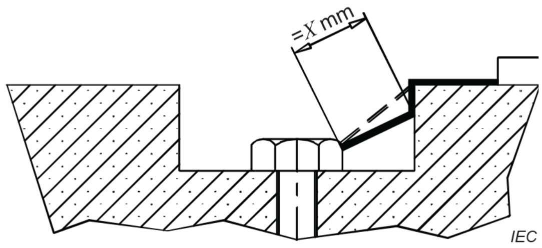
Figure 11 – Creepage distance and clearance through an uncemented joint



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

– – – – – **Clearance** ▬▬▬ **Creepage distance**

Figure 12 – Creepage distance and clearance to a head of screw more than *X*

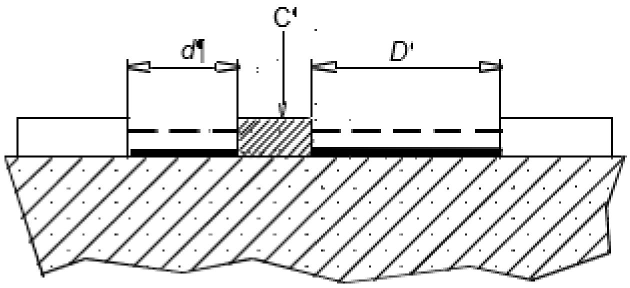


Gap between head of screw and wall of recess too narrow to be taken into account.

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

Clearance **Creepage distance**

Figure 13 – Creepage distance and clearance to a head of screw less than X



C: conductive floating part

Clearance is the distance = $d + D$

Creepage distance is also = $d + D$

Clearance **Creepage distance**

NOTE See Table F.2 for the minimum clearance of d or D.

Figure 14 – Creepage distance and clearance with conductive floating part

Annex A
(informative)

Basic data on withstand characteristics of clearances

Table A.1 – Withstand voltages for an altitude of 2 000 m above sea level *(1 of 2)*

Clearance	Case A Inhomogeneous field			Case B Homogeneous field	
	AC (50/60 Hz)		Impulse (1,2/50 µs)	AC (50/60 Hz)	AC (50/60 Hz) and impulse (1,2/50 µs)
mm	U RMS kV	$\hat{U}$ kV	$\hat{U}$ kV	U RMS kV	$\hat{U}$ kV
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
0,006 25	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
0,062 5	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 *(2 of 2)*

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

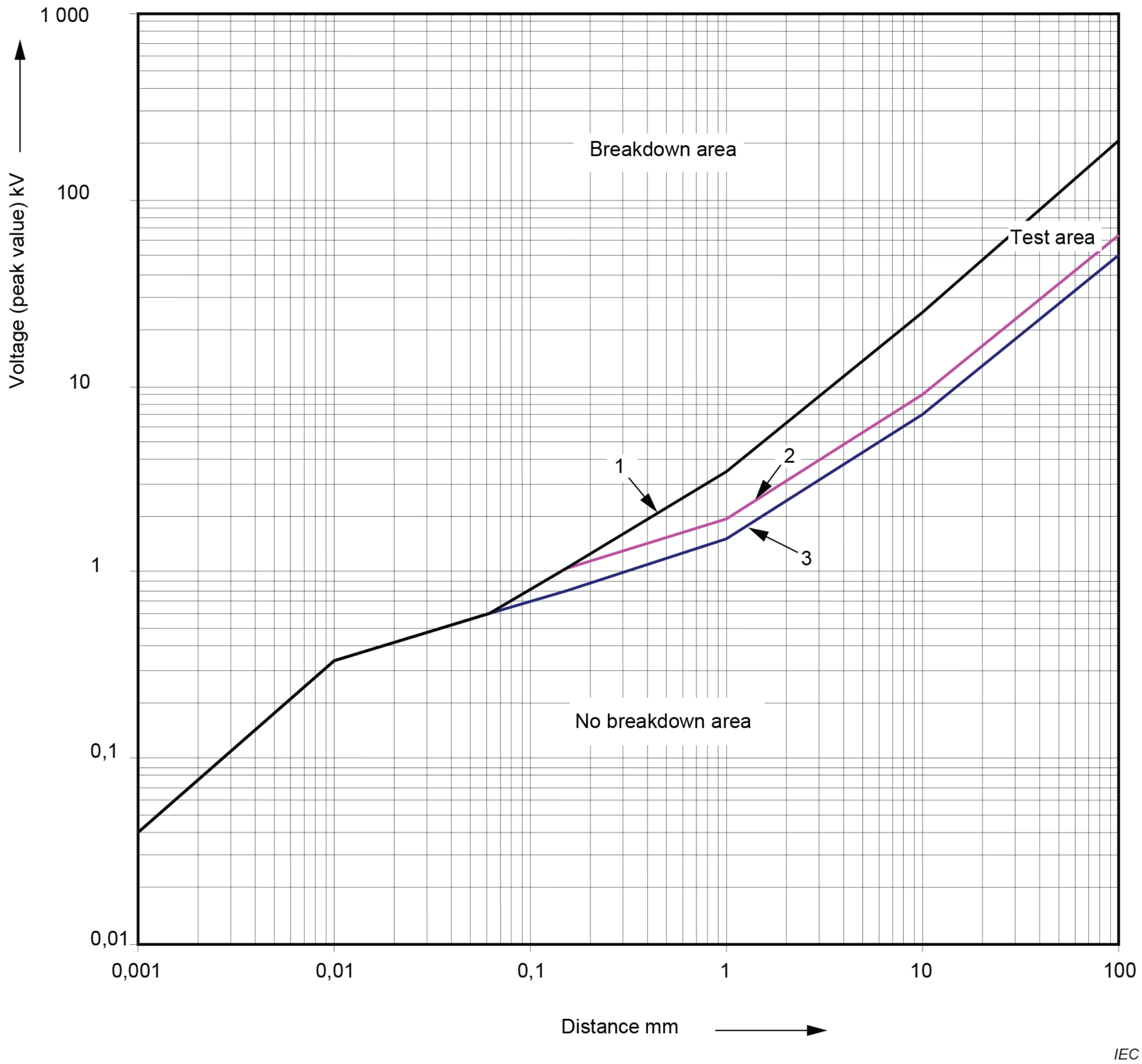
SOURCE The information for **clearances** from 0,001 mm to 0,008 mm, is issued from the document "Electrical breakdown experiments in air for micrometer gaps under various pressures" from P. Hartherz, K. Ben Yahia, L. Müller, R. Pfendtner and W. Pfeiffer (see bibliography).

More details can be found in the thesis of P. Hartherz "Anwendung der Teilentladungsmeßtechnik zur Fehleranalyse in festen Isolierungen unter periodischer Impulsspannungsbelastung" (see bibliography).

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 RMS 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



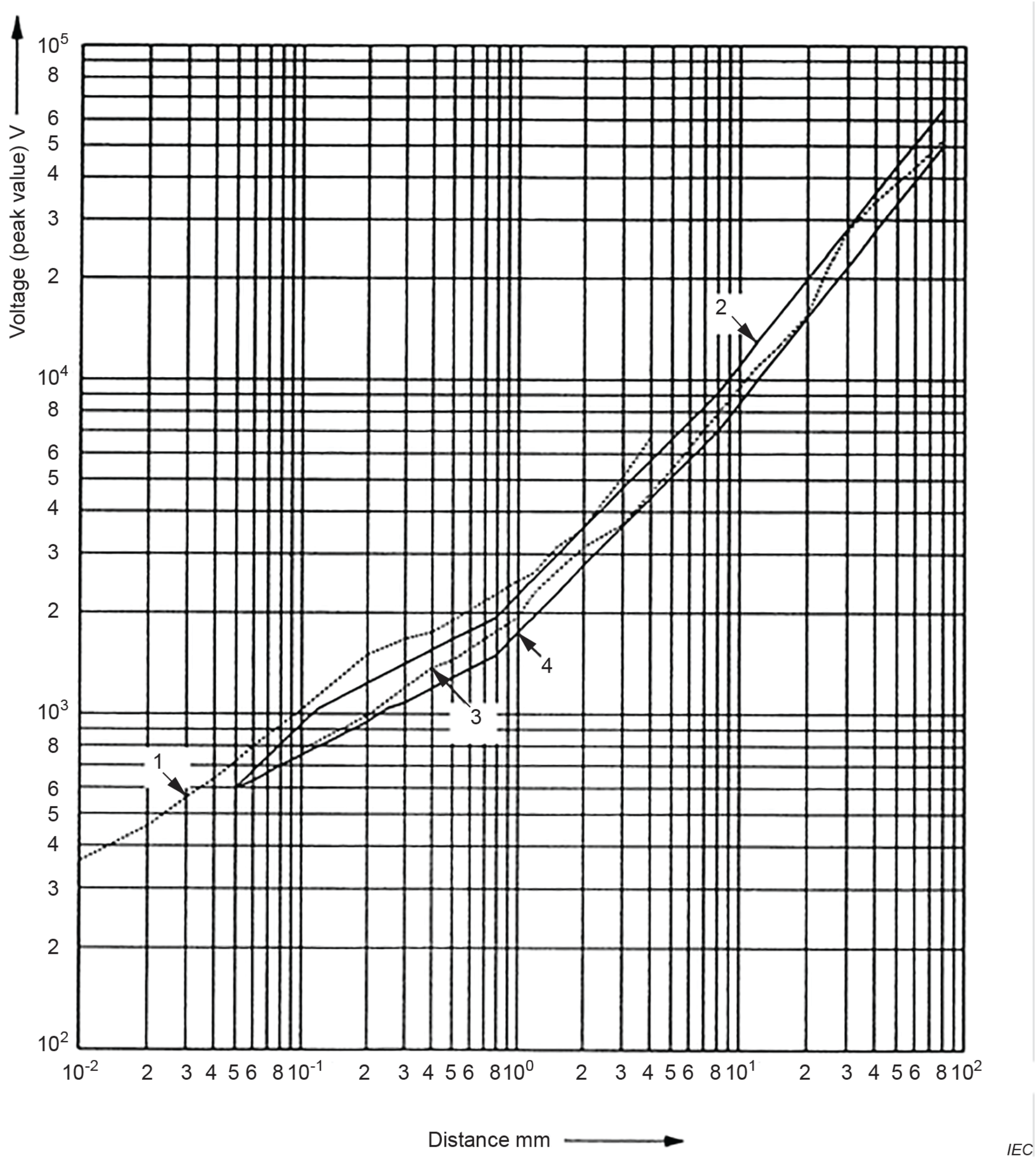
Key

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

2 case A; $\hat{U}$ 1,2/50 µs

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

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



Key

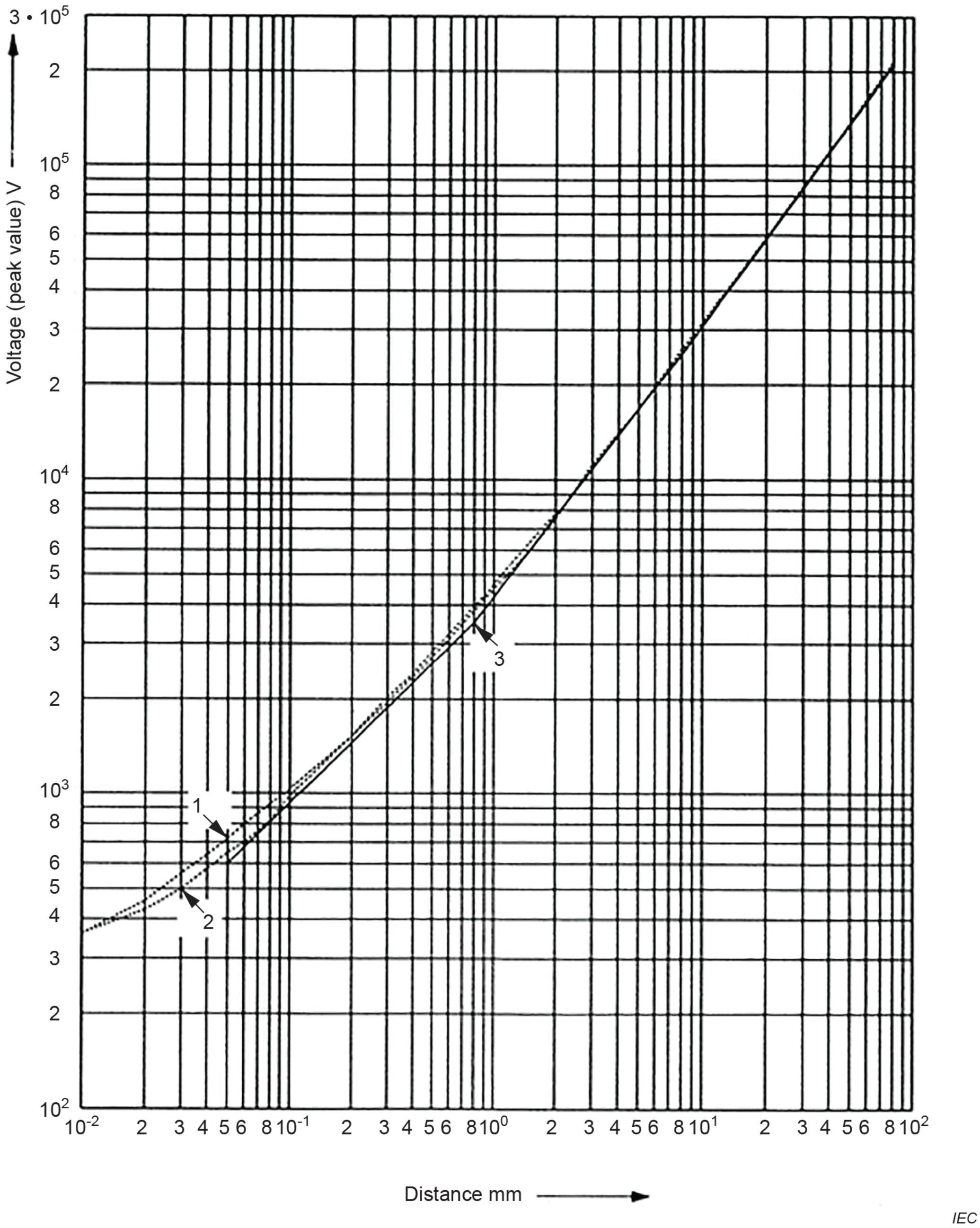
1 $\hat{U}$ 1,2/50 µs according to Pfeiffer, W., ETZ-B, 1976 (see bibliography)

2 Low limits for $\hat{U}$ 1,2/50 µs

3 $\hat{U}$ 50 Hz according to Hermstein, W., ETZ-A, 1969 (see bibliography)

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 $\hat{U}$ 1,2/50 µs according to Pfeiffer, W., ETZ-B, 1976 (see bibliography)

2 $\hat{U}$ 50 Hz according to Dakin, T. et al., Electra, 1974 (see bibliography)

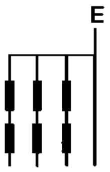
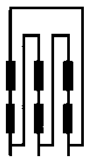
3 Low limits for $\hat{U}$ 1,2/50 µs and $\hat{U}$ 50 Hz

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

Annex B
(informative)

Nominal voltages of mains supply 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 [a]	Nominal voltages presently used in the world				Rated impulse withstand voltage for equipment [a] V			
	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 	Overvoltage category			
V	V	V	V	V	I	II	III	IV
50			12,5 24 25 30 42 48	30 to 60	330	500	800	1 500
100	66/115	66	60		500	800	1 500	2 500
150	120/208[b] 127/220	115, 120, 127	100[c], 110, 120	100 to 200[c] 110 to 220 120 to 240	800	1 500	2 500	4 000
300	220/380, 230/400 240/415, 260/440 277/480	200 [c], 220, 230, 240, 260, 277, 347 380, 400, 415 440, 480	220	220 to 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 to 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
1 250 [d]			1 250	1 250	4 000	6 000	8 000	12 000
1 500 [d]			1 500	1 500	6 000	8 000	10 000	15 000

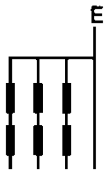
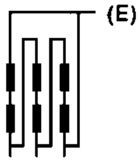
[a] These columns are taken from Table F.1 in which the **rated impulse withstand voltage** values are specified.

[b] Practice in the United States of America and in Canada.

[c] Practice in Japan.

[d] Only applicable for direct current.

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 in IEC 61643 (all parts)

Voltage line-to-neutral derived from nominal voltages AC or DC up to and including[a]	Nominal voltages presently used in the world				Rated impulse withstand voltage for equipment[a] 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 to 60	330	500	800	1 500
100	66/115	66	60		500	800	1 500	2 500
150	120/208 [b] 127/220	115, 120, 127	100 [c] 110, 120	100 to 200[c] 110 to 220 120 to 240	800	1 500	2 500	4 000
300	220/380, 230/400 240/415, 260/440 277/480	200 [c], 220, 230, 240 260, 277	220	220 to 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 to 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
1 250 [d]			1 250	1 250	4 000	6 000	8 000	12 000
1 500 [d]			1 500	1 500	6 000	8 000	10 000	15 000

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

[b] Practice in the United States of America and in Canada.

[c] Practice in Japan.

[d] Only applicable for direct current.

Annex C
(normative)

Partial discharge test methods

C.1 Test circuits

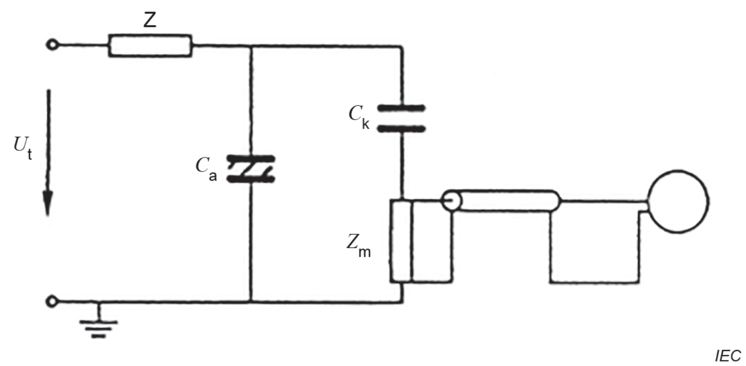
C.1.1 General

Test circuits shall perform as described in IEC 60270. The following circuits given in Annex C 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 Annex C 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

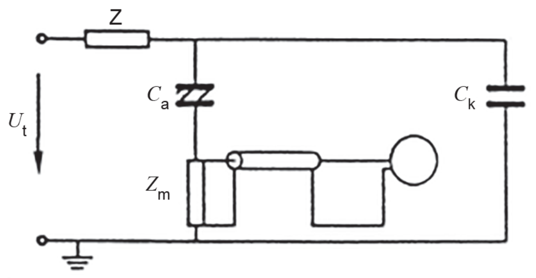
C_a test specimen (usually it can be regarded as a capacitance)

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)



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.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, see 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** (6.4.6.4.1);

– 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 RMS 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 can be unsuitable 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 alternating current and direct current.

C.2.3 Climatic conditions

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

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.3.4).

NOTE Narrowband PD meters are suitable.

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:

$$\Delta f = f_2 - f_1$$

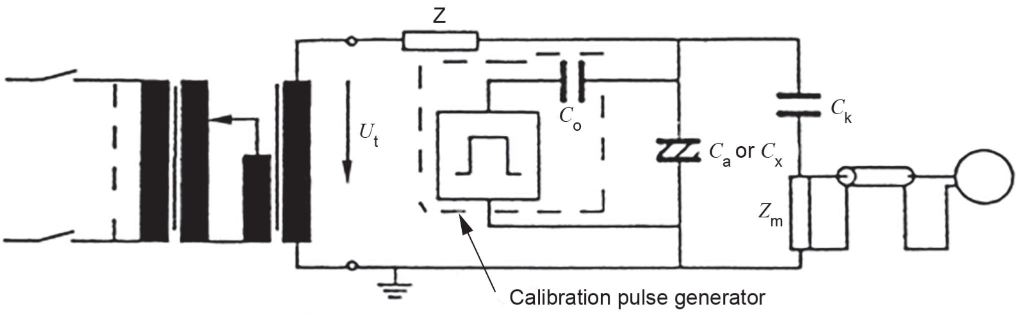
For wideband meters, Δf is in the same order of magnitude as f_2. For narrowband meters, Δf is much less than f_0.

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.

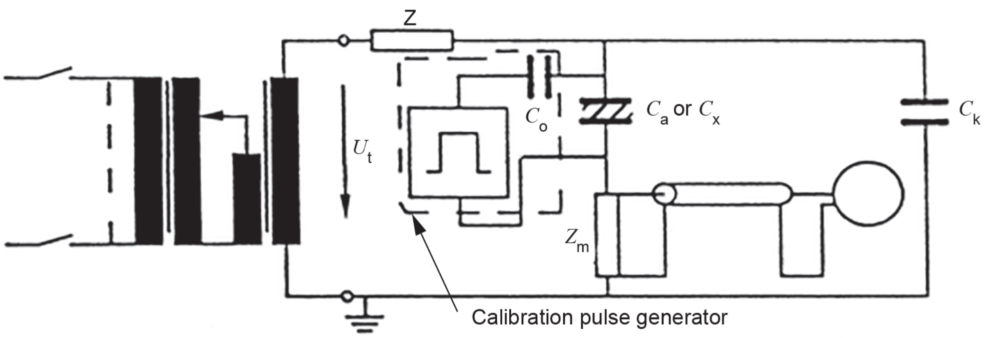
The transformers shall be adjusted according to the specified **partial discharge test voltage** but not energized and their primary windings shall be short-circuited. The **specified discharge magnitude** shall be applied to the terminals of the capacitor by means of the calibration pulse generator.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



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.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 the 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

For the calibration pulse generator, see IEC 60270 that explains the test method and the characteristics to be checked.

Annex D
(informative)

Additional information on partial discharge test methods

D.1 Measurement of partial discharge (PD), 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). 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). Thereby the insulation test voltage specified for the test specimen may not be exceeded.

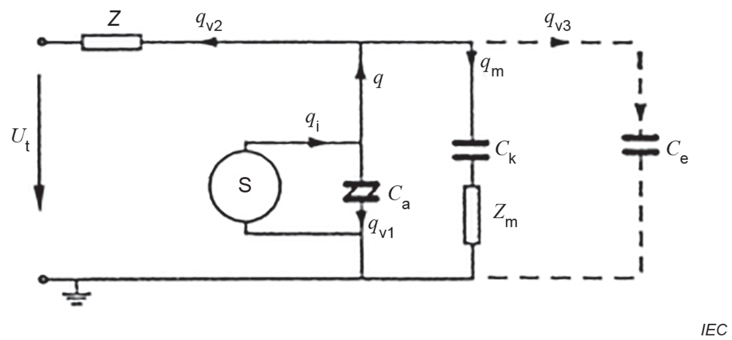
NOTE It can occur that the **partial discharge extinction voltage** is influenced by the time of the voltage stress with values exceeding the **partial discharge inception voltage**. During successive measurements, both **partial discharge inception voltage** and **partial discharge extinction voltage**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

Basically, there are two different kinds of noise sources as described in D.3.2 and D.3.3.

D.3.2 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 **mains supply** is provided. In case of electromagnetic coupling they also occur if the **mains supply** is switched off (including the protective conductor).

D.3.3 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.3.4 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 6.4.6 and used in 5.4.3.3 and 6.4.6 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 peak value of **temporary overvoltage**.

D.4.2 Example 1 (circuit connected to mains supply)

D.4.2.1 Maximum recurring peak voltage U_{rp}

$$U_{rp} = \sqrt{2}\,U_0 \times F_4 = 1{,}1\sqrt{2}\,U_0$$

D.4.2.2 Partial discharge extinction voltage $U_{extinction}$ (basic insulation)

$$U_{extinction} = \sqrt{2}\,U_0 \times F_4 \times F_1$$

$$U_{extinction} = \sqrt{2}\,U_0 \times 1{,}1 \times 1{,}2 = 1{,}32\sqrt{2}\,U_0$$

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

$$U_1 = \sqrt{2}\,U_0 \times F_4 \times F_1 \times F_2$$

$$U_1 = \sqrt{2}\,U_0 \times 1{,}32 \times 1{,}25 = 1{,}65\sqrt{2}\,U_0$$

D.4.3 Example 2 (internal circuit with maximum recurring peak voltage U_{rp})

D.4.3.1 Partial discharge extinction voltage $U_{extinction}$ (basic insulation)

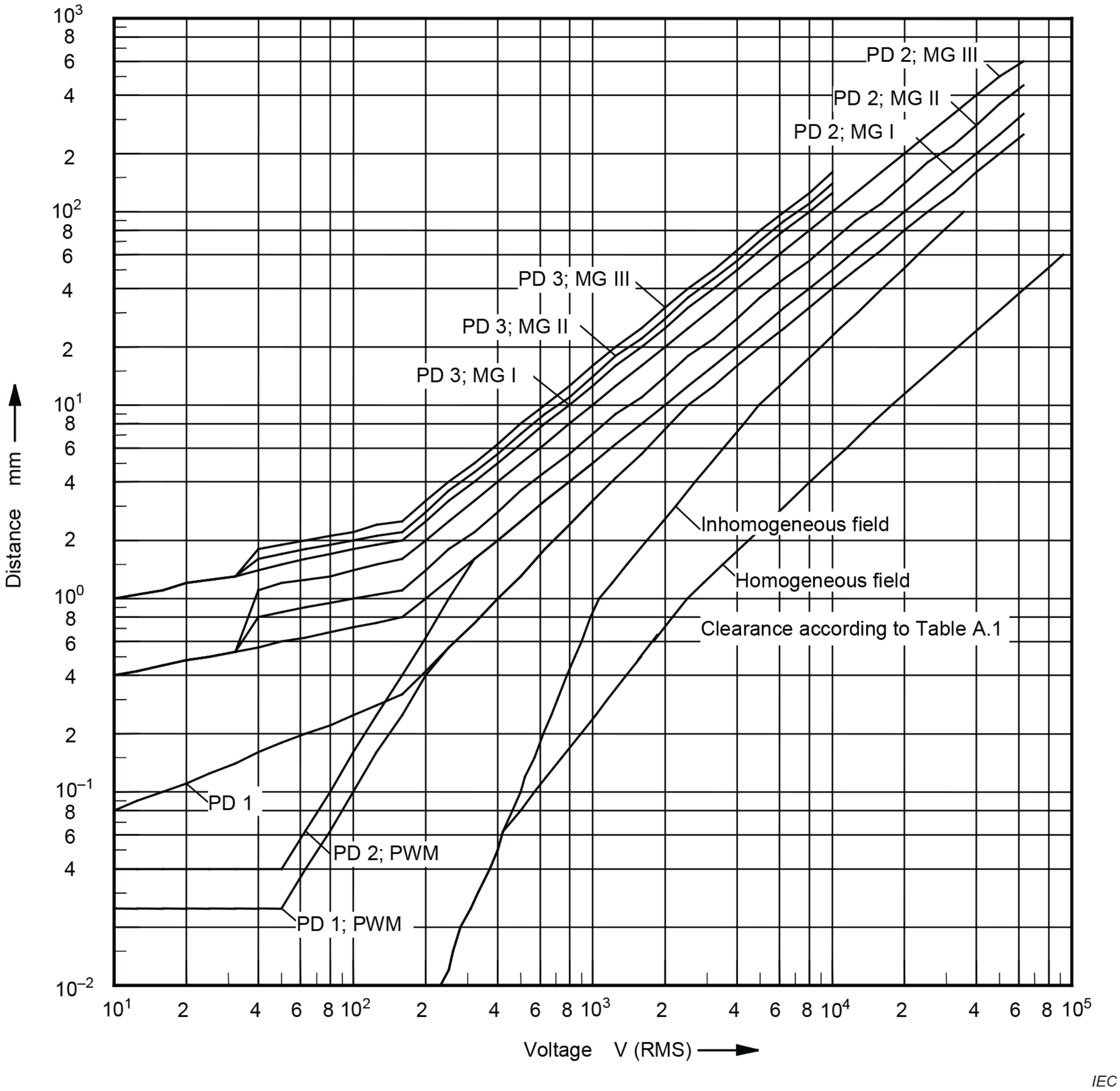
$$U_{extinction} = U_{rp} \times F_1 = U_{rp} \times 1{,}2$$

D.4.3.2 Initial value of the PD test voltage U_1 (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 mains supply

Nominal voltage of the mains supply [a] based on IEC 60038 [c]		Voltage line to neutral derived from nominal voltages AC or DC up to and including	Rated impulse withstand voltage [b]			
			Overvoltage category [d]			
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 to 240	150 [e]	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
	>1 000 ≤ 1 250 [f]	1 250 [f]	4 000	6 000	8 000	12 000
	>1 250 ≤ 1 500 [f]	1 500 [f]	6 000	8 000	10 000	15 000

[a] See Annex B for application to existing different low-voltage **mains supply** and their nominal voltages.

[b] Equipment with these **rated impulse withstand voltages** can be used in installations in accordance with IEC 60364-4-44.

[c] 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.

[d] See 4.3 for an explanation of the **overvoltage categories**.

[e] Nominal voltages for single-phase systems in Japan are 100 V or 100 V to 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).

[f] For DC values only.

Table F.2 – Clearances to withstand transient overvoltages

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

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 3.1.27)</th><th colspan="3">Case B
Homogeneous field
(see 3.1.26)</th></tr>
<tr><th colspan="3">Pollution degree [e]</th><th colspan="3">Pollution degree [e]</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 [b]</td><td>0,01</td><td rowspan="6">0,2 [c, d]</td><td rowspan="8">0,8 [d]</td><td>0,01</td><td rowspan="7">0,2 [c, d]</td><td rowspan="11">0,8 [d]</td></tr>
<tr><td>0,40</td><td>0,02</td><td>0,02</td></tr>
<tr><td>0,50 [b]</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 [b]</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 [b]</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 [b]</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 [b]</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 [b]</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 [b]</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 [b]</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>

[a] This voltage is:

– for **functional insulation**, for **basic insulation** directly exposed to or significantly influenced by **transient overvoltages** from the **mains supply** (see 5.2.2.2, 5.2.2.3 and 5.2.4), the **rated impulse withstand voltage** of the equipment,

– for other **basic insulation** (see 5.2.5), the highest impulse voltage that can occur in the circuit.

For **reinforced insulation**, see 5.2.5.

[b] Preferred values as specified in 4.2.2.1.

[c] 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. A protection by means of a solder resist of high quality is the minimum requirement to allow this **clearance** reduction.

[d] 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.

[e] 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-wire or two-wire AC or DC systems

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

[a] 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.

[b] For relationship to **rated voltage** see 5.3.2.2.

[c] These values correspond to the values given in Table F.1.

[d] For DC values only.

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

Nominal voltage of the mains suppply [c]	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 [b]	Three-phase three-wire systems unearthed [a] or corner-earthed
V	V	V	V
60	63	32	63
110 120 127	125	80	125
150 [d]	160	–	160
200	200		200
208	200	125	200
220 230 240	250	160	250
300 [d]	320	–	320
380 400 415	400	250	400
440	500	250	500
480 500	500	320	500
575	630	400	630
600 [d]	630	–	630
660 690	630	400	630
720 830	800	500	800
960	1 000	630	1 000
1 000 [d]	1 000	–	1 000

[a] 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.

[b] 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.

[c] For relationship to **rated voltage** see 5.3.2.2.

[d] These values correspond to the values given in Table F.1.

Table F.5 – Creepage distances to avoid failure due to tracking *(1 of 2)*

Voltage RMS [a, e]	Minimum creepage distances								
	Printed wiring material								
	Pollution degree								
	1	2 [f]	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 [b]
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) [d]
630	1,8	3,2	1,8	3,2	4,5	6,3	8,0 (7,9) [d]	9,0 (8,4) [d]	10,0 (9,0) [d]
800	2,4	4,0	2,4	4,0	5,6	8,0	10,0 (9,0) [d]	11,0 (9,6) [d]	12,5 (10,2) [d]
1 000	3,2	5,0	3,2	5,0	7,1	10,0	12,5 (10,2) [d]	14,0 (11,2) [d]	16,0 (12,8) [d]
1 250			4,2	6,3	9,0	12,5	16,0 (12,8) [d]	18,0 (14,4) [d]	20,0 (16,0) [d]
1 600			5,6	8,0	11,0	16,0	20,0 (16,0) [d]	22,0 (17,6) [d]	25,0 (20 0) [d]
2 000			7,5	10,0	14,0	20,0	25,0 (20,0) [d]	28,0 (22,4) [d]	32,0 (25,6) [d]
2 500			10,0	12,5	18,0	25,0	32,0 (25,6) [d]	36,0 (28,8) [d]	40,0 (32 0) [d]
3 200			12,5	16,0	22,0	32,0	40,0 (32,0) [d]	45,0 (36,0) [d]	50,0 (40,0) [d]

Table F.5 *(2 of 2)*

Voltage RMS [a, e]	Minimum creepage distances								
	Printed wiring material								
	Pollution degree								
	1	**2** [f]	**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** [b]
V	mm	mm	mm	mm	mm	mm	mm	mm	mm
4 000			16,0	20,0	28,0	40,0	50,0 (40,0) [d]	56,0 (44,8) [d]	63,0 (50,4) [d]
5 000			20,0	25,0	36,0	50,0	63,0 (50,4) [d]	71,0 (56,8) [d]	80,0 (64,0) [d]
6 300			25,0	32,0	45,0	63,0	80,0 (64,0) [d]	90,0 (72,0) [d]	100,0 (80,0) [d]
8 000			32,0	40,0	56,0	80,0	100,0 (80,0) [d]	110,0 (88,0) [d]	125,0 (100,0) [d]
10 000			40,0	50,0	71,0	100,0	125,0 (100,0) [d]	140,0 (112,0) [d]	160,0 (128,0) [d]
12 500			50,0 [c]	63,0 [c]	90,0 [c]	125,0 [c]			
16 000			63,0 [c]	80,0 [c]	110,0 [c]	160,0 [c]			
20 000			80,0 [c]	100,0 [c]	140,0 [c]	200,0 [c]			
25 000			100,0 [c]	125,0 [c]	180,0 [c]	250,0 [c]			
32 000			125,0 [c]	160,0 [c]	220,0 [c]	320,0 [c]			
40 000			160,0 [c]	200,0 [c]	280,0 [c]	400,0 [c]			
50 000			200,0 [c]	250,0 [c]	360,0 [c]	500,0 [c]			
63 000			250,0 [c]	320,0 [c]	450,0 [c]	600,0 [c]			

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.

[a] This voltage is for:

- **functional insulation**, the **steady-state working voltage** (see 5.3.4),
- **basic insulation** and **supplementary insulation** of the circuit energized directly from the **mains supply** (see 5.3.5), the voltage rationalized through Table F.3 or Table F.5, based on the **rated voltage** of the equipment, or the **rated insulation voltage**,
- **basic insulation** and **supplementary insulation** of a system, equipment and internal circuits not energized directly from the **mains supply** (see 5.3.5), the highest RMS 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.

[b] Material group IIIb is not recommended for application in **pollution degree** 3 above 630 V.

[c] Provisional data based on extrapolation. Technical committees who have other information based on experience may use their dimensions.

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

[e] Linear interpolation between two values of voltage is allowed (see 5.3.4, 5.3.5).

[f] See 5.3.3.8.

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

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
10,0	12,309	12,060	11,688
12,0	14,770	14,471	14,025
15,0	18,464	18,091	17,533

NOTE 1 Explanations concerning the influencing factors (air pressure, altitude, temperature, humidity) with respect to electric strength of **clearances** are given in 4.7 and altitude correction in 6.2.2.1.4

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 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) Change of temperature with specified rate of change, test Nb of IEC 60068-2-14: 2009	–10 to +55	–	Cycle duration 24	3
c) Thermal shock (rapid change of temperature, test Na of IEC 60068-2-14:2009	–10 to +55	–	[b]	
d) Damp heat, steady state	30/40 [a]	93	96	1

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

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

[b] Duration of the temperature change depends on the thermal time constant of the test specimen, see IEC 60068-2-14:2009.

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

Voltage[a] (peak value)[b] kV	Minimum clearances in air up to 2 000 m above sea level	
	Case A Inhomogeneous field conditions (see 3.1.27) mm	Case B Homogeneous field conditions (see 3.1.26) mm
0,04	0,001 [c]	0,001 [c]
0,06	0,002 [c]	0,002 [c]
0,1	0,003 [c]	0,003 [c]
0,12	0,004 [c]	0,004 [c]
0,15	0,005 [c]	0,005 [c]
0,20	0,006 [c]	0,006 [c]
0,25	0,008 [c]	0,008 [c]
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

Table F.9 – Additional information concerning the dimensioning of clearances to avoid partial discharge

Voltage[a] (peak value)[b] kV	Minimum clearances in air up to 2 000 m above sea level Case A Inhomogeneous field conditions (see 3.1.27) mm
0,04	As specified for case A in Table F.8
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	[c]
20	
25	
30	
40	
50	
60	
80	
100	

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.8 cannot provide operation without corona (**partial discharges**), especially for **inhomogeneous fields**. In order to provide corona-free operation, it is either preferrable to use larger **clearances**, as given in Table F.9, or to improve the field distribution.

[a] The **clearances** for other voltages are obtained by interpolation.

[b] See Figure 1 for **steady-state peak voltage** and **recurring peak voltage**.

[c] These values are based on experimental data obtained at atmospheric pressure.

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.8 cannot provide operation without corona (**partial discharges**), especially for **inhomogeneous fields**. In order to provide corona-free operation, it is either preferrable to use larger **clearances**, as given in Table F.9, or to improve the field distribution.

[a] The **clearances** for other voltages are obtained by interpolation.

[b] See Figure 1 for **steady-state peak voltage** and **recurring peak voltage**.

[c] Dimensioning without **partial discharge** is not possible under **inhomogeneous field** conditions.

Table F.10 – Altitude correction factors for clearance correction

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

Annex G
(informative)

Determination of clearance distances according to 5.2

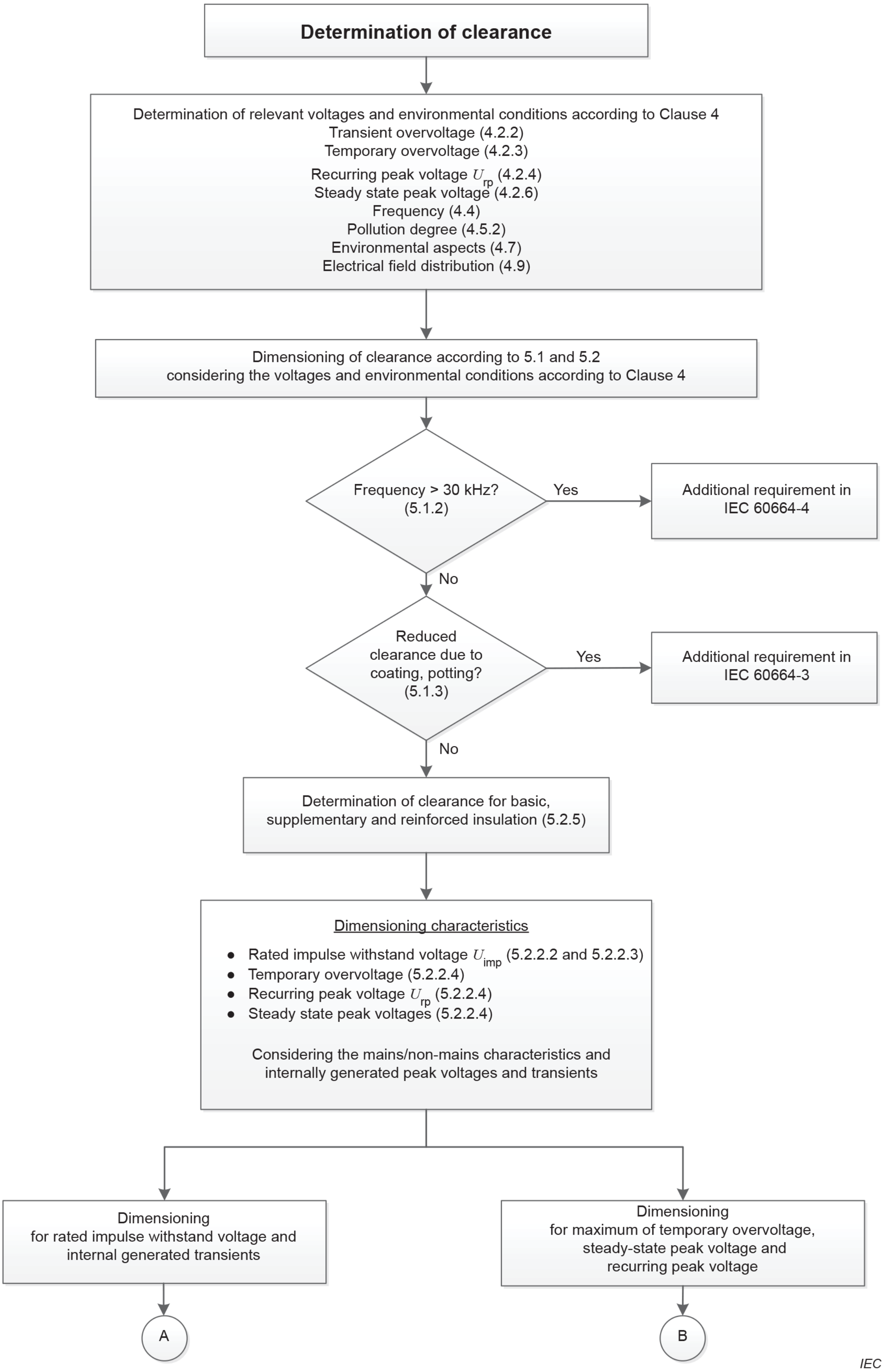
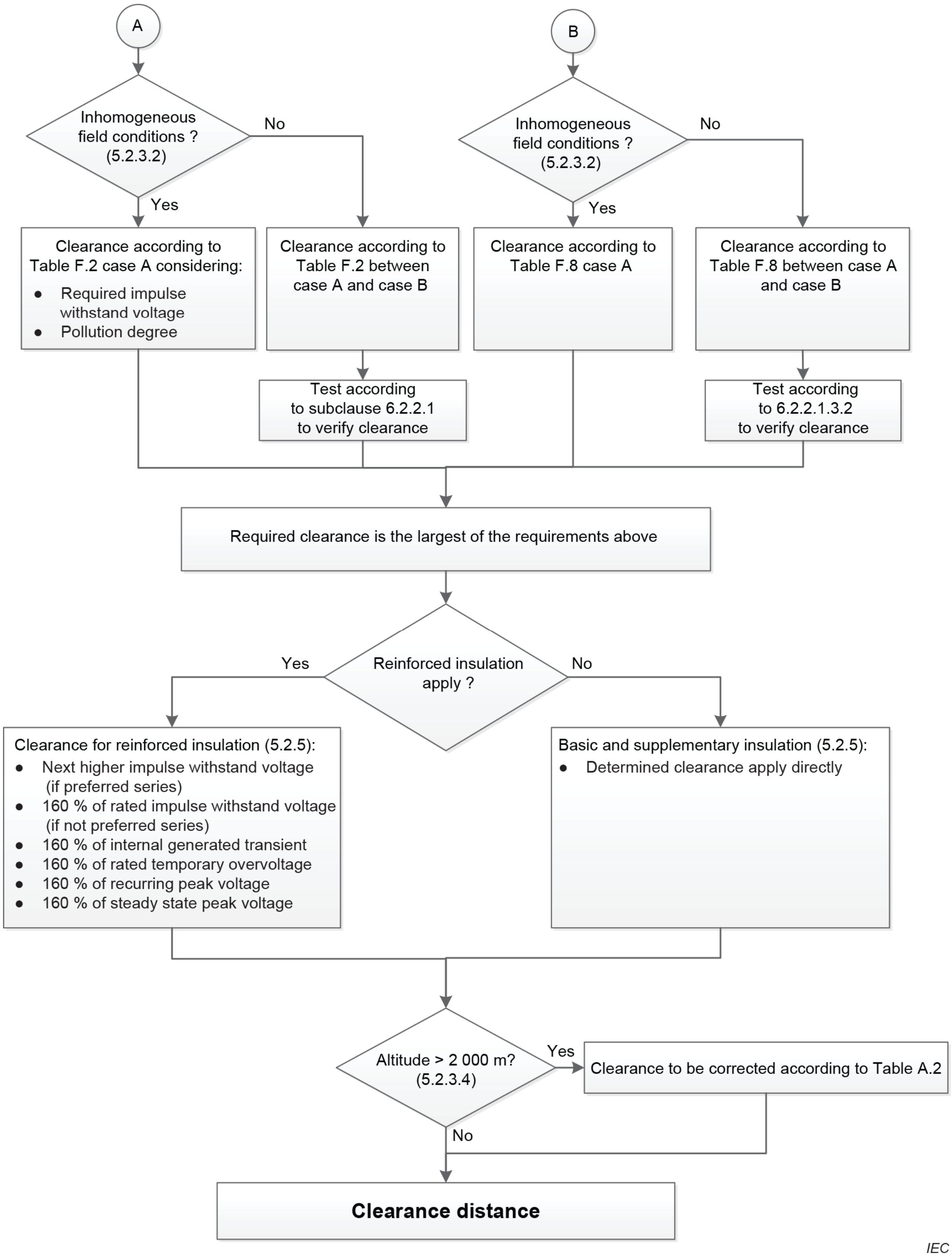


Figure G.1 – Determination of clearance distances according to 5.2 *(1 of 2)*



NOTE 1 This flow-chart is only informative to improve the understanding of 5.2. The mandatory requirement is given in 5.2.

NOTE 2 Dimensioning of **functional insulation** can be determined in a similar way considering 5.2 and 5.2.4.

NOTE 3 When the requirements of IEC 60664-3 Type 1 protection are met, **pollution degree** 1 in IEC 60664-1 is applicable.

Figure G.1 – Determination of clearance distances according to 5.2 *(2 of 2)*

Annex H
(informative)

Determination of creepage distances according to 5.3

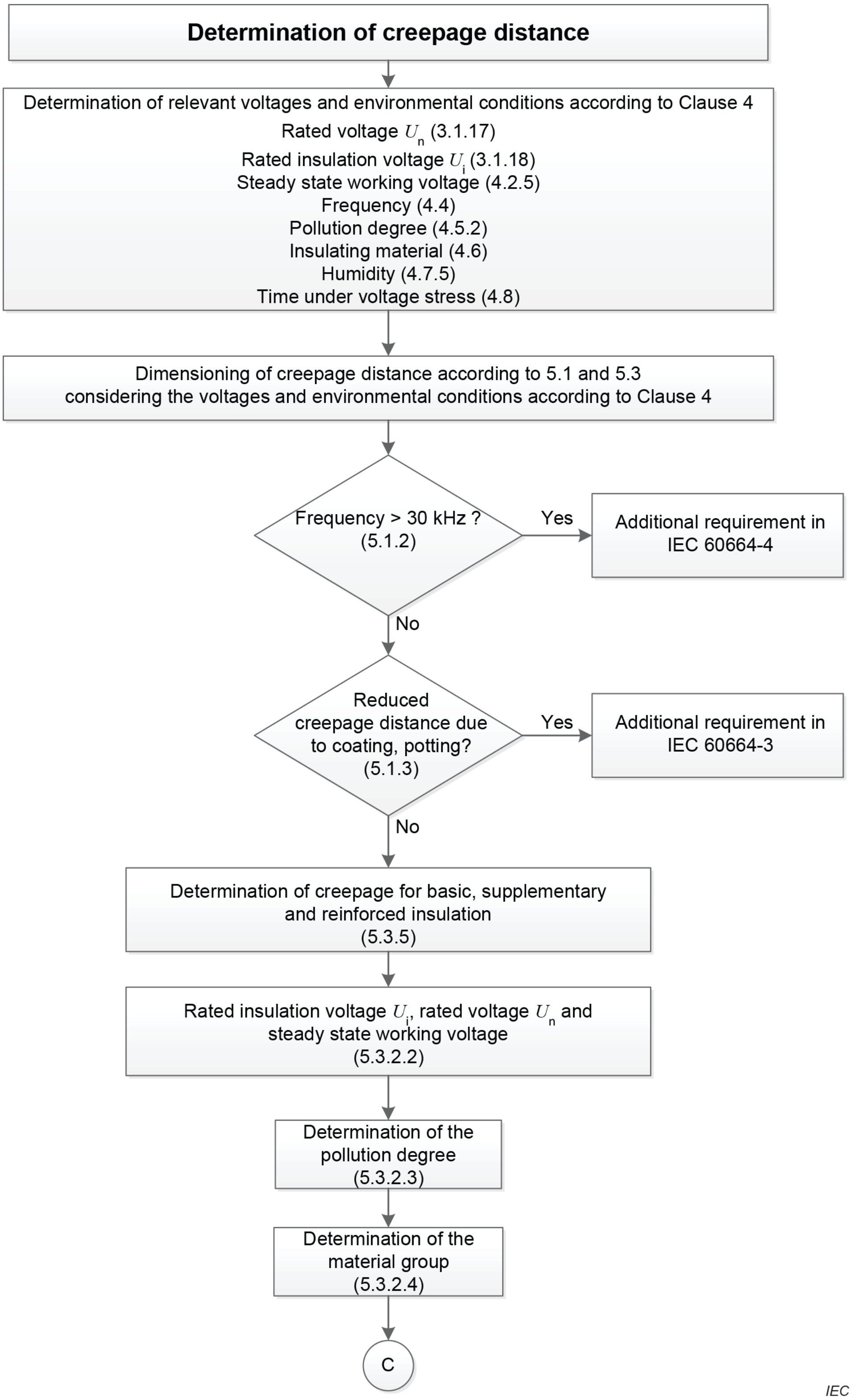
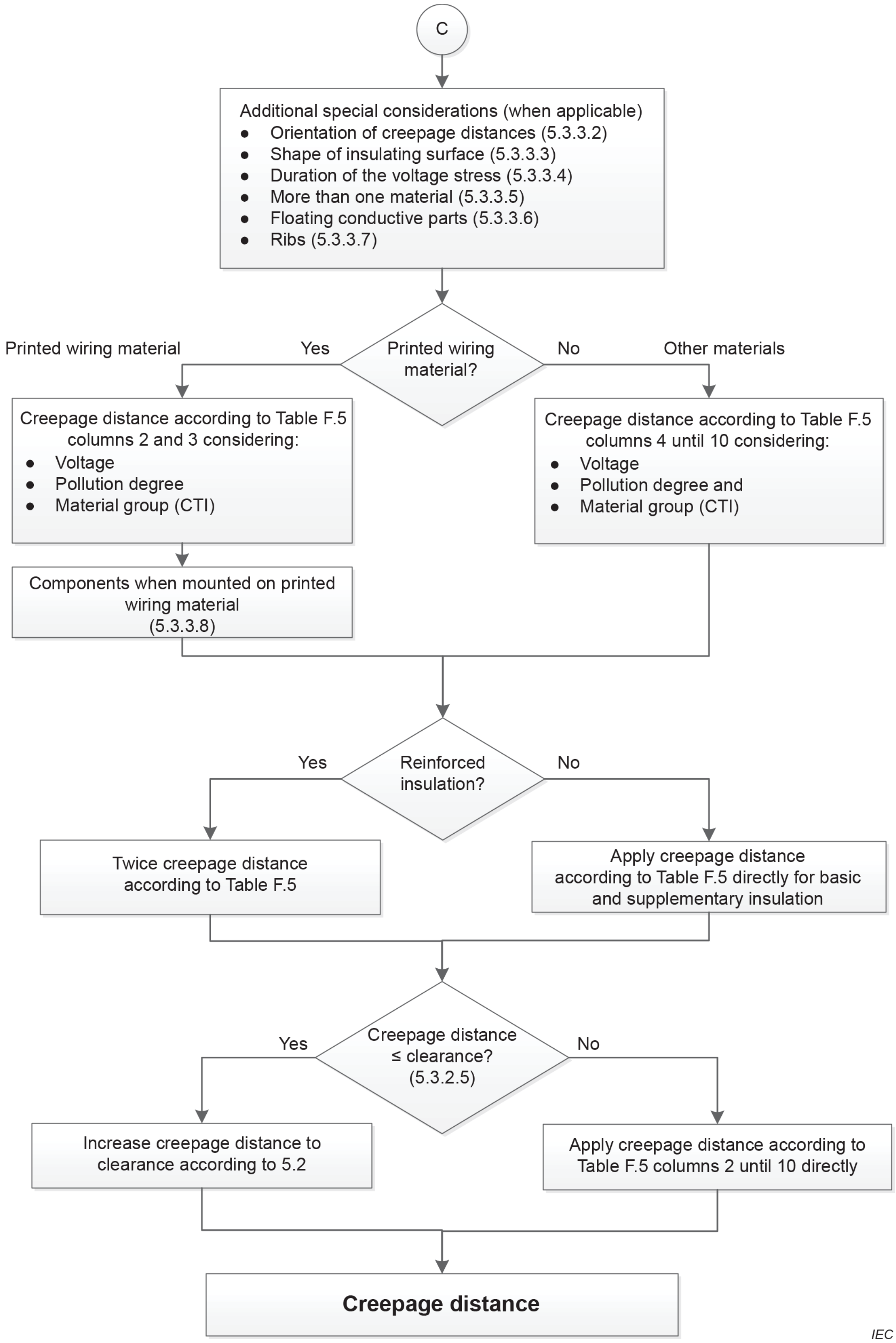


Figure H.1 – Determination of creepage distances according to 5.3 *(1 of 2)*



NOTE 1 This flow-chart is only informative to improve the understanding of 5.3. The mandadoty requirement is given in 5.3.

NOTE 2 Dimensioning of **functional insulation** can be determined in a similar way considering 5.3 and 5.3.4.

NOTE 3 When the requirements of IEC 60664-3 Type 1 protection are met, **pollution degree** 1 in IEC 60664-1 is applicable.

Figure H.1 – Determination of creepage distances according to 5.3 *(2 of 2)*

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