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REDLINE VERSION

INTERNATIONAL STANDARD

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HORIZONTAL STANDARD

Insulation co-ordination –
Part 1: Definitions, principles and rules

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Part 1: Definitions, principles and rules

FOREWORD

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This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

International Standard IEC 60071-1 has been prepared by IEC technical committee 99: Insulation co-ordination and system engineering of high voltage electrical power installations above 1,0 kV AC and 1,5 kV DC.

This ninth edition cancels and replaces the eighth edition published in 2006 and Amendment 1:2010. This edition constitutes a technical revision.

It has the status of a horizontal standard in accordance with IEC Guide 108.

The main changes from the previous edition are as follows:

a) all references are updated to current IEC standards, and the bibliography is deleted;
b) some definitions are clarified in order to avoid overlapping and ensure clear understanding;
c) letter symbols are changed and corrected in order to keep the consistency with relevant IEC standards;
d) some titles are changed to clarify understanding (see Clauses A.2, A.3 and Annex B).

The text of this International Standard is based on the following documents:

CDV	Report on voting
99/199/CDV	99/227/RVC

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

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

A list of all parts in the IEC 60071 series, published under the general title *Insulation co-ordination*, can be found on the IEC website.

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

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- withdrawn,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

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INSULATION CO-ORDINATION –

Part 1: Definitions, principles and rules

1 Scope

This part of IEC 60071 applies to three-phase AC systems having a highest voltage for equipment above 1 kV. It specifies the procedure for the selection of the rated withstand voltages for the phase-to-earth, phase-to-phase and longitudinal insulation of the equipment and the installations of these systems. It also gives the lists of the standard withstand voltages from which the rated withstand voltages ~~should be~~ are selected.

This document ~~recommends~~ describes that the selected withstand voltages ~~should be~~ are associated with the highest voltage for equipment. This association is for insulation co-ordination purposes only. The requirements for human safety are not covered by this document.

Although the principles of this document also apply to transmission line insulation, the values of their withstand voltages ~~may~~ can be different from the standard rated withstand voltages.

The apparatus committees are responsible for specifying the rated withstand voltages and the test procedures suitable for the relevant equipment taking into consideration the recommendations of this document.

NOTE In IEC 60071-2, ~~Application Guide,~~ all rules for insulation co-ordination given in this document are justified in detail, in particular the association of the standard rated withstand voltages with the highest voltage for equipment. When more than one set of standard rated withstand voltages is associated with the same highest voltage for equipment, guidance is provided for the selection of the most suitable set.

This horizontal standard is primarily intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC Guide 108.

One of the responsibilities of a technical committee is, wherever applicable, to make use of horizontal standards in the preparation of its publications. The contents of this horizontal standard will not apply unless specifically referred to or included in the relevant publications.

2 Normative references

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

IEC 60038~~:2002~~, *IEC standard voltages*

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

IEC 60071-2, *Insulation co-ordination – Part 2: Application guidelines*

IEC 60099-4, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

~~IEC 60507, *Artificial pollution tests on high-voltage insulators to be used on a.c. systems*~~

~~IEC 60633, Terminology for high-voltage direct current (HVDC) transmission~~

3 Terms and definitions

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
insulation co-ordination
selection of the dielectric strength of equipment in relation to the operating voltages and overvoltages which can appear on the system for which the equipment is intended, and taking into account the service environment and the characteristics of the available preventing and protective devices

~~[IEC 604-03-08:1987, modified]~~

Note 1 to entry: By "dielectric strength" of the equipment, is meant here its rated insulation level (3.36) or its standard insulation level ~~as defined in 3.35 and 3.36 respectively~~ (3.37).

[SOURCE: IEC 60050-614:2016, 614-03-08, modified – Note 1 to entry has been added]

3.2
external insulation
distances in atmospheric air, and the surfaces in contact with atmospheric air of solid insulation of the equipment which are subject to dielectric stresses and to the effects of atmospheric and other environmental conditions from the site, such as pollution, humidity, vermin, etc.

~~[IEC 604-03-02:1987, modified]~~

Note 1 to entry: External insulation is either weather protected or non-weather protected, designed to operate outside or inside closed shelters, respectively.

[SOURCE: IEC 60050-614:2016, 614-03-02, modified – Note 1 to entry has been added]

3.3
internal insulation
internal distances of the solid, liquid, or gaseous insulation of equipment which are protected from the effects of atmospheric and other external conditions

~~[IEC 604-03-03:1987]~~

[SOURCE: IEC 60050-614:2016, 614-03-03]

3.4
self-restoring insulation
insulation which~~, after a short time,~~ completely recovers its insulating properties within a short time interval after a disruptive discharge ~~during test~~

~~[IEC 604-03-04:1987, modified]~~

Note 1 to entry: Insulation of this kind is generally, but not necessarily, external insulation.

Note 2 to entry: This definition applies only when the discharge is caused by the application of a test voltage during a dielectric test. However, discharges occurring in service may cause a self-restoring insulation to lose partially or completely its original insulating properties.

[SOURCE: IEC 60050-614:2016, 614-03-04]

3.5
non-self-restoring insulation
insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge ~~during test~~

~~[IEC 604-03-05:1987, modified]~~

Note 1 to entry: This definition applies only when the discharge is caused by the application of a test voltage during a dielectric test. However, discharges occurring in service may cause a self-restoring insulation to lose partially or completely its original insulating properties.

[SOURCE: IEC 60050-614:2016, 614-03-05]

3.6
insulation configuration terminal
any of the terminals between any two of which a voltage that stresses the insulation can be applied

Note 1 to entry: The types of terminal are:

a) phase terminal, between which and the neutral is applied in service the phase-to-neutral voltage of the system;

b) neutral terminal, representing, or connected to, the neutral point of the system (neutral terminal of transformers, etc.);

c) earth terminal, always solidly connected to earth in service (tank of transformers, base of disconnectors, structures of towers, ground plane, etc.).

3.7
insulation configuration
complete geometric configuration of the insulation in service, consisting of the insulation and of all terminals and including all elements (insulating and conducting) which influence its dielectric behaviour~~. The following insulation configurations are identified:~~

Note 1 to entry: The insulation configurations defined in 3.7.1 to 3.7.4 are identified.

3.7.1
three-phase insulation configuration
insulation configuration having three phase terminals, one neutral terminal and one earth terminal

3.7.2
phase-to-earth ~~(p-e)~~ insulation configuration
three-phase insulation configuration where two phase terminals are disregarded and, except in particular cases, the neutral terminal is earthed

3.7.3
phase-to-phase~~(p-p)~~ insulation configuration
three-phase insulation configuration where one phase terminal is disregarded. In particular cases, the neutral and the earth terminals are also disregarded

3.7.4
longitudinal~~(t-t)~~ insulation configuration
insulation configuration having two phase terminals and one earth terminal, the phase terminals belonging to the same phase of a three-phase system temporarily separated into two independently energized parts (e.g. open switching devices)

Note 1 to entry: The four terminals belonging to the other two phases are disregarded or earthed. In particular cases one of the two phase terminals considered is earthed.

3.8
nominal voltage of a system
U_n
suitable approximate value of voltage used to designate or identify a system

[SOURCE: IEC 60050-601:1985, 601-01-21, modified – A symbol has been added.]

3.9
highest voltage of a system
U_s
highest value of the phase-to-phase operating voltage (RMS value) which occurs under normal operating conditions at any time and at any point in the system

[SOURCE: IEC 60050-601:1985, 601-01-23, modified – Clear meaning on the voltage has been added.]

3.10
highest voltage for equipment
U_m
highest value of phase-to-phase voltage (RMS value) for which the equipment is designed in respect of its insulation as well as other characteristics which relate to this voltage in the relevant equipment standards

Note 1 to entry: Under normal service conditions specified by the relevant apparatus committee, this voltage can be applied continuously to the equipment.

~~[IEC 604-03-01:1987, modified]~~

[SOURCE: IEC 60050-614:2016, 614-03-01]

3.11
isolated neutral system
system where the neutral point is not intentionally connected to earth, except for high impedance connections for protection or measurement purposes

[SOURCE: IEC 60050-601:1985, 601-02-24~~:1985~~]

3.12
solidly earthed neutral system
system whose neutral point(s) is(are) earthed directly

[SOURCE: IEC 60050-601:1985, 601-02-25~~:1985~~]

3.13
impedance earthed (neutral) system
system whose neutral point(s) is(are) earthed through impedances to limit earth fault currents

[SOURCE: IEC 60050-601:1985, 601-02-26~~:1985~~]

3.14
resonant earthed (neutral) system
system in which one or more neutral points are connected to earth through reactances which approximately compensate the capacitive component of a single-phase-to-earth fault current

~~[IEC 601-02-27:1985]~~

Note 1 to entry: With resonant earthing of a system, the residual current in the fault is limited to such an extent that an arcing fault in air is usually self-extinguishing.

[SOURCE: IEC 60050-601:1985, 601-02-27]

3.15
earth fault factor
k
at a given location of a three-phase system, and for a given system configuration, the ratio of the highest RMS phase-to-earth power-frequency voltage on a healthy phase during a fault to earth affecting one or more phases at any point on the system to the RMS phase-to-earth power-frequency voltage which would be obtained at the given location in the absence of any such fault

~~[IEC 604-03-06:1987]~~

[SOURCE: IEC 60050-614:2016, 614-03-06, modified – A symbol has been added and description on voltage has been modified.

3.16
continuous ~~(power frequency)~~ voltage
power-frequency voltage, considered having constant RMS value, continuously applied to any pair of terminals of an insulation configuration

~~**3.17**~~
~~**classification of voltages and overvoltages**~~
~~according to their shape and duration, voltages and overvoltages are divided in the following classes~~

~~NOTE More details on the following six first voltages and overvoltages are also given in Table 1.~~

3.17
overvoltage
~~any~~ voltage:

– between one phase conductor and earth or across a longitudinal insulation having a peak value exceeding the peak of the highest voltage of the system divided by $\sqrt{3}$;

~~[IEC 604-03-09, modified] or~~

– between phase conductors having a peak value exceeding the amplitude of the highest voltage of the system

~~[IEC 604-03-09:1987, modified]~~

Note 1 to entry: Unless otherwise clearly indicated, such as for surge arresters, overvoltage values expressed in p.u. refer to $U_s \times \sqrt{2}/\sqrt{3}$

[SOURCE: IEC 60050-614: 2016, 614-03-10]

3.17.1
temporary overvoltage
TOV
power-frequency overvoltage of relatively long duration

~~[IEC 604-03-12:1987, modified]~~

Note 1 to entry: The overvoltage may be undamped or weakly damped. In some cases, its frequency may be several times smaller or higher than power frequency.

[SOURCE: IEC 60050-614:2016, 614-03-13]

3.17.2
transient overvoltage
short-duration overvoltage of few milliseconds or less, oscillatory or non-oscillatory, usually highly damped

~~[IEC 604-03-13:1987]~~

Note 1 to entry: Transient overvoltages may be immediately followed by temporary overvoltages. In such cases the two overvoltages are considered as separate events.

[SOURCE: IEC 60050-614:2016, 614-03-14]

~~Transient overvoltages are divided into:~~

3.17.2.1
slow-front overvoltage
SFO
transient overvoltage, usually unidirectional, with time to peak 20 µs < $T_p \leq$ 5 000 µs, and tail duration $T_2 \leq$ 20 ms

3.17.2.2
fast-front overvoltage
FFO
transient overvoltage, usually unidirectional, with time to peak 0,1 µs < $T_1 \leq$ 20 µs, and tail duration T_2 < 300 µs

3.17.2.3
very-fast-front overvoltage
VFFO
transient overvoltage, usually unidirectional with time to peak $T_f \leq$ 0,1 µs, and with or without superimposed oscillations at frequency 30 kHz < f < 100 MHz

3.17.3
combined overvoltage
overvoltage consisting of two voltage components simultaneously applied between each of the two phase terminals of a phase-to-phase (or longitudinal) insulation and earth

Note 1 to entry: It is classified by the component of higher peak value (temporary, slow-front, fast-front or very-fast-front).

3.18
standard voltage shapes for test
~~the following~~ voltage and the overvoltage shapes for test that are ~~standardized~~ determined in amplitude, wave front, wave tail and duration

Note 1 to entry: More details on the following three first standard voltage shapes are given in IEC 60060-1 and also in Table 1.

3.18.1
standard short-duration power-frequency voltage
sinusoidal voltage with frequency between 48 Hz and 62 Hz, and duration of 60 s

3.18.2
standard switching impulse
impulse voltage having a time to peak of 250 µs and a time to half-value of 2 500 µs

3.18.3
standard lightning impulse
impulse voltage having a front time of 1,2 µs and a time to half-value of 50 µs

3.18.4
standard combined switching impulse
for phase-to-phase insulation, combined impulse voltage having two components of equal peak value and opposite polarity

Note 1 to entry: The positive component is a standard switching impulse and the negative one is a switching impulse whose times to peak and half-value should not be less than those of the positive impulse. Both impulses should reach their peak value at the same instant. The peak value of the combined voltage is, therefore, the sum of the peak values of the components.

3.18.5
standard combined voltage
for longitudinal insulation, combined voltage having a standard impulse on one terminal and a power-frequency voltage on the other terminal

Note 1 to entry: The impulse component is applied at the peak of the power-frequency voltage of opposite polarity.

3.19
representative overvoltage
U_{rp}
overvoltage assumed to produce the same dielectric effect on the insulation as the overvoltage of a given class occurring in service due to various origins

Note 1 to entry: Representative overvoltages consist of voltages with the standard shape of the class, and may be defined by one value or a set of values or a frequency distribution of values that characterize the service conditions.

Note 2 to entry: This definition also applies to the continuous power-frequency voltage representing the effect of the service voltage on the insulation.

3.20
overvoltage limiting device
device which limits the peak values of the overvoltages or their durations or both

Note 1 to entry: They are classified as preventing devices (e.g. a preinsertion resistor) or as protective devices (e.g. a surge arrester).

3.21
lightning ~~[or switching]~~ impulse protective level
U_{pl} ~~[or U_{ps}]~~
maximum permissible peak voltage value on the terminals of a protective device subjected to lightning ~~[or switching]~~ impulses under specific conditions

~~[IEC 604-03-56:1987 and IEC 604-03-57:1987]~~

[SOURCE: IEC 60050-614:2016, 614-03-56]

3.22
switching impulse protective level
U_{ps}
maximum permissible peak voltage value on the terminals of a protective device subjected to switching impulses under specific conditions

[SOURCE: IEC 60050-614:2016, IEC 614-03-57]

3.23
performance criterion
basis on which the insulation is selected so as to reduce to an economically and operationally acceptable level the probability that the resulting voltage stresses imposed on the equipment will cause damage to equipment insulation or affect continuity of service

Note 1 to entry: The performance criterion is usually expressed in terms of an acceptable failure rate (number of failures per year, years between failures, risk of failure, etc.) of the insulation configuration.

3.24
withstand voltage
value of the test voltage to be applied under specified conditions in a withstand voltage test, during which a specified number of disruptive discharges is tolerated

Note 1 to entry: The withstand voltage is designated as:

a) conventional assumed withstand voltage, when the number of disruptive discharges tolerated is zero. It is deemed to correspond to a withstand probability P_w = 100 %;

b) statistical withstand voltage, when the number of disruptive discharges tolerated is related to a specified withstand probability. In this document, the specified probability is P_w = 90 %.

Note 2 to entry: ~~In this standard, for non-self-restoring insulation are specified conventional assumed withstand voltages, and for self-restoring insulation are specified statistical withstand voltages.~~ In this document, the conventional assumed withstand voltages are specified for non-self-restoring insulation. The statistical withstand voltages are specified for self-restoring insulation.

3.25
co-ordination withstand voltage
U_{cw}
for each class of voltage, the value of the withstand voltage of the insulation configuration in actual service conditions, that meets the performance criterion

3.26
co-ordination factor
K_c
factor by which the value of the representative overvoltage must be multiplied in order to obtain the value of the co-ordination withstand voltage

3.27
standard reference atmospheric conditions
atmospheric conditions to which the standardized withstand voltages apply ~~(see 5.9)~~

Note 1 to entry: See 5.9.2.

3.28
required withstand voltage
U_{rw}
test voltage that the insulation must withstand in a standard withstand voltage test to ensure that the insulation will meet the performance criterion when subjected to a given class of overvoltages in actual service conditions and for the whole service duration

Note 1 to entry: The required withstand voltage has the shape of the co-ordination withstand voltage, and is specified with reference to all the conditions of the standard withstand voltage test selected to verify it.

3.29
atmospheric correction factor
K_t
factor to be applied to the co-ordination withstand voltage to account for the difference in dielectric strength between the average atmospheric conditions in service and the standard reference atmospheric conditions

Note 1 to entry: It applies to external insulation only, for all altitudes.

Note 2 to entry: For the atmospheric correction factor, the atmospheric conditions taken into account are air pressure, temperature and humidity. For insulation co-ordination purposes, usually only the air pressure correction needs to be taken into account.

~~NOTE 1 The factor K_t allows the correction of test voltages taking into account the difference between the actual atmospheric conditions during test and the standard reference atmospheric conditions. For the factor K_t, the atmospheric conditions taken into account are air pressure, temperature and humidity.~~

~~NOTE 2 For insulation co-ordination purposes usually only the air pressure correction needs to be taken into account.~~

3.30
altitude correction factor
K_a
factor to be applied to the co-ordination withstand voltage to account for the difference in dielectric strength between the average pressure corresponding to the altitude in service and the standard reference pressure

Note 1 to entry: The altitude correction factor ~~K_a~~ is part of the atmospheric correction factor ~~K_t~~.

3.31
safety factor
K_s
overall factor to be applied to the co-ordination withstand voltage, after the application of the atmospheric correction factor (if required), to obtain the required withstand voltage, accounting for all other differences in dielectric strength between the conditions in service during life time and those in the standard withstand voltage test

3.32
actual withstand voltage of an equipment or insulation configuration
U_{aw}
highest possible value of the test voltage that can be applied to an equipment or insulation configuration in a standard withstand voltage test

3.33
test conversion factor
K_{tc}
for a given equipment or insulation configuration, the factor to be applied to the required withstand voltage of a given overvoltage class, in the case where the standard withstand shape of the selected withstand voltage test is that of a different overvoltage class

Note 1 to entry: For a given equipment or insulation configuration: the test conversion factor of the standard voltage shape (a) to the standard voltage shape (b) must be higher than or equal to the ratio between the actual withstand voltage for the standard voltage shape (a) and the actual withstand voltage of the standard voltage shape (b).

3.34
rated withstand voltage
value of the test voltage, applied in a standard withstand voltage test that proves that the insulation complies with one or more required withstand voltages

Note 1 to entry: It is a rated value of the insulation of an equipment.

3.35
standard rated withstand voltage
U_w
standard value of the rated withstand voltage as specified in this document

Note 1 to entry: See 5.6 and 5.7.

3.36
rated insulation level
set of rated withstand voltages which characterize the dielectric strength of the insulation

3.37
standard insulation level
set of standard rated withstand voltages which are associated to U_m as specified in this document

Note 1 to entry: See Table 2 and Table 3.

3.38
standard withstand voltage test
dielectric test performed in specified conditions to prove that the insulation complies with a standard rated withstand voltage

Note 1 to entry: This document covers:

– – short-duration power-frequency voltage tests;
– – switching impulse tests;
– – lightning impulse tests;
– – combined switching impulse tests;
– – combined voltage tests.

Note 2 to entry: More detailed information on the standard withstand voltage tests is given in IEC 60060-1 (see also Table 1 for the test voltage shapes).

Note 3 to entry: The very-fast-front impulse standard withstand voltage tests should be specified by the relevant apparatus committees, if required.

4 Abbreviated terms and symbols

4.1 General

The lists provided below cover only the most frequently used symbols and abbreviations which are useful for insulation co-ordination.

4.2 Subscripts

~~p-e~~	~~related to phase to earth~~
~~t-t~~	~~related to longitudinal~~
max	maximum ~~(IEC 60633)~~
~~p-p~~	~~related to phase to phase~~

4.3 Letter symbols

f	frequency
k	earth fault factor
K_t	atmospheric correction factor
K_a	altitude correction factor
K_c	co-ordination factor
K_s	safety factor
K_tc	test conversion factor
P_w	withstand probability
T_1	front time
T_2	time to half-value of a decreasing voltage
T_p	time to peak value
T_t	total overvoltage duration
U_aw	actual withstand voltage of an equipment or insulation configuration
U_cw	co-ordination withstand voltage
U_m	highest voltage for equipment
U_n	nominal voltage of a system
U_pl	lightning impulse protective level of a surge arrester
U_ps	switching impulse protective level of a surge arrester

U_{rp}	representative overvoltage
U_{rw}	required withstand voltage
U_s	highest voltage of a system
U_w	standard rated withstand voltage

4.4 Abbreviations

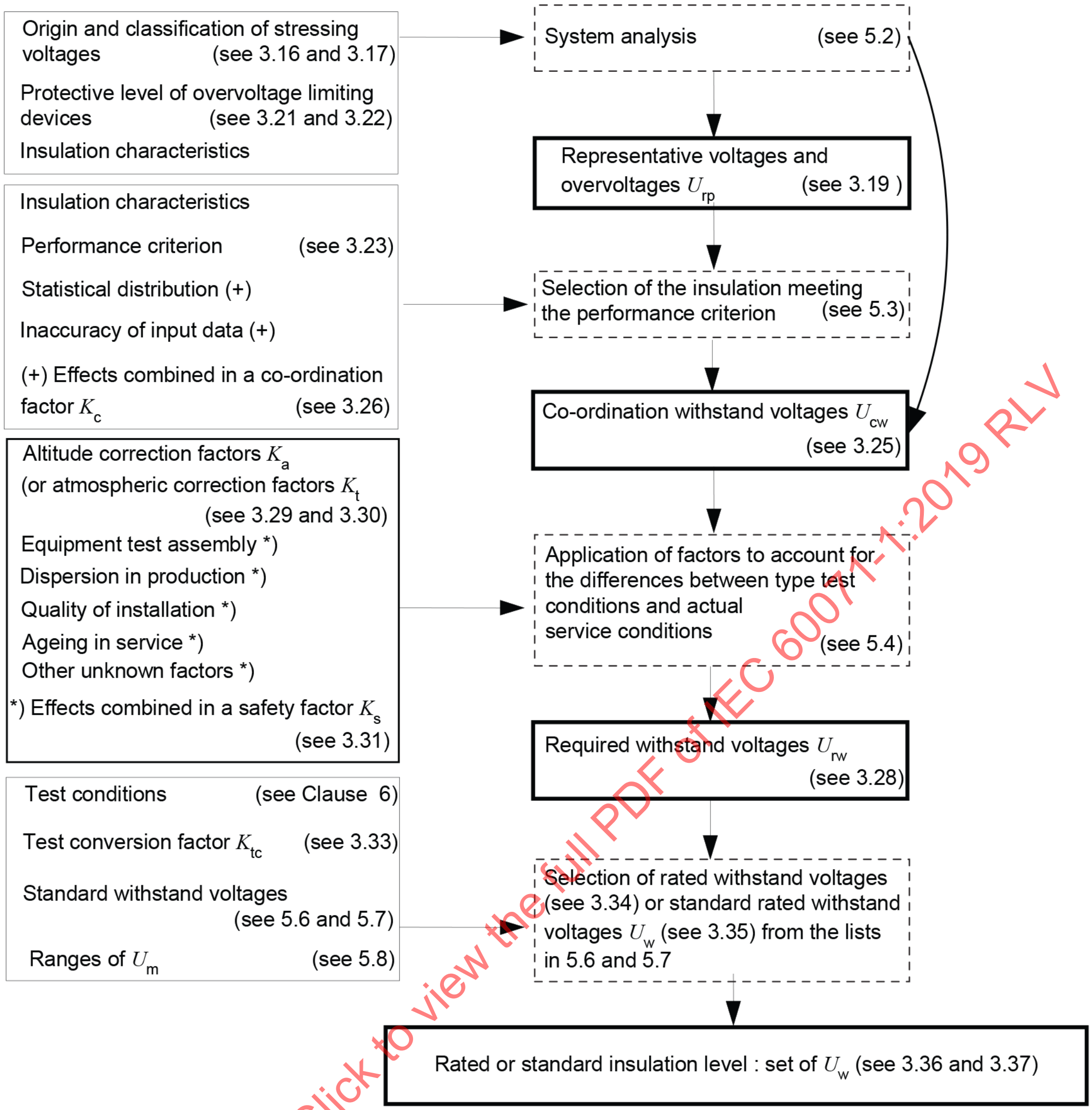
FFO	fast-front overvoltage
ACWV	standard rated short-duration power frequency withstand voltage of an equipment or insulation configuration
LIPL	lightning impulse protective level of a surge arrester
SIPL	switching impulse protective level of a surge arrester
LIWV	standard rated lightning impulse withstand voltage of an equipment or insulation configuration
SFO	slow-front overvoltage
SIWV	standard rated switching impulse withstand voltage of an equipment or insulation configuration
TOV	temporary overvoltage
VFFO	very-fast-front overvoltage

5 Procedure for insulation co-ordination

5.1 General outline of the procedure

The procedure for insulation co-ordination consists of the selection of the highest voltage for the equipment together with a corresponding set of standard rated withstand voltages which characterize the insulation of the equipment needed for the application. This procedure is outlined in Figure 1 and its steps are described in 5.1 to 5.5. The optimization of the selected set of U_w may require reconsideration of some input data and repetition of part of the procedure.

The rated withstand voltages shall be selected from the lists of standard rated withstand voltages given in 5.6 and 5.7. The set of selected standard voltages constitutes a rated insulation level. If the standard rated withstand voltages are also associated with the same U_m according to 5.10, this set constitutes a standard insulation level.



NOTE In brackets the subclauses reporting the definition of the term or the description of the action.

Sided boxes refer to required input

Sided boxes refer to performed actions

Sided boxes refer to obtained results

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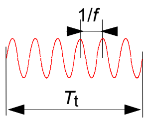
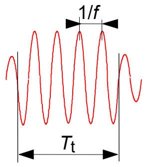
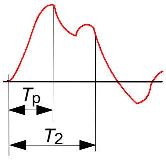
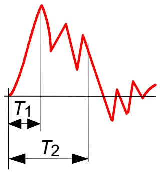
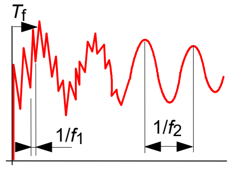
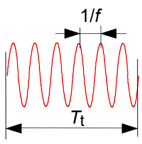
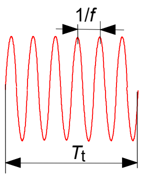
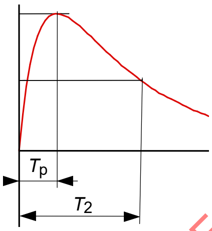
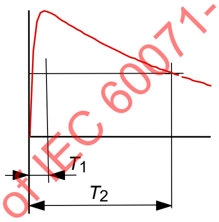
Figure 1 – Flow chart for the determination of rated or standard insulation level

5.2 Determination of the representative voltages and overvoltages (U_{rp})

The voltages and the overvoltages that stress the insulation shall be determined in amplitude, shape and duration by means of a system analysis which includes the selection and location of the overvoltage preventing and limiting devices.

For each class of voltages and overvoltages, this analysis shall then determine a representative voltage and overvoltage, taking into account the characteristics of the insulation with respect to the different behaviour at the voltage or overvoltage shapes in the system and at the standard voltage shapes applied in a standard withstand voltage test as outlined in Table 1.

Table 1 – Classes and shapes of overvoltages, standard voltage shapes and standard withstand voltage tests

Class	Low frequency		Transient		
	Continuous	**Temporary**	**Slow-front**	**Fast-front**	**Very-fast-front**
Voltage or over-voltage shapes					
Range of voltage or over-voltage shapes	f = 50 Hz or 60 Hz $T_t \geq$ 3 600s	10 Hz < f < 500 Hz 0,02 s ≤ T_t ≤ 3 600 s	20 µs < T_p ≤ 5 000 µs T_2 ≤ 20 ms	0,1 µs < T_1 ≤ 20 µs T_2 ≤ 300 µs	T_f ≤ 100 ns 0,3 MHz < f_1 < 100 MHz 30 kHz < f_2 < 300 kHz
Standard voltage shapes	 f = 50 Hz or 60 Hz T_t [a]	 48 Hz ≤ f ≤ 62 Hz T_t = 60 s	 T_p = 250 µs T_2 = 2 500 µs	 T_1 = 1,2 µs T_2 = 50 µs	[a]
Standard withstand voltage test	[a]	Short-duration power frequency test	Switching impulse test	Lightning impulse test	[a]

[a] To be specified by the relevant apparatus committees.

The representative voltages and overvoltages may be characterized either by:

– an assumed maximum, or
– a set of peak values, or
– a complete statistical distribution of peak values.

NOTE In the last case additional characteristics of the overvoltage shapes ~~may~~ could have to be considered.

When the adoption of an assumed maximum is considered adequate, the representative overvoltage of the various classes shall be:

– For the continuous power-frequency voltage: a power-frequency voltage with RMS value equal to the highest voltage of the system, and with duration corresponding to the lifetime of the equipment;
– For the temporary overvoltage: a standard power-frequency short-duration voltage with an RMS value equal to the assumed maximum of the temporary overvoltages divided by $\sqrt{2}$;
– For the slow-front overvoltage: a standard switching impulse with peak value equal to the peak value of the assumed maximum of the slow-front overvoltages;
– For the fast-front overvoltage: a standard lightning impulse with peak value equal to the peak value of the assumed maximum stress of the fast-front overvoltages phase to earth;

NOTE For gas insulated switchgear (GIS) or gas insulated line (GIL) with three-phase enclosure and insulation levels chosen among the lowest ones for a given U_m, the phase-to-phase overvoltages ~~may~~ could need consideration.

– For the very-fast-front overvoltage: the characteristics for this class of overvoltage are specified by the relevant apparatus committees;

– For the slow-front phase-to-phase overvoltage: a standard combined switching impulse with peak value equal to the peak value of the assumed maximum of the slow-front phase-to-phase overvoltages;

– For the slow-front (or fast-front) longitudinal overvoltage: a combined voltage consisting of a standard switching (or lightning) impulse and of a power-frequency voltage, each with peak value equal to the two relevant assumed maximum peak values, and with the instant of impulse peak coinciding with the peak of the power-frequency of opposite polarity.

5.3 Determination of the co-ordination withstand voltages (U_{cw})

The determination of the co-ordination withstand voltages consists of determining the lowest values of the withstand voltages of the insulation meeting the performance criterion when subjected to the representative overvoltages under service conditions.

The co-ordination withstand voltages of the insulation have the shape of the representative overvoltages of the relevant class and their values are obtained by multiplying the values of the representative overvoltages by a co-ordination factor. The value of the co-ordination factor depends on the accuracy of the evaluation of the representative overvoltages and on an empirical, or on a statistical appraisal of the distribution of the overvoltages and of the insulation characteristics.

The co-ordination withstand voltages can be determined as either conventional assumed withstand voltages or statistical withstand voltages. This affects the determination procedure and the values of the co-ordination factor.

Simulations of overvoltage events combined with the simultaneous evaluation of the risk of failure, using the relevant insulation characteristics, permit the direct determination of the statistical co-ordination withstand voltages without the intermediate step of determining the representative overvoltages (see Figure 1).

5.4 Determination of the required withstand voltage (U_{rw})

The determination of the required withstand voltages of the insulation consists of converting the co-ordination withstand voltages to appropriate standard test conditions. This is accomplished by multiplying the co-ordination withstand voltages by factors which compensate the differences between the actual in-service conditions of the insulation and those in the standard withstand voltage tests.

The factors to be applied shall compensate atmospheric conditions by ~~the atmospheric~~ altitude correction factor ~~K_t~~ K_a and the effects listed below by a safety factor K_s.

Effects combined in a safety factor K_s:

– the differences in the equipment assembly;

– the dispersion in the product quality;

– the quality of installation;

– the ageing of the insulation during the expected lifetime;

– other unknown influences.

If, however, these effects cannot be evaluated individually, an overall safety factor, derived from experience, shall be adopted (see IEC 60071-2).

~~The atmospheric correction factor K_t is applicable for external insulation only. K_t shall be applied to account for the differences between the standard reference atmospheric conditions and those expected in service.~~

~~For altitude correction~~ For external insulation, the altitude correction factor K_a which considers only the average air pressure corresponding to the altitude has to be applied. The altitude correction factor K_a has to be applied whatever is the altitude.

If it is necessary to consider temperature, humidity and pressure, the atmospheric correction factor K_t shall be applied instead of K_a.

K_t shall be used in an inverse way.

5.5 Selection of the rated insulation level

The selection of the rated insulation level consists of the selection of the most economical set of standard rated withstand voltages (U_w) of the insulation sufficient to prove that all the required withstand voltages are met.

The highest voltage for equipment is then chosen as the next standard value of U_m equal to or higher than the highest voltage of the system (U_s) where the equipment will be installed.

For equipment to be installed under normal environmental conditions relevant to insulation, U_m shall be at least equal to U_s.

For equipment to be installed outside of the normal environmental conditions relevant to insulation, U_m may be selected higher than the next standard value of U_m equal to or higher than U_s according to the special needs involved.

NOTE 1 As an example, the selection of a U_m value higher than the next standard value of U_m equal to or higher than U_s ~~may~~ can arise when the equipment has to be installed at an altitude higher than 1 000 m in order to compensate the decrease of withstand voltage of the external insulation.

Standardization of tests, as well as the selection of the relevant test voltages, to prove the compliance with U_m, are performed by the relevant apparatus committees (e.g. pollution tests, partial discharge voltage tests).

The withstand voltages to prove that the required temporary, slow-front and fast-front withstand voltages are met, for phase-to-earth, phase-to-phase and longitudinal insulation, may be selected with the same shape as the required withstand voltage, or with a different shape, exploiting, for this last selection, the intrinsic characteristics of the insulation.

The value of the rated withstand voltage is then selected in the list of the standard rated withstand voltages reported in 5.6 and 5.7, as the next value equal to or higher than:

– the required withstand voltage in the case of the same shape,
– the required withstand voltage multiplied by the relevant test conversion factor in the case of a different shape.

NOTE 2 This may allow the adoption of a single standard rated withstand voltage to prove compliance with more than one required withstand voltage, thus giving the possibility of reducing the number of rated withstand voltages that would define a rated insulation level (see, for example, 5.10).

NOTE 3 Generally applicable minimum air clearances to assure a specified impulse withstand voltage are determined with a conservative approach (see Annex A).

For equipment to be used in normal environmental conditions, the rated insulation level should then preferably be selected from Table 2 and Table 3 corresponding to the applicable highest voltage for equipment such that these rated withstand voltages are met.

The selection of the standard rated withstand voltage to prove the compliance with the very-fast-front required withstand voltage shall be considered by the relevant apparatus committees.

For surge arresters the required withstand voltages of the insulating housing are based on the protective levels U_{pl} and U_{ps} with suitable safety factors applied as per the apparatus standard IEC 60099-4. In general, therefore, the withstand voltages shall not be selected from the lists of 5.6 and 5.7.

5.6 List of standard rated short-duration power frequency withstand voltages

The following RMS values, expressed in kV, are standardized as withstand voltages: 10, 20, 28, 38, 50, 70, 95, 115, 140, 185, 230, 275, 325, 360, 395, 460, 510, 570, 630, 680, 710, 790, 830, 880, 960, 975, 1 050, 1 100, 1 200.

~~The following r.m.s. values, expressed in kV, are recommended as withstand voltages : 510, 570, 630, 680, (710, 790, 830, 880, 960, 975 : these last values are under consideration).~~

5.7 List of standard rated impulse withstand voltages

The following peak values, expressed in kV, are standardized as withstand voltages: 20, 40, 60, 75, 95, 125, 145, 170, 200, 250, 325, 380, 450, 550, 650, 750, 850, 950, 1 050, 1 175, 1 300, 1 425, 1 550, 1 675, 1 800, 1 950, 2 100, 2 250, 2 400, 2 550, 2 700, 2 900, 3 100.

5.8 Ranges for highest voltage for equipment

The standard highest voltages for equipment are divided in two ranges:

– **range I**: Above 1 kV to 245 kV included (Table 2). This range covers both transmission and distribution systems. The different operational aspects, therefore, shall be taken into account in the selection of the rated insulation level of the equipment.
– **range II**: Above 245 kV (Table 3). This range covers mainly transmission systems.

5.9 Environmental conditions

5.9.1 Normal environmental conditions

The normal environmental conditions that are of concern for insulation coordination and for which withstand voltages can be usually selected from Table 2 or Table 3 are the following:

a) The ambient air temperature does not exceed 40 °C and its average value, measured over a period of 24 h, does not exceed 35 °C. The minimum ambient air temperature is −10 °C for class "−10 outdoor", −25 °C for class "−25 outdoor" and −40 °C for class "−40 outdoor".
b) The altitude does not exceed 1 000 m above sea level.
c) The ambient air is not significantly polluted by dust, smoke, corrosive gases, vapours or salt. Pollution does not exceed pollution ~~level II~~ class c – Medium, according to ~~Table 1 of IEC 60071-2~~ IEC TS 60815-1.
d) The presence of condensation or precipitation is usual. Precipitation in form of dew, condensation, fog, rain, snow, ice or hoar frost is considered.

NOTE Precipitation characteristics for insulation are described in IEC 60060-1. ~~For other properties, precipitation characteristics are described in IEC 60721-2-2.~~

5.9.2 Standard reference atmospheric conditions

The standard reference atmospheric conditions for which the standardized withstand voltages apply are:

a) temperature: t_0 = 20 °C
b) pressure: p_0 = 1 013 hPa (1 013 mbar)
c) absolute humidity: h_0 = 11 g/m³.

5.10 Selection of the standard insulation level

The association of standard rated withstand voltages with the highest voltage for equipment has been standardized to benefit from the experience gained from the operation of systems designed according to IEC standards and to enhance standardization.

The standard rated withstand voltages are associated with the highest voltage for equipment according to Table 2 for range I and Table 3 for range II. These standard rated withstand voltages are valid for the normal environmental conditions and are adjusted to the standard reference atmospheric conditions.

NOTE For withstand voltages used in some countries and not defined as standard insulation levels, see Annex B.

The associations obtained by connecting standard rated withstand voltages of all columns without crossing horizontal marked lines are defined as standard insulation levels.

Furthermore, the following associations are standardized for phase-to-phase and longitudinal insulation:

– For phase-to-phase insulation, range I, the standard rated short-duration power-frequency and lightning impulse phase-to-phase withstand voltages are equal to the relevant phase-to-earth withstand voltages (Table 2). The values in brackets, however, may be insufficient to prove that the required withstand voltages are met and additional phase-to-phase withstand voltage tests may be needed.
– For phase-to-phase insulation, range II, the standard lightning impulse withstand voltage phase-to-phase is equal to the lightning impulse phase-to-earth.
– For longitudinal insulation, range I, the standard rated short-duration power-frequency and lightning impulse withstand voltages are equal to the relevant phase-to-earth withstand voltages (Table 2).
– For longitudinal insulation, range II, the standard switching impulse component of the combined withstand voltage is given in Table 3, while the peak value of the power-frequency component of opposite polarity is $U_m \times \sqrt{2}/\sqrt{3}$.
– For longitudinal insulation range II, the standard lightning impulse component of the combined withstand voltage is equal to the relevant phase-to-earth withstand voltage (Table 3), while the peak value of the power-frequency component of opposite polarity is $0{,}7 \times U_m \times \sqrt{2}/\sqrt{3}$.

More than one preferred association is foreseen for most of the highest voltages for equipment to allow for the application of different performance criteria or overvoltage patterns.

For the preferred associations, only two standard rated withstand voltages are sufficient to define the rated insulation level of the equipment:

– For equipment in range I:
  a) the standard rated lightning impulse withstand voltage and,
  b) the standard rated short-duration power-frequency withstand voltage.
– For equipment in range II:
  a) the standard rated switching impulse withstand voltage, and
  b) the standard rated lightning impulse withstand voltage.

If technically and economically justified, other associations may be adopted. The recommendations of 5.1 to 5.8 shall be followed in every case. The resulting set of standard rated withstand voltages shall be termed, therefore, rated insulation level. Particular examples are:

– For external insulation, for the higher values of U_m in range **I**, it ~~may~~ can be more economical to specify a standard rated switching impulse withstand voltage instead of a standard rated short-duration power-frequency withstand voltage.
– For internal insulation in range **II**, high temporary overvoltages ~~may~~ can require the specification of a standard rated short-duration power-frequency withstand voltage.

Table 2 – Standard insulation levels for range I (1 kV < U_m ≤ 245 kV)

Highest voltage for equipment, U_m kV (RMS value)	Standard rated short-duration power-frequency withstand voltage kV (RMS value)	Standard rated lightning impulse withstand voltage kV (peak value)
3,6	10	20 40
7,2	20	40 60
12	28	60 75 95
17,5 [a]	38	75 95
24	50	95 125 145
36	70	145 170
52 [a]	95	250
72,5	140	325
100 [b]	(150)	(380)
	185	450
123	(185)	(450)
	230	550
145	(185)	(450)
	230	550
	275	650
170 [a]	(230)	(550)
	275	650
	325	750
245	(275)	(650)
	(325)	(750)
	360	850
	395	950
	460	1 050

NOTE If values in brackets are considered insufficient to prove that the required phase-to-phase withstand voltages are met, additional phase-to-phase withstand voltage tests are needed.

[a] These U_m are non-preferred values in IEC 60038 and~~ thus no most frequently combinations standardized in apparatus standards are given~~ therefore seldom used. These values should not be used for new systems to be constructed in future.

[b] This U_m value is not mentioned in IEC 60038 but it has been introduced in range I in some apparatus standards.

Table 3 – Standard insulation levels for range II (U_m > 245 kV) *(1 of 2)*

Highest voltage for equipment, U_m kV (RMS value)	Standard rated switching impulse withstand voltage			Standard rated lightning impulse withstand voltage [b] kV (peak value)
	Longitudinal insulation [a] kV (peak value)	Phase-to-earth kV (peak value)	Phase-to-phase (ratio to the phase-to-earth peak value)	
300 [c]	750	750	1,50	850
				950
	750	850	1,50	950
				1 050
362	850	850	1,50	950
				1 050
	850	950	1,50	1 050
				1 175
420	850	850	1,60	1 050
				1 175
	950	950	1,50	1 175
				1 300
	950	1 050	1,50	1 300
				1 425
550	950	950	1,70	1 175
				1 300
	950	1 050	1,60	1 300
				1 425
	950 1 050	1 175	1,50	1 425
				1 550
800	1 175	1 300	1,70	1 675
				1 800
	1 175	1 425	1,70	1 800
				1 950
	1 175 1 300	1 550	1,60	1 950
				2 100
1 100	–	1 425 [d]	–	1 950
				2 100
	1 425	1 550	1,70	2 100
				2 250
	1 550	1 675	1,65	2 250
				2 400
	1 675	1 800	1,6	2 400
				2 550

Table 3 *(2 of 2)*

Highest voltage for equipment U_m kV (RMS value)	Standard rated switching impulse withstand voltage Longitudinal insulation [a] kV (peak value)	~~(peak value)~~ Phase-to-earth kV (peak value)	Phase-to-phase (ratio to the phase-to-earth peak value)	Standard rated lightning impulse withstand voltage [b] kV (peak value)
1 200	1 550	1 675	1,70	2 100
				2 250
	1 675	1 800	1,65	2 250
				2 400
	1 800	1 950	1,60	2 550
				2 700

~~NOTE The introduction of U_m above 800 kV is under consideration, and 1050 kV, 1100 kV and 1200 kV are listed as U_m in IEC 60038 Amendment 2, 1997.~~

[a] Value of the impulse voltage component of the relevant combined test while the peak value of the power-frequency component of opposite polarity is $U_m \times \sqrt{2}/\sqrt{3}$.

[b] These values apply as for phase-to-earth and phase-to-phase insulation as well; for longitudinal insulation they apply as the standard rated lightning impulse component of the combined standard rated withstand voltage, while the peak value of the power-frequency component of opposite polarity is $0{,}7 \times U_m \times \sqrt{2}/\sqrt{3}$.

[c] This U_m is a non-preferred value in IEC 60038.

[d] This value is only applicable to the phase-to-earth insulation of single phase equipment not exposed to air.

5.11 Background of the standard insulation level~~s~~

5.11.1 General

The standard insulation levels given in Table 2 and Table 3 reflect the experience of the world, taking into account modern protective devices and methods of overvoltage limitation. The selection of a particular standard insulation level should be based on the insulation co-ordination procedure in accordance with the insulation co-ordination procedure described in IEC 60071-2 ~~(third edition)~~ and should take into account the insulation characteristics of the particular equipment being considered.

In range I, the standard rated short-duration power-frequency or the standard rated lightning impulse withstand voltage should cover the required switching impulse withstand voltages phase-to-earth and phase-to-phase as well as the required longitudinal withstand voltage.

In range II, the standard rated switching impulse withstand voltage should cover the required short-duration power-frequency withstand voltage if no value is required by the relevant apparatus committee.

In order to meet these general requirements, the required withstand voltages should be converted to those voltage shapes for which standard rated withstand voltages are specified using test conversion factors. The test conversion factors are determined from existing results to provide a conservative value for the rated withstand voltages.

This document leaves it to the relevant ~~apparatus~~ technical committee to prescribe a long-duration power-frequency test intended to demonstrate the response of the equipment with respect to ageing of internal insulation or to external pollution ~~(see also IEC 60507)~~.

5.11.2 Standard rated switching impulse withstand voltage

In Table 3, standard rated switching impulse withstand voltages associated with each highest voltage for equipment have been chosen in consideration of the following:

a) for equipment protected against switching overvoltages by surge arresters:
   - the expected values of temporary overvoltages;
   - the characteristics of presently available surge arresters;
   - the co-ordination and safety factors between the protective level of the surge arrester and the switching impulse withstand voltage of the equipment;

b) for equipment not protected against switching overvoltages by surge arresters:
   - the acceptable risk of disruptive discharge considering the probable range of overvoltages occurring at the equipment location;
   - the degree of overvoltage control generally deemed economical, and obtainable by careful selection of the switching devices and in the system design.

5.11.3 Standard rated lightning impulse withstand voltage

In Table 3, standard rated lightning impulse withstand voltages associated with each standard rated switching impulse withstand voltage have been chosen in consideration of the following:

a) for equipment protected by close surge arresters, the low values of lightning impulse withstand level are applicable. They are chosen by taking into account the ratio of lightning impulse protective level to switching impulse protective level likely to be achieved with surge arresters, and by adding appropriate margins;

b) for equipment not protected by surge arresters (or not effectively protected), only the higher values of lightning impulse withstand voltages shall be used. These higher values are based on the typical ratio of the lightning and switching impulse withstand voltages of the external insulation of apparatus (e.g. circuit-breakers, disconnectors, instrument transformers, etc.). They are chosen in such a way that the insulation design will be determined mainly by the ability of the external insulation to withstand the switching impulse test voltages;

c) in a few extreme cases, provision should be made for a higher value of lightning impulse withstand voltage. This higher value shall be chosen from the series of standard values given in 5.6 and 5.7.

6 Requirements for standard withstand voltage tests

6.1 General requirements

Standard withstand voltage tests are performed to demonstrate, with suitable confidence, that the actual withstand voltage of the insulation is not lower than the corresponding specified withstand voltage. The voltages applied in withstand voltage tests are standard rated withstand voltages unless otherwise specified by the relevant apparatus committees.

In general, withstand voltage tests consist of dry tests performed in a standard situation (test arrangement specified by the relevant apparatus committees and the standard reference atmospheric conditions). However, for non-weather protected external insulation, the standard short-duration power-frequency and switching impulse withstand voltage tests consist of wet tests performed under the conditions specified in IEC 60060-1.

During wet tests, the rain shall be applied simultaneously on all air and surface insulation under voltage.

If the atmospheric conditions in the test laboratory differ from the standard reference atmospheric conditions, the test voltages shall be corrected according to IEC 60060-1.

All impulse withstand voltages shall be verified for both polarities, unless the relevant apparatus committees specify one polarity only.

When it has been demonstrated that one condition (dry or wet) or one polarity or a combination of these produces the lowest withstand voltage, then it is sufficient to verify the withstand voltage for this particular condition.

The insulation failures that occur during the test are the basis for the acceptance or rejection of the test specimen. The relevant apparatus committees or technical committee 42 shall define the occurrence of a failure and the method to detect it.

When the standard rated withstand voltage of phase-to-phase (or longitudinal) insulation is equal to that of phase-to-earth insulation, it is recommended that phase-to-phase (or longitudinal) insulation tests and phase-to-earth tests be performed together by connecting one of the two phase terminals to earth.

6.2 Standard short-duration power-frequency withstand voltage tests

A standard short-duration power-frequency withstand voltage test consists of one application of the relevant standard rated withstand voltage to the terminals of the insulation configuration.

Unless otherwise specified by the relevant apparatus committees, the insulation is considered to have passed the test if no disruptive discharge occurs. However, if one disruptive discharge occurs on the self-restoring insulation during a wet test, the test may be repeated once and the equipment is considered to have passed the test if no further disruptive discharge occurs.

When the test cannot be performed (such as for transformers with non-uniform insulation), the relevant apparatus committees may specify frequencies up to few hundred hertz and durations shorter than 1 min. Unless otherwise justified, the test voltages shall be the same.

6.3 Standard impulse withstand voltage tests

A standard impulse withstand voltage test consists of a specified number of applications of the relevant standard rated withstand voltage to the terminals of the insulation configuration. Different test procedures may be selected to demonstrate that the withstand voltages are met with a degree of confidence that experience has shown to be acceptable.

The test procedure shall be selected by the apparatus committees from the following test procedures which are standardized and fully described in IEC 60060-1:

- three-impulse withstand voltage test in which no disruptive discharge is tolerated;
- fifteen-impulse withstand voltage test in which up to two disruptive discharges on the self-restoring insulation are tolerated;
- three-impulse withstand voltage test in which one disruptive discharge on the self-restoring insulation is tolerated. If this occurs, nine additional impulses are applied during which no disruptive discharge is tolerated;
- the up-and-down withstand voltage test with seven impulses per level in which disruptive discharges on self-restoring insulation are tolerated;
- the up-and-down test with one impulse per level, which is recommended only if the conventional deviation, z, defined in IEC 60060-1 is known. The values suggested there, $z = 6$ % for switching and $z = 3$ % for lightning impulses, shall be used if, and only if, is known that $z \leq 6$ % and $z \leq 3$ %, respectively. Otherwise other methods shall be used.

In all the test procedures described above no disruptive discharge is tolerated on the non-self-restoring insulation. In the case of a fifteen-impulse withstand voltage test performed on equipment where both self-restoring and non-self-restoring insulations are involved, the IEC 60060-1 fifteen-impulse withstand voltage test procedure is adapted and used to verify that no disruptive discharge occurs in the non-self-restoring insulation. This two out of fifteen-impulse withstand voltage test adapted procedure is the following for each polarity: It could be taken as an indication that no failure has happened in the non-self-restoring insulation, when the last three impulses have not led to a disruptive discharge. In case of a disruptive discharge at one of the impulse numbers 13 to 15, up to three additional pulses can be applied (maximum 18). When no further disruptive discharge occurs, the test object has passed the test, if not otherwise specified by the relevant technical committee.

– the impulse number is at least 15;
– no disruptive discharges on non-self-restoring insulation shall occur; this is confirmed by five consecutive impulse withstands following the last disruptive discharge;
– the number of disruptive discharges shall not exceed two.

This two out of fifteen-impulse withstand voltage test adapted procedure may finally lead to a maximum possible number of 25 impulses for each polarity.

No statistical meaning can be given to the three-impulse withstand voltage test in which no disruptive discharge is tolerated (P_w is assumed to be 100 %). Its use is limited to cases in which the non-self-restoring insulation may be damaged by a large number of voltage applications.

When selecting a test for equipment in which non-self-restoring insulation is in parallel with self-restoring insulation, serious consideration should be given to the fact that in some test procedures voltages higher than the rated withstand voltage may be applied and many disruptive discharges may occur.

6.4 Alternative test situation

When it is too expensive or too difficult or even impossible, to perform the withstand voltage tests in standard test situations, the apparatus committees, or technical committee 42, shall specify the best solution to prove the relevant standard rated withstand voltages. One possibility is to perform the test in an alternative test situation.

An alternative test situation consists of one or more different test conditions (test arrangements, values or types of test voltages, etc.). It is necessary, therefore, to demonstrate that the physical conditions for the disruptive discharge development, relevant to the standard situation, are not changed.

NOTE A typical example is the use of a single voltage source for the tests of longitudinal insulation, while insulating the base, instead of a combined voltage test. In this case, the demonstration mentioned above concerning the disruptive discharge development is a very stringent condition for the acceptance of the alternative.

6.5 Phase-to-phase and longitudinal insulation standard withstand voltage tests for equipment in range I

6.5.1 Power-frequency tests

For some equipment with 123 kV ≤ U_m ≤ 245 kV, the phase-to-phase (or longitudinal) insulation may require a power-frequency withstand voltage higher than the phase-to-earth power-frequency withstand voltage as shown in Table 2. In such cases the test shall be preferably performed with two voltage sources. One terminal shall be energized with the phase-to-earth power-frequency withstand voltage and the other with the difference between the phase-to-phase (or longitudinal) and the phase-to-earth power-frequency withstand voltages. The earth terminal shall be earthed.

Alternatively, the test may be performed:

– with two equal power-frequency voltage sources in phase opposition, each energizing one phase terminal with half of the phase-to-phase (or longitudinal) insulation power-frequency withstand voltage. The earth terminal shall be earthed;

– with one power-frequency voltage source. The earth terminal may be allowed to assume a voltage to earth sufficient to avoid disruptive discharges to earth or to the earth terminal.

NOTE If, during the test, the terminal earthed in service is carried to a voltage which influences the electrical stresses on the phase terminal (as occurs in compressed gas longitudinal insulation having $U_m \geq 72{,}5$ kV), means ~~should~~ will then be adopted to maintain this voltage as close as possible to the difference between the test voltage of the phase-to-phase (or longitudinal) insulation and that of the phase-to-earth insulation.

6.5.2 Phase-to-phase (or longitudinal) insulation lightning impulse tests

The phase-to-phase (or longitudinal) insulation may require a lightning impulse withstand voltage higher than the standard phase-to-earth withstand voltage as shown in Table 2. In such cases, the relevant tests shall be performed immediately after the phase-to-earth insulation tests increasing the voltage without changing the test arrangement. In evaluating the test results, the impulses leading to disruptive discharge to earth are considered as non-events.

When the number of discharges to earth does not allow the test to be performed, a combined test shall be adopted with an impulse component equal to the phase-to-earth lightning impulse withstand voltage and a power-frequency component with the peak value of opposite polarity equal to the difference between the phase-to-phase (or longitudinal) and the phase-to-earth lightning impulse withstand voltages. Alternatively, for external insulation, the relevant apparatus committees may specify that the phase-to-earth insulation be increased.

6.6 Phase-to-phase and longitudinal insulation standard withstand voltage tests for equipment in range II

The combined voltage withstand voltage test shall be performed meeting the following requirements:

– the test configuration shall suitably duplicate the service configuration, especially with reference to the influence of the earth plane;

– each component of the test voltage shall have the value specified in 5.10;

– the earth terminal shall be connected to earth;

– in phase-to-phase tests the terminal of the third phase shall be either removed or earthed;

– in longitudinal insulation tests the terminals of the other two phases shall be either removed or earthed.

The test shall be repeated for all possible combinations of the phase terminals, unless proved unnecessary by considerations of electrical symmetry.

In the evaluation of the test results, any disruptive discharge is counted. More detailed recommendations for the tests are given by apparatus committees and IEC 60060-1.

For special applications, the relevant apparatus committees may extend to longitudinal insulation lightning impulse withstand voltage tests of range II the same test procedure applicable to equipment of range I.

Annex A
(normative)

Clearances in air to assure a specified impulse withstand voltage installation

A.1 General

In complete installations (e.g. substations) which cannot be tested as a whole, it is necessary to ensure that the dielectric strength is adequate.

The switching and lightning impulse withstand voltages in air at standard reference atmospheric conditions shall be equal to, or greater than, the standard rated switching and lightning impulse withstand voltages as specified in this document. Following this principle, minimum clearances have been determined for different electrode configurations. The minimum clearances specified are determined with a conservative approach, taking into account practical experience.

These clearances are intended solely to address insulation co-ordination requirements. Safety requirements may result in substantially larger clearances.

Tables A.1, A.2 and A.3 are suitable for general application, as they provide minimum clearances ensuring the specified insulation level.

These clearances may be lower if it has been proven by tests on actual or similar configurations that the standard impulse withstand voltages are met, taking into account all relevant environmental conditions which can create irregularities on the surface of electrodes, for example rain, pollution. These distances are therefore not applicable to equipment which has a mandatory impulse type test included in the specification, since a mandatory minimal clearance might hamper the design of equipment, increase its cost and impede progress.

The clearances may also be lower, where it has been confirmed by operating experience that the overvoltages are lower than those expected in the selection of the standard rated withstand voltages or that the gap configuration is more favourable than that assumed for the recommended clearances.

Table A.1 correlates the minimum air clearances with the standard rated lightning impulse withstand voltage for electrode configurations of the rod-structure type and, in addition for range II, of the conductor-structure type. They are applicable for phase-to-earth clearances as well as for clearances between phases (see note in Table A.1).

Table A.2 correlates the minimum air clearances for electrode configurations of the conductor-structure type and the rod-structure type with the standard rated switching impulse withstand voltage phase-to-earth. The conductor-structure configuration covers a large range for normally used configurations.

Table A.3 correlates the minimum air clearances for electrode configurations of the conductor-conductor type and the rod-conductor type with the standard rated switching impulse withstand voltage phase-to-phase. The unsymmetrical rod-conductor configuration is the worst electrode configuration normally encountered in service. The conductor-conductor configuration covers all symmetrical configurations with similar electrode shapes on the two phases. The air clearances applicable in service are determined according to the rules set out in Clauses A.2 and A.3.

A.2 ~~Range I~~ Lightning impulse

The air clearance phase-to-earth and phase-to-phase is determined from Table A.1 for the rated lightning impulse withstand voltage. The standard rated short-duration power-frequency withstand voltage can be disregarded when the ratio of the standard rated lightning impulse withstand voltage to the standard rated short-duration power-frequency withstand voltage is higher than 1,7.

Table A.1 – Correlation between standard rated lightning impulse withstand voltages and minimum air clearances

Standard rated lightning impulse withstand voltage kV	Minimum clearance mm	
	Rod-structure	Conductor-structure
20	60	–
40	60	–
60	90	–
75	120	–
95	160	–
125	220	–
145	270	–
170	320	–
200	380	–
250	480	–
325	630	–
380	750	–
450	900	–
550	1 100	–
650	1 300	–
750	1 500	–
850	1 700	1 600
950	1 900	1 700
1 050	2 100	1 900
1 175	2 350	2 200
1 300	2 600	2 400
1 425	2 850	2 600
1 550	3 100	2 900
1 675	3 350	3 100
1 800	3 600	3 300
1 950	3 900	3 600
2 100	4 200	3 900
2 250	4 500	4 150
2 400	4 800	4 450
2 550	5 100	4 700
2 700	5 400	5 000

NOTE The standard rated lightning impulse withstand voltages are applicable phase-to-phase and phase-to-earth.

For phase-to-earth, the minimum clearance for conductor-structure and rod-structure is applicable.

For phase-to-phase, the minimum clearance for rod-structure is applicable.

A.3 ~~Range II~~ Switching impulse

The phase-to-earth clearance is the higher value of the clearances determined for the rod-structure configuration from Table A.1 for the standard rated lightning impulse withstand voltages, and from Table A.2 for the standard rated switching impulse withstand voltages ~~respectively~~.

The phase-to-phase clearance is the higher value of the clearances determined for the rod-structure configuration from Table A.1 for the standard rated lightning impulse withstand voltages and from Table A.3 for the standard switching impulse withstand voltages ~~respectively~~.

The values are valid for altitudes which have been taken into account in the determination of the required withstand voltages.

The clearances necessary to withstand the standard rated lightning impulse withstand voltage for the longitudinal insulation in range II can be obtained by adding 0,7 times the highest voltage of a system (U_s) phase-to-earth peak to the value of the standard rated lightning impulse withstand voltage and by dividing the sum by 500 kV/m.

The clearances necessary for the longitudinal standard rated switching impulse withstand voltage in range II are smaller than the corresponding phase-to-phase value. Such clearances usually exist only in type tested apparatus and minimum values are therefore not given in this document.

Table A.2 – Correlation between standard rated switching impulse withstand voltages and minimum phase-to-earth air clearances

Standard rated switching impulse withstand voltage kV	Minimum phase-to-earth clearance mm	
	Rod-structure	Conductor-structure
750	1 900	1 600
850	2 400	1 800
950	2 900	2 200
1 050	3 400	2 600
1 175	4 100	3 100
1 300	4 800	3 600
1 425	5 600	4 200
1 550	6 400	4 900
1 675	7 400	5 600
1 800	8 300	6 300
1 950	9 500	7 200

Table A.3 – Correlation between standard rated switching impulse withstand voltages and minimum phase-to-phase air clearances

Standard rated switching impulse withstand voltage			Minimum phase-to-phase clearance mm	
Phase-to-earth kV	Ratio of phase-to-phase value to phase-to-earth value	Phase-to-phase kV	Conductor-conductor parallel	Rod-conductor
750	1,50	1 125	2 300	2 600
850	1,50	1 275	2 600	3 100
850	1,60	1 360	2 900	3 400
950	1,50	1 425	3 100	3 600
950	1,70	1 615	3 700	4 300
1 050	1,50	1 575	3 600	4 200
1 050	1,60	1 680	3 900	4 600
1 175	1,50	1 763	4 200	5 000
1 300	1,70	2 210	6 100	7 400
1 425	1,70	2 423	7 200	9 000
1 550	1,60	2 480	7 600	9 400
1 550	1,70	2 635	8 400	10 000
1 675	1,65	2 764	9 100	10 900
1 675	1,70	2 848	9 600	11 400
1 800	1,60	2 880	9 800	11 600
1 800	1,65	2 970	10 300	12 300
1 950	1,60	3 120	11 200	13 300

Annex B
(informative)

~~Values of~~ Rated insulation levels for ~~1kV < U_m ≤ 245 kV for~~ highest voltages ~~for~~ of equipment, U_m, not standardized by IEC ~~based on current practice in some countries~~

Table B.1 gives the values of rated insulation levels for 1 kV < U_m ≤ 245 kV for highest voltages of equipment U_m not standardized by IEC based on current practice in some countries.

~~Table B.1 – Values of rated insulation levels for 1kV < U_m ≤ 245 kV for highest voltages for equipment U_m not standardized by IEC based on current practice in some countries~~

Table B.1 – Rated insulation levels for highest voltages of equipment, U_m, not standardized by IEC

Highest voltage for equipment, U_m kV (RMS value)	Standard rated short-duration power-frequency withstand voltage kV (RMS value)	Standard rated lightning impulse withstand voltage kV (peak value)
40,5	80	185
	80	190
	85	200
82,5	140	325
	150	380

Bibliography

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

~~IEC 60050(604), *International Electrotechnical Vocabulary (IEV) – Chapter 604: Generation, transmission and distribution of electricity – Operation*~~

~~IEC 60721-2-2, *Classification of environmental conditions – Part 2: Environmental conditions appearing in nature – Precipitation and wind*~~

IEC 60050-614:2016, *International electrotechnical vocabulary – Part 614: Generation, transmission and distribution of electricity – Operation*

IEC 60507, *Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems*

IEC 60633, *High-voltage direct current (HVDC) transmission – Vocabulary*

IEC TS 60815-1, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC Guide 108, *Guidelines for ensuring the coherency of IEC publications – Application of horizontal standards*

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INTERNATIONAL STANDARD

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HORIZONTAL STANDARD

NORME HORIZONTALE

Insulation co-ordination –
Part 1: Definitions, principles and rules

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

INSULATION CO-ORDINATION –

Part 1: Definitions, principles and rules

FOREWORD

International Standard IEC 60071-1 has been prepared by IEC technical committee 99: Insulation co-ordination and system engineering of high voltage electrical power installations above 1,0 kV AC and 1,5 kV DC.

This ninth edition cancels and replaces the eighth edition published in 2006 and Amendment 1:2010. This edition constitutes a technical revision.

It has the status of a horizontal standard in accordance with IEC Guide 108.

The main changes from the previous edition are as follows:

a) all references are updated to current IEC standards, and the bibliography is deleted;
b) some definitions are clarified in order to avoid overlapping and ensure clear understanding;
c) letter symbols are changed and corrected in order to keep the consistency with relevant IEC standards;
d) some titles are changed to clarify understanding (see Clauses A.2, A.3 and Annex B).

The text of this International Standard is based on the following documents:

CDV	Report on voting
99/199/CDV	99/227/RVC

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

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

A list of all parts in the IEC 60071 series, published under the general title *Insulation co-ordination*, can be found on the IEC website.

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

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

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

INSULATION CO-ORDINATION –

Part 1: Definitions, principles and rules

1 Scope

This part of IEC 60071 applies to three-phase AC systems having a highest voltage for equipment above 1 kV. It specifies the procedure for the selection of the rated withstand voltages for the phase-to-earth, phase-to-phase and longitudinal insulation of the equipment and the installations of these systems. It also gives the lists of the standard withstand voltages from which the rated withstand voltages are selected.

This document describes that the selected withstand voltages are associated with the highest voltage for equipment. This association is for insulation co-ordination purposes only. The requirements for human safety are not covered by this document.

Although the principles of this document also apply to transmission line insulation, the values of their withstand voltages can be different from the standard rated withstand voltages.

The apparatus committees are responsible for specifying the rated withstand voltages and the test procedures suitable for the relevant equipment taking into consideration the recommendations of this document.

NOTE In IEC 60071-2, all rules for insulation co-ordination given in this document are justified in detail, in particular the association of the standard rated withstand voltages with the highest voltage for equipment. When more than one set of standard rated withstand voltages is associated with the same highest voltage for equipment, guidance is provided for the selection of the most suitable set.

This horizontal standard is primarily intended for use by technical committees in the preparation of standards in accordance with the principles laid down in IEC Guide 108.

One of the responsibilities of a technical committee is, wherever applicable, to make use of horizontal standards in the preparation of its publications. The contents of this horizontal standard will not apply unless specifically referred to or included in the relevant publications.

2 Normative references

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

IEC 60038, *IEC standard voltages*

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

IEC 60071-2, *Insulation co-ordination – Part 2: Application guidelines*

IEC 60099-4, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

3 Terms and definitions

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
insulation co-ordination
selection of the dielectric strength of equipment in relation to the operating voltages and overvoltages which can appear on the system for which the equipment is intended, and taking into account the service environment and the characteristics of the available preventing and protective devices

Note 1 to entry: By "dielectric strength" of the equipment, is meant here its rated insulation level (3.36) or its standard insulation level (3.37).

[SOURCE: IEC 60050-614:2016, 614-03-08, modified – Note 1 to entry has been added]

3.2
external insulation
distances in atmospheric air, and the surfaces in contact with atmospheric air of solid insulation of the equipment which are subject to dielectric stresses and to the effects of atmospheric and other environmental conditions from the site, such as pollution, humidity, vermin, etc.

Note 1 to entry: External insulation is either weather protected or non-weather protected, designed to operate outside or inside closed shelters, respectively.

[SOURCE: IEC 60050-614:2016, 614-03-02, modified – Note 1 to entry has been added]

3.3
internal insulation
internal distances of the solid, liquid, or gaseous insulation of equipment which are protected from the effects of atmospheric and other external conditions

[SOURCE: IEC 60050-614:2016, 614-03-03]

3.4
self-restoring insulation
insulation which completely recovers its insulating properties within a short time interval after a disruptive discharge

Note 1 to entry: Insulation of this kind is generally, but not necessarily, external insulation.

Note 2 to entry: This definition applies only when the discharge is caused by the application of a test voltage during a dielectric test. However, discharges occurring in service may cause a self-restoring insulation to lose partially or completely its original insulating properties.

[SOURCE: IEC 60050-614:2016, 614-03-04]

3.5
non-self-restoring insulation
insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge

Note 1 to entry: This definition applies only when the discharge is caused by the application of a test voltage during a dielectric test. However, discharges occurring in service may cause a self-restoring insulation to lose partially or completely its original insulating properties.

[SOURCE: IEC 60050-614:2016, 614-03-05]

3.6
insulation configuration terminal
any of the terminals between any two of which a voltage that stresses the insulation can be applied

Note 1 to entry: The types of terminal are:

a) phase terminal, between which and the neutral is applied in service the phase-to-neutral voltage of the system;

b) neutral terminal, representing, or connected to, the neutral point of the system (neutral terminal of transformers, etc.);

c) earth terminal, always solidly connected to earth in service (tank of transformers, base of disconnectors, structures of towers, ground plane, etc.).

3.7
insulation configuration
complete geometric configuration of the insulation in service, consisting of the insulation and of all terminals and including all elements (insulating and conducting) which influence its dielectric behaviour

Note 1 to entry: The insulation configurations defined in 3.7.1 to 3.7.4 are identified.

3.7.1
three-phase insulation configuration
insulation configuration having three phase terminals, one neutral terminal and one earth terminal

3.7.2
phase-to-earth insulation configuration
three-phase insulation configuration where two phase terminals are disregarded and, except in particular cases, the neutral terminal is earthed

3.7.3
phase-to-phase insulation configuration
three-phase insulation configuration where one phase terminal is disregarded. In particular cases, the neutral and the earth terminals are also disregarded

3.7.4
longitudinal insulation configuration
insulation configuration having two phase terminals and one earth terminal, the phase terminals belonging to the same phase of a three-phase system temporarily separated into two independently energized parts (e.g. open switching devices)

Note 1 to entry: The four terminals belonging to the other two phases are disregarded or earthed. In particular cases one of the two phase terminals considered is earthed.

3.8
nominal voltage of a system
U_n
suitable approximate value of voltage used to designate or identify a system

[SOURCE: IEC 60050-601:1985, 601-01-21, modified – A symbol has been added.]

3.9
highest voltage of a system
U_s
highest value of the phase-to-phase operating voltage (RMS value) which occurs under normal operating conditions at any time and at any point in the system

[SOURCE: IEC 60050-601:1985, 601-01-23, modified – Clear meaning on the voltage has been added.]

3.10
highest voltage for equipment
U_m
highest value of phase-to-phase voltage (RMS value) for which the equipment is designed in respect of its insulation as well as other characteristics which relate to this voltage in the relevant equipment standards

Note 1 to entry: Under normal service conditions specified by the relevant apparatus committee, this voltage can be applied continuously to the equipment.

[SOURCE: IEC 60050-614:2016, 614-03-01]

3.11
isolated neutral system
system where the neutral point is not intentionally connected to earth, except for high impedance connections for protection or measurement purposes

[SOURCE: IEC 60050-601:1985, 601-02-24]

3.12
solidly earthed neutral system
system whose neutral point(s) is(are) earthed directly

[SOURCE: IEC 60050-601:1985, 601-02-25]

3.13
impedance earthed (neutral) system
system whose neutral point(s) is(are) earthed through impedances to limit earth fault currents

[SOURCE: IEC 60050-601:1985, 601-02-26]

3.14
resonant earthed (neutral) system
system in which one or more neutral points are connected to earth through reactances which approximately compensate the capacitive component of a single-phase-to-earth fault current

Note 1 to entry: With resonant earthing of a system, the residual current in the fault is limited to such an extent that an arcing fault in air is usually self-extinguishing.

[SOURCE: IEC 60050-601:1985, 601-02-27]

3.15
earth fault factor
k
at a given location of a three-phase system, and for a given system configuration, the ratio of the highest RMS phase-to-earth power-frequency voltage on a healthy phase during a fault to earth affecting one or more phases at any point on the system to the RMS phase-to-earth power-frequency voltage which would be obtained at the given location in the absence of any such fault

[SOURCE: IEC 60050-614:2016, 614-03-06, modified – A symbol has been added and description on voltage has been modified.

3.16
continuous voltage
power-frequency voltage, considered having constant RMS value, continuously applied to any pair of terminals of an insulation configuration

3.17
overvoltage
voltage:

– between one phase conductor and earth or across a longitudinal insulation having a peak value exceeding the peak of the highest voltage of the system divided by $\sqrt{3}$;
– between phase conductors having a peak value exceeding the amplitude of the highest voltage of the system

Note 1 to entry: Unless otherwise clearly indicated, such as for surge arresters, overvoltage values expressed in p.u. refer to $U_s \times \sqrt{2}/\sqrt{3}$

[SOURCE: IEC 60050-614: 2016, 614-03-10]

3.17.1
temporary overvoltage
TOV
power-frequency overvoltage of relatively long duration

Note 1 to entry: The overvoltage may be undamped or weakly damped. In some cases, its frequency may be several times smaller or higher than power frequency.

[SOURCE: IEC 60050-614:2016, 614-03-13]

3.17.2
transient overvoltage
short-duration overvoltage of few milliseconds or less, oscillatory or non-oscillatory, usually highly damped

Note 1 to entry: Transient overvoltages may be immediately followed by temporary overvoltages. In such cases the two overvoltages are considered as separate events.

[SOURCE: IEC 60050-614:2016, 614-03-14]

3.17.2.1
slow-front overvoltage
SFO
transient overvoltage, usually unidirectional, with time to peak 20 µs < $T_p \leq$ 5 000 µs, and tail duration $T_2 \leq$ 20 ms

3.17.2.2
fast-front overvoltage
FFO
transient overvoltage, usually unidirectional, with time to peak 0,1 µs < $T_1 \leq$ 20 µs, and tail duration T_2 < 300 µs

3.17.2.3
very-fast-front overvoltage
VFFO
transient overvoltage, usually unidirectional with time to peak $T_f \leq$ 0,1 µs, and with or without superimposed oscillations at frequency 30 kHz < f < 100 MHz

3.17.3
combined overvoltage
overvoltage consisting of two voltage components simultaneously applied between each of the two phase terminals of a phase-to-phase (or longitudinal) insulation and earth

Note 1 to entry: It is classified by the component of higher peak value (temporary, slow-front, fast-front or very-fast-front).

3.18
standard voltage shapes for test
voltage and the overvoltage shapes for test that are determined in amplitude, wave front, wave tail and duration

Note 1 to entry: More details on the following three first standard voltage shapes are given in IEC 60060-1 and also in Table 1.

3.18.1
standard short-duration power-frequency voltage
sinusoidal voltage with frequency between 48 Hz and 62 Hz, and duration of 60 s

3.18.2
standard switching impulse
impulse voltage having a time to peak of 250 μs and a time to half-value of 2 500 μs

3.18.3
standard lightning impulse
impulse voltage having a front time of 1,2 μs and a time to half-value of 50 μs

3.18.4
standard combined switching impulse
for phase-to-phase insulation, combined impulse voltage having two components of equal peak value and opposite polarity

Note 1 to entry: The positive component is a standard switching impulse and the negative one is a switching impulse whose times to peak and half-value should not be less than those of the positive impulse. Both impulses should reach their peak value at the same instant. The peak value of the combined voltage is, therefore, the sum of the peak values of the components.

3.18.5
standard combined voltage
for longitudinal insulation, combined voltage having a standard impulse on one terminal and a power-frequency voltage on the other terminal

Note 1 to entry: The impulse component is applied at the peak of the power-frequency voltage of opposite polarity.

3.19
representative overvoltage
U_{rp}
overvoltage assumed to produce the same dielectric effect on the insulation as the overvoltage of a given class occurring in service due to various origins

Note 1 to entry: Representative overvoltages consist of voltages with the standard shape of the class, and may be defined by one value or a set of values or a frequency distribution of values that characterize the service conditions.

Note 2 to entry: This definition also applies to the continuous power-frequency voltage representing the effect of the service voltage on the insulation.

3.20
overvoltage limiting device
device which limits the peak values of the overvoltages or their durations or both

Note 1 to entry: They are classified as preventing devices (e.g. a preinsertion resistor) or as protective devices (e.g. a surge arrester).

3.21
lightning impulse protective level
U_{pl}
maximum permissible peak voltage value on the terminals of a protective device subjected to lightning impulses under specific conditions

[SOURCE: IEC 60050-614:2016, 614-03-56]

3.22
switching impulse protective level
U_{ps}
maximum permissible peak voltage value on the terminals of a protective device subjected to switching impulses under specific conditions

[SOURCE: IEC 60050-614:2016, IEC 614-03-57]

3.23
performance criterion
basis on which the insulation is selected so as to reduce to an economically and operationally acceptable level the probability that the resulting voltage stresses imposed on the equipment will cause damage to equipment insulation or affect continuity of service

Note 1 to entry: The performance criterion is usually expressed in terms of an acceptable failure rate (number of failures per year, years between failures, risk of failure, etc.) of the insulation configuration.

3.24
withstand voltage
value of the test voltage to be applied under specified conditions in a withstand voltage test, during which a specified number of disruptive discharges is tolerated

Note 1 to entry: The withstand voltage is designated as:

a) conventional assumed withstand voltage, when the number of disruptive discharges tolerated is zero. It is deemed to correspond to a withstand probability P_w = 100 %;

b) statistical withstand voltage, when the number of disruptive discharges tolerated is related to a specified withstand probability. In this document, the specified probability is P_w = 90 %.

Note 2 to entry: In this document, the conventional assumed withstand voltages are specified for non-self-restoring insulation. The statistical withstand voltages are specified for self-restoring insulation.

3.25
co-ordination withstand voltage
U_{cw}
for each class of voltage, the value of the withstand voltage of the insulation configuration in actual service conditions, that meets the performance criterion

3.26
co-ordination factor
K_c
factor by which the value of the representative overvoltage must be multiplied in order to obtain the value of the co-ordination withstand voltage

3.27
standard reference atmospheric conditions
atmospheric conditions to which the standardized withstand voltages apply

Note 1 to entry: See 5.9.2.

3.28
required withstand voltage
U_{rw}
test voltage that the insulation must withstand in a standard withstand voltage test to ensure that the insulation will meet the performance criterion when subjected to a given class of overvoltages in actual service conditions and for the whole service duration

Note 1 to entry: The required withstand voltage has the shape of the co-ordination withstand voltage, and is specified with reference to all the conditions of the standard withstand voltage test selected to verify it.

3.29
atmospheric correction factor
K_t
factor to be applied to the co-ordination withstand voltage to account for the difference in dielectric strength between the average atmospheric conditions in service and the standard reference atmospheric conditions

Note 1 to entry: It applies to external insulation only, for all altitudes.

Note 2 to entry: For the atmospheric correction factor, the atmospheric conditions taken into account are air pressure, temperature and humidity. For insulation co-ordination purposes, usually only the air pressure correction needs to be taken into account.

3.30
altitude correction factor
K_a
factor to be applied to the co-ordination withstand voltage to account for the difference in dielectric strength between the average pressure corresponding to the altitude in service and the standard reference pressure

Note 1 to entry: The altitude correction factor is part of the atmospheric correction factor.

3.31
safety factor
K_s
overall factor to be applied to the co-ordination withstand voltage, after the application of the atmospheric correction factor (if required), to obtain the required withstand voltage, accounting for all other differences in dielectric strength between the conditions in service during life time and those in the standard withstand voltage test

3.32
actual withstand voltage of an equipment or insulation configuration
U_{aw}
highest possible value of the test voltage that can be applied to an equipment or insulation configuration in a standard withstand voltage test

3.33
test conversion factor
K_{tc}
for a given equipment or insulation configuration, the factor to be applied to the required withstand voltage of a given overvoltage class, in the case where the standard withstand shape of the selected withstand voltage test is that of a different overvoltage class

Note 1 to entry: For a given equipment or insulation configuration: the test conversion factor of the standard voltage shape (a) to the standard voltage shape (b) must be higher than or equal to the ratio between the actual withstand voltage for the standard voltage shape (a) and the actual withstand voltage of the standard voltage shape (b).

3.34
rated withstand voltage
value of the test voltage, applied in a standard withstand voltage test that proves that the insulation complies with one or more required withstand voltages

Note 1 to entry: It is a rated value of the insulation of an equipment.

3.35
standard rated withstand voltage
U_w
standard value of the rated withstand voltage as specified in this document

Note 1 to entry: See 5.6 and 5.7.

3.36
rated insulation level
set of rated withstand voltages which characterize the dielectric strength of the insulation

3.37
standard insulation level
set of standard rated withstand voltages which are associated to U_m as specified in this document

Note 1 to entry: See Table 2 and Table 3.

3.38
standard withstand voltage test
dielectric test performed in specified conditions to prove that the insulation complies with a standard rated withstand voltage

Note 1 to entry: This document covers:

- short-duration power-frequency voltage tests;
- switching impulse tests;
- lightning impulse tests;
- combined switching impulse tests;
- combined voltage tests.

Note 2 to entry: More detailed information on the standard withstand voltage tests is given in IEC 60060-1 (see also Table 1 for the test voltage shapes).

Note 3 to entry: The very-fast-front impulse standard withstand voltage tests should be specified by the relevant apparatus committees, if required.

4 Abbreviated terms and symbols

4.1 General

The lists provided below cover only the most frequently used symbols and abbreviations which are useful for insulation co-ordination.

4.2 Subscripts

max maximum

4.3 Letter symbols

f	frequency
k	earth fault factor
K_t	atmospheric correction factor
K_a	altitude correction factor
K_c	co-ordination factor
K_s	safety factor

K_{tc}	test conversion factor
P_w	withstand probability
T_1	front time
T_2	time to half-value of a decreasing voltage
T_p	time to peak value
T_t	total overvoltage duration
U_{aw}	actual withstand voltage of an equipment or insulation configuration
U_{cw}	co-ordination withstand voltage
U_m	highest voltage for equipment
U_n	nominal voltage of a system
U_{pl}	lightning impulse protective level of a surge arrester
U_{ps}	switching impulse protective level of a surge arrester
U_{rp}	representative overvoltage
U_{rw}	required withstand voltage
U_s	highest voltage of a system
U_w	standard rated withstand voltage

4.4 Abbreviations

FFO	fast-front overvoltage
ACWV	standard rated short-duration power frequency withstand voltage of an equipment or insulation configuration
LIPL	lightning impulse protective level of a surge arrester
SIPL	switching impulse protective level of a surge arrester
LIWV	standard rated lightning impulse withstand voltage of an equipment or insulation configuration
SFO	slow-front overvoltage
SIWV	standard rated switching impulse withstand voltage of an equipment or insulation configuration
TOV	temporary overvoltage
VFFO	very-fast-front overvoltage

5 Procedure for insulation co-ordination

5.1 General outline of the procedure

The procedure for insulation co-ordination consists of the selection of the highest voltage for the equipment together with a corresponding set of standard rated withstand voltages which characterize the insulation of the equipment needed for the application. This procedure is outlined in Figure 1 and its steps are described in 5.1 to 5.5. The optimization of the selected set of U_w may require reconsideration of some input data and repetition of part of the procedure.

The rated withstand voltages shall be selected from the lists of standard rated withstand voltages given in 5.6 and 5.7. The set of selected standard voltages constitutes a rated insulation level. If the standard rated withstand voltages are also associated with the same U_m according to 5.10, this set constitutes a standard insulation level.

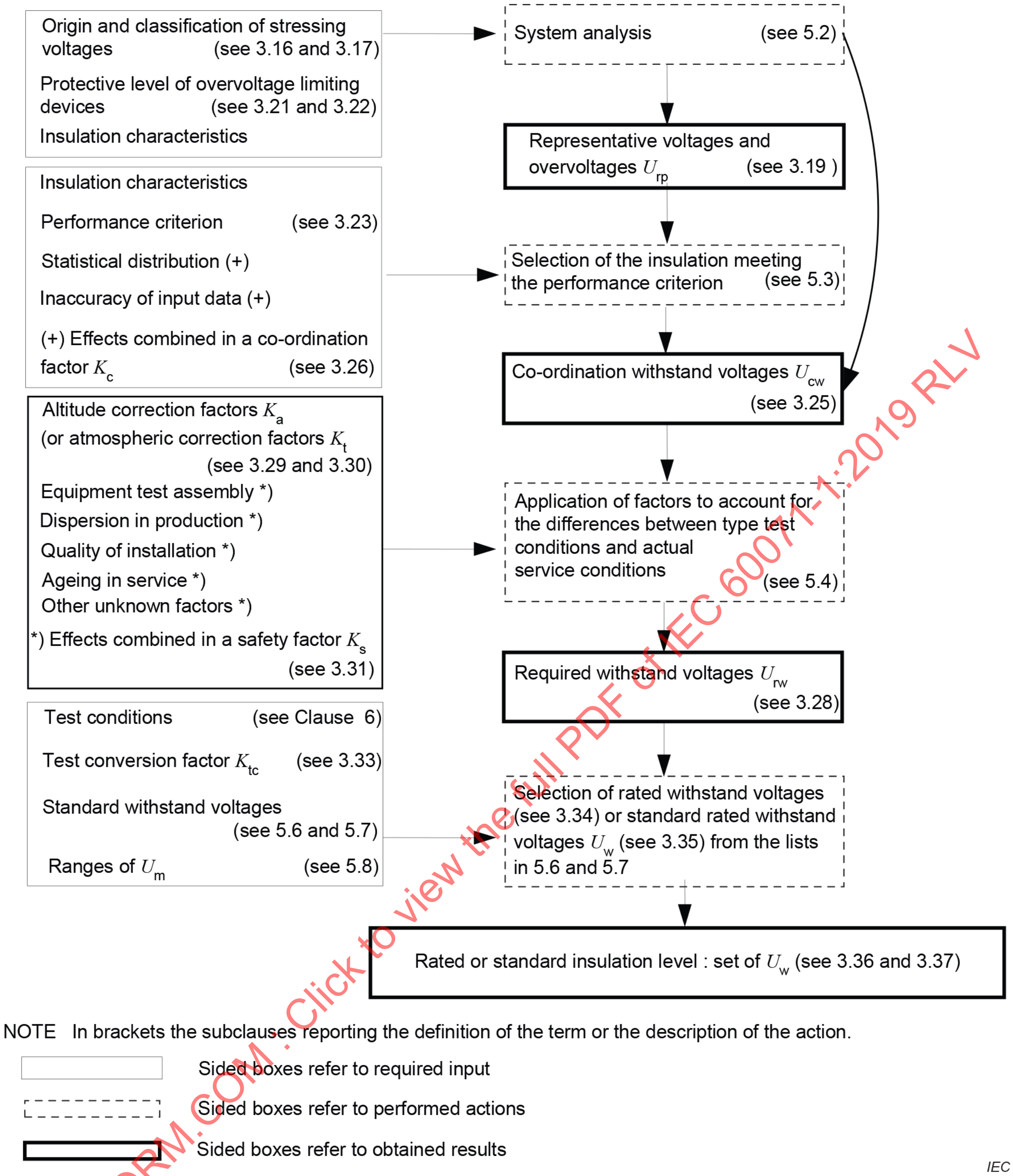


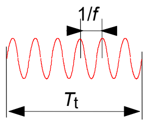
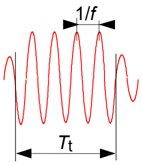
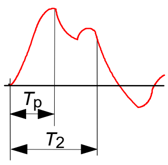
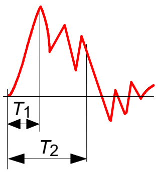
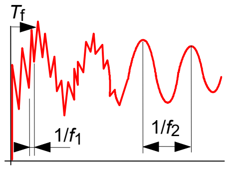
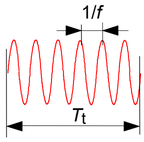
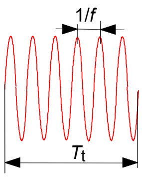
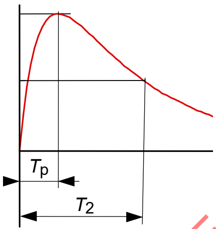
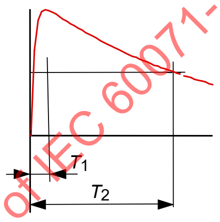
Figure 1 – Flow chart for the determination of rated or standard insulation level

5.2 Determination of the representative voltages and overvoltages (U_{rp})

The voltages and the overvoltages that stress the insulation shall be determined in amplitude, shape and duration by means of a system analysis which includes the selection and location of the overvoltage preventing and limiting devices.

For each class of voltages and overvoltages, this analysis shall then determine a representative voltage and overvoltage, taking into account the characteristics of the insulation with respect to the different behaviour at the voltage or overvoltage shapes in the system and at the standard voltage shapes applied in a standard withstand voltage test as outlined in Table 1.

Table 1 – Classes and shapes of overvoltages, standard voltage shapes and standard withstand voltage tests

Class	Low frequency		Transient		
	Continuous	Temporary	Slow-front	Fast-front	Very-fast-front
Voltage or over-voltage shapes					
Range of voltage or over-voltage shapes	f = 50 Hz or 60 Hz $T_t \geq$ 3 600s	10 Hz < f < 500 Hz 0,02 s $\leq T_t \leq$ 3 600 s	20 µs < $T_p \leq$ 5 000 µs $T_2 \leq$ 20 ms	0,1 µs < $T_1 \leq$ 20 µs $T_2 \leq$ 300 µs	$T_f \leq$ 100 ns 0,3 MHz < f_1 < 100 MHz 30 kHz < f_2 < 300 kHz
Standard voltage shapes	 f = 50 Hz or 60 Hz T_t [a]	 48 Hz $\leq f \leq$ 62 Hz T_t = 60 s	 T_p = 250 µs T_2 = 2 500 µs	 T_1 = 1,2 µs T_2 = 50 µs	[a]
Standard withstand voltage test	[a]	Short-duration power frequency test	Switching impulse test	Lightning impulse test	[a]

[a] To be specified by the relevant apparatus committees.

The representative voltages and overvoltages may be characterized either by:

– an assumed maximum, or
– a set of peak values, or
– a complete statistical distribution of peak values.

NOTE In the last case additional characteristics of the overvoltage shapes could have to be considered.

When the adoption of an assumed maximum is considered adequate, the representative overvoltage of the various classes shall be:

– For the continuous power-frequency voltage: a power-frequency voltage with RMS value equal to the highest voltage of the system, and with duration corresponding to the lifetime of the equipment;
– For the temporary overvoltage: a standard power-frequency short-duration voltage with an RMS value equal to the assumed maximum of the temporary overvoltages divided by $\sqrt{2}$;
– For the slow-front overvoltage: a standard switching impulse with peak value equal to the peak value of the assumed maximum of the slow-front overvoltages;
– For the fast-front overvoltage: a standard lightning impulse with peak value equal to the peak value of the assumed maximum stress of the fast-front overvoltages phase to earth;

NOTE For gas insulated switchgear (GIS) or gas insulated line (GIL) with three-phase enclosure and insulation levels chosen among the lowest ones for a given U_m, the phase-to-phase overvoltages could need consideration.

– For the very-fast-front overvoltage: the characteristics for this class of overvoltage are specified by the relevant apparatus committees;
– For the slow-front phase-to-phase overvoltage: a standard combined switching impulse with peak value equal to the peak value of the assumed maximum of the slow-front phase-to-phase overvoltages;
– For the slow-front (or fast-front) longitudinal overvoltage: a combined voltage consisting of a standard switching (or lightning) impulse and of a power-frequency voltage, each with peak value equal to the two relevant assumed maximum peak values, and with the instant of impulse peak coinciding with the peak of the power-frequency of opposite polarity.

5.3 Determination of the co-ordination withstand voltages (U_{cw})

The determination of the co-ordination withstand voltages consists of determining the lowest values of the withstand voltages of the insulation meeting the performance criterion when subjected to the representative overvoltages under service conditions.

The co-ordination withstand voltages of the insulation have the shape of the representative overvoltages of the relevant class and their values are obtained by multiplying the values of the representative overvoltages by a co-ordination factor. The value of the co-ordination factor depends on the accuracy of the evaluation of the representative overvoltages and on an empirical, or on a statistical appraisal of the distribution of the overvoltages and of the insulation characteristics.

The co-ordination withstand voltages can be determined as either conventional assumed withstand voltages or statistical withstand voltages. This affects the determination procedure and the values of the co-ordination factor.

Simulations of overvoltage events combined with the simultaneous evaluation of the risk of failure, using the relevant insulation characteristics, permit the direct determination of the statistical co-ordination withstand voltages without the intermediate step of determining the representative overvoltages (see Figure 1).

5.4 Determination of the required withstand voltage (U_{rw})

The determination of the required withstand voltages of the insulation consists of converting the co-ordination withstand voltages to appropriate standard test conditions. This is accomplished by multiplying the co-ordination withstand voltages by factors which compensate the differences between the actual in-service conditions of the insulation and those in the standard withstand voltage tests.

The factors to be applied shall compensate atmospheric conditions by altitude correction factor K_a and the effects listed below by a safety factor K_s.

Effects combined in a safety factor K_s:

– the differences in the equipment assembly;
– the dispersion in the product quality;
– the quality of installation;
– the ageing of the insulation during the expected lifetime;
– other unknown influences.

If, however, these effects cannot be evaluated individually, an overall safety factor, derived from experience, shall be adopted (see IEC 60071-2).

For external insulation, the altitude correction factor K_a which considers only the average air pressure corresponding to the altitude has to be applied. The altitude correction factor K_a has to be applied whatever is the altitude.

If it is necessary to consider temperature, humidity and pressure, the atmospheric correction factor K_t shall be applied instead of K_a.

K_t shall be used in an inverse way.

5.5 Selection of the rated insulation level

The selection of the rated insulation level consists of the selection of the most economical set of standard rated withstand voltages (U_w) of the insulation sufficient to prove that all the required withstand voltages are met.

The highest voltage for equipment is then chosen as the next standard value of U_m equal to or higher than the highest voltage of the system (U_s) where the equipment will be installed.

For equipment to be installed under normal environmental conditions relevant to insulation, U_m shall be at least equal to U_s.

For equipment to be installed outside of the normal environmental conditions relevant to insulation, U_m may be selected higher than the next standard value of U_m equal to or higher than U_s according to the special needs involved.

NOTE 1 As an example, the selection of a U_m value higher than the next standard value of U_m equal to or higher than U_s can arise when the equipment has to be installed at an altitude higher than 1 000 m in order to compensate the decrease of withstand voltage of the external insulation.

Standardization of tests, as well as the selection of the relevant test voltages, to prove the compliance with U_m, are performed by the relevant apparatus committees (e.g. pollution tests, partial discharge voltage tests).

The withstand voltages to prove that the required temporary, slow-front and fast-front withstand voltages are met, for phase-to-earth, phase-to-phase and longitudinal insulation, may be selected with the same shape as the required withstand voltage, or with a different shape, exploiting, for this last selection, the intrinsic characteristics of the insulation.

The value of the rated withstand voltage is then selected in the list of the standard rated withstand voltages reported in 5.6 and 5.7, as the next value equal to or higher than:

– the required withstand voltage in the case of the same shape,
– the required withstand voltage multiplied by the relevant test conversion factor in the case of a different shape.

NOTE 2 This may allow the adoption of a single standard rated withstand voltage to prove compliance with more than one required withstand voltage, thus giving the possibility of reducing the number of rated withstand voltages that would define a rated insulation level (see, for example, 5.10).

NOTE 3 Generally applicable minimum air clearances to assure a specified impulse withstand voltage are determined with a conservative approach (see Annex A).

For equipment to be used in normal environmental conditions, the rated insulation level should then preferably be selected from Table 2 and Table 3 corresponding to the applicable highest voltage for equipment such that these rated withstand voltages are met.

The selection of the standard rated withstand voltage to prove the compliance with the very-fast-front required withstand voltage shall be considered by the relevant apparatus committees.

For surge arresters the required withstand voltages of the insulating housing are based on the protective levels U_{pl} and U_{ps} with suitable safety factors applied as per the apparatus standard IEC 60099-4. In general, therefore, the withstand voltages shall not be selected from the lists of 5.6 and 5.7.

5.6 List of standard rated short-duration power frequency withstand voltages

The following RMS values, expressed in kV, are standardized as withstand voltages: 10, 20, 28, 38, 50, 70, 95, 115, 140, 185, 230, 275, 325, 360, 395, 460, 510, 570, 630, 680, 710, 790, 830, 880, 960, 975, 1 050, 1 100, 1 200.

5.7 List of standard rated impulse withstand voltages

The following peak values, expressed in kV, are standardized as withstand voltages: 20, 40, 60, 75, 95, 125, 145, 170, 200, 250, 325, 380, 450, 550, 650, 750, 850, 950, 1 050, 1 175, 1 300, 1 425, 1 550, 1 675, 1 800, 1 950, 2 100, 2 250, 2 400, 2 550, 2 700, 2 900, 3 100.

5.8 Ranges for highest voltage for equipment

The standard highest voltages for equipment are divided in two ranges:

– **range I**: Above 1 kV to 245 kV included (Table 2). This range covers both transmission and distribution systems. The different operational aspects, therefore, shall be taken into account in the selection of the rated insulation level of the equipment.
– **range II**: Above 245 kV (Table 3). This range covers mainly transmission systems.

5.9 Environmental conditions

5.9.1 Normal environmental conditions

The normal environmental conditions that are of concern for insulation coordination and for which withstand voltages can be usually selected from Table 2 or Table 3 are the following:

a) The ambient air temperature does not exceed 40 °C and its average value, measured over a period of 24 h, does not exceed 35 °C. The minimum ambient air temperature is −10 °C for class "−10 outdoor", −25 °C for class "−25 outdoor" and −40 °C for class "−40 outdoor".
b) The altitude does not exceed 1 000 m above sea level.
c) The ambient air is not significantly polluted by dust, smoke, corrosive gases, vapours or salt. Pollution does not exceed pollution class c – Medium, according to IEC TS 60815-1.
d) The presence of condensation or precipitation is usual. Precipitation in form of dew, condensation, fog, rain, snow, ice or hoar frost is considered.

NOTE Precipitation characteristics for insulation are described in IEC 60060-1.

5.9.2 Standard reference atmospheric conditions

The standard reference atmospheric conditions for which the standardized withstand voltages apply are:

a) temperature: t_0 = 20 °C
b) pressure: p_0 = 1 013 hPa (1 013 mbar)
c) absolute humidity: h_0 = 11 g/m^3.

5.10 Selection of the standard insulation level

The association of standard rated withstand voltages with the highest voltage for equipment has been standardized to benefit from the experience gained from the operation of systems designed according to IEC standards and to enhance standardization.

The standard rated withstand voltages are associated with the highest voltage for equipment according to Table 2 for range I and Table 3 for range II. These standard rated withstand voltages are valid for the normal environmental conditions and are adjusted to the standard reference atmospheric conditions.

NOTE For withstand voltages used in some countries and not defined as standard insulation levels, see Annex B.

The associations obtained by connecting standard rated withstand voltages of all columns without crossing horizontal marked lines are defined as standard insulation levels.

Furthermore, the following associations are standardized for phase-to-phase and longitudinal insulation:

– For phase-to-phase insulation, range I, the standard rated short-duration power-frequency and lightning impulse phase-to-phase withstand voltages are equal to the relevant phase-to-earth withstand voltages (Table 2). The values in brackets, however, may be insufficient to prove that the required withstand voltages are met and additional phase-to-phase withstand voltage tests may be needed.
– For phase-to-phase insulation, range II, the standard lightning impulse withstand voltage phase-to-phase is equal to the lightning impulse phase-to-earth.
– For longitudinal insulation, range I, the standard rated short-duration power-frequency and lightning impulse withstand voltages are equal to the relevant phase-to-earth withstand voltages (Table 2).
– For longitudinal insulation, range II, the standard switching impulse component of the combined withstand voltage is given in Table 3, while the peak value of the power-frequency component of opposite polarity is $U_m \times \sqrt{2}/\sqrt{3}$.
– For longitudinal insulation range II, the standard lightning impulse component of the combined withstand voltage is equal to the relevant phase-to-earth withstand voltage (Table 3), while the peak value of the power-frequency component of opposite polarity is $0{,}7 \times U_m \times \sqrt{2}/\sqrt{3}$.

More than one preferred association is foreseen for most of the highest voltages for equipment to allow for the application of different performance criteria or overvoltage patterns.

For the preferred associations, only two standard rated withstand voltages are sufficient to define the rated insulation level of the equipment:

– For equipment in range I:
  a) the standard rated lightning impulse withstand voltage and,
  b) the standard rated short-duration power-frequency withstand voltage.
– For equipment in range II:
  a) the standard rated switching impulse withstand voltage, and
  b) the standard rated lightning impulse withstand voltage.

If technically and economically justified, other associations may be adopted. The recommendations of 5.1 to 5.8 shall be followed in every case. The resulting set of standard rated withstand voltages shall be termed, therefore, rated insulation level. Particular examples are:

– For external insulation, for the higher values of U_m in range I, it can be more economical to specify a standard rated switching impulse withstand voltage instead of a standard rated short-duration power-frequency withstand voltage.
– For internal insulation in range II, high temporary overvoltages can require the specification of a standard rated short-duration power-frequency withstand voltage.

Table 2 – Standard insulation levels for range I (1 kV < U_m ≤ 245 kV)

Highest voltage for equipment, U_m kV (RMS value)	Standard rated short-duration power-frequency withstand voltage kV (RMS value)	Standard rated lightning impulse withstand voltage kV (peak value)
3,6	10	20 40
7,2	20	40 60
12	28	60 75 95
17,5 [a]	38	75 95
24	50	95 125 145
36	70	145 170
52 [a]	95	250
72,5	140	325
100 [b]	(150)	(380)
	185	450
123	(185)	(450)
	230	550
145	(185)	(450)
	230	550
	275	650
170 [a]	(230)	(550)
	275	650
	325	750
245	(275)	(650)
	(325)	(750)
	360	850
	395	950
	460	1 050

NOTE If values in brackets are considered insufficient to prove that the required phase-to-phase withstand voltages are met, additional phase-to-phase withstand voltage tests are needed.

[a] These U_m are non-preferred values in IEC 60038 and therefore seldom used. These values should not be used for new systems to be constructed in future.

[b] This U_m value is not mentioned in IEC 60038 but it has been introduced in range I in some apparatus standards.

Table 3 – Standard insulation levels for range II (U_m > 245 kV) *(1 of 2)*

Highest voltage for equipment, U_m kV (RMS value)	Standard rated switching impulse withstand voltage: Longitudinal insulation [a] kV (peak value)	Standard rated switching impulse withstand voltage: Phase-to-earth kV (peak value)	Standard rated switching impulse withstand voltage: Phase-to-phase (ratio to the phase-to-earth peak value)	Standard rated lightning impulse withstand voltage [b] kV (peak value)
300 [c]	750	750	1,50	850
				950
	750	850	1,50	950
				1 050
362	850	850	1,50	950
				1 050
	850	950	1,50	1 050
				1 175
420	850	850	1,60	1 050
				1 175
	950	950	1,50	1 175
				1 300
	950	1 050	1,50	1 300
				1 425
550	950	950	1,70	1 175
				1 300
	950	1 050	1,60	1 300
				1 425
	950 1 050	1 175	1,50	1 425
				1 550
800	1 175	1 300	1,70	1 675
				1 800
	1 175	1 425	1,70	1 800
				1 950
	1 175 1 300	1 550	1,60	1 950
				2 100
1 100	–	1 425 [d]	–	1 950
				2 100
	1 425	1 550	1,70	2 100
				2 250
	1 550	1 675	1,65	2 250
				2 400
	1 675	1 800	1,6	2 400
				2 550

Table 3 *(2 of 2)*

Highest voltage for equipment U_m kV (RMS value)	Standard rated switching impulse withstand voltage			Standard rated lightning impulse withstand voltage [b] kV (peak value)
	Longitudinal insulation [a] kV (peak value)	(peak value) Phase-to-earth kV (peak value)	Phase-to-phase (ratio to the phase-to-earth peak value)	
1 200	1 550	1 675	1,70	2 100
				2 250
	1 675	1 800	1,65	2 250
				2 400
	1 800	1 950	1,60	2 550
				2 700

[a] Value of the impulse voltage component of the relevant combined test while the peak value of the power-frequency component of opposite polarity is $U_m \times \sqrt{2}/\sqrt{3}$.

[b] These values apply as for phase-to-earth and phase-to-phase insulation as well; for longitudinal insulation they apply as the standard rated lightning impulse component of the combined standard rated withstand voltage, while the peak value of the power-frequency component of opposite polarity is $0{,}7 \times U_m \times \sqrt{2}/\sqrt{3}$.

[c] This U_m is a non-preferred value in IEC 60038.

[d] This value is only applicable to the phase-to-earth insulation of single phase equipment not exposed to air.

5.11 Background of the standard insulation level

5.11.1 General

The standard insulation levels given in Table 2 and Table 3 reflect the experience of the world, taking into account modern protective devices and methods of overvoltage limitation. The selection of a particular standard insulation level should be based on the insulation co-ordination procedure in accordance with the insulation co-ordination procedure described in IEC 60071-2 and should take into account the insulation characteristics of the particular equipment being considered.

In range I, the standard rated short-duration power-frequency or the standard rated lightning impulse withstand voltage should cover the required switching impulse withstand voltages phase-to-earth and phase-to-phase as well as the required longitudinal withstand voltage.

In range II, the standard rated switching impulse withstand voltage should cover the required short-duration power-frequency withstand voltage if no value is required by the relevant apparatus committee.

In order to meet these general requirements, the required withstand voltages should be converted to those voltage shapes for which standard rated withstand voltages are specified using test conversion factors. The test conversion factors are determined from existing results to provide a conservative value for the rated withstand voltages.

This document leaves it to the relevant technical committee to prescribe a long-duration power-frequency test intended to demonstrate the response of the equipment with respect to ageing of internal insulation or to external pollution.

5.11.2 Standard rated switching impulse withstand voltage

In Table 3, standard rated switching impulse withstand voltages associated with each highest voltage for equipment have been chosen in consideration of the following:

a) for equipment protected against switching overvoltages by surge arresters:
   - the expected values of temporary overvoltages;
   - the characteristics of presently available surge arresters;
   - the co-ordination and safety factors between the protective level of the surge arrester and the switching impulse withstand voltage of the equipment;

b) for equipment not protected against switching overvoltages by surge arresters:
   - the acceptable risk of disruptive discharge considering the probable range of overvoltages occurring at the equipment location;
   - the degree of overvoltage control generally deemed economical, and obtainable by careful selection of the switching devices and in the system design.

5.11.3 Standard rated lightning impulse withstand voltage

In Table 3, standard rated lightning impulse withstand voltages associated with each standard rated switching impulse withstand voltage have been chosen in consideration of the following:

a) for equipment protected by close surge arresters, the low values of lightning impulse withstand level are applicable. They are chosen by taking into account the ratio of lightning impulse protective level to switching impulse protective level likely to be achieved with surge arresters, and by adding appropriate margins;

b) for equipment not protected by surge arresters (or not effectively protected), only the higher values of lightning impulse withstand voltages shall be used. These higher values are based on the typical ratio of the lightning and switching impulse withstand voltages of the external insulation of apparatus (e.g. circuit-breakers, disconnectors, instrument transformers, etc.). They are chosen in such a way that the insulation design will be determined mainly by the ability of the external insulation to withstand the switching impulse test voltages;

c) in a few extreme cases, provision should be made for a higher value of lightning impulse withstand voltage. This higher value shall be chosen from the series of standard values given in 5.6 and 5.7.

6 Requirements for standard withstand voltage tests

6.1 General requirements

Standard withstand voltage tests are performed to demonstrate, with suitable confidence, that the actual withstand voltage of the insulation is not lower than the corresponding specified withstand voltage. The voltages applied in withstand voltage tests are standard rated withstand voltages unless otherwise specified by the relevant apparatus committees.

In general, withstand voltage tests consist of dry tests performed in a standard situation (test arrangement specified by the relevant apparatus committees and the standard reference atmospheric conditions). However, for non-weather protected external insulation, the standard short-duration power-frequency and switching impulse withstand voltage tests consist of wet tests performed under the conditions specified in IEC 60060-1.

During wet tests, the rain shall be applied simultaneously on all air and surface insulation under voltage.

If the atmospheric conditions in the test laboratory differ from the standard reference atmospheric conditions, the test voltages shall be corrected according to IEC 60060-1.

All impulse withstand voltages shall be verified for both polarities, unless the relevant apparatus committees specify one polarity only.

When it has been demonstrated that one condition (dry or wet) or one polarity or a combination of these produces the lowest withstand voltage, then it is sufficient to verify the withstand voltage for this particular condition.

The insulation failures that occur during the test are the basis for the acceptance or rejection of the test specimen. The relevant apparatus committees or technical committee 42 shall define the occurrence of a failure and the method to detect it.

When the standard rated withstand voltage of phase-to-phase (or longitudinal) insulation is equal to that of phase-to-earth insulation, it is recommended that phase-to-phase (or longitudinal) insulation tests and phase-to-earth tests be performed together by connecting one of the two phase terminals to earth.

6.2 Standard short-duration power-frequency withstand voltage tests

A standard short-duration power-frequency withstand voltage test consists of one application of the relevant standard rated withstand voltage to the terminals of the insulation configuration.

Unless otherwise specified by the relevant apparatus committees, the insulation is considered to have passed the test if no disruptive discharge occurs. However, if one disruptive discharge occurs on the self-restoring insulation during a wet test, the test may be repeated once and the equipment is considered to have passed the test if no further disruptive discharge occurs.

When the test cannot be performed (such as for transformers with non-uniform insulation), the relevant apparatus committees may specify frequencies up to few hundred hertz and durations shorter than 1 min. Unless otherwise justified, the test voltages shall be the same.

6.3 Standard impulse withstand voltage tests

A standard impulse withstand voltage test consists of a specified number of applications of the relevant standard rated withstand voltage to the terminals of the insulation configuration. Different test procedures may be selected to demonstrate that the withstand voltages are met with a degree of confidence that experience has shown to be acceptable.

The test procedure shall be selected by the apparatus committees from the following test procedures which are standardized and fully described in IEC 60060-1:

– three-impulse withstand voltage test in which no disruptive discharge is tolerated;

– fifteen-impulse withstand voltage test in which up to two disruptive discharges on the self-restoring insulation are tolerated;

– three-impulse withstand voltage test in which one disruptive discharge on the self-restoring insulation is tolerated. If this occurs, nine additional impulses are applied during which no disruptive discharge is tolerated;

– the up-and-down withstand voltage test with seven impulses per level in which disruptive discharges on self-restoring insulation are tolerated;

– the up-and-down test with one impulse per level, which is recommended only if the conventional deviation, z, defined in IEC 60060-1 is known. The values suggested there, z = 6 % for switching and z = 3 % for lightning impulses, shall be used if, and only if, is known that $z \leq 6$ % and $z \leq 3$ %, respectively. Otherwise other methods shall be used.

In all the test procedures described above no disruptive discharge is tolerated on the non-self-restoring insulation. In the case of a fifteen-impulse withstand voltage test performed on equipment where both self-restoring and non-self-restoring insulations are involved, the IEC 60060-1 fifteen-impulse withstand voltage test procedure is adapted and used to verify that no disruptive discharge occurs in the non-self-restoring insulation. This two out of fifteen-impulse withstand voltage test adapted procedure is the following for each polarity: It could be taken as an indication that no failure has happened in the non-self-restoring insulation, when the last three impulses have not led to a disruptive discharge. In case of a disruptive discharge at one of the impulse numbers 13 to 15, up to three additional pulses can be applied (maximum 18). When no further disruptive discharge occurs, the test object has passed the test, if not otherwise specified by the relevant technical committee.

No statistical meaning can be given to the three-impulse withstand voltage test in which no disruptive discharge is tolerated (P_w is assumed to be 100 %). Its use is limited to cases in which the non-self-restoring insulation may be damaged by a large number of voltage applications.

When selecting a test for equipment in which non-self-restoring insulation is in parallel with self-restoring insulation, serious consideration should be given to the fact that in some test procedures voltages higher than the rated withstand voltage may be applied and many disruptive discharges may occur.

6.4 Alternative test situation

When it is too expensive or too difficult or even impossible, to perform the withstand voltage tests in standard test situations, the apparatus committees, or technical committee 42, shall specify the best solution to prove the relevant standard rated withstand voltages. One possibility is to perform the test in an alternative test situation.

An alternative test situation consists of one or more different test conditions (test arrangements, values or types of test voltages, etc.). It is necessary, therefore, to demonstrate that the physical conditions for the disruptive discharge development, relevant to the standard situation, are not changed.

A typical example is the use of a single voltage source for the tests of longitudinal insulation, while insulating the base, instead of a combined voltage test. In this case, the demonstration mentioned above concerning the disruptive discharge development is a very stringent condition for the acceptance of the alternative.

6.5 Phase-to-phase and longitudinal insulation standard withstand voltage tests for equipment in range I

6.5.1 Power-frequency tests

For some equipment with 123 kV ≤ U_m ≤ 245 kV, the phase-to-phase (or longitudinal) insulation may require a power-frequency withstand voltage higher than the phase-to-earth power-frequency withstand voltage as shown in Table 2. In such cases the test shall be preferably performed with two voltage sources. One terminal shall be energized with the phase-to-earth power-frequency withstand voltage and the other with the difference between the phase-to-phase (or longitudinal) and the phase-to-earth power-frequency withstand voltages. The earth terminal shall be earthed.

Alternatively, the test may be performed:

– with two equal power-frequency voltage sources in phase opposition, each energizing one phase terminal with half of the phase-to-phase (or longitudinal) insulation power-frequency withstand voltage. The earth terminal shall be earthed;

– with one power-frequency voltage source. The earth terminal may be allowed to assume a voltage to earth sufficient to avoid disruptive discharges to earth or to the earth terminal.

NOTE If, during the test, the terminal earthed in service is carried to a voltage which influences the electrical stresses on the phase terminal (as occurs in compressed gas longitudinal insulation having $U_m \geq 72,5$ kV), means will then be adopted to maintain this voltage as close as possible to the difference between the test voltage of the phase-to-phase (or longitudinal) insulation and that of the phase-to-earth insulation.

6.5.2 Phase-to-phase (or longitudinal) insulation lightning impulse tests

The phase-to-phase (or longitudinal) insulation may require a lightning impulse withstand voltage higher than the standard phase-to-earth withstand voltage as shown in Table 2. In such cases, the relevant tests shall be performed immediately after the phase-to-earth insulation tests increasing the voltage without changing the test arrangement. In evaluating the test results, the impulses leading to disruptive discharge to earth are considered as non-events.

When the number of discharges to earth does not allow the test to be performed, a combined test shall be adopted with an impulse component equal to the phase-to-earth lightning impulse withstand voltage and a power-frequency component with the peak value of opposite polarity equal to the difference between the phase-to-phase (or longitudinal) and the phase-to-earth lightning impulse withstand voltages. Alternatively, for external insulation, the relevant apparatus committees may specify that the phase-to-earth insulation be increased.

6.6 Phase-to-phase and longitudinal insulation standard withstand voltage tests for equipment in range II

The combined voltage withstand voltage test shall be performed meeting the following requirements:

- the test configuration shall suitably duplicate the service configuration, especially with reference to the influence of the earth plane;
- each component of the test voltage shall have the value specified in 5.10;
- the earth terminal shall be connected to earth;
- in phase-to-phase tests the terminal of the third phase shall be either removed or earthed;
- in longitudinal insulation tests the terminals of the other two phases shall be either removed or earthed.

The test shall be repeated for all possible combinations of the phase terminals, unless proved unnecessary by considerations of electrical symmetry.

In the evaluation of the test results, any disruptive discharge is counted. More detailed recommendations for the tests are given by apparatus committees and IEC 60060-1.

For special applications, the relevant apparatus committees may extend to longitudinal insulation lightning impulse withstand voltage tests of range II the same test procedure applicable to equipment of range I.

Annex A
(normative)

Clearances in air to assure a specified impulse withstand voltage installation

A.1 General

In complete installations (e.g. substations) which cannot be tested as a whole, it is necessary to ensure that the dielectric strength is adequate.

The switching and lightning impulse withstand voltages in air at standard reference atmospheric conditions shall be equal to, or greater than, the standard rated switching and lightning impulse withstand voltages as specified in this document. Following this principle, minimum clearances have been determined for different electrode configurations. The minimum clearances specified are determined with a conservative approach, taking into account practical experience.

These clearances are intended solely to address insulation co-ordination requirements. Safety requirements may result in substantially larger clearances.

Tables A.1, A.2 and A.3 are suitable for general application, as they provide minimum clearances ensuring the specified insulation level.

These clearances may be lower if it has been proven by tests on actual or similar configurations that the standard impulse withstand voltages are met, taking into account all relevant environmental conditions which can create irregularities on the surface of electrodes, for example rain, pollution. These distances are therefore not applicable to equipment which has a mandatory impulse type test included in the specification, since a mandatory minimal clearance might hamper the design of equipment, increase its cost and impede progress.

The clearances may also be lower, where it has been confirmed by operating experience that the overvoltages are lower than those expected in the selection of the standard rated withstand voltages or that the gap configuration is more favourable than that assumed for the recommended clearances.

Table A.1 correlates the minimum air clearances with the standard rated lightning impulse withstand voltage for electrode configurations of the rod-structure type and, in addition for range II, of the conductor-structure type. They are applicable for phase-to-earth clearances as well as for clearances between phases (see note in Table A.1).

Table A.2 correlates the minimum air clearances for electrode configurations of the conductor-structure type and the rod-structure type with the standard rated switching impulse withstand voltage phase-to-earth. The conductor-structure configuration covers a large range for normally used configurations.

Table A.3 correlates the minimum air clearances for electrode configurations of the conductor-conductor type and the rod-conductor type with the standard rated switching impulse withstand voltage phase-to-phase. The unsymmetrical rod-conductor configuration is the worst electrode configuration normally encountered in service. The conductor-conductor configuration covers all symmetrical configurations with similar electrode shapes on the two phases. The air clearances applicable in service are determined according to the rules set out in Clauses A.2 and A.3.

A.2 Lightning impulse

The air clearance phase-to-earth and phase-to-phase is determined from Table A.1 for the rated lightning impulse withstand voltage. The standard rated short-duration power-frequency withstand voltage can be disregarded when the ratio of the standard rated lightning impulse withstand voltage to the standard rated short-duration power-frequency withstand voltage is higher than 1,7.

Table A.1 – Correlation between standard rated lightning impulse withstand voltages and minimum air clearances

Standard rated lightning impulse withstand voltage	Minimum clearance mm	
kV	Rod-structure	Conductor-structure
20	60	–
40	60	–
60	90	–
75	120	–
95	160	–
125	220	–
145	270	–
170	320	–
200	380	–
250	480	–
325	630	–
380	750	–
450	900	–
550	1 100	–
650	1 300	–
750	1 500	–
850	1 700	1 600
950	1 900	1 700
1 050	2 100	1 900
1 175	2 350	2 200
1 300	2 600	2 400
1 425	2 850	2 600
1 550	3 100	2 900
1 675	3 350	3 100
1 800	3 600	3 300
1 950	3 900	3 600
2 100	4 200	3 900
2 250	4 500	4 150
2 400	4 800	4 450
2 550	5 100	4 700
2 700	5 400	5 000

NOTE The standard rated lightning impulse withstand voltages are applicable phase-to-phase and phase-to-earth.

For phase-to-earth, the minimum clearance for conductor-structure and rod-structure is applicable.

For phase-to-phase, the minimum clearance for rod-structure is applicable.

A.3 Switching impulse

The phase-to-earth clearance is the higher value of the clearances determined for the rod-structure configuration from Table A.1 for the standard rated lightning impulse withstand voltages, and from Table A.2 for the standard rated switching impulse withstand voltages.

The phase-to-phase clearance is the higher value of the clearances determined for the rod-structure configuration from Table A.1 for the standard rated lightning impulse withstand voltages and from Table A.3 for the standard switching impulse withstand voltages.

The values are valid for altitudes which have been taken into account in the determination of the required withstand voltages.

The clearances necessary to withstand the standard rated lightning impulse withstand voltage for the longitudinal insulation in range II can be obtained by adding 0,7 times the highest voltage of a system (U_s) phase-to-earth peak to the value of the standard rated lightning impulse withstand voltage and by dividing the sum by 500 kV/m.

The clearances necessary for the longitudinal standard rated switching impulse withstand voltage in range II are smaller than the corresponding phase-to-phase value. Such clearances usually exist only in type tested apparatus and minimum values are therefore not given in this document.

Table A.2 – Correlation between standard rated switching impulse withstand voltages and minimum phase-to-earth air clearances

Standard rated switching impulse withstand voltage kV	Minimum phase-to-earth clearance mm	
	Rod-structure	Conductor-structure
750	1 900	1 600
850	2 400	1 800
950	2 900	2 200
1 050	3 400	2 600
1 175	4 100	3 100
1 300	4 800	3 600
1 425	5 600	4 200
1 550	6 400	4 900
1 675	7 400	5 600
1 800	8 300	6 300
1 950	9 500	7 200

Table A.3 – Correlation between standard rated switching impulse withstand voltages and minimum phase-to-phase air clearances

Standard rated switching impulse withstand voltage			Minimum phase-to-phase clearance mm	
Phase-to-earth kV	Ratio of phase-to-phase value to phase-to-earth value	Phase-to-phase kV	Conductor-conductor parallel	Rod-conductor
750	1,50	1 125	2 300	2 600
850	1,50	1 275	2 600	3 100
850	1,60	1 360	2 900	3 400
950	1,50	1 425	3 100	3 600
950	1,70	1 615	3 700	4 300
1 050	1,50	1 575	3 600	4 200
1 050	1,60	1 680	3 900	4 600
1 175	1,50	1 763	4 200	5 000
1 300	1,70	2 210	6 100	7 400
1 425	1,70	2 423	7 200	9 000
1 550	1,60	2 480	7 600	9 400
1 550	1,70	2 635	8 400	10 000
1 675	1,65	2 764	9 100	10 900
1 675	1,70	2 848	9 600	11 400
1 800	1,60	2 880	9 800	11 600
1 800	1,65	2 970	10 300	12 300
1 950	1,60	3 120	11 200	13 300

Annex B
(informative)

Rated insulation levels for highest voltages of equipment, U_m, not standardized by IEC

Table B.1 gives the values of rated insulation levels for 1 kV < U_m ≤ 245 kV for highest voltages of equipment U_m not standardized by IEC based on current practice in some countries.

Table B.1 – Rated insulation levels for highest voltages of equipment, U_m, not standardized by IEC

Highest voltage for equipment, U_m kV (RMS value)	**Standard rated short-duration power-frequency withstand voltage** kV (RMS value)	**Standard rated lightning impulse withstand voltage** kV (peak value)
40,5	80	185
	80	190
	85	200
82,5	140	325
	150	380

Bibliography

IEC 60050-614:2016, *International electrotechnical vocabulary – Part 614: Generation, transmission and distribution of electricity – Operation*

IEC 60507, *Artificial pollution tests on high-voltage ceramic and glass insulators to be used on a.c. systems*

IEC 60633, *High-voltage direct current (HVDC) transmission – Vocabulary*

IEC TS 60815-1, *Selection and dimensioning of high-voltage insulators intended for use in polluted conditions – Part 1: Definitions, information and general principles*

IEC Guide 108, *Guidelines for ensuring the coherency of IEC publications – Application of horizontal standards*

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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COORDINATION DE L'ISOLEMENT –

Partie 1: Définitions, principes et règles

AVANT-PROPOS

1) La Commission Electrotechnique Internationale (IEC) est une organisation mondiale de normalisation composée de l'ensemble des comités électrotechniques nationaux (Comités nationaux de l'IEC). L'IEC a pour objet de favoriser la coopération internationale pour toutes les questions de normalisation dans les domaines de l'électricité et de l'électronique. A cet effet, l'IEC – entre autres activités – publie des Normes internationales, des Spécifications techniques, des Rapports techniques, des Spécifications accessibles au public (PAS) et des Guides (ci-après dénommés "Publication(s) de l'IEC"). Leur élaboration est confiée à des comités d'études, aux travaux desquels tout Comité national intéressé par le sujet traité peut participer. Les organisations internationales, gouvernementales et non gouvernementales, en liaison avec l'IEC, participent également aux travaux. L'IEC collabore étroitement avec l'Organisation Internationale de Normalisation (ISO), selon des conditions fixées par accord entre les deux organisations.
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La Norme internationale IEC 60071-1 a été établie par le comité d'études 99: Installations électriques de tension supérieure à 1,0 kV en courant alternatif et 1,5 kV en courant continu: Coordination de l'isolement et conception.

Cette neuvième édition annule et remplace la huitième édition parue en 2006 et son Amendement 1:2010. Cette édition constitue une révision technique.

Elle a le statut d'une norme horizontale conformément au Guide 108 de l'IEC.

Les principales modifications par rapport à l'édition précédente sont les suivantes:

a) toutes les références ont été mises à jour en faveur des normes IEC actuelles et la bibliographie est supprimée;

b) certaines définitions ont été modifiées afin d'éviter les chevauchements et de favoriser une bonne compréhension;

c) les symboles littéraux ont été modifiés et corrigés afin de garantir la cohérence avec les normes IEC concernées;

d) plusieurs titres ont été modifiés en vue d'une meilleure compréhension (voir les Articles A.2 et A.3, ainsi que l'Annexe B).

Le texte de cette Norme internationale est issu des documents suivants:

CDV	Rapport de vote
99/199/CDV	99/227/RVC

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à l'approbation de cette Norme internationale.

Cette publication a été rédigée selon les Directives ISO/IEC, Partie 2.

Une liste de toutes les parties de la série IEC 60071, publiées sous le titre général *Coordination de l'isolement*, peut être consultée sur le site web de l'IEC.

Le comité a décidé que le contenu de la publication de base et de ses amendements ne serait pas modifié avant la date de stabilité indiquée sur le site web de l'IEC sous "http://webstore.iec.ch" dans les données relatives à la publication recherchée. A cette date, la publication sera

- reconduite,
- supprimée,
- remplacée par une édition révisée, ou
- amendée.

IMPORTANT – Le logo "*colour inside*" qui se trouve sur la page de couverture de cette publication indique qu'elle contient des couleurs qui sont considérées comme utiles à une bonne compréhension de son contenu. Les utilisateurs devraient, par conséquent, imprimer cette publication en utilisant une imprimante couleur.

COORDINATION DE L'ISOLEMENT –

Partie 1: Définitions, principes et règles

1 Domaine d'application

La présente partie de l'IEC 60071 s'applique aux réseaux à tension alternative triphasée dont la tension la plus élevée pour le matériel est supérieure à 1 kV. Elle spécifie la procédure à suivre pour le choix des tensions de tenue assignées normalisées pour l'isolation phase-terre, l'isolation entre phases et l'isolation longitudinale du matériel et des installations de ces réseaux. Elle donne également les listes des valeurs normalisées parmi lesquelles les tensions de tenue assignées normalisées sont choisies.

Le présent document décrit que les tensions de tenue choisies sont associées aux tensions les plus élevées pour le matériel. Cette association est destinée aux seules fins de la coordination de l'isolement. Les exigences concernant la sécurité des personnes ne sont pas couvertes par le présent document.

Bien que les principes du présent document s'appliquent également à l'isolation des lignes de transport d'énergie, les valeurs des tensions de tenue peuvent être différentes des tensions de tenue assignées normalisées.

Il appartient aux comités de produits de spécifier les tensions de tenue et les procédures d'essai appropriées aux matériels correspondants, en prenant les recommandations du présent document en considération.

NOTE Toutes les règles relatives à la coordination de l'isolement données dans le présent document sont justifiées en détail dans l'IEC 60071-2, en particulier en ce qui concerne l'association des tensions de tenue assignées normalisées avec les tensions les plus élevées pour le matériel. Lorsque plusieurs séries de tensions de tenue assignées normalisées sont associées à la même valeur de la tension la plus élevée pour le matériel, une ligne directrice est donnée pour le choix de la série la plus appropriée.

Cette norme horizontale est essentiellement destinée à l'usage des comités d'études dans la préparation des normes, conformément aux principes établis dans le Guide 108 de l'IEC.

Une des responsabilités d'un comité d'études est, partout où cela est possible, de se servir des normes horizontales lors de la préparation de ses publications. Le contenu de cette norme horizontale ne s'appliquera pas, à moins qu'il ne soit spécifiquement désigné ou inclus dans les publications concernées.

2 Références normatives

Les documents suivants cités dans le texte constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l’édition citée s’applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 60038, *Tensions normales de l'IEC*

IEC 60060-1, *Technique des essais à haute tension – Partie 1: Définitions et exigences générales*

IEC 60071-2, *Coordination de l'isolement – Partie 2: Lignes directrices en matière d'application*

IEC 60099-4, *Parafoudres – Partie 4: Parafoudres à oxyde métallique sans éclateur pour réseaux à courant alternatif*

3 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse http://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse http://www.iso.org/obp

3.1
coordination de l'isolement
sélection de la tenue diélectrique des matériels, en fonction des tensions de service et des surtensions qui peuvent apparaître dans le réseau auquel ces matériels sont destinés et compte tenu de l'environnement en service et des caractéristiques des dispositifs de prévention et de protection disponibles

Note 1 à l'article: La «rigidité diélectrique» des matériels est prise ici au sens de niveau d'isolement assigné (3.36) ou de niveau d'isolement normalisé (3.37).

[SOURCE: IEC 60050-614:2016, 614-03-08, modifié – La Note 1 à l'article a été ajoutée.]

3.2
isolation externe
distances dans l'air atmosphérique et sur les surfaces des isolations solides d'un matériel en contact avec l'air atmosphérique, qui sont soumises aux contraintes diélectriques et à l'influence des conditions atmosphériques ou d'autres conditions environnementales provenant du site comme la pollution, l'humidité, les animaux, etc.

Note 1 à l'article: L'isolation externe est soit protégée, soit exposée, selon qu'elle est conçue pour être utilisée à l'extérieur ou à l'intérieur d'abris fermés.

[SOURCE: IEC 60050-614:2016, 614-03-02, modifié – La Note 1 à l'article a été ajoutée]

3.3
isolation interne
distances internes dans l'isolation solide, liquide ou gazeuse des matériels qui sont à l'abri de l'influence des conditions atmosphériques ou d'autres agents externes

[SOURCE: IEC 60050-614, 614-03-03]

3.4
isolation autorégénératrice
isolation qui retrouve intégralement ses propriétés isolantes en un intervalle de temps court après une décharge disruptive

Note 1 à l'article: Une isolation de ce type est généralement, mais pas nécessairement, une isolation externe.

Note 2 à l'article: Cette définition s'applique uniquement quand la décharge est provoquée par l'application d'une tension d'essai lors d'un essai diélectrique. Cependant, des décharges apparaissant en service peuvent conduire une isolation autorégénératrice à perdre partiellement ou complètement ses propriétés isolantes d'origine.

[SOURCE: IEC 60050-614, 614-03-04]

3.5
isolation non autorégénératrice
isolation qui perd ses propriétés isolantes, ou ne les retrouve pas intégralement, après une décharge disruptive

Note 1 à l'article: Cette définition s'applique uniquement quand la décharge est provoquée par l'application d'une tension d'essai lors d'un essai diélectrique. Cependant, des décharges apparaissant en service peuvent conduire une isolation autorégénératrice à perdre partiellement ou complètement ses propriétés isolantes d'origine.

[SOURCE: IEC 60050-614, 614-03-05]

3.6
borne de la configuration de l'isolation
l'une ou l'autre des deux bornes entre lesquelles peut être appliquée une tension qui soumet l'isolation à une contrainte

Note 1 à l'article: Les types de bornes sont:

a) borne de phase, en service, la tension phase-neutre du réseau est appliquée entre cette borne et le neutre;
b) borne de neutre, représentant le point neutre du réseau, ou y étant connectée (borne de neutre de transformateur, etc.);
c) borne de terre, toujours mise directement à la terre en service (cuve de transformateur, socle de sectionneur, structure de pylône, plaque de mise à la terre, etc.)

3.7
configuration de l'isolation
configuration géométrique complète de l'isolation en service comprenant l'isolation et toutes ses bornes et incluant tous les éléments (isolants et conducteurs) qui influencent son comportement diélectrique

Note 1 à l'article: Les configurations de l'isolation définies en 3.7.1 à 3.7.4 sont identifiées.

3.7.1
configuration de l'isolation triphasée
configuration de l'isolation ayant trois bornes de phase, une borne de neutre et une borne de terre

3.7.2
configuration de l'isolation phase-terre
configuration d'isolation triphasée dans laquelle il n'est pas tenu compte des bornes de deux phases et, sauf cas particuliers, dans laquelle la borne de neutre est mise à la terre

3.7.3
configuration de l'isolation phase-phase
configuration d'isolation triphasée dans laquelle il n'est pas tenu compte d'une borne de phase. Dans des cas particuliers, les bornes de neutre et de terre ne sont également pas prises en compte

3.7.4
configuration de l'isolation longitudinale
configuration de l'isolation ayant deux bornes de phase et une borne de terre, les bornes de phase appartenant à la même phase d'un réseau triphasé, séparée temporairement en deux parties indépendantes sous tension (par exemple, appareils de connexion ouverts)

Note 1 à l'article: Les quatre bornes appartenant aux deux autres phases ne sont pas prises en compte ou sont mises à la terre. Dans des cas particuliers, l'une des deux bornes de phase prises en compte est mise à la terre.

3.8
tension nominale d'un réseau
U_n
valeur arrondie appropriée de la tension utilisée pour dénommer ou identifier un réseau

[SOURCE: IEC 60050-601:1985, 601-01-21, modifié – Un symbole a été ajouté.]

3.9
tension la plus élevée d'un réseau
U_s
valeur la plus élevée de la tension de service entre phases (valeur efficace) qui se présente à un instant et en un point quelconque du réseau dans des conditions d'exploitation normales

[SOURCE: IEC 60050-601:1985, 601-01-23, modifié – Un signification claire de la tension a été ajoutée.]

3.10
tension la plus élevée pour le matériel
U_m
valeur la plus élevée de la tension entre phases (valeur efficace) pour laquelle le matériel est spécifié en ce qui concerne son isolement ainsi que certaines autres caractéristiques qui sont rattachées à cette tension dans les normes proposées pour chaque matériel

Note 1 à l'article: Dans les conditions normales de service spécifiées par le comité de produit correspondant, cette tension peut être appliquée au matériel en permanence.

[SOURCE: IEC 60050-614:2016, 614-03-01]

3.11
réseau à neutre isolé
réseau dont aucun point neutre n'a de connexion intentionnelle avec la terre, à l'exception des liaisons à haute impédance destinées à des dispositifs de protection ou de mesure

[SOURCE: IEC 60050-601:1985, 601-02-24]

3.12
réseau à neutre directement à la terre
réseau dont le ou les points neutres sont reliés directement à la terre

[SOURCE: IEC 60050-601:1985, 601-02-25]

3.13
réseau à neutre non directement à la terre
réseau dont le ou les points neutres sont reliés à la terre par l'intermédiaire d'impédances destinées à limiter les courants de défaut à la terre

[SOURCE: IEC 60050-601:1985, 601-02-26]

3.14
réseau compensé par bobine d'extinction
réseau dont un ou plusieurs points neutres sont reliés à la terre par des réactances compensant approximativement la composante capacitive du courant de défaut monophasé à la terre

Note 1 à l'article: Pour un réseau compensé par bobine d'extinction, le courant résiduel dans le défaut est limité à tel point qu'un arc de défaut dans l'air est généralement autoextinguible.

[SOURCE: IEC 60050-601:1985, 601-02-27]

3.15
facteur de défaut à la terre
$\boldsymbol{k}$
en un emplacement donné d'un réseau triphasé, et pour un schéma d'exploitation donné de ce réseau, rapport entre, d'une part, la tension efficace la plus élevée, à la fréquence du

réseau, entre une phase saine et la terre pendant un défaut à la terre affectant une phase quelconque ou plusieurs phases en un point quelconque du réseau, et d'autre part la valeur efficace de la tension entre phase et terre à la fréquence du réseau qui serait obtenue à l'emplacement pris en compte en l'absence du défaut

[SOURCE: IEC 60050-614:2016, 614-03-06, modifié – Un symbole a été ajouté et la description de la tension a été modifiée]

3.16
tension continue
tension à la fréquence du réseau, réputée comme ayant une valeur efficace constante, appliquée en permanence à toute paire de bornes d'une configuration d'isolation

3.17
surtension
tension:

– entre un conducteur de phase et la terre ou à travers une isolation longitudinale dont la valeur de crête dépasse la valeur de crête correspondant à la tension la plus élevée du réseau divisée par $\sqrt{3}$
– entre conducteurs de phase dont la valeur de crête dépasse l'amplitude de la tension le plus élevée du réseau

Note 1 à l'article: Sauf indication contraire clairement stipulée, comme pour les parafoudres, les valeurs de surtension exprimées en p.u. renvoient à $U_s \times \sqrt{2}/\sqrt{3}$.

[SOURCE: IEC 60050-614:2016, 614-03-10]

3.17.1
surtension temporaire
TOV
surtension à fréquence industrielle de durée relativement longue

Note 1 à l'article: La surtension peut être non amortie ou faiblement amortie. Dans certains cas, sa fréquence peut être inférieure ou supérieure à la fréquence industrielle dans un rapport de plusieurs unités.

Note 2 à l'article: L'abréviation "TOV" est dérivée du terme anglais développé correspondant "temporary overvoltage".

[SOURCE: IEC 60050-614:2016, 614-03-13]

3.17.2
surtension transitoire
surtension de courte durée, ne dépassant pas quelques millisecondes, oscillatoire ou non, généralement fortement amortie

Note 1 à l'article: Les surtensions transitoires peuvent être immédiatement suivies par des surtensions temporaires. S'il en est ainsi, les deux types de surtensions sont considérés comme des événements séparés.

[SOURCE: IEC 60050-614:2016, 614-03-14]

3.17.2.1
surtension à front lent
SFO
surtension transitoire, généralement unidirectionnelle, de durée T_p jusqu'à la valeur de crête telle que 20 µs < $T_p \leq$ 5 000 µs, et de durée de queue $T_2 \leq$ 20 ms

Note 1 à l'article: L'abréviation "SFO" est dérivée du terme anglais développé correspondant "slow-front overvoltage".

3.17.2.2
surtension à front rapide
FFO
surtension transitoire, généralement unidirectionnelle, de durée T_p jusqu'à la valeur de crête telle que 0,1 µs < T_1 ≤ 20 µs, et de durée de queue T_2 < 300 µs

Note 1 à l'article: L'abréviation "FFO" est dérivée du terme anglais développé correspondant "fast-front overvoltage".

3.17.2.3
surtension à front très rapide (very-fast-front overvoltage)
VFFO
surtension transitoire, généralement unidirectionnelle, de durée jusqu'à la valeur de crête T_f ≤ 0,1 µs, et avec ou sans oscillations superposées de fréquence 30 kHz < f < 100 MHz

Note 1 à l'article: L'abréviation "VFFO" est dérivée du terme anglais développé correspondant "very-fast-front overvoltage".

3.17.3
surtension combinée
surtension consistant en deux composantes de tension appliquées simultanément entre chacune des deux bornes de phase d'une isolation entre phases (ou longitudinale) et la terre

Note 1 à l'article: Elle est classée selon la composante de la valeur de crête la plus élevée (temporaire, à front lent, à front rapide ou à front très rapide).

3.18
formes de tension normalisées pour essai
formes de tensions et de surtensions pour essai qui sont déterminées en termes d'amplitude, de front d'onde, d'extrémité d'onde et de durée

Note 1 à l'article: Plus de détails sur les trois premières formes de tension normalisées suivantes sont donnés dans l'IEC 60060-1 ainsi que dans le Tableau 1.

3.18.1
tension normalisée de courte durée à fréquence industrielle
tension sinusoïdale de fréquence comprise entre 48 Hz et 62 Hz et de durée égale à 60 s

3.18.2
tension normalisée de choc de manœuvre
tension de choc ayant une durée jusqu'à la crête de 250 µs et une durée jusqu'à la mi-valeur de 2 500 µs

3.18.3
tension normalisée de choc de foudre
tension de choc ayant une durée de front de 1,2 µs et une durée jusqu'à la mi-valeur de 50 µs

3.18.4
tension normalisée de choc de manœuvre combinée
pour l'isolation entre phases, une tension de choc combinée ayant deux composantes de valeurs de crête égales et de polarités opposées

Note 1 à l'article: La composante positive est une tension de choc de manœuvre normalisée et la composante négative est une tension de choc de manœuvre dont les durées jusqu'à la crête et jusqu'à la mi-valeur ne sont pas inférieures à celles de la composante positive. Il convient que les deux tensions de choc atteignent leur valeur de crête au même instant. Par conséquent, la valeur de crête de la tension combinée est la somme des valeurs de crête de leurs composantes.

3.18.5
tension normalisée combinée
pour l'isolation longitudinale, une tension combinée ayant un choc normalisé sur une borne et une tension à fréquence industrielle sur l'autre borne

Note 1 à l'article: La composante de choc est appliquée à la valeur de crête de la tension à fréquence industrielle de polarité opposée.

3.19
surtension représentative
U_{rp}
surtension présumée produire le même effet diélectrique sur l'isolation que la surtension d'une catégorie donnée apparaissant en service dues à diverses origines

Note 1 à l'article: Elles sont constituées de tensions ayant la forme normalisée de la catégorie en question et peuvent être définies par une valeur, un ensemble de valeurs ou une distribution statistique des valeurs qui caractérisent les conditions de service

Note 2 à l'article: Cette définition s'applique également à la tension permanente à fréquence industrielle qui représente l'effet de la tension de service sur l'isolation.

3.20
dispositif de limitation des surtensions
dispositif qui limite les valeurs de crête des surtensions ou leurs durées ou les deux

Note 1 à l'article: Ces dispositifs sont classés en dispositifs de prévention (tel que résistance de préinsertion) ou en dispositifs de protection (tel que parafoudre).

3.21
niveau de protection au choc de foudre
U_{pl}
valeur de crête maximale de la tension admissible aux bornes d'un dispositif de protection soumis, dans des conditions spécifiées, à des chocs de foudre

[SOURCE: IEC 60050-6014:2016, 614-03-56]

3.22
niveau de protection aux surtensions de manœuvre
U_{ps}
valeur de crête maximale de la tension admissible aux bornes d'un dispositif de protection soumis, dans des conditions spécifiées, à des chocs de manœuvre

[SOURCE: IEC 60050-6014:2016, 614-03-57]

3.23
critère de performance
base sur laquelle est choisie l'isolation de façon à réduire à un niveau acceptable, du point de vue de l'économie et de celui de l'exploitation, la probabilité que les contraintes diélectriques résultantes imposées aux matériels causent des dommages aux isolations des matériels ou affectent la continuité du service

Note 1 à l'article: Le critère de performance est habituellement exprimé par un taux de défaillance acceptable (nombre de défaillances par année, nombre d'années entre défaillances, risque de défaillance, etc.) de la configuration de l'isolation.

3.24
tension de tenue
valeur de la tension d'essai à appliquer, dans des conditions spécifiées, lors d'un essai de tension de tenue pendant lequel un nombre spécifié de décharges disruptives est toléré

Note 1 à l'article: La tension de tenue est désignée par:

a) tension de tenue présumée conventionnelle, lorsque le nombre de décharges disruptives toléré est nul. Cette valeur est réputée correspondre à une probabilité de tenue P_w = 100 %;

b) tension de tenue statistique, lorsque le nombre de décharges disruptives toléré est relatif à une probabilité de tenue spécifiée. Dans le présent document, la probabilité spécifiée est P_w = 90 %.

Note 2 à l'article: Dans le présent document, les tensions de tenue présumées conventionnelles sont spécifiées pour l'isolation non autorégénératrice. Les tensions de tenue statistiques le sont pour l'isolation autorégénératrice.

3.25
tension de tenue de coordination
U_{cw}
pour chaque catégorie de tension, valeur de la tension de tenue de la configuration de l'isolation, dans les conditions réelles de service, qui satisfait au critère de performance

3.26
facteur de coordination
K_c
facteur par lequel il faut que la valeur de la surtension représentative soit multipliée pour obtenir la valeur de la tension de tenue de coordination

3.27
conditions atmosphériques normalisées de référence
conditions atmosphériques auxquelles les tensions de tenue assignées normalisées s'appliquent

Note 1 à l'article: Voir 5.9.2.

3.28
tension de tenue exigée
U_{rw}
tension d'essai qu'il faut que l'isolation tienne dans un essai de tension de tenue normalisée pour s'assurer que l'isolation satisfera au critère de performance lorsqu'elle sera soumise à une catégorie donnée de surtensions dans les conditions réelles de service et pendant toute la durée de service

Note 1 à l'article: La tension de tenue exigée a la forme de la tension de tenue de coordination et elle est spécifiée en se référant à toutes les conditions de l'essai de tension de tenue normalisée choisi pour vérifier cette tenue.

3.29
facteur de correction atmosphérique
K_t
facteur à appliquer à la tension de tenue de coordination pour tenir compte de la différence de tenue diélectrique entre les conditions atmosphériques moyennes en service et les conditions atmosphériques normalisées de référence.

Note 1 à l'article: Le facteur de correction atmosphérique ne s'applique qu'à l'isolation externe, pour toutes les altitudes

Note 2 à l'article: Pour le facteur de correction atmosphérique, les conditions atmosphériques prises en compte sont la pression de l'air, la température et l'humidité. En général, pour les besoins de coordination de l'isolement, il n'est nécessaire de prendre en compte que la correction de pression de l'air.

3.30
facteur de correction d'altitude
K_a
facteur à appliquer à la tension de tenue de coordination pour tenir compte de la différence de tenue diélectrique entre la pression moyenne correspondant à l'altitude en service et la pression normalisée de référence

Note 1 à l'article: Le facteur de correction d'altitude fait partie du facteur de correction atmosphérique.

3.31
facteur de sécurité
K_s
facteur global à appliquer à la tension de tenue de coordination, après application du facteur de correction atmosphérique (si exigé), pour obtenir la tension de tenue exigée en tenant compte de toutes les autres différences de tenue diélectrique entre les conditions en service au cours de la durée de vie et celles de l'essai de tension de tenue normalisée

3.32
tension de tenue réelle d'un matériel ou d'une configuration de l'isolation
U_{aw}
valeur la plus élevée possible de la tension d'essai qui peut être appliquée à un matériel ou à une configuration d'isolation dans un essai de tension de tenue normalisée

3.33
facteur de conversion d'essai
K_{tc}
pour un matériel ou une configuration d'isolation donné, facteur à appliquer à la tension de tenue exigée d'une catégorie de surtension donnée, dans le cas où la forme de la tension de tenue normalisée de l'essai de tension de tenue choisi est celle d'une catégorie de surtension différente

Note 1 à l'article: Pour une configuration de matériel ou d'isolation donnée: le facteur de conversion d'essai de la forme de la tension normalisée (a) en forme de tension normalisée (b) doit être supérieur ou égal au rapport entre la tension de tenue réelle pour la forme de tension normalisée (a) et la tension de tenue réelle de la forme de tension normalisée (b).

3.34
tension de tenue assignée
valeur de la tension d'essai, appliquée dans un essai de tension de tenue normalisée, qui permet de vérifier que l'isolation satisfait à une ou plusieurs des tensions de tenue exigées

Note 1 à l'article: C'est une valeur assignée d'isolation d'un matériel.

3.35
tension de tenue assignée normalisée
U_w
valeur normalisée de la tension de tenue assignée telle recommandée dans le présent document

Note 1 à l'article: Voir 5.6 et 5.7.

3.36
niveau d'isolement assigné
ensemble de tensions de tenue assignées qui caractérisent la rigidité diélectrique de l'isolation

3.37
niveau d'isolement normalisé
ensemble de tensions de tenue assignées normalisées associées à U_m comme spécifié dans le présent document

Note 1 à l'article: Voir Tableau 2 et Tableau 3.

3.38
essai de tension de tenue normalisée
essai diélectrique effectué dans des conditions spécifiées pour démontrer que l'isolation satisfait à une tension de tenue assignée normalisée

Note 1 à l'article: Le présent document couvre:

– les essais à la tension de courte durée à fréquence industrielle;
– les essais au choc de manœuvre;
– les essais au choc de foudre;
– les essais au choc de manœuvre combinés;
– les essais à la tension combinée.

Note 2 à l'article: Des informations détaillées complémentaires sur les essais de tension de tenue normalisée sont données dans l'IEC 60060-1 (voir également le Tableau 1 pour les formes de la tension d'essai).

Note 3 à l'article: Il convient que les essais de tension de tenue normalisée au choc à front très rapide soient spécifiés par les comités de produit concernés, si exigé.

4 Termes abrégés et symboles

4.1 Généralités

Les listes fournies ci-dessous ne couvrent que les symboles et les abréviations utilisés le plus fréquemment et qui sont utiles pour la coordination de l'isolement.

4.2 Indices

max maximum

4.3 Symboles littéraux

f	fréquence
k	facteur de défaut à la terre
K_t	fateur de correction atmosphérique
K_a	facteur de correction d'altitude
K_c	facteur de coordination
K_s	facteur de sécurité
K_{tc}	facteur de conversion d'essai
P_w	probabilité de tenue
T_1	durée de front
T_2	durée jusqu'à la mi-valeur d'une tension décroissante
T_p	durée jusqu'à la valeur de crête
T_t	durée totale de surtension
U_{aw}	tension de tenue réelle d'un matériel ou d'une configuration de l'isolation
U_{cw}	tension de tenue de coordination
U_m	tension la plus élevée pour le matériel
U_n	tension nominale d'un réseau
U_{pl}	niveau de protection au choc de foudre d'un parafoudre
U_{ps}	niveau de protection au choc de manœuvre d'un parafoudre
U_{rp}	surtension représentative
U_{rw}	tension de tenue exigée
U_s	tension la plus élevée d'un réseau
U_w	tension de tenue assignée normalisée

4.4 Abréviations

FFO	surtension à front rapide (*fast-front overvoltage*)
ACWV	tension de tenue assignée normalisée de courte durée à fréquence industrielle d'un matériel ou d'une configuration de l'isolation (*power frequency withstand voltage*)
LIPL	niveau de protection au choc de foudre d'un parafoudre (*lightning impulse protective level*)
SIPL	niveau de protection au choc de manœuvre d'un parafoudre (*switching impulse protective level*)
LIWV	tension de tenue assignée normalisée au choc de foudre d'un matériel ou d'une configuration de l'isolation (*lightning impulse withstand*