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IEC 60071-1

Eight edition
2006-01

Insulation co-ordination –

Part 1: Definitions, principales and rules

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

INSULATION CO-ORDINATION –

Part 1: Definitions, principles and rules

FOREWORD

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International Standard IEC 60071-1 has been prepared by IEC technical committee 28: Insulation co-ordination.

This eighth edition cancels and replaces the seventh edition published in 1993 and constitutes a technical revision.

The main changes from the previous edition are as follows:

– in the definitions (3.26, 3.28 and 3.29) and in the environmental conditions (5.9) taken into account clarification of the atmospheric and altitude corrections involved in the insulation co-ordination process;
– in the list of standard rated short-duration power frequency withstand voltages reported in 5.6 addition of 115 kV;

– in the list of standard rated impulse withstand voltages reported in 5.7, addition of 200 kV and 380 kV;

– in the standard insulation levels for range I (1kV < $U_m \leq$ 245 kV) (Table 2) addition of the highest voltage for equipment U_m = 100 kV;

– in the standard insulation levels for range II (U_m > 245 kV) (Table 3) replacement of 525 kV by 550 kV and of 765 kV by 800 kV;

– in order to remove that part in the next revision of IEC 60071-2, addition of Annex A dealing with clearances in air to assure a specified impulse withstand voltage in installation;

– in Annex B, limitation at two U_m values for the values of rated insulation levels for 1kV < $U_m \leq$ 245 kV for highest voltages for equipment U_m not standardized by IEC based on current practice in some countries.

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

FDIS	Report on voting
28/176/FDIS	28/177/RVC

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

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

The IEC 60071 comprises the following parts under the general title *Insulation co-ordination:*

Part 1: Definitions, principles and rules

Part 2: Application guide

Part 4: Computational guide to insulation co-ordination and modelling of electrical networks

Part 5: Procedures for high-voltage direct current (HVDC) converter stations

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

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

INSULATION CO-ORDINATION –

Part 1: Definitions, principles and rules

1 Scope

This part of IEC 60071 applies to three-phase a.c. 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 selected.

This standard recommends that the selected withstand voltages should be 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 standard.

Although the principles of this standard also apply to transmission line insulation, the values of their withstand voltages may 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 standard.

NOTE In IEC 60071-2, Application Guide, all rules for insulation co-ordination given in this standard 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.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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 guide*

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.

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 By "dielectric strength" of the equipment, is meant here its rated or its standard insulation level as defined in 3.35 and 3.36 respectively.

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

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]

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

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

NOTE Insulation of this kind is generally, but not necessary, external insulation

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 The definitions of 3.4 and 3.5 apply 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.

3.6
insulation configuration terminal
any of the terminals between any two of which a voltage that stresses the insulation can be applied. 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. It includes all elements (insulating and conducting) which influence its dielectric behaviour. The following insulation configurations are identified:

3.7.1
three-phase insulation configuration
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 belong to the same phase of a three-phase system temporarily separated into two independently energized parts (e.g. open switching devices). 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

[IEC 601-01-21:1985]

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

[IEC 601-01-23:1985, modified]

3.10
highest voltage for equipment
U_m
highest value of phase-to-phase voltage (r.m.s. 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. 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]

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

[IEC 601-02-24:1985]

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

[IEC 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

[IEC 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 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.

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 r.m.s. 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 r.m.s. 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]

3.16
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 Unless otherwise clearly indicated, such as for surge arresters, overvoltage values expressed in p.u. refer to $U_s \times \sqrt{2}/\sqrt{3}$

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.

3.17.1
continuous (power frequency) voltage
power-frequency voltage, considered having constant r.m.s. value, continuously applied to any pair of terminals of an insulation configuration

3.17.2
temporary overvoltage
TOV
power frequency overvoltage of relatively long duration

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

NOTE The overvoltage may be undamped or weakly damped. In some cases its frequency may be several times smaller or higher than power frequency.

3.17.3
transient overvoltage
short-duration overvoltage of few milliseconds or less, oscillatory or non-oscillatory, usually highly damped

[IEC 604-03-13:1987]

NOTE Transient overvoltages may be immediately followed by temporary overvoltages. In such cases the two overvoltages are considered as separate events.

Transient overvoltages are divided into:

3.17.3.1
slow-front overvoltage
SFO
transient overvoltage, usually unidirectional, with time to peak 20 µs < T_p ≤ 5 000 µs, and tail duration T_2 ≤ 20 ms

3.17.3.2
fast-front overvoltage
FFO
transient overvoltage, usually unidirectional, with time to peak 0,1 µs < T_1 ≤ 20 µs, and tail duration T_2 ≤ 300 µs

3.17.3.3
very-fast-front overvoltage
VFFO
transient overvoltage, usually unidirectional with time to peak T_f ≤ 0,1 µs, and with or without superimposed oscillations at frequency 30 kHz < f < 100 MHz

3.17.4
combined 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. 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 shapes are standardized:

NOTE 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, a combined impulse voltage having two components of equal peak value and opposite polarity.

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, a combined voltage having a standard impulse on one terminal and a power frequency voltage on the other terminal. The impulse component is applied at the peak of the power frequency voltage of opposite polarity

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

They 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 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. 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]

3.22
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. This 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

3.23
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. 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 standard, the specified probability is P_w = 90 %.

NOTE In this standard, for non-self-restoring insulation are specified conventional assumed withstand voltages, and for self-restoring insulation are specified statistical withstand voltages.

3.24
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

3.25
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

3.26
standard reference atmospheric conditions
atmospheric conditions to which the standardized withstand voltages apply (see 5.9)

3.27
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. 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

3.28
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

It applies to external insulation only, for all altitudes

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.

3.29
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 The altitude correction factor K_a is part of the atmospheric correction factor K_t.

3.30
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

3.31
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

3.32
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 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).

3.33
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. It is a rated value of the insulation of an equipment

3.34
standard rated withstand voltage
U_w
standard value of the rated withstand voltage as specified in this standard (see 5.6 and 5.7)

3.35
rated insulation level
set of rated withstand voltages which characterize the dielectric strength of the insulation

3.36
standard insulation level
set of standard rated withstand voltages which are associated to U_m as specified in this standard (see Table 2 and Table 3)

3.37
standard withstand voltage test
dielectric test performed in specified conditions to prove that the insulation complies with a standard rated withstand voltage

NOTE 1 This standard covers:

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

NOTE 2 More detailed information on the standard withstand voltage tests are given in IEC 60060-1 (see also Table 1 for the test voltage shapes).

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

4 Symbols and abbreviations

4.1 General

The list covers 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}	the 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

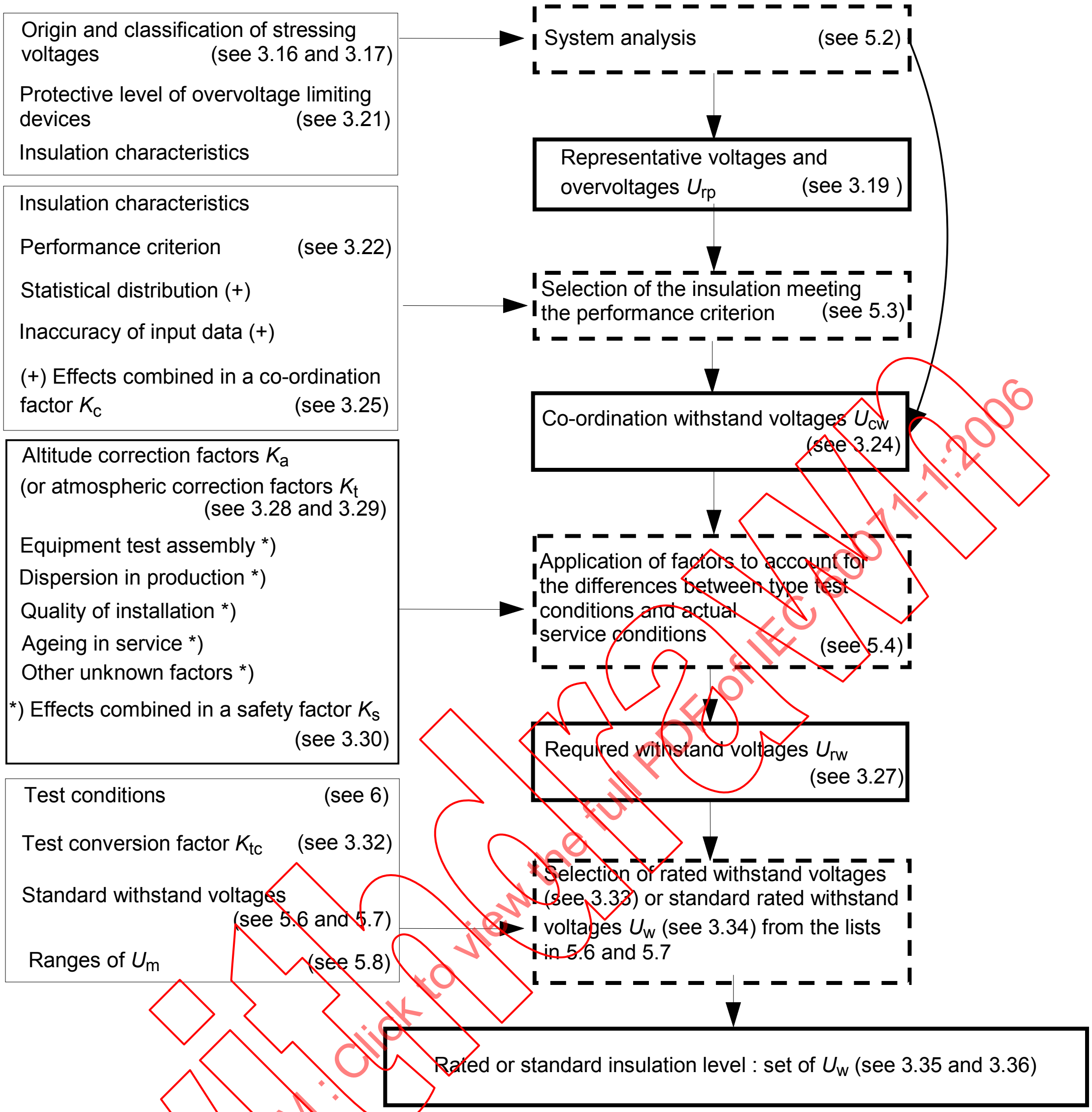
FFO	fast-front overvoltage
ACWV	standard rated short-duration power frequency withstand voltage of an equipment or insulation configuration
LIPL	lightning impulse protective level of a surge arrester
SIPL	switching impulse protective level of a surge arrester
LIWV	standard rated lightning impulse withstand 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.



IEC 2781/05

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

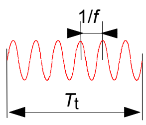
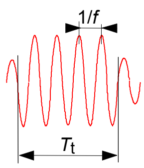
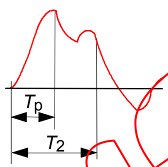
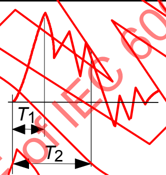
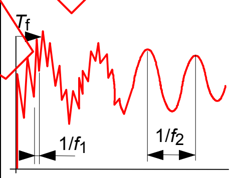
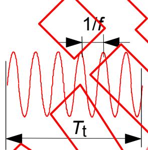
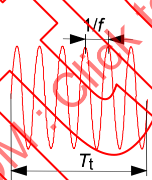
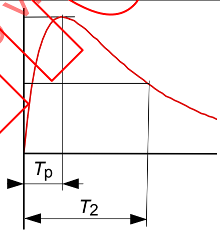
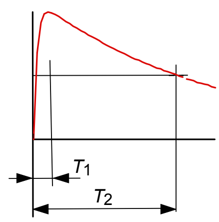
Figure 1 – Flow chart for the determination of rated or standard insulation level

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 ≥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 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 r.m.s. 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 r.m.s. 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 of the fast-front overvoltages phase to earth.

  NOTE For GIS or GIL with three-phase enclosure and insulation levels chosen among the lowest ones for a given U_m, the phase-to-phase overvoltages may 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.

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 correction factor K_t 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, 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.

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 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 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 arise when the equipment has to be installed at an altitude higher than 1000 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 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 (e.g. see 5.10).

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 r.m.s. 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.

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, 1050, 1175, 1300, 1425, 1550, 1675, 1800, 1950, 2100, 2250, 2400.

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 – Medium, according to Table 1 of IEC 60071-2.

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 condition for which the standardized withstand voltages apply are:

a) temperature: t_0 = 20 °C

b) pressure: b_0 = 101,3 kPa (1013 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.

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 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 require the specification of a standard rated short-duration power-frequency withstand voltage.

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

Highest voltage for equipment (U_m) kV (r.m.s. value)	Standard rated short-duration power-frequency withstand voltage kV (r.m.s. 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	1050

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.

[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)

Highest voltage for equipment (U_m) kV (r.m.s. 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 1050
362	850	850	1,50	950 1050
	850	950	1,50	1050 1175
420	850	850	1,60	1050 1175
	950	950	1,50	1175 1300
	950	1050	1,50	1300 1425
550	950	950	1,70	1175 1300
	950	1050	1,60	1300 1425
	950 1050	1175	1,50	1425 1550
800	1175	1300	1,70	1675 1800
	1175	1425	1,70	1800 1950
	1175 1300	1550	1,60	1950 2100

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 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.

5.11 Background of the standard insulation levels

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.

IEC 60071-1 leaves it to the relevant apparatus 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 lighting 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:

– 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 ≥ 72,5 kV), means should 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.