

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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

**Technique des essais à haute tension –
Partie 1: Définitions et exigences générales**



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HIGH-VOLTAGE TEST TECHNIQUES –**Part 1: General definitions and test requirements**

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International Standard IEC 60060-1 has been prepared by IEC technical committee 42: High-voltage test techniques.

This third edition of IEC 60060-1 cancels and replaces the second edition, published in 1989, and constitutes a technical revision.

The significant technical changes with respect to the previous edition are as follows:

- a) The general layout and text was updated and improved to make the standard easier to use.
- b) Artificial pollution test procedures were removed as they are now described in IEC 60507.
- c) Measurement of impulse current has been transferred to a new standard on current measurement (IEC 62475).
- d) The atmospheric correction factors are now presented as formulas.

- e) A new method has been introduced for the calculation of the time parameters of lightning impulse waveforms. This improves the measurement of the time parameters of lightning impulses with oscillations or overshoot.

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

FDIS	Report on voting
42/277/FDIS	42/282/RVD

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

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

A list of all the parts in the IEC 60060 series, under the general title *High-voltage test techniques*, can be found on the IEC website.

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

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- withdrawn;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

HIGH-VOLTAGE TEST TECHNIQUES –

Part 1: General definitions and test requirements

1 Scope

This part of IEC 60060 is applicable to:

- dielectric tests with direct voltage;
- dielectric tests with alternating voltage;
- dielectric tests with impulse voltage;
- dielectric tests with combinations of the above.

This part is applicable to tests on equipment having its highest voltage for equipment U_m above 1 kV.

NOTE 1 Alternative test procedures may be required to obtain reproducible and significant results. The choice of a suitable test procedure should be made by the relevant Technical Committee.

NOTE 2 For voltages U_m above 800 kV meeting some specified procedures, tolerances and uncertainties may not be achievable.

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 60060-2, *High-voltage test techniques – Part 2: Measuring systems*

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

IEC 60507:1991, *Artificial pollution tests on high-voltage insulators to be used on a.c. systems*

IEC 61083-1, *Instruments and software used for measurement in high-voltage impulse tests – Part 1: Requirements for instruments*

IEC 61083-2, *Digital recorders for measurements in high-voltage impulse tests – Part 2: Evaluation of software used for the determination of the parameters of impulse waveforms*

IEC 62475, *High-current test techniques: Definitions and requirements for test currents and measuring systems*

3 Terms and definitions

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

3.1 Definitions related to characteristics of discharges

3.1.1

disruptive discharge

failure of insulation under electric stress, in which the discharge completely bridges the insulation under test, reducing the voltage between electrodes to practically zero

NOTE 1 Non-sustained disruptive discharge in which the test object is momentarily bridged by a spark or arc may occur. During these events the voltage across the test object is momentarily reduced to zero or to a very small value. Depending on the characteristics of the test circuit and the test object, a recovery of dielectric strength may occur and may even allow the test voltage to reach a higher value. Such an event should be interpreted as a disruptive discharge unless otherwise specified by the relevant Technical Committee.

NOTE 2 A disruptive discharge in a solid dielectric produces permanent loss of dielectric strength; in a liquid or gaseous dielectric the loss may be only temporary.

3.1.2

sparkover

disruptive discharge that occurs in a gaseous or liquid dielectric

3.1.3

flashover

disruptive discharge that occurs over the surface of a dielectric in a gaseous or liquid dielectric

3.1.4

puncture

disruptive discharge that occurs through a solid dielectric

3.1.5

disruptive-discharge voltage value of a test object

value of the test voltage causing disruptive discharge, as specified, for the various tests, in the relevant clauses of the present standard

3.1.6

non-disruptive discharge

discharge between intermediate electrodes or conductors where the test voltage does not collapse to zero

NOTE 1 Such an event should not be interpreted as a disruptive discharge unless so specified by the relevant Technical Committee.

NOTE 2 Some non-disruptive discharges are termed "partial discharges" and are dealt with in IEC 60270.

3.2 Definitions relating to characteristics of the test voltage

3.2.1

prospective characteristics of a test voltage

characteristics which would have been obtained if no disruptive discharge had occurred. When a prospective characteristic is used, this shall always be stated.

3.2.2

actual characteristics of a test voltage

those characteristics which occur during the test at the terminals of the test object

3.2.3

value of the test voltage

as defined in the relevant clauses of this standard

3.2.4

withstand voltage of a test object

specified prospective voltage value which characterizes the insulation of the object with regard to a withstand test

NOTE 1 Unless otherwise specified, withstand voltages are referred to standard reference atmospheric conditions (see 4.3.1).

NOTE 2 This applies to external insulation only.

3.2.5

assured disruptive-discharge voltage of a test object

specified prospective voltage value which characterizes its performance with regard to a disruptive-discharge test

3.3 Definitions relating to tolerance and uncertainty

3.3.1

tolerance

constitutes the permitted difference between the measured value and the specified value

NOTE 1 This difference should be distinguished from the uncertainty of a measurement.

NOTE 2 A pass/fail decision is based on the measured value, without consideration of the measurement uncertainty.

3.3.2

uncertainty (of measurement)

parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could be reasonably attributed to the measurand

[IEV 311-01-02]

NOTE 1 In this standard, all uncertainty values are specified at a level of confidence of 95 %.

NOTE 2 Uncertainty is positive and given without sign.

NOTE 3 It should not be confused with the tolerance of a test-specified value or parameter.

3.4 Definitions relating to statistical characteristics of disruptive-discharge voltage values

3.4.1

disruptive-discharge probability of a test object

p

probability that one application of a certain prospective voltage value of a given shape will cause disruptive discharge in the test object

NOTE The parameter p may be expressed as a percentage or a proper fraction.

3.4.2

withstand probability of a test object

q

probability that an application of a certain prospective voltage value of a given shape does not cause a disruptive discharge on the test object

NOTE If the disruptive-discharge probability is p , the withstand probability q is $(1 - p)$.

3.4.3

p % disruptive-discharge voltage of a test object

U_p

prospective voltage value which has p % probability of producing a disruptive discharge on the test object

NOTE 1 Mathematically the p % disruptive-discharge voltage is the quantile of the order p (or p quantile) of the breakdown voltage.

NOTE 2 U_{10} is called the “statistical withstand voltage” and U_{90} is called the “statistical assured disruptive-discharge voltage”.

3.4.4

50 % disruptive-discharge voltage of a test object

U_{50}

prospective voltage value which has a 50 % probability of producing a disruptive discharge on the test object

3.4.5

arithmetic mean value of the disruptive-discharge voltage of a test object,

U_a

$$U_a = \frac{1}{n} \sum_{i=1}^n U_i$$

where

U_i is the measured disruptive-discharge voltage and

n is the number of observations (discharges).

NOTE For symmetric distributions U_a is identical to U_{50} .

3.4.6

standard deviation of the disruptive voltage of a test object

s

a measure of the dispersion of the disruptive voltage estimated by

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (U_i - U_a)^2}$$

where

U_i is the i^{th} measured disruptive voltage and

U_a is the arithmetic mean of the disruptive voltages (in most cases it is identical to U_{50}).

n is the number of observations (discharges).

NOTE 1 It can also be evaluated by the difference between the 50 % and 16 % disruptive-discharge voltages (or between the 84 % and 50 % disruptive-discharge voltages). It is often expressed in per unit or percentage value referred to the 50 % disruptive-discharge voltage.

NOTE 2 For successive disruptive-discharge tests the standard deviation s is defined by the formula. For multiple level and up-and-down tests it is defined by the difference of the quantiles. The methods are equivalent because, between $p = 16$ % and $p = 84$ % all distribution functions are nearly identical.

3.5 Definitions relating to classification of insulation in test objects

3.5.1

external insulation

air insulation and the exposed surfaces of solid insulation of the equipment, which are subject both to dielectric stresses and to the direct effects of atmospheric and other external conditions

3.5.2

internal insulation

internal solid, liquid or gaseous elements of the insulation of equipment protected from the direct effects of external conditions such as pollution, humidity and vermin

3.5.3

self-restoring insulation

insulation which completely recovers its insulating properties after a disruptive discharge caused by the application of a test voltage

[IEV 604-03-04, modified]

3.5.4

non-self-restoring insulation

insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge caused by the application of a test voltage

[IEV 604-03-05, modified]

NOTE In high-voltage apparatus, parts of both self-restoring and non-self-restoring insulation are always operating in combination and some parts may be degraded by repeated or continued voltage applications. The behaviour of the insulation in this respect should be taken into account by the relevant Technical Committee when specifying the test procedures to be applied.

4 General requirements

4.1 General requirements for test procedures

The test procedures applicable to particular types of test objects, for example, the test voltage, the polarity to be used, the preferred order if both polarities are to be used, the number of applications and the interval between applications shall be specified by the relevant Technical Committee, having regard to such factors as:

- the required accuracy of the test results;
- the random nature of the observed phenomena;
- any polarity dependence of the measured characteristics and
- the possibility of progressive deterioration with repeated voltage applications.

At the time of a test, the test object shall be complete in all essential details, and it should have been processed in the normal manner for similar equipment.

At the time of a test, the test object should have become acclimatised as much as practicable to the ambient atmospheric conditions of the test area. The period allocated to reach equilibrium should be recorded.

4.2 Arrangement of the test object in dry tests

The disruptive-discharge characteristics of a test object with external insulation may be affected by its general arrangement (for example, proximity effects such as distance in air from other live or earthed structures, height above ground level and the arrangement of its high-voltage lead). The general arrangement should be specified by the relevant Technical Committee.

NOTE 1 A clearance to extraneous structures not less than 1,5 times the length of the shortest possible discharge path on the test object usually makes such proximity effects negligible. In wet or pollution tests, or wherever the voltage distribution along the test object and the electric field around its energized electrode are sufficiently independent of external influences, smaller clearances may be acceptable, provided that discharges do not occur to extraneous structures.

NOTE 2 In the case of a.c. or positive switching-impulse voltage tests above 750 kV (peak) the influence of an extraneous structure may be considered as negligible if its distance from the energized electrode is also not less than the height of this electrode above the ground plane. A guide for recommended minimum clearance is given in Figure 1, as a function of the highest test voltage. Significant shorter clearances may be suitable in individual

cases. However, an experimental adaptation or a field calculation, taking into account a voltage dependent maximum field strength as described in the literature [1, 2]¹, is recommended.

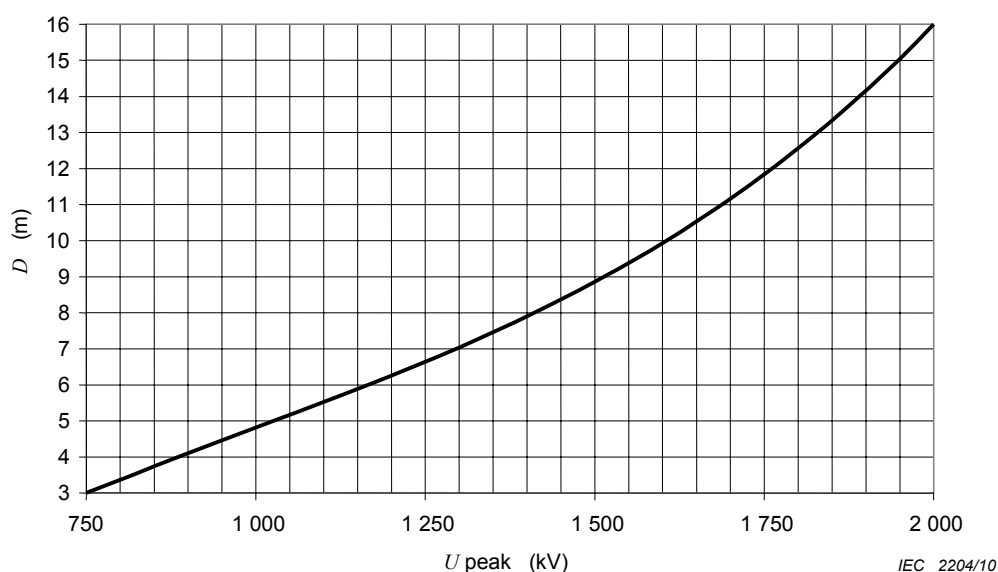


Figure 1 – Recommended minimum clearance D of extraneous live or earthed objects to the energized electrode of a test object, during an a.c. or positive switching impulse test at the maximum voltage U applied during test

If not otherwise specified by the relevant Technical Committee, the test should be made at ambient atmospheric conditions in the test area without extraneous precipitation or pollution. The procedure for voltage application shall be as specified in the relevant clauses of this standard.

4.3 Atmospheric corrections in dry tests

4.3.1 Standard reference atmosphere

The standard reference atmosphere is:

- temperature $t_0 = 20\text{ °C}$;
- absolute pressure $p_0 = 1\,013\text{ hPa}$ (1 013 mbar) ;
- absolute humidity $h_0 = 11\text{ g/m}^3$.

NOTE 1 An absolute pressure of 1 013 hPa corresponds to the height of 760 mm of the mercury column in a mercury barometer at 0 °C. If the barometer height is H mm of mercury, the atmospheric pressure in hectopascal is approximately:

$$p = 1,333 H \text{ hPa}$$

Correction for temperature with respect to the height of the mercury column is considered to be negligible.

NOTE 2 Instruments automatically correcting pressure to sea level are not suitable and should not be used.

4.3.2 Atmospheric correction factors for air gaps

The disruptive discharge of external insulation depends upon the atmospheric conditions. Usually, the disruptive-discharge voltage for a given path in air is increased by an increase in either air density or humidity. However, when the relative humidity exceeds about 80 %, the disruptive-discharge voltage becomes irregular, especially when the disruptive discharge occurs over an insulating surface.

¹ Numbers in square brackets refer to the Bibliography.

NOTE Atmospheric corrections do not apply to flashover, only to sparkover.

The disruptive-discharge voltage is proportional to the atmospheric correction factor K_t that results from the product of two correction factors:

- the air density correction factor k_1 (see 4.3.4.1);
- the humidity correction factor k_2 (see 4.3.4.2).

$$K_t = k_1 k_2$$

4.3.3 Application of correction factors

4.3.3.1 Standard procedure

By applying correction factors, a disruptive-discharge voltage measured in given test conditions (temperature t , pressure p , humidity h) may be converted to the value, which would have been obtained under the standard reference atmospheric conditions (t_0 , p_0 , h_0).

Disruptive-discharge voltages, U , measured at given test conditions are corrected to U_0 corresponding to standard reference atmosphere by dividing by K_t :

$$U_0 = U / K_t$$

The test report shall always contain the actual atmospheric conditions during the test and the correction factors applied.

4.3.3.2 Converse procedure

Conversely, where a test voltage is specified for standard reference conditions, it shall be converted into the equivalent value under the test conditions and this may require an iterative procedure.

If not otherwise specified by the relevant Technical Committee, the voltage U to be applied during a test on external insulation is determined by multiplying the specified test voltage U_0 by K_t :

$$U = U_0 K_t$$

However, as U enters into the calculation of K_t , an iterative procedure might have to be used (see Annex E).

NOTE 1 The test for the correct choice of U for the calculation of K_t is to divide U by K_t . If the result is the specified test voltage, U_0 , then a correct choice of U has been made. If U_0 is too high, U has to be reduced but if it is too low, it has to be increased.

NOTE 2 When K_t is close to unity, iterative calculation is not necessary.

NOTE 3 In correcting power-frequency voltage the peak value has to be used, because the discharge behaviour is based on the peak value.

4.3.4 Correction factor components

4.3.4.1 Air density correction factor, k_1

The air density correction factor k_1 depends on the relative air density δ and can be generally expressed as:

$$k_1 = \delta^m$$

where m is an exponent given in 4.3.4.3.

When the temperatures t and t_0 are expressed in degrees Celsius and the atmospheric pressures p and p_0 are expressed in the same units, the relative air density is:

$$\delta = \frac{p}{p_0} \times \frac{273+t_0}{273+t}$$

The correction is considered reliable for $0,8 < k_1 < 1,05$.

4.3.4.2 Humidity correction factor, k_2

The humidity correction factor may be expressed as:

$$k_2 = k^w$$

where w is an exponent given in 4.3.4.3 and k is a parameter that depends on the type of test voltage and may be obtained as a function of the ratio of absolute humidity, h , to the relative air density, δ , using the following equations (Figure 2):

DC $k = 1 + 0,014(h/\delta - 11) - 0,00022(h/\delta - 11)^2$ for $1 \text{ g/m}^3 < h/\delta < 15 \text{ g/m}^3$

AC $k = 1 + 0,012(h/\delta - 11)$ for $1 \text{ g/m}^3 < h/\delta < 15 \text{ g/m}^3$

Impulse $k = 1 + 0,010(h/\delta - 11)$ for $1 \text{ g/m}^3 < h/\delta < 20 \text{ g/m}^3$

NOTE The impulse equation is based on experimental results for positive lightning-impulse waveforms. This equation also applies to negative lightning-impulse voltages and switching-impulse voltages.

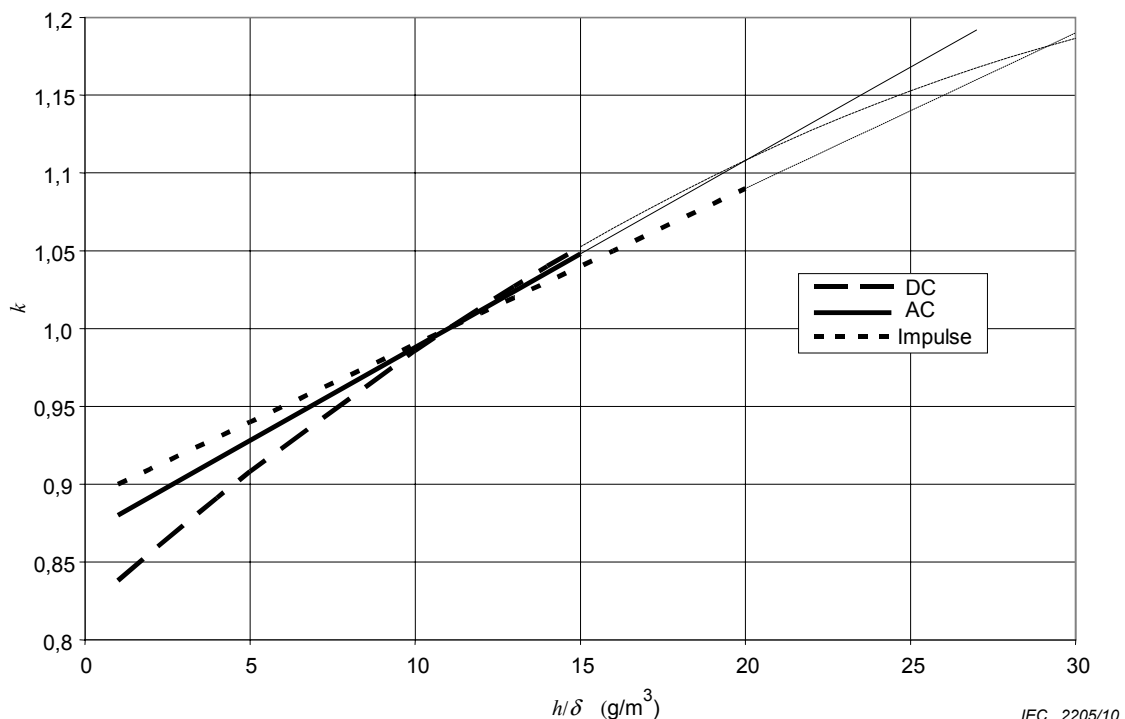


Figure 2 – k as a function of the ratio of the absolute humidity h to the relative air density δ (see 4.3.4.2 for limits of applicability)

For U_m below 72,5 kV (or approximately gap lengths $l < 0,5$ m) no humidity correction can at present be specified.

NOTE For specific apparatus, the relevant Technical Committee has specified other procedures (e.g. IEC 62271-1).

4.3.4.3 Exponents m and w

As the correction factors depend on the type of pre-discharges, this fact can be taken into account by considering the parameter:

$$g = \frac{U_{50}}{500 L \delta k}$$

where U_{50} is the 50 % disruptive-discharge voltage (measured or estimated) at the actual atmospheric conditions, in kilovolt peak,

L is the minimum discharge path in m,

δ is the relative air density and

k is the dimension less parameter defined in 4.3.4.2.

In the case of a withstand test where an estimate of the 50 % disruptive-discharge voltage is not available, U_{50} can be assumed to be 1,1 times the test voltage, U_0 .

The exponents, m and w , are obtained from Table 1 for the specified ranges of g (Figure 3).

Table 1 – Values of exponents, m for air density correction and w for humidity correction, as a function of the parameter g

g	m	w
$<0,2$	0	0
0,2 to 1,0	$g(g-0,2)/0,8$	$g(g-0,2)/0,8$
1,0 to 1,2	1,0	1,0
1,2 to 2,0	1,0	$(2,2-g)(2,0-g)/0,8$
$>2,0$	1,0	0

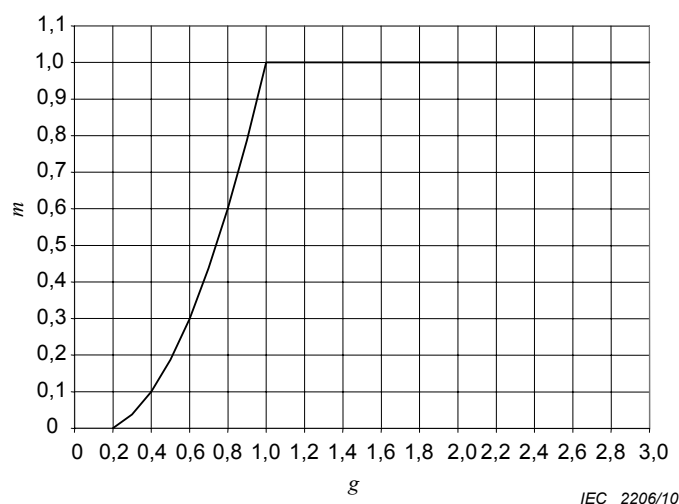


Figure 3a – Values of exponent m for air density correction as a function of parameter g

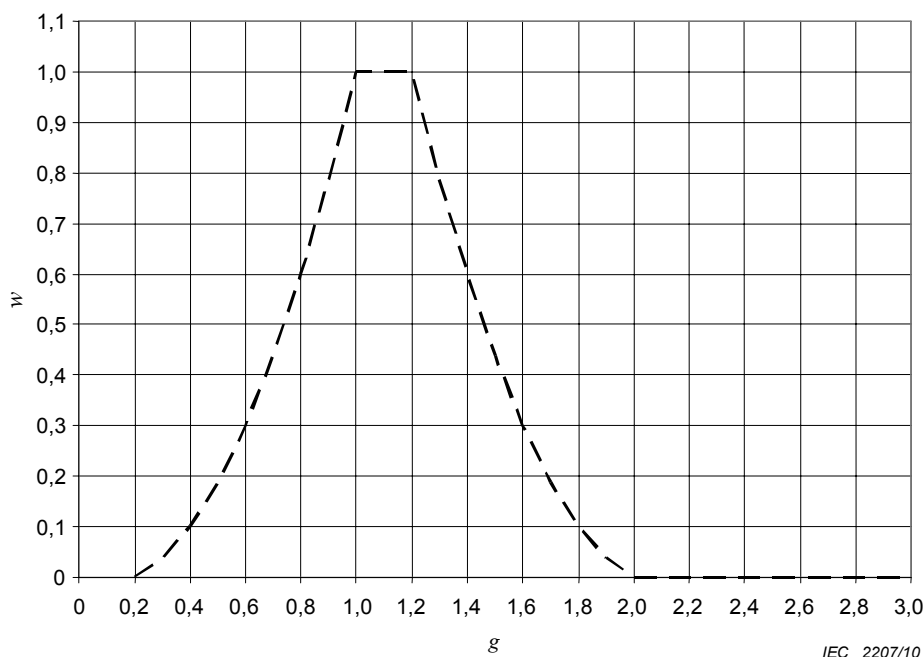


Figure 3b – Values of exponent w for humidity correction as a function of parameter g

Figure 3 – Values of exponents m and w

4.3.5 Measurement of atmospheric parameters

4.3.5.1 Humidity

The humidity should preferably be determined with an instrument measuring directly the absolute humidity with an expanded uncertainty not larger than 1 g/m^3 .

Measurement of relative humidity and the ambient temperature can also be used for the determination of the absolute humidity, using the formula below, provided that the accuracy of the absolute humidity determination in this case is the same as required above.

$$h = \frac{6,11 \times R \times e^{\frac{17,6 \times t}{243+t}}}{0,4615 \times (273 + t)}$$

where

h is the absolute humidity in g/m^3 ,

R is the relative humidity in percent and

t is the ambient temperature in $^{\circ}\text{C}$.

NOTE This measurement may also be made by means of a ventilated wet and dry bulb hygrometer. The absolute humidity as a function of the thermometer readings is determined from Figure 4, which also permits determination of the relative humidity. It is important to provide adequate airflow so as to reach a steady state and to read the thermometers carefully in order to avoid excessive errors in the determination of the humidity.

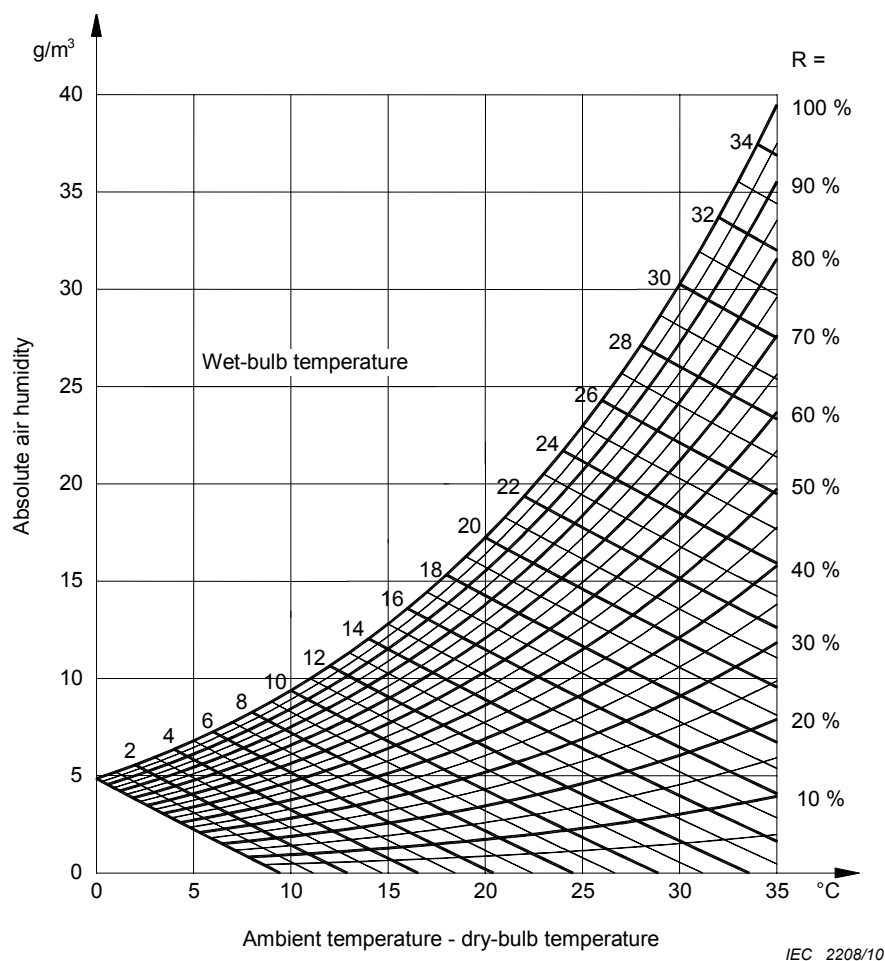


Figure 4 – Absolute humidity of air as a function of dry- and wet-bulb thermometer readings

4.3.5.2 Temperature

The ambient temperature should be measured with an expanded uncertainty of not larger than 1 °C.

4.3.5.3 Absolute pressure

The ambient absolute pressure should be measured with an expanded uncertainty of not larger than 2 hPa.

4.3.6 Conflicting requirements for testing internal and external insulation

While withstand levels are specified under standard reference atmospheric conditions, cases will arise where the application of atmospheric corrections (due to atmospheric conditions differing from the standard reference ones) results in the withstand level for internal insulation appreciably in excess of that for the associated external insulation. In such cases measures to enhance the withstand level of the external insulation shall be adopted to permit application of the correct test voltage to the internal insulation. These measures should be specified by the relevant Technical Committee with reference to the requirements of particular classes of apparatus and could include immersion of the external insulation in liquids or compressed gases.

For those cases where the test voltage of the external insulation is higher than that of the internal insulation, the external insulation can only be correctly tested when the internal

insulation is especially designed with increased strength. If not, the internal insulation should be tested with the rated value and the external insulation be tested by means of test fixtures unless the relevant Technical Committee states otherwise, in which case it shall specify the test procedure to be used.

4.4 Wet tests

4.4.1 Wet test procedure

This wet test procedure is intended to simulate the effect of natural rain on external insulation. It is recommended for tests with all types of test voltages and on all types of apparatus.

The relevant Technical Committee should specify the arrangement of the test object during the test.

The test object shall be sprayed with water of prescribed resistivity and temperature (see Table 2) falling on it as droplets (avoiding fog and mist) and directed so that the vertical and horizontal components of the spray intensity are approximately equal. These intensities are measured with a divided collecting vessel having openings of 100 cm² to 750 cm², one horizontal and one vertical with the vertical opening facing the spray.

The position of the test object relative to the vertical and horizontal rain components shall be specified by the relevant Technical Committee.

In general, the reproducibility of wet test results is less than that for other high-voltage discharge or withstand tests. To minimize the dispersion, the following precautions shall be taken:

- The collecting vessel shall be placed close to the test object, but avoiding the collection of drops or splashes from it. During the measuring period, it should be moved slowly over a sufficient area to average the effect of non-uniformities of the spray from individual nozzles. This measuring zone shall have a width equal to that of the test object and a maximum height of 1 m.
- For test objects between 1 m and 3 m in height, the individual measurements shall be made at the top, centre and bottom of the test object. Each measuring zone shall cover only one third of the height of the test object.
- For test objects exceeding 3 m in height, the number of measuring zones shall be increased to cover the full height of the test object without overlapping.
- The above procedures shall be suitably adapted for test objects having large horizontal dimensions.
- The spread of results may be reduced if the test object is cleaned with a surface-active detergent, which has to be removed before the beginning of wetting.
- The spread of results may also be affected by local anomalous (high or low) precipitation rates. It is recommended to detect these by localized measurements and to improve the uniformity of the spray, if necessary.

The spray apparatus shall be adjusted to produce, within the specified tolerances, precipitation conditions at the test object given in Table 2.

Any type and arrangement of nozzles meeting the requirements given in Table 2 may be used.

Table 2 – Precipitation conditions for standard procedure

Precipitation condition	Unit	Range
Average precipitation rate of all measurements:		
– vertical component	[mm/min]	1,0 to 2,0
– horizontal component	[mm/min]	1,0 to 2,0
Limits for any individual measurement and for each component	[mm/min]	±0,5 from average
Temperature of water	[°C]	Ambient temperature ±15
Conductivity of water	[µS/cm]	100 ± 15

The water temperature and resistivity shall be measured on a sample collected immediately before the water reaches the test object. They may also be measured at other locations (e.g., in a storage reservoir) provided that a check ensures that no significant change occurs by the time the water reaches the test object.

The test object shall be pre-wetted initially for at least 15 min under the above-specified conditions and these conditions shall remain within the specified tolerances throughout the test, which should be performed without interrupting the wetting. The pre-wetting time shall not include the time needed for adjusting the spray. It is also possible to perform an initial pre-wetting by unconditioned mains water for 15 min, followed without interruption of the spray by a second pre-wetting for at least 2 min before the test begins, using water with all the correct precipitation conditions, which should be measured immediately before starting the test.

Unless otherwise specified by the relevant Technical Committee, the test procedure for wet tests shall be the same as that specified for the corresponding dry tests. The test duration for an a.c. test shall be 60 s, if not otherwise specified. In general, for alternating and direct voltage wet withstand tests, it is recommended that one flashover should be permitted provided that in a repeat test no further flashover occurs.

NOTE For a.c. apparatus of large dimensions, such as those having a maximum rated voltage, U_m , higher than 800 kV, no appropriate wet test procedure is available at present.

4.4.2 Atmospheric corrections for wet tests

A density correction factor shall be applied as specified in 4.3, but no humidity correction factor shall be applied for wet tests.

4.5 Artificial pollution tests

Artificial pollution tests are intended to provide information on the behaviour of external insulation under conditions representative of pollution in service, although they do not necessarily simulate any particular service conditions. They are described in IEC 60507.

5 Tests with direct voltage

5.1 Definitions for direct voltage tests

5.1.1

value of the test voltage

arithmetic mean value

5.1.2

ripple

periodic deviation from the arithmetic mean value of the test voltage

5.1.3

ripple amplitude

half the difference between the maximum and minimum values

NOTE In cases where the ripple shape is nearly sinusoidal, true r.m.s. values multiplied by $\sqrt{2}$ are acceptable for determination of the ripple amplitude.

5.1.4

ripple factor

ratio of the ripple amplitude to the value of test voltage

5.1.5

voltage drop

instantaneous reduction of the test voltage for a short duration of up to a few seconds

NOTE Voltage drop may be caused by non-disruptive discharges.

5.2 Test voltage

5.2.1 Requirements for the test voltage

5.2.1.1 Voltage shape

The test voltage, as applied to the test object, should be a direct voltage with not more than 3 % ripple factor, unless otherwise specified by the relevant Technical Committee.

NOTE Increasing ripple amplitude is directly related to increasing resistive load currents. Dielectric testing where heavy streamers are present may cause excessive ripple and/or voltage drop. Wet testing and pollution testing by their very nature require sources suitable for high resistive currents, see IEC 60507.

5.2.1.2 Tolerances

For test durations not exceeding 60 s, the measured values of the test voltage shall be maintained within ± 1 % of the specified level throughout the test. For test durations exceeding 60 s, the measured value of the test voltage shall be maintained within ± 3 % of the specified level throughout the test.

NOTE It is emphasized that the tolerance constitutes the permitted difference between the specified value and that actually measured. This difference should be distinguished from the uncertainty of a measurement (see 3.3.1).

The source characteristics should be sufficient to allow charging of the capacitance of the test object in a reasonably short time. In the case of wet or pollution tests, the source, including its storage capacitance, should also be adequate to supply the transient discharge currents of the test object with a voltage drop of < 10 %.

5.2.2 Generation of the test voltage

The test voltage is generally obtained by means of transformer rectifier circuits. The requirements to be met by the test-voltage source depend considerably upon the type of apparatus that is to be tested and on the test conditions. These requirements are determined mainly by the value and nature of the test current to be supplied, the important constituents of which are indicated in 5.2.4.

5.2.3 Measurement of the test voltage

The measurement of the arithmetic mean value, the ripple factor and any transient in the test voltage shall be made with approved measuring systems (see IEC 60060-2).

Attention is drawn to the requirements the on response characteristics of converting devices used for measuring ripple, transients or voltage stability.

5.2.4 Measurement of the test current

When measurements of current are made through the test object, a number of separate components may be recognized. These differ from each other by several orders of magnitude for the same test object and test voltage. They consist of:

- the capacitive current, due to the initial application of the test voltage and to any ripple or other fluctuations imposed on it;
- the dielectric absorption current, due to slow charge displacements within the insulation and persisting for periods of a few seconds up to several hours. This process is partially reversible, currents of the opposite polarity being observed when the test object is discharged and short-circuited;
- the continuous leakage current, which is the final steady direct current attained at constant applied voltage after the above components have decayed to zero;
- partial discharge currents.

Measurement of the first three components necessitates the use of instruments covering a wide range of current magnitudes. It is important to ensure that the instrument, or the measurement of any one component of the current, is not adversely affected by the other components. Information concerning the condition of the insulation may sometimes be obtained by observing current variations with respect to time, during non-destructive tests.

The relative magnitude and the importance of each component of current depend on the type and the condition of the test object, the purpose for which the test is being made and the duration of the test. Accordingly, the measurement procedures should be specified by the relevant Technical Committee, especially when it is required to distinguish a particular component.

Current measurements shall be made with a calibrated measuring system.

Measurements of partial discharge pulse currents are made with special instruments, which are dealt with in IEC 60270.

NOTE Voltage protective devices should always be used in d.c. current measurement circuits due to the possibility of disruptive-discharge currents occurring that are much larger than the normal currents.

5.3 Test procedures

5.3.1 Withstand voltage tests

The voltage should be applied to the test object starting at a value sufficiently low to prevent any effect of overvoltage due to switching transients. It should be raised sufficiently slowly to permit reading of the measuring instruments, but not so slowly as to cause unnecessary prolongation of stress to the test object near the test voltage U . These requirements are in general met if the rate of rise is about 2 % of U per second when the applied voltage is above 75 % of U . It shall be maintained for the specified time and then reduced by discharging the circuit capacitance, including that of the test object, through a suitable resistor.

The test duration shall be specified by the relevant Technical Committee taking into consideration that the time to reach the steady-state voltage distribution depends on the resistances and capacitances of the test object components. When not otherwise specified by the relevant Technical Committee, the duration of a withstand test shall be 60 s.

The polarity of the voltage or the order in which voltages of each polarity are applied, and any required deviation from the above specifications, shall be specified by the relevant Technical Committee.

The requirements of the test are satisfied if no disruptive discharge occurs on the test object.

5.3.2 Disruptive-discharge voltage tests

The voltage shall be applied and raised continuously, as for a withstand voltage test, until a disruptive discharge occurs on the test object. The last value of the test voltage recorded before the instant of the disruptive discharge shall be recorded. This shall be repeated for the number of times n specified in the test procedure to give a set of n measured voltages.

The relevant Technical Committee shall specify the rate of voltage rise, the number of voltage applications and the procedure for evaluating the test results (see Annex A).

5.3.3 Assured disruptive-discharge voltage tests

The voltage shall be applied and raised continuously, as for a withstand voltage test, until a disruptive discharge occurs on the test object. The last value of the test voltage reached just before the instant of the disruptive discharge shall be recorded. This shall be repeated for the number of times n specified in the test procedure to give a set of n measured voltages.

The requirements of the test are satisfied if no voltage in this set exceeds the assured disruptive-discharge voltage.

The relevant Technical Committee shall specify the number of voltage applications and the rate of voltage rise.

6 Tests with alternating voltage

6.1 Definitions for alternating voltage tests

6.1.1

peak value of an alternating voltage

average of the magnitudes of the positive and negative peak values

NOTE In many cases instruments measuring only one polarity peak are used. Measuring only one polarity is acceptable as long as waveform symmetry is within the limits set in 6.2.1.1.

6.1.2

value of the test voltage

its peak value divided by $\sqrt{2}$

NOTE The relevant Technical Committee may require a measurement of the r.m.s. value of the test voltage instead of the peak value for cases where the r.m.s. value may be of importance, for instance, when thermal effects are involved.

6.1.3

r.m.s. value

square root of the mean value of the square of the voltage values during a complete cycle

6.1.4

voltage drop

instantaneous reduction of the test voltage for a short duration of up to a few periods

6.2 Test Voltage

6.2.1 Requirements for the test voltage

6.2.1.1 Voltage waveshape

The test voltage shall be an alternating voltage generally having a frequency in the range 45 Hz to 65 Hz, normally referred to as power-frequency test voltage. Special tests may be required at frequencies considerably below or above this range, as specified by the relevant Technical Committee.

NOTE IEC 60060-3 describes alternating test voltages for frequencies from 10 Hz to 500 Hz.

The voltage waveshape shall approximate to a sinusoid with the difference of the magnitudes of the positive and negative peak values being less than 2 %.

The results of a high-voltage test are thought to be unaffected by small deviations from a sinusoid if the ratio of peak to r.m.s. values equals $\sqrt{2}$ within ± 5 %.

For some test circuits in common use greater deviations have to be accepted. Note that the test object, especially if it has non-linear characteristics, may considerably affect the deviation from a sinusoid.

NOTE In addition to the above requirement, the total harmonic distortion (THD) can be used to characterize the wave shape distortion as this might be important for partial discharge pattern recognition measurements. Specifications may be given by the relevant Technical Committee.

6.2.1.2 Tolerances

For test durations not exceeding 60 s, the measured values of the test voltage shall be maintained within ± 1 % of the specified level throughout the test. For test durations exceeding 60 s the measured value of the test voltage shall be maintained within ± 3 % of the specified level throughout the test.

The test voltage source including the supporting capacitances should be adequate to supply the transient discharge currents also in the case of wet and pollution tests with a voltage drop of ≤ 20 %.

NOTE It is emphasized that the tolerance constitutes the permitted difference between the specified value and that actually measured. This difference should be distinguished from the uncertainty of a measurement (see 3.1.1).

6.2.2 Generation of the test voltage

6.2.2.1 General requirements

The test voltage is generally supplied from a step-up transformer. Alternatively, it may be generated by means of a series-resonant or parallel-resonant circuit.

The voltage in the test circuit shall be stable enough to be practically unaffected by varying leakage currents. Non-disruptive discharges in the test object shall not reduce the test voltage to such an extent and for such a time that the measured disruptive-discharge voltage of the test object is significantly affected.

NOTE Attention is drawn to the possibility that such non-disruptive discharges may cause large over swings of voltage between the terminals of the test object. This phenomenon may cause failure of the test object or of the testing source. Introduction of a resistance to the high-voltage circuit can dampen such overvoltage transients but the resistance should be of a sufficiently low value so as not to affect the test voltage delivered to the test object.

The total capacitance of the test object and of any additional capacitor should be sufficient to ensure that the measured disruptive-discharge voltage is unaffected by non-disruptive partial discharges or pre-discharges in the test object. A capacitance in the range from 0,5 nF to 1,0 nF is generally sufficient.

6.2.2.2 Requirements for the transformer test circuit

High-voltage tests normally result in load currents with superimposed time varying current pulses as voltage is increased. The magnitude and duration of the current pulses is influenced by the test arrangement, the conductors used to connect the test object, atmospheric conditions, the characteristics of the test source and other factors. It is normal for apparatus to produce some current pulses since the test voltages are much higher than the operational voltages and these devices often lack large electrodes and ground shields to keep the test object electrically quiet. Since the current pulses are of short duration, voltage drops may be unrecognized by conventional AC measuring systems. The voltage stability of an a.c. test

system used in tests with time varying leakage current pulses can be verified by using a voltage measuring system with sufficient bandwidth.

For dry tests below 100 kV on samples of solid insulation, insulating liquids or combinations of the two a test source rated current of >100 mA and a system (transformer, regulator, etc. or generator) short circuit impedance of <20 % is generally sufficient.

For dielectric tests above 100 kV on external self-restoring insulation (low capacitance test objects such as insulators, circuit breakers and switches) a test source rated current of >100 mA and a system short circuit impedance of <20 % is generally sufficient for dry tests where no streamers are present.

For dielectric tests above 100 kV test system current ratings of 1 A and system short circuit impedances <20 % may be necessary if continuous streamers are encountered or if wet tests are performed. When continuous streamers are present it is recommended that faster responding voltage measurements are made to ensure that the test voltage is held within the voltage drop limit for the duration of the test. Alternatively, counter measures such as increasing electrode diameters or using larger connecting conductors can be used to reduce the streamers.

Short duration current pulses encountered at any test voltage are mostly supplied from the charge stored in capacitance in the test circuit. It is recommended that for tests above 100 kV a circuit capacitance greater than or equal to 1 000 pF be installed.

For tests under artificial pollution, steady state current ratings of 1 A to 5 A may be necessary. See IEC 60507.

6.2.2.3 The series-resonant circuit

The series-resonant circuit consists essentially of an inductor in series with a capacitive test object or load connected to a medium-voltage power source. Alternatively it may consist of a capacitor in series with an inductive test object. By varying the circuit parameters or the supply frequency, the circuit can be tuned to resonance, when a voltage considerably greater than that of the source and of substantially sinusoidal shape is applied to the test object.

The stability of the resonance conditions and of the test voltage depends on the stability of the supply frequency and of the test system characteristic, described by the quality factor, which is the ratio between test reactive power and power loss.

When a discharge occurs, the circuit capacitance discharges instantaneously and then the follow-through current from the source is relatively low. The limited follow-through current generally results in less damage to the test object.

The series-resonant circuit is especially useful when testing capacitive objects in which the leakage currents on the external insulation are small in comparison with the capacitive currents through the test object or the energy to form a disruptive discharge is very small. A series resonant circuit can supply higher leakage currents as additional capacitance is added to the circuit. A series-resonant circuit is also useful for testing reactors with sufficient circuit capacitance.

The series resonant circuit may be unsuitable for testing external insulation under wet or polluted conditions, unless the requirements of 6.2.2.1 are satisfied. In general, wet tests can be performed with adequate preload capacitance added.

6.2.3 Measurement of the test voltage

The measurement of the value of the test voltage, the r.m.s. value, and the transient drops shall be made with an approved measuring system (see IEC 60060-2).

6.2.4 Measurement of the test current

The current is usually measured by a conventional current transformer coupled to the ground lead of the test object. It can also be measured in the high-voltage lead to the test object.

Current measurements shall be made with a calibrated measuring system.

NOTE The current can also be measured in the earthed lead of the step-up transformer or resonance reactor, provided the current of any parallel capacitor can be neglected.

6.3 Test procedures

6.3.1 Withstand voltage tests

The voltage shall be applied to the test object starting at a value sufficiently low to prevent any effect of overvoltages due to switching transients or due to uncontrolled resonance conditions. It should be raised sufficiently slowly to permit reading of the measuring instrument but not so slowly as to cause unnecessary prolongation of the stressing of the test object near to the test voltage U . These requirements are in general met if the rate of rise is about 2 % of U per second, when the applied voltage is above 75 % of U . It shall be maintained for the specified time and then rapidly decreased, but not suddenly interrupted as this may generate switching transients, which could cause damage or erratic test results.

The test duration shall be specified by the relevant Technical Committee and shall be independent of the frequency in the range from 45 Hz to 65 Hz. If not specified by the relevant Technical Committee the duration of a withstand test shall be 60 s.

The requirements of the test are satisfied if no disruptive discharge occurs on the test object.

6.3.2 Disruptive-discharge voltage tests

The voltage shall be applied and raised continuously, as for a withstand voltage test, until a disruptive discharge occurs on the test object. The last value of the test voltage recorded before the instant of the disruptive discharge shall be recorded. This shall be repeated for the number of times n specified in the test procedure to give a set of n measured voltages.

The relevant Technical Committee shall specify the rate of rise of the voltage, the number of voltage applications and the procedure for evaluating the test results (see Annex A).

6.3.3 Assured disruptive-discharge voltage tests

The voltage shall be applied and raised continuously, as for a withstand voltage test, until a disruptive discharge occurs on the test object. The last value of the test voltage recorded before the instant of the disruptive discharge shall be recorded. This shall be repeated for the number of times n specified in the test procedure to give a set of n measured voltages.

The requirements of the test are satisfied if no voltage in this set exceeds the assured disruptive-discharge voltage.

The relevant Technical Committee shall specify the number of voltage applications and the rate of rise of the voltage.

7 Tests with lightning-impulse voltage

7.1 Definitions for lightning-impulse voltage tests

7.1.1

impulse voltage

intentionally applied aperiodic transient voltage, which usually rises rapidly to a peak value and then falls more slowly to zero

NOTE For special purposes, impulses having approximately linearly rising fronts or transients of oscillating or approximately rectangular form are used.

7.1.2

lightning-impulse voltage

impulse voltage with a front time less than 20 μs

7.1.3

full lightning-impulse voltage

lightning-impulse voltage, which is not interrupted by a disruptive discharge (see Figure 5)

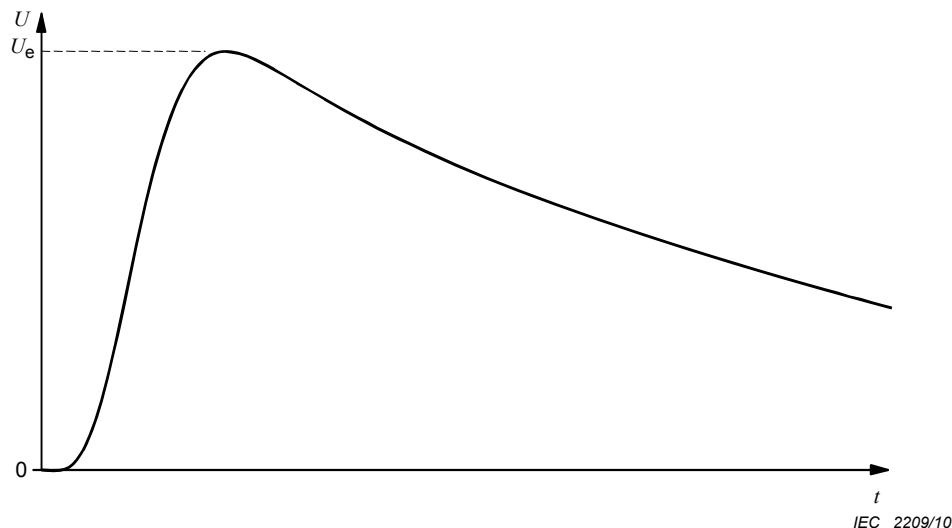


Figure 5 – Full lightning-impulse voltage

7.1.4

overshoot

increase of amplitude of an impulse voltage due to a damped oscillation at the peak caused by the circuit

NOTE Such oscillations (frequency range usually 0,1 MHz to 2 MHz) are caused by circuit inductance and sometimes cannot be avoided in large circuits or for inductive test objects. Methods for evaluation of overshoot are given in Annex B.

7.1.5

recorded curve

graphical or digital representation of the test data of an impulse voltage

7.1.6

base level

level of a record of an impulse measuring system when there is zero input to the recording instrument

7.1.7**base curve**

estimate of a full lightning-impulse voltage without a superimposed oscillation (see Annex B)

7.1.8**residual curve** $R(t)$

difference between the recorded curve and the base curve (see Annex B)

7.1.9**extreme value** U_e

maximum value of the recorded curve measured from the base level in the same sense as the applied impulse

7.1.10**base curve maximum** U_b

maximum value of the base curve

7.1.11**test voltage function**

amplitude-frequency function which is defined to represent the response of insulation to impulses with overshoot. It is given by:

$$k(f) = \frac{1}{1 + 2,2f^2}$$

where f is the frequency in MHz (see Figure 6).

NOTE 1 Different test voltage curves for different types of insulation may be specified by the relevant Technical Committee when more test data becomes available.

NOTE 2 Applying this function as a filter to the residual voltage curve allows the calculation of the value of the test voltage of the equivalent full lightning-impulse voltage (see Annex B, Annex C and Annex D).

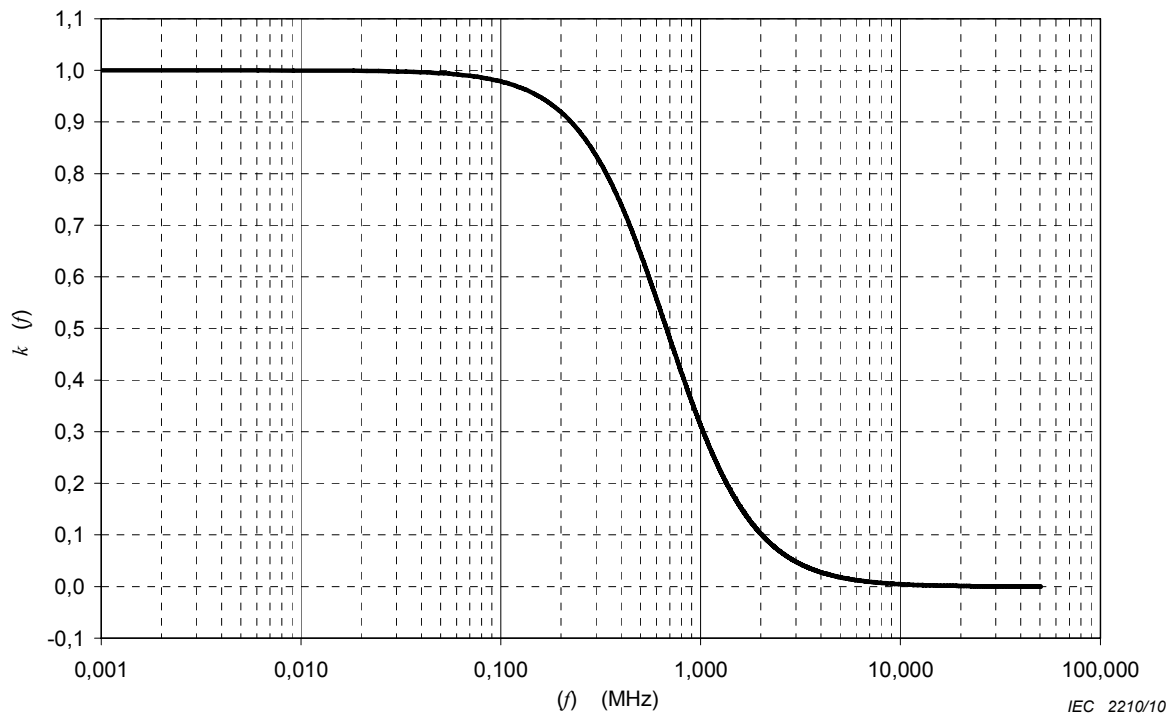


Figure 6 – Test voltage function

7.1.12

filtered residual curve

$R_f(t)$

residual curve filtered by the test voltage function

7.1.13

test voltage curve

summation of the base curve and the filtered residual curve

NOTE This is a mathematical representation of the filtering process and is not a physical entity or an equivalent impulse.

7.1.14

equivalent smooth impulse

estimated lightning-impulse voltage without overshoot having a peak value equal to the maximum value of the test voltage curve and the same front time and time to half-value as the related test voltage curve

NOTE An equivalent smooth impulse has the same dielectric breakdown behaviour as the recorded curve.

7.1.15

value of the test voltage

U_t

maximum value of the test voltage curve measured from the base level in the same sense as the applied impulse

7.1.16

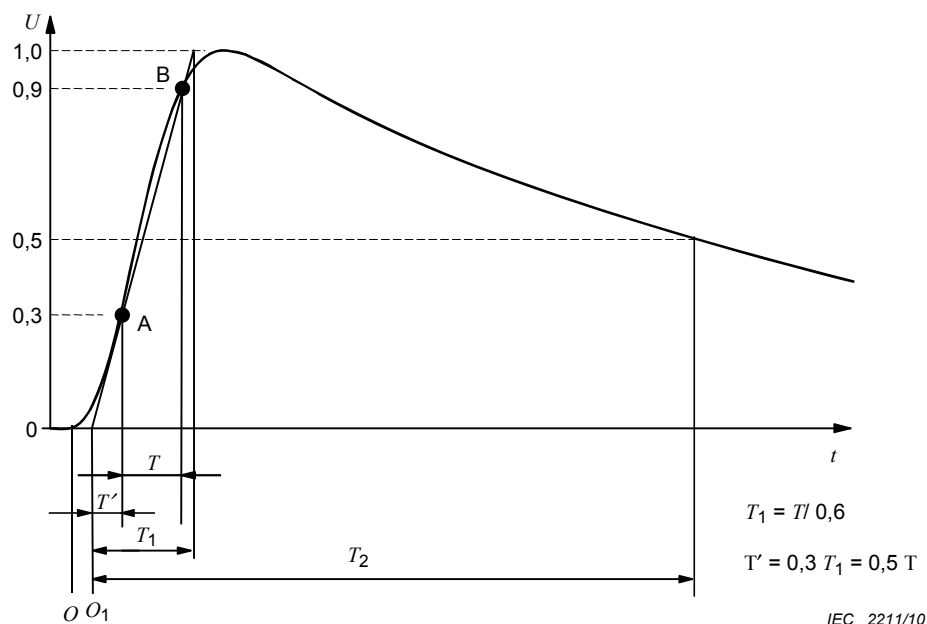
overshoot magnitude

β

difference between the extreme value of the recorded curve and the maximum value of the base curve

7.1.17**relative overshoot magnitude** β'

ratio of the overshoot magnitude to the extreme value, usually expressed as a percentage

7.1.18**front time** T_1 virtual parameter defined as $1/0,6$ times the interval T between the instants when the impulse is 30 % and 90 % of the peak value on the test voltage curve (points A and B, Figure 7)**Figure 7 – Full impulse voltage time parameters****7.1.19****virtual origin** O_1 instant preceding that corresponding to point A, of the test voltage curve (see Figure 7) by a time $0,3 T_1$

NOTE For records having linear time scales, this is the intersection with the time axis of a straight line drawn through the reference points A and B on the front.

7.1.20**average rate of rise**

slope of the best fitting straight line, calculated from the recorded curve, using all the data points between the 30 % and 90 % of the extreme value levels and usually expressed in kilovolts per microsecond

NOTE In the case of noise or oscillations at the 30 % and 90 % levels, the data set is bounded by the first point after the last crossing of the 30 % level and by the last point before the first crossing of the 90 % level.

7.1.21**peak time** T_e extreme value, U_e , divided by the average rate of rise

7.1.22

time to half-value

T_2

virtual parameter defined as the time interval between the virtual origin, O_1 , and the instant when the test voltage curve has decreased to half the test voltage value (see Figure 7)

7.1.23

voltage time interval

T_λ

time interval for which the recorded curve exceeds λU_e where $0 < \lambda < 1$ (see Figure 8)

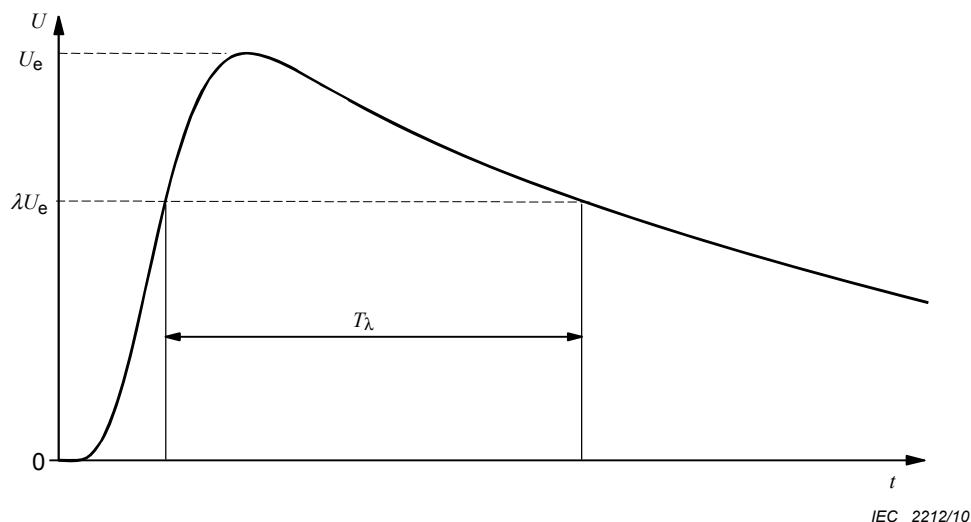


Figure 8 – Voltage time interval

7.1.24

voltage integral

integral of the recorded curve with respect to time over a specified time interval (see Figure 9).

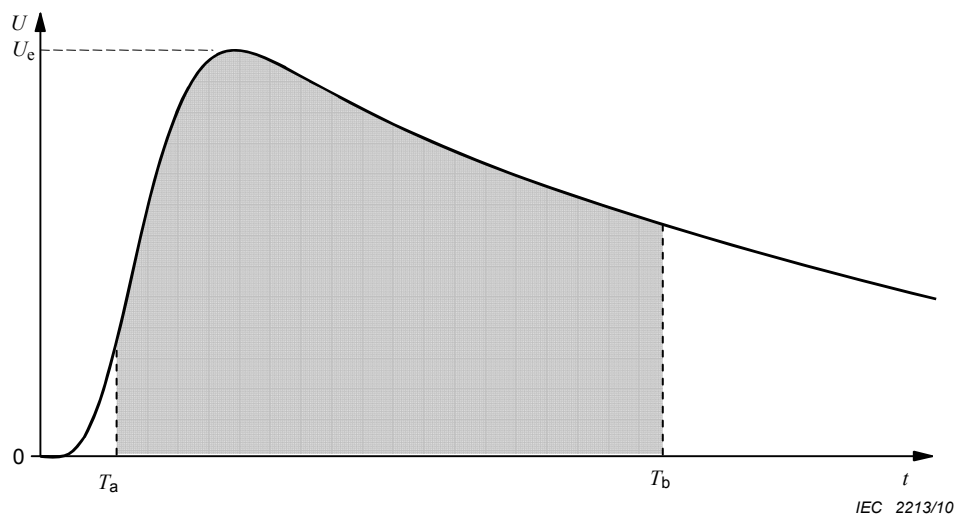


Figure 9 – Voltage integral

7.1.25**chopped lightning-impulse voltage**

lightning-impulse voltage during which a disruptive discharge causes a rapid collapse of the voltage, practically to zero value (see Figure 10 to Figure 12).

7.1.26**instant of chopping**

instant at which the extrapolation of the line between the 70 % and 10 % points (C and D) on the voltage collapse crosses the level immediately before the collapse (see Figure 10 and Figure 11).

7.1.27**time to chopping**

T_C

virtual parameter defined as the time interval between the virtual origin O_1 and the instant of chopping (see Figure 10 and Figure 11).

7.1.28**characteristics related to the voltage collapse during chopping**

two points C and D at 70 % and 10 % of the voltage immediately before the voltage collapse (see Figure 11)

NOTE 1 The duration of the voltage collapse is defined as 1/0,6 times the time interval between points C and D. The steepness of the voltage collapse is the ratio of the voltage at the instant of chopping to the duration of voltage collapse.

NOTE 2 The use of points C and D is for definition purposes only; it is not implied that the duration and steepness of chopping can be measured with any degree of accuracy using conventional measuring systems.

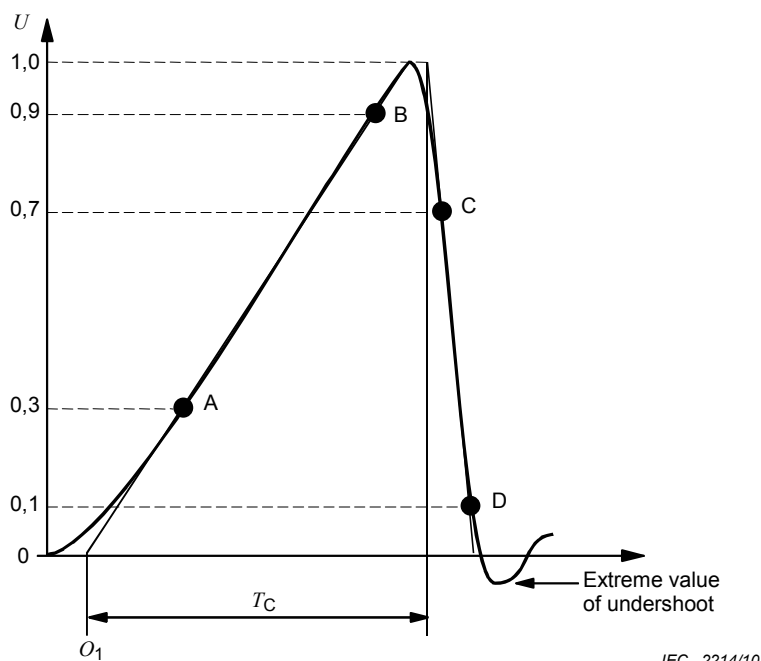


Figure 10 – Lightning-impulse voltage chopped on the front

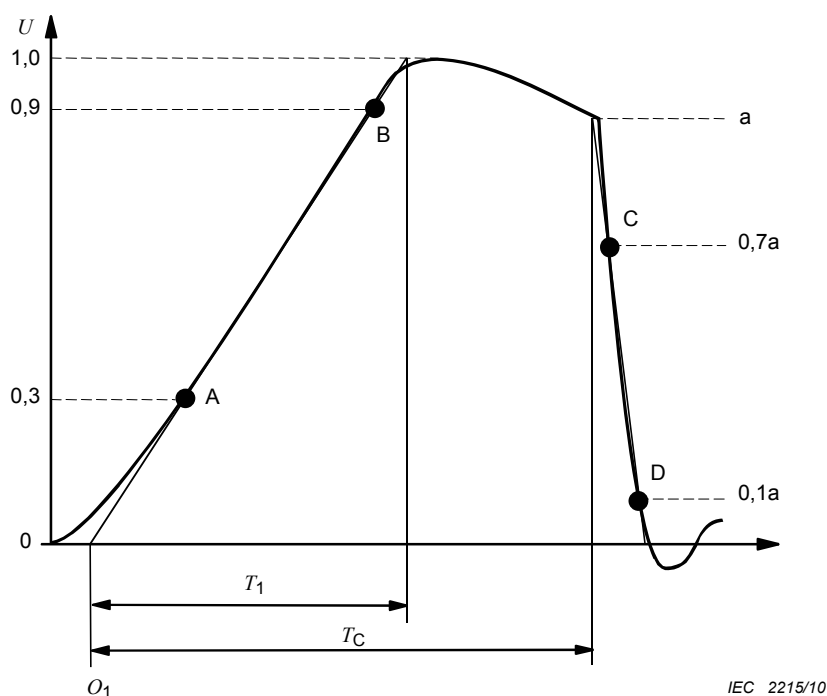


Figure 11 – Lightning-impulse voltage chopped on the tail

7.1.29

extreme value of the undershoot of an impulse

maximum amplitude measured from the base level in the opposite sense to the applied impulse (see Figure 10).

7.1.30

linearly rising front-chopped impulse

voltage rising with approximately constant steepness, until it is chopped by a disruptive discharge

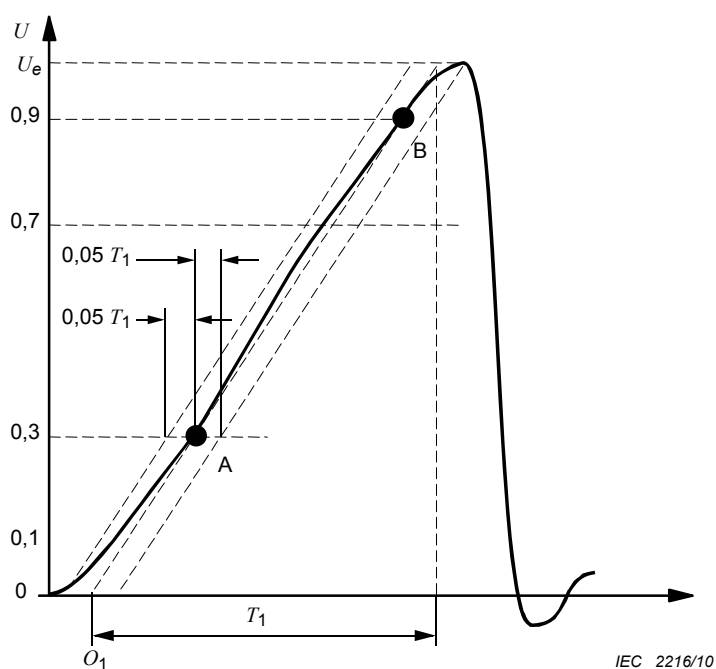


Figure 12 – Linearly rising front chopped impulse

NOTE 1 To define such an impulse, the best fitting straight line is drawn through the part of the front between 30 % and 90 % of the peak magnitude; the intersections of this with the 30 % and 90 % voltage values then being designated A and B, respectively (see Figure 12).

The impulse is defined by:

- the maximum voltage U_e ;
- the front time T_1 and
- the virtual steepness S : $S = U_e / T_1$.

This is the slope of the straight line drawn through the points A and B, usually expressed in kilovolts per microsecond.

This chopped impulse is considered to be approximately linearly rising if the front, from 30 % amplitude up to the instant of chopping, is entirely enclosed between two lines parallel to the line AB, but displaced from it in time by $\pm 0,05 T_1$ (see Figure 12).

NOTE 2 The value and the tolerance on the virtual steepness S should be specified by the relevant Technical Committee.

7.1.31

Definitions for voltage/time curves

7.1.31.1

voltage/time curve for linearly rising impulse voltage

curve relating the discharge voltage to the front time T_1

NOTE The curve is obtained by applying impulse voltages of different steepness (see Figure 13).

7.1.31.2

voltage/time curve for impulse voltage of constant prospective shape

curve relating the disruptive-discharge voltage of the test object to the time to chopping, which may occur on the front, at the peak or on the tail

NOTE The curve is obtained by applying impulse voltages with different prospective peak values (see Figure 13).

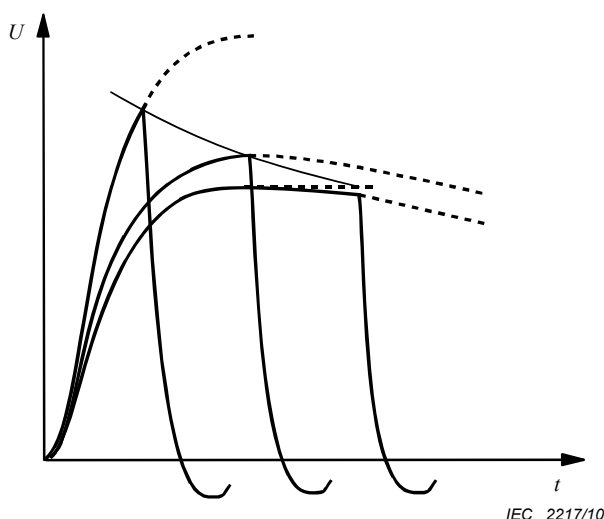


Figure 13 – Voltage/time curve for impulses of constant prospective shape

7.2 Test voltage

7.2.1 Standard lightning-impulse voltage

The standard lightning-impulse voltage is a smooth full lightning-impulse voltage having a front time of 1,2 μ s and a time to half-value of 50 μ s and described as a 1,2/50 impulse.

7.2.2 Tolerances

If not otherwise specified by the relevant Technical Committee, the following differences are accepted between specified values for the standard impulse and those calculated from the test voltage curve:

- Test voltage value: $\pm 3 \%$.
- Front time: $\pm 30 \%$.
- Time to half-value: $\pm 20 \%$.

If not otherwise specified by the relevant Technical Committee, the relative overshoot magnitude shall not exceed 10 %.

For certain test circuits and test objects, standard waveshapes within the stated tolerances may be impossible to realise. In such cases extension of front time T_1 or overshoot may be necessary. Guidance for such cases should be given by the relevant Technical Committee.

NOTE The peak time, T_e , the voltage time interval, T_λ and the voltage integral are parameters under consideration for alternate characterization of lightning-impulse voltages. Values may be assigned by the relevant Technical Committee.

7.2.3 Standard chopped lightning-impulse voltage

This is a standard impulse chopped by an external gap with a time-to-chopping value between 2 μs to 5 μs .

Other times to chopping may be specified by the relevant Technical Committee. The duration of voltage collapse should be much faster than the front time of the impulse and limits may be set by the relevant Technical Committee. The requirements for measurement and the associated uncertainties are given in IEC 60060-2.

7.2.4 Special lightning-impulse voltages

In some cases oscillating lightning-impulse voltages may be applied. This offers the possibility of producing impulses with shorter front times or with extreme values corresponding to a generator efficiency greater than 1.

NOTE For details see IEC 60060-3.

7.2.5 Generation of the test voltage

The impulse is usually produced by an impulse generator consisting essentially of a number of capacitors that are charged in parallel from a direct voltage source, then switched into series and discharged into an impulse-forming circuit that includes the test object.

7.2.6 Measurement of the test voltage and determination of impulse shape

The measurement of the test voltage value, the time parameters and the overshoot or oscillations on the test voltage shall be made with approved measuring systems (see IEC 60060-2). The measurement shall be made with the test object in the circuit and, in general, the impulse shape shall be checked for each test object. Where a number of test objects of the same design and size are tested under identical conditions, the shape needs only to be verified once.

For a chopped lightning impulse the collapse can occur on the front, at the peak or on the tail. For a front chopped lightning-impulse voltage the test voltage curve is the recorded curve. Impulses chopped on the tail are treated as full waves for the evaluation of test voltage and front time, which can be determined from reduced voltage impulses (e.g. $\leq 50 \%$) that do not cause chopping. The chopping can be accomplished by an external chopping gap or may occur due to a disruptive-discharge in the internal or external insulation of the test object.

With some test objects or test arrangements there may be a flattening of the peak or a rounding off of the voltage before the final voltage collapse. Similar effects may also be observed due to the imperfections of the measuring system. Exact determination of the parameters related to chopping requires the presence of both a sharp discontinuity and a fast measuring system. Other cases are left to the relevant Technical Committees for consideration.

Determination of the impulse shape by calculation from the test circuit parameters is not considered to be satisfactory.

7.2.7 Measurement of current during tests with impulse voltages

The relevant Technical Committee shall specify the characteristics of a current flowing in the test object that should be measured during tests with high impulse voltages. When this type of measurement is used for comparative purposes wave shape is of importance and the measurement of the absolute value of this current may be of lesser importance. For guidance see IEC 62475.

7.3 Test procedures

7.3.1 Withstand voltage tests

The recommended test procedure depends on the nature of the test object, as defined in 3.5. The relevant Technical Committee shall specify which procedure shall be applied. In procedures A, B and C the voltage applied to the test object is only the specified withstand value, while in procedure D several voltage levels have to be applied.

NOTE The statistical precision of the procedures is different, but for insulation coordination (IEC 60071) it is assumed that the outcome of the tests is identical.

7.3.1.1 Withstand voltage test: Procedure A

Three impulses of the specified shape and polarity at the specified withstand voltage level are applied to the test object. The requirements of the test are satisfied if no indication of failure is obtained, using methods of detection specified by the relevant Technical Committee.

NOTE This procedure is recommended for tests on degradable or non-self-restoring insulation.

7.3.1.2 Withstand voltage test: Procedure B

Fifteen impulses of the specified shape and polarity at the specified withstand voltage level are applied to the test object. The requirements of the test are satisfied if not more than two disruptive discharges occur in the self-restoring part of the insulation and if no indication of failure in the non-self-restoring insulation is obtained by the detection methods specified by the relevant Technical Committee.

NOTE If not otherwise specified by the relevant Technical Committee, 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.

7.3.1.3 Withstand voltage test: Procedure C

Three impulses of the specified shape and polarity at the specified withstand voltage level are applied to the test object. If no disruptive discharge occurs the test object has passed the test. If more than one disruptive discharge occurs the test object has failed to pass the test. If one disruptive discharge occurs in the self-restoring part of the insulation, then nine additional impulses are applied and if no disruptive discharge occurs the test object has passed the test.

If any detection of failure in a non-self-restoring part of insulation is observed with the detection methods specified by the relevant Technical Committee during any part of the test, the test object has failed to pass the test.

7.3.1.4 Withstand voltage test: Procedure D

For self-restoring insulation the 10 % impulse disruptive-discharge voltage U_{10} , may be evaluated by using statistical test procedures described in Annex A.

These test methods permit either direct evaluation of U_{10} , and U_{50} or indirect evaluation of U_{10} .

In the latter case U_{10} is derived from the U_{50} value using the relationship:

$$U_{10} = U_{50}(1 - 1,3s)$$

The relevant Technical Committee shall specify the value to be assumed for the standard deviation s of the disruptive-discharge voltage. For dry tests on air insulation, without any other insulation involved, the per-unit value $s = 0,03$ can be used.

The test object is deemed to be satisfactory if U_{10} is not less than the specified impulse withstand voltage.

The following test methods can be used to evaluate U_{50} :

- a) the multiple-level method (see Clause A.1.1) with $m \geq 4$ voltage levels, and $n_i \geq 10$ impulses per level;
- b) the up-and-down method (see Clause A.1.2) with $n = 1$ impulse per group and $m \geq 20$ useful applications.

To evaluate U_{10} the up-and-down withstand method, with $n = 7$ impulses per group and at least eight useful groups, can be used.

In all cases the voltage interval between levels ΔU should be approximately from 1,5 % to 3 % of the estimated value of U_{50} .

7.3.2 Procedures for assured disruptive-discharge voltage tests

The procedures for an assured disruptive-discharge voltage test are similar to those described in 7.3.1 with the appropriate changes between discharge and withstand conditions.

The relevant Technical Committee may also specify other procedures for specific test objects.

8 Tests with switching-impulse voltage

8.1 Definitions for switching-impulse voltage tests

8.1.1

switching-impulse voltage

impulse voltage with a front time of 20 μ s or longer

8.1.2

value of the test voltage

maximum value, if not otherwise specified by the relevant Technical Committee

8.1.3

time to peak

T_p

time interval from the true origin to the time of maximum value of a switching-impulse voltage

NOTE Because of the long duration of the maximum voltage, there can be practical problems in determining this time and methods are given in 8.2.3.

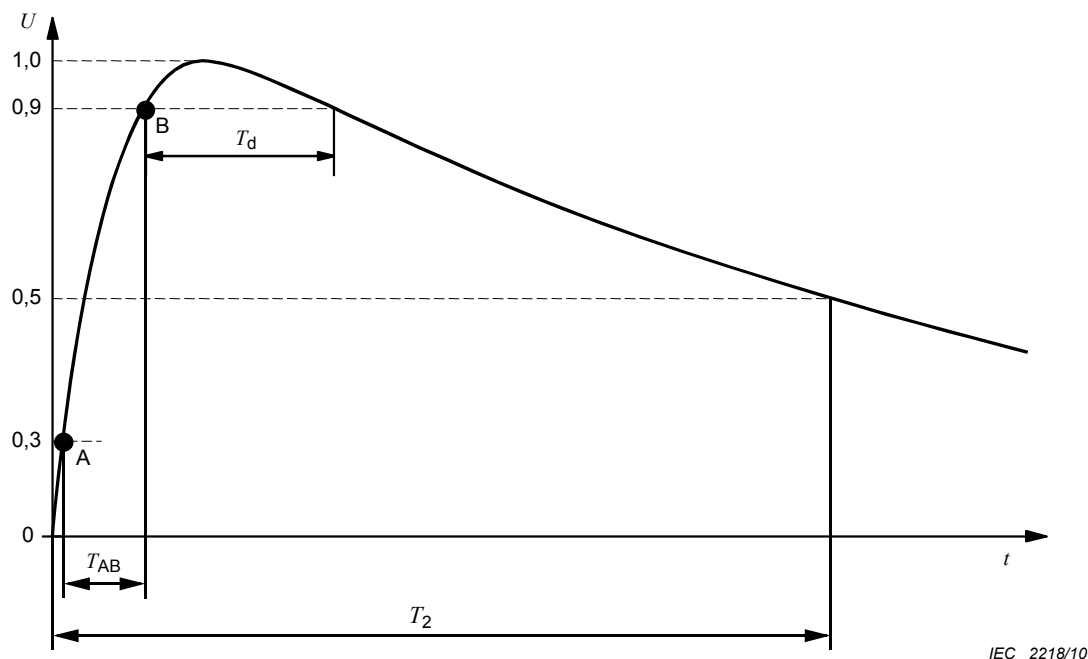


Figure 14 – Switching-impulse voltage

8.1.4

true origin

O

instant where the recorded curve begins a monotonic increase (or decrease)

8.1.5

time to half-value

T_2

time interval between the true origin and the instant when the voltage has first decreased to half the maximum value (see Figure 14)

8.1.6

time above 90 %

T_d

time interval during which the switching-impulse voltage exceeds 90 % of its maximum value (see Figure 14)

8.1.7

time to zero

T_z

time interval between the true origin and the instant when the voltage has its first passage through zero

NOTE Specification of the time above 90 % and time to zero instead of the time to half-value is found useful, for instance, when the form of the impulse is dictated by saturation phenomena in the test object or the test circuit, or where the severity of the test on important parts of internal insulation of the test object is considered to be highly dependent on these parameters. When specifying a switching-impulse voltage, only one set of parameters related to the waveshape is generally given. The particular time parameters defined should be clearly indicated by reference, for example, to a T_p/T_2 or $T_p/T_d/T_z$, impulse.

Additional parameters may be specified by the relevant Technical Committee when considering specific tests.

8.2 Test voltage

8.2.1 Standard switching-impulse voltage

The standard switching-impulse voltage is an impulse having a time to peak T_p of 250 μs and a time to half-value T_2 of 2 500 μs . It is described as a 250/2 500 impulse.

8.2.2 Tolerances

If not otherwise specified by the relevant Technical Committee, the following differences are accepted between specified values and those actually recorded, both for standard and special impulses:

Value of the test voltage	$\pm 3 \%$
Time to peak	$\pm 20 \%$
Time to half-value	$\pm 60 \%$

In certain cases, for instance with low impedance test objects, it may be difficult to adjust the shape of the impulse to within the tolerances recommended. In such cases other tolerances or other impulse shapes may be specified by the relevant Technical Committee.

8.2.3 Time-to-peak evaluation

8.2.3.1 Standard switching-impulse voltages

For standard switching-impulse voltages:

$$T_p = K T_{AB},$$

where K is a dimensionless constant given by

$$K = 2,42 - 3,08 \times 10^{-3} T_{AB} + 1,51 \times 10^{-4} T_2$$

and where T_{AB} and T_2 are in microseconds and $T_{AB} = t_{90} - t_{30}$.

NOTE In IEC 60060-3 $T_p = 2,4 T_{AB}$, is used for standard switching-impulse voltages.

8.2.3.2 Non-standard impulses

For non-standard impulses, the time to peak can be determined by various methods of digital curve fitting dependant on the actual shape.

NOTE If required by uncertainty considerations, the method of time-to-peak evaluation should be stated.

8.2.4 Special switching-impulse voltages

For special purposes, when the use of the standard switching-impulse voltage is not considered sufficient or appropriate, special switching-impulse voltages of either aperiodic or oscillating form may be prescribed by the relevant Technical Committee.

NOTE For details of oscillating switching-impulse voltages see IEC 60060-3.

8.2.5 Generation of the test voltage

Switching-impulse voltages are usually generated by a conventional impulse generator.

NOTE They can also be generated by the application of a voltage impulse to the low-voltage winding of a testing transformer (or of a transformer to be tested) but it is difficult to reach the standard parameters as specified in 8.2.1 and 8.2.2.

The elements of a circuit for generating switching-impulse voltages should be chosen so as to avoid excessive distortion of the impulse shape due to non-disruptive-discharge currents in the test object. Such currents can reach quite large values, especially during pollution tests on external insulation at high voltages. In test circuits having high internal impedance, they may cause severe distortion of the voltage or even prevent a disruptive discharge from occurring.

8.2.6 Measurement of test voltage and determination of impulse shape

The measurement of the maximum voltage value and the time parameters shall be made with approved measuring systems (see IEC 60060-2). The measurement shall be made with the test object in the circuit and, in general, the impulse shape shall be checked for each test object. Where a number of test objects of the same design and size are tested under identical conditions, the shape needs only to be verified once.

8.2.7 Measurement of current during tests with impulse voltages

The relevant Technical Committee shall specify the characteristics of a current flowing in the test object that should be measured during tests with high impulse voltages. When this type of measurement is used for comparative purposes wave shape is of importance and the measurement of the absolute value of this current may be of lesser importance. For guidance see IEC 62475.

8.3 Test procedures

The test procedures are in general the same as for lightning-impulse voltage testing and similar statistical considerations apply (see 7.3 and Annex A). Unless otherwise specified by the relevant Technical Committee, the standard deviation, in per unit value, of the disruptive-discharge voltage for dry and wet tests on air insulation, without any other insulation involved, can be assumed to be:

$$s = 0,06$$

Correspondingly larger voltage intervals ΔU may be used when applying the multiple level or the up-and-down procedures.

NOTE With switching-impulse voltages, disruptive discharges frequently occur at random times well before the peak. In presenting the results of discharge tests made in accordance with 7.3.1.4, the relationship between disruptive-discharge probability and voltage is generally expressed in terms of the prospective maximum value. However, another method is also in use in which the actual disruptive-discharge voltage for every impulse is measured; the probability distribution of the measured voltage values is then determined by the method described for Class 3 tests in Annex A.

9 Tests with combined and composite voltages

9.1 Definitions for combined- and composite-voltage tests

9.1.1

combined voltage

test voltage which appears between the two energized terminals of a three-terminal test object with the third terminal earthed, when energizing is provided by two different test voltages (see Clauses 5 to 8) generated by two separate test voltage sources (see Figure 15).

NOTE Combined voltages are applied for testing, for example, the longitudinal insulation of switching equipment and the phase-to-phase insulation of three-phase systems and equipment. The voltages are applied on different terminals of the test object.

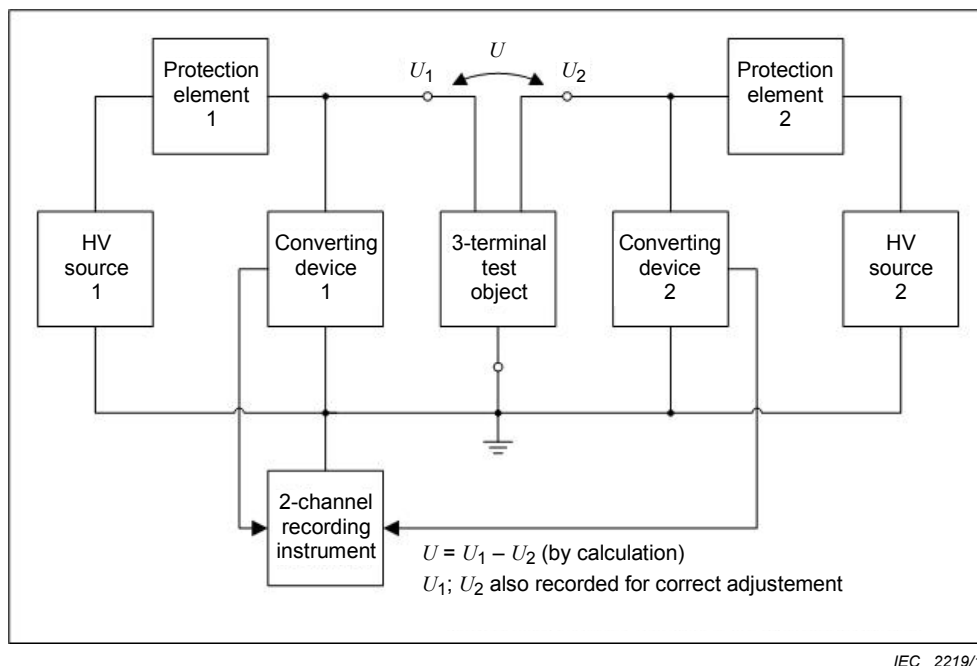


Figure 15 – Circuit for a combined voltage test

9.1.2

value of a combined voltage

maximum potential difference between the two energized terminals of the test object (see Figure 16a)

9.2

composite voltage

superposition of two different test voltages (see Clauses 5 to 8) generated by the suitable connection of two separate test voltages sources (see Figure 16b and Figure 17)

NOTE Both voltages are applied at one terminal of the test object.

9.2.1

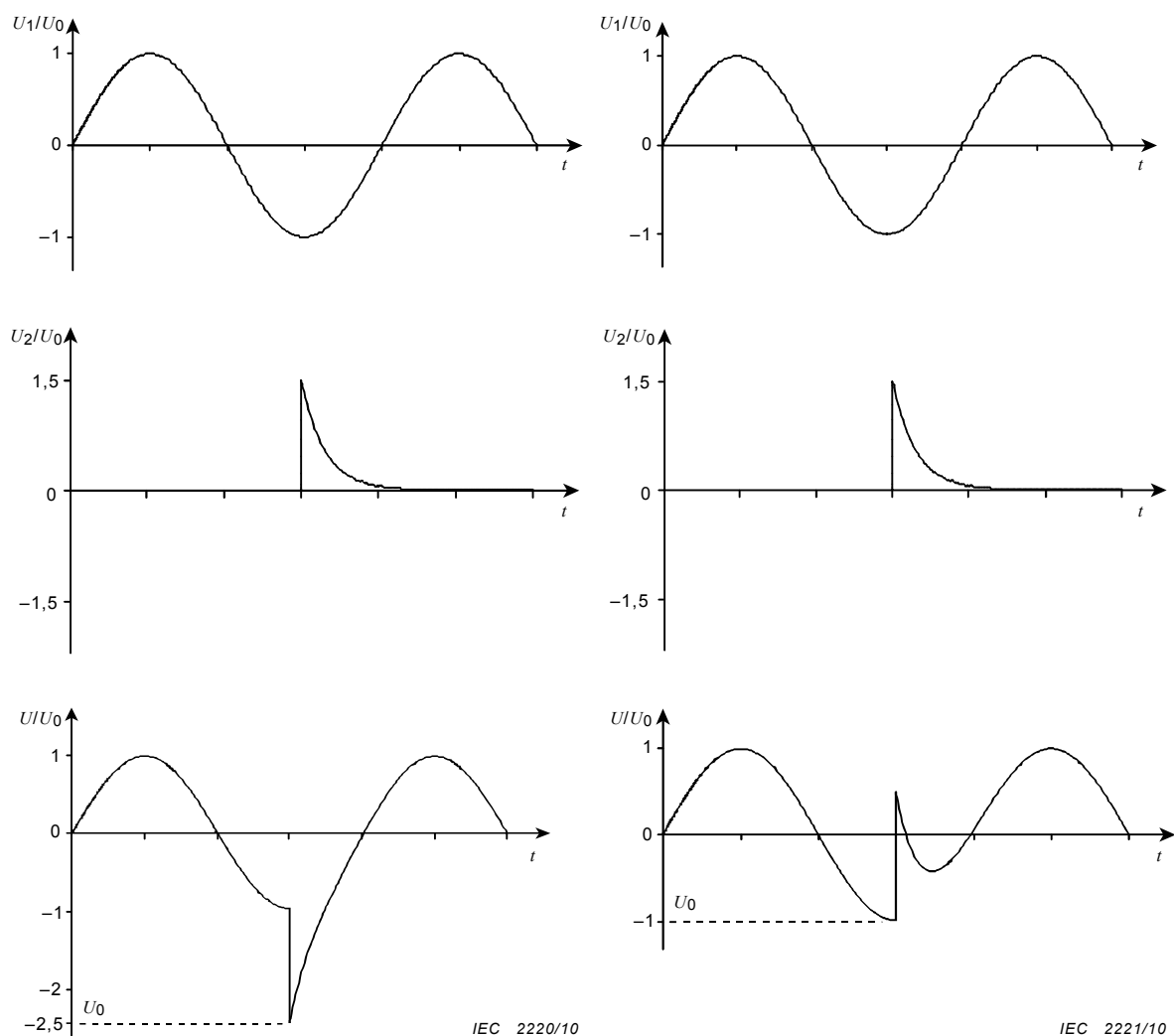
value of a composite voltage

maximum absolute value measured at the test object (see Figure 16b)

9.2.2

voltage components

two test voltages, characterized according to the relevant clauses of this standard and causing the combined or composite test voltage stress at the test object



NOTE 1 In Figure 16a, the combined voltage is $U = U_1 - U_2$.

NOTE 2 In Figure 16b, the combined voltage is $U = U_1 + U_2$.

Figure 16a – Combined voltage between two HV terminals

Figure 16b – Combined voltage between one HV terminal and earth

Figure 16 – Schematic example for combined and composite voltage

9.2.3

time delay

Δt

time interval between the instants when the two voltage components reach their maximum values (see Figure 18)

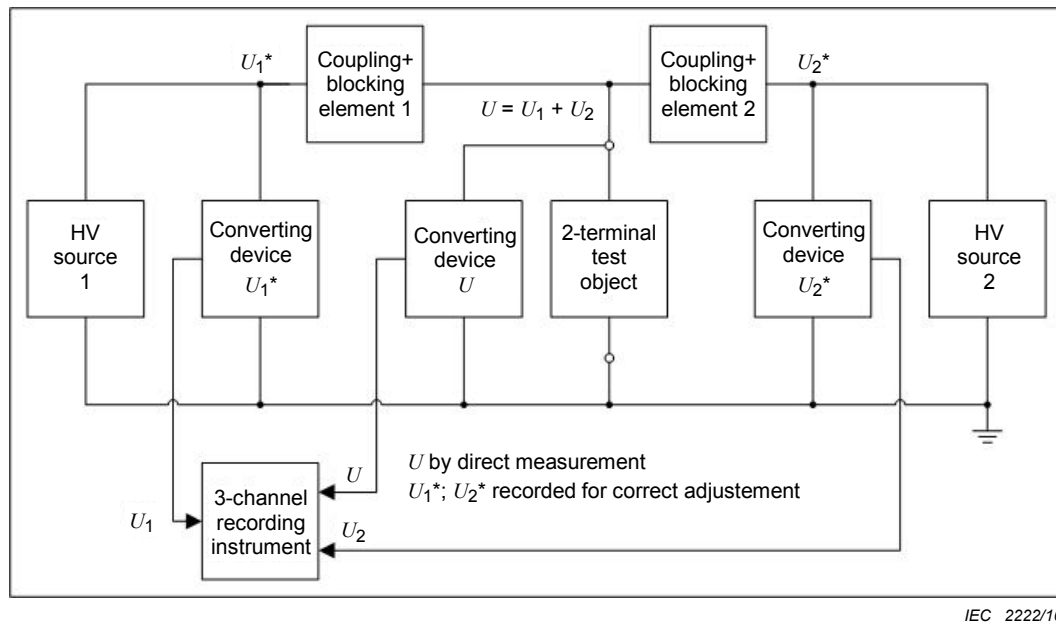


Figure 17 – Circuit for a composite voltage test

9.2.4 Tolerances

If not otherwise specified by the relevant Technical Committee a difference of $\pm 5\%$ between a specified and the actually recorded voltage value is acceptable.

The tolerance of the time delay is $\pm 0,05 T_p$, where T_p is the front time or the time to peak of an impulse or a quarter of a cycle of an alternating voltage. T_p is the longer time of the two voltages involved.

9.2.5 Generation

For generation two single voltage sources are connected, each via a protecting element to one of the HV terminals of the test object (Figure 15). The protecting element shall be selected so that the related source in case of a disruptive discharge of the test object is protected against the voltage stress of the other source.

Due to the coupling of the two sources the shapes and amplitudes of the two voltage components will differ from those generated by the same sources used separately. The permitted limits for voltage drop on the a.c. component shall be specified by the relevant Technical Committee.

NOTE See, for example, IEC 62271-1[E5].

9.2.6 Measurement

Both voltage measurement systems arranged between each of the HV terminals of the test object and earth shall fulfil the requirements of IEC 60060-2 for the measurement of both voltage components, because the systems are coupled. See Figure 15. It is recommended to record them by a dual-channel recording instrument according to IEC 61083-1 that enables the direct evaluation of the combined voltage from its two voltage components. The result can be displayed as shown in Figure 16a.

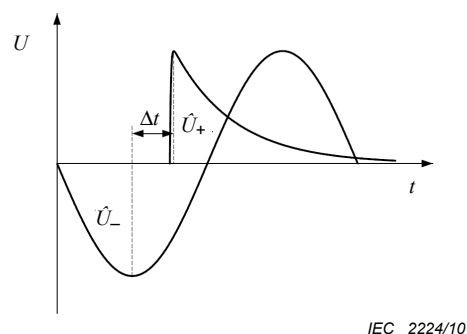
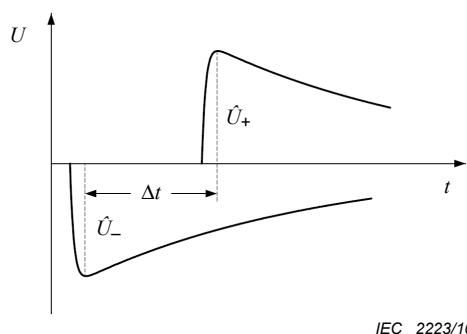


Figure 18a – Combination of two impulse voltages

Figure 18b – Combination of an impulse voltage and a power-frequency alternating voltage

Figure 18 – Definition of time delay Δt

9.3 Composite test voltages

9.3.1 Parameters

A composite test voltage, generated by two voltage components both according to this standard, shall be characterized by the following parameters:

- by its voltage value;
- by the time delay;
- by the parameters of its two components according to the relevant clauses of this standard.

9.3.2 Tolerances

If not otherwise specified by the relevant Technical Committee a difference of $\pm 5\%$ between a specified and the actually recorded voltage value is accepted.

The tolerance of the time delay is $\pm 0,05 T_p$, where T_p is the front time or the time to peak of an impulse or a quarter of a cycle of an alternative voltage. T_p is the longer time of the two voltages involved.

9.3.3 Generation

For generation two single voltage sources are connected together and the HV terminal of the test object is at the connection point. See Figure 17. Each connection is realised by an element, which couples one voltage and blocks the other. The interaction of the two sources shall be considered. For the sources itself, see the relevant clauses of this standard.

9.3.4 Measurement

The voltage and time characteristic of the composite voltage shall be measured against earth with a measuring system arranged at the connection point of the test object. See Figure 17. The measuring system shall fulfil the requirements of IEC 60060-2 for both voltage components. It is recommended to also measure the output voltage of each voltage source directly (see Figure 17) and to record the three voltages synchronously.

9.4 Test procedures

Test procedures and arrangement of test objects with combined and composite voltages are left to the relevant Technical Committee.

For atmospheric corrections the parameter g (4.3.4.3) shall be calculated considering the combined or composite test voltage value. The parameter k_1 and k_2 (4.3.4.1 and 4.3.4.2) shall be calculated for the higher of the two test voltages and be applied to both.

Annex A (informative)

Statistical treatment of test results

A.1 Classification of tests

Disruptive-discharge test procedures can be divided into three classes for the purpose of statistical evaluation.

A.1.1 Class 1: Multiple-level tests (Figure A.1)

In a Class 1 test, n_i voltage applications (e.g. lightning-impulse voltages), causing $k_i \leq n_i$ disruptive discharges, are applied at each of m voltage levels, U_i ($i = 1, 2, \dots, m$), with the difference between adjacent voltage levels being $\Delta U = U_{i+1} - U_i$ ($i=1, 2, \dots, m-1$). While this procedure is usually employed with impulse voltages, tests with alternating and direct voltages of specified stressing time also fall into this class.

NOTE The parameters should be selected as follows: $m \geq 5$, $n_i \geq 10$ for all $i=1, 2, \dots, m$; $\Delta U = (0,01 \text{ to } 0,06) U_{50}$.

The test results are the n_i voltage applications and the corresponding number, k_i , of disruptive discharges at each voltage level U_i ($i=1, 2, \dots, m$).

A.1.2 Class 2: Up-and-down tests (Figure A.2)

In a Class 2 test, m accepted groups of n essentially equal voltage stresses are applied at voltage levels U_i ($i=1, 2, \dots, l$). The voltage level for each succeeding group of stresses is increased or decreased by a small amount ΔU according to the result of the previous group of stresses.

Two testing procedures are commonly used: the withstand procedure, aimed at finding voltage levels corresponding to low disruptive-discharge probabilities and the discharge procedure, which finds voltage levels corresponding to high disruptive-discharge probabilities. In the withstand procedure, the voltage level is increased by an amount ΔU if no disruptive discharge occurs in a group of n voltage applications, otherwise the voltage level is decreased by the same amount. In the discharge procedure, the voltage level is increased by ΔU if one or more withstands occur; otherwise it is decreased by the same amount.

When $n = 1$, the two procedures converge to the procedure of the up-and-down 50 % disruptive-discharge voltage test.

Tests with other values of n are also used to determine voltages corresponding to other disruptive-discharge probabilities. The results are the k_i number of stress groups applied at the voltage levels U_i . The first U_i level to be taken into account is that at which at least two preceding groups of stresses have been applied. The total number of useful groups is

$$m = \sum_{i=1}^l k_i \text{ at the voltage levels } i=1 \dots l.$$

NOTE Tests with $n = 7$ give the 10 % and the 90 % disruptive-discharge voltages which are defined as withstand and disruptive voltages respectively (see clause 7.3.1.4). The other parameters should be selected as follows $\Delta U = (0,01 \text{ to } 0,03) U_{50}$ and $m > 15$.