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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

IEC 60060-1:2010

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

HIGH-VOLTAGE TEST TECHNIQUES –

Part 1: General definitions and test requirements

FOREWORD

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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- withdrawn;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.

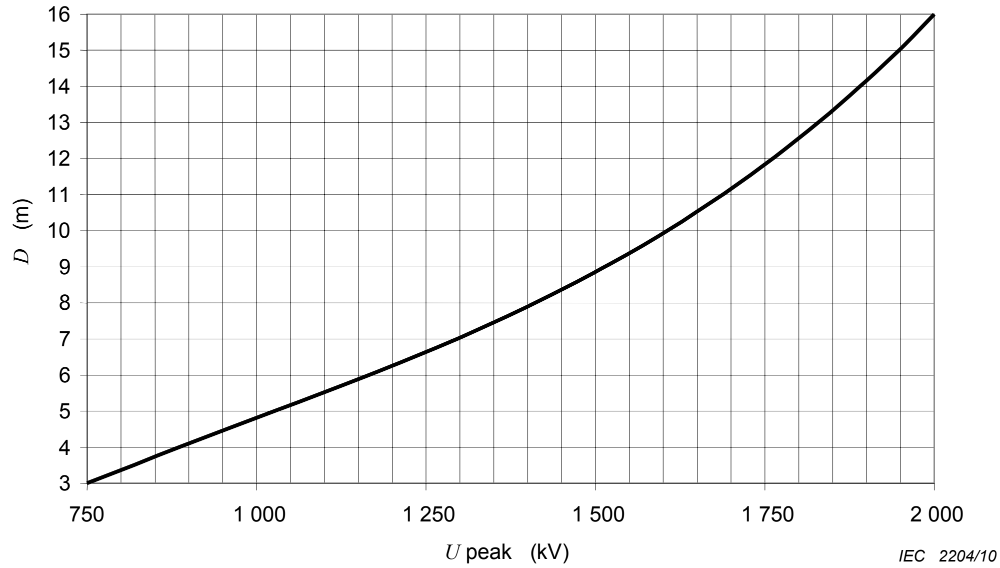

Figure 1 – Recommended minimum clearance *D* of extraneous live or earthed objects to the energized electrode of a test object, during an a.c. or positive switching impulse test at the maximum voltage *U* applied during test

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 °C ;

– absolute pressure p_0 = 1 013 hPa (1 013 mbar) ;

– absolute humidity h_0 = 11 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:

$$k_1 = \delta^m$$