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BRITISH STANDARD

BS EN 60060-3:2006
Incorporating corrigendum no. 1

High voltage test techniques —

Part 3: Definitions and requirements for on-site tests

The European Standard EN 60060-3:2006 has the status of a British Standard

ICS 17.220.20; 19.080

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British Standards

National foreword

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English version

High voltage test techniques
Part 3: Definitions and requirements for on-site tests
(IEC 60060-3:2006)

Techniques des essais à haute tension
Partie 3: Définitions et prescriptions
pour des essais sur site
(CEI 60060-3:2006)

Hochspannungs-Prüftechnik
Teil 3: Begriffe und Anforderungen
für Vor-Ort-Prüfungen
(IEC 60060-3:2006)

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Foreword

The text of document 42/203/FDIS, future edition 1 of IEC 60060-3, prepared by IEC TC 42, High-voltage testing techniques, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60060-3 on 2006-02-01.

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Endorsement notice

The text of the International Standard IEC 60060-3:2006 was approved by CENELEC as a European Standard without any modification.

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INTRODUCTION

The requirements specified in IEC 60060-1 and IEC 60060-2 cannot always be achieved during on-site tests, due to a variety of external factors not present in factory and laboratory tests such as external electric and magnetic fields, weather conditions, etc.

On-site high-voltage tests are required:

– as withstand tests as part of a commissioning procedure on equipment to demonstrate that transport from manufacturer to site, and the erection on-site complies with manufacturer's specification;

– as withstand tests after on-site repair, to demonstrate that the equipment has been successfully repaired, and is in a suitable condition to return to service;

– for diagnostic purposes, e.g. PD measurement, to demonstrate if the insulation is still free from dangerous defects, and as an indication of life expectation.

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HIGH-VOLTAGE TEST TECHNIQUES –

Part 3: Definitions and requirements for on-site testing

1 Scope

This part of IEC 60060 is applicable to the following on-site test voltages and in service stresses, which are in relation to IEC 60060-1:

– direct voltage;
– alternating voltage;
– lightning impulse voltage of aperiodic or oscillating shape;
– switching impulse voltage of aperiodic or oscillating shape.

For special tests the following voltages are used:

– very low frequency voltage;
– damped alternating voltage.

This standard is applicable to equipment with a highest voltage U_m greater than 1 kV. The selection of on-site test voltages, test procedures and test voltage levels for apparatus, equipment or installations is under the responsibility of the relevant technical committee. For special applications, on-site test voltages different from those described in this standard may be specified by the relevant technical committee.

NOTE 1 The different voltage waveforms listed above do not necessarily provide equal stress on the test object.

NOTE 2 The selection of the test voltage levels should take the larger tolerances and measuring uncertainties into account.

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

IEC 60060-2:1994, *High-voltage test techniques – Part 2: Measuring systems*

IEC 60071-1:1993, *Insulation co-ordination – Part 1: Definitions, principles and rules*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. For all other definitions relating to testing procedures, see IEC 60060-1, and for those relating to measuring systems, see IEC 60060-2. Definitions of parameters are given in the relevant clauses of this standard.

3.1
on-site test
test at the place of use of the apparatus, equipment or installation that is to be tested, and with the test object as far as possible in its service condition

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3.2
impulse voltage
intentionally applied aperiodic or oscillating transient voltage, which usually rises rapidly to a peak value and then its enveloping curve falls more slowly to zero

(IEC 60060-1:1989, Term 3, modified)

3.3
lightning and switching impulse voltages
a distinction is made between **lightning and switching impulse voltages** on the basis of duration of the front. Impulses with front duration up to 20 µs are defined as **lightning impulse voltages** and those with longer fronts are defined as **switching impulse voltages**

Generally, **switching impulse voltages** are also characterized by total durations considerably longer than those of **lightning impulse voltages.**

(IEC 60060-1:1989, Term 3.1)

3.4
characteristics of the test voltage
those characteristics specified in this standard for designating the different types of voltage excursion that define the test voltage

(IEC 60060-1:1989, Term 4.2)

3.5
prospective characteristics of a test voltage
the characteristics which would have been obtained if no disruptive discharge had occurred. When a prospective characteristic is used, this shall always be stated

(IEC 60060-1:1989, Term 4.2.1)

3.6
actual characteristics of a test voltage
characteristics that occur during the test at the terminals of the test object

(IEC 60060-1:1989, Term 4.2.2)

3.7
value of the test voltage
as defined in the relevant clauses of the present standard

(IEC 60060-1:1989, Term 4.2.3)

3.8
classification of insulation in test objects
insulation systems of apparatus and high-voltage structures must basically be classified into **self-restoring** and **non-self-restoring insulation** and may consist of **external** and/or **internal insulation**

(IEC 60060-1:1989, Term 5)

3.8.1
external insulation
distances in atmospheric air, and the surfaces in contact with atmospheric air of solid insulation of the equipment which are subject to dielectric stresses and to the effects of atmospheric and other external conditions such as pollution, humidity, vermin, etc.

(IEC 60071-1:1993, Term 3.2)

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3.8.2
internal insulation
internal solid, liquid or gaseous insulation, which are protected from the effects of atmospheric and other external conditions

(IEC 60071-1:1993, Term 3.3)

3.8.3
self-restoring insulation
insulation that completely recovers its insulating properties after a certain time interval following a disruptive discharge caused by the application of a test voltage

(IEC 60071-1:1993, Term 3.4, modified)

3.8.4
non-self-restoring insulation
insulation that loses its insulating properties, or does not recover them completely, after a disruptive discharge caused by the application of a test voltage

(IEC 60071-1:1993, term 3.5, modified)

NOTE In high-voltage apparatus, parts of both self-restoring and non-self-restoring insulation often operate 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.

3.9
measuring systems and their components

3.9.1
measuring system
complete set of devices suitable for performing a high-voltage measurement

(IEC 60060-2:1994, Term 3.1.1, modified)

NOTE 1 A **measuring system** is usually comprised of the following components: a converting device with the leads required for connecting this device to the test object and the connections to earth, a transmission system connecting the output terminals of the device to the indicating or recording instruments with its attenuating, terminating and adapting impedance or networks, and indicating or recording instruments together with any connections to the HV source.

These components can be arranged in one compact unit together with the HV source. This usually applies to portable test equipment for medium-voltage apparatus.

NOTE 2 **Measuring systems** which are based on non-conventional principles are acceptable if they meet the accuracy requirements specified in this standard.

NOTE 3 The environment in which a **measuring system** functions, its clearances to live and earthed structures and the presence of electric or magnetic fields may significantly affect its accuracy.

3.9.2
record of performance of a measuring system
detailed record, established by the user, describing the system and containing evidence that the requirements given in this standard have been met. This evidence shall include the results of the initial **acceptance test** and the schedule and results of each subsequent **performance test** and **performance check**

(IEC 60060-2:1994, Term 3.1.2)

3.9.3
approved measuring system
a **measuring system** that is shown to comply with the requirements of this standard by:

– an initial performance test;
– successive **performance checks** and **performance tests**;
– inclusion of the results of these tests in the **record of performance**.

The system is approved only for the arrangements and operating conditions included in its **record of performance**

(IEC 60060-2:1994, Term 3.1.3, modified)

3.9.4
reference measuring system
measuring system having sufficient accuracy and stability for use in the approval (calibration) of other systems by making simultaneous comparative measurements with specific types of waveform and ranges of voltage or current

(IEC 60060-2:1994, Term 3.1.4)

NOTE A reference measuring system (maintained in accordance with the requirements of IEC 60060-2:1994) can be used as an approved measuring system but the converse is not true.

3.9.5
converting device
device for converting the high voltage to be measured into another quantity, compatible with the indicating or recording instrument. Usually voltage dividers or high-voltage measuring impedances are used

(IEC 60060-2:1994, Term 3.2, modified)

NOTE Other examples of converting devices are voltage transformers, optical sensors and electric-field probes.

3.9.6
transmission system
set of devices that transfers the output signal of a converting device to an indicating and/or recording instrument

NOTE 1 A transmission system generally consists of a coaxial cable with its terminating impedances, but it may include attenuators or other devices connected between the converting device and the instrument. For example, an optical link includes the transmitter, the optical cable and the receiver as well as related amplifiers.

NOTE 2 A transmission system may be partially or completely included in the converting device.

(IEC 60060-2:1994, Term 3.3)

3.9.7
indicating or recording instrument
device intended to display or provide a record of the value of a measurand or a derived quantity

(IEC 60060-2:1994, Term 3.4)

3.9.8
scale factor of a measuring system
factor by which the value of the instrument reading is to be multiplied to obtain the value of the input quantity. The assigned scale factor is that determined at the most recent **performance test**

NOTE 1 For many measuring systems the value of the input quantity is displayed directly (i.e., the scale factor of the measuring system is unity).

NOTE 2 A measuring system may have more than one scale factor, for example, it may have different scale factors for different frequency ranges or impulse shapes.

(IEC 60060-2:1994, Term 3.5, modified)

3.9.9
dynamic behaviour of a measuring system
behaviour of the **measuring system** in case of a transient change of the input quantity described by the step response or the amplitude/frequency response

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3.9.10
uncertainty of a measurement
parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand

3.9.11
tolerance
permitted difference between the measured value and the specified value – to be distinguished from measuring errors, which are the differences between the measured values and the true values

NOTE 1 The measured test voltage is required to lie within the stated tolerance of the specified test level. Test levels are specified by the relevant technical committee. The true value is not exactly known; it is estimated to lie within the range of the measurement uncertainty with the stated coverage probability. The true, but unknown, value may thus lie outside the tolerance range, especially in the case when the measured value is close to the limits of the tolerance range and its uncertainty is partially outside.

NOTE 2 The measured value is the displayed value multiplied by the scale factor. The true value is unknown and would be the mean value of an infinitely large number of identical measurements.

3.9.12
rated measuring voltage
maximum level of voltage of specified frequency or waveform for which a **measuring system** can be used, and for which it is within the uncertainty limits given in this standard

(IEC 60060-2:1994, term 3.9.1, modified)

3.9.13
operating voltage or current range
range of voltage or current of specified frequency or waveform in which a **measuring system** can be used, and for which it is within the uncertainty limits given in this standard

(IEC 60060-2:1994, Term 3.9.2, modified)

NOTE The limits of the operating range are chosen by the user and verified by the **performance tests** specified in IEC 60060-2.

3.9.14
operating time (for direct or alternating voltages)
time during which the **measuring system** can operate at its rated measuring voltage and for which it is within the uncertainty limits given in this standard

(IEC 60060-2:1994, Term 3.9.3, modified)

3.9.15
maximum rate of application
of **impulse voltages** with a specified waveform, at which the **measuring system** can operate within the uncertainty limits given in this standard for a specified time at its rated measuring voltage or rated measuring current

(IEC 60060-2:1994, Term 3.9.4, modified)

3.9.16
acceptance test
a test on a device or **measuring system** before it is accepted for use. The **acceptance test** includes type tests (performed on a device of the same design) and routine tests (performed on every device) to assess its specific characteristics, for example, measurement of temperature coefficient of an element, withstand test, etc. In addition, the **acceptance test** on a **measuring system** includes the first **performance test**

(IEC 60060-2:1994, Term 3.10.1)

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3.9.17
performance test
test on a complete **measuring system** to characterize it for operating conditions on-site

3.9.18
performance check
procedure to ensure that the most recent **performance test** is still valid. The **performance check** is carried out on-site

(IEC 60060-2:1994, Term 3.10.3, modified)

3.9.19
reference record (for impulse voltage measurement only)
record taken under specified conditions in a **performance test** and retained for comparison with records to be taken in future tests or checks under similar conditions

(IEC 60060-2:1994, Term 3.10.4)

4 Common tests and checks on a measuring system

4.1 Acceptance test

Acceptance tests on components of a measuring system shall be performed in accordance with the specification of IEC 60060-2.

4.2 Performance test

The **performance test** for the on-site **measuring system** shall be made in accordance with IEC 60060-2. The test can be carried out under any conditions as long as evidence is given that the measuring system can perform correctly under conditions found on-site.

The test shall be made when a **performance check** shows that the assigned scale factor has changed significantly. The cause of the change shall be clarified before the **performance test** is made.

It is recommended that the **performance test** be repeated annually, but in any case, it shall be repeated at least once every five years.

4.3 Performance check

4.3.1 General

For **measuring systems** assembled on-site a **performance check** of the system scale factor shall be made on the test site before testing, to demonstrate that the **measuring system** has not been influenced by transport to site, and that it is correctly assembled.

For other **measuring systems** of proven reliability a **performance test** carried out at least annually can replace the performance checks on-site.

NOTE This refers mainly to high-voltage “testers” with built-in **measuring systems** used for on-site tests in medium-voltage systems.

The scale factor of the **measuring system** shall be checked by one of the following methods.

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4.3.2 Method 1: Check of the scale factor of the components

The scale factors of the converting device, transmission system and measuring instrument shall be checked using internal or external calibrators having an uncertainty of 1 %. If the scale factors differ from their calibrated values in the **record of performance** by not more than 3 %, the assigned scale factor is taken as still valid. If any difference exceeds 3 % then a new assigned scale factor shall be determined in a **performance test** in accordance with IEC 60060-2.

NOTE Calibrators can be ratio meters, reference voltage sources, bridges, etc.

4.3.3 Method 2: Comparison with a transportable approved measuring system

Both **measuring systems** shall be connected in parallel during the **on-site test**. The test shall be performed at least at one voltage level, preferably above 20 % of the highest voltage to be applied during the tests. Simultaneous readings shall be taken on both systems. If the difference in measured voltages is less than 5 %, the measuring system is accepted. Otherwise further checks shall be made, e.g. a **performance check** or **performance test** shall be carried out in accordance with IEC 60060-2.

4.4 Record of performance

A history of performance checks and performance tests shall be kept in a record of performance.

5 Tests with direct voltage

5.1 General

The provisions of this clause are pertinent to test voltages for dielectric tests as described in IEC 60060-1.

5.2 Definitions for direct voltage tests

5.2.1
value of the test voltage
arithmetic mean value

(IEC 60060-1:1989, Term 12.1)

5.2.2
ripple
periodic deviation from the arithmetic mean **value of the test voltage**

5.2.3
ripple amplitude
half the difference between the maximum and minimum values

(IEC 60060-1:1989, term 12.2, modified)

NOTE In practical cases true r.m.s. values multiplied by an estimated factor of 1,4 are also acceptable for determination of the ripple amplitude.

5.2.4
ripple factor
ratio of the ripple amplitude to the **value of test voltage**

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5.3 Test voltage

5.3.1 Requirements for the test voltage

5.3.1.1 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 that the **ripple factor** may be affected by the presence of the test object and by the test conditions.

NOTE In cases when higher ripple is suspected, a measurement of the ripple is recommended.

5.3.1.2 Tolerance

The measured **value of the test voltage** shall be maintained within ± 3 % of the specified level throughout the test, if not otherwise specified by the relevant technical committee. For test duration exceeding 60 s, the measured voltage shall be maintained within ± 5 % of the specified level throughout the test.

5.3.1.3 Generation of test voltage

The test voltage is generally obtained by means of rectifiers. The requirements to be met by the voltage source depend considerably upon the type of apparatus that is to be tested and on the **on-site test** conditions. These requirements are determined mainly by the possible impedance variation of the test circuit.

The source characteristics should be sufficient to permit charging of the capacitance of the test object in a reasonably short time. However, for extremely long installed cables, longer charging times are sometimes necessary. The source, including its storage capacitance, should also be adequate to supply the non-transient leakage and absorption currents of the test object.

5.4 Measurement of the test voltage

5.4.1 Measurement with an approved measuring system

The measurement of the **value of the test voltage** and if necessary the **ripple amplitude,** should be made with an **approved measuring system** that has passed the tests and checks specified in Clause 4. Furthermore it shall have an **operating time** that is sufficient for the duration of the on-site test. Attention is also drawn to the requirements of IEC 60060-2 for response characteristics of devices used for measuring **ripple amplitude**, transients or voltage stability.

5.4.2 Requirements for an approved measuring system

The general requirement is to measure the **value of the test voltage** (arithmetic mean) with overall uncertainty of 5 %. These uncertainty limits shall also not be exceeded in the presence of **ripple** if the **ripple factor** is less than 3 %.

The **ripple** amplitude shall be measured with an overall uncertainty of 10 % of the **ripple** amplitude.

5.4.3 Stability of the scale factor

The scale factor of the **measuring system** shall not vary by more than ±2 % within the range of voltage use, the ambient temperature and humidity ranges, and for the clearances given in the **record of performance**.

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NOTE 1 A converting device for direct voltage should be constructed so as to conduct directly to earth all discharge or leakage currents on its external surface and to keep internal discharge or leakage current negligible relative to the measuring system current.

NOTE 2 To maintain a low ratio between the leakage and measuring currents, a measuring system current as high as 0,5 mA at the rated voltage may be necessary.

5.4.4 Dynamic behaviour for measuring rising voltages

The experimental response time T_N of an **approved measuring system** shall not be larger than 0,5 s. This will permit measurement with the uncertainty specified in 5.4.2 when voltage is increased at the rate specified for withstand tests in 5.6.

NOTE If the voltage divider is to be used for the measurement of the ripple voltage, its bandwidth should be at least five times the ripple fundamental frequency.

5.4.5 Connection to the test object

The connections to the test object from the test source and voltage divider should be made with conductors of sufficient diameter to avoid excessive discharges and corona. The ground connections to the test object should be short and of sturdy construction to avoid voltage differences if flashovers occur in the test circuit.

5.5 Tests and checks on measuring systems

Tests and checks shall be performed in accordance with Clause 4 of this standard.

5.6 Withstand voltage test procedure

The voltage shall 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 instruments, but not so slowly as to cause unnecessary prolongation of 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 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 requirements of the test are satisfied if there is no disruptive discharge.

NOTE Procedures for diagnostic tests should be defined by the relevant technical committee.

6 Tests with alternating voltage

6.1 General

The provisions of this clause are pertinent to test voltages for withstand tests and diagnostic tests as described in IEC 60060-1.

6.2 Definitions for alternating voltage tests

6.2.1
value of the test voltage
peak value divided by the square root of two

(IEC 60060-1:1989, Term 15.1.1)

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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.

6.2.2
peak value
maximum value of an alternating voltage. Small high-frequency oscillations, arising for instance from non-disruptive discharges shall, however, be disregarded

(IEC 60060-1:1989, Term 15.2, modified)

6.2.3
r.m.s. value
square root of the mean value of the square of the voltage values during a complete cycle of the alternating voltage

(IEC 60060-1:1989, Term 15.3)

6.3 Test voltage

6.3.1 Voltage waveshape

The test voltage shall be a sinusoidal alternating voltage generally having a frequency in the range of 10 Hz to 500 Hz, if there is no limitation given by the relevant technical committee.

The test voltage waveshape shall approximate a sinusoid with both half-cycles closely alike. The result of a high-voltage test is thought to be unaffected by small deviations from a sinusoid if the ratio of the peak to r.m.s. values is within $\sqrt{2} \pm 15$ %.

NOTE If the ratio of peak to r.m.s. values is not within $\sqrt{2} \pm 5$ %, it should be verified that positive and negative peaks do not differ by more than 2 %.

6.3.2 Tolerance

The measured **value of the test voltage** shall be maintained within ±3 % of the specified level throughout the test, if not otherwise specified by the relevant technical committee. For test duration exceeding 60 s the measured voltage shall be maintained within ±5 % of the specified level throughout the test.

6.3.3 Generation of the test voltage

The test voltage is usually supplied by step-up transformers or by resonant circuits. Resonant circuits may be tuned into resonance by adjustable reactors or frequency converters.

The test 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 for the test object is significantly affected.

6.3.3.1 The transformer circuit

In order to have the test voltage practically unaffected by varying leakage currents the short-circuit current, delivered by the transformer when the test object is short-circuited at the test voltage, should be large enough in comparison with the leakage currents. In any case for dry tests on **external self-restoring insulation** (insulators, disconnecting switches, etc.) a short-circuit current not less than 0,1 A, (r.m.s.) is required.

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

NOTE If any protective resistor external to the test transformer does not exceed 10 kΩ, the effective terminal capacitance of the transformer may be regarded as being in parallel with the test object.

6.3.3.2 The series resonant circuit

The series resonant circuit consists essentially of an inductor in series with a capacitive test object or load and connected to a medium-voltage power source (exciter transformer). 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 in resonance, a voltage considerably greater than that of the source and of substantially sinusoidal shape will be applied to the test object.

The stability of the resonance conditions and of the test voltage depends on the constancy of the supply frequency and of the test circuit characteristics.

When a discharge occurs, the source delivers a relatively low current, which limits the damage to the dielectric of the test object.

The series resonant circuit is especially useful when testing objects such as cables, capacitors or gas-insulated systems in which the leakage currents on the **external insulation** are very small in comparison with the capacitive currents through the test object or the energy to form a disruptive discharge is very small.

6.4 Measurement of the test voltage

6.4.1 Measurement with an approved measuring system

The measurement of the peak (or r.m.s. if required) value shall be made with an **approved measuring system** that has passed the tests and checks specified in Clause 4. Furthermore it shall have an **operating time** that is sufficient for the duration of the on-site test.

The measurement shall be made with the test object in the circuit.

NOTE The value of the test voltage of the pure sinusoidal output of series resonant systems will be correctly determined both by average responding and true r.m.s. responding meters, provided the scale factor has been established in accordance with the provisions of 4.2.

6.4.2 Requirements for an approved measuring system

The general requirement is to measure the peak **value of the test voltage** with an uncertainty of 5 %.

6.4.3 Stability of the scale factor

The scale factor of the **measuring system** shall not vary by more than ±2 % within the range of voltage use, the ambient temperature and humidity ranges, and for the clearances given in the **record of performance**.

6.4.4 Dynamic behaviour

The dynamic behaviour of a **measuring system** is considered to be adequate for the measurement of the peak voltage if the scale factor is constant within ±2 % in the frequency range of use.

NOTE The content of harmonics should be taken into account when the frequency range is chosen.

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6.4.5 Connection to the test object

The connections to the test object from the test source and voltage divider should be made with conductors of sufficient diameter to avoid excessive discharges and corona. The ground connections to the test object should be short and of sturdy construction to avoid voltage differences if flashovers occur in the test circuit.

6.5 Tests and checks on measuring systems

Tests and checks shall be performed in accordance with Clause 4 of this standard.

6.6 Withstand voltage test procedure

If not otherwise specified by the relevant technical committee, 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. 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; if not specified the duration of a withstand test shall be 60 s. The requirements of the test are satisfied if no disruptive discharge occurs.

NOTE Procedures for diagnostic tests should be defined by the relevant technical committee.

7 Tests with lightning impulse voltage

7.1 General

The provisions of this clause are pertinent to test voltages for withstand tests and diagnostic tests as described in IEC 60060-1.

7.2 Definitions for lightning impulse voltage tests

These definitions apply to aperiodic and oscillating **impulse voltages**. Both types of **impulse voltage** might be applied for high-voltage tests on-site.

7.2.1
full lightning impulse voltage
lightning impulse voltage that is not interrupted by a disruptive discharge

(IEC 60060-1:1989, Term 18.1.1)

7.2.2
aperiodic lightning impulse voltage
impulse voltage that rises rapidly to a peak value and then falls without oscillations more slowly to zero. See Figure 1.

NOTE The standard **lightning impulse voltage** 1,2/50 defined in IEC 60060-1 is an example of an aperiodic **impulse voltage**.

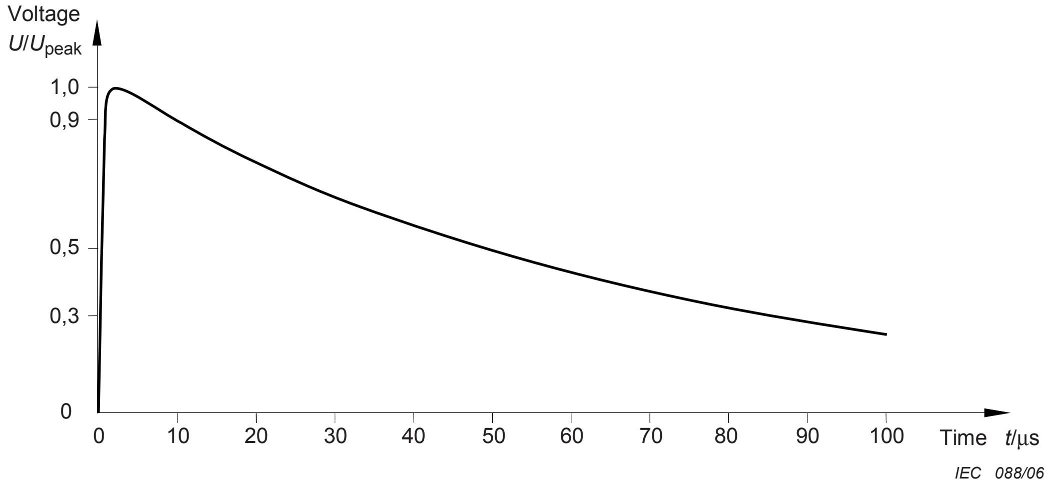
7.2.3
oscillating lightning impulse voltage
impulse voltage that rises rapidly to a peak value and then falls to zero with damped oscillations of a frequency between 15 kHz and 400 kHz with or without polarity changes. It is characterized by its enveloping curve and the frequency of the oscillations. See Figure 2.

7.2.4
value of the test voltage
peak value

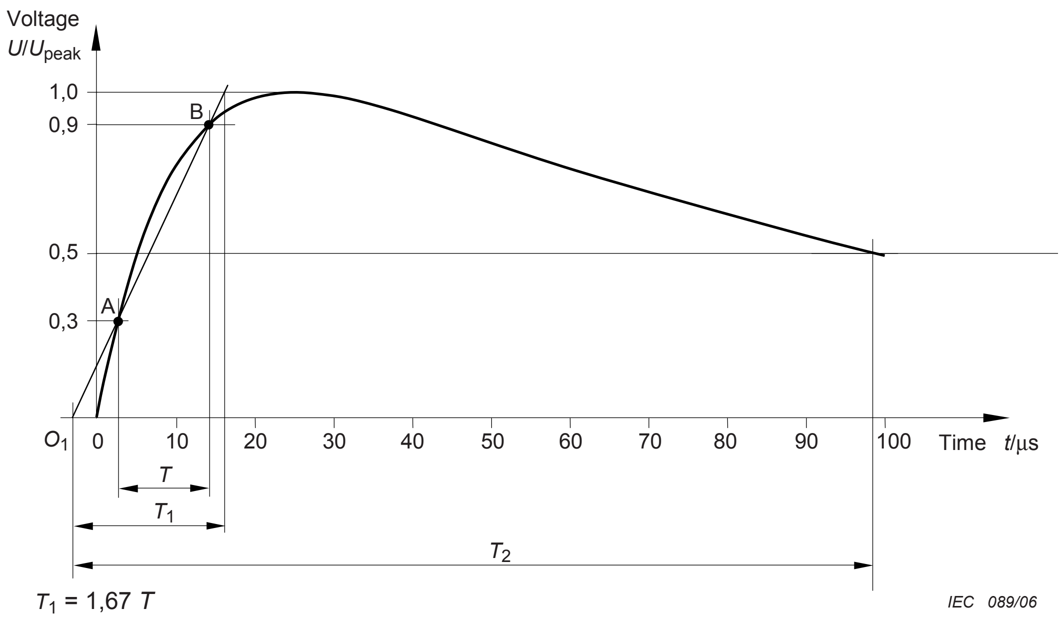
(IEC 60060-1:1989, Term 18.1.3, modified)

In case of a disruptive discharge on the front it is the prospective peak value.

NOTE In case of superimposed oscillations the peak value should be evaluated in accordance with IEC 60060-1.



a) T_1/T_2 = 0,8/50 µs



b) T_1/T_2 = 20/100 µs

Figure 1 – Aperiodic lightning impulse

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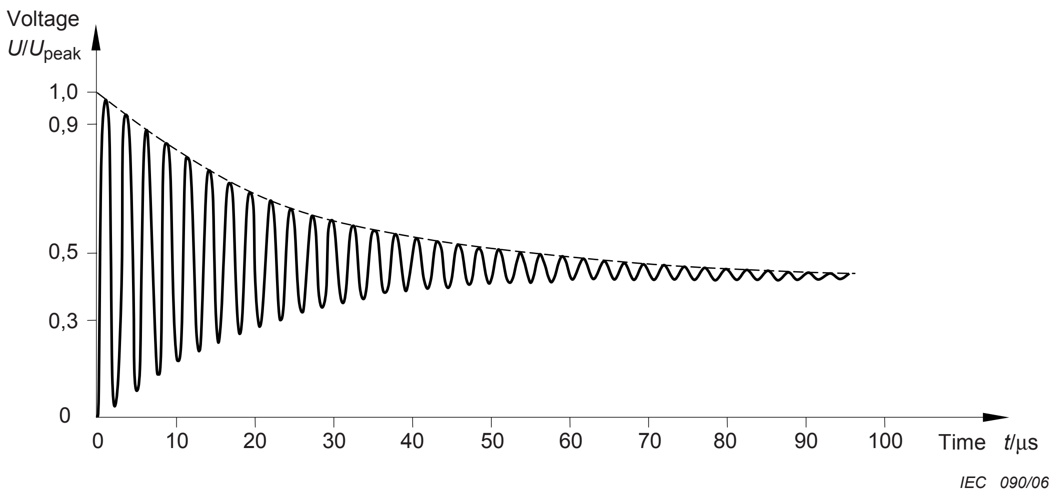
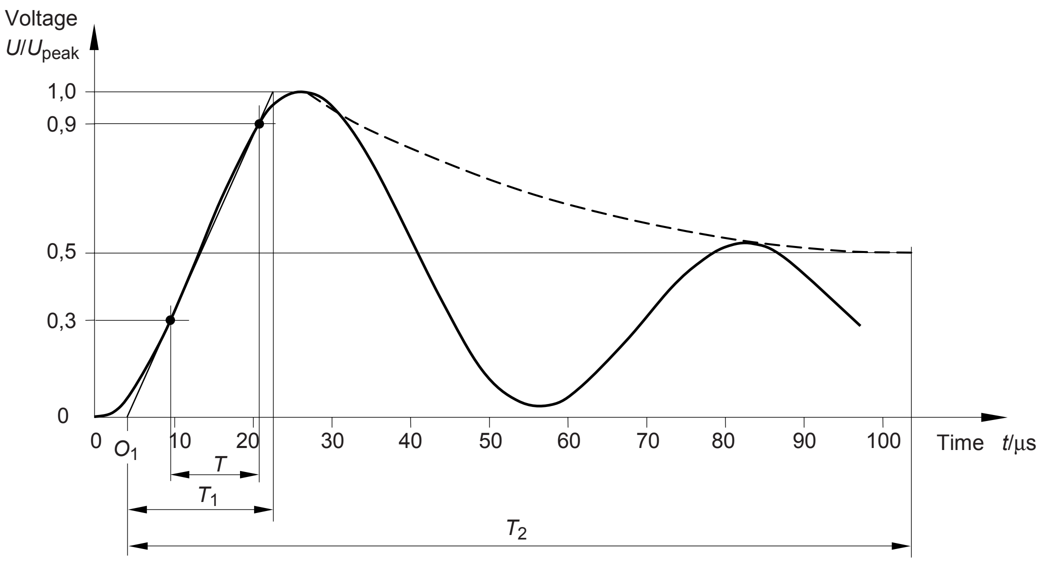


a) T_1/T_2 = 0,8/50 µs, 370 kHz



T_1 = 1,67 T

b) T_1/T_2 = 20/100 µs, 16 kHz

Figure 2 – Oscillating lightning impulse

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7.2.5
front time
***T*₁**

virtual parameter that for both types of **lightning impulse voltages** is defined as 1,67 times the interval *T* between the instants when the **impulse** is 30 % and 90 % of the peak value

(IEC 60060-1:1989, Term 18.1.4)

7.2.6
virtual origin
O_1

precedes, by 0,3 T_1, the instant when the **impulse voltage** reaches 30 % of the peak value (see Figures 1 and 2). For linear time scales this is the intersection between the time axis and the straight line through 30 % and 90 %

(IEC 60060-1:1989, Term 18.1.5, modified)

7.2.7
time-to-half-value
T_2

virtual parameter of an **aperiodic lightning impulse voltage** defined as the time between the virtual origin O_1 and the instant when the voltage has decreased to half the peak value

The time-to-half-value of an **oscillating lightning impulse voltage** is a virtual parameter defined as the time between the virtual origin O_1 and the instant when the envelope of the oscillating voltage has decreased to half the peak value.

7.3 Test voltage

7.3.1 Full lightning impulse voltage

The **impulse voltage** shall have a front time T_1 in the range of 0,8 µs to 20 µs and a time-to-half-value T_2 in the range of 40 µs to 100 µs.

NOTE Superimposed oscillations for **aperiodic impulse voltages** should not exceed 5 % of the peak value.

7.3.2 Tolerance

The measured **value of the test voltage** shall be within ±5 % of the specified value unless otherwise specified by the relevant technical committee.

NOTE Limits for acceptable time parameters are given in 7.3.1.

7.3.3 Generation of test voltage

The **lightning 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 and then discharged in series into a circuit that includes the test object. For the generation of **aperiodic impulse**s this circuit includes resistors and capacitive load. For the generation of **oscillating lightning impulse**s the circuit contains inductance, e.g. an inductor is switched between the generator and the capacitive load. For the same generator this oscillating circuit enables the generation of oscillating **impulses** with peak values about twice that of aperiodic impulses.

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7.4 Measurement of the test voltage and determination of the impulse voltage shape

7.4.1 Measurement with an approved measuring system

The measurement of the peak value, the time parameters and the oscillations of the test voltage shall be made with an **approved measuring system** that has passed the tests and checks specified in Clause 4. Furthermore it shall have a **maximum rate of application** that is sufficient for the number of tests to be applied in the on-site test.

The measurement shall be made with the test object in the circuit and, in general, the impulse shape should be checked for each test object.

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

7.4.2 Requirements for an approved measuring system

The general requirements are as follows:

– to measure the peak value of **full lightning impulse voltages** with an uncertainty of 5 %;

– to measure the time parameters of both types of **impulse voltages** and the frequency of **oscillating impulse voltages** which define the waveform with an uncertainty of 10 %;

– to measure superimposed oscillations to ensure that they do not exceed the level of ±5 %.

7.4.3 Stability of the scale factor

The scale factor of the measuring system shall not vary by more than ±2 % for the ranges of the ambient temperature and clearances given in the **record of performance**.

7.4.4 Dynamic behaviour

The dynamic behaviour of a **measuring system** is adequate for the measurement of the peak voltage and time parameters over the range of waveforms specified in the **record of performance** when:

– the scale factor is constant within ±2 % for **full lightning impulse voltages** in the range of front times specified and

– the uncertainty of the time parameters measured by the system is within 10 %.

7.4.5 Connection to the test object

The converting device shall be connected directly to the terminals of the test object.

7.5 Tests and checks on measuring systems

7.5.1 General

Tests and checks shall be performed in accordance with Clause 4 of this standard.

NOTE It is recommended to check the dynamic behaviour by a **reference record**.

7.5.2 Interference check

An interference check shall be made on-site on each **measuring system** (voltage or current) with the input terminals of its cable or other transmission system short-circuited without changing the earth connections of the cable or transmission system. An interfering condition at the input of the **voltage measuring system** shall be produced by generating the maximum test voltage. The output shall be recorded. The amplitude of the measured interference shall be less than 2 % of the output of the **measuring system** when measuring the voltage.

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Interference greater than 2 % is permitted provided it is shown that it does not affect the measurement.

7.6 Withstand voltage test procedures

The recommended test procedure depends on the nature of the test object as defined in 3.4.

NOTE Procedures for diagnostic tests should be defined by the relevant technical committee.

7.6.1 Withstand voltage test: Procedure A

Three **impulse voltages** of the specified shape and polarity at the rated 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**.

7.6.2 Withstand voltage test: Procedure B

Fifteen **impulse voltages** of the specified shape and polarity at the 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 part of the insulation is obtained, using methods of detection specified by the relevant technical committee.

NOTE The indication of a failure is under review for the next edition of IEC 60060-1.

7.6.3 Other withstand voltage tests

The relevant technical committee may define particular withstand voltage tests and acceptance criteria for the relevant apparatus if necessary.

8 Tests with switching impulse voltage

8.1 General

The provisions of this clause are pertinent to test voltages for withstand tests and diagnostic tests as described in IEC 60060-1.

8.2 Definitions for switching impulse voltage tests

These definitions apply to aperiodic **impulse voltages** and to oscillating **impulse voltages**. Both types of **impulse voltages** might be applied for high-voltage tests on-site.

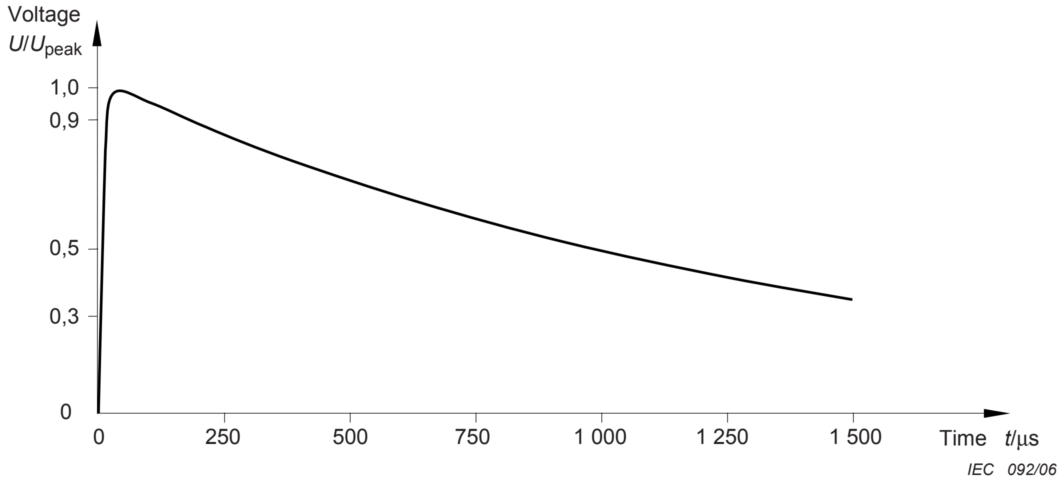
8.2.1
aperiodic switching impulse voltage
switching impulse voltage as defined in 3.3, which rises rapidly to a peak value and then falls without oscillations more slowly to zero. See Figure 3.

NOTE The standard **switching impulse voltage** 250/2 500 defined in IEC 60060-1 is an example of an **aperiodic impulse voltage**.

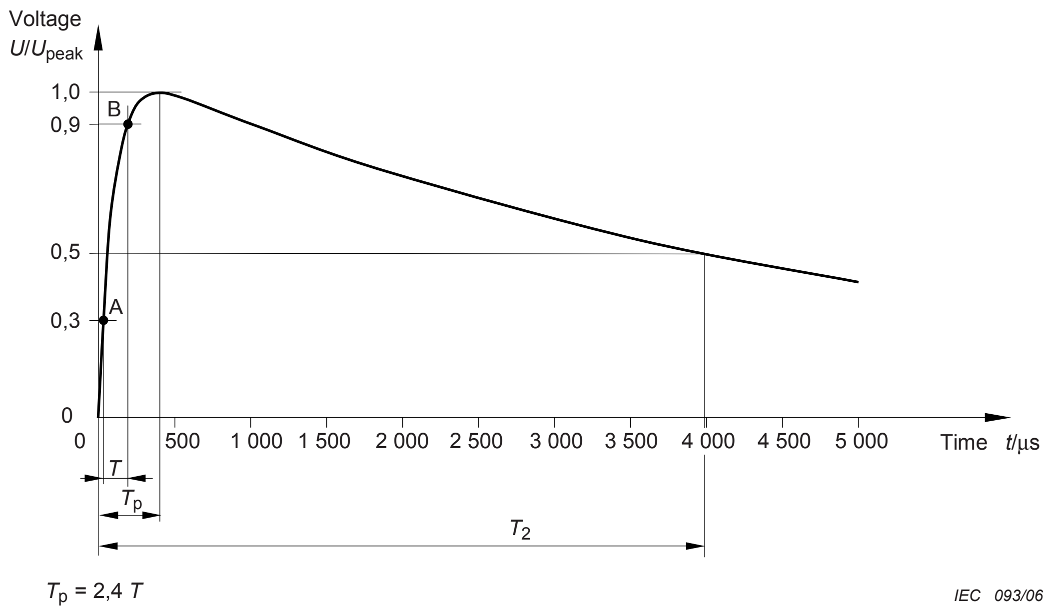
8.2.2
oscillating switching impulse voltage
switching impulse voltage, as defined in 3.3, that rises rapidly to a peak value and then falls to zero with damped oscillations of a frequency between 1 kHz and 15 kHz with or without polarity reversals. It is characterized by its enveloping curve and the frequency of the oscillations. See Figure 4.

8.2.3
value of the test voltage
peak value

In case of a disruptive discharge in the front, it is the prospective peak value.



a) T_p/T_2 = 20/1 000 µs



b) T_p/T_2 = 400/4 000 µs

Figure 3 – Aperiodic switching impulse

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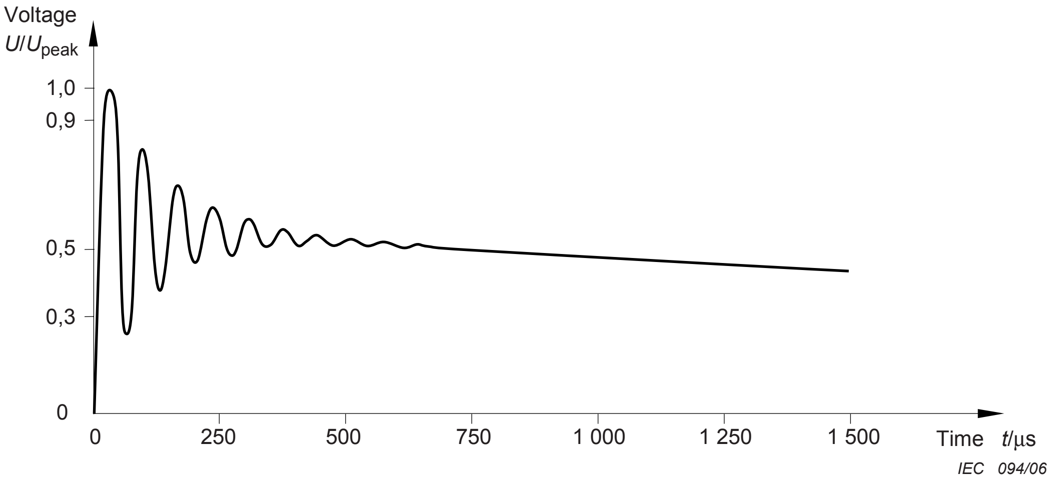
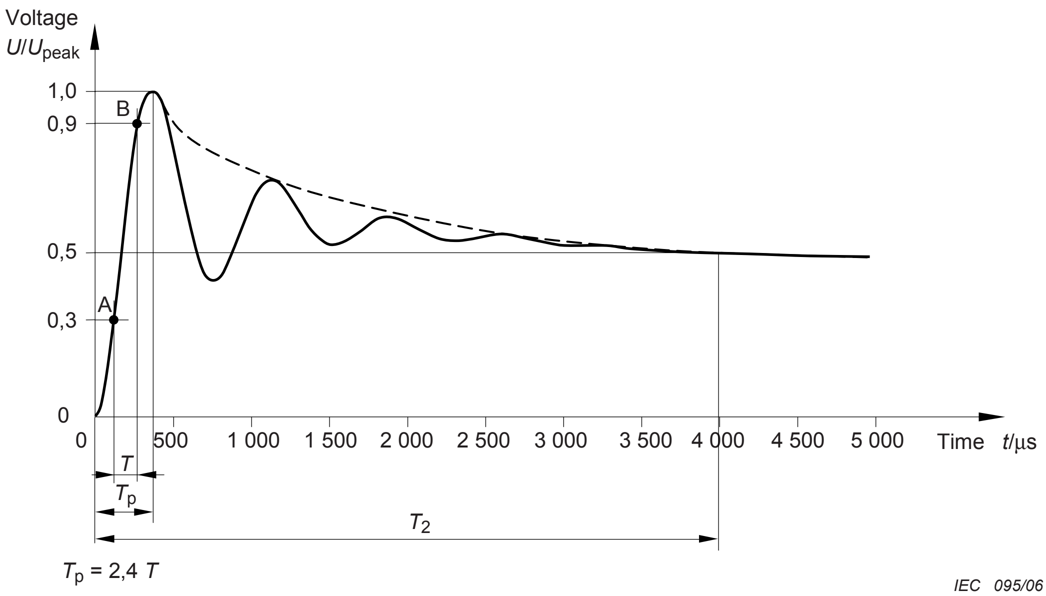


a) T_p/T_2 = 20/1 000 µs, 15 kHz



b) T_p/T_2 = 400/4 000 µs, 1 kHz

Figure 4 – Oscillating switching impulse

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8.2.4
time-to peak
T_p
time between the actual origin and the instant when the **impulse voltage** has reached its peak value, defined as 2,4 times the interval *T* between the instants when the **impulse voltage** is 30 % and 90 % of the peak value

8.2.5
time–to-half-value
T_2
for an **aperiodic switching impulse voltage**, parameter defined as the time between the actual origin and the instant when the voltage has decreased to half-value.

For an **oscillating switching impulse voltage**, parameter defined as the time between the actual origin and the instant when the envelope of the **oscillating switching impulse voltage** has decreased to half-value

8.2.6
frequency of an oscillating impulse voltage
inverse of the time difference between two successive peaks

8.3 Test voltage

8.3.1 Switching impulse voltage

The **impulse voltage** shall have a time to peak T_p between 20 µs and 400 µs and a time to half-value T_2 between 1 000 µs and 4 000 µs.

8.3.2 Tolerance

The measured **value of the test voltage** shall be within ±5 % of the specified value unless otherwise specified by the relevant technical committee.

NOTE Limits for acceptable time parameters are given in 8.3.1.

8.3.3 Generation of test voltage

The **switching impulse voltage** is usually produced by an impulse generator consisting essentially of a number of capacitors that are charged in parallel from a direct voltage source and then discharged in series into a circuit that includes the test object. For the generation of **aperiodic switching impulse voltages** this circuit includes resistors and the capacitive load. For the generation of **oscillating switching impulse voltages** the circuit contains inductance, e.g. an inductor is switched between the generator and the capacitive load. This oscillating circuit enables the generation of **oscillating switching impulse voltages** with peak values about twice of that of aperiodic pulses.

Switching impulse voltages can also be generated by the application of a voltage impulse to the low-voltage winding of a test transformer.

8.4 Measurement of the test voltage and determination of the impulse shape

8.4.1 Measurement with an approved measuring system

The measurement of the peak value, the time parameters and the frequency of the test voltage shall be made with an **approved measuring system** that has passed the tests and checks specified in Clause 4. Furthermore it shall have a **maximum rate of application** that is sufficient for the number of tests to be applied in the on-site test.

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The measurement shall be made with the test object in the circuit and, in general, the **impulse voltage** shape shall be checked for each test object.

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

8.4.2 Requirements for an approved measuring system

The general requirements are as follows:

– to measure the peak value of **switching impulse voltages** with an uncertainty of 5 %;

– to measure the time parameters of both types of **impulse voltages** and the frequency of oscillating **impulse voltages** which define the waveform with an uncertainty of 10 %.

8.4.3 Stability of the scale factor

The scale factor of the measuring system shall not vary by more than ±2 % for the ranges of the ambient temperature and clearances given in the **record of performance**.

8.4.4 Dynamic behaviour

The dynamic behaviour of a **measuring system** is adequate for the measurement of the peak voltage and time parameters over the range of waveforms specified in the **record of performance** when

– the scale factor is constant within ±2 % for **switching impulse voltages** in the range of times to peak specified, and

– the uncertainty of the time parameters measured by the system is within 10 %.

8.4.5 Connection to the test object

The converting device shall be connected directly to the terminals of the test object.

8.5 Tests and checks on measuring systems

8.5.1 General

Tests and checks shall be performed in accordance with Clause 4 of this standard.

NOTE It is recommended to check the dynamic behaviour by a **reference record.**

8.5.2 Interference check

An interference check shall be made on-site on each **measuring system** (voltage or current) with the input terminals of its cable or other transmission system short-circuited without changing the earth connections of the cable or other transmission system. An interfering condition at the input of the **voltage measuring system** shall be produced by generating the maximum test voltage. The output shall be recorded. The amplitude of the measured interference shall be less than 2 % of the output of the **measuring system** when measuring the voltage. Interference greater than 2 % is permitted provided it is shown that it does not affect the measurement.

8.6 Withstand voltage test procedures

The recommended test procedure depends on the characteristics of the test object as defined in 3.8.

NOTE The indication of a failure is under review for the next edition of IEC 60060-1.

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8.6.1 Withstand voltage test: Procedure A

Three **impulse voltages** of the specified shape and polarity at the rated 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.**

8.6.2 Withstand voltage test: Procedure B

Fifteen **impulse voltages** of the specified shape and polarity at the 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 part of the insulation is obtained, using methods of detection specified by the relevant technical committee.

NOTE The indication of a failure is under review for the next edition of IEC 60060-1.

8.6.3 Other withstand voltage tests

The relevant technical committee may define particular withstand voltage tests and acceptance criteria for the relevant apparatus if necessary.

9 Tests with very low frequency voltages

9.1 General

The provisions of this clause are pertinent to special tests.

9.2 Definitions for very low frequency voltage tests

9.2.1
very low frequency (VLF) voltage
alternating voltage of very low frequency with a wave shape between rectangular and sinusoidal

9.2.2
value of the test voltage
peak value of the **VLF** voltage

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 physical effects in the insulation depend on that.

9.2.3
peak value
maximum value of a **VLF** voltage disregarding small high-frequency oscillations

9.2.4
r.m.s. value
square root of the mean value of the square of the voltage values during a complete cycle of the alternating voltage

(IEC 60060-1:1989, Term 15.3)

NOTE 1 For a pure sine wave this value is the peak value divided by the square root of two.

NOTE 2 For a pure rectangular wave this value is equal to the peak value.

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9.3 Test voltage

9.3.1 Voltage wave shape

The test voltage should be an alternating voltage having a frequency between 0,01 Hz and 1 Hz.

NOTE With respect to the wide frequency range the relevant technical committee should specify the frequency range dependent on physical effects in the test object, the test duration and the voltage value.

Sinusoidal **VLF** voltage waveshape shall approximate a sinusoid with both half-cycles closely alike. The result of a high-voltage test is thought to be unaffected by small deviations from a sinusoid if the ratio of the peak to **r.m.s.** values is within $\sqrt{2} \pm 15$ %.

NOTE If the ratio of peak to **r.m.s.** values is not within $\sqrt{2} \pm 5$ %, it should be verified that positive and negative peaks do not differ by more than 2 %.

Rectangular **VLF** voltage wave shape shall approximate a rectangular wave with both half-cycles closely alike. The polarity change should be controlled to avoid overvoltages caused by transients. The ratio of peak to **r.m.s**. values shall be within 1,0 ± 5 %.

9.3.2 Tolerance

The measured **value of the test voltage** shall be within ±5 % of the specified value unless otherwise specified by the relevant technical committee.

9.3.3 Generation of the test voltage

Generation of **sinusoidal VLF** voltage is achieved, for example, by controlled charging of the capacitive test object from a positive and a negative HVDC source. Controllable resistors discharge the test object accordingly.

Generation of **rectangular VLF** voltage is also achieved for example on the basis of a HVDC source. The polarity reversal is realized by a switchable rectifier in connection with an oscillating circuit consisting of an inductance and the capacitances of the storage capacitor and the test object.

The requirements to be met by the voltage source depend considerably upon the type of apparatus that is to be tested and on the on-site test conditions. These requirements are determined mainly by the value and nature of the test current to be supplied. The source characteristics should be chosen to achieve rated voltage on the test object. The source, including its storage capacitance, should also be adequate to supply the leakage and absorption current and any internal and external non-disruptive discharge currents without voltage drop exceeding 15 %.

9.4 Measurement of the test voltage

9.4.1 Measurement with an approved measuring system

The measurement of the test voltage shall be made with an **approved measuring system** that has passed the tests and checks specified in Clause 4. Furthermore it shall have an **operating time** that is sufficient for the duration of the on-site test.

The measurement shall be made with the test object in the circuit.

9.4.2 Requirements for an approved measuring system

The general requirement is to measure the **peak value of the test voltage** with an overall uncertainty of 5 %.

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9.4.3 Stability of the scale factor

The scale factor of the measuring system shall not vary by more than ±2 % for the ranges of the ambient temperature, humidity and clearances given in the **record of performance**.

9.4.4 Dynamic behaviour

The response time T_N of an **approved measuring system** shall not be larger than 0,5 ms. The dynamic behaviour of a **measuring system** is considered to be adequate if the scale factor is constant within ±2 % between 0,5 and 2 times the frequency of the VLF voltage.

9.4.5 Connection to the test object

The converting device shall be connected directly to the terminals of the test object.

9.5 Tests and checks on measuring systems

Tests and checks shall be performed in accordance with Clause 4 of this standard.

NOTE An approved measuring system for DC and AC voltages that has been shown to have a flat frequency response (within ± 2 %) between DC and power frequency is considered to be an approved measuring system for VLF voltages.

9.6 Test procedure

The test procedure should be specified by the relevant technical committee considering the wave shape, the test frequency, the **value of the test voltage** and the **test duration**.

10 Tests with damped alternating voltages

10.1 General

The provisions of this clause are pertinent to special tests.

10.2 Definitions for damped alternating voltage tests

10.2.1
damped alternating voltage
starting from a (negative or positive) charging voltage level and having damped sinusoidal oscillation around the zero level. It is characterized by the peak value, the **circuit frequency** and the **damping factor**. See Figure 5.

10.2.2
value of the test voltage
peak value

10.2.3
peak value
U_p
maximum voltage applied to the test object equal to the charging voltage

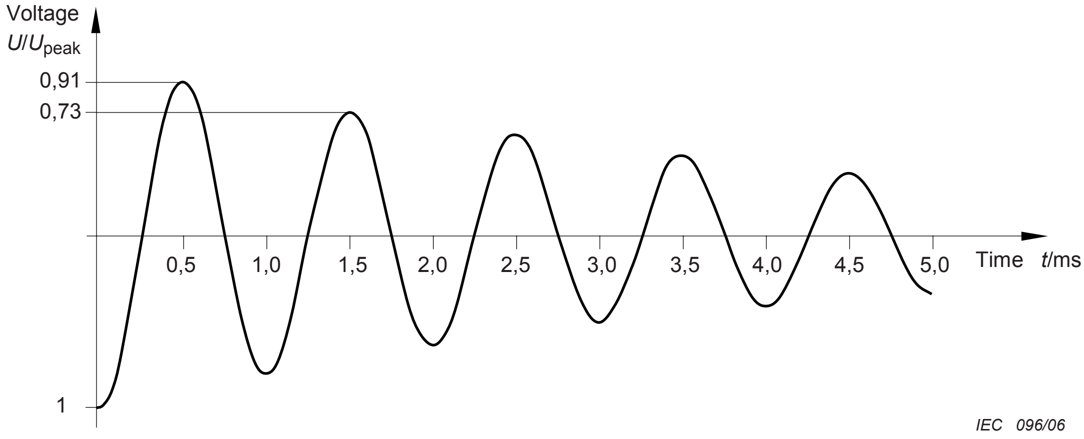

Figure 5 – Damped alternating voltage (f_r = 1 kHz, D_f = 0,2)

10.2.4
circuit frequency
f_r
reciprocal of the time between two successive peaks of same polarity

10.2.5
damping factor
D_f
voltage difference between the first and second peak of same polarity, divided by the voltage value of the first peak

10.3 Test voltage

10.3.1 Voltage wave shape

The damped alternating voltage is characterized by a **circuit frequency** of between 20 Hz and 1 000 Hz and a **damping factor** generally ranging up to 40 %.

10.3.2 Tolerance

The measured **value of the test voltage** shall be within ±5 % of the specified value unless otherwise specified by the relevant technical committee.

NOTE Limits for acceptable **circuit frequencies** and **damping factors** are given in 10.3.1, no additional tolerances shall be applied.

10.3.3 Generation of the test voltage

Damped alternating voltages are generated by the discharge of the charged test object capacitance through a suitable inductance. The test circuit basically consists of a HV direct voltage source, an inductor, a capacitor and a suitable switch. When the charging voltage is reached the switch is closed, generating on the test object a damped alternating voltage.

The circuit frequency is determined by the values of the inductance and the capacitance. In order to reduce the influence of the capacitance of the test object on the circuit frequency an additional storage capacitor could be connected in parallel to the test object. The damping factor depends on the characteristics of the test circuit and the test object.

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10.4 Measurement of the test voltage

10.4.1 Measurement with an approved measuring system

The measurement of the peak value shall be made with an **approved measuring system** that has passed the tests and checks specified in Clause 4. Furthermore it shall have a **maximum rate of application** that is sufficient for the number of tests to be applied in the on-site test.

The measurement shall be made with the test object in the circuit and, in general, the **circuit frequency** f_r and the **damping factor** D_f should be measured for each test object.

NOTE The determination of the **circuit frequency** f_r and the **damping factor** D_f by calculation from test circuit parameters is not considered to be satisfactory.

10.4.2 Requirements for an approved measuring system

The general requirements are as follows:

– to measure the peak value of the test voltage within its frequency range with an overall uncertainty of 5 %;
– to measure the **circuit frequency** f_r and the **damping factor** D_f with an uncertainty of 10 %.

10.4.3 Stability of the scale factor

The scale factor of the measuring system shall not vary by more than ±2 % for the ranges of the ambient temperature, humidity and clearances given in the **record of performance**.

10.4.4 Dynamic behaviour

The dynamic behaviour of a **measuring system** is considered to be adequate for the measurement of the peak voltage and time parameters if the scale factor is constant within ±2 % within the frequency range from DC to 1 000 Hz.

In the case of a **measuring system** used exclusively on test systems with a maximum **circuit frequency** f_r lower than 1 000 Hz, the dynamic behaviour of this **measuring system** is considered to be adequate for the measurement of the peak voltage and time parameters if the scale factor is constant within ±2 % within the frequency range from DC to the actual maximum **circuit frequency** f_r.

10.4.5 Connection to the test object

The converting device shall be connected directly to the terminals of the test object.

10.5 Tests and checks on measuring systems

10.5.1 General

Tests and checks shall be performed in accordance with Clause 4 of this standard.

10.5.2 Interference check

An interference check shall be made on-site on each **measuring system** (voltage or current) with the input terminals of its cable or other transmission system short-circuited without changing the earth connections of the cable or other transmission system. An interfering condition at the input of the **voltage measuring system** shall be produced by generating the maximum test voltage. The output shall be recorded. The amplitude of the measured interference shall be less than 2 % of the output of the **measuring system** when measuring the voltage. Interference greater than 2 % is permitted, provided it is shown that it does not affect the measurement.

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10.6 Test procedure

The recommended procedures for these tests should be specified by the relevant technical committee, which may also define acceptance criteria for the relevant HV apparatus.

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Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60060-1 + corr. March	1989 1990	High-voltage test techniques Part 1: General definitions and test requirements	HD 588.1 S1	1991
IEC 60060-2	1994	High-voltage test techniques Part 2: Measuring systems	EN 60060-2	1994
IEC 60071-1	1993	Insulation co-ordination Part 1: Definitions, principles and rules	EN 60071-1[1)]	1995

[1)] EN 60071-1 is superseded by EN 60071-1:2006, which is based on IEC 60071-1:2006.

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