BS EN 61180:2016

BSI Standards Publication

High-voltage test techniques for low-voltage equipment — Definitions, test and procedure requirements, test equipment

National foreword

This British Standard is the UK implementation of EN 61180:2016. It is identical to IEC 61180:2016. It supersedes BS EN 61180-1:1995 and BS EN 61180-2:1995, which are withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PEL/42, Testing techniques for high voltages and currents.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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English Version

High-voltage test techniques for low-voltage equipment - Definitions, test and procedure requirements, test equipment (IEC 61180:2016)

Techniques des essais à haute tension pour matériel à basse tension - Définitions, exigences et modalités relatives aux essais, matériel d'essai
(IEC 61180:2016)

Hochspannungs-Prüftechnik für Niederspannungsgeräte - Begriffe, Prüfung und Prüfbedingungen, Prüfgeräte
(IEC 61180:2016)

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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European foreword

The text of document 42/341/FDIS, future edition 1 of IEC 61180, prepared by IEC/TC 42 "High-voltage and high-current test techniques" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61180:2016.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2017-04-29
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2019-07-29

This document supersedes EN 61180-1:1994 and EN 61180-2:1994.

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Endorsement notice

The text of the International Standard IEC 61180:2016 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 61000-4-5:2014	NOTE	Harmonized as EN 61000-4-5:2014 (not modified).
IEC 61010-1	NOTE	Harmonized as EN 61010-1.
IEC 61010-2-030:2010	NOTE	Harmonized as EN 61010-2-030:2010 (not modified).

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

Publication	Year	Title	EN/HD	Year
IEC 60060-1	2010	High-voltage test techniques - Part 1: General definitions and test requirements	EN 60060-1	2010
IEC 60060-2	2010	High-voltage test techniques - Part 2: Measuring systems	EN 60060-2	2011
IEC 60068-1	2013	Environmental testing - Part 1: General and guidance	EN 60068-1	2014
IEC 60335	series	Household and similar electrical appliances - Safety	EN 60335	series
IEC 60664-1	2007	Insulation coordination for equipment within low-voltage systems - Part 1: Principles, requirements and tests	EN 60664-1	2007
IEC 61083-1	2001	Instruments and software used for measurement in high-voltage impulse tests - Part 1: Requirements for instruments	EN 61083-1	2001
IEC 61083-2	2013	Instruments and software used for measurement in high-voltage and high-current tests - Part 2: Requirements for software for tests with impulse voltages and currents	EN 61083-2	2013
ISO/IEC Guide 98-3	2008	Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)	-	-

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

HIGH-VOLTAGE TEST TECHNIQUES FOR LOW-VOLTAGE EQUIPMENT –

Definitions, test and procedure requirements, test equipment

FOREWORD

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International Standard IEC 61180 has been prepared by IEC technical committee 42: High-voltage and high-current test techniques.

This 1st edition of IEC 61180 cancels and replaces the 1st edition of IEC 61180-1, issued in 1992, and the 1st edition of IEC 61180-2, issued in 1994.

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

FDIS	Report on voting
42/341/FDIS	42/342/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.

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 the specific publication. At this date, the publication will be

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

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

HIGH-VOLTAGE TEST TECHNIQUES FOR LOW-VOLTAGE EQUIPMENT –

Definitions, test and procedure requirements, test equipment

1 Scope

This International Standard is applicable to:

- dielectric tests with direct voltage;
- dielectric tests with alternating voltage;
- dielectric tests with impulse voltage;
- test equipment used for dielectric tests on low-voltage equipment.

This standard is applicable only to tests on equipment having a rated voltage of not more than 1 kV a.c. or 1,5 kV d.c.

This standard is applicable to type and routine tests for objects which are subjected to high voltage tests as specified by the technical committee.

The test equipment comprises a voltage generator and a measuring system. This standard covers test equipment in which the measuring system is protected against external interference and coupling by appropriate screening, for example a continuous conducting shield. Therefore, simple comparison tests are sufficient to ensure valid results.

This standard is not intended to be used for electromagnetic compatibility tests on electric or electronic equipment

NOTE Tests with the combination of impulse voltages and currents are covered by IEC 61000-4-5.

This standard provides the relevant technical committees as far as possible with:

- defined terms of both general and specific applicability;
- general requirements regarding test objects and test procedures;
- methods for generation and measurement of test voltages;
- test procedures;
- methods for the evaluation of test results and to indicate criteria for acceptance;
- requirements concerning approved measuring devices and checking methods;
- measurement uncertainty.

Alternative test procedures may be required and these should be specified by the relevant technical committees.

Care should be taken if the test object has voltage limiting devices, as they may influence the results of the test. The relevant technical committees should provide guidance for testing objects equipped with voltage limiting devices.

2 Normative references

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

IEC 60060-1:2010, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60060-2:2010, *High-voltage test techniques – Part 2: Measuring systems*

IEC 60068-1:2013, *Environmental testing – Part 1: General and guidance*

IEC 60335(all parts): *Household and similar electrical appliances – Safety*

IEC 60664-1:2007, *Insulation co-ordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 61083-1:2001, *Instruments and software used for measurement in high-voltage impulse test – Part 1: Requirements for instruments*

IEC 61083-2:2013, *Instruments and software used for measurement in high-voltage and high-current tests – Part 2: Requirements for software for tests with impulse voltages and currents*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurements (GUM)*

3 Terms and definitions

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

3.1 General terms

3.1.1
clearance
distance between two conductive parts along a string stretched across the shortest path between these conductive parts

[SOURCE: IEC 60050-441:1984, 441-17-31]

3.1.2
creepage distance
shortest distance along the surface of a solid insulating material between two conductive parts

[SOURCE: IEC 60050-151: 2001, 151-15-50]

3.2 Definitions related to disruptive discharge and test voltages

3.2.1
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

3.2.2
withstand voltage
specified voltage value which characterizes the insulation of the object with regard to a withstand test

Note 1 to entry: Unless otherwise specified, withstand voltages are referred to standard reference atmospheric conditions (see 4.2).

3.3 Characteristics related to the test equipment

3.3.1
calibration
set of operations that establishes, by reference to standards, the relationship which exists, under specified conditions, between an indication and a result of a measurement

Note 1 to entry: The determination of the scale factor is included in the calibration.

[SOURCE: IEC 60050-311:2001, 311-01-09, modified: note modified]

3.3.2
type test
conformity test made on one or more items representative of the production

Note 1 to entry: For a measuring system, this is a test performed on a component or on a complete measuring system of the same design to characterize it under operating conditions.

[SOURCE: IEC 60050-151: 2001, 151-16-16, modified:note added]

3.3.3
routine test
conformity test made on each individual item during or after manufacture

Note 1 to entry: This is a test performed on each component or on each complete measuring system to characterize it under operating conditions.

[SOURCE: IEC 60050-151: 2001, 151-16-17, modified:note added]

3.3.4
performance test
test performed on a complete measuring system to characterize it under operating conditions

3.3.5
test equipment
complete set of devices needed to generate and measure the test voltage or current applied to a test object

3.3.6
reference measuring system
measuring system with its calibration traceable to relevant national and/or international standards, and having sufficient accuracy and stability for use in the approval of other systems by making simultaneous comparative measurements with specific types of waveform and ranges of voltage

3.3.7
assigned scale factor
scale factor of a measuring system determined at the most recent performance test

Note 1 to entry: A measuring system may have more than one assigned scale factor; for example, it may have several ranges, each with a different scale factor.

3.4 Characteristics related to direct voltage tests

3.4.1
value of the test voltage
arithmetic mean value

3.4.2
ripple
periodic deviation from the arithmetic mean value of the test voltage

3.4.3
ripple amplitude
half the difference between the maximum and minimum values

Note 1 to entry: 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.

3.4.4
ripple factor
ratio of the ripple amplitude to the value of test voltage

3.5 Characteristics related to alternating voltage tests

3.5.1
peak value
average of the magnitudes of the positive and negative maximum values

3.5.2
r.m.s. value
square root of the mean value of the square of the voltage values during a complete cycle

3.5.3
true r.m.s. value
value obtained from

$$I_{\mathrm{rms}} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,\mathrm{d}t}$$

where

0 is the time instant ($t = 0$) of an a.c. periodic wave, convenient for the beginning of integration;

T is the time taken over an integral number of cycles;

$i(t)$ is the instantaneous value of the current.

Note 1 to entry: The true r.m.s. value can in general be calculated from a digitized record of any periodic waveform, provided a sufficient number of samples have been taken.

Note 2 to entry: In cases with varying frequency, no strict formula for true r.m.s. value can be given.

3.5.4
total harmonic distortion
THD
the ratio of the rms value of the harmonic content of an alternating quantity to the rms value of the fundamental component of the quantity

[SOURCE: IEC 60050-551: 1998, 551-17-06]

3.6 Characteristics related to impulse tests (see Figure 1)

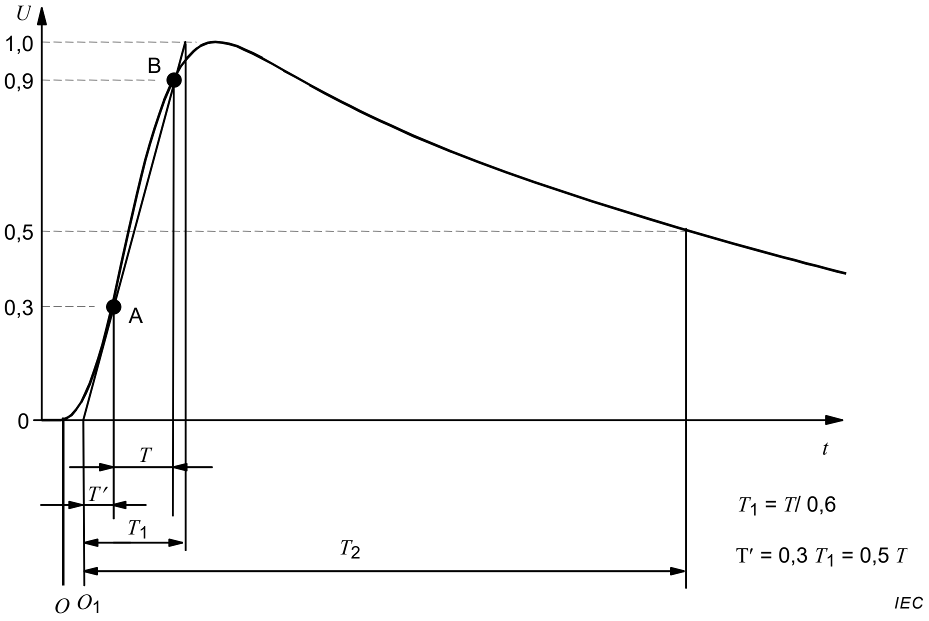

Figure 1 – Full impulse voltage time parameters

Note 1 to entry: Oscillations are negligible.

3.6.1
impulse voltage
intentionally applied aperiodic transient voltage which usually rises rapidly to a peak value and then falls more slowly to zero

3.6.2
peak value
maximum value

3.6.3
value of the test voltage
for an impulse without overshoot or oscillations, its peak value

Note 1 to entry: The determination of the peak value, in the case of oscillations or overshoot on standard impulses, is considered in IEC 60060-1.

3.6.4
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 1)

3.6.5
virtual origin
O_1
instant preceding point A, of the test voltage curve (see Figure 1) by a time 0,3 T_1

Note 1 to entry: 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.

3.6.6
time to half-value

T_2

virtual parameter defined as the time interval between the virtual origin O_1 and the instant when the voltage has decreased to half the peak value

3.6.7
recorded curve

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

3.7 Definitions relating to tolerance and uncertainty

3.7.1
tolerance

permitted difference between the measured value and the specified value

3.7.2
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

Note 1 to entry: Uncertainty is positive and given without sign.

[SOURCE: IEC 60050-311:2001, 311-01-02]

3.7.3
error

measured quantity value minus a reference quantity value

[SOURCE: ISO/IEC Guide 98-3:2008, GUM 2.3.2]

3.7.4
standard uncertainty

u

uncertainty of the result of a measurement expressed as a standard deviation

Note 1 to entry: The standard uncertainty associated with an estimate of a measurand has the same dimension as the measurand.

Note 2 to entry: In some cases, the relative standard uncertainty of a measurement may be appropriate. The relative standard uncertainty of measurement is the standard uncertainty divided by the measurand, and is therefore dimensionless.

[SOURCE: ISO/IEC Guide 98-3:2008, GUM 2.3.1]

3.7.5
combined standard uncertainty

u_c

standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities

[SOURCE: ISO/IEC Guide 98-3:2008, GUM 2.3.4]

3.7.6
expanded uncertainty

U

quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

Note 1 to entry: Expanded uncertainty is the closest match to the term “overall uncertainty”.

Note 2 to entry: The true, but unknown test-voltage value may lie outside the limits given by the uncertainty because the coverage probability is $<$ 100 % (see 3.7.7).

[SOURCE: ISO/IEC Guide 98-3:2008, GUM 2.3.5, modified:notes added]

3.7.7
coverage factor

k

numerical factor used as multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty

Note 1 to entry: For 95 % coverage probability and normal (Gaussian) probability distribution the coverage factor is approximately $k = 2$.

[SOURCE: ISO/IEC Guide 98-3:2008, GUM 2.3.6, modified:note added]

3.7.8
type A evaluation

method of evaluation of an uncertainty by statistical analysis of a series of observations

3.7.9
type B evaluation

method of evaluation of an uncertainty by means other than statistical analysis of a series of observations

3.7.10
national metrology institute

institute designated by national decision to develop and maintain national measurement standards for one or more quantities

4 General requirements

4.1 General

Unless otherwise specified by the relevant technical committee, the test object should be clean and dry, stabilized to ambient environmental conditions and the voltage application shall be as specified in the relevant clauses of this standard. The test procedures applicable to particular types of test objects, should be specified by the relevant technical committee, having regard to such factors as:

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

This includes for example, the polarity to be used, the preferred order if both polarities are to be used, the number of applications and the interval between applications, and any conditioning and preconditioning.

The connections between the test equipment and the object subjected to the high voltage test shall be direct and as short as possible. Loops of the connections should be avoided to minimize oscillations on the front of the impulse. The leads should be as close to each other as possible in order to minimize the area between the leads.

These requirements shall also apply for the qualification of the measuring system, e.g. the test equipment to be calibrated and the reference measuring system.

The manufacturer of the test equipment shall give information on the characteristics of the test equipment, so that the generated voltage is still within the allowed tolerances when testing the object subjected to the high voltage test.

4.2 Atmospheric conditions for test procedures and verification of test equipment

The atmospheric conditions for test procedures and the verification of test equipment shall be those stated for testing in IEC 60068-1:

Temperature	15 °C to 35 °C
Air pressure	86 kPa to 106 kPa
Relative humidity	25 % to 75 %
Absolute humidity	≤ 22 g/m^3

The actual atmospheric conditions during the test shall be recorded.

For the purpose of testing, where the atmospheric conditions are within the ranges specified in this standard, corrections to the test voltage due to variations of the temperature, humidity and air pressure do not need to be applied.

When the atmospheric conditions during the test are not within the ranges specified in this standard, the method in Annex C shall be used, by agreement, for test voltage correction.

4.3 Procedures for qualification and use of measuring systems

4.3.1 General principles

Every approved measuring system shall undergo initial tests, followed by periodic performance tests throughout its service life, as specified in 4.3.2. The initial tests consist of type tests and routine tests.

The performance tests shall prove that the measuring systems can measure the intended test voltages within the uncertainties given in this standard, and that the measurements are traceable to national and/or international standards of measurement. The system is approved only for the arrangements and operating conditions included in its record of performance, as specified in 4.3.3.

A major requirement for measuring systems is stability within the specified range of operating conditions so that the scale factor remains constant over long periods.

The assigned scale factor is determined in the performance test by calibration. Any calibration shall be traceable to national and/or international standards. The user shall ensure that any calibration is performed by competent personnel using reference measuring systems and suitable procedures.

Alternatively, any user may choose to have the performance tests made by a national metrology institute or by a calibration laboratory accredited for the quantity to be calibrated.

Calibrations performed by a national metrology institute, or by a laboratory accredited for the quantities calibrated and reported under the accreditation, are considered traceable to national and/or international standards.

In all cases, the user shall include the test data in the record of performance.

4.3.2 Schedule of performance tests

To maintain the quality of a measuring system, the assigned scale factor(s) shall be determined by periodic performance tests. The interval between performance tests shall be not longer than 1 year unless otherwise stated by the manufacturer and based on experience demonstrating long-term stability.

Performance tests shall be made following major repairs to the measuring system and whenever a circuit arrangement that is beyond the limits given in the record of performance is to be used.

4.3.3 Requirements for the record of performance

The results of all tests, including the conditions under which the results were obtained, shall be kept in the record of performance (stored in paper format or electronically if permitted by quality systems and local laws) established and maintained by the user. The record of performance shall uniquely identify the components of the measuring system and shall be structured so that performance of the measuring system can be traced over time.

The record of performance shall comprise at least the following information:

- General description of the measuring system.
- Results of type and routine tests on the measuring system.
- Results of subsequent performance tests on the measuring system.

The general description of the measuring system usually comprises main data and capabilities of the measuring system, such as the rated operating voltage, waveform(s), range(s) of clearances, operating time, or maximum rate of voltage applications. For many measuring systems, information on the transmission system as well as high-voltage and ground-return arrangements are important. If required, a description is also given of components of the measuring system, including for example the type and identification of the measuring instrument.

4.3.4 Uncertainty

The uncertainty of all measurements made under this International Standard shall be evaluated according to ISO/IEC Guide 98-3. Uncertainty of measurement shall be distinguished from the tolerance. A pass/fail decision is based solely on the measured value in relation to the pass/fail criteria. The measurement uncertainty shall not be applied to the measured value to make the pass/fail decision. Procedures for evaluating uncertainties given in 4.4.7 are specified in accordance with the principles of ISO/IEC Guide 98-3, and are considered sufficient for the instrumentation and measurement arrangements commonly used in high-voltage testing. However, users may select other appropriate procedures from ISO/IEC Guide 98-3, some of which are outlined in Annex A and Annex B.

In general, the measurand to be considered is the scale factor of the measuring system, but in some cases other quantities, such as the time parameters of an impulse voltage and their associated errors, should also be considered.

NOTE 1 Other measurands for specific converting devices are in common use. For example, a voltage divider is characterized by the voltage ratio and its uncertainty in the assigned measurement ranges used. A voltage transformer is characterized by the ratio error, the phase displacement and the corresponding uncertainties.

According to the ISO/IEC Guide 98-3, the uncertainty of a measurement is determined by combining the uncertainty contributions of Type A and Type B (see 4.4.7). These contributions are obtained from measurement results, manufacturers' handbooks, calibration certificates and from estimating reasonable values of the influence quantities during the measurement. Influence quantities considered in 4.4 include temperature effects, influence of the load, dynamic behaviour of the measuring system and long and short term stability influence. Other effects, including limited resolution of the measuring instrument, may be included if necessary.

The uncertainty shall be given as the expanded uncertainty for a coverage probability of approximately 95 % corresponding to a coverage factor k=2 under the assumption of a normal distribution.

NOTE 2 In this International Standard, the uncertainties of the scale factor and of voltage measurement (4.4.1 to 4.4.6) are expressed by the relative uncertainties instead of the absolute uncertainty normally considered in the ISO/IEC Guide 98-3.

4.4 Tests and test requirements for an approved measuring system and its components

4.4.1 Calibration – Determination of the scale factor

The assigned scale factor of the measuring system shall be determined by calibration according to the specified performance tests. The assigned scale factor is a single value for the assigned measurement range. If necessary, several assigned measurement ranges with different scale factors may be defined.

Scale factor(s) is (are) determined for a complete measuring system by comparison with a reference measuring system.

The input voltage used for calibration should be of the same type, frequency or waveform as voltages to be measured. If this condition is not fulfilled, the related uncertainty contributions shall be estimated.

Calibration shall be performed by connecting a reference measuring system, traceable to a national metrology institute, in parallel with the measuring system to be calibrated. Care shall be taken to avoid ground loops between the converting device(s) and measuring instrument(s). Simultaneous readings shall be taken on both systems. The value of the input quantity obtained for each measurement by the reference measuring system is divided by the corresponding reading of the instrument in the system under test to obtain a value F_i of its scale factor. The procedure is repeated n times to obtain the mean value F_g of the scale factor of the system under test at one voltage level U_g. The mean value is given by:

$$F_\mathrm{g} = \frac{1}{n}\sum_{i=1}^{n} F_{i,g}$$

The relative standard deviation s_g of F_g is given by:

$$s_g = \frac{1}{F_g}\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(F_{i,g} - F_\mathrm{g})^2}$$

and the Type A relative standard uncertainty u_g of the mean value F_g is given by (Annex A):

$$u_\mathrm{g} = \frac{s_g}{\sqrt{n}}$$

Usually no more than n = 10 independent readings are necessary.

For measurement of direct and alternating voltages, independent readings should be obtained either by applying the test voltage and taking n readings or by applying the test voltage n times and taking a reading each time. For impulse voltages, n impulses are applied.

The scale factor determination shall be made at the minimum and maximum levels of the assigned measurement range and on at least three approximately equally spaced intermediate levels (Figure 2). The assigned scale factor F is taken as the mean value of all scale factors F_g recorded at h voltage levels:

$$F = \frac{1}{h}\sum_{g=1}^{h} F_g \quad \text{for } h \geq 5$$

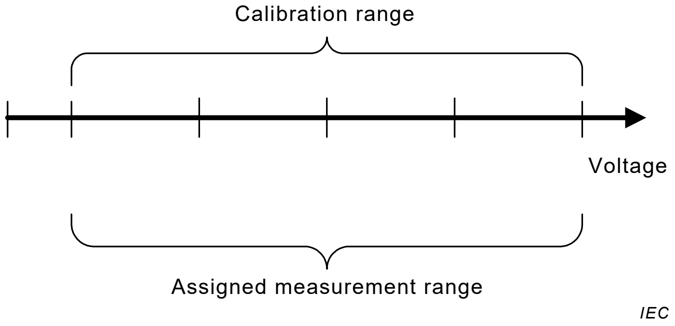

Figure 2 – Calibration by comparison over the full voltage range

The standard uncertainty of the determination of the assigned scale factor F is obtained as the largest of the single standard uncertainties of type A (Figure 3):

$$u_A = \max_{g=1}^{h} u_g .$$

The effect of a non-linearity in F is estimated as a Type B standard uncertainty expressed by:

$$u_{Bo} = \frac{1}{\sqrt{3}} \max_{g=1}^{h} \left| \frac{F_g}{F} - 1 \right| .$$

A rounded value F_o may be taken as the assigned scale factor if the difference between F_o and F is introduced as an uncertainty contribution of Type B in the estimate of the expanded uncertainty of the scale factor F_o.

The individual scale factors and their uncertainties at the h voltage levels should be given in the calibration certificate.

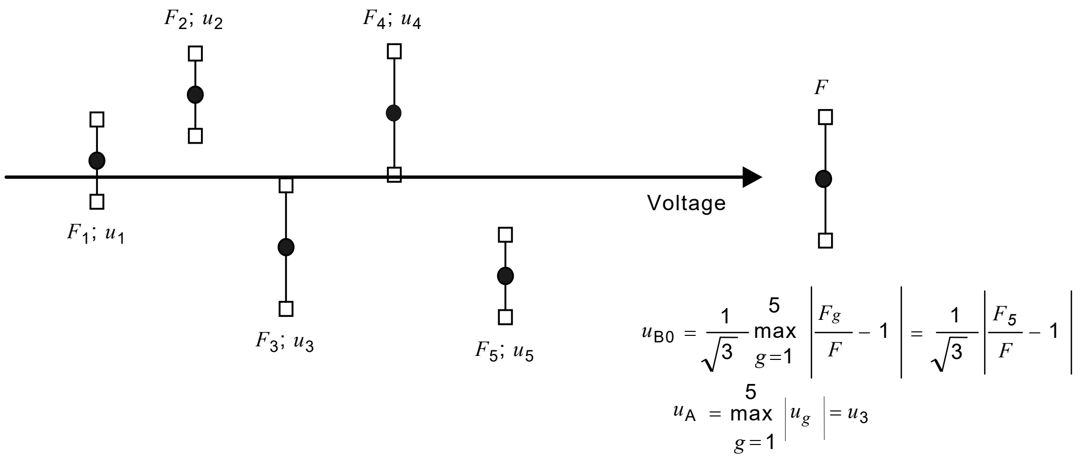

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Figure 3 – Uncertainty contributions of the calibration (example with a minimum of 5 voltage levels)

4.4.2 Influence of load

Each comparison test shall be made first with the minimum load (the reference measuring system alone) and be repeated with the maximum load (resistive, capacitive, inductive or any combination of these) allowed by the manufacturer of the test equipment.

The uncertainty contribution of the load shall be taken into account by:

$$u_{Bl} = \frac{1}{\sqrt{3}} \left| \frac{F_{Maxload}}{F_{Minload}} - 1 \right|$$

This is needed especially when the voltage is not directly measured on the high-voltage side at the test object terminals.

4.4.3 Dynamic behaviour

4.4.3.1 General

The response of a component or a measuring system shall be determined in conditions representative of its use, particularly clearances to earthed and energized structures. The preferred methods of measurement are the amplitude/frequency response for direct or alternating voltages, and determination of the scale factors and time.

NOTE Additional information on unit step-response measurements is given in Annex C of IEC 60060-2:2010.

A type B estimate of the relative standard uncertainty related to the dynamic behaviour is given by:

$$u_{B2} = \frac{1}{\sqrt{3}} \max_{i=1}^{k} \left| \frac{F_i}{F} - 1 \right|$$

where k is the number of scale factor determinations within a frequency range, or within a range of impulse time parameters defining the nominal epoch. F_i are the individual scale factors and F is the mean scale factor within the nominal epoch.

4.4.3.2 Determination of the amplitude/frequency response

The system or component is subjected to a sinusoidal input of known amplitude, usually at low level, and the output is measured. This measurement is repeated for an appropriate range of frequencies. The deviations of the scale factor are evaluated according to the above formula (4.4.3.1).

4.4.3.3 Reference method for impulse voltage measuring systems

Records of the impulse voltage taken for calibration of the scale factor described in 4.4.1 are used for the limits of the nominal epoch, and the uncertainty contribution of voltage and time-parameter measurements shall be evaluated according to the above formula (4.4.3.1).

NOTE For additional information on unit step response measurement and evaluation, see Annex C of IEC 60060-2:2010.

4.4.4 Short-term stability

The maximum voltage of the assigned measurement range shall be applied to the measuring system continuously (or at the assigned rate for impulses) for a period appropriate to the anticipated use. The scale factor shall be measured as soon as the maximum voltage has been reached and again immediately before the voltage is reduced.

The period of voltage application should not be longer than the assigned operating time, but can be limited to a time sufficient to reach equilibrium.

NOTE The short term stability test is intended to cover the effects of self-heating on the converting device.

The result of the test is an estimate of the change of scale factor within the voltage application time from which the standard uncertainty contribution is obtained as a type B estimate:

$$u_{B3} = \frac{1}{\sqrt{3}} \cdot \left| \frac{F_{after}}{F_{before}} - 1 \right| ,$$

where F_{before} and F_{after} are the scale factors before and after the short-term stability test.

4.4.5 Long-term stability

The stability of the scale factor shall be considered and evaluated over a long time-span and is usually estimated as an uncertainty contribution valid for a projected time of use (usually until the next calibration), T_{use}. The evaluation can be based on manufacturer's data or on results of a series of performance tests. The result of the evaluation is an estimate of a change of the scale factor. The evaluation delivers a standard uncertainty contribution, which is a type B estimate:

$$u_{B4} = \frac{1}{\sqrt{3}} \cdot \left| \frac{F_2}{F_1} - 1 \right| \cdot \frac{T_{use}}{T_2 - T_1} ,$$

where F_1 and F_2 are the scale factors of two consecutive performance tests made at times T_1 and T_2.

In cases where a number of performance test results are available, the long-term stability can be characterised by the type A contribution:

$$u_{B4} = \frac{T_{use}}{T_{mean}} \sqrt{\frac{\sum_{i=1}^{n} \left(\frac{F_i}{F_m} - 1 \right)^2}{n(n-1)}} ,$$

where the results of repeated performance tests are the scale factors F_i, with a mean value F_m and repeated with a mean time interval T_{mean}.

NOTE The long-term stability is usually stated for a period of one year.

4.4.6 Ambient temperature effect

The scale factor of a measuring system can be affected by ambient temperature. This can be quantified by determination of the scale factor at different ambient temperatures or by computations based on properties of components. Details of test or calculations shall be included in the record of performance.

The result of a test or calculation is an estimate of a change of the scale factor due to ambient temperature. The related standard uncertainty is the following type B estimate:

$$u_{B5} = \frac{1}{\sqrt{3}} \cdot \left| \frac{F_T}{F} - 1 \right| ,$$

where F_T is the scale factor at the considered temperature and F is that at calibration temperature.

If the deviation F_T from F is greater than 1 %, a correction of the scale factor is recommended.

NOTE Self-heating effect is covered by the short-term stability test.

A temperature correction factor for the scale factor may be used in cases where the ambient temperature varies over a wide range. Any temperature corrections to be used should be listed in the record of performance. For cases where temperature correction has been applied, the uncertainty u_{B5} of the temperature correction factor may be taken as the uncertainty contribution.

4.4.7 Uncertainty calculation of the scale factor

4.4.7.1 General

A simplified procedure to determine the expanded uncertainty of the assigned scale factor F of a measuring system is given here. It is based on several assumptions, which in many cases may be true, but should be verified in each individual case. The main assumptions are:

a) There is no correlation between the measurement quantities.

b) Standard uncertainties evaluated by the method of Type B are assumed to have a rectangular distribution.

c) The largest three uncertainty contributions to uncertainty have approximately equal magnitude.

These assumptions lead to a procedure of evaluation of the expanded uncertainty of the scale factor F, both for the calibration situation and for the use of an approved measuring system in measurements.

The expanded uncertainty of calibration U_{cal} is estimated from the uncertainty of the calibration of the reference system and from influence of other quantities explained in this clause, such as stability of the reference measuring system and ambient parameters during the calibration.

The expanded uncertainty of a measurement U_M of the test quantity is evaluated from the uncertainty of the calibration of the scale factor of the approved measuring system and from the influence of other quantities discussed in 4.4, such as the stability of the measuring system and ambient parameters during the measurement as they are not considered in the calibration certificate.

Further methods for estimating uncertainty are given in the ISO/IEC Guide 98-3:2008 and are also described in Annex A.

4.4.7.2 Uncertainty of the calibration

The relative expanded uncertainty of a calibration of the scale factor U_cal is calculated from the uncertainty of the reference measuring system and the Type A and Type B uncertainties explained in this clause:

$$U_\mathrm{cal} = k \cdot u_\mathrm{cal} = 2\sqrt{u_\mathrm{ref}^2 + u_\mathrm{A}^2 + \sum_{i=0}^{N} u_{\mathrm{B}i}^2}\ ,$$

where:

$k = 2$ is the coverage factor for a coverage probability of approximately 95 % and normal distribution;

u_ref is the combined standard uncertainty of the scale factor of the reference measuring system at its calibration;

u_A is the statistical Type-A uncertainty in the determination of the scale factor;

$u_{\mathrm{B}0}$ is the non-linearity contribution to standard uncertainty determined during calibration of the scale factor (4.4.1);

$u_{\mathrm{B}i}$ is the contribution to the combined standard uncertainty of the scale factor caused by the i^th influence quantity and evaluated as a Type B contribution (Annex A). These contributions are related to the reference measuring system, and arise from non-linearity, short- and long-term instabilities, etc., and are determined either by additional measurements or estimated from other data sources according to 4.4.2 to 4.4.6. Influences related to the approved measuring systems, such as its short-term stability, and resolution of the measurement shall also be taken into account if they are significant during the calibration.

In cases where the assumptions mentioned above are not valid, the procedures given in Annex A or, if necessary, in the ISO/IEC Guide 98-3:2008 shall be applied.

The number N of Type B uncertainty contributions may differ for the different types of test voltages (Clauses 5 to 7). More information on the Type B contributions is given in the relevant clauses.

4.4.7.3 Uncertainty of measurement using an approved measuring system

Estimation of the expanded uncertainty of measurement of the test voltage value is the responsibility of the user. However, this estimation may be given for a defined range of measurement conditions in conjunction with the calibration certificate.

The relative expanded uncertainty of measurement of the test voltage value U_M is calculated from the combined standard uncertainty of the assigned scale factor as determined in the calibration of the approved measuring system and additional Type B uncertainty contributions explained in this clause:

$$U_M = k \cdot u_\mathrm{M} = 2\sqrt{u_\mathrm{cal}^2 + \sum_{i=1}^{N} u_{\mathrm{B}i}^2}\ ,$$

where:

k = 2	is the coverage factor for a coverage probability of approximately 95 % and normal distribution;
u_M	is the combined standard uncertainty of the measurement using the approved measuring system, valid for a projected time of use, e.g. a calibration interval;
u_cal	is the combined standard uncertainty of the scale factor of the approved measuring system determined at the calibration (see 4.4.7.2);
$u_{\mathrm{B}i}$	is the contribution to the combined standard uncertainty of the scale factor of the approved measuring system and caused by the i^th influence quantity, evaluated as a Type B contribution. These contributions are related to normal use of the approved measuring system, and arise from non-linearity, short- and long-term instabilities, etc., and are determined according to 4.4.2 to 4.4.6 based either on additional measurements or estimated from other data sources. Other significant influences shall also be taken into account, e.g. resolution of instrument display of the approved measuring system.

The calibration certificate may include information on both the uncertainty of the calibration, U_cal, and the relative expanded uncertainty of measurement of the test voltage value, U_M, when using the approved measuring system under stated, predefined conditions.

In cases where the assumptions mentioned above in 4.4.7.1 are not valid, the procedures given in Annex A or, if necessary in the ISO/IEC Guide 98-3:2008, shall be applied.

The number N of Type B uncertainty contributions may differ for the different types of test quantities (Clauses 5 to 7, voltages and time parameters).

4.4.8 Uncertainty calculation of time parameter measurement (impulse voltages only)

4.4.8.1 General

An approved measuring system for impulse voltages shall be able to measure the time parameters (T_1, T_2,) within the specified uncertainty limits when the parameter lies within its specified range. For front time this is usually the nominal epoch. The experimental proof can be given either by the comparison or the component method.

NOTE The estimation of the uncertainty of time parameters results in an absolute uncertainty value.

4.4.8.2 Uncertainty of the time parameter calibration

The front times T_1 of n impulse voltages shall be evaluated simultaneously with the measuring system under test, denoted by X, and the reference system, denoted by N. The error of the reference measuring system is assumed to be negligible. The mean error of the front times is:

$$\Delta T_1 = \frac{1}{n}\sum_{i=1}^{n}\left(T_{1\mathrm{X,i}} - T_{1\mathrm{N,i}}\right)$$

and the experimental standard deviation is:

$$s(\Delta T_1) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\Delta T_{1,\mathrm{i}} - \Delta T_1\right)^2}$$

where $\Delta T_{1,i}$ is the i^{th} difference of the front times measured by the systems X and N.

Usually no more than $n = 10$ independent readings are necessary.

NOTE In general, the front times are evaluated from the same records of N and X, used to evaluate the peak values for determining the scale factor (clause 4.4.7).

From $s(\Delta T_1)$, the Type A standard uncertainty is calculated:

$$u_{\mathrm{A}} = \frac{s(\Delta T_1)}{\sqrt{n}} .$$

The comparison is performed at a suitable voltage level using at least two front times, including the minimum and maximum T_1 values of the nominal epoch, for which the measuring system is to be approved. An additional T_1 value in the middle of the nominal epoch can be added. The standard uncertainty Type A of the time parameter measurement is obtained as the largest of the single standard uncertainties determined for the different T_1 values. For each of the different T_1 values, the mean error $\Delta T_{1,\mathrm{j}}$ is calculated as described above. The overall mean of the $m \geq 2$ mean errors is:

$$\Delta T_{1\mathrm{m}} = \frac{1}{m}\sum_{j=1}^{m} \Delta T_{1,\mathrm{j}} .$$

The maximum difference between the individual values $\Delta T_{1,\mathrm{j}}$ and their mean value $\Delta T_{1\mathrm{m}}$ is taken to determine the Type B uncertainty u_{B} by:

$$u_{\mathrm{B}} = \frac{1}{\sqrt{3}} \max_{j=1}^{m} \left| \Delta T_{1,\mathrm{j}} - \Delta T_{1\mathrm{m}} \right| .$$

More general, the reference measuring system N may be characterised in the same manner by its mean error of the front time, denoted by $\Delta T_{1\mathrm{ref}}$, as stated in its calibration certificate for the nominal epoch. The resultant error of the calibrated system X itself for front time measurements is:

$$\Delta T_{1\mathrm{cal}} = \Delta T_{1\mathrm{m}} + \Delta T_{1\mathrm{ref}} .$$

The expanded uncertainty of the time parameter calibration, equal to that of the resultant mean error, $\Delta T_{1\mathrm{cal}}$, is determined by:

$$U_{\mathrm{cal}} = k \cdot u_{\mathrm{cal}} = 2\sqrt{u_{\mathrm{ref}}^2 + u_{\mathrm{A}}^2 + u_{\mathrm{B}}^2} ,$$

where:

u_{cal}	is the combined standard uncertainty of the mean front time error, $\Delta T_{1\mathrm{cal}}$, of the calibrated measuring system;
$k = 2$	is the coverage factor for a coverage probability of approximately 95 % and normal distribution;
u_{ref}	is the combined standard uncertainty of the mean front time error, $\Delta T_{1\mathrm{ref}}$, of the reference measuring system;
u_{A}	is Type A standard uncertainty of the mean front time error, $\Delta T_{1\mathrm{m}}$, of the calibrated measuring system;

u_B is Type B standard uncertainty of the mean front time error ΔT_{1m} of the calibrated measuring system.

Additional contributions to the expanded uncertainty U_{cal} may be important in special cases and shall be considered.

4.4.8.3 Uncertainty of time parameter measurement using an approved measuring system

Estimation of the expanded uncertainty of a time parameter measurement is the responsibility of the user. However, this estimation may be given for defined range of measuring conditions in conjunction with the calibration certificate.

If the expanded uncertainty of the time parameter calibration is less than 70 % of the expanded uncertainty specified for time parameter measurement in this standard, it can generally be assumed that the uncertainty of the approved measuring system for time parameter measurement U_M is equal to U_{cal}.

The expanded uncertainty of the time parameter measurement U_M shall be calculated according to:

$$U_M = k \cdot u_M = 2\sqrt{u_{cal}^2 + \sum_{i=1}^{N} u_{Bi}^2} \ ,$$

where:

u_{cal} is the combined standard uncertainty of the mean front time error, ΔT_{1cal}, of the calibrated measuring system;

$k = 2$ is the coverage factor for a coverage probability of approximately 95 % and normal distribution;

u_{Bi} is the contribution to the combined standard uncertainty of the time parameter of an impulse using the approved measuring system and caused by the i^{th} influence quantity and evaluated as a Type B contribution. These contributions are related to normal use of the approved measuring system, and arise for example from long-term instabilities, software influence, etc., but also from the influence of having non-perfect impulse shapes. They are determined according to 4.4.2 to 4.4.6, based either on additional measurements or estimated from other data sources. In some situations further influences shall also be taken into account, e.g. resolution of instrument displays;

u_M is the combined standard uncertainty of the time parameter of an impulse voltage measured with the approved measuring system, valid for an projected period of use.

Additional contributions to the expanded uncertainty may be important in special cases and shall be considered when calculating U_M, e.g. when the impulse voltage is superimposed by front oscillations.

When the approved measuring system is used to measure impulse voltages without oscillations, the measured time parameter T_{1meas} can be corrected by the resultant error ΔT_{1cal} of the relevant time parameter determined in the calibration:

$$T_{1corr} = T_{1meas} - \Delta T_{1cal} \ .$$

The same procedures can be applied to other time parameters.

5 Tests with direct voltage

5.1 General

In the area of low voltage equipment, dielectric tests with direct voltage cannot be covered by tests with alternating voltage where the peak value equals the direct test voltage. This is due to different effects of partial discharge, leakage currents and stress duration on the insulation.

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, shall be a direct voltage with not more than 3 % ripple factor, unless otherwise specified by the relevant technical committee.

The verification of the ripple factor shall be done under worst load conditions. 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.

It is important to maintain the d.c. voltage without significant increase in ripple and to keep a constant arithmetic mean value of the voltage up to the tripping current.

5.2.1.2 Tolerance

If not otherwise specified by the relevant technical committee, a tolerance of ± 3 % is acceptable between the specified and the measured test voltage values throughout the test.

5.2.2 Generation of the test voltage

The test voltage is generally obtained by means of rectifiers or by controlled electronic circuits. The requirements to be met by the test voltage source depend considerably upon the type of apparatus which 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 source characteristics should be such as to permit charging of the capacitance of the test object in a reasonably short time. The source, including its storage capacitance, should also be adequate to supply the leakage, absorption and partial discharge currents in order to maintain the test voltage within the tolerance of ± 3 %.

5.2.3 Measurement of the test voltage

5.2.3.1 Requirements for an approved measuring system

5.2.3.1.1 General

The general requirement is to measure the test voltage value (arithmetic mean value) with an expanded uncertainty $U_M \leq 3$ %.

The uncertainty limits shall not be exceeded in the presence of ripple, the magnitude of which is within the limits specified in 5.2.1.1, for a purely resistive load at the maximum current and at the minimum test voltage specified.

NOTE Attention is drawn to the possible presence of alternating voltages coupled to the measuring system and affecting the reading of the measuring instrument.

5.2.3.1.2 Uncertainty contributions

For a direct voltage measuring system, the expanded uncertainty of measurement U_{M} shall be evaluated with a coverage probability of 95 %, according to 4.4.7 and – if necessary – Annex A and Annex B. Tests for assessing contributions to uncertainty which are usually considered are summarized in Table 1. Other contributions can be important in some cases and shall also be considered.

5.2.3.1.3 Dynamic behaviour for measuring voltage changes

The time constant of the high-voltage measuring system shall not be greater than 0,25 s for the measurement of direct voltages that rise or fall with rates in the order of 1 % of the test voltage value per second.

NOTE In general, the instruments used for the measurement of the test voltage value (i.e. the arithmetic mean), are not affected by the ripple present. However, if instruments with fast response are used, it may become necessary to ensure that the measurement is not adversely affected by the ripple.

5.2.3.2 Tests on an approved measuring system

The tests according to 4.4, summarized in Table 1, are necessary for the qualification of a direct voltage measuring system as well as for the estimation of the expanded uncertainty of measurement.

The results of the type and routine tests can be taken from manufacturer's data. Routine tests shall be performed on each component.

Table 1 – Tests required for an approved direct voltage measuring system

Type of test	Type test	Routine test	Performance test
Influence of load	4.4.2		
Dynamic behaviour	4.4.3		
Scale factor at calibration		4.4.1	4.4.1
Short-term stability		4.4.4	
Long-term stability	4.4.5		4.4.5 (if applicable)
Ambient temperature effect	4.4.6		

5.3 Test procedures

5.3.1 Withstand voltage tests

The voltage shall be applied to the test object starting at a value sufficiently low to prevent any effect of overvoltage due to switching transients. It should be raised sufficiently slow 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.

These requirements are, in general, met if the rate of rise is about 5 % of the estimated final voltage per second when the applied voltage is above 75 % of this voltage. It shall be maintained for the specified time and then reduced by discharging the smoothing capacitor and the test object through a suitable resistor.

The test duration at the specified test voltage shall be 60 s if not specified by the relevant technical committee.

The test duration should take into consideration that the time to reach the steady state voltage distribution depends on the resistances and capacitances of the test object components.

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

Unless otherwise specified by the relevant technical committee, the tripping current of the generator shall be adjusted to 10 mA for type tests of test objects.

For routine testing, the tripping current may be adjusted to lower levels.

6 Tests with alternating voltage

6.1 Test voltage

6.1.1 Requirements for the test voltage

6.1.1.1 Voltage waveshape

The alternating test voltage, as applied to the test object, should generally have 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 a technical committee.

The voltage waveshape shall be substantially sinusoidal. The ratio between the peak value and the r.m.s. value is $\sqrt{2} \pm 3$ %. The total harmonic distortion (THD) of the test voltage shall be less than 5 % under full load conditions.

The test voltage is the r.m.s. value.

NOTE In the area of low-voltage equipment the r.m.s. value is used to specify the test voltage, although the important factor for breakdown is the peak value.

6.1.1.2 Tolerance

If not otherwise specified by the relevant technical committee, a tolerance of ±3 % is acceptable between the specified and the measured test voltage values throughout the test.

6.1.2 Generation of the test voltage

6.1.2.1 Requirements for the test circuit

One of the following alternatives shall be used.

Alternative A:

At the test voltage, the prospective short-circuit current at the test object and the tripping current of the generator shall be in accordance with Table 2.

Table 2 – Minimum currents of the test circuit

Testvoltage V	**Minimum currents** mA	
	prospective short-circuit current	**tripping current**
≤ 4 000	200	100
> 4 000 and ≤ 10 000	80	40
> 10 000	40	20
NOTE The values are identical as in IEC 60335.		

If high capacity loading limits the a.c. test voltage, it may be necessary to perform a d.c. test as an alternative where the direct test voltage equals the peak value of the alternating voltage. The relevant technical committee should specify when testing with direct voltage is acceptable.

Alternative B:

If the test voltage is obtained by means of controlled electronic circuits, the requirement is to supply the leakage, absorption and partial discharge currents without voltage drops exceeding 3 % at the maximum tripping current according to Table 2.

6.1.3 Measurement of the test voltage

6.1.3.1 Requirements for an approved measuring system

6.1.3.1.1 General

The general requirement is to measure the test voltage value (peak/√2 or r.m.s. value) at its rated frequency with an expanded uncertainty $U_\mathrm{M} \leq 3$ %.

6.1.3.1.2 Uncertainty contributions

For an alternating voltage measuring system the expanded uncertainty U_M shall be evaluated with a coverage probability of 95 % according to 4.4.7. Tests for assessing contributions to uncertainty which are usually considered are summarized in Table 3. Other contributions can be important in some cases and shall also be considered.

6.1.3.1.3 Dynamic behaviour

The amplitude-frequency response of a measuring system, intended for operation at one single fundamental frequency f_nom, shall be within the marked area of Figure 4, derived from the uncertainty requirements. Number pairs in the diagram show the normalised frequency (logarithmic scale) and the corresponding deviation at the corner points of the limit lines. Performance shall be proven from f_nom to $7\,f_\mathrm{nom}$ by tests or circuit analysis. The amplitude-frequency response outside this range is given for information only.

A measuring system can also be approved for a range of fundamental frequencies (e.g. 45 Hz to 65 Hz). In this case, the scale factor shall be constant within 1 % from the lowest fundamental frequency f_nom1 up to the highest fundamental frequency f_nom2. The amplitude-frequency response inside the interval f_nom1 to $7\,f_\mathrm{nom2}$, shall be within the marked area of Figure 5. Number pairs in the diagram show the normalised frequency and the corresponding permitted deviation from the ideal response at the corner points of the limit lines. Performance shall be proven from f_nom1 to $7\,f_\mathrm{nom2}$ by tests or circuit analysis. The amplitude-frequency response outside this range is given for information only.

Special requirements on dynamic behaviour may be specified by the relevant technical committee.

NOTE 1 Measuring systems complying with these requirements are considered to have a frequency response suitable for measurement of the total harmonic distortion (THD) on the test voltage.

NOTE 2 The frequency response outside the marked area, although not required, does represent good practice.

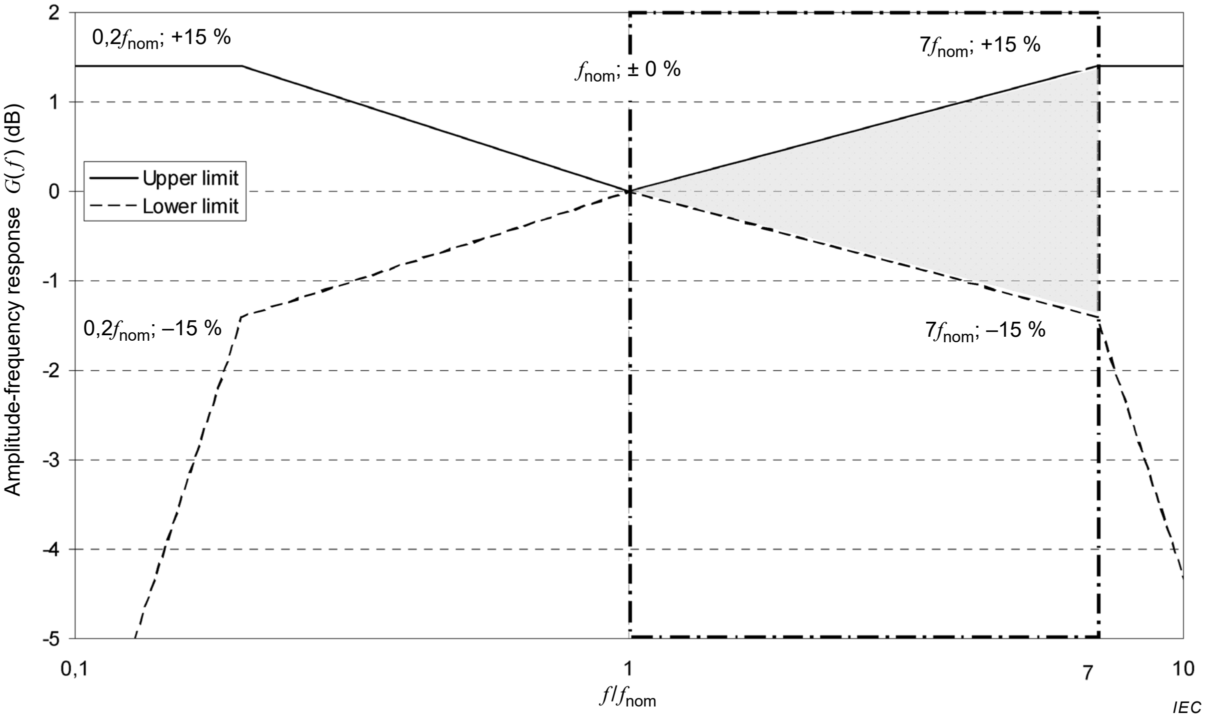


Figure 4 – Shaded area for acceptable normalised amplitude-frequency responses of measuring systems intended for single fundamental frequencies f_{nom} (to be tested in the range (1....7) f_{nom})

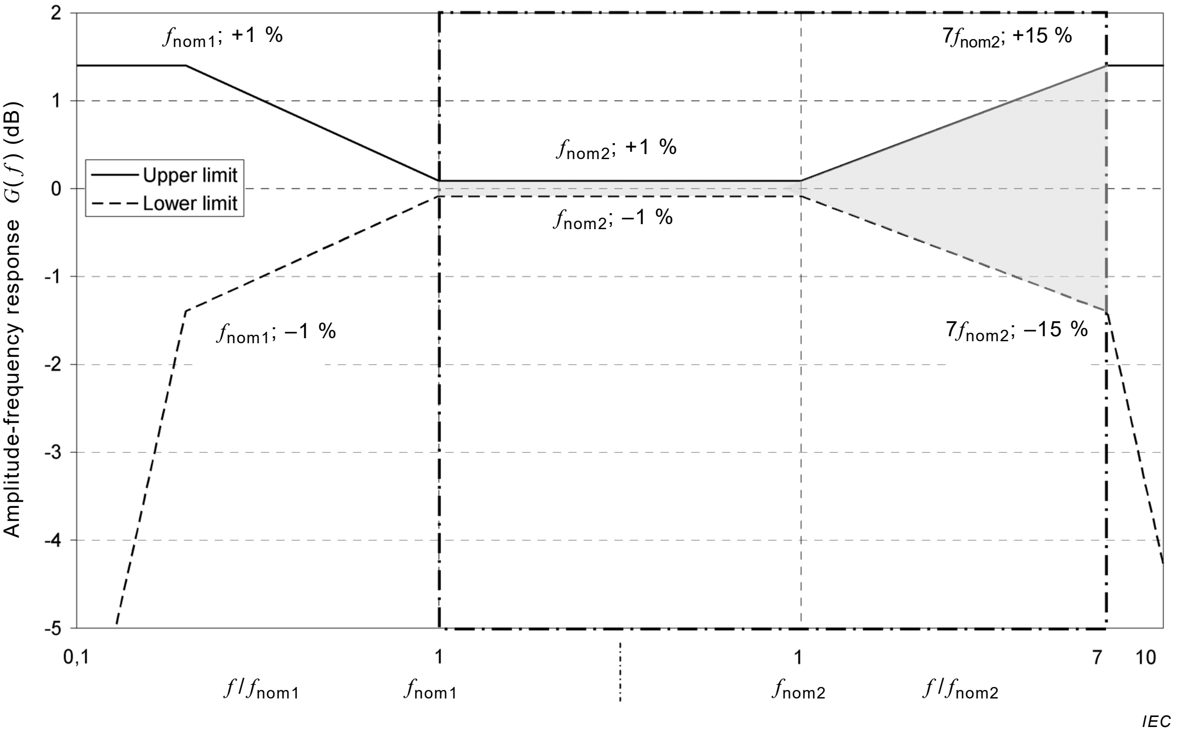


Figure 5 – Shaded area for acceptable normalised amplitude-frequency responses of measuring systems intended for a range of fundamental frequencies f_{nom1} to f_{nom2} (to be tested in the range f_{nom1} to 7 f_{nom2})

6.1.3.2 Dynamic behaviour test

To determine the dynamic behaviour, the system is subjected to a sinusoidal input of known amplitude, usually at low level, and the output is measured. This measurement is repeated for the range of frequencies between 1 and 7 times the test frequency. The result shall be in accordance with 6.1.3.1.

6.1.3.3 Tests on an approved measuring system

The tests according to 4.4, summarized in Table 3, are necessary for the qualification of an alternating voltage measuring system, as well as for the estimation of the expanded uncertainty of measurement.

The results of the type and routine tests can be taken from manufacturer's data. Routine tests shall be performed on each unit.

Table 3 – Tests required for an approved alternating voltage measuring system

Type of test	Type test	Routine test	Performance test
Scale factor at the calibration		4.4.1	4.4.1
Influence of load	4.4.2		
Dynamic behaviour	4.4.3/6.1.3.2		
Short-term stability		4.4.4	
Long-term stability	4.4.5		4.4.5 (if applicable)
Ambient temperature effect	4.4.6		

6.2 Test procedures

6.2.1 Withstand voltage tests

The a.c. test voltage shall be raised uniformly from 0 V to the test voltage value within not more than 5 s.

If not specified by the relevant technical committee the test duration at the specified test voltage shall be 60 s and shall be independent of the frequency in the range from 45 Hz to 65 Hz.

For routine testing, the tripping current may be adjusted to lower levels.

Unless otherwise specified by the relevant technical committee, the requirements of the test are satisfied if no tripping of the test equipment occurs.

It is recommended that for safety reasons the current should be reduced to 3 mA.

7 Tests with impulse voltage

7.1 Test voltage

7.1.1 General

For an impulse measuring system, the performance tests also show that its dynamic performance is adequate for the specified measurements and that the level of any interference is less than the specified limits.

7.1.2 Requirements for the test voltage

7.1.2.1 Standard impulse voltage

The standard impulse voltage is a smooth full impulse voltage having a front time of 1,2 µs and a time to half-value of 50 µs and described as a 1,2/50 impulse, Figure 6. Other impulse shapes may be specified by the relevant technical committee. For other impulse shapes, the relevant technical committee shall define the value of the test voltage, taking into account the type of test and test object.

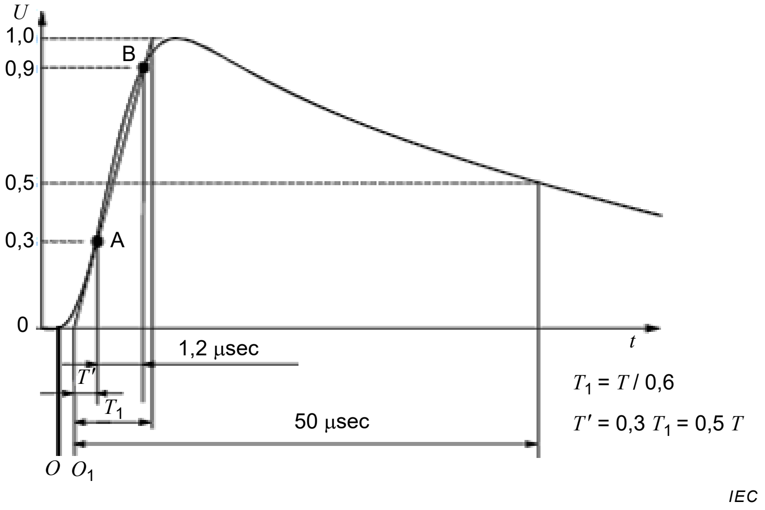


Figure 6 – 1,2/50 µs standard impulse voltage

7.1.2.2 Tolerances on standard impulse

If not otherwise decided by the relevant technical committee, the following differences are accepted between specified values for the standard impulse and those calculated from the impulse waveform:

Peak value	±3 %
Front time	±30 %
Time to half-value	±20 %

In commonly used impulse generator circuits, oscillations on that part of the impulse-front during which the voltage does not exceed 90 % of the peak value have generally negligible influence on test results. The impulse should be essentially unidirectional.

In specific cases, such as during tests on low impedance objects, e.g. large capacitors, it may be impossible to adjust the shape of the impulse within the tolerances recommended, to keep the oscillations within the specified limits, or to avoid a polarity reversal. Such cases should be dealt with by the relevant technical committee and should take into account the provisions of IEC 60060-1.

7.1.3 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.

7.1.4 Measurement of the test voltage and determination of impulse shape

The measurement of the test voltage value and the time parameters of the test voltage shall be made with approved measuring systems. 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. Where high capacitive loading does not allow the impulse waveshape to be obtained within the specified tolerances, it may be necessary to adapt the test setup or the devices.

NOTE For disruptive discharge see IEC 60060-1:2010, Clause 7.

The measurement may be made with the impulse generator not connected to the test object when the impedance of the test object has a negligible effect on the amplitude and waveform of the test voltage. This shall be verified prior to using this measurement technique.

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

More than one impulse may be necessary to establish consistent operation.

7.2 Test procedures

7.2.1 Verification of impulse voltage waveshape

The waveshape of the impulse voltage applied to the test object(s) shall be verified using peak values not less than 50 % of the test voltage level. In the case of identical test objects, this verification only needs to be performed once at the beginning of the series.

7.2.2 Impulse voltage tests

Five impulses of the specified shape and of each polarity shall be applied at the impulse voltage level. The requirements of the test are satisfied if no indication of disruptive discharge or partial breakdown is obtained.

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 is 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.

The relevant technical committee shall specify the criteria for identification and evaluation of partial breakdown, where applicable.

7.3 Measurement of the test voltage

7.3.1 Requirements for an approved measuring system

The general requirements are:

to measure the test voltage value with an expanded uncertainty $U_{M1} \leq 3$ %;

to measure the time parameters which define the waveform with an expanded uncertainty $U_{M3} \leq 10$ %.

NOTE No recommendations are given for the measurement of voltage collapse since no IEC apparatus committee has yet specified a requirement.

7.3.2 Uncertainty contributions

For a lightning impulse voltage measuring system, the expanded uncertainty of measurement U_M shall be evaluated with a coverage probability of 95 %. Tests for assessing contributions to uncertainty which are usually considered are summarized in Table 4. Other contributions can be important in some cases and shall also be considered.

7.3.3 Dynamic behaviour

The dynamic behaviour of a measuring system is adequate for the measurement of peak voltage and time parameters over the nominal epoch for waveforms specified in the record of performance when the expanded uncertainty of the time parameters measurement is not greater than 10 %.

Table 4 – Tests required for an approved impulse voltage measuring system

Type of test	Type test	Routine test	Performance test
Scale factor at the calibration		4.4.1	4.4.1
Time parameter		4.4.8	4.4.8
Influence of load	4.4.2		
Dynamic behaviour	4.4.3		
Short-term stability		4.4.4	
Long-term stability	4.4.5		4.4.5 (if applicable)
Ambient temperature effect	4.4.6		

7.3.4 Requirements for measuring instrument

The measuring instrument shall comply with IEC 61083-1 and IEC 61083-2.

8 Reference measurement systems

8.1 Requirements for reference measuring systems

8.1.1 Direct voltage

The reference measuring system shall enable direct voltage measurement with an expanded uncertainty $U_M \leq 1$ % over its range of use. The uncertainty shall not be influenced by a ripple factor up to 3 %.

8.1.2 Alternating voltage

The reference measuring system shall enable alternating voltage measurement with an expanded uncertainty $U_M \leq 1$ % over its range of use.

8.1.3 Impulse voltages

According to IEC 60060-2 the requirements for an Impulse voltage reference measuring system are ≤ 1 % for the peak value and ≤ 5 % for the time parameters.

8.2 Calibration of a reference measuring system

8.2.1 General

The compliance of a reference measuring system with the relevant requirements given in 8.1 of this standard shall be shown by the reference method.

8.2.2 Reference method: comparative measurement

The satisfactory performance of a reference measuring system shall be shown by calibration against another suitable reference measuring system, which itself is traceable to national or international standards of measurement.

The satisfactory performance of an impulse reference measuring system shall be shown by calibration by comparison measurements at the relevant test voltage with waveforms of two or more different front times covering the range of the nominal epoch.

8.3 Interval between successive calibrations of reference measuring systems

The interval between calibrations shall be determined according to national regulations. If there is no regulation it is recommended that the calibrations shall be repeated at least once every year.

8.4 Use of reference measuring systems

It is recommended that reference measuring systems should be used only for comparative measurements in performance tests. However, a reference measuring system may be used as an approved measuring system provided it is maintained in accordance with the requirements of this standard, and such use is shown not to affect its performance as a reference system. An approved measuring system may not be used as a reference measuring system.

Annex A
(informative)

Uncertainty of measurement

A.1 General

Subclause 4.4 describes a simplified procedure to evaluate the uncertainty of measurement under conditions usually applicable and fully sufficient in high-voltage measurement. In some cases it may, however, be necessary or desirable to evaluate uncertainties in a more complex manner. Annex A gives a survey on how to proceed in these cases, and Annex B describes an application example.

Each measurement of a quantity is to some degree imperfect, and the result of a measurement is only an approximation (“estimate”) of the “true” value of the measurand. The uncertainty of measurement makes a clear statement on the quality of a measurement. It enables the user to compare and weight the measurement results, e.g. obtained from different laboratories, and it provides information as to whether or not a measurement result is within the limits specified by a standard. A Guide to the expression of Uncertainty in Measurement (GUM) was first published in 1993 by the International Organization for Standardization (ISO) and has been re-issued in 2008, with minor modifications as the ISO/IEC Guide 98-3:2008. It is now the internationally accepted document for the estimation of measurement uncertainty.

The GUM as a guide provides general rules for evaluating and expressing uncertainty in a broad spectrum of measurements at various levels of uncertainty. It is therefore necessary to extract from the GUM a set of specific rules that deals with the specific field of high-voltage measurement and its level of accuracy and complexity. Corresponding to the basic principles of the GUM, uncertainties are grouped into two categories according to their methods of evaluation. Both methods are based on probability distributions of the quantities influencing the measurement and on standard uncertainties quantified by variances or standard deviations. This allows a uniform treatment of both categories of uncertainties and an evaluation of a combined standard uncertainty of the measurand. Within the scope of this standard, an expanded uncertainty corresponding to a coverage probability of approximately 95 % is required.

The basic principles of the GUM and examples of how to determine uncertainties in high voltage measurements are presented in the following clauses. The formulae and examples given herein are valid for uncorrelated input quantities, which is often the case in high-voltage measurements.

A.2 Terms and definitions in addition to 3.7

A.2.1
measurable quantity
attribute of a phenomenon, body or substance that may be distinguished qualitatively and determined quantitatively

A.2.2
value of a quantity
magnitude of a particular quantity generally expressed as unit of measurement multiplied by a number

A.2.3
measurand
specific quantity subjected to measurement

A.2.4
variance
expectation of the square of the deviation of a random variable about its expectation

A.2.5
correlation
relationship between two or several random variables within a distribution of two or more random variables

A.2.6
coverage probability
fraction, usually large, of the distribution of values that as a result of a measurement could reasonably be attributed to the measurand

A.3 Model function

Each measurement can be described by a functional relationship f:

$$Y = f\left(X_1, X_2, \ldots, X_i, \ldots, X_\mathrm{N}\right) \tag{A.1}$$

where Y is the measurand and X_i are the different input quantities numbered from 1 to N. In the meaning of the GUM the model function f comprises all measurement values, influencing quantities, corrections, correction factors, physical constants, and any other data that can contribute a significant amount to the value of Y and its uncertainty. It may exist as a single or manifold analytical or numerical expression, or a combination of both. In general the input quantities X_i are random variables and described by observations x_i ("input estimates") having specific probability distributions and being associated with standard uncertainties $u(x_i)$ of Type A or Type B. The combination of both types of uncertainty according to the rules of the GUM yields the standard uncertainty $u(y)$ of the output estimate y.

NOTE 1 The model function f in (A.1) is also valid for the input and output estimates x_i and y, respectively.

NOTE 2 In a series of observations, the k'$^{\mathrm{th}}$ observed value of the quantity X_i is denoted x_{ik}.

A.4 Type A evaluation of standard uncertainty

The evaluation method of Type A is applied to quantities that vary randomly and for which n independent observations have been obtained under the same conditions of measurement. In general, a normal (Gaussian) probability distribution of the n observations x_{ik} can be assumed (Figure A.1).

NOTE X_i might be a scale factor, a test voltage value or a time parameter with the observations x_{ik}.

The arithmetic mean value $\overline{x}_i$ of the observations x_{ik} is defined by:

$$\overline{x}_i = \frac{1}{n}\sum_{k=1}^{n}\overline{x}_{ik} \ , \tag{A.2}$$

which is considered to be the best estimate of X_i. Its Type A standard uncertainty is equal to the experimental standard deviation of the mean:

$$u\left(\overline{x}_i\right) = s\left(\overline{x}_i\right) = \frac{s\left(x_i\right)}{\sqrt{n}} \tag{A.3}$$

where $s(x)$ is the experimental standard deviation (of the individual values):

$$s(x_i) = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}(x_{ik} - \bar{x}_i)^2} \; . \tag{A.4}$$

The quadratic values of $s^2(x_i)$ and $s^2(\bar{x}_i)$ are called sample variances and variances of the mean, respectively. The number of observations should be $n \geq 10$, otherwise the reliability of a Type A evaluation of standard uncertainty has to be checked by means of the effective degrees of freedom (see Clause A.8).

In some cases a pooled estimate of variance sp2 may be available from a large number of previous observations under well-defined conditions. Then the standard uncertainty of a comparable measurement with a small number n (n = 1, 2, 3, …) is better estimated by $u(\bar{x}_i) = s_\mathrm{p} / \sqrt{n}$ than by formula (A.3).

A.5 Type B evaluation of standard uncertainty

The evaluation method of Type B applies to all cases other than the statistical analysis of a series of observations. The standard uncertainty of Type B is evaluated by scientific judgment based on all available information on the possible variability of an input quantity X_i with observations x_i, such as the:

- method of evaluating the quantities,
- uncertainty of calibration of the measuring system and its components,
- non-linearity of dividers and measuring instruments,
- dynamic behavior, e. g. scale factor variation with frequency or impulse shape,
- short-term stability, self-heating,
- long-term stability, drift,
- ambient conditions during measurement,
- proximity effect of nearby objects,
- effects caused by software used in instruments or in evaluation of results,
- limited resolution of digital instruments, reading of analogue instruments.

Information on the input quantities and uncertainties can be obtained from actual and previous measurements, calibration certificates, data in handbooks and standards, manufacturer's specifications or knowledge of the characteristics of relevant materials or instruments. The following cases of a Type B evaluation of uncertainties can be identified:

a) Often only a single input value x_i and its standard uncertainty $u(x_i)$ is known, e.g. a single measured value, a correction value or a reference value from literature. This value and its uncertainty will be adopted in the model function (A.1). In case $u(x_i)$ is unknown, it has to be calculated from other relevant uncertainty data or be estimated on the basis of experience.

b) The uncertainty of a device is quoted as a standard uncertainty multiplied by the coverage factor k, e.g. the expanded standard uncertainty U of a digital voltmeter in a calibration certificate (Claus A.7). When the voltmeter is used in a complex measuring system it contributes to uncertainty by:

$$u(x_\mathrm{i}) = \frac{U}{k} \tag{A.5}$$

where k is the coverage factor. Instead of expressing the expanded uncertainty and coverage factor, one may find a statement on the confidence level, e.g. 68,3 %, 95,45 % or 99,7 %. In general, a normal distribution according to Figure A.1 can be assumed and the statement on the confidence level is equivalent to the coverage factor k = 1, 2 or 3, respectively.

c) The value x_i of an input quantity X_i is estimated to lie within the interval a_- to a_+ with a certain probability distribution $p(x_i)$. Often there is no specific knowledge of $p(x_i)$ and a rectangular distribution of the probable values is then assumed (Figure A.2). Then the expected value of X_i is the midpoint $\overline{x_i}$ of the interval:

$$\overline{x_i} = \frac{(a_- + a_+)}{2} \tag{A.6}$$

and the associated standard uncertainty:

$$u(x_\mathrm{i}) = \frac{a}{\sqrt{3}} \tag{A.7}$$

where $a = (a_+ - a_-)/2$.

In some cases other probability distributions may be more appropriate, such as trapezoidal, triangular or normal distributions.

NOTE The standard uncertainty is $u(x_i) = a/\sqrt{6}$ for the triangular distribution and $u(x_i) = \sigma$ for the normal distribution. This means that the rectangular distribution yields a larger standard uncertainty than the other distributions.

The ISO/IEC Guide 98-3:2008 states that a Type B uncertainty should not be double-counted if the particular effect has already contributed to a Type A uncertainty. Furthermore, the evaluation of uncertainty should be realistic and based on standard uncertainties, avoiding the use of personal or any other factors of safety to obtain larger uncertainties than those evaluated according to the GUM. Often an input quantity X_i has to be adjusted or corrected to eliminate systematic effects of significant magnitude, e.g. on the basis of a temperature or voltage dependence. However, the uncertainty $u(x_i)$ associated with this correction shall still be taken into account.

Double-counting of uncertainty contributions may occur when a digital recorder is used for repetitive impulse measurements, e.g. when calibrating the scale factor. The dispersion of the n measurement values producing a Type A standard uncertainty may be partially caused by a limited resolution of the recorder and its internal noise. The resolution does not need to be considered again, in full, but rather only in a small portion as a residual Type B uncertainty. However, if the digital recorder is then used during an impulse voltage test to obtain a single measurement value, the limited resolution has to be considered in a Type B uncertainty.

The evaluation of Type B uncertainties requires extensive knowledge and experience on the relevant physical relationships, influence quantities and measurement techniques. As the evaluation itself is not an exact science leading to only a single solution, it is not uncommon that experienced test engineers may judge the measurement process in a different manner and obtain different Type B uncertainty values.

A.6 Combined standard uncertainty

Each standard uncertainty $u(x_i)$ of the estimate x_i of each input quantity X_i evaluated by method Type A or Type B contributes to the standard uncertainty of the output quantity by:

$$u_\mathrm{i}(y) = c_\mathrm{i}\, u(x_\mathrm{i}) \tag{A.8}$$

where c_i is the sensitivity coefficient. It describes how the output estimate y is influenced by small variations of the input estimate x_i. It can be evaluated directly as the partial derivative of the model function f:

$$c_\mathrm{i} = \frac{\partial f}{\partial X_\mathrm{i}}\Big|_{X_\mathrm{i}=x_\mathrm{i}} = \frac{\partial f}{\partial x_\mathrm{i}}, \tag{A.9}$$

or by using equivalent numerical and experimental methods. The sign of c_i may be positive or negative. In cases where input quantities are uncorrelated, the sign needs not be considered further since only the quadratic value of standard uncertainties is used in the next steps.

The N standard uncertainties $u_i(y)$ defined by formula (A.8) contribute to a combined standard uncertainty $u_\mathrm{c}(y)$ of the output quantity according to the "law of propagation of uncertainty":

$$u_\mathrm{c}^2(y) = u_1^2(y) + u_2^2(y) + \ldots + u_\mathrm{N}^2(y) = \sum_{i=1}^{N} u_\mathrm{i}^2(y) \tag{A.10}$$

from which $u_\mathrm{c}(y)$ is evaluated as the positive square root:

$$u_\mathrm{c}(y) = \sqrt{\sum_{i=1}^{N} u_\mathrm{i}^2(y)} = \sqrt{\sum_{i=1}^{N} \left[c_\mathrm{i}\, u(x_\mathrm{i})\right]^2} \ . \tag{A.11}$$

If the output quantity Y is a product or quotient of the input quantities X_i a similar relationship as shown in (A.10) and (A.11) can be obtained for the relative uncertainties $u_\mathrm{c}(y)/|y|$ and $u(x_i)/|x_i|$. The law of propagation of uncertainty thus applies to both types of the model function for uncorrelated input quantities.

In a case where correlation exists, linear terms will be present in the law of propagation of uncertainty, and the sign of the sensitivity coefficients becomes relevant. Correlation occurs when, for example, the same instrument is used for measuring two or more input quantities. To avoid complicated calculation, the correlation can be removed by adding additional input quantities in the model function f with appropriate corrections and uncertainties. In some cases, the presence of correlated input quantities may even reduce the combined uncertainty. Taking correlation into account is thus mainly essential for sophisticated uncertainty analysis to achieve a very accurate estimation of uncertainty. Correlation will not be discussed further in this standard.

A.7 Expanded uncertainty

In the field of high-voltage and high-current measurements, as in most other industrial applications, a statement of uncertainty corresponding to a coverage probability of approximately p = 95 % is required. This is achieved by multiplying the combined standard uncertainty $u_\mathrm{c}(y)$ in (A.11) by a coverage factor k:

$$U = k u_\mathrm{c}(y), \tag{A.12}$$

where U is the expanded uncertainty. The coverage factor k = 2 is used in cases where a normal distribution can be attributed to y and $u_\mathrm{c}(y)$ has sufficient reliability, i.e. the effective degrees of freedom of $u_\mathrm{c}(y)$ is sufficiently large (see Clause A.8). Otherwise a value $k > 2$ has to be determined to obtain p = 95 %.

NOTE 1 In some older standards the term “overall uncertainty” is used. In the majority of cases this term is interpreted as an expanded uncertainty U with the coverage factor being equal to 2.

NOTE 2 Since uncertainties are defined as positive numbers, the sign of U is always positive. Of course, in cases where U is used in the meaning of an uncertainty interval, it is quoted k as $\pm U$.

A.8 Effective degrees of freedom

The assumption of a normal distribution of the expanded uncertainty is, in general, fulfilled in cases where several (i.e. $N \geq 3$) uncertainty components of comparable value and well-defined probability distribution (Gaussian, rectangular, etc.) contribute to the combined standard uncertainty and where the Type A uncertainty is based on $n \geq 10$ repeated observations. These conditions are fulfilled in many calibrations of voltage measuring systems. When the assumption of a normal distribution is not justified, a value of $k > 2$ shall be evaluated to obtain a coverage probability of approximately 95 %. The appropriate coverage factor can be evaluated on the basis of the effective degrees of freedom v_{eff} of the standard uncertainty $u_{\mathrm{c}}(y)$:

$$v_{\mathrm{eff}} = \frac{u_{\mathrm{c}}^4(y)}{\sum_{i=1}^{N} \frac{u_{\mathrm{i}}^4(y)}{v_{\mathrm{i}}}}, \tag{A.13}$$

where $u_i(y)$ is given by (A.8) for $i = 1, 2, \ldots, N$ and v_i is the corresponding degrees of freedom. Reliable values of v_i are:

- $v_i = n - 1$ for a Type A uncertainty based on n independent observations,
- $v_i \geq 50$ for a Type B uncertainty taken from a calibration certificate, and when the coverage probability is stated to be not less than 95 %,
- $v_i = \infty$ for a Type B uncertainty assuming a rectangular, Figure A.2, distribution within a_- and a_+

The effective degrees of freedom can then be calculated by formula (A.13) and the coverage factor be taken from Table A.1 which is based on a t-distribution evaluated for a coverage probability of p = 95,45 %. If v_{eff} is not an integer interpolate or truncate v_{eff} to the next lower integer.

Table A.1 – Coverage factor k for effective degrees of freedom v_{eff} (p = 95,45 %)

v_{eff}	1	2	3	4	5	6	7	8	10	20	50	∞
k	13,97	4,53	3,31	2,87	2,65	2,52	2,43	2,37	2,28	2,13	2,05	2,00

A.9 Uncertainty budget

The uncertainty budget of a measurement is a detailed analysis of all sources and values of uncertainty according to the model function f. The relevant data should be kept for inspection in the form of a table equal or comparable to Table A.2. The last line indicates the values of the measurement result y, the combined uncertainty $u_{\mathrm{c}}(y)$ and the effective degrees of freedom v_{eff}.

Table A.2 – Schematic of an uncertainty budget

Quantity X_i	Value x_i	Standard uncertainty contribution $u(x_i)$	Degrees of freedom v_i / v_{eff}	Sensitivity coefficient c_i	Contribution to combined standard uncertainty $u_i(y)$
X_1	x_1	$u\ (x_1)$	v_1	c_1	$u_1(y)$
X_2	x_2	$u\ (x_2)$	v_2	c_2	$u_2(y)$
:	:	:	:	:	:
X_N	x_N	$u\ (x_\mathrm{N})$	v_N	c_N	$u_\mathrm{N}(y\ )$
$\boldsymbol{Y}$	$\boldsymbol{y}$		$\boldsymbol{v}_\mathbf{eff}$		$\boldsymbol{u}_\mathbf{c}(\boldsymbol{y})$

NOTE Validated software is commercially available or may be developed by the user from general software that enables automated calculation of the quantities in Table A.2 from the model equation f.

A.10 Statement of the measurement result

In calibration and test certificates the measurand Y shall be expressed as $y \pm U$ for a coverage probability (or: level of confidence) of approximately p = 95 %. The numerical value of the expanded uncertainty U shall be rounded to give not more than two significant figures. If rounding down reduces the value by more than 0,05U, the rounded-up value shall be used. The numerical value of y shall be rounded to the least significant figure that could be affected by the expanded uncertainty.

EXAMPLE 1 The result of a voltage measurement is stated in one of the following ways:

(227,2 ± 2,4) kV,

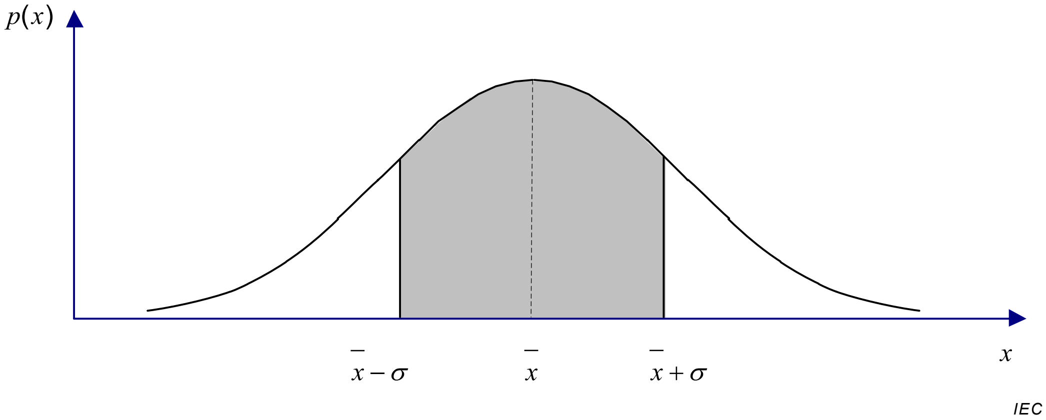
227,2 × (1 ± 0,011) kV, or

227,2 × (1 ± $1{,}1 \cdot 10^{-2}$) kV.

An explanatory note should be added informing of the coverage probability *p* and the coverage factor k.

EXAMPLE 2 The following complete wording is recommended (the terms in brackets apply to the cases where v_{eff} *< 50,* i.e. $k > 2{,}05$ according to Table A.1*)*:

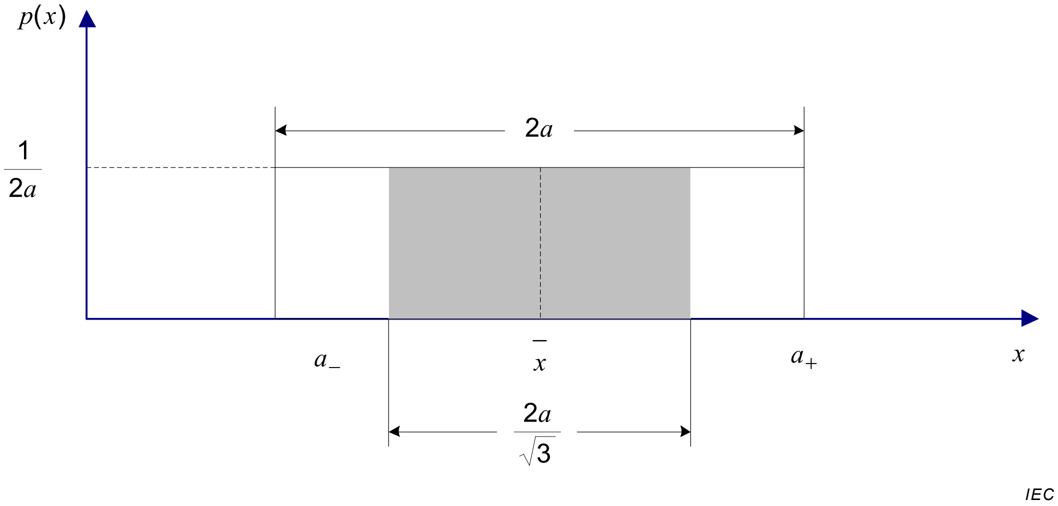
“The reported expanded uncertainty of measurement is stated as the uncertainty of measurement multiplied by the coverage factor k = 2 *(*$k = XX$*)*, which for a normal distribution *(*t-distribution with v_{eff} = YY effective degrees of freedom*)* corresponds to a coverage probability of approximately 95 %. The standard uncertainty of measurement has been determined in accordance with IEC 60060-2.”



The shaded area indicates the standard uncertainty above and below $\overline{x}_i$.

Figure A.1 – Normal probability distribution $p(x)$

The shaded area indicates the standard uncertainty above and below $\overline{x}_i$.



The shaded area indicates the standard uncertainty above and below $\overline{x}_i$.

Figure A.2 – Rectangular probability distribution $p(x)$

Annex B
(informative)

Example for the calculation of measuring uncertainties in high-voltage measurements

An AC measuring system of rated voltage 500 V, denoted by X, is calibrated by an accredited calibration laboratory. The calibration is performed up to V_{Xmax} = 500 V by comparison with a reference measuring system, denoted by N (Table B.1). The scale factor and the relative expanded uncertainty of the reference system N at 20 °C is F_{N} = 1,025 and U_{N} = 0,8 % (k=2), including an uncertainty contribution estimated for the long-term instability.

During the calibration, ambient temperature is (15 ± 2) °C. Since the scale factor of N was calibrated at 20 °C, it is corrected by -0,3 % according to its temperature coefficient, yielding the actual value F_{N} = 1,022 at 15 °C. This correction, however, is not very accurate and, furthermore, due to the temperature variation within ±2 °C during the calibration, the probable values of F_{N} are assumed to lie within an interval of ±0,001 around F_{N} with rectangular distribution. The comparison measurements are performed at h = 5 voltage levels of about 20 %, 40 %, and 100 % of V_{Xmax}. At each voltage level, simultaneous readings of the voltages V_{N} and V_{X} are taken for n = 10 voltage applications. Further investigations on the dynamic behaviour, short-term stability, temperature interval, and interference show an influence on the scale factor of the test object, F_{X}, within ±0,2 % each. Its long-term stability is estimated on the basis of the manufacturer’s data to lie within ±0,3 % until the next calibration.

The model equation for calculating the value of F_{X} and its combined standard uncertainty can be developed as follows. In the ideal case, both measuring systems indicate the same value of the AC test voltage V (Table B.1):

$$V = F_{\mathrm{N}} V_{\mathrm{N}} = F_{\mathrm{X}} V_{\mathrm{X}} . \qquad \text{(B.1)}$$

This leads to the basis formula for calculating the scale factor of the system under test:

$$F_{\mathrm{X}} = \frac{V_{\mathrm{N}}}{V_{\mathrm{X}}} F_{\mathrm{N}} . \qquad \text{(B.2)}$$

As described above, the scale factors of both systems are subject to several influence quantities such as drift, temperature, etc. They contribute to the scale factor values and their uncertainties as well. These contributions are denoted here by $\Delta F_{\mathrm{N},1}$, $\Delta F_{\mathrm{N},2}$, ... for the reference system, and by $\Delta F_{\mathrm{X},1}$, $\Delta F_{\mathrm{X},2}$, ... for the system under test. In general, each contribution to the scale factor F_{N} or F_{X} consists of an error and a standard uncertainty. The error is taken to correct the scale factor, the correction being of opposite sign. The uncertainty contribution is related to the relevant scale factor F_{N} or F_{X} and evaluated in a similar way as described in Clause A.5, i.e., either by assuming a rectangular probability distribution within an interval $\pm a_i$, leading to a standard uncertainty $u_i = a_i/\sqrt{3}$, or, in the case of a calibrated component, by dividing its expanded uncertainty U by the coverage factor k. The contribution $\Delta F_{\mathrm{N,m}}$ or $\Delta F_{\mathrm{X},i}$ needs not always have an error (or the error is assumed being negligibly small), and then it consists only of the uncertainty contribution u_i.

The basis formula (B.2) is supplemented by the contributions $\Delta F_{\mathrm{N,m}}$ and $\Delta F_{\mathrm{X},i}$ to obtain the complete model function for determining the scale factor F_{X} and its combined standard uncertainty. Since correlation between the influence quantities is neglected, (B.2) can then be written in the general version:

$$F_{\mathrm{X}} - \sum_{i} \Delta F_{\mathrm{X,i}} = \frac{V_{\mathrm{N}}}{V_{\mathrm{X}}} \left(F_{\mathrm{N}} - \sum_{m} \Delta F_{\mathrm{N,m}} \right). \tag{B.3}$$

NOTE 1 As per definition, the errors inserted on both sides of the equation have a negative sign. They are defined as ΔF = (indicated value) – (correct value).

For the relevant case, the scale factor F_{X} of the AC measuring system can be expressed by:

$$F_{\mathrm{X}} = \frac{V_{\mathrm{N}}}{V_{\mathrm{X}}} \left(F_{\mathrm{N}} - \Delta F_{\mathrm{N}} \right) + \sum_{i=1}^{5} \Delta F_{\mathrm{X,i}} \ , \tag{B.4}$$

where:

ΔF_{N} is the contribution caused by the lower temperature of the reference system,

$\Delta F_{\mathrm{X,1}}$ is the contribution caused by the nonlinearity of the quotient,

$\Delta F_{\mathrm{X,2}}$ is the contribution caused by the short-term instability of the system under test,

$\Delta F_{\mathrm{X,3}}$ is the contribution caused by the long-term instability of the system under test,

$\Delta F_{\mathrm{X,4}}$ is the contribution caused by the dynamic behaviour of the system under test,

$\Delta F_{\mathrm{X,5}}$ is the contribution caused by the temperature variation of the system under test.

NOTE 2 In this example, ΔF_{N} consists both of a correction and an uncertainty contribution to the scale factor F_{N}, whereas the terms ΔF_{X1} to ΔF_{X5} contribute only to the uncertainty of the scale factor F_{X}. For convenience, the uncertainty contributions ΔF_{X1} to ΔF_{X5} are directly related to F_{X} , i.e. the sensitivity coefficients of these input quantities have already been taken into consideration.

The comparison measurement at a single voltage level between the measuring system X and the reference system N yields n = 10 pairs of measured values V_{N} and V_{X}, from which the quotients $V_{\mathrm{N}}/V_{\mathrm{X}}$, their mean and the experimental standard deviation $s(V_{\mathrm{N}}/V_{\mathrm{X}})$ are calculated. An example for the values measured at a voltage level of about 40 % V_{Xmax} is given in Table B.1. In the same manner, the quotients $V_{\mathrm{N}}/V_{\mathrm{X}}$ and standard deviations $s(V_{\mathrm{N}}/V_{\mathrm{X}})$ are obtained for in total h = 5 voltage levels up to 500 V (Table B.2).

Table B.1 – Result of the comparison measurement up to 500 V at a single voltage level

Number of measurements	**Reference system** V_{N} V	**System under test** V_{X} V	**Quotient** $V_{\mathrm{N}}/V_{\mathrm{X}}$
1	191,4	190,8	1,0031
2	191,6	190,9	1,0037
3	190,7	189,9	1,0042
4	189,9	189,0	1,0048
5	190,9	189,9	1,0053
6	191,2	190,3	1,0047
7	191,3	190,4	1,0047
8	191,2	190,4	1,0042
9	190,6	189,9	1,0037
10	191,3	190,7	1,0031
Mean of $V_{\mathrm{N}}/V_{\mathrm{X}}$ at about 40 % V_{Xmax}			**1,0042**
Experimental standard deviation $s(V_{\mathrm{N}}/V_{\mathrm{X}})$:			**$0{,}73 \cdot 10^{-3}$**

Table B.2 – Summary of results for h = 5 voltage levels (V_{Xmax} = 500 V)

g No.	Voltage level % of V_{Xmax}	V_N/V_X	$s(V_N/V_X)$
1	18	1,0032	$0{,}71 \cdot 10^{-3}$
2	38	1,0042	$0{,}73 \cdot 10^{-3}$
3	63	1,0045	$0{,}81 \cdot 10^{-3}$
4	83	1,0065	$0{,}68 \cdot 10^{-3}$
5	100	1,0101	$0{,}85 \cdot 10^{-3}$ (= $s_{\max}$)
Mean		**1,0057**	

The mean of the five quotients V_N/V_X in Table B.2 is 1,0057. To be on the safe side of the uncertainty estimation, the Type A standard uncertainty of V_N/V_X is evaluated from the maximum standard deviation $s_{\max}$ = 0,85*10^{-3} according to (A.3):

$$u_A = \frac{s_{\max}}{\sqrt{n}} = \frac{0{,}85 \cdot 10^{-3}}{\sqrt{10}} = 0{,}27 \cdot 10^{-3}.$$

The deviation of the quotients V_N/V_X from their mean characterises the nonlinearity of system X. The maximum deviation is a_1 = 4,4*10^{-3} at 100 % of V_{Xmax} (Table B.2). The Type B standard uncertainty of V_N/V_X, originating from nonlinearity, is thus $a_1/\sqrt{3}$ = 2,54*10^{-3} according to (A.7). This value is multiplied by the relevant sensitivity coefficient $c_1 = \partial F_X/\partial(V_N/V_X) = F_N - \Delta F_N$ = 1,025 – 0,003 * 1,025 = 1,022 to obtain the Type B uncertainty contribution:

$$u_{B1} = \frac{a_1}{\sqrt{3}}\left(F_N - \Delta F_N\right) = \frac{4{,}4*10^{-3}}{\sqrt{3}} 1{,}022 = 2{,}6*10^{-3}.$$

The values and standard uncertainties of all input quantities are entered on the right side of the model formula (B.4). The model formula can be evaluated manually, using the equations given in Annex A, or with the aid of special software which should be validated for calculating uncertainties. The result of the evaluation is summarized in Table B.3. In the last line, the assigned scale factor F_X, its combined standard uncertainty, and the effective degrees of freedom are given. The large value ν_{eff} = 180 indicates normal distribution of the probable values of F_X, and thus k = 2 is valid (see Annex A, Table A.1).

The estimate of uncertainty is not very precise and high numerical precision is not required.

Finally, the complete result of the calibration of the approved measuring system is expressed by the assigned scale factor and its expanded uncertainty:

F_X = 1,028 ± 11*10^{-3} = 1,028(1 ± 0,011) for a coverage probability of not less than 95 % (k = 2).

The relative expanded uncertainty of the assigned scale factor is U = 1,1 %. Since it contains an uncertainty contribution of the long-term stability, it can be applied as the expanded uncertainty of the test voltage until the next calibration of the approved measuring system, provided the stability of the scale factor is checked by intermediate performance tests (see 4.4).

NOTE 3 The simplified method of Clause 5 delivers an identical relative expanded uncertainty of the assigned scale factor.

Table B.3 – Uncertainty budget of the assigned scale factor F_X

Quantity	Value	Standard uncertainty contribution	Degrees of freedom	Sensitivity coefficient	Contribution to combined standard uncertainty
F_N	1,025	0,004 [a]	50	1,0057	$4,0*10^{-3}$
ΔF_N	0,003	0,000577 [b]	∞	-1,0057	$-0,58*10^{-3}$
V_N/V_X	1,0057	$0,27*10^{-3}$ [a]	9	1,022	$0,28*10^{-3}$
$\Delta F_{X,1}$	0	$2,60*10^{-3}$ [b]	∞	1	$2,6*10^{-3}$
$\Delta F_{X,2}$	0	$1,19*10^{-3}$ [b]	∞	1	$1,2*10^{-3}$
$\Delta F_{X,3}$	0	$1,78*10^{-3}$ [b]	∞	1	$1,8*10^{-3}$
$\Delta F_{X,4}$	0	$1,19*10^{-3}$ [b]	∞	1	$1,2*10^{-3}$
$\Delta F_{X,5}$	0	$1,19*10^{-3}$ [b]	∞	1	$1,2*10^{-3}$
F_X	1,0278		180		$5,54*10^{-3}$

[a] Normal distribution.

[b] Rectangular distribution.

Annex C
(informative)

Atmospheric correction

C.1 Standard reference atmosphere

Temperature	t_0 = 20 °C;
Absolute pressure	p_0 = 1013 hPa (1 013 mbar);
Absolute humidity	h_0 = 11 g/m^3.

An absolute pressure of 1013 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.

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

C.2 Atmospheric correction factor

C.2.1 General

Normal laboratory conditions are specified in IEC 60068-1:

Temperature:	15 °C to 35 °C;
Air pressure:	860 hPa to 1060 hPa at sea level;
Relative humidity	25 % to 75 %.

The applied test voltage can be defined under normal laboratory conditions according to IEC 60060-1:

$$U = K_t{}^* \ U_0$$

where

U is the applied test voltage;

U_0 is the specified test voltage;

K_t is the atmospheric correction factor.

The applied test voltage is proportional to the correction factor K_t that results from the product of two correction factors:

- the air density correction factor k_1
- the humidity correction factor k_2

$$K_t = k_1{}^* \ k_2$$

C.2.2 Humidity correction factor *k*2

No humidity correction can at present be specified for low voltage equipment.

However, when the relative humidity exceeds about 80 %, the disruptive discharge applied test voltage becomes irregular, especially when the disruptive discharge occurs over an insulating surface.

C.2.3 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:

$$k_1 = \delta^{\mathrm{m}}$$

The exponent *m is* obtained from curve 1 of Figure A.1 for the specified ranges according to IEC 60664-1:

m = 0,9163 for $0{,}001 < d \le 0{,}01$ mm;

m = 0,3305 for $0{,}01 < d \le 0{,}0625$ mm;

m = 0,6361 for $0{,}0625 < d \le 1$ mm;

m = 0,8539 for $1 < d \le 10$ mm;

m = 0,9243 for $10 < d \le 100$ mm.

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:

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

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

In IEC 60664-1 the applied test voltage is given at 2 000 m. For calculation of the air density correction factor to define the test voltage at any altitude, the air pressure at 2 000 m altitude p_0 = 80 kPa is to be regarded as absolute pressure.

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