

BS EN 60060-2:2011



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High-voltage test techniques

Part 2: Measuring systems

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National foreword

This British Standard is the UK implementation of EN 60060-2:2011. It is identical to IEC 60060-2:2010. It supersedes BS EN 60060-2:1995, which is withdrawn.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.

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ISBN 978 0 580 58321 6

ICS 17.220.20; 19.080

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 March 2011.

Amendments issued since publication

Amd. No.	Date	Text affected
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EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 60060-2

January 2011

ICS 17.220.20; 19.080

Supersedes EN 60060-2:1994 + A11:1998

English version

High-voltage test techniques - Part 2: Measuring systems (IEC 60060-2:2010)

Techniques des essais à haute tension -
Partie 2: Systèmes de mesure
(CEI 60060-2:2010)

Hochspannungs-Prüftechnik -
Teil 2: Messsysteme
(IEC 60060-2:2010)

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

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Ref. No. EN 60060-2:2011 E

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Foreword

The text of document 42/281/FDIS, future edition 3 of IEC 60060-2, prepared by IEC TC 42, High-voltage testing techniques, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 60060-2 on 2011-01-01.

This European Standard supersedes EN 60060-2:1994 + A11:1998.

The significant technical changes with respect to EN 60060-2:1994+A11:1998 are as follows:

- a) The general layout and text was updated and improved to make the standard easier to use.
- b) The standard was revised to align it with EN 60060-1.
- c) The treatment of measurement uncertainty estimation has been expanded.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

- | | | |
|--|-------|------------|
| – latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement | (dop) | 2011-10-01 |
| – latest date by which the national standards conflicting with the EN have to be withdrawn | (dow) | 2014-01-01 |

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 60060-2:2010 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 60051 series	NOTE	Harmonized in EN 60051 series (not modified).
IEC 60060-3:2006	NOTE	Harmonized as EN 60060-3:2006 (not modified).
IEC 60071-1:2006	NOTE	Harmonized as EN 60071-1:2006 (not modified).
IEC 60270	NOTE	Harmonized as EN 60270.
IEC 62475	NOTE	Harmonized as EN 62475.
ISO/IEC 17025:2005	NOTE	Harmonized as EN ISO/IEC 17025:2005 (not modified).

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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

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

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60052	-	Voltage measurement by means of standard air gaps	EN 60052	-
IEC 60060-1	-	High-voltage test techniques - Part 1: General definitions and test requirements	EN 60060-1	-
IEC 61083-1	-	Instruments and software used for measurement in high-voltage impulse tests - Part 1: Requirements for instruments	EN 61083-1	-
IEC 61083-2	-	Digital recorders for measurements in high-voltage impulse tests - Part 2: Evaluation of software used for the determination of the parameters of impulse waveforms	EN 61083-2	-
ISO/IEC Guide 98-3	2008	Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)	-	-

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HIGH-VOLTAGE TEST TECHNIQUES –

Part 2: Measuring systems

1 Scope

This part of IEC 60060 is applicable to complete measuring systems, and to their components, used for the measurement of high voltages during laboratory and factory tests with direct voltage, alternating voltage and lightning and switching impulse voltages as specified in IEC 60060-1. For measurements during on-site tests see IEC 60060-3.

The limits on uncertainties of measurements stated in this standard apply to test levels stated in IEC 60071-1:2006. The principles of this standard apply also to higher levels but the uncertainty may be greater.

This standard:

- defines the terms used;
- describes methods to estimate the uncertainties of high-voltage measurements;
- states the requirements which the measuring systems shall meet;
- describes the methods for approving a measuring system and checking its components;
- describes the procedures by which the user shall show that a measuring system meets the requirements of this standard, including the limits set for the uncertainty of measurement.

2 Normative references

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

IEC 60052, *Voltage measurement by means of standard air gaps*

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

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

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

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

NOTE Further related standards, guides, etc. on subjects included in this International Standard are given in the bibliography.

3 Terms and definitions

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

3.1 Measuring systems

3.1.1

measuring system

complete set of devices suitable for performing a high-voltage measurement; software, used to obtain or calculate measuring results, also forms a part of the measuring system

NOTE 1 A measuring system usually comprises the following components:

- a converting device with the leads required for connecting this device to the test object or into the circuit and the connections to earth;
- a transmission system connecting the output terminals of the converting device to the measuring instruments with its attenuating, terminating and adapting impedances or networks;
- a measuring instrument together with any connection to the power supply. Measuring systems which comprise only some of the above components or which are based on non-conventional principles are acceptable if they meet the uncertainty requirements specified in this document.

NOTE 2 The environment in which a measuring system functions, its clearances to live and earthed structures and the presence of electric or magnetic fields may significantly affect the measurement result and its uncertainty.

3.1.2

record of performance

detailed record, established and maintained by the user, describing the measuring system and containing evidence that the requirements given in this standard have been met

NOTE This evidence includes the results of the initial performance test and the schedule and results of each subsequent performance test and performance check.

3.1.3

approved measuring system

measuring system that is shown to comply with one or more of the sets of requirements set out in this document

3.1.4

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

NOTE A reference measuring system (maintained according to the requirements of this standard) may be used as an approved measuring system but the converse is not true.

3.2 Components of a measuring system

3.2.1

converting device

device for converting the quantity to be measured (measurand) into a quantity, compatible with the measuring instrument

3.2.2

voltage divider

converting device consisting of a high-voltage and a low-voltage arm such that the input voltage is applied across the complete device and the output voltage is taken from the low-voltage arm

NOTE The elements of the two arms are usually resistors or capacitors or combinations of these. The device is designated by the type and arrangement of its elements (for example, resistive, capacitive or resistive-capacitive).

3.2.3

voltage transformer

converting device consisting of a transformer in which the secondary voltage, in normal conditions of use, is substantially proportional to the primary voltage and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections

[IEC 60050-321: 1986, 321-03-01]

3.2.4

voltage converting impedance

converting device which carries a current proportional to the applied voltage to be measured with a current measuring instrument

3.2.5

electric-field probe

converting device for the measurement of the amplitude and waveform of an electric field

NOTE An electric-field probe may be used to measure the waveform of the voltage producing the field provided that the measurement is not affected by corona or space charges.

3.2.6

transmission system

set of devices that transfers the output signal of a converting device to a measuring instrument

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

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

3.2.7

measuring instrument

device intended to make measurements, alone or in conjunction with supplementary devices

[IEC 60050-300: 2001, 311-03-01]

3.3 Scale factors

3.3.1

scale factor of a measuring system

factor by which the value of the measuring-instrument reading is multiplied to obtain the value of the input quantity of the complete measuring system

NOTE 1 A measuring system may have multiple scale factors for different assigned measurement ranges, frequency ranges or waveforms.

NOTE 2 For measuring systems that display the value of the input quantity directly, the nominal scale factor of the measuring system is unity.

3.3.2

scale factor of a converting device

factor by which the output of the converting device is multiplied to obtain its input quantity

NOTE The scale factor of a converting device may be dimensionless (for example, the ratio of a divider) or may have dimensions (for example, the impedance of a voltage converting impedance).

3.3.3

scale factor of a transmission system

factor by which the output of a transmission system is multiplied to obtain its input quantity

3.3.4

scale factor of a measuring instrument

factor by which the instrument reading is multiplied to obtain its input quantity

3.3.5

assigned scale factor

F

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

NOTE A measuring system may have more than one assigned scale factor; for example, it may have several ranges and/or nominal epochs, each with a different scale factor.

3.4 Rated values

3.4.1

operating conditions

specified ranges of conditions under which a measuring system will operate within the specified uncertainty limits

3.4.2

rated operating voltage

maximum level of voltage of specified frequency or waveform at which a measuring system is designed to be used

NOTE The rated operating voltage may be higher than the upper limit of the assigned measurement range.

3.4.3

assigned measurement range

range of voltage of specified frequency or waveform, characterized by a single scale factor, in which a measuring system may be used

NOTE 1 The limits of the assigned measurement range are chosen by the user and verified by the performance tests specified in this standard.

NOTE 2 A measuring system can have more than one assigned measurement range with different scale factors.

3.4.4

assigned operating time

longest time during which a measuring system for direct or alternating voltages can operate at the upper limit of the assigned measurement range

3.4.5

assigned rate of application

highest rate of specified voltage impulses for a specified time interval, at which the measuring system can operate at its upper limit of the assigned measurement range

NOTE The rate is usually given as applications per minute and the time interval in minutes or hours.

3.5 Definitions related to dynamic behaviour

3.5.1

response of a measuring system,

G

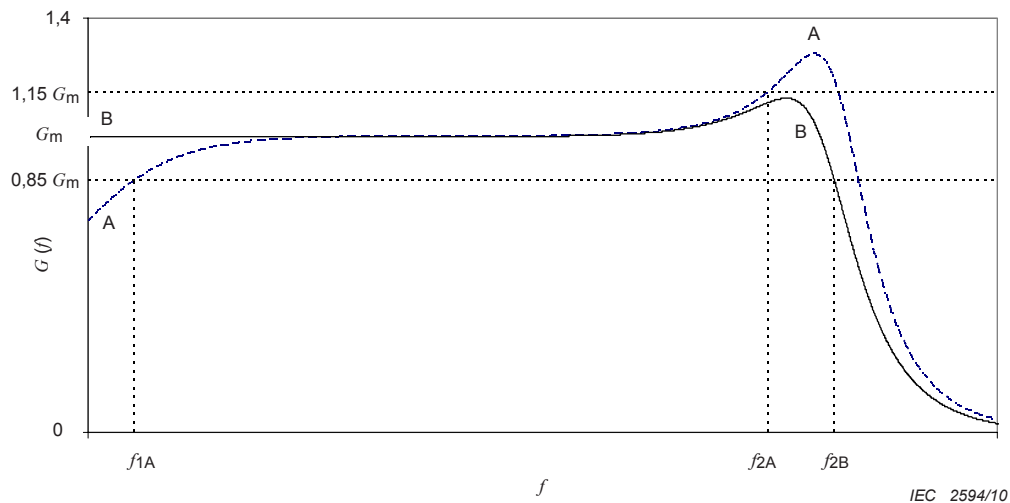
output, as a function of time or frequency, when a specified voltage is applied to the input of the system

3.5.2

amplitude-frequency response,

$G(f)$

ratio of the output to the input of a measuring system as a function of frequency f , when the input is sinusoidal (see Figure 1)



NOTE Lower and upper limit frequencies are shown on curve A.

Curve B shows a constant response down to direct voltage.

Figure 1 – Amplitude-frequency response with examples for limit frequencies (f_1 ; f_2)

3.5.3

step response,

$G(t)$

output of a measuring system as a function of time when the input is a step function

NOTE For more information on step response and step-response parameters see Annex C.

3.5.4

nominal epoch (impulse voltage only),

τ_{N1}

range of values between the minimum ($t_{\min}$) and the maximum ($t_{\max}$) of the relevant time parameter of impulse voltage for which the measuring system is to be approved

NOTE 1 The relevant time parameter is:

- the front time T_1 for full and tail-chopped lightning impulses
- the time to chopping T_c for front-chopped impulses
- the time to peak T_p for switching impulses

NOTE 2 A measuring system may have one, two or more nominal epochs for different waveforms. For example, a particular measuring system might be approved:

- for full and tail-chopped lightning impulses with an assigned scale factor F_1 over a nominal epoch τ_{N1} from $T_1 = 0,8 \mu\text{s}$ to $T_1 = 1,8 \mu\text{s}$, even though the tolerance is $0,84 \mu\text{s}$ to $1,56 \mu\text{s}$;
- or front-chopped lightning impulses with an assigned scale factor F_2 over a nominal epoch τ_{N2} from $T_c = 0,5 \mu\text{s}$ to $T_c = 0,9 \mu\text{s}$;
- for switching impulses with an assigned scale factor F_3 over a nominal epoch τ_{N3} from $T_p = 150 \mu\text{s}$ to $T_p = 500 \mu\text{s}$.

NOTE 3 "Front-chopped impulse" is used to designate a chopped impulse with a time to chopping that falls in the range $0,5 \mu\text{s}$ to the time of the extreme value. This is to be distinguished from a "tail-chopped impulse" which has a time to chopping greater than the time of the extreme value.

3.5.5
limit frequencies,
 f_1 and f_2

lower and upper limits of the range within which the amplitude-frequency response is nearly constant (Figure1)

NOTE These limits are where the response first deviates by a certain amount (e.g. plus/minus 15 %) from the constant value. The permissible deviation should be related to acceptable uncertainties of a measuring system.

3.6 Definitions related to uncertainty

3.6.1
tolerance

permitted difference between the measured value and the specified value

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

NOTE 2 The measured test voltage is required to lie within the stated tolerance of the specified test level.

3.6.2
error

measured quantity value minus a reference quantity value

[ISO/IEC Guide 99 (VIM 2.16)]

3.6.3
uncertainty (of measurement)

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

[IEC 60050-300: 2001, 311-01-02]

NOTE 1 Uncertainty is positive and given without sign.

NOTE 2 Uncertainty of voltage measurement should not be confused with the tolerance of a specified test voltage.

NOTE 3 For more information see Annexes A and B.

3.6.4
standard uncertainty,
 u

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

[ISO/IEC Guide 98-3 (GUM 2.3.1)]

NOTE 1 The standard uncertainty associated with an estimate of a measurand has the same dimension as the measurand.

NOTE 2 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.

3.6.5
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

[ISO/IEC Guide 98-3 (GUM 2.3.4)]

3.6.6**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

[ISO/IEC Guide 98-3 (GUM 2.3.5)]

NOTE 1 Expanded uncertainty is the closest match to the term “overall uncertainty” used in earlier editions of this standard.

NOTE 2 The true, but unknown test-voltage value may lie outside the limits given by the uncertainty because the coverage probability is < 100 % (see 3.6.7).

3.6.7**coverage factor,** **k**

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

[ISO/IEC Guide 98-3 (GUM 2.3.6)]

NOTE For 95 % coverage probability and normal (Gaussian) probability distribution the coverage factor is approximately $k = 2$.

3.6.8**type A evaluation**

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

3.6.9**type B evaluation**

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

3.6.10**traceability**

property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons, all having stated uncertainties

[IEC 60050-300: 2001, 311-01-15]

3.6.11**National Metrology Institute**

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

3.7 Definitions related to tests on measuring systems**3.7.1****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

[IEC 60050-300: 2001, 311-01-09]

NOTE The determination of the scale factor is included in the calibration.

3.7.2

type test

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

[IEC 60050-151: 2001, 151-16-16]

NOTE For a measuring system, this is understood as a test performed on a component or on a complete measuring system of the same design to characterize it under operating conditions.

3.7.3

routine test

conformity test made on each individual item during or after manufacture

[IEC 60050-151: 2001, 151-16-17]

NOTE This is understood as a test performed on each component or on each complete measuring system to characterize it under operating conditions.

3.7.4

performance test

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

3.7.5

performance check

simple procedure to ensure that the result of the most recent performance test is still valid

3.7.6

reference record (impulse measurements only)

record taken under specified conditions in a performance test and retained for comparison with records to be taken in future tests or checks under the same conditions

NOTE Reference records are often called “fingerprints” and used as characteristics of dynamic behaviour. In impulse voltage measurements they are usually taken from step response measurements (Annex C).

4 Procedures for qualification and use of measuring systems

4.1 General principles

Every approved measuring system shall undergo initial testing, followed by performance tests (periodic, see 4.2) and performance checks (periodic, see 4.3) throughout its service life. The initial tests consist of type tests (performed on a component or system of the same design) and routine tests (performed on every component or system).

The performance tests and checks 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.

A major requirement for a converting device, a transmission system, and a measuring instrument used in a measuring system is stability within the specified range of operating conditions so that the scale factor of the measuring system remains constant over long periods.

The assigned scale factor is determined in the performance test by calibration. The user shall apply tests given in this standard to qualify their measuring system(s). 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. In all cases, the user shall include the test data into the record of performance.

Any calibration shall be traceable to national and/or international standards. The user shall ensure that any self-made calibration is performed by competent personnel using reference measuring systems and suitable procedures.

NOTE 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.

4.2 Schedule of performance tests

To maintain the quality of a measuring system, its assigned scale factor(s) shall be determined by periodic performance tests. The interval between performance tests shall be based on evaluation of past stability of the measuring system. It is recommended that the performance test should be repeated annually, but the maximum interval shall not be longer than five years.

NOTE Long intervals between performance tests can increase the risk of an undetected change in the measurement system.

Performance test shall be made after 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.

When a performance test is required because a performance check shows that the assigned scale factor is no longer valid, the cause of this change shall be investigated before the performance test is made.

4.3 Schedule of performance checks

Performance checks shall be made at intervals based on the recorded stability of the measuring system as shown in the record of performance. The interval from the last performance test or the last performance check shall not be longer than one year.

For a new or repaired measuring system, performance checks shall be made at short intervals to demonstrate its stability.

No reference method is identified for the performance checks because the required accuracy is less than that required for performance tests.

4.4 Requirements for the record of performance

4.4.1 Contents of the record of performance

The results of all tests and checks, 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 converting device, transmission system(s) and measuring instrument(s) and, if performed, on the measuring system.
- Results of subsequent performance tests on the measuring system.
- Results of subsequent performance checks on the measuring system.

NOTE 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 the

components of the measuring system, including for example the type and identification of the measuring instrument.

4.4.2 Exceptions

For measuring systems or components manufactured before the date of issue of the second edition of IEC60060-2, i.e. 1994, the required evidence may not be available for some part(s) of the type and routine test. Then performance tests and checks made in accordance with earlier versions of this standard are deemed adequate provided they show the scale factor is stable. The results of these previous checks shall also be entered in the record of performance.

Approved measuring systems comprising several pieces of equipment used inter-changeably may be covered by a single record of performance including all the combinations possible with the least amount of duplication possible. Specifically, each converting device shall be covered individually, but transmission systems and measuring instruments may be covered generically.

4.5 Operating conditions

A measuring system shall be connected directly to the terminals of the test object, or in such a way that the voltage difference between test object terminals and the measuring system is negligible. The parasitic coupling between the test and measuring circuit should be minimized.

NOTE 1 Parasitic coupling may need to be investigated.

An approved measuring system shall have an uncertainty within the specifications of this standard throughout the ranges of operating and environmental conditions given in the record of performance.

The assigned operating time for measuring systems for direct and alternating voltage shall be specified.

NOTE 2 The recommended minimum value for the assigned operating time is 1 h.

The maximum rate of application for impulse voltages shall be specified.

NOTE 3 The recommended minimum value for the maximum rate of application is one or two impulses/min and to be specified depending on the size of the converting device.

The range of environmental conditions, under which the components of the measuring system fulfil the requirements of this standard, shall be stated.

4.6 Uncertainty

The uncertainty of all measurements made under this International Standard shall be evaluated according to ISO/IEC Guide 98-3.

Procedures for evaluating uncertainties have been selected from ISO/IEC Guide 98-3 and presented in this standard. These simplified procedures of clause 5 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 uncertainty.

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 5.10, 5.11 and Annex A). The contributions are obtained from measurement results, from manufacturers' handbooks, calibration certificates and from estimating reasonable values of the influence quantities during the measurement. For example influence quantities mentioned in clause 5 include temperature and proximity effects. Others, like limited resolution of the measuring instrument, may be added if necessary.

NOTE 2 The resolution of a measuring instrument, e.g. one with few significant digits, may be a significant source of uncertainty.

During the actual voltage test, it is usually necessary to consider additional influencing quantities, apart from the calibration uncertainty of the scale factor stated in the calibration certificate, in order to obtain the uncertainty of measurement of the test voltage value.

Some guidance on determining uncertainty contributions, that need to be considered, and on their combination is given in Clause 5 and Annexes A and B. 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 3 In this International Standard, the uncertainties of the scale factor and of voltage measurement (5.2 to 5.10) are expressed by the relative uncertainties instead of the absolute uncertainty normally considered in the ISO/IEC Guide 98-3. The direct application of the ISO/IEC Guide 98-3 and consideration of the absolute uncertainties are shown in 5.11 for time parameters as well as in Annexes A and B.

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

5.1 General requirements

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.

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.

Due to the large size of the equipment and the real environmental conditions, the calibration should preferably be performed on site by comparison with a reference measuring system.

Smaller size measuring systems or their components may be transported to another laboratory for calibration in an arrangement that simulates the operating conditions, provided that the interference test, when specified, is performed in the test facility of the user.

If a converting device is sensitive to proximity effects, the range of clearances where the assigned scale factor is valid shall be determined and entered in the record of performance. One or more ranges of clearances and respective scale factors may be assigned.

The scale factor of a measuring system shall be determined in the assigned measurement range, preferably by comparison with a reference measuring system. However, as reference measuring systems are not always available at higher voltages, the comparison may be made at voltages as low as 20 % of the assigned measurement range, provided that linearity has been determined from this point up to the limit of the assigned measurement range. One of the methods given in 5.3 shall be used for this extension.

All equipment used in establishing the scale factors of measuring systems shall have calibrations traceable to national and/or international standards.

NOTE 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.

Conditions significant for the result of the calibration of the approved measuring system shall be included in the record of performance.

5.2 Calibration – Determination of the scale factor

5.2.1 Calibration of measuring systems by comparison with a reference measuring system (preferred method)

5.2.1.1 Comparison measurement

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.

For the comparison, a reference measuring system, traceable to a National Metrology Institute, shall be connected 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:

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

The relative standard deviation s_g of F_g is given by:

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

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

$$u_g = \frac{s_g}{\sqrt{n}}$$

NOTE 1 Usually no more than $n = 10$ independent readings are necessary.

NOTE 2 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 impulses, n impulses are applied.

A measuring system with several assigned measuring ranges (for example a voltage divider with several low-voltage arms) or different transmission systems shall be calibrated for each range or transmission system. Measuring systems with secondary attenuators may be calibrated on one setting only, provided that the load on the output of the converting device can be shown to be constant for all settings by other tests. For such cases the full range of secondary attenuators shall be calibrated separately.

The scale factor shall be determined over the assigned measurement range by one of the following methods described in 5.2.1.2 (preferred), 5.2.1.3 and 5.2.2.

5.2.1.2 Comparison over the full assigned measurement range

This test includes both the determination of the assigned scale factor and the determination of linearity. The scale factor determination shall be made by direct comparison with a reference measuring system 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:

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

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

$$u_{B0} = \frac{1}{\sqrt{3}} \max_{g=1}^h \left| \frac{F_g}{F} - 1 \right|.$$

NOTE 1 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 .

NOTE 2 The individual scale factors and their uncertainties at the h voltage levels should be given in the calibration certificate.

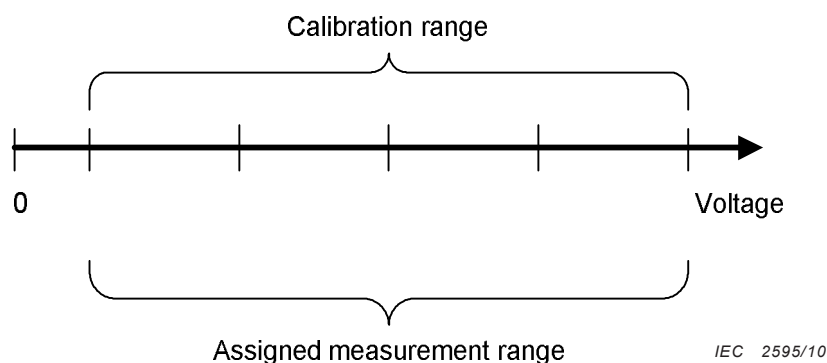


Figure 2 – Calibration by comparison over the full voltage range

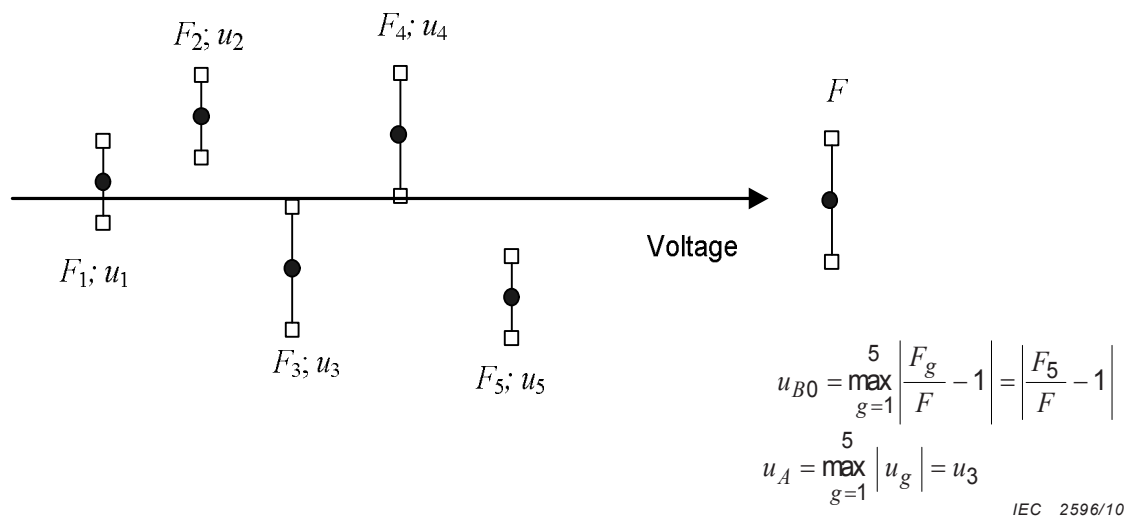


**Figure 3 – Uncertainty contributions of the calibration
(example with minimum of 5 voltage levels)**

5.2.1.3 Comparison over limited voltage range

In cases where the assigned measurement range exceeds the capability of the reference measuring system, the scale factor shall be determined by comparison up to the maximum voltage of the reference measuring system. The comparison shall always be carried out at a voltage that is not lower than 20 % of the upper limit of the assigned measurement range (Figure 4).

The comparison shall be complemented by a linearity test in accordance with 5.3. The uncertainty contribution related to linearity shall be considered in the calculation of measurement uncertainty when using the measuring system, see 5.10.3.

The comparison with the reference measuring system is carried out at $a \geq 2$ voltage levels, where the highest voltage level is equal to the maximum voltage of the reference measuring system. The necessary linearity test is carried out at $b \geq 2$ voltage levels, with one level equal to the maximum level of comparison (see 5.3). The voltage levels shall further be chosen such that they comprise at least the minimum and the maximum levels of the assigned measurement range, and that

$$a + b \geq 6$$

The assigned scale factor F is taken as the mean value of the scale factors recorded with the reference measuring system:

$$F = \frac{1}{a} \sum_{g=1}^a F_g$$

The standard uncertainty Type A of the scale factor F_m is obtained as the largest of the single standard uncertainties u_g

$$u_A = \max_{g=1}^a u_g$$

and a non-linearity contribution for the calibration values

$$u_{B0} = \frac{1}{\sqrt{3}} \max_{g=1}^a \left| \frac{F_g}{F} - 1 \right|.$$

NOTE A rounded value F_0 may be taken as the assigned scale factor if the difference between F_0 and F is introduced as an uncertainty contribution of Type B in the estimate of the expanded uncertainty of the scale factor F_0 .

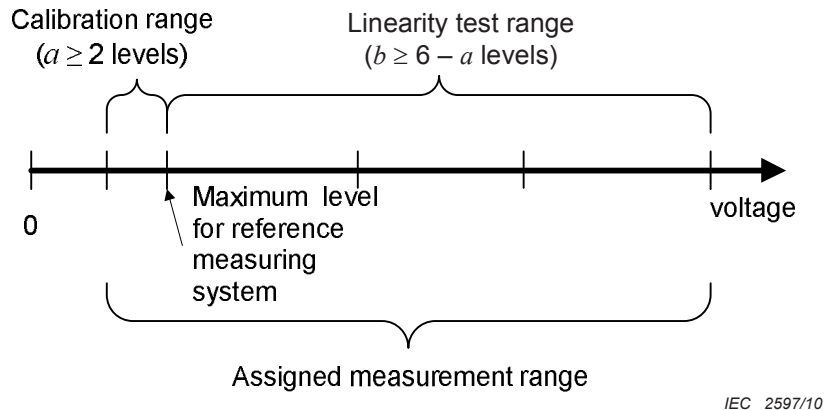


Figure 4 – Calibration by comparison over a limited voltage range, with an additional linearity test

5.2.2 Determination of the scale factor of a measuring system from the scale factors of its components (alternative method)

The assigned scale factor of the measuring system shall be determined as the product of the scale factors of its converting device, its transmission system, any secondary attenuator, and its measuring instrument.

For the converting device and the transmission system or their combination, the scale factor shall be measured by one of the methods given below. Separate tests are not required for transmission systems that consist only of cables. The scale factor of a measuring instrument is determined according to the relevant standard (see e.g. IEC 61083-1 and IEC 61083-2) or by performing a calibration and testing according to this Clause 5.

The determination of the scale factor of a component may be made by one of the following methods:

- comparison with a reference component (e.g. a voltage divider compared with a reference voltage divider) or the application of a precise low-voltage calibrator;
- simultaneous measurements of its input and output quantities;
- a bridge method or precise low-voltage ratio measurement;
- calculation based on measured impedances.

NOTE 1 Care should be taken to ensure that the appropriate "stray" capacitance or coupling and the mutual influence of the components are included in the measurement.

For each component of the measuring system the Type A and Type B contributions to uncertainty shall be estimated (5.2 to 5.9) and the combined uncertainty for each component