

INTERNATIONAL STANDARD

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High-current test techniques – Definitions and requirements for test currents and measuring systems

Techniques des essais à haute intensité – Définitions et exigences relatives aux courants d'essai et systèmes de mesure



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CONTENTS

FOREWORD.....	8
1 Scope.....	10
2 Normative references	10
3 Terms and definitions	10
3.1 Measuring systems.....	11
3.2 Components of a measuring system	11
3.3 Scale factors	12
3.4 Rated values	13
3.5 Definitions related to the dynamic behaviour	13
3.6 Definitions related to uncertainty	14
3.7 Definitions related to tests on measuring systems	16
4 Procedures for qualification and use of a measuring system.....	17
4.1 General principles	17
4.2 Schedule of performance tests	17
4.3 Schedule of performance checks.....	17
4.4 Requirements for the record of performance.....	18
4.4.1 Contents of the record of performance.....	18
4.4.2 Exceptions.....	18
4.5 Operating conditions	18
4.6 Uncertainty.....	19
5 Tests and test requirements for an approved measuring system.....	20
5.1 General requirements.....	20
5.2 Calibration – Determination of the scale factor	20
5.2.1 Calibration of a measuring system by comparison with a reference measuring system (preferred method)	20
5.2.2 Determination of the scale factor of a measuring system from those of its components	24
5.3 Linearity test	25
5.3.1 Application	25
5.3.2 Alternative methods in order of suitability	26
5.4 Dynamic behaviour.....	26
5.5 Short-term stability	27
5.5.1 Method	27
5.5.2 Steady-state current	27
5.5.3 Impulse current and short-time current	28
5.5.4 Periodic impulse current and periodic short-time current.....	28
5.6 Long-term stability.....	29
5.7 Ambient temperature effect	29
5.8 Effect of nearby current paths	30
5.9 Software effect	32
5.10 Uncertainty calculation	32
5.10.1 General	32
5.10.2 Uncertainty of calibration.....	32
5.10.3 Uncertainty of measurement using an approved measuring system	33
5.11 Uncertainty calculation of time-parameter measurements (impulse currents only).....	34
5.11.1 General	34

5.11.2	Uncertainty of the time-parameter calibration.....	34
5.11.3	Uncertainty of a time-parameter measurement using an approved measuring system	35
5.12	Interference test	36
5.12.1	Application	36
5.12.2	Current-converting shunts and current transformers with iron	37
5.12.3	Inductive measuring systems without iron (Rogowski coils)	38
5.13	Withstand tests	38
5.13.1	Voltage withstand tests.....	38
5.13.2	Current withstand tests.....	39
6	Steady-state direct current	39
6.1	Application	39
6.2	Terms and definitions	39
6.3	Test current.....	39
6.3.1	Requirements	39
6.3.2	Tolerances	39
6.4	Measurement of the test current.....	40
6.4.1	Requirements for an approved measuring system.....	40
6.4.2	Uncertainty contributions	40
6.4.3	Dynamic behaviour	40
6.4.4	Calibrations and tests on an approved measuring system.....	40
6.4.5	Performance check.....	41
6.5	Measurement of ripple amplitude.....	41
6.5.1	Requirements for an approved measuring system.....	41
6.5.2	Uncertainty contributions	41
6.5.3	Dynamic behaviour for ripple	41
6.5.4	Calibrations and tests on an approved ripple-current measuring system.....	42
6.5.5	Measurement of the scale factor at the ripple frequency	42
6.5.6	Performance check for ripple current measuring system	42
6.6	Test procedures	43
7	Steady-state alternating current.....	43
7.1	Application	43
7.2	Terms and definitions	43
7.3	Test current.....	43
7.3.1	Requirements	43
7.3.2	Tolerances	44
7.4	Measurement of the test current.....	44
7.4.1	Requirements for an approved measuring system.....	44
7.4.2	Uncertainty contributions	44
7.4.3	Dynamic behaviour	44
7.4.4	Calibrations and tests on an approved measuring system.....	46
7.4.5	Performance check.....	47
7.5	Test procedures	47
8	Short-time direct current.....	47
8.1	Application	47
8.2	Terms and definitions	48
8.3	Test currents.....	49
8.3.1	Requirements for the test current	49

8.3.2	Tolerances	49
8.4	Measurement of the test current.....	49
8.4.1	Requirements for an approved measuring system.....	49
8.4.2	Uncertainty contributions	49
8.4.3	Dynamic behaviour	49
8.4.4	Calibrations and tests on an approved measuring system.....	50
8.4.5	Performance check.....	51
8.4.6	Linearity test.....	51
8.5	Test procedures	51
9	Short-time alternating current	51
9.1	Application	51
9.2	Terms and definitions	52
9.3	Test current.....	53
9.3.1	Requirements for the test current	53
9.3.2	Tolerances	53
9.4	Measurement of the test current.....	54
9.4.1	Requirements for an approved measuring system.....	54
9.4.2	Uncertainty contributions	54
9.4.3	Dynamic behaviour	54
9.4.4	Calibrations and tests on an approved measuring system.....	55
9.4.5	Performance check.....	56
9.4.6	Linearity test.....	56
9.4.7	Interference test	57
9.5	Test procedures	57
10	Impulse currents.....	57
10.1	Application	57
10.2	Terms and definitions	57
10.3	Test current.....	61
10.3.1	General	61
10.3.2	Tolerances	61
10.4	Measurement of the test current.....	62
10.4.1	Requirements for an approved measuring system.....	62
10.4.2	Uncertainty contributions	62
10.4.3	Dynamic behaviour	62
10.4.4	Calibrations and tests on an approved measuring system.....	64
10.4.5	Performance check.....	64
10.5	Test procedures	65
11	Current measurement in high-voltage dielectric testing.....	65
11.1	Application	65
11.2	Terms and definitions	65
11.3	Measurement of the test current.....	66
11.3.1	Requirements for an approved measuring system.....	66
11.3.2	Uncertainty contributions	66
11.3.3	Dynamic behaviour	66
11.3.4	Calibrations and tests on an approved measuring system.....	66
11.3.5	Performance check.....	67
11.3.6	Linearity test.....	67
11.3.7	Interference test	67
11.4	Test procedures	67

12 Reference measuring systems.....	67
12.1 General.....	67
12.2 Interval between subsequent calibrations of reference measuring systems.....	67
Annex A (informative) Uncertainty of measurement.....	68
Annex B (informative) Examples of the uncertainty calculation in high-current measurements	76
Annex C (informative) Step-response measurements.....	82
Annex D (informative) Convolution method for estimation of dynamic behaviour from step-response measurements	85
Annex E (informative) Constraints for certain wave shapes.....	88
Annex F (informative) Temperature rise of measuring resistors.....	90
Annex G (informative) Determination of r.m.s. values of short-time a.c. current	91
Annex H (informative) Examples of IEC standards with high current tests	98
Bibliography.....	100
 Figure 1 – Examples of amplitude frequency responses for limit frequencies ($f_1; f_2$).	14
Figure 2 – Calibration by comparison over full assigned measurement range.....	22
Figure 3 – Uncertainty contributions of the calibration (example with the minimum of 5 current levels).....	23
Figure 4 – Calibration by comparison over a limited current range with a linearity test (see 5.3) providing extension up to the largest value in the assigned measurement range	24
Figure 5 – Linearity test of the measuring system with a linear device in the extended voltage range.....	26
Figure 6 – Short-term stability test for steady-state current.....	28
Figure 7 – Short-term stability test for impulse current and short-time current.....	28
Figure 8 – Short-term stability test for periodic impulse-current and periodic short-time current.....	29
Figure 9 – Test circuit for effect of nearby current path for current-converting shunts and current transformers with iron.	31
Figure 10 – Test circuit for effect of nearby current path for inductive measuring systems without iron (Rogowski coils).....	31
Figure 11 – Principle of interference test circuit.	37
Figure 12 – Interference test on the measuring system $i_1(t)$ based on current-converting shunt or current transformer with iron in a typical 3-phase short-circuit set-up (example).	37
Figure 13 – Test circuit for interference test for inductive systems without iron.	38
Figure 14 – Acceptable normalized amplitude-frequency response of an a.c. measuring system intended for a single fundamental frequency f_{nom}	45
Figure 15 – Acceptable normalized amplitude-frequency response of an a.c. measuring system intended for a range of fundamental frequencies f_{nom1} to f_{nom2}	46
Figure 16 – Example of short-time direct current.....	48
Figure 17 – Example of short-time alternating current.	52
Figure 18 – Exponential impulse current.	58
Figure 19 – Exponential impulse current – oscillating tail.	58
Figure 20 – Impulse current – Rectangular, smooth.	59

Figure 21 – Impulse current – Rectangular with oscillations.....	59
Figure A.1 – Normal probability distribution $p(x)$ of a continuous random variable x	75
Figure A.2 – Rectangular symmetric probability distribution $p(x)$ of the estimate x of an input quantity X	75
Figure B.1 – Comparison between the system under calibration X and the reference system N	81
Figure C.1 – Circuit to generate current step using a coaxial cable.....	82
Figure C.2 – Circuit to generate current step using a capacitor.....	82
Figure C.3 – Definition of response parameters with respect to step response.....	84
Figure E.1 – Attainable combinations of time parameters (shaded area) for the 8/20 impulse at maximum 20 % undershoot and for 20 % tolerance on the time parameters	88
Figure E.2 – Locus for limit of attainable time parameters as a function of permissible undershoot for the 8/20 impulse.....	89
Figure E.3 – Locus for limit of attainable time parameters as a function of permissible undershoot for the 30/80 impulse.....	89
Figure G.1 – Equivalent circuit of short-circuit test.....	91
Figure G.2 – Symmetrical a.c. component of an alternating short-circuit current	92
Figure G.3 – Numerical evaluation of r.m.s value showing both instantaneous current and instantaneous squared value of the current.....	93
Figure G.4 – Three-crest method	94
Figure G.5 – Evaluation of conventional r.m.s. value of an arc current using the three-crest method.....	95
Figure G.6 – Evaluation of equivalent r.m.s value of a short-time current during a short-circuit test.....	96
Figure G.7 – Relation between peak factor k and power factor $\cos(\varphi)$	97
Table 1 – Required tests for steady-state direct current	40
Table 2 – Required tests for ripple current	42
Table 3 – Required tests for steady-state alternating current	46
Table 4 – Tolerance requirement on test-current parameters for short-time direct current.....	49
Table 5 – Required tests for short-time direct current.....	50
Table 6 – Tolerance requirements on the short-time alternating current test parameters	53
Table 7 – List of typical tests in a high-power laboratory and required minimum frequency range of the measuring system.....	54
Table 8 – Tolerance requirements on scale factor	55
Table 9 – Required tests for short-time alternating current.....	55
Table 10 – Examples of exponential impulse-current types	61
Table 11 – Required tests for impulse current.....	64
Table 12 – Required tests for impulse current in high-voltage dielectric testing.....	66
Table A.1 – Coverage factor k for effective degrees of freedom ν_{eff} ($p = 95,45 \%$)	73
Table A.2 – Schematic of an uncertainty budget	74
Table B.1 – Result of the comparison measurement	78
Table B.2 – Result of the comparison measurement	78
Table B.3 – Uncertainty budget for calibration of scale factor F_x	79
Table B.4 – Result of linearity test	80

Table B.5 – Uncertainty budget of scale factor $F_{X,mes}$	81
Table H.1 – List of typical tests with short-time alternating current	98
Table H.2 – List of typical tests with exponential impulse current	99
Table H.3 – List of typical tests with rectangular impulse current	99

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**HIGH-CURRENT TEST TECHNIQUES –
DEFINITIONS AND REQUIREMENTS FOR TEST CURRENTS
AND MEASURING SYSTEMS**

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International Standard IEC 62475 has been prepared by IEC technical committee 42: High-voltage test techniques.

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

FDIS	Report on voting
42/278/FDIS	42/283/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.

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HIGH-CURRENT TEST TECHNIQUES – DEFINITIONS AND REQUIREMENTS FOR TEST CURRENTS AND MEASURING SYSTEMS

1 Scope

This International Standard is applicable to high-current testing and measurements on both high-voltage and low-voltage equipment. It deals with steady-state and short-time direct current (as e.g. encountered in high-power d.c. testing), steady-state and short-time alternating current (as e.g. encountered in high-power a.c. testing), and impulse-current. In general, currents above 100 A are considered in this International Standard, although currents less than this can occur in tests.

NOTE This standard also covers fault detection during, for example, lightning impulse testing.

This standard:

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

2 Normative references

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

IEC 60051-2:1984, *Direct acting analogue electrical measuring instruments and their accessories – Part 2: Special requirements* for ammeters and voltmeters

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

IEC 61180-1, *High-voltage test techniques for low-voltage equipment – Part 1: Definitions, test and procedure requirements*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM: 1995)*

NOTE Further related standards, guides, etc. on subjects included in this 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 measurements of a quantity to be measured (measurand). Software used to obtain or calculate measurement results also forms a part of the measuring system

NOTE 1 A high-current measuring system usually comprises the following components:

- converting device with either terminals to connect this device in circuit or appropriate coupling to the circuit, and connections to earth;
- transmission system(s) connecting the output terminals of the converting device to the measuring instrument(s) with its attenuating, terminating, and adapting impedances or networks; and
- measuring instrument(s) together with any connections 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 standard.

NOTE 2 The environment in which a measuring system functions, its clearances to live, current carrying, and earthed structures, and the presence of electromagnetic 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. 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 standard

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 current

NOTE A reference measuring system (maintained according to the requirements of this standard) can 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

current-converting shunt

resistor across which the voltage is proportional to the current to be measured

3.2.3

current transformer

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

[IEC 60050-321:1986, 321-02-01]

NOTE Current transformers are usually defined for a single frequency, but special designs with a wide frequency range are possible.

3.2.4

Rogowski coil

inductive current-converting device without iron; measuring systems based on a Rogowski coil include an integrating circuit (passive, active, or numerical)

NOTE Measuring systems based on a Rogowski coil can be designed for current measurements in a wide range of frequencies.

3.2.5

transmission system

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

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(s). 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.

3.2.6

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 to be 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 current ranges, frequency ranges or waveforms.

NOTE 2 Some measuring systems display the value of the input quantity directly (i.e., the 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 to be multiplied to obtain its input quantity

NOTE The scale factor of a converting device may be dimensionless (for example, the ratio of a current transformer) or may have dimensions (for example, related to the impedance of a current-converting shunt).

3.3.3

scale factor of a transmission system

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

3.3.4

scale factor of a measuring instrument

factor by which the instrument reading is to be 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, each with a different scale factor.

3.4 Rated values**3.4.1****operating conditions**

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

3.4.2**rated current**

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

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

3.4.3**assigned measurement range**

range of current of specified frequency or waveform in which a measuring system can be used within the uncertainty limits given in this standard, characterized by a single scale factor

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 may have more than one assigned measurement range, with different scale factors established for the different ranges.

3.4.4**assigned operating time**

longest time during which a d.c. or a.c. current measuring system can operate at the upper limit of the assigned measurement range within the uncertainty limits given in this standard

3.4.5**assigned rate of application**

highest rate of specified short-time currents or impulse currents that can be applied in a given time interval, at which the measuring system can operate at the upper limit of the assigned measurement range and stay within the uncertainty limits given in this standard

NOTE The assigned rate of application could for example be expressed as the number of applications per minute and the time interval in minutes or hours.

3.5 Definitions related to the dynamic behaviour**3.5.1****response of a measuring system,** g or G

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

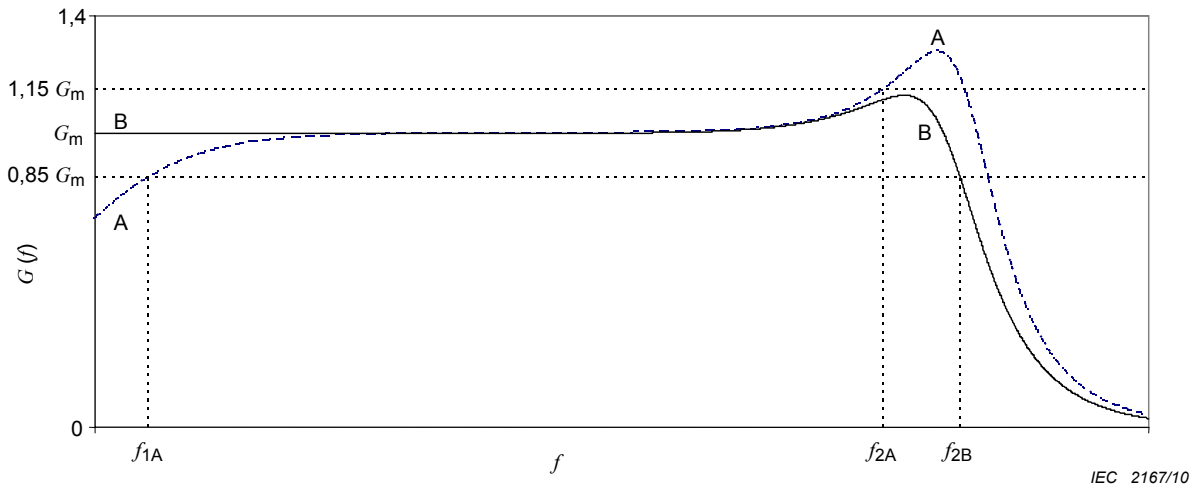
3.5.2**amplitude-frequency response** $G(f)$

ratio of the output to the input of a measuring system as a function of frequency, f , when the input is sinusoidal

3.5.3 limit frequencies

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

NOTE These limits are where the response first deviates by a certain amount (e.g. $\pm 15\%$) from the constant value. The permissible deviation should be related to acceptable uncertainties of a measuring system (see Figure 1).



NOTE Upper and lower limit frequencies are shown on curve A. Curve B shows a constant response down to direct current.

Figure 1 – Examples of amplitude frequency responses for limit frequencies (f_1 ; f_2)

3.5.4 step response

$g(t)$

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

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

3.6 Definitions related to uncertainty

3.6.1 tolerance

permitted difference between the measured value and the test specified value

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

NOTE 2 The measured test current is required to lie within the stated tolerance of the specified test level. The relevant technical committee should specify test levels.

3.6.2 uncertainty (of measurement)

parameter, associated with the result of a measurement, that characterizes 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 a measurement should not be confused with the tolerance of a test-specified value or parameter.

NOTE 3 For more information see Annex A and Annex B.

3.6.3 standard uncertainty

 u

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

[ISO/IEC Guide 98-3:2008, 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 a measurement is the standard uncertainty divided by the measurand, and is therefore dimensionless.

3.6.4 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 98-3:2008, GUM 2.3.4]

3.6.5 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 98-3:2008, GUM 2.3.5, modified, i.e. without the notes]

NOTE Expanded uncertainty is the closest match to the term “overall uncertainty” used in earlier editions of the related documents.

3.6.6 coverage factor

 k

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

(ISO/IEC Guide 98-3:2008, GUM 2.3.6, modified, i.e. without the note)

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

3.6.7 error

measured quantity value minus a reference quantity value

[ISO/IEC Guide 99:2007, VIM 2.1.6]

3.6.8 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, modified, i.e. without the notes]

3.6.9

type A evaluation

method of evaluation of uncertainty by statistical analysis of observations

3.6.10

type B evaluation

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

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

NOTE 1 This term is based on the "uncertainty" approach.

NOTE 2 The relationship between the indications and the results of measurement can be expressed, in principle, by a calibration diagram.

NOTE 3 The determination of the scale factor is included in the calibration.

[IEC 60050-300:2001, 311-01-09, modified, i.e. by the addition of NOTE 3]

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 For a measuring system this is understood as a test performed on each component or on each complete measuring system during or after manufacture 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

4 Procedures for qualification and use of a measuring system

4.1 General principles

Every approved measuring system is required to undergo initial testing, followed by subsequent 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 system can measure the intended test currents 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, transmission system(s) and measuring instrument(s) used in a measuring system is stability within their 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.

Test facilities shall use the tests given in this standard to qualify their measuring systems. 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.

Any calibration shall be traceable to national and/or international standards. It is the responsibility of the user to ensure that all calibrations are performed by competent personnel using reference measuring systems and suitable procedures.

NOTE Calibrations performed by a laboratory accredited according to ISO/IEC 17025 for the quantities calibrated and reported under the accreditation, are considered traceable to national and/or international standards of measurement.

4.2 Schedule of performance tests

To maintain the quality of a measuring system, its assigned scale factor(s) shall be determined by the periodic performance tests according to 5.2. 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 and in any case it shall be repeated at least once every five years.

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

A 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 its record of performance. The interval from the last performance test or the last performance check should 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 complete 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 rated current, waveform(s), range(s) of clearances, operating time, or maximum rate of current applications. For many measuring systems, information on the transmission system as well as on the ground return and earthing arrangements is fundamentally important. If needed, a description of the components of the measuring system should be given, including, for example, the type and identification of the measuring instrument.

4.4.2 Exceptions

In the case of measuring systems or components manufactured before the date of issue of this standard, the required evidence may not be available for some of the type and routine tests (for example, 5.7 and 5.13). Then, the performance tests (in accordance with 6.4.4, 7.4.4, 8.4.4, 9.4.4 or 10.4.4 as relevant) and checks made in accordance with earlier standards 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.

Measuring systems comprising several pieces of equipment used interchangeably, 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

The current-converting shunt and/or current transformer of a current measuring system shall be connected in series with the test object. The connections should be of the lowest practicable impedance.

The Rogowski coil of a current measuring system shall be situated concentric around a straight part of the current-carrying conductor. The axes of the current conductor and the plane of the coil should be perpendicular in order to minimize sensitivity of the system to external magnetic fields.

NOTE 1 The direction of a current-carrying conductor often shows a 90° angle at a certain distance from the Rogowski coil. It has been shown that for the Rogowski coil situated at a distance of more than 2 times the coil radius from the 90° angle, the influence is negligible.

NOTE 2 Parasitic coupling may need to be investigated.

A measuring system shall have uncertainty low enough for its intended operating conditions.

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

NOTE 3 The recommended minimum value for the assigned operating time is 1 h.

The assigned rate of application of short-time current or impulse currents shall be specified.

NOTE 4 The recommended minimum value for the maximum rate of application is two per minute.

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

4.6 Uncertainty

The uncertainty of all measurements made under this 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 are considered sufficient for the instrumentation and measurement arrangements commonly used in high-current testing: however, users may select other appropriate procedures from ISO/IEC Guide 98-3, as they are given in Annex A and Annex B.

In general, the measurand is the scale factor of the measuring system, but in some cases, other quantities, such as the time parameters of high-current impulses and their associated errors, should be considered.

NOTE 1 Other measurands for specific converting devices are in common use. For example, a current-converting shunt is characterized by the resistance and its uncertainties in the ranges used. A current transformer is characterized by the ratio error, the phase displacement, and the corresponding uncertainties.

According to ISO/IEC Guide 98-3, the uncertainty of a measurand is determined by combining the uncertainty contributions of type A and type B (see Annex A). The contributions are obtained from measurement results, from manufacturer's handbooks, calibration certificates, and from estimating reasonable values of the influence quantities during the measurement. Such influence quantities can include for example temperature effects, interference (effect of nearby current paths), etc.

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

During an actual current test in the test laboratory, it is usually necessary to consider additional influence quantities, apart from the calibration uncertainty of the scale factor as stated in the calibration certificate, in order to obtain the uncertainty of a measurement of the test current.

Guidance on determining uncertainty contributions that need to be considered and on their combination is given in Clause 5, Annex A, and Annex B. The uncertainty shall be given as the expanded uncertainty for a coverage probability of approximately 95 % corresponding in most cases to a coverage factor $k = 2$ under the assumption of a normal distribution.

NOTE 3 In this standard, the uncertainties of the scale factor and of current measurements (5.2 to 5.10) are expressed by the relative uncertainties instead of the absolute uncertainty normally considered in ISO/IEC Guide 98-3. The direct application of the GUM and consideration of the absolute uncertainties are shown in 5.11 for time parameters and in Annex A and Annex B.

5 Tests and test requirements for an approved measuring system

5.1 General requirements

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

In the case of impulse measuring systems and short-time a.c. and short-time d.c. measuring systems, the performance test also shows that the dynamic performance of the system is adequate for the specified measurements and that the level of any interference is less than the specified limits.

In high-current tests, the size of the apparatus, the levels of current used, and the interaction between the test and measuring circuits often make it preferable to perform calibrations at the test facility of the user.

However, 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, if specified, is performed in the test facility of the user. The simulated arrangement shall represent the operating conditions and shall be described in the record of performance.

If a converting device (and/or other component of the measuring system) is sensitive to the presence of nearby current paths, the range of clearances where the assigned scale factor is valid determined and given in the record of performance. One or more ranges of clearances and respective scale factors can be assigned. In the case where the clearance is fixed, the proximity effect is covered by the calibration.

The scale factor(s) of a measuring system shall be determined in each assigned measurement range, preferably by comparison with a reference measuring system. However, as reference measuring systems are not always available at higher currents, calibration by comparison may be made at currents as low as 5 % of the assigned measurement range, provided that the linearity has been proved from this point up to the limit of the assigned measurement range. One of the linearity test 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 measurement 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 a measuring system 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 current used for calibration should be of the same type, frequency, or waveform as currents to be measured. If this condition is not fulfilled, the related uncertainty contributions shall be considered.

For the comparison, a reference measuring system, traceable to a National Metrology Institute, shall be connected in series with the measuring system to be calibrated. Care shall be taken to avoid those ground loops between the converting device and measuring instrument(s) that produce unacceptable interference. 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 $F_{i,g}$ of its scale factor at one current level I_g . The procedure is repeated to obtain n independent readings. The arithmetic mean (average) value $\overline{F_g}$ of the scale factor of the system under calibration at one current level I_g is given by:

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

The relative experimental (sample) standard deviation s_g of the individual scale factor values $F_{i,g}$ is given by:

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

and the type A relative standard uncertainty u_g of the mean value $\overline{F_g}$ is given by:

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

NOTE 1 Usually no more than $n = 10$ readings are necessary. If less than 10 readings are taken, evaluation should be in accordance with Annex A.

NOTE 2 For measurement of direct and alternating currents, independent readings may be obtained either by applying the test current and taking n readings or by applying the test current n times and taking a reading each time. For impulses and short-time currents, n high-current events are applied.

A measuring system with several assigned measurement ranges shall be calibrated for each range to determine its scale factor. Measuring systems with secondary attenuators may be calibrated on one setting only, provided that the load at the output of the converting device can be shown to be constant for all settings by other tests. In such cases, the full range of settings of the secondary attenuators shall be calibrated separately.

The scale factor shall be determined over each assigned measurement range by one of the following two methods.

5.2.1.2 Comparison over the full assigned measurement range

This test includes both the determination of assigned scale factor and determination of linearity. The scale factor determination shall be done by comparison with a reference measuring system according to 5.2.1.1 at the minimum and maximum levels of the assigned measurement range and at least at three approximately equally spaced intermediate levels (see Figure 2). The assigned scale factor F is taken as the mean value of all scale factors $\overline{F_g}$ recorded at h current levels.

$$F = \frac{1}{h} \sum_{g=1}^h \overline{F}_g$$

where the number of current levels $h \geq 5$.

The standard uncertainty u_F of the determination of the assigned scale factor $\overline{F}$ is given by the combination of a type B contribution u_{B1} of non-linearity of the mean values $\overline{F}_g$ and a type B contribution u_{B2} based on the maximum of the type A standard uncertainties of the recorded scale factors $\overline{F}_g$:

$$u_F = \sqrt{u_{B1}^2 + u_{B2}^2} = \sqrt{\frac{1}{3} \left(\max_{g=1}^h \left| \frac{\overline{F}_g}{\overline{F}} - 1 \right| \right)^2 + \left(\max_{g=1}^h (u_g) \right)^2}$$

NOTE 1 The h determinations of scale factor $\overline{F}_g$ do not constitute a statistical ensemble since they have not been obtained under the same conditions, especially concerning the current level. It is therefore not possible to obtain the uncertainty of the assigned scale factor with statistical methods (i.e. type A). Instead, an estimation type B has to be carried out, and is here based on two contributions. The spread of $\overline{F}_g$ observed over the current levels, is characterized by the maximum deviation from the mean, and evaluated as a rectangular probability distribution. The statistical spreads of type A in the determinations of the individual $\overline{F}_g$ results, at each current level are taken into account by using the maximum value of the individual u_g values, and evaluated as a normal distribution (See Figure 3).

NOTE 2 A rounded value F_o may be taken as the assigned scale factor F 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 .

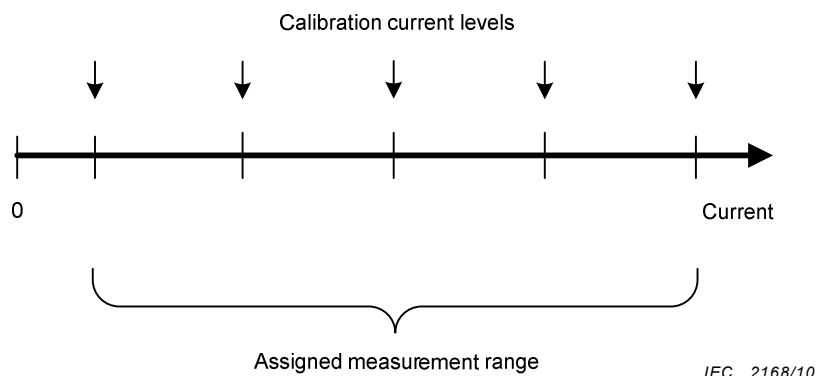


Figure 2 – Calibration by comparison over full assigned measurement range

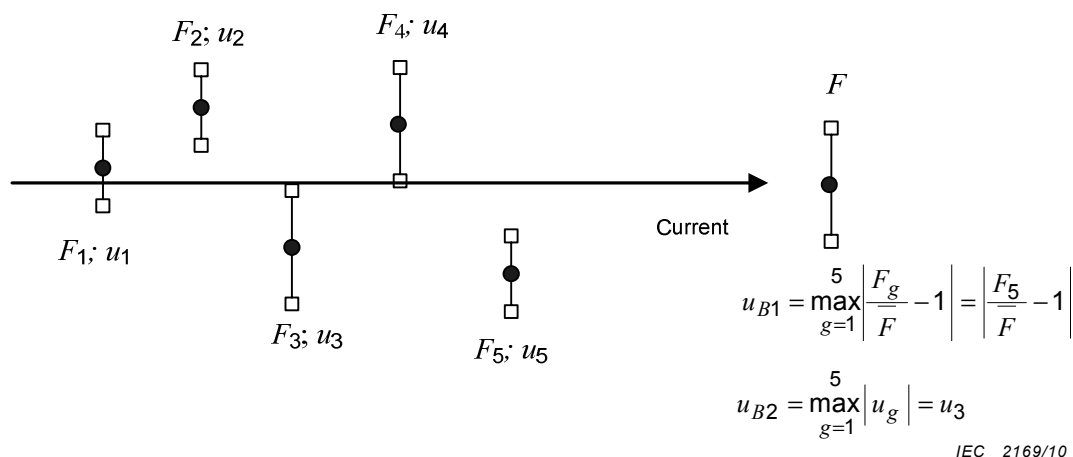


**Figure 3 – Uncertainty contributions of the calibration
(example with the minimum of 5 current levels)**

5.2.1.3 Comparison over limited current range

In cases where the assigned measurement range exceeds the capability of the available reference measuring system, the assigned scale factor shall be determined by comparison according to 5.2.1.1 up to the maximum current of the reference measuring system. The comparison shall, in any case, be carried out at a current that is not lower than 5 % of the upper limit of the assigned measurement range (see Figure 4).

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

$$\begin{aligned} a &\geq 2 \\ a + b &\geq 6 \end{aligned}$$

where the linearity measurements b are considered in 5.3.

The assigned scale factor, F , is taken as the mean value of the scale factors $\overline{F}_g$ recorded via comparison with the reference measuring system according to 5.2.1:

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

The standard uncertainty u_F for the determination of the assigned scale factor F (calibration values) is given by the combination of the type B contributions of non-linearity of F and the type B contribution based on the maximum of the type A standard uncertainty of the recorded scale factors $\overline{F}_g$:

$$u_F = \sqrt{\frac{1}{3} \left(\max_{g=1}^a \left| \frac{\overline{F}_g}{F} - 1 \right| \right)^2 + \frac{1}{3} \left(\max_{g=1}^a (u_g) \right)^2}$$

NOTE A rounded value F_0 may be taken as the assigned scale factor if the difference between F_0 and $\overline{F}_g$ is introduced as an uncertainty contribution of type B in the estimate of the expanded uncertainty of the scale factor F_0 .

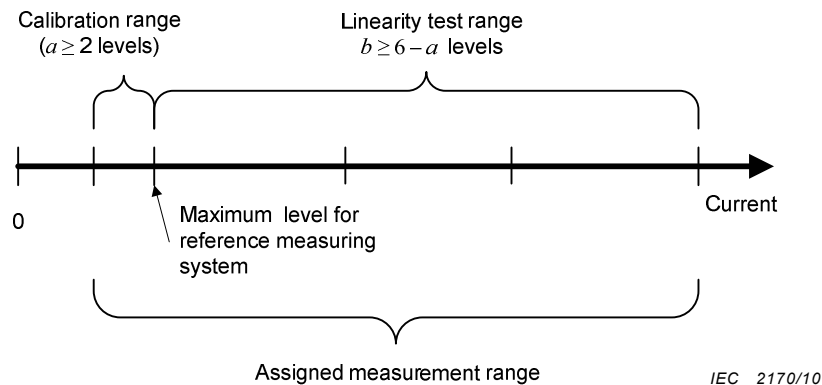


Figure 4 – Calibration by comparison over a limited current range with a linearity test (see 5.3) providing extension up to the largest value in the assigned measurement range

5.2.2 Determination of the scale factor of a measuring system from those of its components

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. 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 IEC standard (see Clause 2) or by performing calibrations to prove traceability for the quantity to be measured by the instrument.

NOTE 1 The accuracy class stated for analogue instruments in accordance with IEC 60051-2, is related to the fiducial value, i.e. it is an uncertainty stated as a percentage of the upper limit of the measuring range of the instrument. At lower deflections the relative error will be correspondingly larger.

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

- simultaneous measurements of its input and output quantities;
- by comparison with a reference component (e.g. a current-converting shunt with a reference current-converting shunt);
- a bridge method;
- calculation based on measured impedances;
- from steady-state portion of its step-response (see Annex C), where the dynamic performance for the scale factor thus obtained can be investigated using convolution techniques (Annex D).

NOTE 2 Care should be taken to ensure that the appropriate "stray" coupling and the mutual influence of the components are considered when performing the measurement.

The scale factor of a current-converting shunt may be determined by d.c. measurements, provided that the dynamic behaviour has been determined separately.

An estimation of relevant type A and type B contributions to uncertainty (see also 5.3 to 5.9) shall be made, for each component of the measuring system, and the combined uncertainty valid for each component is determined according to 5.10, taking into account the uncertainty contributions of the of the measuring devices used for the calibrations.

NOTE 3 Estimation of contributions to uncertainty in the component calibration method requires analysis of each component over the full range of conditions – current, temperature, effect of nearby current paths, etc. – that may influence the result. This analysis is complex and requires deep understanding of the measurement process.

The expanded uncertainty of the current measurement, using the measuring system, shall be obtained by combining these combined uncertainties of the components according to the provisions of ISO/IEC Guide 98-3. See also Annex A and Annex B

Further tests related to estimation of uncertainty shall be made on converting device, transmission system(s) (other than cables) and measuring instrument(s) in accordance with all the tests described in 5.3 to 5.9.

Estimation of uncertainty of time parameter measurement shall be made applying the provisions of 5.11 and the same principles as for measurement of the value of the test current.

5.3 Linearity test

5.3.1 Application

The linearity test is only intended to provide an extension of the validity of the assigned scale factor from the maximum current at which a calibration according to 5.2.1.3 has been carried out, up to the upper limit of the assigned measurement range, usually equal to the rated current of the measuring system (see Figure 4).

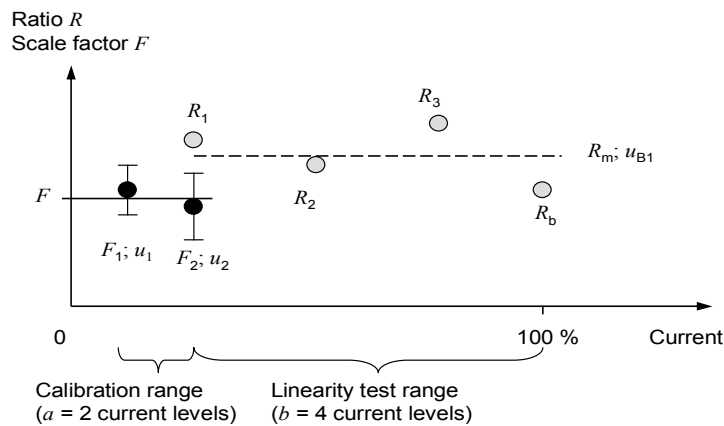
Some types of converting devices show in principle no change in linearity behaviour over the lifetime of the device, e.g. a shunt. For such devices the first linearity test shall be made, but subsequent linearity tests may be replaced by advancing scientific arguments proving that the linearity is not affected by foreseeable processes in the device.

The output of the measuring system shall be compared with the output of a comparison device or system that has proven its linearity or can be shown – at least through its principle and theory (such as e.g. Rogowski coil) – to be linear over the full assigned measurement range of the system under the linearity test. Failure to prove the linearity using such method does not necessarily mean the measuring system is non-linear. In this case another method suitable for the linearity test shall be chosen.

The ratio R between the corresponding readings of the measuring system and the comparison device or system, shall be established as described in 5.2.1.1 for b current levels I_g ranging from the upper limit of the assigned measurement range down to a current at which the scale factor has been determined.

Evaluation of linearity is based on the maximum deviation of the ratios $R_{i,g}$ from their mean $\overline{R_g}$, where $R_{i,g}$ are the individual ratios of the measured current to the corresponding input current of the comparison device. The maximum deviation is taken as a type B estimate of the relative standard uncertainty u_{lin} related to non-linearity of the scale factor in the extended current range higher than the maximum current at which calibration has been carried out:

$$u_{lin} = \frac{1}{\sqrt{3}} \times \max_{g=1}^b \left| \frac{R_{i,g}}{\overline{R_g}} - 1 \right|$$



IEC 2171/10

Figure 5 – Linearity test of the measuring system with a linear device in the extended voltage range

5.3.2 Alternative methods in order of suitability

5.3.2.1 Comparison with an approved measuring system

The output of the measuring system shall be checked against the output of an approved measuring system according to the procedure described in 5.3.1.

The linearity of the approved measuring system shall preferably have been established by calibration in accordance with 5.2.1.

5.3.2.2 Estimation of temperature rise of current-converting shunt

The impulse current, or the short-time current, carried by a current-converting shunt, raises the temperature of its resistance element and this can alter its scale factor significantly. The extent of this effect on the linearity and its dependence on current can be established by calculation based on the temperature coefficient of the resistance element (see Annex F).

5.3.2.3 Comparison with Rogowski coil

The output from a rigid Rogowski coil in a fixed position is in principle linear and can be used for the linearity test according to the procedure described in 5.3.1.

5.4 Dynamic behaviour

The dynamic behaviour of the scale factor of the measuring system or a component may be affected by various influence quantities depending on the type of current to be measured and the measurement conditions. Further requirements are given in the specific clauses for the relevant current. A type B estimate of the scale-factor relative standard uncertainty u_{dyn} related to the dynamic behaviour is given by:

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

where

k is the number of scale-factor determinations within a range of impulse parameters or a frequency range;

F_i is the individual scale factors;

$\overline{F}$ is the mean (average) scale factor within a range of impulse-time parameters or a frequency range.

Some types of converting devices show, in principle, no change in dynamic behaviour over their lifetime. For such devices the first dynamic performance test must be made, but subsequent dynamic performance tests may be replaced by advancing scientific arguments proving that dynamic performance is not affected by foreseeable processes in the device.

5.5 Short-term stability

5.5.1 Method

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

A current equal to the maximum current of the assigned measurement range shall be applied to the converting device continuously (or in the case of impulses, at the assigned rate of application) for a period appropriate to the anticipated use.

NOTE The period of current application need not be longer than the assigned operating time, but can be limited to a time sufficient to reach thermal equilibrium.

The scale factor shall be measured at the beginning and at the end of the applied current or, in the case of a series of impulses, at the end of a series of impulses. The measurement of the scale factor can be made either by comparison with another approved measuring system or by other suitable methods. If other methods are chosen, the scale factor may be determined with the converting device dismantled from the test circuit. In this case, the measurement shall be carried out as soon as possible after the application of the current or the series of impulses so that the scale factor does not change appreciably. The recommended maximum time is 20 min.

The result of the test is an estimate of a change of the scale factor, from which the relative standard uncertainty contribution u_{st} is obtained as a type B estimate:

$$u_{st} = \frac{1}{\sqrt{3}} \times \left| \frac{F_{\text{after}}}{F_{\text{before}}} - 1 \right|$$

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

5.5.2 Steady-state current

The scale factor shall be measured before or at the start of the application of the current. The rated current shall be applied to the converting device continuously until thermal stability is reached. The scale factor shall then be measured immediately after (or at the end of) the application of the current (see Figure 6).

In certain cases some time has to be permitted for reconnection of the converting device. This time should not be more than 20 % of the thermal time constant of the converting device, and shall in any case not be longer than 20 min.

As an alternative method, the temperature of the resistive element of the shunt can be measured during the test. The scale factor relevant to conditions after the test can then either be determined directly by measurement under artificial heating of the shunt, or by recording the scale factor during the cooling process and extrapolation of the curve back to the last instant of current application.

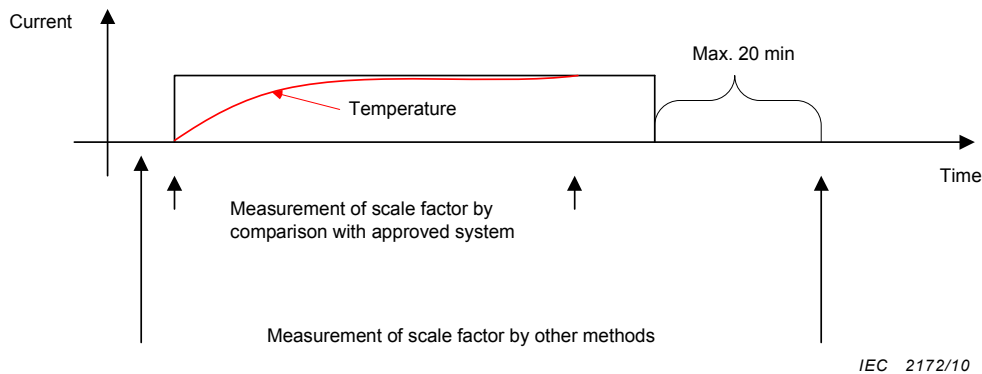


Figure 6 – Short-term stability test for steady-state current

5.5.3 Impulse current and short-time current

The scale factor shall be measured before or at the start of the application of the current and immediately after or at the end of the application of the current. The rated current shall be applied to the converting device (see Figure 7).

In addition, the scale factor shall be just measured before or at the intended next application of an impulse, to prove that the current-free time has been long enough for the scale factor to return to the original value.

NOTE In the case of a short-time d.c./a.c. current, the scale factor evaluated before and after a single current application may be a proper measure of the short-term stability.

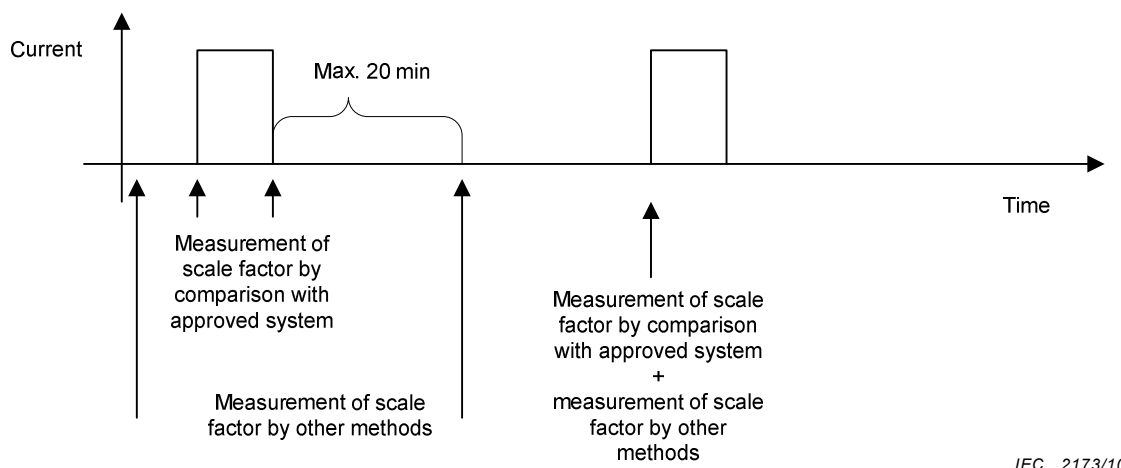


Figure 7 – Short-term stability test for impulse current and short-time current

5.5.4 Periodic impulse current and periodic short-time current

The scale factor shall be measured before or at the start of the application of a series of impulses/short-time currents and immediately after or at the end of the application of a series of impulses/short-time currents (see Figure 8). The rated current shall be applied to the converting device.

In addition, the scale factor shall be measured just before or at the intended start of a new series of impulses, to prove that the current-free time has been long enough for the scale factor to return to the original value.

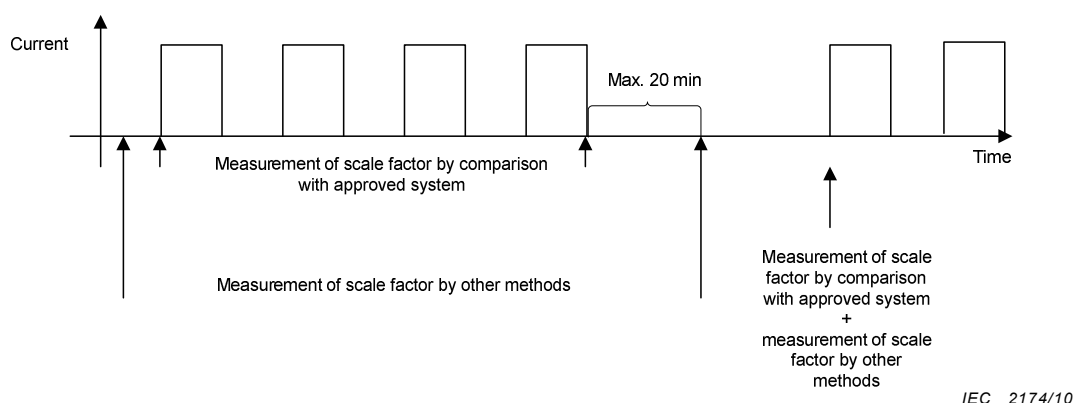


Figure 8 – Short-term stability test for periodic impulse-current and periodic short-time current

5.6 Long-term stability

The stability of the scale factor shall be considered and evaluated for a long span of time, and is generally estimated as an uncertainty contribution valid for a projected time of use T_{use} until the next calibration. 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 from which the relative standard uncertainty contribution u_{lt} is obtained as a type B estimate:

$$u_{\text{lt}} = \frac{1}{\sqrt{3}} \times \left| \frac{F_2}{F_1} - 1 \right| \times \frac{T_{\text{use}}}{T_2 - T_1}$$

where F_1 and F_2 are the scale factors at two subsequent 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 characterized by the type A contribution:

$$u_{\text{lt}} = \frac{T_{\text{use}}}{T_{\text{interval}}} \sqrt{\frac{\sum_{i=1}^n \left(\frac{F_i}{\bar{F}_i} - 1 \right)^2}{n-1}}$$

where F_i are the scale factors determined at performance tests repeated at a mean time interval of T_{interval} . The mean value of the scale factors F_i is $\bar{F}_i$.

5.7 Ambient temperature effect

The variations of the scale factor or a parameter (for example, the resistance or the transformer ratio error) of a device due to changes of the ambient temperature can be determined by computation using the temperature coefficients of single elements (see for example Annex F) or by making measurements on the single elements at different temperatures.

The influence of ambient temperature can also be quantified by determination of the scale factor at different ambient temperatures.

The data and calculations shall be reported in the record of performance; they may be taken from manufacturer's data.

The result of the test (or calculation) is an estimate of a change of the scale factor due to ambient temperature. From this, the relative standard uncertainty contribution u_{temp} is obtained as a type B estimate:

$$u_{\text{temp}} = \frac{1}{\sqrt{3}} \times \max \left| \frac{F_{T_i}}{F_{\text{cal}}} - 1 \right|$$

where

F_{T_i} is the scale factor at a particular temperature T_i ;

F_{cal} is the scale factor at the temperature during the calibration.

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

Temperature correction factors may be used in cases where the ambient temperature varies over a wide range. Any temperature corrections to be used shall be listed in the record of performance.

In cases where temperature correction has been applied, the uncertainty contribution u_{temp} shall be taken as the uncertainty of the temperature correction factor.

5.8 Effect of nearby current paths

Influence on current measurements, i.e. interference due to mutual-inductance effects of nearby high-current path(s), such as found for instance in three-phase test circuits, can be determined by measurements performed for representative distances of the current-converting device from possibly interfering circuit(s). Grounding/earthing should be the same as in the normal test situation.

The test is performed with no current in the converting device under test and a suitable current in the nearby circuit, whereas readings are taken from both measuring system under test and the nearby current circuit (see Figure 9 and Figure 10).

The result of the test is an estimate of the influence on the measurement, from which the relative standard uncertainty contribution u_{prox} is obtained as a type B estimate:

$$u_{\text{prox}} = \frac{1}{\sqrt{3}} \times \left| \frac{i_{\text{prox}}}{i_{\text{nearby}}} - 1 \right|$$

where

i_{prox} is the reading of the (interference) current of the measuring system under test;

i_{nearby} is the current applied to the nearby conductor.

In case of multiple-phase test circuits, it is assumed that the current carried by the nearby conductor(s) for the purpose of 5.8 is approximately equal to the current applied to the converting device of the investigated measuring system in a real high-current test. Different values for the standard uncertainty contribution u_{prox} may be obtained for different ranges of distances.

NOTE 1 Some test facilities may choose to approve their measuring systems for only a single set of distances, or for a few sets or ranges of distances.

NOTE 2 The test of the effect of nearby current paths on the converting device should be performed once for each set-up, or range of set-ups.

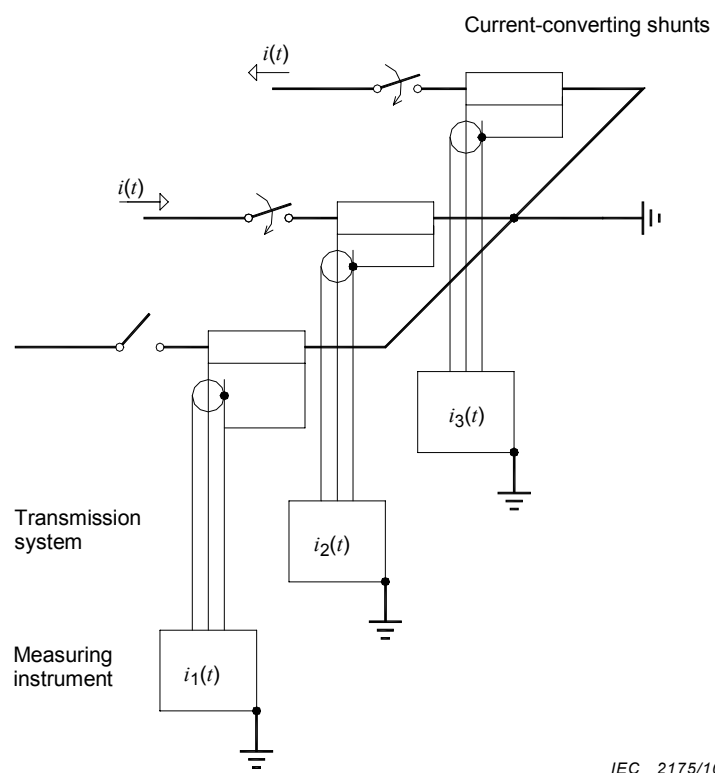


Figure 9 – Test circuit for effect of nearby current path for current-converting shunts and current transformers with iron

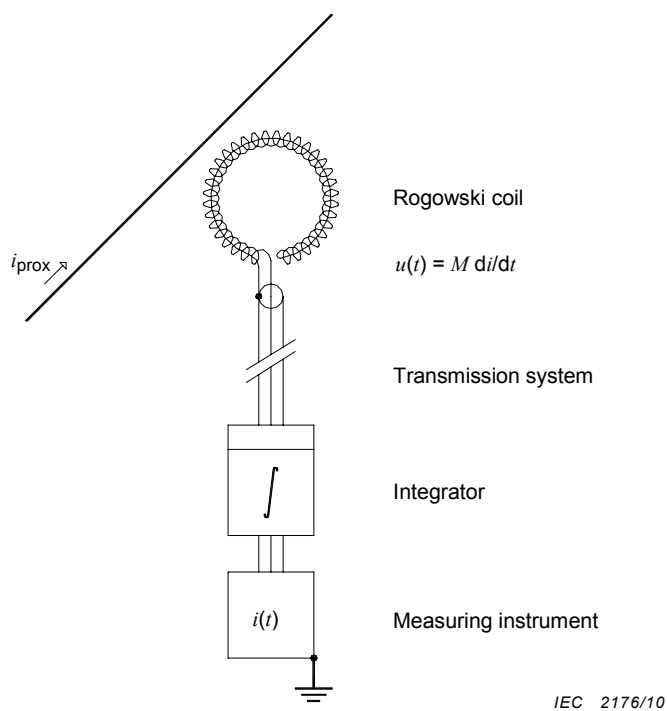


Figure 10 – Test circuit for effect of nearby current path for inductive measuring systems without iron (Rogowski coils)

5.9 Software effect

The way the software handles evaluation of measured data may introduce an uncertainty that has to be estimated. This can be done for instance by evaluation of a synthetically established set of data from a test-data generator, followed by a comparison with the established reference values of the data.

The result of the evaluation is an estimate of the influence of the data processing, from which the relative standard uncertainty contribution u_{sf} is obtained as a type B estimate.

5.10 Uncertainty calculation

5.10.1 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 as follows:

- there is no correlation between the measurement quantities;
- standard uncertainties evaluated by the method of type B are assumed to have a rectangular distribution; and,
- there are at least three dominant uncertainty contributions that are similar in magnitude.

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

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

The expanded uncertainty of a measurement U_{mes} of the test quantity is evaluated from the uncertainty of calibration of the scale factor of the approved measuring system and in addition from influence of other quantities discussed in 5.10.3, such as stability of the approved measuring system and ambient parameters during the measurement.

Further methods for estimating uncertainty are given in ISO/IEC Guide 98-3 and are discussed in Annex A and Annex B.

5.10.2 Uncertainty of calibration

The expanded uncertainty of a calibration U_{cal} is calculated from the uncertainty of the reference measuring system and from the type A and type B uncertainty contributions explained in this clause:

$$U_{\text{cal}} = k \times u_{\text{cal}} = 2 \times \sqrt{u_{\text{C ref}}^2 + u_{\text{F}}^2 + \sum_{i=1}^N u_{\text{Bi}}^2}$$

where

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

u_{cal} is the combined standard uncertainty of the scale factor of the approved measuring system determined at its calibration;

$u_{\text{C ref}}$	is the combined standard uncertainty of the scale factor of the reference measuring system determined at its calibration;
u_F	is the standard uncertainty of the determination of the scale factor performed according to 5.2.1 or in 5.2.2;
u_{Bi}	is the contribution to combined uncertainty of the scale factor caused by the i^{th} influence quantity and evaluated as a type B contribution. These contributions are related to the reference measuring system and arise from non-linearity, short- and long-term instabilities, etc.; they are determined according to 5.3 to 5.9 and based either on additional measurements or estimated from other data sources. Influences related to the approved measuring system, such as its short-term stability and resolution of the measurement, have also to 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 and Annex B or, if necessary, in ISO/IEC Guide 98-3, shall be applied.

The number N of type B uncertainty contributions may differ for different types of test currents (Clauses 6 to 11). More information on the type B contributions is given in the relevant clauses.

If the assigned scale factor of the measuring system is calculated from those of its components (5.2.2), the standard uncertainties of the calibration of the components shall be combined with those describing additional conditions of the measuring system and its environment (see Annex A and Annex B).

5.10.3 Uncertainty of measurement using an approved measuring system

Estimation of the expanded uncertainty of a measurement 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 a measurement U_{mes} is calculated from the combined standard uncertainty of the assigned scale factor of the approved measuring system as determined in the calibration and additional uncertainty contributions related to the use of the approved measuring system. It is estimated by:

$$U_{\text{mes}} = k \times u_{\text{C mes}} = 2 \times \sqrt{u_{\text{C cal}}^2 + \sum_{i=1}^N u_{\text{Bi}}^2}$$

where

$k = 2$	is the coverage factor for a coverage probability of approximately 95 % and normal distribution;
$u_{\text{C mes}}$	is the combined standard uncertainty of the measurement using the approved measuring system, valid for a projected period of use, e.g. a calibration interval;
$u_{\text{C cal}}$	is the combined standard uncertainty of the scale factor of the approved measuring system determined at the calibration;
u_{Bi}	is the contribution to the combined uncertainty of the scale factor of the approved measuring system caused by the i^{th} influence quantity evaluated as a type B contribution. These contributions are related to a normal use of the approved measuring system and arise from non-linearity, short- and long-term instabilities, etc.; they are determined according to 5.3 to 5.9 and are based either on additional measurements or estimated from other data sources. Other significant influences shall also be taken into account, e.g. the resolution of the instrument display in the approved measuring system.

NOTE A calibration certificate may include information on both the uncertainty of the calibration, U_{cal} , and the uncertainty of measurement of the test current, U_{mes} , when using the approved measuring system under stated, predefined conditions.

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

The number N of type B uncertainty contributions may differ for different types of test currents (Clauses 6 to 11). More information on the type B contributions is given in the relevant clauses.

5.11 Uncertainty calculation of time-parameter measurements (impulse currents only)

5.11.1 General

An approved measuring system for impulse current shall be able to measure each time parameter within the specified uncertainty limit provided the parameter lies within its specified range. For front time this is usually the nominal epoch, see 10.2.9. The experimental proof may be given either by the comparison or the component method. The proof may also be given by calculation, using the convolution method based on the experimental step response (Annex C and Annex D).

The general procedure for evaluating the time parameters and their uncertainties is described below for the front time T_1 , determined by the comparison method. It is applicable to other time parameters in the same way.

Definitions of time parameters for impulse currents are given in Clause 10.

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

5.11.2 Uncertainty of the time-parameter calibration

The front time T_1 of n impulse currents shall be measured simultaneously by the measuring system under test, denoted as X, and the reference measuring system, denoted as N. The error of the reference measuring system is assumed to be negligible. The arithmetic mean error of the front times is:

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

and the experimental standard deviation of the individual front-time errors is:

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

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

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

NOTE 2 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 (see 5.2.1.1).

From $s_{\Delta T_1}$, the type A standard uncertainty of the mean front-time errors is calculated as:

$$u_A = \frac{s_{\Delta T_1}}{\sqrt{n}}$$

The comparison is performed at a suitable current level with a front time being the minimum and maximum T_1 values that the measuring system will be used for. The different front times are distinguished by an ordinal number, j , as $T_{1,j}$. For each T_1 value, the mean difference $\Delta T_{1,j}$ is calculated as described above.

The overall mean of the $n \geq 2$ mean errors is:

$$\overline{\Delta T_{1m}} = \frac{1}{n} \sum_{j=1}^n \overline{\Delta T_{1,j}}$$

The maximum deviation of the individual values $\Delta T_{1,j}$ from their mean value ΔT_{1m} is used to determine the type B uncertainty u_B as:

$$u_B = \frac{1}{\sqrt{3}} \max_{j=1}^n \left| \overline{\Delta T_{1,j}} - \overline{\Delta T_{1m}} \right|$$

NOTE 3 If the measuring system is used for one single front time, only one comparison measurement is needed.

The expanded uncertainty of the time-parameter calibration, equal to that of the resultant mean error, ΔT_{1cal} , is determined as:

$$U_{cal} = k \times u_{cal} = 2 \times \sqrt{u_{cref}^2 + u_A^2 + u_B^2}$$

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_{cref} is the combined standard uncertainty of the mean front-time error, ΔT_{1ref} , of the reference measuring system;
- u_A is the type A standard uncertainty of the mean front-time error, ΔT_{1cal} , of the calibrated measuring system;
- u_B is the type B standard uncertainty of the mean front-time error, ΔT_{1cal} , of the calibrated measuring system.

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

5.11.3 Uncertainty of a 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 a defined range of measurement conditions in the calibration certificate.

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

Calculation of the expanded uncertainty of the time-parameter measurement U_{mes} shall be calculated according to the following formula:

$$U_{mes} = k \times u_{mes} = 2 \times \sqrt{u_{cal}^2 + \sum_{i=1}^N u_{Bi}^2}$$

where

- $u_{c\text{ cal}}$ is the combined standard uncertainty of the mean front-time error, $\Delta T_{1\text{cal}}$, 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 combined uncertainty of the measurement of time parameter of an impulse, using the approved measuring system caused by the i^{th} influence quantity to the time parameter and evaluated as a type B contribution. These contributions are related to a normal use of the approved measuring system and arise for example from short- and long-term instabilities, software effects, etc., but also due to non-perfect impulse shapes. Determination of these contributions according to 5.3 to 5.9 is based either on additional measurements or other data sources. In some situations, further influences must also be taken into account, e.g. the resolution of the instrument display in the approved measuring system;
- $u_{c\text{ mes}}$ is the combined standard uncertainty of the time parameter measured with the approved measuring system, valid for a projected period of use.

Additional contributions to the expanded uncertainty may be important in special cases and shall be considered in calculation of U_{mes} , e.g. when the impulse current exhibits oscillations on the front.

NOTE 1 No correction for time parameter measurement is required, as long as the sum of the observed relative mean error $\frac{\Delta T_{1,j}}{T_1}$ and its relative expanded uncertainty U_{mes} is less than 70 % of the required relative uncertainty for the relevant time-parameter measurement.

NOTE 2 The influence of the time-parameter variation on the test result is supposed to be small.

NOTE 3 The expanded uncertainty of a corrected time parameter, $T_{1\text{corr}}$, should be established according to this clause.

5.12 Interference test

5.12.1 Application

Interference test is required for steady-state a.c., short-time a.c./d.c., and impulse-current measuring systems.

Interference test is made to ensure adequate immunity to interference of the current measuring system in a given circuit under given operating conditions. Interference may be induced by the transient electromagnetic field or conducted by either the signal or the supply lines.

The test shall be made on the measuring system whereas its transmission system (measuring cable) according to 5.12.2 or 5.12.3, whichever is relevant, is kept without any change of the earth connections. An interfering condition shall be produced at the input of the measuring system, for example by operation of an appropriate device producing a current representative of the waveform to be applied in the high-current test, and the output shall be recorded. The interference test shall be made at a suitable current with each type of current that is to be used or expected in or nearby the high-current test set-up, including multi-phase and chopped currents.

The interference ratio shall be determined as the maximum amplitude of the measured interference divided by the output of the measuring system when measuring the test current.

The interference ratio recorded should not exceed 1 %. Higher values can be accepted if it is shown that the uncertainty requirements are still met.

NOTE 1 A measuring system for short-time alternating current is considered an impulse measuring system with respect to the interference test.

NOTE 2 The influence of nearby current paths is considered in 5.8.

5.12.2 Current-converting shunts and current transformers with iron

During the interference test, the converting device of the measuring system shall be mounted in the current circuit, as under the normal high-current test conditions, and it shall carry the test current. The transmission system (measuring cable), disconnected from the converting device, shall be either short-circuited (coaxially in case of a coaxial cable) or terminated by its characteristic impedance at the input end (whichever best represents normal measurement conditions) and earthed in the same way as in normal measurements (see Figure 11).

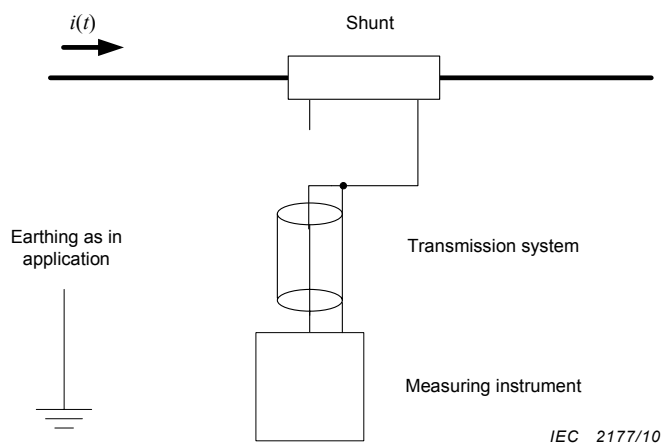


Figure 11 – Principle of interference test circuit

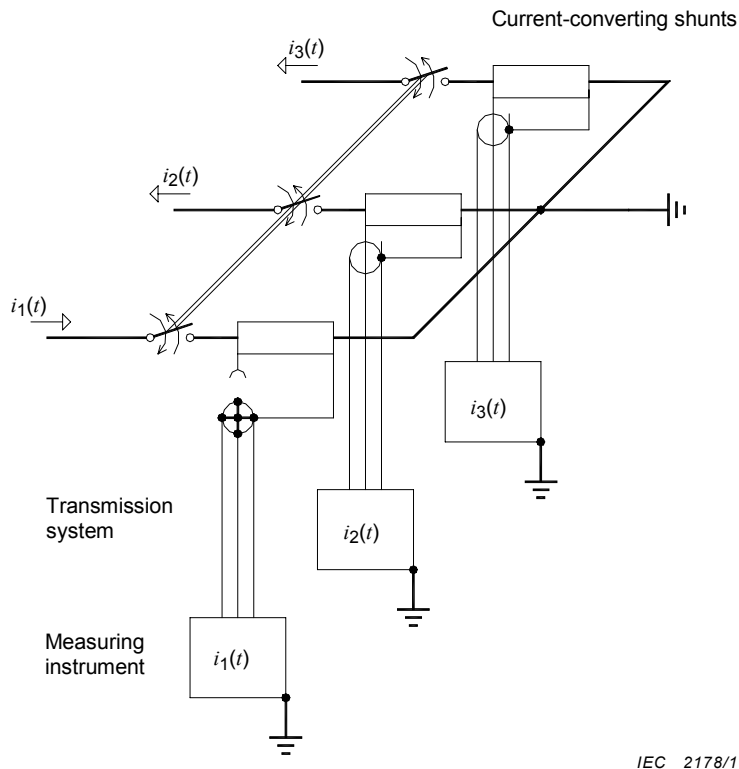


Figure 12 – Interference test on the measuring system $i_1(t)$ based on current-converting shunt or current transformer with iron in a typical 3-phase short-circuit set-up (example)

5.12.3 Inductive measuring systems without iron (Rogowski coils)

For measuring systems comprising inductive converting devices without iron, such as Rogowski coils, it is essential to prove sufficient immunity of the winding and internal elements to interference (proper coaxial design, shielding to avoid capacitive pick-up, etc.). Therefore, during interference tests, the transmission system (measuring cable) shall be connected to the output of the converting device in the same way as for normal measurements including the earthing, while the converting device itself is shifted from its normal concentric position, so that it remains perpendicular and close to, but not around the high-current carrying conductor (see Figure 13). The distance of the Rogowski-coil axis from the interfering current path should be relevant to the conditions of the laboratory; in the case of a nearby-earthed current path, it should be approximately equal to half the diameter of the Rogowski coil; in cases with a high-potential current path, the distance is adequately larger as required by the necessary clearance.

NOTE The interference test is also a test for the effect of nearby current paths. However, the clearance to the current conductor is small, and possibly not representative of the clearance sought in the test in 5.8. In such cases, a second test can be made for a more representative clearance.

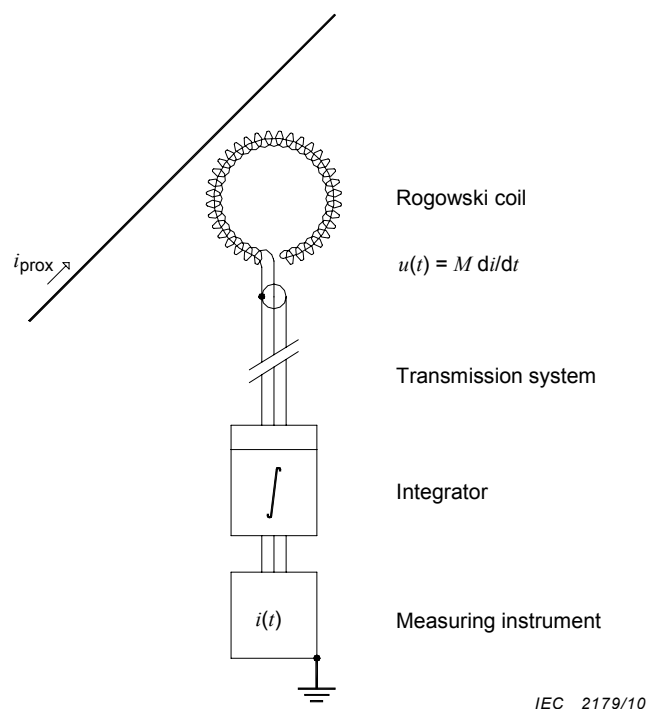


Figure 13 – Test circuit for interference test for inductive systems without iron

5.13 Withstand tests

5.13.1 Voltage withstand tests

Voltage withstand tests are applicable only to converting devices intended for operation at elevated potentials.

The converting device shall pass a dry withstand test performed with a voltage of the required frequency or shape at a level of 110 % of its rated voltage. For the procedures of withstand tests, see IEC 60060-1 or IEC 61180-1.

The withstand tests shall be performed at the polarity or polarities at which the system is to be used.

NOTE Design of any component of an approved measuring system should be such that it can withstand without any change of its characteristics, a possible disruptive discharge at the test object.

5.13.2 Current withstand tests

5.13.2.1 Short-time withstand current

When short-time withstand current test is required, the converting device shall be part of the measuring system and shall be subjected to a short-time withstand current at its rated current. The measuring system shall fulfil requirements on scale factor at this current and there shall be no evidence of damage to the converting device.

5.13.2.2 Peak withstand current

When peak withstand current test is required, the converting device shall be part of the measuring system and shall be subjected to a peak withstand current at its rated current. The measuring system shall fulfil requirements on scale factor at this current and there shall be no evidence of damage to the converting device.

6 Steady-state direct current

6.1 Application

Test applications are considered for measurements of high steady-state d.c. currents.

Procedures given below for measurement of test current are applicable to both calibration and measurement.

6.2 Terms and definitions

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

6.2.1

value of the d.c. test current

arithmetic mean (average) value of the test current

6.2.2

ripple

periodic deviation from the arithmetic mean value of the current. The amplitude of the ripple is defined as half the difference between the maximum and minimum values

6.2.3

ripple factor

ratio of the ripple amplitude to the arithmetic mean value of the current

6.3 Test current

6.3.1 Requirements

The test current shall be a direct current with not more than 7 % ripple factor, unless otherwise specified by the relevant technical committee. Further test requirements may be defined in apparatus specific standards.

6.3.2 Tolerances

Unless otherwise specified by the relevant technical committee, the tolerance requirement on the test current shall be ± 3 % throughout the test.

NOTE 1 It is emphasized that the tolerance constitutes the permitted difference between the specified value and that actually measured. This difference should be distinguished from the uncertainty of a measurement.

NOTE 2 The relevant technical committee may specify other tolerance limits, e.g. 0 % to +5 %.

6.4 Measurement of the test current

6.4.1 Requirements for an approved measuring system

The general requirement is to measure the value of the test current with an expanded uncertainty U_{mes} (with a coverage probability of 95 %) of not more than 3 % if not otherwise defined in the relevant apparatus standard.

6.4.2 Uncertainty contributions

For a d.c. current measuring system, the expanded uncertainty U_{mes} shall be evaluated according to 5.10.3 and, if necessary, according to Annex A and Annex B. The individual contributions to be considered are given in Table 1. The information given here is for guidance only; other contributions can be important in some cases and shall be considered as well.

6.4.3 Dynamic behaviour

There are no requirements on dynamic behaviour of a measuring system used to measure only the value of the d.c test current (arithmetic mean value). For ripple measurements see 6.5.3.

6.4.4 Calibrations and tests on an approved measuring system

Table 1 – Required tests for steady-state direct current

Type of test	Type test	Routine test	Performance test	Performance check
Scale factor of measuring system at the calibration			5.2 and 5.10.2	
Scale factor check				6.4.5
Extension of linearity		5.3 (if applicable)	5.3 (if applicable)	
Dynamic behaviour of measuring system				
Short-term stability		5.5		
Long-term stability	5.6		5.6 (if applicable)	
Ambient temperature effect	5.7			
Effect of nearby current paths on converting device	5.8 (if applicable)			
Software effect	5.9 (if applicable)			
Dry voltage withstand test on converting device		5.13.1 (if applicable)		
Current withstand test	–			
Scale factor of converting device		5.2		
Scale factor of transmission system other than a cable		5.2		
Scale factor of measuring instrument		5.2		
Responsibility	On components: manufacturer		On measuring system: user	
Recommended repetition rate	Once only (type and routine test)		Proposed annually, but at least every 5 years	According to stability, but at least annually

The compliance with type test requirements can be proved by tests on a device of the same design or sometimes be derived from manufacturer's data. Routine tests shall be performed on each device. See 4.6 for details and 4.4.2 for exceptions.

6.4.5 Performance check

6.4.5.1 General

The scale factor of an approved measuring system can be checked by one of the following methods.

6.4.5.2 Check of the scale factors of the components

The scale factor(s) of each component shall be checked using an internal, or an external, calibrator having an expanded uncertainty not exceeding 1 %. If the scale factors of individual components differ from their previous values by not more than 1 %, the previous assigned scale factor of the measuring system is taken as still valid. If any difference exceeds 1 %, then a new value of the assigned scale factor shall be determined in a performance test as described in 5.2.

NOTE DC measurements of the resistance of a current-converting shunt are in general sufficient for performance checks.

6.4.5.3 Check of the scale factor of the measuring system

A comparison shall be made with another approved measuring system with the procedure of 5.2.1. If the difference between the two measured values is not larger than 3 %, the previous assigned scale factor is taken as still valid. If it is larger, then the assigned scale factor shall be determined in a performance test (see 5.2).

6.5 Measurement of ripple amplitude

6.5.1 Requirements for an approved measuring system

The ripple amplitude shall be measured with an expanded uncertainty (with a coverage probability of 95 %) of not more than 10 % of the ripple amplitude or 1 % of the value of the d.c. test current, whichever is larger.

Separate measuring systems may be used to measure the value of the d.c. test current and of the ripple amplitude, or the same converting device may be used with two separate instruments.

6.5.2 Uncertainty contributions

For a measuring system for ripple current, the expanded uncertainty U_{mes} shall be evaluated according to 5.10.3 and, if necessary, Annex A and Annex B. The individual contributions to uncertainty to be considered are given in Table 2. The information given here is for guidance only; other contributions can be important in some cases and shall be considered as well.

6.5.3 Dynamic behaviour for ripple

6.5.3.1 Requirements

In general, it can be assumed that the requirement on uncertainty due to dynamic behaviour is fulfilled if the upper –3 dB limit frequency f_2 of the amplitude-frequency response of the measuring system is greater than 10 times the fundamental frequency f of the ripple and if the lower –3 dB limit frequency f_1 is smaller than 1/10 of the fundamental frequency f of the ripple.

6.5.3.2 Direct determination of the amplitude-frequency response

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 an appropriate range of frequencies.

6.5.4 Calibrations and tests on an approved ripple-current measuring system

The tests specified here shall be applied only to systems used to measure the ripple amplitude.

Table 2 – Required tests for ripple current

Type of test	Type test	Routine test	Performance test	Performance check
Scale factor of measuring system at the calibration			6.5.5 and 5.2	
Scale factor check				6.5.6
Dynamic behaviour for ripple			6.5.3	
Long-term stability	5.6			
Ambient temperature effect	5.7			
Responsibility	On components: manufacturer		On measuring system: user	
Recommended repetition rate	Once only (type and routine test)		Proposed annually, but at least every 5 years	According to stability, but at least annually

The compliance with type test requirements can be proved by tests on a device of the same design or sometimes be derived from manufacturer's data. Routine tests shall be performed on each device. See 4.6 for details and 4.4.2 for exceptions.

Other uncertainty contributions can be important in individual cases and the information given here is for guidance only.

6.5.5 Measurement of the scale factor at the ripple frequency

The scale factor of the measuring system shall be determined at the fundamental frequency f of the ripple, with an expanded uncertainty of not more than 3 %. This scale factor may be determined as the product of the scale factors of the components.

6.5.6 Performance check for ripple current measuring system

6.5.6.1 General

The scale factor of an approved measuring system can be checked by one of the following methods.

6.5.6.2 Check of the scale factors of the components

The scale factor(s) of each component shall be checked using an internal or an external calibrator having an expanded uncertainty not exceeding 3 %. If the scale factors of individual components differ from their previous values by not more than 3 %, the previous assigned scale factor of the measuring system is taken as still valid. If any difference exceeds 3 %, then a new value of the assigned scale factor shall be determined in a performance test (see 5.2).

NOTE DC measurements of the resistance of a current-converting shunt are in general sufficient for performance checks.

6.5.6.3 Check of the scale factor of the measuring system

A comparison shall be made with another approved measuring system according to the procedure of 5.2.1. If the difference between the two measured values is not larger than 10 %, the previous assigned scale factor is taken as still valid. If it is larger, then the assigned scale factor shall be determined in a performance test (see 5.2).

6.6 Test procedures

Test procedures are defined by the relevant technical committee or shall be based on agreement with the client.

7 Steady-state alternating current

7.1 Application

Test applications are considered for tests with steady-state alternating current.

Procedures given below for measurement of test current are applicable to both calibration and measurement.

7.2 Terms and definitions

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

7.2.1

value of the a.c. test current

true r.m.s. value of the test current

7.2.2

true r.m.s. value

value obtained from

$$I_{\text{rms}} = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt}$$

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 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 (see Clause G.4).

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

7.2.3

peak value

$\hat{I}_{\text{ss}}$

maximum instantaneous magnitude of the current

7.3 Test current

7.3.1 Requirements

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

The current wave shape shall approximate a sinusoid with the difference between the magnitudes of the positive and negative peak values being less than 2 %.

The results of a high-current test are thought to be unaffected by small deviations from a sinusoid if the total relative harmonic distortion (THD) does not exceed 5 % of the r.m.s. value of the fundamental component.

$$\text{THD} = \frac{\sqrt{\sum_{n=2}^{50} I_n^2}}{I_1}$$

where

I_1 is the r.m.s value of the fundamental component of the current;

I_n is the r.m.s value of the n^{th} harmonic component starting from $n = 2$.

For some test circuits in common use, greater deviations have to be accepted. For instance, the test object, especially if it has non-linear impedance characteristics, may cause a considerable deviation from a sinusoid.

7.3.2 Tolerances

If not otherwise specified by the relevant technical committee, the tolerance requirement on the test current shall be ± 3 % throughout the test.

NOTE 1 It is emphasized that the tolerance constitutes the permitted difference between the test-specified value and the value actually measured. This difference should be distinguished from the uncertainty of a measurement.

NOTE 2 The relevant technical committee may specify other tolerance limits, e.g. 0 % to +5 %.

7.4 Measurement of the test current

7.4.1 Requirements for an approved measuring system

The general requirement is to measure the value of the test current with an expanded uncertainty U_{mes} (with a coverage probability of 95 %) not exceeding 3 % if not otherwise defined in the relevant apparatus standard.

7.4.2 Uncertainty contributions

For an a.c. current measuring system, the expanded uncertainty shall be evaluated according to 5.10.3 and, if necessary, Annex A and Annex B. The individual uncertainty contributions to be considered are given in Table 3. The information given here is for guidance only; other contributions can be important in some cases and shall be considered as well.

7.4.3 Dynamic behaviour

7.4.3.1 Requirements

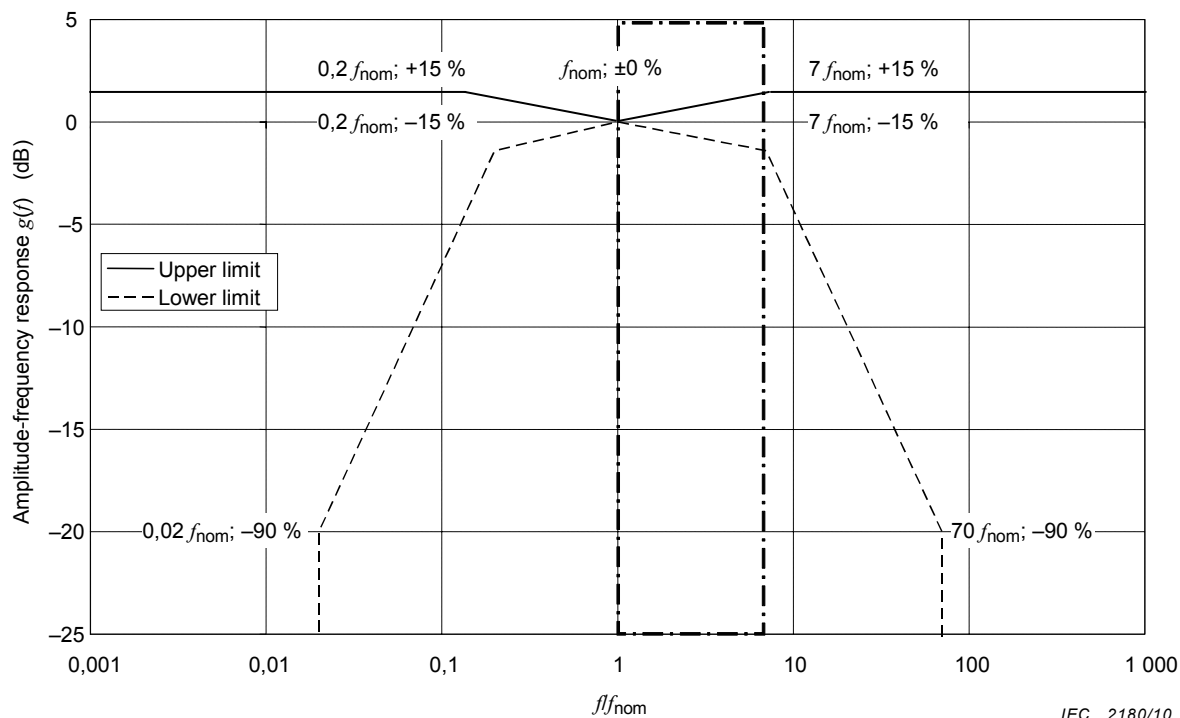
The amplitude-frequency response of a measuring system intended for operation at one single fundamental frequency f_{nom} shall appear (in the frequency range depicted in Figure 14 by dash-and-dot lines) within the upper and lower limits indicated by solid and dashed lines. The limits have been derived from the uncertainty requirements. The number pairs in the diagram give the normalized frequencies (seen in the logarithmic scale) and the corresponding permitted deviations from the ideal response at the corner points of the limit lines. The performance from f_{nom} to $7 f_{\text{nom}}$ shall be proven either by test or by circuit analysis. The amplitude-frequency response limits outside this range are given for information only. The uncertainty contribution u_{dyn} is taken as zero.

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

NOTE 1 The restrictions given on dynamic behaviour are intended to ensure that amplitude errors of the frequency components other than the fundamental will not contribute significantly to the measured value of the test

current. Measuring systems complying with these requirements are furthermore considered to have a frequency response suitable for measurements of the total harmonic distortion (THD) on the test current.

NOTE 2 The frequency response shown outside the range indicated by dash-and-dot lines, although not required, does represent good practice.



IEC 2180/10

Figure 14 – Acceptable normalized amplitude-frequency response of an a.c. measuring system intended for a single fundamental frequency f_{nom}

A measuring system can also be approved for a range of fundamental frequencies. The scale factor (and consequently the amplitude-frequency response) of a measuring system shall in such case be constant within 1 % from the lowest fundamental frequency $f_{\text{nom}1}$ up to the highest fundamental frequency $f_{\text{nom}2}$. The response outside the interval $f_{\text{nom}1}$ to $f_{\text{nom}2}$, but inside the interval $f_{\text{nom}1}$ to $7 f_{\text{nom}2}$ (i.e. in the frequency range up to the vertical dash-and-dot lines in Figure 15) shall appear within the upper and lower limits indicated by solid and dashed lines. The limits have been derived from the uncertainty requirements. The number pairs in the diagram give the normalized frequencies (seen in the logarithmic scale) and the corresponding permitted deviations from the ideal response at the corner points of the limit lines. The performance from $f_{\text{nom}1}$ to $7 f_{\text{nom}2}$ shall be proven by tests or by circuit analysis. The amplitude-frequency response limits outside this range are given for information only.

The uncertainty contribution u_{dyn} due to the variation of scale factor over the frequency range $f_{\text{nom}1}$ to $f_{\text{nom}2}$ shall be evaluated according to 5.4.

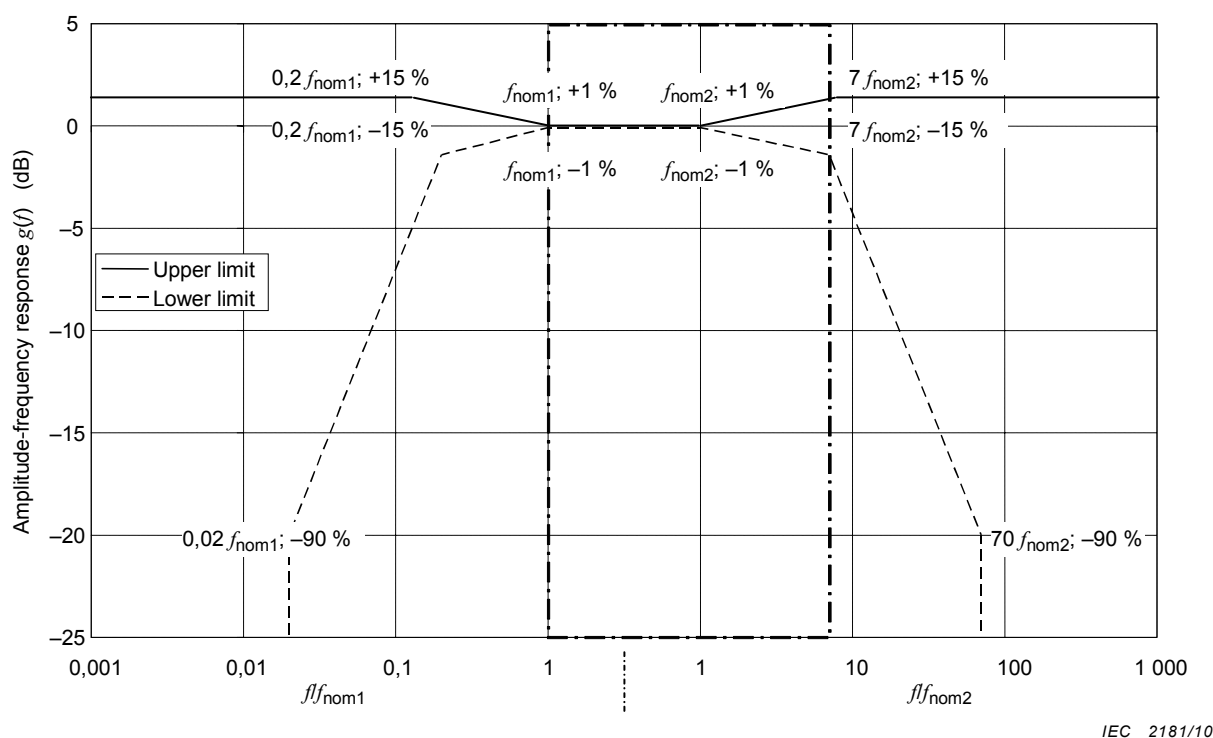


Figure 15 – Acceptable normalized amplitude-frequency response of an a.c. measuring system intended for a range of fundamental frequencies f_{nom1} to f_{nom2}

7.4.3.2 Direct determination of the amplitude-frequency response

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 an appropriate range of frequencies.

7.4.4 Calibrations and tests on an approved measuring system

Table 3 – Required tests for steady-state alternating current

Type of test	Type test	Routine test	Performance test	Performance check
Scale factor of measuring system at the calibration			5.2	
Scale factor check				7.4.5
Extension of linearity		5.3 (if applicable)	5.3 (f applicable)	
Dynamic behaviour of the measuring system		7.4.3 and 5.4		
Short-term stability of converting device		5.5		
Long-term stability	5.6		5.6 (if applicable)	
Ambient temperature effect	5.7			
Effect of nearby current paths on the converting device	5.8 (if applicable)			
Software effect	5.9 (if applicable)			
Interference test			5.12	

Type of test	Type test	Routine test	Performance test	Performance check
Dry voltage withstand test on converting device		5.13.1 (if applicable)		
Current withstand test		–		
Scale factor of converting device		5.2		
Scale factor of transmission system other than a cable		5.2		
Scale factor of measuring instrument		5.2		
Responsibility	On components: manufacturer		On measuring system: user	
Recommended repetition rate	Once only (type and routine test)		According to stability, but at least every 5 years	According to stability, but at least annually

The compliance with requirements of the type tests can be proved by tests on a device of the same design or be derived from manufacturer's data. Routine tests shall be performed on each device. See 4.6 for details and 4.4.2 for exceptions.

7.4.5 Performance check

7.4.5.1 General

The scale factor of an approved measuring system can be checked by one of the following methods.

7.4.5.2 Check of the scale factors of the components

The scale factor(s) of each component can be checked using an internal or an external calibrator having an expanded uncertainty not exceeding 1 %. If the scale factors of individual components differ from their previous values by not more than 1 %, the previous assigned scale factor of the measuring system is taken as still valid. If any difference exceeds 1 %, then a new value of the assigned scale factor shall be determined in a performance test (see 5.2).

NOTE DC measurements of the resistance of a current-converting shunt are in general sufficient for performance checks.

7.4.5.3 Check of the scale factor of the measuring system

A comparison is made with another approved measuring system following the procedure of 5.2.1. If the difference between the two measured values is not larger than 3 %, the previous assigned scale factor is taken as still valid. If it is larger, then the assigned scale factor shall be determined in a performance test (see 5.2).

7.5 Test procedures

Test procedures are defined by the relevant technical committee or shall be based on agreement with the client.

8 Short-time direct current

8.1 Application

Test applications are considered for high-power testing with direct current. The short-time direct current is a d.c. current with limited duration (e.g. up to 1 s) as encountered for instance in high-power (short-circuit) d.c. tests. Due to current interruptions during the measurements of characteristic quantities, there may be transient phenomena, possibly

significant for the interference susceptibility of current and voltage measuring systems of a high-power laboratory.

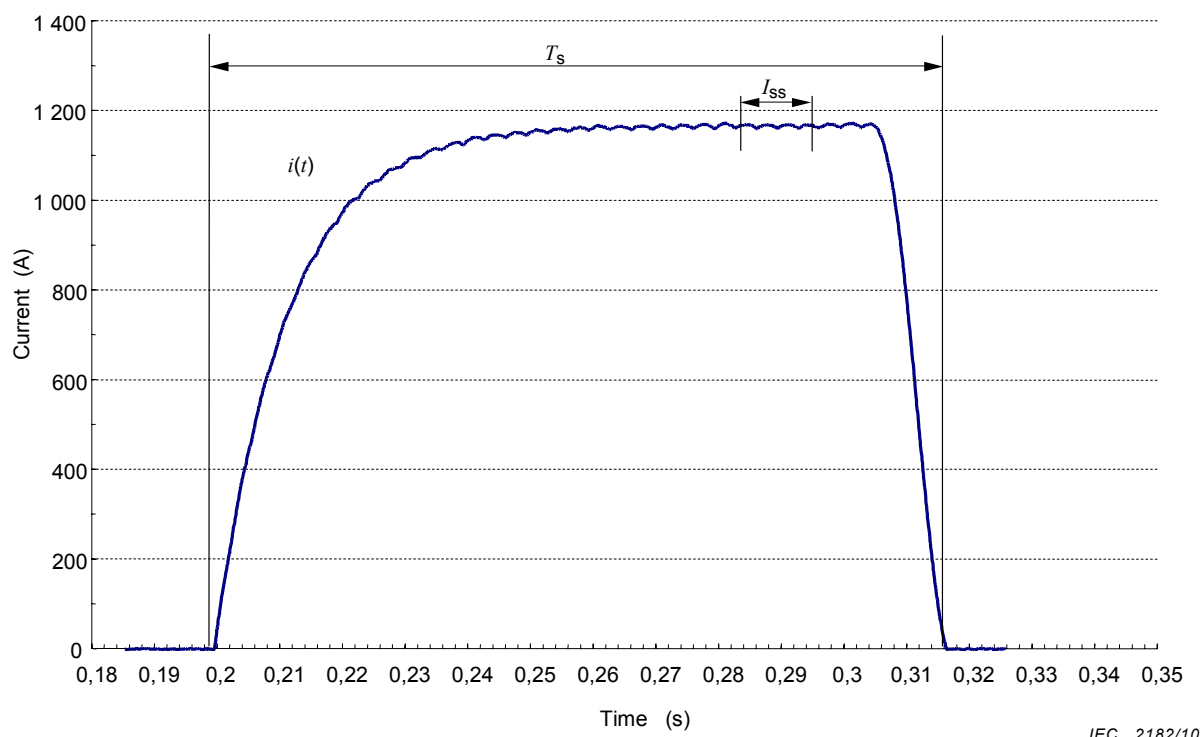


Figure 16 – Example of short-time direct current

Procedures given below for measurement of test current are applicable to both calibration and measurement.

8.2 Terms and definitions

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

8.2.1

peak value

$\hat{i}_{ss}$
maximum instantaneous magnitude of the current

8.2.2

steady-state d.c. current

I_{ss}
arithmetic mean (average) value of current at steady state, i.e. when the current is above 90 % of the peak value

8.2.3

time constant of the circuit

τ
ratio of inductance over resistance of the circuit

NOTE 1 The time constant is the time in which an exponentially rising current reaches $(1 - e^{-1})$ of its steady-state value. The time constant measured is not necessarily equal to the time constant calculated from resistance and inductance values.

NOTE 2 Inductance of the circuit can change due to saturation effects in ferromagnetic materials and due to the fact that the circuit may be different at switching on and at switching off.