



DPC: 22/30396253 DC

BSI Group Headquarters

389 Chiswick High Road London W4 4AL

Tel: +44 (0)20 8996 9000

Fax: +44 (0)20 8996 7400

www.bsigroup.com

Date: 31 January 2022

Origin: International

Latest date for receipt of comments: 15 March 2022

Project No. 2019/01508

Responsible committee: PEL/42 Testing techniques for high voltages and currents

Interested committees:

Title: Draft BS EN 60060-2 Ed.4.0 High-voltage test techniques. Part 2: Measuring systems.

Please notify the secretary if you are aware of any keywords that might assist in classifying or identifying the standard or if the content of this standard

- i) has any issues related to 3rd party IPR, patent or copyright
- ii) affects other national standard(s)
- iii) requires additional national guidance or information

WARNING: THIS IS A DRAFT AND MUST NOT BE REGARDED OR USED AS A BRITISH STANDARD. THIS DRAFT IS NOT CURRENT BEYOND 15 March 2022

This draft is issued to allow comments from interested parties; all comments will be given consideration prior to publication. No acknowledgement will normally be sent. **See overleaf for information on the submission of comments.**

No copying is allowed, in any form, without prior written permission from BSI except as permitted under the Copyright, Designs and Patent Act 1988 or for circulation within a nominating organization for briefing purposes. Electronic circulation is limited to dissemination by e-mail within such an organization by committee members.

Further copies of this draft may be purchased from BSI Shop <http://shop.bsigroup.com> or from BSI Customer Services, Tel: +44(0) 20 8996 9001 or email cservices@bsigroup.com. British, International and foreign standards are also available from BSI Customer Services.

Information on the co-operating organizations represented on the committees referenced above may be obtained from <https://standardsdevelopment.bsigroup.com/>.

Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
- All comments should be submitted online at <https://standardsdevelopment.bsigroup.com/>. You will need to register in order to comment.

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
------------------	------------------------

1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



42/401/CD

COMMITTEE DRAFT (CD)

PROJECT NUMBER: IEC 60060-2 ED4	
DATE OF CIRCULATION: 2022-01-21	CLOSING DATE FOR COMMENTS: 2022-04-15
SUPERSEDES DOCUMENTS: 42/364/RR	

IEC TC 42 : HIGH-VOLTAGE AND HIGH-CURRENT TEST TECHNIQUES	
SECRETARIAT: Canada	SECRETARY: Mr Howard G. Sedding
OF INTEREST TO THE FOLLOWING COMMITTEES: TC 14,TC 17,TC 36,TC 37,TC 122	PROPOSED HORIZONTAL STANDARD: ☒ Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.
FUNCTIONS CONCERNED: ☐ EMC ☐ ENVIRONMENT ☐ QUALITY ASSURANCE ☐ SAFETY	

This document is still under study and subject to change. It should not be used for reference purposes.

Recipients of this document are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

TITLE:
High-voltage test techniques - Part 2: Measuring systems

NOTE FROM TC/SC OFFICERS:

CONTENTS

1		
2	Introduction relevant for CD only.....	6
3	FOREWORD.....	7
4	1 Scope.....	9
5	2 Normative references	9
6	3 Terms and definitions	9
7	3.1 Measuring systems	10
8	3.2 Components of a measuring system	10
9	3.3 Scale factors.....	11
10	3.4 Rated values.....	12
11	3.5 Definitions related to dynamic behaviour.....	12
12	3.6 Definitions related to uncertainty.....	14
13	3.7 Definitions related to tests on measuring systems.....	15
14	4 Procedures for qualification and use of measuring systems	16
15	4.1 General principles.....	16
16	4.2 Schedule of performance tests.....	17
17	4.3 Schedule of performance checks	17
18	4.4 Requirements for the record of performance	17
19	4.4.1 Contents of the record of performance.....	17
20	4.4.2 Exceptions.....	18
21	4.5 Operating conditions	18
22	4.6 Uncertainty	18
23	5 Tests and test requirements for an approved measuring system and its	
24	components.....	19
25	5.1 General requirements	19
26	5.2 Calibration – Determination of the scale factor.....	20
27	5.2.1 Calibration of measuring systems by comparison with a reference	
28	measuring system (preferred method)	20
29	5.2.2 Determination of the scale factor of a measuring system from the scale	
30	factors of its components (alternative method).....	23
31	5.3 Linearity test in addition to comparison over the limited voltage range	24
32	5.3.1 Application.....	24
33	5.3.2 Alternative methods in order of suitability	25
34	5.4 Dynamic behaviour	26
35	5.4.1 General	26
36	5.4.2 Determination of the amplitude/frequency response of AC measuring	
37	systems	26
38	5.4.3 Reference method for impulse voltage measuring systems	26
39	5.5 Short-term stability.....	26
40	5.6 Long-term stability	27
41	5.7 Ambient temperature effect.....	27
42	5.8 Proximity effect.....	28
43	5.9 Software effect.....	28
44	5.10 Uncertainty calculation of the scale factor	28
45	5.10.1 General	28
46	5.10.2 Uncertainty of the calibration	29
47	5.10.3 Uncertainty of measurement using an approved measuring system	30

48	5.11	Uncertainty calculation of time parameter measurement (impulse voltages only)	30
49			
50	5.11.1	General	30
51	5.11.2	Uncertainty of the time parameter calibration	31
52	5.11.3	Uncertainty of time parameter measurement using an approved measuring system	32
53			
54	5.12	Interference test (transmission system and instrument for impulse voltage measurements)	33
55			
56	5.13	Withstand tests of converting device	33
57	6	Measurement of direct voltage	34
58	6.1	Requirements for an approved measuring system	34
59	6.1.1	General	34
60	6.1.2	Uncertainty contributions	34
61	6.1.3	Requirement on converting device	34
62	6.1.4	Dynamic behaviour for measuring voltage changes	34
63	6.2	Tests on an approved measuring system	35
64	6.3	Performance check	36
65	6.3.1	General	36
66	6.3.2	Comparison with an approved measuring system	36
67	6.3.3	Check of the scale factors of the components	36
68	6.4	Measurement of ripple amplitude	36
69	6.4.1	Requirements	36
70	6.4.2	Uncertainty contributions	36
71	6.4.3	Calibrations and tests on an approved ripple voltage measuring system	36
72	6.4.4	Measurement of the scale factor at the ripple frequency	37
73	6.4.5	Dynamic behaviour by amplitude/frequency response	37
74	6.4.6	Performance check for ripple measuring system	37
75	7	Measurement of alternating voltage	37
76	7.1	Requirements for an approved measuring system	37
77	7.1.1	General	37
78	7.1.2	Uncertainty contributions	37
79	7.1.3	Dynamic behaviour	38
80	7.2	Tests on an approved measuring system	40
81	7.3	Dynamic behaviour test	40
82	7.4	Performance check	40
83	7.4.1	General	40
84	7.4.2	Comparison with an approved measuring system	40
85	7.4.3	Check of the scale factors of the components	40
86	8	Measurement of lightning impulse voltage	41
87	8.1	Requirements for an approved measuring system	41
88	8.1.1	General	41
89	8.1.2	Uncertainty contributions	41
90	8.1.3	Requirement on measuring instrument	42
91	8.1.4	Dynamic behaviour	42
92	8.1.5	Connection to the test object	42
93	8.2	Tests on an approved measuring system	42
94	8.3	Performance test on measuring systems	43
95	8.3.1	Reference method (preferred)	43

96	8.3.2	Alternative method supplemented by a measurement of the step response according to Annex C	43
97			
98	8.4	Dynamic behaviour test.....	44
99	8.4.1	Comparison with a reference measuring system (preferred)	44
100	8.4.2	Alternative method based on step response parameters (Annex C)	44
101	8.5	Performance check	44
102	8.5.1	Comparison with an approved measuring system	44
103	8.5.2	Check of the scale factors of the components.....	45
104	8.5.3	Dynamic behaviour check by reference record.....	45
105	9	Measurement of switching impulse voltage	45
106	9.1	Requirements for an approved measuring system.....	45
107	9.1.1	General	45
108	9.1.2	Uncertainty contribution.....	45
109	9.1.3	Requirements for the measuring instrument.....	45
110	9.1.4	Dynamic behaviour	45
111	9.1.5	Connection to the test object	45
112	9.2	Tests on an approved measuring system	46
113	9.3	Performance test on measuring systems	46
114	9.3.1	Reference method (preferred).....	46
115	9.3.2	Alternative methods supplemented by a step response measurement.....	46
116	9.4	Dynamic behaviour test by comparison	46
117	9.5	Performance check	46
118	9.5.1	Scale factor check by comparison with an approved measuring system	46
119	9.5.2	Check of the scale factors of the components.....	47
120	9.5.3	Dynamic behaviour check by reference record.....	47
121	10	Measuring systems for combined tests	48
122	11	Measuring systems for composite tests	48
123	12	Reference measuring systems.....	49
124	12.1	Requirements for reference measuring systems.....	49
125	12.1.1	Direct voltage	49
126	12.1.2	Alternating voltage.....	49
127	12.1.3	Full and chopped lightning and switching impulse voltages	49
128	12.2	Calibration of a reference measuring system	49
129	12.2.1	General	49
130	12.2.2	Reference method: Comparative measurement.....	49
131	12.2.3	Alternative method for impulse voltages: Measurement of scale factor and evaluation of step response parameters.....	49
132			
133	12.3	Interval between successive calibrations of reference measuring systems	49
134	12.4	Use of reference measuring systems	50
135	Annex A (informative)	Uncertainty of measurement.....	51
136	Annex B (informative)	Examples for the calculation of measuring uncertainties in high-voltage measurements.....	59
137			
138	Annex C (informative)	Step response measurements	68
139	Annex D (informative)	Convolution method for the determination of dynamic behaviour from step response measurements	73
140			
141	Bibliography		76
142			
143	Figure 1 – Amplitude-frequency response with examples for limit frequencies (f_1 ; f_2)		13

144	Figure 2 – Calibration by comparison over the full voltage range	21
145	Figure 3 – Uncertainty contributions of the calibration (example with minimum of 5	
146	voltage levels)	22
147	Figure 4 – Calibration by comparison over a limited voltage range, with an additional	
148	linearity test.....	23
149	Figure 5 – Linearity test of the measuring system with a linear device in the extended	
150	voltage range.....	25
151	Figure 6 – Short-circuiting arrangement for the interference test. The divider output	
152	can be left open or shorted, and the measurement cable input is shorted and grounded	
153	using a coaxial shorting plug.....	33
154	Figure 7 – Shaded area for acceptable normalised amplitude-frequency responses of	
155	measuring systems intended for single fundamental frequencies f_{nom} (to be tested in	
156	the range $(1 \dots 7) f_{\text{nom}}$).....	39
157	Figure 8 – Shaded area for acceptable normalised amplitude-frequency responses of	
158	measuring systems intended for a range of fundamental frequencies f_{nom1} to f_{nom2}	
159	(to be tested in the range f_{nom1} to $7 f_{\text{nom2}}$).....	39
160	Figure A.1 –Normal probability distribution $p(x)$	58
161	Figure A.2 –Rectangular probability distribution $p(x)$	58
162	Figure B.1 –Comparison between the system under test, X, and the reference system,	
163	N 67	
164	Figure B.2 – Front time deviation $\Delta T_{1,j}$ of system X, related to the reference system N,	
165	and their mean ΔT_{1m} in the range of $T_1 = 0,8 \mu\text{s} \dots 1,6 \mu\text{s}$	67
166	Figure C.1 –Definitions of response parameters.....	71
167	Figure C.2 –A unit-step response $g(t)$ showing an initial distortion of initial distortion	
168	time T_0	72
169	Figure C.3 –Suitable circuits for step response measurement	72
170		
171	Table 1 – Tests required for an approved direct voltage measuring system.....	35
172	Table 2 – Required tests for uncertainty contributions in ripple measurement	37
173	Table 3 – Tests required for an approved alternating voltage measuring system.....	40
174	Table 4 – Tests required for an approved lightning impulse voltage measuring system	42
175	Table 5 – Tests required for a switching impulse voltage measuring system	48
176	Table 6 – Recommended response parameters for impulse voltage reference	
177	measuring systems	50
178	Table A.1 – Coverage factor k for effective degrees of freedom ν_{eff} ($p = 95 \%$).....	56
179	Table A.2 – Schematic of an uncertainty budget	57
180	Table B.1 – Result of the comparison measurement at a single voltage level g	60
181	Table B.2 – Summary of results for $h = 5$ voltage levels ($V_{X\text{max}} = 500 \text{ kV}$).....	61
182	Table B.3 –Uncertainty budget of the assigned scale factor F_X	62
183	Table B.4 –Uncertainty budget of the assigned scale factor F	64
184	Table B.5 –Calibration result for front time T_1 and deviations	65
185	Table B.6 –Uncertainty budget of the front time deviation $\Delta T_{1\text{cal}}$	66

186

187

188

Introduction relevant for CD only

189
190
191
192

A sweeping review has been made on usage of “may” incorrectly being used as indication of possibility: The review is based on ISO/IEC Directives Part 2: 2018, which in Table 5 states “May” signifies permission expressed by the document, whereas “can” refers to the ability of a user of the document or to a possibility open to him/her.

193
194
195

All internal clause references etc. in the document have been changed from pure text into active Hyperlinks. This makes it possible to look up references by simply clicking the reference. This feature can be carried over into pdf versions.

196
197

A review of definitions has been made in order to align, where applicable, to IEC 60050 as published in electropedia.org

198
199

The requirement that “Note to entry” (in definitions) shall always be numbered even if only one, has been implemented

200

INTERNATIONAL ELECTROTECHNICAL COMMISSION

HIGH-VOLTAGE TEST TECHNIQUES –

Part 2: Measuring systems

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 60060-2 has been prepared by IEC technical committee 42: High-voltage test techniques. It is an International Standard.

This fourth edition of IEC 60060-2 cancels and replaces the third edition, published in 2010, and constitutes a technical revision.

The significant technical changes with respect to the previous edition are as follows:

- a) The general layout and text were updated and improved to make the standard easier to use.
- b) The standard was revised to align it with IEC 60060-1 Edition 4.
- c) The treatment of measurement uncertainty estimation has been expanded.
- d) This document is now applicable to measuring systems used in testing at all standard insulation levels specified in IEC 60071-1.
- e) The measurement uncertainty requirement for the front time of the standard lightning impulse voltage has been changed from 10% to 15%, for testing at all standard insulation levels specified in IEC 60071-1.

- f) Parameter “time-to-peak” of the switching impulse defined in IEC 60060-1 Ed.3 has now been replaced by “front time” in IEC 60060-1 Ed.4. Necessary changes have been made in this document to accommodate this change in IEC 60060-1.
- g) Annex B.1 has been significantly revised to align more closely with the provisions of Clause 5, including using the same nomenclature.

The text of this International Standard is based on the following documents:

Draft	Report on voting
XX/XX/FDIS	XX/XX/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.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

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

HIGH-VOLTAGE TEST TECHNIQUES –

Part 2: Measuring systems

1 Scope

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

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

This standard:

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

2 Normative references

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

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

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

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

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

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

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

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

3 Terms and definitions

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

3.1 Measuring systems

3.1.1

measuring system

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

NOTE 1 to entry A measuring system usually comprises the following components:

– a converting device with the leads required for connecting this device to the test object or into the circuit and the connections to earth;

– a transmission system connecting the output terminals of the converting device to the measuring instruments with its attenuating, terminating and adapting impedances or networks;

– a measuring instrument together with any connection to the power supply. Measuring systems which comprise only some of the above components or which are based on non-conventional principles are acceptable if they meet the uncertainty requirements specified in this document.

NOTE 2 to entry The environment in which a measuring system functions, its clearances to live and earthed structures and the presence of electric or magnetic fields

significantly affect the measurement result and its uncertainty.

3.1.2

record of performance

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

NOTE 1 to entry This evidence includes the results of the initial performance test and the schedule and results of each subsequent performance test and performance check.

3.1.3

approved measuring system

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

3.1.4

reference measuring system

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

NOTE 1 to entry A reference measuring system (maintained according to the requirements of this standard) may be used as an approved measuring system but the converse is not true.

3.2 Components of a measuring system

3.2.1

converting device

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

3.2.2

voltage divider

device comprising resistors, inductors, capacitors, transformer(s) or a combination of these components such that, between two points of the device, a desired fraction of the voltage applied to the device as a whole can be obtained

[SOURCE: IEC 60050-312:2001, 312-02-32]

3.2.3**voltage transformer**

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

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

3.2.4**voltage converting impedance**

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

3.2.5**electric-field probe**

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

NOTE 1 to entry An electric-field probe can be used to measure the waveform of the voltage producing the field provided that the measurement is not affected by corona or space charges.

3.2.6**transmission system**

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

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

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

3.2.7**measuring instrument**

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

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

3.3 Scale factors**3.3.1****scale factor of a measuring system**

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

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

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

3.3.2**scale factor of a converting device**

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

NOTE 1 to entry The scale factor of a converting device can be dimensionless (for example, the ratio of a divider) or can have dimensions (for example, the impedance of a voltage converting impedance).

3.3.3**scale factor of a transmission system**

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

3.3.4**scale factor of a measuring instrument**

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

3.3.5**assigned scale factor** F

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

NOTE 1 to entry A measuring system can have more than one assigned scale factor; for example, it can have several ranges and/or nominal epochs, each with a different scale factor.

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

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

3.4.2**rated operating voltage**

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

NOTE 1 to entry The rated operating voltage can be higher than the upper limit of the assigned measurement range.

3.4.3**assigned measurement range**

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

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

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

3.4.4**assigned operating time**

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

3.4.5**assigned rate of application**

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

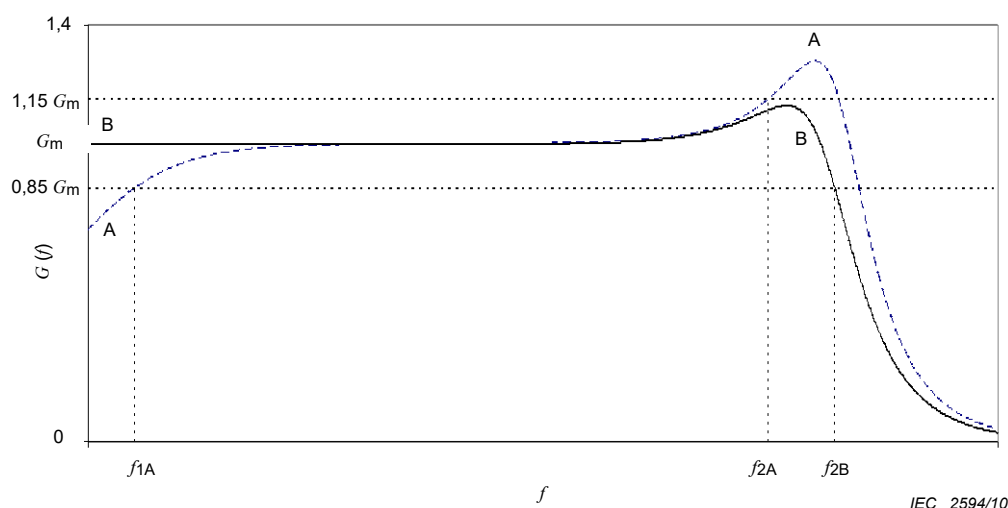
NOTE 1 to entry The rate is usually given as applications per minute and the time interval in minutes or hours.

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

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

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

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



NOTE 1 to entry Lower and upper limit frequencies are shown on curve A. Curve B shows a constant response down to direct voltage.

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

3.5.3 step response,

$G(t)$
output of a measuring system as a function of time when the input is a step function

NOTE 1 to entry For more information on step response and step-response parameters see Annex C.

3.5.4 nominal epoch (impulse voltage only),

τ_{N1}
range of values between the minimum ($t_{\min}$) and the maximum ($t_{\max}$) of the relevant time parameter of impulse voltage for which the measuring system is to be approved

NOTE 1 to entry The relevant time parameter is:

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

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

- for full and tail-chopped lightning impulses with an assigned scale factor F_1 over a nominal epoch τ_{N1} from $T_1 = 0,8 \mu\text{s}$ to $T_1 = 1,8 \mu\text{s}$, even though the tolerance is $0,84 \mu\text{s}$ to $1,56 \mu\text{s}$;
- or front-chopped lightning impulses with an assigned scale factor F_2 over a nominal epoch τ_{N2} from $T_c = 0,5 \mu\text{s}$ to $T_c = 0,9 \mu\text{s}$;
- for switching impulses with an assigned scale factor F_3 over a nominal epoch τ_{N3} from $T_1 = 100 \mu\text{s}$ to $T_1 = 340 \mu\text{s}$.

NOTE 3 to entry In Note 2, time to peak has been replaced by front time. Numerical values have been adjusted accordingly.

NOTE 4 to entry "Front-chopped impulse" is used to designate a chopped impulse with a time to chopping that falls in the range $0,5 \mu\text{s}$ to the time of the extreme value. This is to be distinguished from a "tail-chopped impulse" which has a time to chopping greater than the time of the extreme value.

3.5.5**limit frequencies,** f_1 and f_2

lower and upper limits of the range within which the amplitude-frequency response is nearly constant (Figure 1)

NOTE 1 to entry 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.

3.6 Definitions related to uncertainty**3.6.1****tolerance**

permitted difference between the measured value and the specified value

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

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

3.6.2**error**

measured quantity value minus a reference quantity value

[SOURCE: ISO/IEC Guide 99:2007 2.16]

3.6.3**uncertainty (of measurement)**

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

[SOURCE: IEC 60050-311:2001, 311-01-02, modified – Notes 1-3 have been replaced.]

NOTE 1 to entry Uncertainty is positive and given without sign.

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

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

3.6.4**standard uncertainty,** u

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

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

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

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

3.6.5**combined standard uncertainty,** u_c

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

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

3.6.6**expanded uncertainty,***U*

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

[SOURCE: ISO/IEC Guide 98-3:2008 2.3.5, modified – Notes 1 and 2 have been replaced.]

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

NOTE 2 to entry The true, but unknown test-voltage value can lie outside the limits given by the uncertainty because the coverage probability is < 100 %.

3.6.7**coverage factor,***k*

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

[SOURCE: ISO/IEC Guide 98-3, 2008 GUM 2.3.6, modified – Note 1 has been modified.]

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

3.6.8**type A evaluation**

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

3.6.9**type B evaluation**

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

3.6.10**traceability**

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

Note 1 to entry The concept is often expressed by the adjective traceable.

Note 2 to entry The unbroken chain of comparisons is called a traceability chain.

Note 3 to entry In French, the way in which the relationship with the standards is determined is called “raccordement aux étalons”.

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

3.6.11**National Metrology Institute**

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

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

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

[SOURCE: IEC 60050-311:2001, 311-01-09, modified – Notes 1 and 2 replaced by Note 1.]

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

3.7.2

type test

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

[SOURCE: IEC 60050-151:2001, 151-16-16, modified – Note 1 has been added.]

NOTE 1 to entry 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

[SOURCE: IEC 60050-151:2001, 151-16-17, modified – Note 1 has been added.]

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

3.7.4

performance test

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

3.7.5

performance check

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

3.7.6

reference record (impulse measurements only)

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

NOTE 1 to entry Reference records are often called “fingerprints” and used as characteristics of dynamic behaviour. In impulse voltage measurements they are usually taken from step response measurements (Annex C).

4 Procedures for qualification and use of measuring systems

4.1 General principles

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

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

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

The assigned scale factor is determined in the performance test by calibration. The user shall apply tests given in this standard to qualify their measuring system(s). Any calibration shall be traceable to national and/or international standards.

In all cases, the test results shall be kept in the record of performance.

NOTE Calibrations performed by a National Metrology Institute, or by a laboratory accredited for the quantities calibrated and reported under the accreditation, are traceable to national and/or international standards.

4.2 Schedule of performance tests

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

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

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

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

4.3 Schedule of performance checks

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

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

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

4.4 Requirements for the record of performance

4.4.1 Contents of the record of performance

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

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

- General description of the measuring system.
- Results of type and routine tests on the converting device, transmission system(s) and measuring instrument(s) and, if performed, on the measuring system.
- Results of subsequent performance tests on the measuring system.
- Results of subsequent performance checks on the measuring system.

NOTE The general description of the measuring system usually comprises main data and capabilities of the measuring system, such as the rated operating voltage, waveform(s), range(s) of clearances, operating time, or maximum rate of voltage applications. For many measuring systems, information on the transmission system as well

as high-voltage and ground-return arrangements are important. If required, a description is also given of the components of the measuring system, including for example the type and identification of the measuring instrument.

4.4.2 Exceptions

For measuring systems or components manufactured before the date of issue of the second edition of IEC60060-2, i.e. 1994, the required evidence can be unavailable for some part(s) of the type and routine test. Then performance tests and checks made in accordance with earlier versions of this standard are deemed adequate provided they show the scale factor is stable. The results of these previous checks shall also be entered in the record of performance.

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

4.5 Operating conditions

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

NOTE 1 It is often necessary to investigate parasitic coupling.

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

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

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

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

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

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

4.6 Uncertainty

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

Procedures for evaluating uncertainties have been selected from ISO/IEC Guide 98-3 and presented in this standard. These simplified procedures of clause 5 are considered sufficient for the instrumentation and measurement arrangements commonly used in high-voltage testing; however, users may select other appropriate procedures from ISO/IEC Guide 98-3, some of which are outlined in Annex A and Annex B.

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

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

According to the ISO/IEC Guide 98-3, the uncertainty of a measurement is determined by combining the uncertainty contributions of Type A and Type B (see 5.10, 5.11 and Annex A). The contributions are obtained from measurement results, from manufacturers' handbooks, calibration certificates and from estimating reasonable values of the influence quantities during the measurement. For example, influence quantities mentioned in clause 5 include temperature and proximity effects. Others, like limited resolution of the measuring instrument, may be added if necessary.

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

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

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

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

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

5.1 General requirements

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

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

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

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

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

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

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

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

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

5.2 Calibration – Determination of the scale factor

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

5.2.1.1 Comparison measurement

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

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

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

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

The relative standard deviation s_g of F_g is given by:

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

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

$$u_g = \frac{s_g}{\sqrt{n}} \quad (3)$$

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

NOTE 2 For measurement of direct and alternating voltages, independent readings should be obtained either by applying the test voltage and taking n readings or by applying the test voltage n times and taking a reading each time. For impulses, n impulses are applied.

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

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

5.2.1.2 Comparison over the full assigned measurement range

This test includes both the determination of the assigned scale factor and the determination of linearity. The scale factor determination shall be made by direct comparison with a reference measuring system at the minimum and maximum levels of the assigned measurement range and on at least three approximately equally spaced intermediate levels (Figure 2). The assigned scale factor F is taken as the mean value of all scale factors F_g recorded at h voltage levels:

$$F = \frac{1}{h} \sum_{g=1}^h F_g \quad \text{for } h \geq 5 \quad (4)$$

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

$$u_A = \max_{g=1}^h u_g \quad (5)$$

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

$$u_{B0} = \frac{1}{\sqrt{3}} \max_{g=1}^h \left| \frac{F_g}{F} - 1 \right| \quad (6)$$

NOTE 1 A rounded value F_o can be taken as the assigned scale factor if the difference between F_o and F is introduced as an uncertainty contribution of Type B in the estimate of the expanded uncertainty of the scale factor F_o .

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

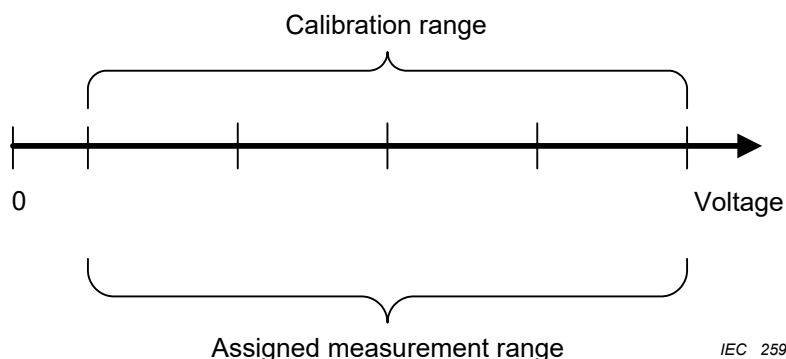
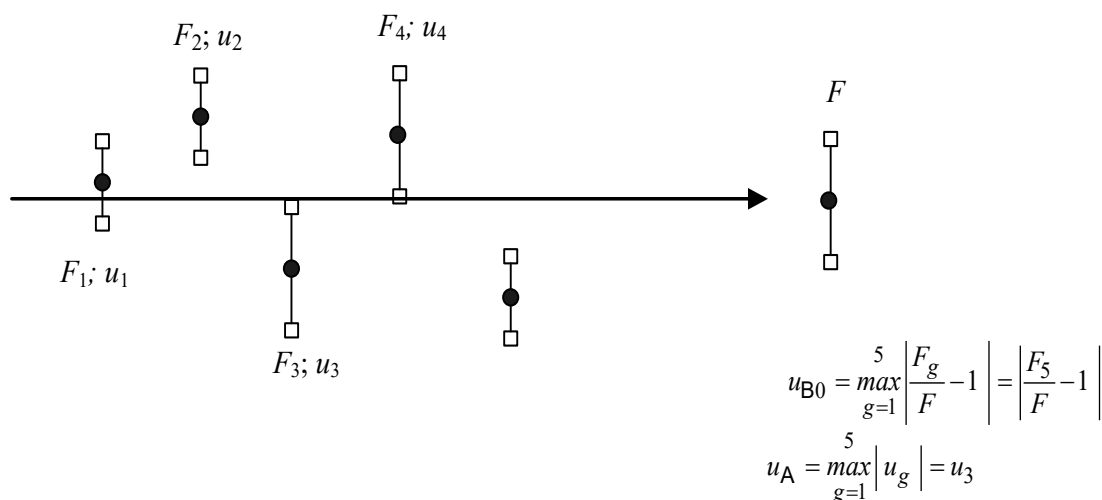


Figure 2 – Calibration by comparison over the full voltage range



IEC 2596/10

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

5.2.1.3 Comparison over limited voltage range

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

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

The comparison with the reference measuring system is carried out at $a \geq 2$ voltage levels, where the highest voltage level is equal to the maximum voltage of the reference measuring system. The necessary linearity test is carried out at $b \geq 2$ voltage levels, with one level equal to the maximum level of comparison (see 5.3). The voltage levels shall further be chosen such that they comprise at least the minimum and the maximum levels of the assigned measurement range, and that $a + b \geq 6$

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

$$F = \frac{1}{a} \sum_{g=1}^a F_g \quad (7)$$

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

$$u_A = \max_{g=1}^a u_g \quad (8)$$

and a non-linearity contribution for the calibration values