BS EN 61083-2:2013

BSI Standards Publication

Instruments and software used for measurement in high-voltage and high-current tests

Part 2: Requirements for software for tests with impulse voltages and currents

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National foreword

This British Standard is the UK implementation of EN 61083-2:2013. It is identical to IEC 61083-2:2013. It supersedes BS EN 61083-2:1997 which is withdrawn.

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

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

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

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

Appareils et logiciels utilisés pour les mesures pendant les essais à haute tension et haute intensité -
Partie 2: Exigences pour le logiciel pour les essais avec des tensions et des courants de choc
(CEI 61083-2:2013)

Messgeräte und Software für Messungen bei Hochspannungs- und Hochstrom-Prüfungen -
Teil 2: Anforderungen an die Software bei Prüfungen mit Stoßspannungen und -strömen
(IEC 61083-2:2013)

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CENELEC

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

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Foreword

The text of document 42/318/FDIS, future edition 2 of IEC 61083-2, prepared by IEC/TC 42 "High-voltage testing techniques" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 61083-2:2013.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2014-01-24
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2016-04-24

This document supersedes EN 61083-2:1997.

EN 61083-2:2013 includes the following significant technical changes with respect to EN 61083-2:1997:

a) the test data generator software has been updated;

b) the number of reference impulse waveforms included in the test data generator has been significantly increased;

c) all reference values have been recalculated according to new definitions in EN 60060-1 and EN 62475;

d) methods for estimating the uncertainty of parameter evaluation has been introduced and are in line with the procedure introduced in EN 60060-2.

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

Endorsement notice

The text of the International Standard IEC 61083-2:2013 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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

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

Publication	Year	Title	EN/HD	Year
IEC 60060-1	2010	High-voltage test techniques - Part 1: General definitions and test requirements	EN 60060-1	2010
IEC 60060-2	-	High-voltage test techniques - Part 2: Measuring systems	EN 60060-2	-
IEC 60060-3	2006	High voltage test techniques - Part 3: Definitions and requirements for on-site testing	EN 60060-3 + corr. October	2006 2006
IEC 61083-1	2001	Instruments and software used for measurement in high-voltage impulse tests - Part 1: Requirements for instruments	EN 61083-1	2001
IEC 62475	2010	High-current test techniques - Definitions and requirements for test currents and measuring systems	EN 62475	2010
ISO/IEC Guide 98-3	-	Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)	-	-

CONTENTS

INTRODUCTION

IEC 61083-1 specifies the test requirements for digital recorders. Digital recorders, like analogue oscilloscopes, are susceptible to changes in their characteristics. However, the more stringent testing (than is practical for analogue oscilloscopes) specified for digital recorders for standard impulse voltage and current measurement has led to the accuracy of digital recorders being more clearly demonstrated.

This part of IEC 61083 applies to software used to process digital records to provide the values of the relevant impulse parameters. The raw data are retained for comparison with the processed data. However, since the parameters of the test impulse (including the test value) are to be read from the processed data, it is important to establish tests to ensure that the reading of parameters is adequately performed. The problem is how to ensure this, while permitting users to develop a wide range of techniques.

This problem is further complicated by the different needs of various users, ranging from single-purpose test laboratories, for example those of a cable manufacturer who may only test a few objects which are capacitive, to large high-voltage test/research laboratories, which may perform tests on a very wide range of objects, which have a correspondingly wide range of impedances.

The approach taken in this part of IEC 61083 is to provide, from a test data generator software, waveforms (and ranges of their parameters) which a user can employ to verify that a procedure gives values within the specified ranges. To reduce the amount of testing required, the waveforms are divided into groups, and the user needs only to check those groups that are appropriate for the high-voltage and/or high-current tests to be performed in his/her laboratory.

New definitions for lightning impulse parameters and switching impulse time-to-peak evaluation are introduced in IEC 60060-1. The changes in these definitions have lead to significant changes in some of the reference values in this standard. The number of impulse records in the test data generator has been increased to cover a wider range of impulse shapes seen in on-site testing.

INSTRUMENTS AND SOFTWARE USED FOR MEASUREMENT IN HIGH-VOLTAGE AND HIGH-CURRENT TESTS –

Part 2: Requirements for software for tests with impulse voltages and currents

1 Scope and object

This part of IEC 61083 is applicable to software used for evaluation of impulse parameters from recorded impulse voltages and currents. It provides test waveforms and reference values for the software required to meet the measuring uncertainties and procedures specified in IEC 60060-1, IEC 60060-2, IEC 60060-3 and IEC 62475.

Hardware with built-in firmware that cannot accept external numerical input data is not covered by this standard.

The object of this standard is to

- establish the tests which are necessary to show that the performance of the software complies with the requirements of the relevant IEC standards;
- define the terms specifically related to digital processing;
- specify reference values and the acceptance limits for the reference impulses;
- specify the requirements for the record of performance;
- define the methods to assess the contribution of software to the measurement uncertainty.

2 Normative references

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

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

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

IEC 60060-3:2006, *High-voltage test techniques – Part 3: Definitions and requirements for on–site testing*

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

IEC 62475:2010, *High-current test techniques – Definitions and requirements for test currents and measuring systems*

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

3 Terms and definitions

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

NOTE References to definitions of relevant impulse parameters, as shown in the relevant clauses of IEC 60060-1:2010, IEC 60060-3:2006 and IEC 62475:2010 are listed in Tables 1 and 2.

3.1
raw data
original record of sampled and quantized information obtained when a digital recorder converts an analogue signal into a digital form, possibly corrected for offset or multiplied by a scale factor

3.2
processed data
data obtained by any processing (other than correction for offset and/or multiplying by a scale factor) of the raw data

[SOURCE: IEC 61083-1:2001, definition 1.3.3.5, modified – "constant scale factor" replaced by "scale factor"; NOTE not retained]

3.3
internal noise level
standard deviation of the samples recorded when a constant voltage is applied to the input of the digital recorder

3.4
reference impulse
waveform supplied by the test data generator (TDG)

3.5
sampling rate
sampling frequency
number of samples of a signal taken per unit time

[SOURCE: IEC 60050-704:1993, definition 704-23-03]

3.6
resolution (in digital processing)
measure of the accuracy with which a digital system can distinguish between the magnitudes of two samples of a signal

Note 1 to entry: Resolution is usually expressed as the number of bits necessary to express in binary form the maximum number of possible different signal levels which can be recognized by the system.

[SOURCE: IEC 60050-807:1998, definition 807-01-02]

3.7
test data generator
TDG
computer program that generates digital reference data files, representative of synthesized and recorded impulse waveforms

Table 1 – References to impulse voltage parameter definitions

	IEC 60060-1:2010								IEC 60060-3:2006				
Impulse group/ Evaluation algorithm	U_t Value of the test voltage	T_p Time to peak	β Relative overshoot magnitude	T_1 Front time	T_c Time to chopping	T_2 Time to half-value	U_e Extreme value	Average rate of rise	U_t Value of the test voltage	T_p Time to peak	T_1 Front time	T_2 Time to half-value	f Oscillation frequency
Full lightning impulse voltage (LI)	7.1.15, Annex B		7.1.17, Annex B	7.1.18, Annex B		7.1.22, Annex B	7.1.9	7.1.20	(7.2.4)		(7.2.5)	(7.2.7)	
Front chopped lightning impulse voltage (LIC-A1, LIC-M1 to LIC-M3)	7.1.15, 7.2.6				7.1.27		7.1.9	7.1.20					
Tail chopped lightning impulse voltage (LIC-M4 to LIC-M5)	7.1.15, Annex B		7.1.17, Annex B	7.1.18, Annex B	7.1.27, Annex B		7.1.9	7.1.20					
Switching impulse voltage (SI)	8.1.2	8.1.3				8.1.5			(8.2.3)	(8.2.4)		(8.2.5)	
Oscillating lightning impulse voltage (OLI)									7.2.4		7.2.5	7.2.7	8.2.6
Oscillating switching impulse voltage (OSI)									8.2.3	8.2.4		8.2.5	8.2.6

NOTE Some definitions of parameters (shown in parenthesis) in IEC 60060-3:2006 are different from those in IEC 60060-1:2010. For IEC 60060-3, reference values are only provided for oscillating lightning and oscillating switching impulse parameters.

Table 2 – References to impulse current parameter definitions

	IEC 62475:2010				
Impulse group / Evaluation algorithm	I_p Peak value of current	T_1 Front time	T_2 Time to half-value	T_d Duration	T_t Total duration
Exponential impulse current (IC-M1 to IC-M7, IC-M9)	10.2.3	10.2.4	10.2.6		
Rectangular impulse current (IC-M8)	10.2.3			10.2.7	10.2.8

4 Test data generator (TDG)

4.1 Principle

The test data generator (TDG) is a computer program that generates digital reference data files, representative of both synthetic and recorded impulse waveforms. These reference impulses shall be processed by the software under test, and the parameters evaluated from the processed data shall fall within the acceptance limits given in Annex A. In this way the performance of the software can be verified.

The TDG is an integral part of this standard and is provided as compiled code for a computer running Windows[1] operating system. TDG is a menu-driven program with a built-in help file.

4.2 Data format

The reference data files generated by the TDG simulate the raw data, which would be obtained from the digital recorder of the user. The reference data files are written in a two column ASCII format. Their respective values are given in terms of seconds and in volts or amperes. If the data format or range expected by the software under test does not correspond to the format or range provided by the TDG, a suitable conversion program shall be used.

NOTE Software which cannot read TDG reference impulses (either in the direct or converted form) is not covered by this standard.

5 Values and acceptance limits for the parameters of the reference impulses

A round-robin test has been performed, in which a number of laboratories independently calculated values for parameters of the reference impulses. Statistical mean values from this round-robin test were taken as the reference values of the parameters listed in Tables 1 and 2.

Requirements for acceptance limits have been set based on the needs of the application.

These parameters of the reference impulses are given in Tables A.1 to A.6.

6 Software testing

6.1 General

The TDG is designed to provide data files simulating digital recorder output for the purpose of testing software used to determine the impulse parameters as defined in IEC 60060-1,

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1 Windows is the trade name of a product supplied by Microsoft. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

IEC 60060-3 and IEC 62745. The references to relevant clauses of these standards are listed in Tables 1 and 2.

The impulses in the TDG are grouped in six groups, according to the impulse type:

LI: full lightning impulse;

LIC: front or tail chopped lightning impulse;

SI: switching impulse;

IC: impulse current;

OLI: oscillating lightning impulse;

OSI: oscillating switching impulse.

6.2 Performance test

The performance test for an algorithm is executed by evaluating all reference impulses in the selected group, for example, group LI.

The performance test shall be performed for each version of the evaluation algorithm and for a set of sampling rates, resolutions and noise levels relevant for the application.

Evidence that the evaluation algorithm actually used during tests is the same as the version that has been verified according to this standard (and for which results are entered in the record of performance) shall be entered into the record of performance.

The performance test can be performed either for one, several or all evaluation algorithm(s) referred to in Tables 1 and 2.

The settings of the TDG shall be chosen to match the settings of the digital recorder (or recorders) that is to be used with the software. These include selection of sampling rate, resolution and internal noise level. The resulting TDG record simulates the output of this digital recorder when recording the selected reference impulse. The reference impulses are shown in Annex A.

Each reference impulse for the evaluation algorithm selected by the user is generated by the TDG and represents input to the software instead of an actual output of the digital recorder. The values of the parameters determined by the software under test are compared to the acceptance limits given in Annex A. The software under test is judged to have passed the test for a group if the values of the parameters calculated by the software under test are within the specified acceptance limits for all impulses in that group.

6.3 Uncertainty contribution for IEC 60060-2 and/or IEC 62475

The calculation of the uncertainty of high-voltage measurement according to IEC 60060-2 and high-current measurement according to IEC 62475 includes a contribution due to the uncertainty of the applied software. This is derived from the acceptance limits of the considered parameters (Annex A). By a simplified procedure, the standard uncertainty contribution of the software for a certain parameter may be taken as a type B estimate from the maximum value of the half-width of the acceptance limit of the relevant waveforms (i = 1…n) shown in Annex A:

$$u_{B7} = \frac{1}{\sqrt{3}} \max_{i=1}^{n} \left(\text{half - width of the acceptance limit} \right).$$

These standard uncertainty contributions are listed in Table 3.

NOTE 1 For the terms and definitions see IEC 60060-2:2010 or IEC 62475:2010, especially 3.6, 4.6, 5.9 and Annex A in either standard. The symbol u_{B7} follows the numbering used in both those standards (5.2.1.3 to 5.9).

NOTE 2 The acceptance range of the measured parameter according to this standard is the reference value plus/minus its acceptance limit given in Annex A.

Table 3 – Standard uncertainty contributions of software to the overall uncertainty according to the simplified procedure

Impulse group/ Evaluation algorithm	U_t, U_p, I_p %	T_1, T_p, T_d %	T_2, T_t %	β' %
LI	0,058	1,2	0,58	0,58
LIC	0,58	1,2	1,2	0,58
SI	0,29	2,9	1,2	
IC	0,58	1,2	1,2	
OLI	0,29	1,2	1,2	
OSI	0,29	1,2	1,2	

When software is used for the evaluation of different types of waveforms (see Tables 1 and 2), a different standard uncertainty may be applied for each type.

If the estimated standard uncertainty becomes too large, the method of Annex B, or any method in line with ISO/IEC Guide 98-3 can be used.

7 Record of performance of the software

A list of evaluation algorithms for which software is validated shall be specified in the record of performance of the measuring system (see IEC 61083-1 and IEC 60060-2).

The record of performance shall include:

– version number of the TDG and its relevant settings;

– name of the tested software, its version number and release date;

– the type(s) of the algorithm(s) for which the tests were performed;

– list of parameters for which the software was tested and passed.

Annex A
(normative)

Reference values and acceptance limits for the parameters of TDG impulses

Table A.1 – Reference values and their acceptance limits for full lightning impulses (LI) *(1 of 6)*

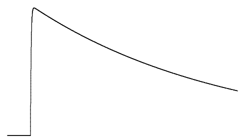
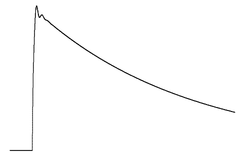
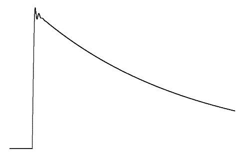
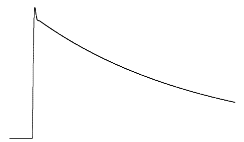
Designation in test data generator	Reference impulse	Description	U_t		T_1		T_2		β'	
			Reference value kV	**Acceptance limit** % of U_t	**Reference value** µs	**Acceptance limit** % of T_1	**Reference value** µs	**Acceptance limit** % of T_2	**Reference value** %	**Acceptance limit** %, abs.
LI-A1		Superposition of two ideal exponential functions	1 049,6	± 0,10	0,840	± 2	60,16	± 1,0	0,0	± 1,0
LI-A2		Slow oscillations	1 037,6	± 0,10	1,693	± 2	47,48	± 1,0	5,1	± 1,0
LI-A3		Fast oscillations	1 000,2	± 0,10	1,117	± 2	48,15	± 1,0	4,6	± 1,0
LI-A4		Overshoot 8 %, f = 500 kHz	856,01	± 0,10	0,841	± 2	47,80	± 1,0	7,9	± 1,0

Table A.1 *(2 of 6)*

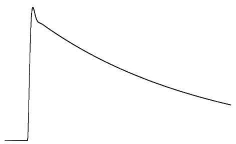
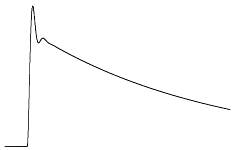
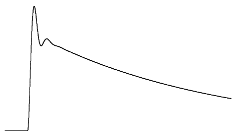
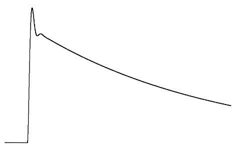
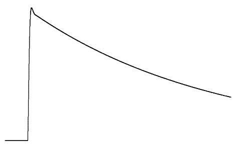
Designation in test data generator	Reference impulse	Description	U_t Reference value kV	U_t Acceptance limit % of U_t	T_1 Reference value µs	T_1 Acceptance limit % of T_1	T_2 Reference value µs	T_2 Acceptance limit % of T_2	β' Reference value %	β' Acceptance limit %, abs.
LI-A5		Overshoot 8 %, *f* = 200 kHz	71,972	± 0,10	1,711	± 2	47,71	± 1,0	7,7	± 1,0
LI-A6		Overshoot 18 %, *f* = 200 kHz	100,17	± 0,10	1,762	± 2	41,58	± 1,0	17,7	± 1,0
LI-A7		Overshoot 20 %, *f* = 200 kHz	104,35	± 0,10	2,122	± 2	38,36	± 1,0	20,1	± 1,0
LI-A8		Overshoot 15 %, *f* = 250 kHz	96,012	± 0,10	1,503	± 2	44,92	± 1,0	14,8	± 1,0
LI-A9		Overshoot 4 %, *f* = 300 kHz	55,928	± 0,10	1,215	± 2	55,74	± 1,0	4,0	± 1,0

Table A.1 *(3 of 6)*

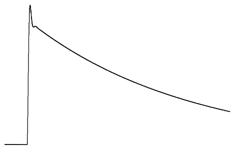
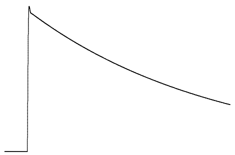
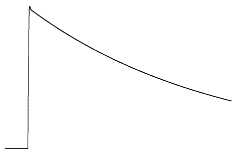
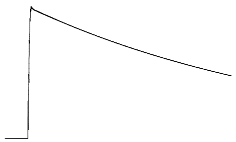
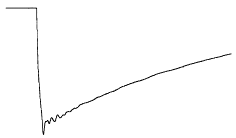
Designation in test data generator	Reference impulse	Description	U_t Reference value kV	U_t Acceptance limit % of U_t	T_1 Reference value µs	T_1 Acceptance limit % of T_1	T_2 Reference value µs	T_2 Acceptance limit % of T_2	β' Reference value %	β' Acceptance limit %, abs.
LI-A10		Overshoot 12 %, f = 400 kHz	81,929	± 0,10	0,924	± 2	42,66	± 1,0	12,0	± 1,0
LI-A11		Overshoot 4 %, f =800 kHz	86,597	± 0,10	0,578	± 2	56,37	± 1,0	4,1	± 1,0
LI-A12		Overshoot 2 %, f = 900 kHz	85,584	± 0,10	0,587	± 2	57,36	± 1,0	2,3	± 1,0
LI-M1		Front oscillations	952,09	± 0,10	1,123	± 2	85,60	± 1,0	2,1	± 1,0
LI-M2		Long duration overshoot	-1 041,7	± 0,10	3,356	± 2	61,25	± 1,0	9,2	± 1,0

Table A.1 *(4 of 6)*

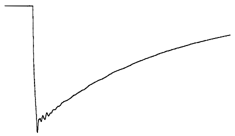
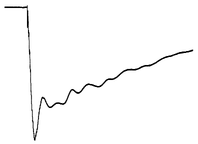
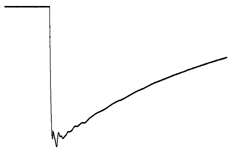
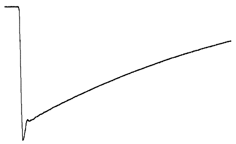
Designation in test data generator	Reference impulse	Description	U_t Reference value kV	U_t Acceptance limit % of U_t	T_1 Reference value µs	T_1 Acceptance limit % of T_1	T_2 Reference value µs	T_2 Acceptance limit % of T_2	β' Reference value %	β' Acceptance limit %, abs.
LI-M3		Short duration overshoot	-1 026,5	± 0,10	2,150	± 2	41,75	± 1,0	9,2	± 1,0
LI-M4		Oscillations, transformer testing	-267,14	± 0,10	0,987	± 2	56,22	± 1,0	4,8	± 1,0
LI-M5		Oscillations, transformer testing	-55,003	± 0,10	2,746	± 2	42,11	± 1,0	18,7	± 1,0
LI-M6		Oscillations, transformer testing	-166,87	± 0,10	1,356	± 2	54,74	± 1,0	3,8	± 1,0
LI-M7		Oscillations, transformer testing	-1 272,3	± 0,10	1,482	± 2	50,03	± 1,0	11,2	± 1,0

Table A.1 *(5 of 6)*

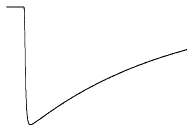
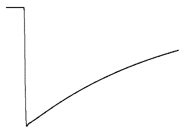
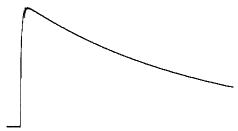
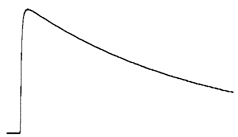
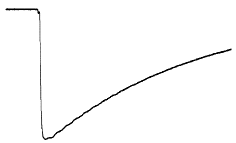
Designation in test data generator	Reference impulse	Description	U_t Reference value kV	U_t Acceptance limit % of U_t	T_1 Reference value µs	T_1 Acceptance limit % of T_1	T_2 Reference value µs	T_2 Acceptance limit % of T_2	β' Reference value %	β' Acceptance limit %, abs.
LI-M8		Long front, smooth	-99,732	± 0,10	1,515	± 2	49,36	± 1,0	-0,5	± 1,0
LI-M9		Short front, some overshoot	-100,04	± 0,10	0,828	± 2	46,65	± 1,0	1,4	± 1,0
LI-M10		Heavy front oscillations	100,26	± 0,10	1,666	± 2	60,85	± 1,0	0,0	± 1,0
LI-M11		Heavy front oscillations	299,32	± 0,10	1,661	± 2	60,95	± 1,0	-0,5	± 1,0
LI-M12		Changing offset level, oscillations at peak	-4,319 3	± 0,10	1,292	± 2	52,27	± 1,0	-1,8	± 1,0

Table A.1 *(6 of 6)*

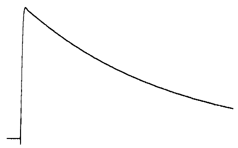
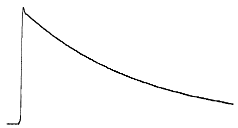
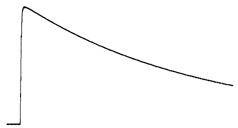
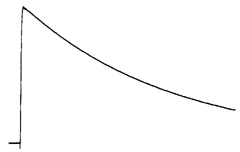
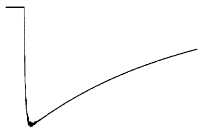
Designation in test data generator	Reference impulse	Description	U_t Reference value kV	U_t Acceptance limit % of U_t	T_1 Reference value µs	T_1 Acceptance limit % of T_1	T_2 Reference value µs	T_2 Acceptance limit % of T_2	β' Reference value %	β' Acceptance limit %, abs.
LI-M13		Oscillations after onset	39,460	± 0,10	1,537	± 2	46,94	± 1,0	1,8	± 1,0
LI-M14		Oscillations after onset, and overshoot	48,549	± 0,10	0,933	± 2	37,48	± 1,0	4,3	± 1,0
LI-M15		Oscillations after onset, and overshoot	497,97	± 0,10	1,017	± 2	59,19	± 1,0	-0,1	± 1,0
LI-M16		Front oscillations	369,21	± 0,10	0,920	± 2	47,53	± 1,0	0,8	± 1,0
LI-M17		Heavy oscillations at front and peak	-99,346	± 0,10	1,775	± 2	53,31	± 1,0	1,3	± 1,0

Table A.2 – Reference values and their acceptance limits for chopped lightning impulses (LIC) *(1 of 2)*

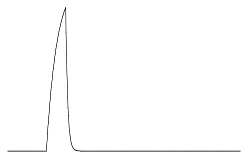
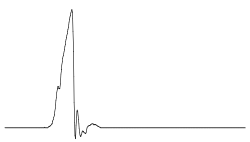
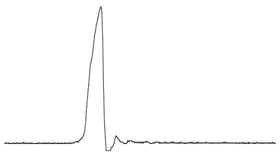
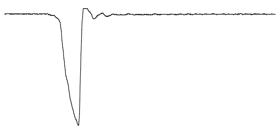
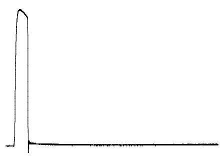
Designation in test data generator	Reference impulse	Description	U_p, U_t		T_1		T_c		β'	
			Reference value kV	Acceptance limit % of U_p or U_t	Reference value µs	Acceptance limit % of T_1	Reference value µs	Acceptance limit % of T_c	Reference value %	Acceptance limit %, abs.
LIC-A1		Front chopped lighting impulse	872,2	± 1,0			0,543	± 2		
LIC-M1		Front oscillations, chopped	850,0	± 1,0			0,569	± 2		
LIC-M2		Front chopped	0,289 0	± 1,0			0,514	± 2		
LIC-M3		Front chopped	-0,303 6	± 1,0			0,568	± 2		
LIC-M4		Tail chopped	0,147 8	± 1,0	1,305	± 2	6,00	± 2	-0,2	± 1

Table A.2 *(2 of 2)*

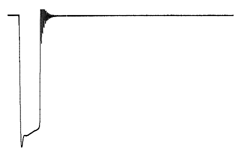
Designation in test data generator	Reference impulse	Description	U_p, U_t		T_1		T_c		β'	
			Reference value kV	Acceptance limit % of U_p or U_t	Reference value µs	Acceptance limit % of T_1	Reference value µs	Acceptance limit % of T_c	Reference value %	Acceptance limit %, abs.
LIC-M5		Tail chopped	-389,9	± 1,0	0,857	± 2	9,24	± 2	6,8	± 1

Table A.3 – Reference values and their acceptance limits for switching impulses (SI)

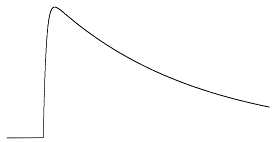
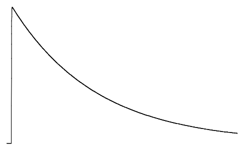
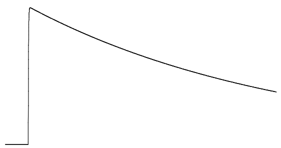
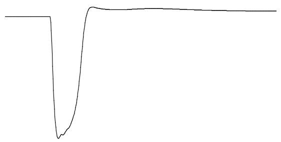
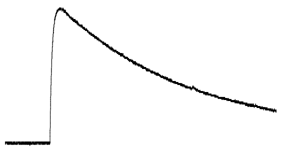
Designation in test data generator	Reference impulse	Description	U_p		T_p		T_2	
			Reference value kV	**Acceptance limit** % of U_p	**Reference value** µs	**Acceptance limit** % of T_p	**Reference value** µs	**Acceptance limit** % of T_2
SI-A1		Switching impulse, 250/2 500	950,28	± 0,10	250,7	± 2	2 512	± 2
SI-A2		Switching impulse, 20/1 300	0,987 67	± 0,10	19,89	± 2	1 321	± 2
SI-A3		Switching impulse, 43/4 000	99,219	± 0,10	43,08	± 2	3 987	± 2
SI-M1		Measured during transformer test	–0,590 7	± 0,5	186,6	± 5	655	± 2
SI-M2		Measured switching impulse	3,680	± 0,5	218	± 5	2 407	± 2

Table A.4 – Reference values and their acceptance limits for current impulses (IC) *(1 of 2)*

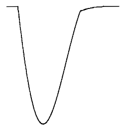
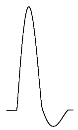
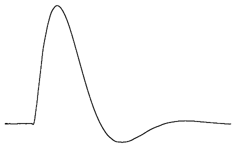
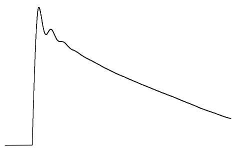
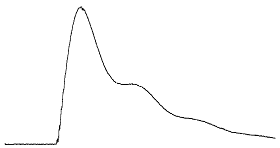
Designation in test data generator	Reference impulse	Description	I_p		T_1, T_d		T_2, T_t	
			Reference value kA	Acceptance limit % of I_p	Reference value µs	Acceptance limit % of T_1 or T_d	Reference value µs	Acceptance limit % of T_2 or T_t
IC-M1		Impulse current, 8/20	–10,001	± 0,2	8,82	± 2	21,31	± 2
IC-M2		Impulse current, 4/10	100,42	± 0,2	4,237	± 2	9,13	± 2
IC-M3		Impulse current, 8/20	64,28	± 0,2	7,75	± 2	20,53	± 2
IC-M4		Impulse current, 10/350	100,00	± 0,2	23,47	± 2	398,9	± 2
IC-M5		Impulse current Ah-component	150,01	± 0,2	17,09	± 2	48,34	± 2

Table A.4 *(2 of 2)*

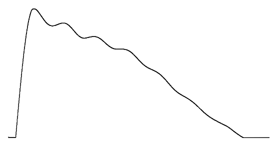
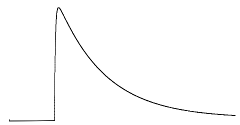
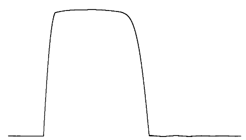
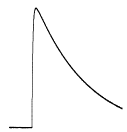
Designation in test data generator	Reference impulse	Description	I_p Reference value kA	I_p Acceptance limit % of I_p	T_1, T_d Reference value µs	T_1, T_d Acceptance limit % of T_1 or T_d	T_2, T_t Reference value µs	T_2, T_t Acceptance limit % of T_2 or T_t
IC-M6		Impulse current 30/300	12,464	± 0,2	27,91	± 2	274,0	± 2
IC-M7		Impulse current 1/15	20,495	± 0,2	1,009	± 2	17,65	± 2
IC-M8		Rectangular impulse current	0,229 4	± 1,0	2 051	± 2	2 678	± 2
IC-M9		Impulse current 1/15	10,156	± 0,2	0,968	± 2	17,68	± 2

Table A.5 – Reference values and their acceptance limits for oscillating lightning impulses (OLI)

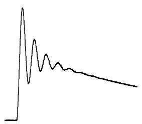
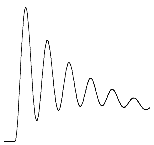
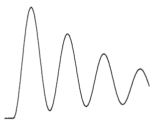
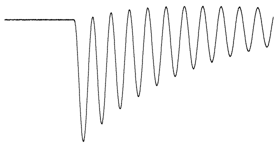
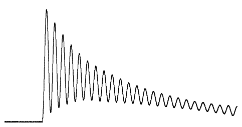
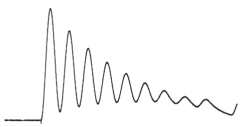
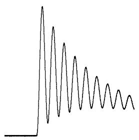
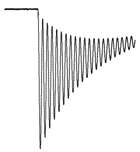
Designation in test data generator	Reference impulse	Description	U_p		T_1		T_2	
			Reference value kV	Acceptance limit % of U_p	Reference value µs	Acceptance limit % of T_1	Reference value µs	Acceptance limit % of T_2
OLI-M1		Oscillating lightning impulse, f = 110 kHz	203,3	± 0,5	3,280	± 2	32,89	± 2
OLI-M2		Oscillating lightning impulse, f = 60 kHz	203,1	± 0,5	5,80	± 2	52,0	± 2
OLI-M3		Oscillating lightning impulse, f = 35 kHz	201,7	± 0,5	9,68	± 2	83,0	± 2
OLI-M4		Oscillating lightning impulse, f = 70 kHz	-809,9	± 0,5	4,935	± 2	69,1	± 2

Table A.6 – Reference values and their acceptance limits for oscillating switching impulses (OSI)

Designation in test data generator	Reference impulse	Description	U_p		T_p		T_2	
			Reference value kV	Acceptance limit % of U_p	Reference value µs	Acceptance limit % of T_p	Reference value µs	Acceptance limit % of T_2
OSI-M1		Oscillating switching impulse, f = 4,7 kHz	204,2	± 0,5	110,7	± 2	134 6	± 2
OSI-M2		Oscillating switching impulse, f = 2,0 kHz	202,9	± 0,5	248,9	± 2	177 9	± 2
OSI-M3		Oscillating switching impulse, f = 3,6 kHz	784,6	± 0,5	144,7	± 2	136 5	± 2
OSI-M4		Oscillating switching impulse, f = 8,3 kHz	-1 521,1	± 0,5	63,2	± 2	121 5	± 2

Annex B
(informative)

Alternative method for uncertainty estimation

B.1 Uncertainty of reference values

The reference values are based on the average results from a number of software packages provided by members of the maintenance team. Each software package was independently developed to implement the definitions of IEC 60060-1, IEC 60060-3 and IEC 62475.

The outcome of this evaluation process is presented in Tables B.1 to B.6. The reference value of a parameter is the mean value $\bar{x}$ of n independent evaluations of this parameter:

$$\bar{x} = \frac{1}{n}\sum_{k=1}^{n} x_k \ .$$

The experimental standard deviation of these n independent observations is

$$s(x_k) = \sqrt{\frac{1}{n-1}\sum_{k=1}^{n}\left(x_k - \bar{x}\right)^2} \ .$$

The expanded uncertainty is

$$U_x = t \times \frac{s(x_k)}{\sqrt{n}} \ ,$$

where t is a factor from the t-distribution leading to confidence level of about 95 % (k = 2).

NOTE Samples which deviated by more than 3 times of standard deviation of the sample population were not included in calculating the mean value $\bar{x}$ and its expanded uncertainty U_x.

The acceptance limits in Tables A.1 to A.6 should be higher than the evaluated standard uncertainties; on the other hand they should be lower than the overall uncertainty limits set for measuring systems in IEC 60060-2 and IEC 62475. The values in Tables A.1 to A.6 fall between these limits.

B.2 Contribution of software to the uncertainty estimate of IEC 60060-2

Instead of using the acceptance limits in 6.3, the differences between the reference values x_{REF} and the values evaluated by the software under test can be used as basis for the uncertainty estimation.

After identifying the n waveforms relating to the algorithm of the software to be qualified, the maximum observed difference from the reference value can be used to obtain the first component for standard uncertainty:

$$u_{B71} = \frac{1}{\sqrt{3}} \max_{i=1}^{n} \left| \frac{x_i - x_{REF,i}}{x_{REF,i}} \right|$$

or in the case of β', when the uncertainty is given in absolute terms:

$$u_{B71} = \frac{1}{\sqrt{3}} \max_{i=1}^{n} \left| \beta_i' - \beta_{REF,i}' \right|$$

In addition, the uncertainty of the reference values should be considered. For this purpose the mean ($\bar{x}$), expanded uncertainty (U_x) and the number of observations (n) of the determination of each reference value are listed in Tables B.1 to B.6. In the tables the expanded uncertainty is given on confidence level of c. 95 % (k = 2).

This component for the standard uncertainty is given by

$$u_{B72} = \frac{1}{2} \max_{i=1}^{n} U_{x,i}$$

where $U_{x,i}$ are the expanded uncertainties for $x_{REF,i.}$

The standard uncertainty of the software is given by

$$u_{B7} = \sqrt{u_{B71}{}^2 + u_{B72}{}^2}$$

Table B.1 – Expanded uncertainties (U_x) of the lightning impulse reference values *(1 of 2)*

LI	U_t			T_1			T_2			β'			U_e			Average rate of rise kV/µs		
	$\overline{x}$ kV	U_x % of $\overline{x}$	n	$\overline{x}$ µs	U_x % of $\overline{x}$	n	$\overline{x}$ µs	U_x % of $\overline{x}$	n	$\overline{x}$ %	U_x %, abs.	n	$\overline{x}$ kV	U_x % of $\overline{x}$	n	$\overline{x}$ kV/µs	U_x % of $\overline{x}$	n
LI-A1	1 049,60	0,002	8	0,839 84	0,011	8	60,156	0,003	8	0,001	0,003	5	1 049,588	0,000 1	6	1 193	0,5	3
LI-A2	1 037,63	0,008	8	1,693	0,12	8	47,479	0,011	8	5,14	0,02	7	1 049,906	0,000 7	6	547	0,7	3
LI-A3	1 000,2	0,02	8	1,117	0,3	8	48,15	0,04	8	4,575	0,007	7	1 023,67	0,002	6	914	0,2	3
LI-A4	856,01	0,005	8	0,841	0,3	8	47,802	0,012	8	7,88	0,02	7	874,260	0,000 0	6	1 020	1,0	3
LI-A5	71,972	0,006	8	1,711	0,3	8	47,705	0,02	8	7,74	0,05	7	72,536 0	0,000 0	6	43,30	0,14	3
LI-A6	100,170	0,005	8	1,762	0,4	8	41,576	0,02	8	17,73	0,02	7	101,930 0	0,000 0	6	59,66	0,2	3
LI-A7	104,349	0,011	8	2,122	0,5	8	38,36	0,04	8	20,15	0,07	7	105,878 6	0,000 7	6	51,7	0,3	3
LI-A8	96,012	0,009	8	1,503	0,3	8	44,924	0,02	8	14,75	0,03	7	97,812 8	0,000 6	6	66,3	0,6	3
LI-A9	55,928	0,007	8	1,215 2	0,12	8	55,737	0,015	8	4,02	0,02	7	56,271 0	0,000 0	6	47,0	0,4	3
LI-A10	81,929	0,009	8	0,924	0,4	8	42,659	0,02	8	12,01	0,05	7	84,338 0	0,000 0	6	89,5	0,4	3
LI-A11	86,597	0,004	8	0,578	0,3	8	56,367	0,009	8	4,066	0,010	7	87,902 7	0,0002	6	149	1,4	3
LI-A12	85,584	0,004	8	0,587 4	0,2	8	57,358	0,009	8	2,267	0,007	7	86,194 0	0,0000	6	147,4	0,8	3
LI-M1	952,09	0,007	8	1,123	0,4	8	85,603	0,02	8	2,082	0,003	7	960,13	0,005	6	845	0,6	3
LI-M2	-1041,7	0,015	8	3,356	0,09	8	61,249	0,006	8	9,18	0,02	7	–1 070,04	0,008	6	–267,2	0,5	3
LI-M3	-1026,5	0,02	8	2,150	0,13	8	41,749	0,015	8	9,17	0,02	7	–1 070,07	0,006	6	–399,4	0,3	3
LI-M4	-267,14	0,03	7	0,987	0,4	6	56,22	0,06	7	4,82	0,02	5	–276,986	0,003	6	–266,3	0,15	3
LI-M5	-55,003	0,010	8	2,746	0,4	8	42,11	0,05	8	18,71	0,08	7	–56,401	0,015	6	–20,66	0,3	3
LI-M6	-166,865	0,005	8	1,355 6	0,02	8	54,739	0,007	8	3,837	0,014	7	–169,921	0,001	6	–119,9	0,5	3
LI-M7	-1 272,3	0,02	8	1,482	0,3	8	50,03	0,05	8	11,20	0,04	7	–1 296,6	0,013	6	–907	1,0	3
LI-M8	-99,732	0,004	8	1,514 7	0,08	8	49,358	0,004	8	-0,55	0,02	7	–99,709	0,002	6	–65,0	0,3	3
LI-M9	-100,035	0,006	8	0,828 3	0,08	8	46,654	0,02	8	1,382	0,007	7	–100,761	0,004	6	–119,4	0,6	3
LI-M10	100,258	0,004	8	1,666	0,09	8	60,853	0,003	8	–0,007	0,011	6	100,867	0,003	6	48,7	2	3
LI-M11	299,324	0,004	8	1,661 1	0,07	8	60,946	0,005	8	–0,457	0,002	7	300,482	0,002	6	161,9	0,3	3

Table B.1 *(2 of 2)*

LI	U_t			T_1			T_2			β'			U_e			Average rate of rise kV/µs		
	$\bar{x}$ kV	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ %	U_x %, abs.	n	$\bar{x}$ kV	U_x % of $\bar{x}$	n	$\bar{x}$ kV/µs	U_x % of $\bar{x}$	n
LI-M12	–4,319 3	0,008	8	1,292	0,2	8	52,266	0,011	8	–1,76	0,05	7	–4,326 09	0,003	6	–3,35	2	3
LI-M13	39,460	0,004	8	1,537	0,2	8	46,937	0,013	8	1,763	0,014	7	39,605 1	0,002	6	26,12	0,2	3
LI-M14	48,549	0,012	8	0,933	0,2	7	37,479	0,04	8	4,27	0,04	7	49,213	0,015	6	54,4	0,5	3
LI-M15	497,97	0,005	8	1,016 6	0,11	8	59,187	0,007	8	–0,08	0,02	7	499,945	0,002	6	477	0,6	3
LI-M16	369,21	0,005	8	0,919 8	0,10	8	47,531	0,010	8	0,833	0,006	7	371,709	0,003	6	390	4	3
LI-M17	–99,346	0,003	8	1,774 7	0,04	7	53,312 4	0,002	8	1,327	0,003	7	–101,21	0,05	6	–45,8	1,1	3

Table B.2 – Expanded uncertainties (U_x) of the chopped lightning impulse reference values

LIC	U_p, U_t			T_1			T_c			β'			U_e			Average rate of rise V/µs		
	$\bar{x}$ kV	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ %	U_x %, abs.	n	$\bar{x}$ kV	U_x % of $\bar{x}$	n	$\bar{x}$ kV/µs	U_x % of $\bar{x}$	n
LIC-A1	872,21	0,005	5				0,543 01	0,005	5									
LIC-M1	850,0	0,07	5				0,569 1	0,12	5									
LIC-M2	0,289 03	0,02	5				0,514	0,4	5									
LIC-M3	–0,303 60	0,02	4				0,567 9	0,2	5									
LIC-M4	0,147 81	0,03	6	1,305	0,6	6	6,00	0,3	6	-0,16	0,05	5	0,1480	0,2	4	0,114	3	3
LIC-M5	–389,9	0,05	6	0,857	0,9	5	9,24	0,2	6	6,85	0,04	5	–397,8	0,04	4	–452	3	3

Table B.3 – Expanded uncertainties (U_x) of the switching impulse reference values

SI	U_p			T_p			T_2		
	$\bar{x}$ kV	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n
SI-A1	950,28	0,004	6	251	0,8	5	2 512,5	0,02	6
SI-A2	0,987 67	0,004	6	19,9	2	5	1 320,79	0,009	6
SI-A3	99,218 6	0,001 3	6	43,1	2	5	3 987,3	0,011	6
SI-M1	–0,590 7	0,11	6	187	3	6	655	1,4	6
SI-M2	3,680	0,13	6	218	4	5	2 410	2	6

Table B.4 – Expanded uncertainties (U_x) of the impulse current reference values

IC	I_p			T_1			T_2		
	$\bar{x}$ kA	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n
IC-M1	–10,001	0,08	6	8,822	0,03	6	21,313	0,02	6
IC-M2	100,418	0,009	6	4,237 12	0,003	5	9,1273	0,004	5
IC-M3	64,281	0,011	6	7,747 1	0,010	6	20,533	0,013	6
IC-M4	100,001	0,003	6	23,470	0,007	6	399	0,6	6
IC-M5	150,01	0,05	6	17,09	0,5	6	48,34	0,3	6
IC-M6	12,464	0,02	6	27,914	0,008	6	274,014	0,004	6
IC-M7	20,495	0,02	6	1,009	0,3	6	17,648	0,06	6
IC-M8	0,229 37	0,04	5	2 050,54	0,007	5	2 678,3	0,009	5
IC-M9	10,155 8	0,009	4	0,967 6	0,06	5	17,68	0,3	5

Table B.5 – Expanded uncertainties (U_x) of the oscillating lightning impulse reference values

OLI	U_p			T_1			T_2			f		
	$\bar{x}$ kV	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ Hz	U_x % of $\bar{x}$	n
OLI-M1	203,3	0,14	6	3,280	0,3	6	32,9	0,8	6	111,3	0,8	6
OLI-M2	203,1	0,10	6	5,802	0,13	6	52,0	0,7	6	60,9	0,3	6
OLI-M3	201,7	0,10	6	9,68	0,2	6	83,0	0,5	6	36,4	0,5	6
OLI-M4	–809,9	0,11	6	4,935	0,2	6	69,1	0,3	6	71,9	0,3	6

Table B.6 – Expanded uncertainties (U_x) of the oscillating switching impulse reference values

OSI	U_p			T_p			T_2			f		
	$\bar{x}$ kV	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ µs	U_x % of $\bar{x}$	n	$\bar{x}$ Hz	U_x % of $\bar{x}$	n
OSI-M1	204,2	0,2	6	110,7	0,3	5	1 346	0,7	6	4,721	0,15	6
OSI-M2	202,9	0,10	6	248,9	0,2	5	1 780	1,3	6	2,048	0,4	6
OSI-M3	784,6	0,09	6	144,72	0,10	5	1 370	1,3	6	3,55	1,1	6
OSI-M4	–1 521	0,13	6	63,2	0,3	5	1 215	1,0	6	8,33	0,9	6

B.3 Example

B.3.1 General

The software related standard uncertainty u_{B7} for the peak value of chopped lightning impulses shall be determined. The related waveforms in Annex A are LIC-A1 and LIC-M1 to M5. Table B.7 shows

- the reference values and acceptance limits from Annex A;
- the expanded uncertainty values from Annex B; and
- the values evaluated by the software under test and their deviation from reference values.

Table B.7 – Example of uncertainty estimation

Waveform	**Reference value** (from Table A.2)	**Acceptance limit** (from Table A.2)	**Expanded uncertainty of the reference value** (from Table B.2)	**Evaluated value**	**Deviation from reference value**
	x_{REFi} kV	%	U_i %	x_i kV	$\left\lvert \frac{x_i - x_{REFi}}{x_{REFi}} \right\rvert$ %
LIC-A1	872,2	1,0	0,005	873,4	0,14
LIC-M1	850,0	1,0	0,07	851,4	0,16
LIC-M2	0,289 0	1,0	0,02	0,288	0,36
LIC-M3	–0,303 6	1,0	0,02	–0,303 9	0,10
LIC-M4	0,147 8	1,0	0,03	0,148 3	0,33
LIC-M5	389,9	1,0	0,05	–391	0,28
Max. value			0,07		0,36

B.3.2 Estimation according to 6.3

All deviations from reference values fall within acceptance limits. Resulting uncertainty contribution is

$$u_{B7} = \frac{1}{\sqrt{3}} \times 1\,\% = 0{,}58\ \%$$

B.3.3 Estimation according to Annex B

Lower uncertainty contribution can be reached by considering the uncertainties of the reference values and the deviations from them. According to this annex we get:

$$u_{B71} = \frac{1}{\sqrt{3}} \times 0{,}36\ \% = 0{,}21\ \%\ ,$$

$$u_{B72} = \frac{1}{2} \times 0{,}07\ \% = 0{,}04\ \%\ \text{ and}$$

$$u_{B7} = \sqrt{{u_{B71}}^2 + {u_{B72}}^2} = \sqrt{0{,}21\ \%^2 + 0{,}04\ \%^2} = 0{,}21\%\ .$$

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