BRITISH STANDARD

BS EN 61083-1:2001
IEC 61083-1:2001

Instruments and software used for measurement in high-voltage impulse tests —

Part 1: Requirements for instruments

The European Standard EN 61083-1:2001 has the status of a British Standard

ICS 17.220.20

National foreword

This British Standard is the official English language version of EN 61083-1:2001. It is identical with IEC 61083-1:2001. It supersedes BS EN 61083-1:1993 which will be withdrawn on 2004-03-01.

The UK participation in its preparation was entrusted to Technical Committee PEL/42, Testing techniques for high voltages and currents, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

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Appareils et logiciels utilisés pour les mesures pendant les essais de choc à haute tension
Partie 1: Prescriptions pour les appareils
(CEI 61083-1:2001)

Messgeräte und Software bei Stoßspannungs- und Stoßstromprüfungen
Teil 1: Anforderungen an Messgeräte
(IEC 61083-1:2001)

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CENELEC

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Foreword

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This European Standard supersedes EN 61083-1:1993 and HD 479 S1:1986.

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Annexes designated "normative" are part of the body of the standard.
Annexes designated "informative" are given for information only.
In this standard, annexes A, B, C and ZA are normative and annex D is informative.
Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61083-1:2001 was approved by CENELEC as a European Standard without any modification.

CONTENTS

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

Part 1: Requirements for instruments

1 General

1.1 Scope

This part of IEC 61083 is applicable to **digital recorders**, including digital oscilloscopes, **analogue oscilloscopes** and **peak voltmeters** used for measurements during tests with high impulse voltages and high impulse currents. It specifies the measuring characteristics and calibrations required to meet the measuring uncertainties and procedures specified in IEC 60060-2.

This part

- defines the terms specifically related to **digital recorders**, **analogue oscilloscopes** and **peak voltmeters**,
- specifies the necessary requirements for such instruments to ensure their compliance with the requirements for high-voltage and for high-current impulse tests, and
- establishes the tests and procedures necessary to demonstrate their compliance.

Only **digital recorders** that permit access to **raw data** from permanent or temporary storage are covered by this standard. The **raw data**, with relevant scaling information, may be

- printed graphically, or
- stored in digital format.

1.2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of IEC 61083. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of IEC 61083 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60060-1:1989, *High-voltage test techniques – Part 1: General definitions and test requirements*

IEC 60060-2:1994, *High-voltage test techniques – Part 2: Measuring systems*
Amendment 1 (1996)

IEC 61000-4-4:1995, *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques – Section 4: Electrical fast transient/burst immunity test.* Basic EMC Publication

1.3 Terms and definitions

For the purposes of this part of IEC 61083, the following terms and definitions apply.

1.3.1 General definitions

1.3.1.1
digital recorder
instrument, including a digital oscilloscope, which can make a temporary digital record of a high-voltage or high-current impulse, that can be converted into a permanent record. The digital record can be displayed in the form of an analogue graph

NOTE The waveform may be displayed on a screen, plotted or printed. This process may change the appearance of the waveform due to the processing involved.

1.3.1.2
analogue oscilloscope
instrument, which can make a temporary analogue record of a scaled high-voltage or high-current impulse, that can be converted into a permanent record. The permanent record can be displayed in the form of a graph or photograph of the screen of the oscilloscope

1.3.1.3
peak voltmeter
instrument, which can measure the peak value of a scaled high-voltage or high-current impulse without short-duration overshoot or high-frequency oscillation (see clause 4)

1.3.1.4
warm-up time
time interval from when the instrument is first switched on to when the instrument meets operational requirements

1.3.1.5
operating range
range of input voltage for which the instrument can be used within the uncertainty limits given in this standard

1.3.1.6
output of an instrument

1.3.1.6.1
output of a digital recorder
numerical value recorded by a **digital recorder** at a specific instant

1.3.1.6.2
output of an analogue oscilloscope
deflection of the trace of an **analogue oscilloscope** at a specific instant

1.3.1.6.3
output of a peak voltmeter
display of a **peak voltmeter**

1.3.1.7
offset
output of an instrument for zero input

1.3.1.8
full-scale deflection
minimum input voltage, which produces the nominal maximum output of the instrument in the specified range

1.3.1.9
non-linearity of amplitude
deviation of the actual **output of an instrument** from the nominal value, which is determined by dividing the input voltage by the **scale factor**

NOTE The static non-linearity for a d.c. input voltage may be different from the non-linearity under dynamic condition.

1.3.1.10
scale factor
factor by which the output corrected for **offset** is multiplied in order to determine the measured value of the input quantity. The **scale factor** includes the ratio of any built-in or external attenuator and is determined by calibration

1.3.1.10.1
static scale factor
scale factor for a direct voltage input

1.3.1.10.2
impulse scale factor
scale factor for an input representing the shape of the relevant impulse

1.3.2 Definitions specific for digital recorders and analogue oscilloscopes

1.3.2.1
rise time
time interval within which the response to an applied step passes from 10 % to 90 % of its steady-state amplitude

1.3.2.2
time-scale factor
factor by which the interval measured from the record is multiplied in order to determine the value of that time interval

1.3.2.3
non-linearity of time base
variation of the **time-scale factors** measured in different parts of the trace or digital record from their mean value

1.3.3 Definitions specific for digital recorders

1.3.3.1
rated resolution *r*
rated resolution is expressed by the reciprocal of two to the power of the rated number of bits N of the A/D converter, namely $r = 2^{-N}$

1.3.3.2
sampling rate
number of samples taken per unit of time

NOTE The sampling time interval is the reciprocal of the **sampling rate**.

1.3.3.3
record length
duration of the record expressed either in a time unit or as the total number of samples

1.3.3.4
raw data
original record of sampled and quantized information obtained when a **digital recorder** converts an analogue signal into a digital form

The correction of the output for **offset** to give a zero-based record is permitted, as is multiplying the record by a constant **scale factor**. Records processed in this way are still considered as **raw data**

NOTE 1 This information may be made available in binary, octal, hexadecimal or decimal form.

NOTE 2 The scaling information relevant to the digital record should also be stored.

1.3.3.5
processed data
data obtained by any processing (other than correction for **offset** and/or multiplying by a constant **scale factor**) of the **raw data**

NOTE **Digital recorders**, which do not allow access to the **raw data**, are not covered by this standard.

1.3.3.6
base line
value of the output of the recorder during the initial flat part of the record of the impulse. It is the mean of at least 20 samples in the initial flat part of the record

1.3.3.7
quantization characteristic
characteristic showing the relationship between the output of the **digital recorder** and the direct voltage on the input which produces this output (see figure 1)

NOTE The average slope of the **quantization characteristic** is equal to the reciprocal of the **static scale factor**.

1.3.3.8
code *k*
integer used to identify a digital level

1.3.3.9
code bin width $w(k)$
range of input voltage allocated to **code *k*** (see figure 2)

1.3.3.10
average code bin width w_0
product of the **full-scale deflection** and the **rated resolution** (see figure 2)

NOTE The **average code bin width** is approximately equal to the **static scale factor.**

1.3.3.11
integral non-linearity $s(k)$
difference between corresponding points on the measured **quantization characteristic** and on the ideal **quantization characteristic** that is based on the **static scale factor** (see figure 1)

1.3.3.12
differential non-linearity *d*(*k*)
difference between a measured **code bin width** and the **average code bin width** divided by the **average code bin width** (see figure 2):

$$d(k) = \frac{w(k) - w_0}{w_0}$$

1.4 Operating conditions

The range of operating conditions given in table 1 are those under which the instrument shall operate and meet the accuracy requirements specified for the instrument.

Table 1 – Operating conditions

Condition	Range
Environment	
Ambient temperature	5 °C to 40 °C
Ambient relative humidity (non-condensing)	10 % to 90 %
Mains supply	
Supply voltage	Rated voltage ±10 % (r.m.s.)
	Rated voltage ±12 % (a.c. peak)
Supply frequency	Rated frequency ±5 %

Any exceptions to the values given in table 1 shall be explicitly and clearly stated in the record of performance with an indication that they are exceptions.

1.5 Calibration and test methods

1.5.1 Impulse calibration

Impulse calibration is the reference method to establish the **impulse scale factor** of approved **digital recorders**, **analogue oscilloscopes** and **peak voltmeters**. It is also the reference method to check the time parameter determination from the records of **digital recorders** and **analogue oscilloscopes**. Requirements on reference calibration impulses for calibrating instruments used in approved measuring systems are given in table 2. The waveshapes are chosen from table 2 according to the type and polarity of the high voltage or current impulses to be measured. The peak value and time parameters of the applied calibration impulses shall be within the limits given in table 2, and the actual values shall be entered in the record of performance.

The polarity of the calibration impulses shall be that of the impulse to be measured. The output corresponding to the calibration impulse shall be evaluated for at least 10 impulses. The maximum deviation of the output peak values from their mean value shall be less than 1 % of the mean value. The **impulse scale factor** is the quotient of the input peak value and the mean peak value of the outputs.

The time parameters of at least 10 impulses shall be evaluated. The maximum deviation of each time parameter shall be less than 2 % of the mean value.

This impulse calibration shall be made on each range of use for tests. Care should be taken to avoid overloading the devices with low input impedance.

NOTE A **digital recorder** can be calibrated for an exponential current impulse using the full lightning impulse of a reference impulse generator, and switching impulse for 10/350 impulse current (the 10/350 µs impulse current is under consideration for inclusion in the future revision of the IEC 60060 series).

Table 2 – Requirements for reference impulse generators

Impulse type	Parameter being measured	Value	Uncertainty [1)] %	Short-term stability [2)] %
Full and standard chopped lightning impulse	Time-to-half value	55 µs to 65 µs	≤ 2	≤ 0,2
	Front time	0,8 µs to 0,9 µs	≤ 2	≤ 0,5
	Peak voltage	Within **operating range**	≤ 0,7	≤ 0,2
Front chopped lightning impulse	Time-to-chopping	0,45 µs to 0,55 µs	≤ 2	≤ 1
	Peak voltage	Within **operating range**	≤ 1	≤ 0,2
Switching impulse	Time-to-peak	15 µs to 300 µs	≤ 2	≤ 0,2
	Time-to-half value	2 600 µs to 4 200 µs	≤ 2	≤ 0,2
	Peak voltage	Within **operating range**	≤ 0,7	≤ 0,2
Rectangular impulse	Duration	0,5 ms to 3,5 ms	≤ 2	≤ 0,5
	Peak value	Within **operating range**	≤ 2	≤ 1

1) The uncertainty is determined in accordance with annex H of IEC 60060-2 by a traceable calibration where the mean of a sequence of at least 10 impulses is evaluated.

2) The short-term stability is the standard deviation of a sequence of at least 10 impulses.

1.5.2 Step calibration

A direct voltage V_{CAL}, which is known to within 0,1 % and within the **operating range** of the instrument, is applied to the input and then short-circuited to ground by an appropriate switching device, preferably based on a mercury-wetted relay. The resultant transition to zero level is recorded as the output $O(t)$ (an example is shown in figure 5) and evaluated within the time interval specified in 1.5.3. Several records of the response may be averaged to reduce the random noise. The deviation of the sample values $O(t)$ from their mean O_s shall be within the limits specified for the **scale factor** when t ranges within the time interval given in 1.5.3. At least 10 records of steps shall be evaluated in this manner. The deviation of each of the 10 O_s values from their overall mean, O_{sm}, shall also be within the limits specified for the **scale factor**. The **impulse scale factor** is the quotient of the input voltage V_{CAL} and O_{sm}. The **rise time** of the step shall be less than 10 % of the lower limit of the time interval specified in 1.5.3.

This voltage calibration shall be made in each range of use for tests. Care should be taken to avoid overloading of recorders with low input impedance.

This test shall be done using both polarities. If the **scale factors** determined agree to within ±1 %, then this method is valid. If not, impulse calibration according to 1.5.1 of appropriate polarity shall be used.

1.5.3 Constancy of scale factor within time interval

A direct voltage within the **operating range** of the **digital recorder** or **analogue oscilloscope** is applied to the input and then short-circuited to ground by an appropriate switching device, preferably based on a mercury-wetted relay. The resultant transition to zero level of the step response is recorded and evaluated within the following time intervals:

0,5 T_1 to T_{2max}	for full lightning impulses and exponential current impulses;
0,5 T_c to T_c	for front-chopped impulses;
0,5 T_p to T_{2max}	for switching impulses, and 10/350 µs current impulses;
0,5 (T_t – T_d) to T_t	for rectangular current impulses.

Within these time intervals, the settling level of the recorded step response shall be constant within the limits specified for the **impulse scale factor**.

Several records of the response may be averaged to reduce the random noise.

This **scale factor** constancy calibration shall be made in each range used for tests.

NOTE T_1, T_2 and T_c are defined in IEC 60060-1. T_{2max} is the maximum value of T_2, that is to be measured by the system.

1.5.4 Time base

The time-base of the instrument is calibrated using a time-mark generator or a high-frequency oscillator. Values of the **time-scale factor** shall be measured from the record at approximately 20 %, 40 %, 60 %, 80 % and 100 % of the time sweep.

This time-base calibration shall be made in each **sampling rate** used for tests.

1.5.5 Rise time

Apply a step with a rise time which is less than 20 % of the limit specified for the instrument. Measure the rise time of the output as the time from 10 % to 90 % of the settling level. The amplitude of the applied step shall be (95 ± 5) % of the **full-scale deflection**.

This rise-time shall be determined for each vertical setting used for tests.

1.5.6 Voltage deflection characteristic of analogue oscilloscopes

Direct voltages from 0 %, 10 %, 20 % … 100 % of the **full-scale deflection** are applied to the oscilloscope. For each input voltage, the vertical deflection of the trace is measured. The relationship between the vertical deflection and the input is the deflection characteristic from which the voltage deflection coefficient is determined.

NOTE The deflection characteristic measured for a given input range is, in general, representative for all ranges. The influence of the attenuators is determined by impulse calibration (see 1.5.1 or 1.5.2). Care should be taken to avoid thermal overloading of low-input impedance attenuators.

1.5.7 Determination of static differential and integral non-linearities

A direct voltage of $0{,}2 \cdot n \cdot 2^{-N}$ **full-scale deflection** is applied to the recorder low-voltage input where n is increased from 1 to $5 \cdot 2^{N}$. For each d.c. input voltage, a record of the output is taken and the mean of at least 100 samples is calculated. The relationship between the mean output and input values is the **quantization characteristic** from which the static integral and differential non-linearities are determined (see figures 1 and 2). A procedure of determination of these non-linearities is given in annex A.

NOTE The differential and integral non-linearities measured for a given input range is, in general, representative for all ranges of the **digital recorder**. The influence of any attenuator is determined by impulse or step calibration (see 1.5.1 or 1.5.2). Care should be taken to avoid thermal overloading of low-input impedance attenuators.

1.5.8 Differential non-linearity under dynamic conditions

Apply a symmetrical triangular wave to the recorder low-voltage input. The amplitude shall be within (95 ± 5) % of **full-scale deflection**. The slope shall be greater than or equal to f.s.d/$0{,}4T_x$, where f.s.d. is the **full-scale deflection** (for T_x, see 2.1.2.1). The frequency of the triangular wave shall not be harmonically related to the sampling frequency. Take a record and calculate a histogram of the occurrence of every digital level. Repeat M times and calculate the cumulative histogram. M shall be large enough so that the mean value of the occurrence is greater than or equal to 100.

This procedure should produce a histogram with an approximately uniform part and large peaks on each side. This uniform part shall be larger than or equal to 80 % **full-scale deflection.** The deviation of each point from the average over this approximately uniform part divided by this average gives the **differential non-linearity**.

NOTE The dynamic **differential non-linearity** measured for a given input range is, in general, representative for all ranges of the **digital recorder**. The influence of any attenuator is determined by impulse or step calibration (see 1.5.1 or 1.5.2). Care should be taken to avoid thermal overloading of low-input impedance attenuators.

1.5.9 Internal noise level

1.5.9.1 Digital recorders

A direct voltage within the range of the **digital recorder** shall be applied. Enough records shall be taken at a specified **sampling rate** to acquire at least 1 000 samples. The standard deviation of these samples is taken as the internal noise level.

NOTE This data can be collected during the determination of static differential and integral non-linearities according to annex A.

1.5.9.2 Oscilloscopes

A direct voltage within the range of the oscilloscope shall be applied at a specified sweep. Half the peak-to-peak variation of the vertical deflection is taken as the internal noise level.

1.5.10 Interference

The interference tests according to B.3.1 shall be made.

1.6 Input impedance

Depending on the type of measuring system used, the input impedance of the instrument should match the nominal impedance of the coaxial cable within ±2 % (for example, for resistor dividers or shunts) or be not less than 1 MΩ with not more than 50 pF in parallel (for example, for capacitive or damped capacitive dividers).

NOTE The matching impedance may also be externally connected immediately at the input of the instrument.

2 Digital recorders for impulse tests

2.1 Requirements for impulse measurements

2.1.1 Requirements for digital recorders used in approved measuring systems

The overall uncertainty of a **digital recorder** used in an approved measuring system according to IEC 60060-2 shall be not more than (at a confidence level of not less than 95 %, see annex H of IEC 60060-2)

- 2 % in the peak voltage (current) measurement of full and standard-chopped lightning impulses, switching impulses and rectangular impulses;
- 3 % in the peak voltage measurement of front-chopped lightning impulses;
- 4 % in the measurement of the time parameters (front time, time to chopping, etc.) of the impulse.

These uncertainties shall be estimated according to annex H of IEC 60060-2.

The **digital recorder** shall allow storage of the **raw data** at least until the test is accepted.

2.1.2 Individual requirements

In order to stay within the limits given in 2.1.1, the limits for individual contributions given in 2.1.2 should usually be met. In some cases, one or more of these limits may be exceeded provided the permitted overall uncertainty is not exceeded.

2.1.2.1 Sampling rate

The **sampling rate** shall be not less than $30/T_x$ where T_x is the time interval to be measured.

NOTE T_x = 0,6 T_1 is the time interval between T_{30} and T_{90} of the lightning impulse to be measured. For a 1,2/50 lightning impulse, the permitted lower value of front time T_1 is 0,84 μs. Therefore, a **sampling rate** of at least 60×10^6 s^{-1} is required.

To measure front oscillations the **sampling rate** shall be at least 6 f_{max} where f_{max} is the maximum frequency of front oscillations that should be reproduced by the measuring system (see 9.1.2 of IEC 60060-2).

2.1.2.2 Rated resolution

A **rated resolution** of 2^{-8} (0,4 % of the **full-scale deflection**) or better is required for tests where the impulse parameters are to be evaluated. For tests which involve signal processing other than impulse parameter evaluation, a **rated resolution** of 2^{-9} (0,2 % of the **full-scale deflection**) or better is recommended.

NOTE The best resolution available from an **analogue oscilloscope** is about 0,3 % of the **full-scale deflection**. Hence the above limit of 0,2 % **full-scale deflection** ensures that a **digital recorder** used for comparative measurements, for example, to determine the transfer impedance of transformers, will perform at least as well as an oscilloscope.

2.1.2.3 Impulse scale factor

The **impulse scale factor** shall be determined with an uncertainty of not more than 1 %. It shall be constant within ±1 % over the time intervals given in 1.5.3.

2.1.2.4 Rise time

The **rise time** shall not be more than 3 % of T_x where T_x is the time interval to be measured.

For the measurement of lightning impulses, the **rise time** shall be not more than 15 ns in order to reproduce superimposed oscillations within the frequency limits given in 9.1.2 of IEC 60060-2.

NOTE **Rise times** less than, or of the order of, one sampling interval cannot be accurately determined without special repetitive triggering features.

2.1.2.5 Interference

The maximum amplitude of any deflection from the base magnitude in the interference test shall be less than 1 % of the **full-scale deflection** in the ranges used for impulse tests.

NOTE An interference performance test is required by IEC 60060-2 for the complete impulse measuring system.

2.1.2.6 Record length

The **record length** shall be sufficiently long to allow the required parameter (for example, T_2 or T_P) to be evaluated or a specific phenomenon to be observed. Specific **record lengths** should be specified by the relevant technical committee.

2.1.2.7 Non-linearity of amplitude

The static **integral non-linearity** shall be within ±0,5 % of **full-scale deflection**. The **differential non-linearity** shall be within ±0,8 w_0, for both static and dynamic tests.

2.1.2.8 Non-linearity of time base

The **integral non-linearity** of the time base shall be not more than 0,5 % of T_x where T_x is the time interval to be measured.

2.1.2.9 Internal noise level

The internal noise level shall be less than 0,4 % of the **full-scale deflection** for measurements of the waveform parameters and less than 0,1 % of the **full-scale deflection** for measurements involving signal processing.

2.1.2.10 Operating range

The lower limit of the **operating range** shall be not less than 4/*N* of **full-scale deflection** where *N* is the number of bits.

NOTE 1 This means that the peak amplitude is not less than 50 % of the **full-scale deflection** for an 8-bit **digital recorder**, 40 % for a 10-bit **digital recorder** or 33 % for a 12-bit **digital recorder**.

NOTE 2 For tests which require comparison of records, a lower limit of the **operating range** of not less that 6/*N* of the **full-scale deflection** is recommended.

2.1.3 Requirements for digital recorders used in reference measuring systems

2.1.3.1 General requirements

These instruments are used in reference measuring systems specified in IEC 60060-2 for the calibration of approved measuring systems by comparison measurements. The peak and time parameters are in general determined as the mean of at least 10 measurements. The overall uncertainty of a **digital recorder** used in a reference measuring system according to IEC 60060-2 shall be not more than (at a confidence level of not less than 95 %; see annex H of IEC 60060-2)

- 0,7 % in the peak voltage (current) measurement of full and standard-chopped lightning impulses, switching impulses and rectangular impulses;
- 2 % in the peak voltage measurement of front-chopped lightning impulses;
- 3 % in the measurement of the time parameters (front time, time to chopping, etc.) of the impulse.

2.1.3.2 Individual requirements

In order to stay within the limits given in 2.1.3.1, the limits given in 2.1.2 and the following additional requirements shall be met.

- The **sampling rate** shall be not less than $30/T_x$. For front-chopped impulses, the **sampling rate** shall be not less than $100 \cdot 10^6$ s^{-1}.
- The lower limit of the **operating range** shall be not less than 6/*N* of the **full-scale deflection**.
- The **impulse scale factor** shall be determined with an uncertainty of not more than 0,5 %.
- It shall be constant within ±0,5 % over the time intervals given in 1.5.3.
- The interference voltage shall be not more than 0,5 %.

2.1.4 Tests

The tests required for **digital recorders** by this standard are shown in table 3.

All calibration equipment shall be traceable, either directly or indirectly, to international or national standards. The procedures of the calibrations shall be recorded.

Table 3 – Tests required for digital recorders

Type of test	Reference to test method	Reference to test requirement		Test classification			
		Complete recorder at one setting of the input attenuator	Complete recorder at each setting of the input attenuator	Type test	Routine test	Performance test	Performance check
Static **integral non-linearity**	1.5.7	2.1.2.7		X			
Static **differential non-linearity**	1.5.7	2.1.2.7		X			
Dynamic **differential non-linearity**	1.5.8	2.1.2.7			X		
Non-linearity of time base	1.5.4	2.1.2.8		X			
Impulse scale factor	1.5.1 or 1.5.2		2.1.2.3		X	X	X
Constancy of **scale factor**	1.5.3		2.1.2.3		X	X	X
Rise time	1.5.5		2.1.2.4	X			
Internal noise level	1.5.9	2.1.2.9		X			
Interference	1.5.10, B.3	2.1.2.5, B.3.1		X			

2.1.4.1 Type tests

Type tests shall be performed for one **digital recorder** of a series. These type tests are to be performed by the manufacturer of the **digital recorder**. If type test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

2.1.4.2 Routine tests

Routine tests shall be performed for each **digital recorder**. These routine tests are to be performed by the manufacturer of the **digital recorder**. If routine test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

Routine tests shall also be carried out after repair of the **digital recorder**.

2.1.4.3 Performance tests

Performance tests shall be performed on each new **digital recorder** and be repeated once a year. The date and results of each performance test shall be recorded in the record of performance.

A performance test on the instrument is also required if performance checks on the instrument indicate that the **impulse scale factor** has changed by more than 1 %.

2.1.4.4 Performance checks

Performance checks on the instrument are required only if performance checks on the complete measuring system indicate that the assigned **scale factor** has changed significantly (see 4.2 of IEC 60060-2).

Performance checks shall be made for each setting of the instrument that is to be used in the impulse tests. This check shall include the possible external attenuator, if it was not calibrated with divider or shunt.

If it is shown that the **static** and **impulse scale factors** differ by not more than 0,5 %, then direct voltage calibration described in annex C may be used in place of the step test given in 1.5.2.

2.1.5 Record of performance

The record of performance of a **digital recorder** shall include the following information.

a) Nominal characteristics
   1) Identification (serial number, type, etc.)
   2) **Rated resolution**
   3) Range of **sampling rates**
   4) Maximum **record length**
   5) Triggering capabilities
   6) Value of the maximum and minimum input voltage
   7) Input impedance
   8) Range of waveshapes
   9) **Warm-up time**
   10) Range of operating conditions
b) Results of type tests
c) Results of routine tests
d) Performance tests
   1) Date and time of each performance test
   2) Results of each performance test
e) Performance checks
   1) Date and time of each performance check
   2) Result – pass/fail (if fail, record of action taken)

3 Analogue oscilloscopes for impulse tests

3.1 Requirements for impulse measurements

3.1.1 Requirements for analogue oscilloscopes used in approved measuring systems

The overall uncertainty of an **analogue oscilloscope** used in an approved measuring system according to IEC 60060-2 shall be not more than (at a confidence level of not less than 95 %, see annex H of IEC 60060-2):

- 2 % in the peak voltage (current) measurement of full and standard-chopped lightning impulses, switching impulses and rectangular impulses,
- 3 % in the peak voltage measurement of front-chopped lightning impulses,
- 4 % in the measurement of the time parameters (front time, time to chopping, etc.) of the impulse.

All calibration shall be carried out by using the same camera (or digital camera) which will be used during the actual tests. In case of adjustable enlargement, no change is permitted between calibration and testing.

3.1.2 Individual requirements

In order to stay within the limits given in 3.1.1, the limits for individual contributions given in 3.1.2 should usually be met. In some cases, one or more of these limits may be exceeded provided the permitted overall uncertainty is not exceeded.

3.1.2.1 Operating range

The **operating range** denotes the effective screen area within which voltage and time measurements can be made with the overall uncertainty specified in 3.1.1 and within which the individual requirements are met.

3.1.2.2 Non-linearity of voltage deflection

The non-linearity of the voltage deflection shall be not more than 1 % in the **operating range**. Otherwise, calibration impulses (see figure 3) or calibration traces (see figure 4) shall be displayed on the oscillogram together with the measured impulse, enabling the voltage calibration within the limits specified above.

3.1.2.3 Non-linearity of time base

The **integral non-linearity** of the time base shall be not more than 2 % of T_x where T_x is the time interval to be measured. Otherwise, time marks or calibration impulses shall be displayed on the oscillogram together with the measured impulse, enabling the time calibration within the limits specified above (see figure 4).

3.1.2.4 Impulse scale factor

The **impulse scale factor** shall be determined with an uncertainty of not more than 1 %. It shall be constant within ±1 % over the time intervals given in 1.5.3.

3.1.2.5 Rise time

The **rise time** shall not be more than 3 % of T_x where T_x is the time interval to be measured.

For the measurement of lightning impulses, the **rise time** shall be not more than 15 ns in order to reproduce superimposed oscillations within the frequency limits given in 9.1.2 of IEC 60060-2.

3.1.2.6 Interference

The maximum amplitude of any deflection from the base magnitude in the interference test shall be less than 1 % of the **full-scale deflection** in the **operating ranges** used for the impulse tests.

NOTE An interference performance test is required by 6.4 of IEC 60060-2, for the complete impulse measuring system.

3.1.3 Tests

The tests required for **analogue oscilloscopes** by this standard are shown in table 4.

All calibration equipment shall be traceable, either directly or indirectly, to international or national standards. The procedures of the calibrations shall be recorded.

Table 4 – Tests required for analogue oscilloscopes

Type of test	Reference to test method	Reference to test requirement		Test classification			
		Complete scope at one setting of the input attenuator	Complete scope at each setting of the input attenuator	Type test	Rou-tine test	Per-form-ance test	Per-form-ance check
Voltage deflection characteristics	1.5.6	3.1.2.2				X	
Non-linearity of time base	1.5.4	3.1.2.3		X		X	
Impulse scale factor	1.5.1 or annex A		3.1.2.4		X	X	X
Constancy of scale factor	1.5.3		3.1.2.4		X	X	X
Rise time	1.5.5		3.1.2.5	X			
Interference	1.5.10	3.1.2.6		X			

3.1.3.1 Type tests

Type tests shall be performed for one **analogue oscilloscope** of a series. These type tests are to be performed by the manufacturer of the oscilloscope. If type test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

3.1.3.2 Routine tests

Routine tests shall be performed for each **analogue oscilloscope**. These routine tests are to be performed by the manufacturer of the oscilloscope. If routine test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

Routine tests shall also be carried out after repair of the **analogue oscilloscope**.

3.1.3.3 Performance tests

Performance tests shall be performed on each new **analogue oscilloscope** and repeated once a year by the user. The date and results of each performance test shall be recorded in the record of performance.

Performance test on the instrument is also required if performance checks on the instrument indicate that the **impulse scale factor** has changed by more than 1 %.

3.1.3.4 Performance checks

Performance checks on the instrument are required only if performance checks on the complete measuring system indicate that the assigned **scale factor** has changed significantly (see 4.2 of IEC 60060-2).

Performance checks shall be made for each setting of the instrument that is to be used in the impulse tests. This check shall include the possible external attenuator, if it was not calibrated with divider or shunt.

If it is shown that the **static** and **impulse scale factors** differ by not more than 0,5 %, then direct voltage calibration described in annex C may be used in place of the step test given in 1.5.2.

3.1.4 Record of performance

The record of performance of an **analogue oscilloscope** shall include the following information:

a) Nominal characteristics
   1) Identification (serial number, type, etc.)
   2) Range of sweep times
   3) Value of the maximum and minimum input voltage
   4) Range of waveshapes
   5) **Operating range** (effective screen area)
   6) **Warm-up time**
   7) Range of operating conditions
   8) Input impedance
   9) Built-in calibrator
b) Results of type test
c) Results of routine test
d) Performance tests
   1) Date and time of each performance test
   2) Results of each performance test
e) Performance checks
   1) Date and time of each performance check
   2) Result – pass/fail (if fail, record of action taken)

4 Peak voltmeters for impulse tests

4.1 Requirements for impulse measurements

A **peak voltmeter** measures the highest peak of the impulse. However, the highest peak of an impulse does not always correspond to the value of the test voltage (see annex D). This situation limits the use of a **peak voltmeter** by itself to those cases where the impulse shape is known to be quite smooth with no short-duration overshoot or high-frequency oscillation. In all other cases, the **peak voltmeter** must be used in parallel with a suitable recording instrument so that the reading of the **peak voltmeter** can be corrected, if necessary.

4.1.1 General requirements for peak voltmeters

The overall uncertainty of a **peak voltmeter** used in an approved measuring system according to IEC 60060-2 shall be not more than (at a confidence level of not less than 95 %; see annex H of IEC 60060-2)

- 2 % in the peak voltage (current) measurement of full and standard-chopped lightning impulses and of switching impulses;
- 3 % in the peak voltage measurement of front-chopped lightning impulses.

4.1.2 Individual requirements

In order to stay within the limits given in 4.1.1, the limits for individual contributions given in 4.1.2 should usually be met. In some cases, one or more of these limits may be exceeded provided the permitted overall uncertainty is not exceeded.

4.1.2.1 Operating range

The **operating range** denotes the voltage range within which impulse peak voltages can be measured with the overall uncertainty specified in 4.1.1 and within which the following individual requirements are met.

4.1.2.2 Impulse scale factor

The **impulse scale factor** shall be determined with an uncertainty of not more than 1 %.

Furthermore, the **scale factor** shall be constant within ±1 % during the reading-hold time specified for the **peak voltmeter** until manual or automatic resetting.

4.1.2.3 Non-linearity of voltage range

The non-linearity of the voltage range shall be not more than 1 % in the **operating range**.

4.1.2.4 Interference

The error in the peak value measurement resulting from electromagnetic interference shall be less than 1 % of the smallest permissible deflection in the **operating ranges** used for impulse tests.

4.1.3 Tests

The tests required for **peak voltmeters** are shown in table 5 of this standard.

All calibration equipment shall be traceable, either directly or indirectly, to international or national standards. The procedures of the calibrations shall be recorded.

Table 5 – Tests required for peak voltmeters

Type of test	Reference to test method	Reference to test requirement		Test classification			
		Complete meter at one setting of the input attenuator	Complete meter at each setting of the input attenuator	Type test	Rou-tine test	Per-form-ance test	Per-form-ance check
Non-linearity of voltage range	1.5.1	4.1.2.3		X			
Impulse scale factor	1.5.1		4.1.2.2		X	X	X
Interference	1.5.10	4.1.2.4		X			

4.1.3.1 Type tests

Type tests shall be performed for one **peak voltmeter** of a series. These type tests are to be performed by the manufacturer of the **peak voltmeter**. If type test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

4.1.3.2 Routine tests

Routine tests shall be performed for each **peak voltmeter**. These routine tests are to be performed by the manufacturer of the **peak voltmeter**. If routine test results are not available from the manufacturer, tests to verify the equipment shall be arranged by the user.

Routine tests shall also be carried out after a repair of the **peak voltmeter**.

4.1.3.3 Performance tests

Performance tests shall be performed on each new **peak voltmeter** and repeated once a year by the user. The date and results of each performance test shall be recorded in the record of performance.

Performance test on the instrument is also required if performance checks on the instrument indicate that the **impulse scale factor** has changed by more than 1 %.

4.1.3.4 Performance checks

Performance checks on the instrument are required only if performance checks on the complete measuring system indicate that the assigned **scale factor** has changed significantly (see 4.2 of IEC 60060-2).

Performance checks shall be made for each setting of the instrument, which is to be used in the impulse tests. If external attenuator is used, and not calibrated with divider or shunt, it shall be included in this performance check.

4.1.4 Record of performance

The record of performance of a **peak voltmeter** shall include the following information:

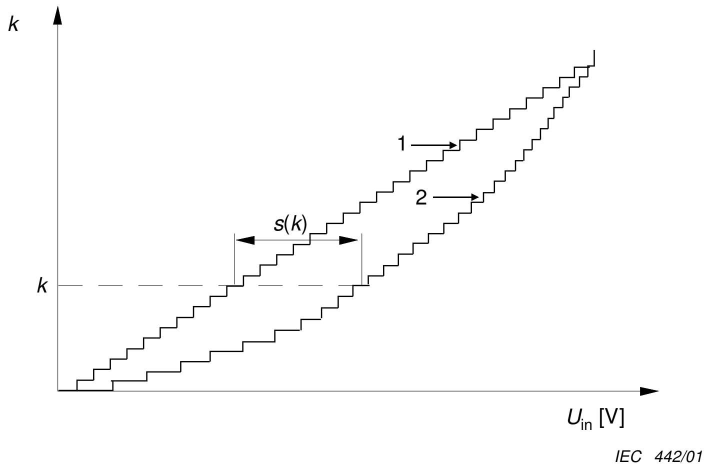
a) Nominal characteristics
   1) Identification (serial number, type etc.)
   2) **Rated resolution** (if applicable)
   3) Value of the maximum and minimum input voltage
   4) Range of waveshapes
   5) **Operating range**
   6) Reading-hold time (if applicable)
   7) **Warm-up time**
   8) Range of operating conditions
   9) Input impedance

b) Results of type test

c) Results of routine tests

d) Performance tests
   1) Date and time of each performance tests
   2) Results of performance tests

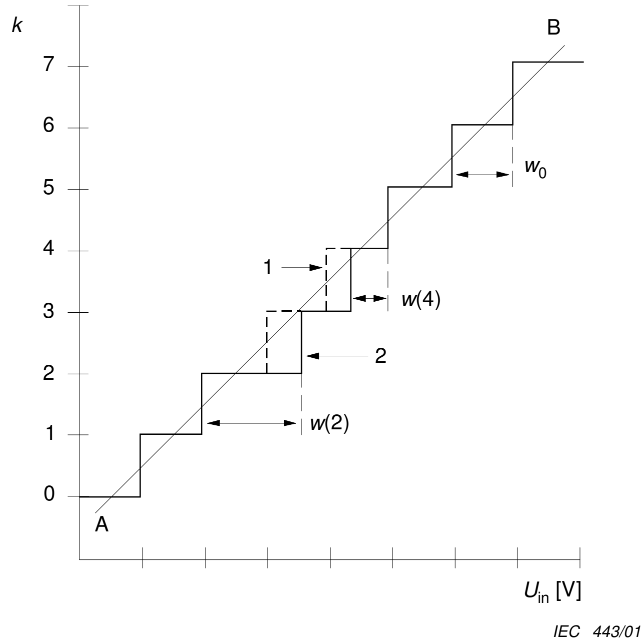
e) Performance checks
   1) Date and time of each performance check
   2) Result – pass/fail (if fail, record of action taken)



Curve 1: **Quantization characteristic** of an ideal 5-bit **digital recorder**

Curve 2: **Quantization characteristic** of a non-linear 5-bit **digital recorder**
(The low resolution of 5 bits has been chosen to clarify the illustration.)

Figure 1 – Integral non-linearity *s*(*k*) at code *k*

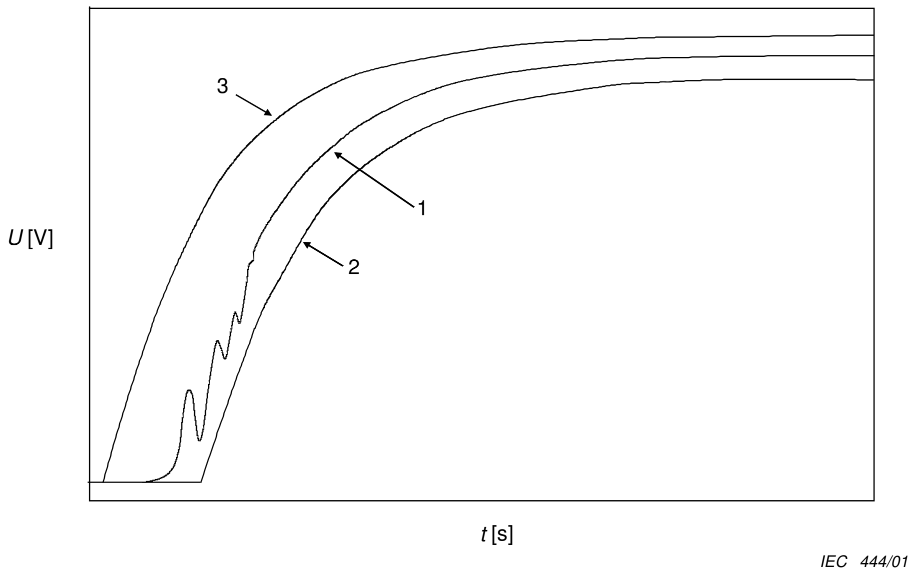


Curve 1: **Quantization characteristic** of an ideal 3-bit **digital recorder**

Curve 2: **Quantization characteristic** of a 3 bit **digital recorder**
showing large *d*(*k*) at codes *k* = 2, 3 and 4

Line AB: A straight line joining the midpoints of the **code** bins of an ideal **digital recorder**
(The low resolution of 3 bits has been chosen to clarify the illustration.)

Figure 2 – Differential non-linearity *d*(*k*) and code bin width *w*(*k*) under d.c. conditions



(The three records were shifted in time to clarify the figure.)

Figure 3 – Calibration by comparison

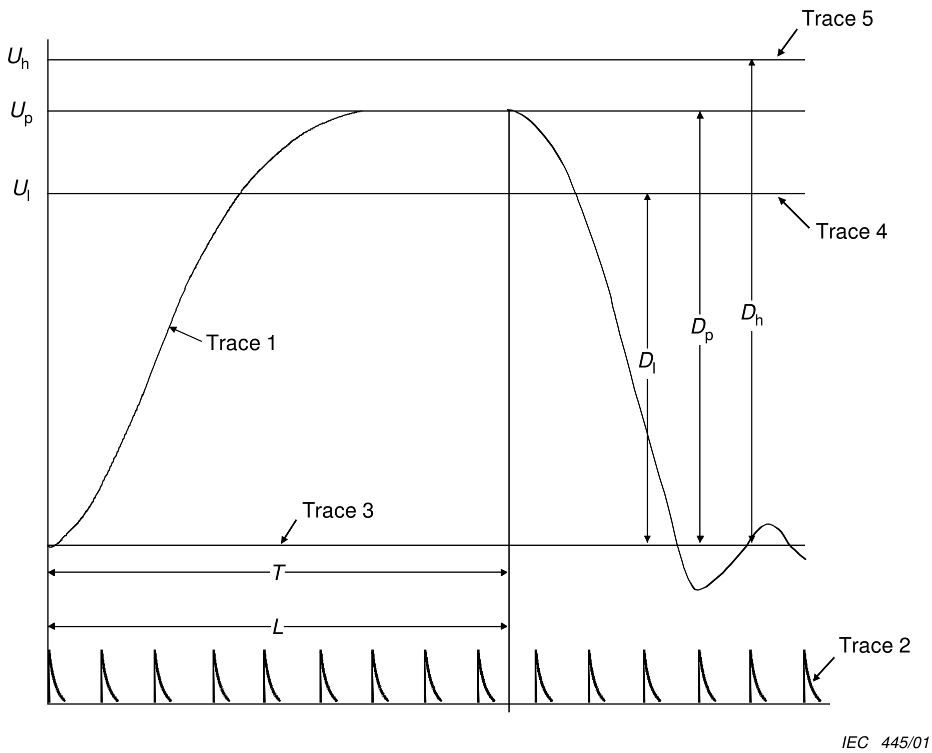
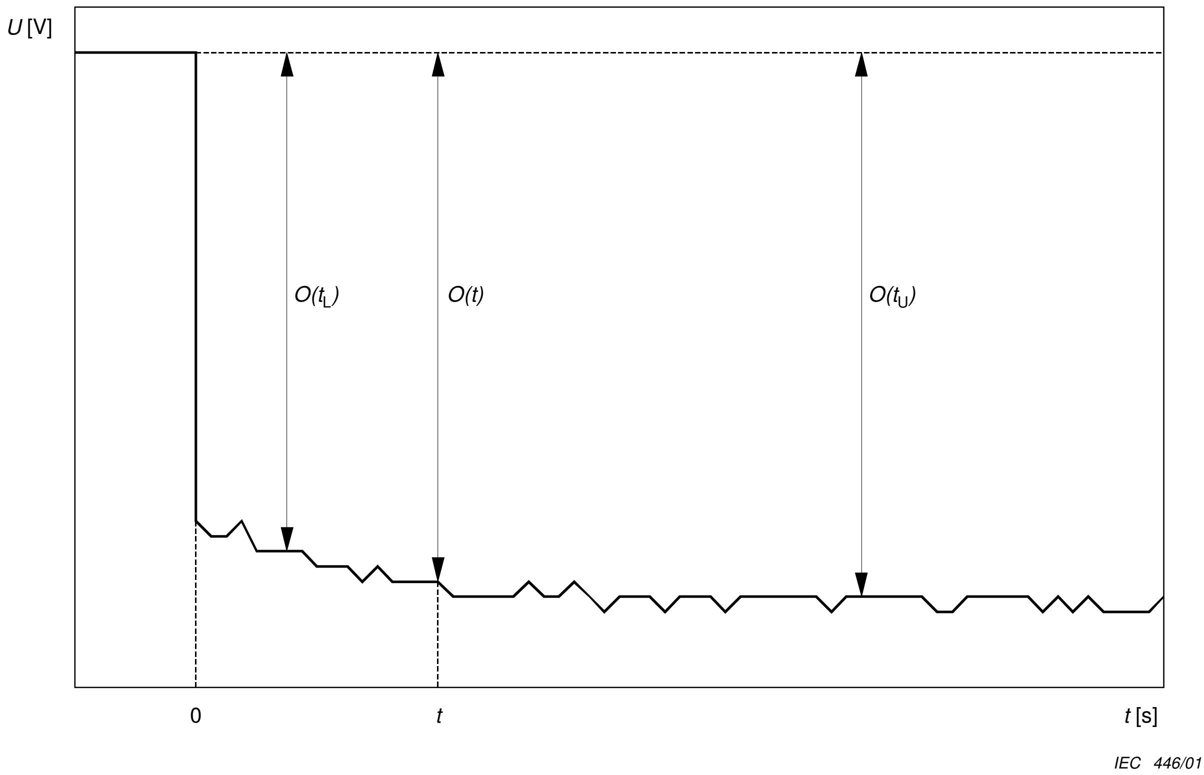


Figure 4 – Separate calibration of voltage and time



(Step calibration. T_L and t_U are the lower and upper limits for the time interval of scale factor constancy test (see 1.5.3).

Figure 5 – Step calibration

Annex A
(normative)

Procedure for determination of non-linearities of a digital recorder

Step A: Apply a voltage $V(i)$ slightly lower (by about 2 % of the nominal full-scale voltage) than the minimum voltage which can be recorded by the **digital recorder**. Take a record and store the input voltage as $V(i)$ and the average value of the record as $A(i)$ with $i = 1$.

Step B: Raise the input voltage by an increment (ΔV) small compared with the product of the full-scale voltage and the **rated resolution**. This increment should be between 1/10 and 1/4 of the **average code bin width**. Take a record and store the input voltage as $V(i+1)$ and the average value of the record as $A(i+1)$.

Step C: Repeat step B using the same increment of voltage and increasing i by 1 to as high as is needed to cover the **full-scale deflection** of the **digital recorder**. Store the input voltages $V(i)$ and recorded average values $A(i)$.

Step D: If the values $A(i)$ are scaled (i.e. they are in volts), calculate the ideal threshold values from

$$T(k) = \frac{f \times s \times d}{2^{\mathrm{N}}}(k + 1/2)$$

If the values $A(i)$ are not scaled (i.e. they are average values of A/D converter output **codes**) the ideal threshold values are

$$T(k) = k + 1/2$$

Here N is the rated number of bits and k is the binary code (from 0 to $2^{\mathrm{N}} - 1$).

Step E: Locate each actual **code** transition threshold $c(k)$ from **code** k to **code** $k + 1$ by (see figure A)

a) finding $A(n)$ for the largest value of n such that $A(n)$ is less than or equal to $T(k)$;

b) finding $A(m)$ for the smallest value of $m > n$ such that $A(m)$ is more than $T(k)$;

c) the **code** transition threshold $c(k)$ from **code** k to **code** $k + 1$ is, by linear interpolation:

$$c(k) = V(n) + \frac{T(k) - A(n)}{A(m) - A(n)}[V(m) - V(n)]$$

Step F: The centre voltage of each **code** bin k is $p(k)$. It is the average of the two **code** transition thresholds that delineate level k:

$$p(k) = 1/2[c(k) + c(k-1)]$$

The width, $w(k)$ of each **code** bin k is:

$$w(k) = c(k) - c(k-1)$$

Step G: Determine the **static scale factor** F_s from:

$$F_s = \frac{p(k_2) - p(k_1)}{k_2 - k_1}$$

where $(k_2 - k_1)$ is greater than or equal to 90 % of 2^N.

Step H: Determine the static **integral non-linearity** $s(k)$ for each **code** bin from:

$$s(k) = p(k) - p(k_1) - (k - k_1)F_s$$

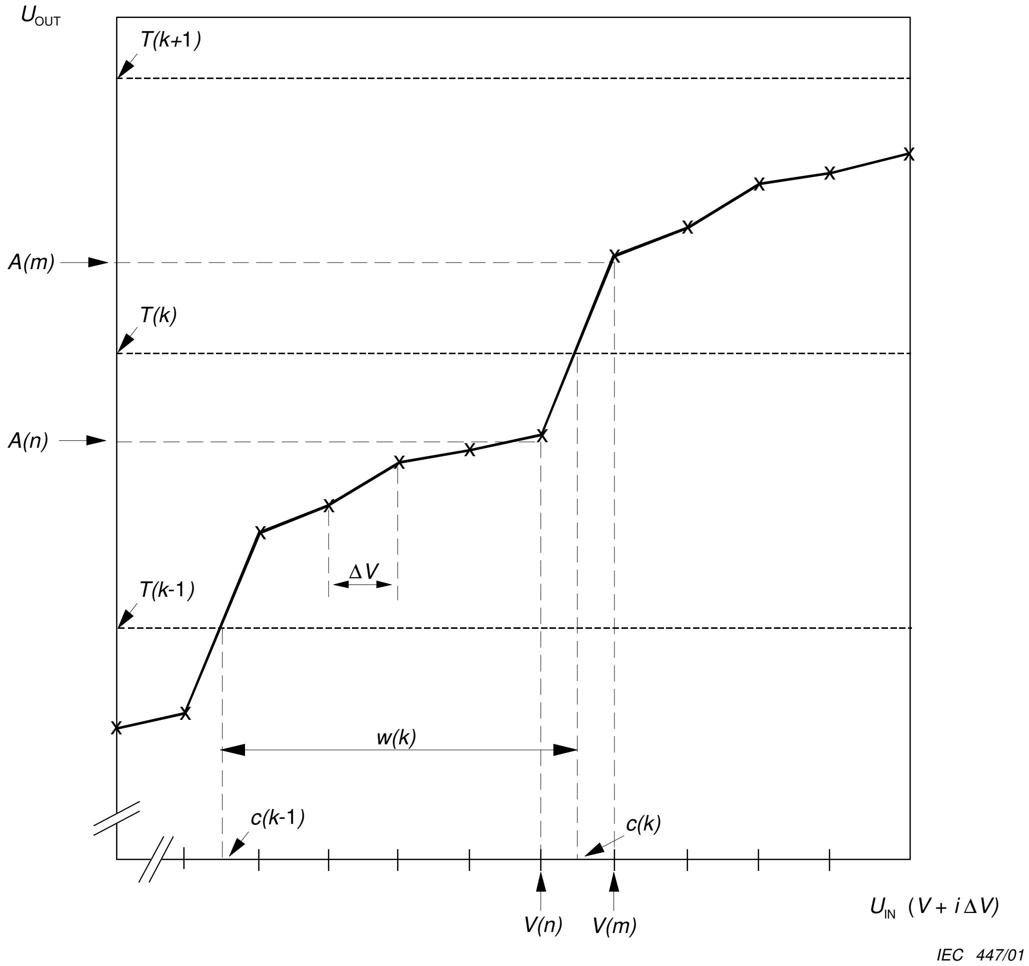
Convert the result into per cent of full scale:

$$S(k) = 100\,\% \times \frac{s(k)}{\max[A(i)] - \min[A(i)]}$$

Step I: Determine the **differential non-linearity** $d(k)$ under d.c. condition for each **code** bin from:

$$d(k) = \frac{w(k) - F_s}{F_s}$$

NOTE When **differential non-linearity** is within ±0,8, all **code bin widths**, $w(k)$, are within the range (1 ± 0,8) of the **average code bin width**, w_0, that is 0,2 w_0 < $w(k)$ < 1,8 w_0. In general the **differential non-linearity** varies from one **code** to another and is a function of the rate of change of the recorded signal.



Part of a measured **quantization characteristic** identifying *n, m, A(n), A(m), V(n)* and *V(m)*. The *k*th **code** transition threshold *c(k)* is where the line joining (*V(n), A(n)*) and (*V(m), A(m)*) intersects the *k*th threshold level *T(k)*.

Figure A.1 – Determination of non-linearities

Annex B
(normative)

Electromagnetic interference in high-voltage laboratories

B.1 General

The shielding of general-purpose instruments may not be adequate for use in a high-voltage laboratory. Interference may be induced by the transient electromagnetic field or conducted by either the signal or the supply lines.

Interference may attain high levels, especially in the case of chopped impulses. The following precautions will reduce such interference.

B.2 Precautions

B.2.1 Electromagnetic shielding

Interference due to electromagnetic fields penetrating direct into the instrument may be reduced by placing the instrument in a Faraday cage having sufficient attenuation in the frequency range of interest. Such a Faraday cage consists of a metal enclosure, which ensures conductivity across permanent and mobile joints. This metal enclosure may be a shielded control room or an instrument enclosure. The instrument enclosure may consist of two parts: one with high shielding efficiency (completely enclosing the instrument) which is required for real time recording of the impulse, and the other open to allow access to the computer, plotter, and printer which operate after the impulse.

B.2.2 Reduction of conducted interference from the supply line

Conducted interference on the mains supply can be reduced by inserting a filter (effective in the range from some tens of kilohertz to some tens of megahertz). An isolating transformer with low inter-winding capacitance should be interfaced between the instrument and the mains supply.

B.2.3 Reduction of interference on the signal line

Interference due to current flowing in the shield of the measuring cable may be reduced by an adequate earthing at the voltage divider side, by using triaxial cable with the outer shield grounded at both input and instrument ends, and/or by cable running through a metallic conduit connected at both ends to the local grounds. Inner and outer shields should be bonded at the input end. Avoiding loops between the measuring cable and the earth returns can also reduce interference.

Interference due to potential differences, induced or applied between the terminals of the measuring cable, may be reduced by using an input voltage as high as possible, namely by operating the instrument on its maximum range, or by inserting an external attenuator between the receiving end of the cable and the instrument.

B.2.4 Signal transmission by optical means

Signal transmission by optical means (either analogue or digital) may be used to reduce interference provided the characteristics of any such link are adequate to meet the requirements of IEC 60060-2.

B.3 Individual interference tests

These tests are made in order to check the sensitivity of the instrument to each of the different types of interference listed above.

The tests are not applicable if the instrument is operated in a well-shielded area (for example, in a shielded control room).

NOTE Current injection into the shield of measuring and control cables can be checked in the following ways.

The cables shall be connected to the instrument in the same way as for normal operation. The transient current to be injected into the shield of the cable should preferably have a main damped oscillation with a peak value of 100 A and a frequency of 1 MHz.

On this main oscillation is a superimposed oscillation of peak value of 10 A and frequency of 10 MHz to 20 MHz and a duration of not less than 10 ms. A possible test circuit is shown in figure B.1.

B.3.1 Transients superimposed on the power supply

A burst immunity test (level 3) shall be made for the power supply according to IEC 61000-4-4. The instrument passes the test when it keeps its performance within specification limits during the application of the burst.

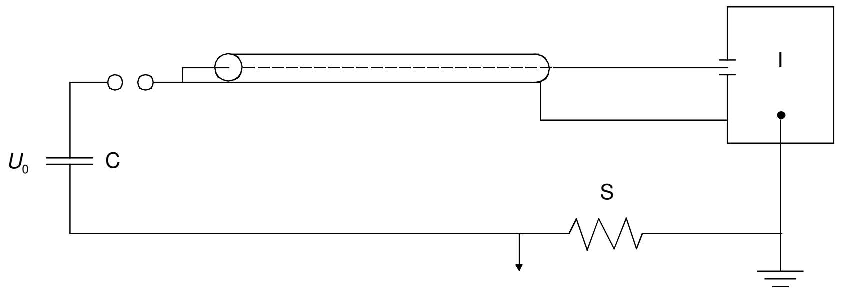
B.3.2 Application of electric and magnetic fields

The instrument without measuring cable, including any additional shielding added to it, shall be subjected to rapidly changing electric and magnetic fields representative of those produced by the HV test circuits. Tests in HV laboratories have indicated fields up to 100 kV/m and 1 000 A/m.

These fields may be obtained by the discharge of a capacitor via a sphere gap as shown in figure B.2.

For tests with electric field, the line connected to the capacitor shall be terminated by its surge impedance (R = Z). For tests with magnetic fields, the line connected to the capacitor shall be short-circuited (R = 0). The corresponding transient characteristics are determined by the parameters of that test circuit and are, for the voltage, a step with a rise-time of about 50 ns and, for the current, a damped oscillation with a frequency of about 0,5 MHz.

NOTE An oil or compressed gas immersed sphere gap may be used to check the instrument employed for monitoring impulse tests on SF_6 insulation. The corresponding voltage and current transients will show a shorter rise time (of a few nanoseconds) and a higher frequency initial oscillation (a few tens of megahertz), respectively.



Components

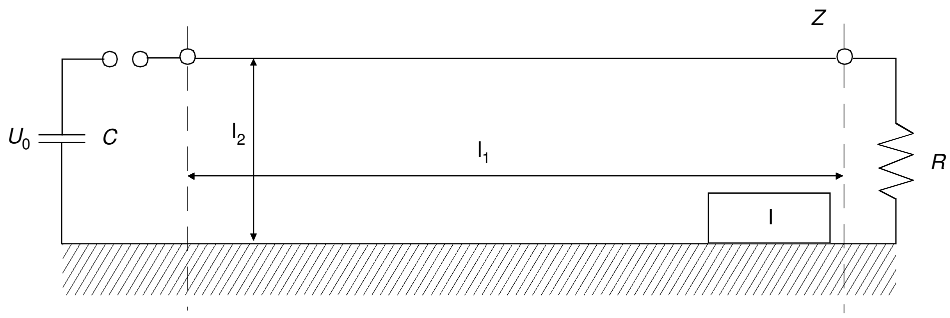
S = current measuring shunt

U_0 = charging voltage

I = instrument

C = capacitor

Figure B.1 – Current injection into the shield of the cable



Component

I = instrument placed at the end of the line

Z = Characteristic impedance: C = 20 nF; l_1 = 5 m; l_2 = 1 m
For the electric field test, U_0 = 40 kV ($R = Z$)
For the magnetic field test, U_0 = 100 kV (R = 0)

Figure B.2 – Application of electric and magnetic fields

Annex C
(normative)

Calibration method for analogue oscilloscopes – Separate calibration of voltage and time

The calibration consists of five traces, all obtained with the same setting of the time base as shown in figure 4.

Trace 1: The trace of the impulse

Trace 2: The trace of the time marks

Trace 3: The trace at zero input (the **base line**)

Trace 4: The trace of a direct input voltage U_1 being slightly smaller than the peak of trace 1

Trace 5: The trace of a direct input voltage U_2 being slightly larger than the peak of trace 1

The peak value and the time parameters of trace 1 are obtained from the records by interpolation.

Calibrators, whether internal or external, used in routine checks to determine the values of the deflection coefficients should have an uncertainty of not more than 0,5 % of each displayed calibration signal.

Annex D
(informative)

Analysis of impulse waveform

D.1 Analysis of the impulse waveform

The analysis of the impulse waveform requires the sequential determination from the mean curve of

a) baseline value and maximum (or minimum) of the mean curve;

b) peak value as their difference;

c) lines and points at 10 %, 30 %, 50 %, 70 % and 90 % of the peak value;

d) magnitude of all other waveform characteristics as computed differences between line and point pairs.

There are several ways to analyse analogue and digital records. These could be by use of software, cursors or analogue record such as plot, print or photograph. The method of processing that is used in testing shall be used in calibration.

Calibration records need not be retained but a summary of the results shall be retained, i.e. the mean values of the impulse parameters and the standard deviations.

In any methods used, the requirements in IEC 60060-1 as regards oscillations and overshoot superimposed on the waveshapes shall be fulfilled.

D.2 Mean curve of a digital record

The mean curve of a digital record may be determined in any one of a number of ways, for example, by fitting the record to a model, or by smoothing the data with a digital filter, etc. The techniques used shall be tested according to IEC 61083-2 and shall meet the relevant requirements specified therein.

D.3 Mean curve of an analogue record

A mean curve may be drawn by hand and modified until agreement is reached among the parties concerned in the test. Alternatively, the analogue record may be digitized and treated according to IEC 61083-2 and shall meet the relevant requirements specified therein.

D.4 Reference documents

IEC 61083-2:1996, *Digital recorders for measurements in high-voltage impulse tests – Part 2: Evaluation of software used for the determination of the parameters of impulse waveforms*

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

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 + corr. Mar.	1989 1990	High-voltage test techniques Part 1: General definitions and test requirements	HD 588.1 S1	1991
IEC 60060-2 A1 -	1994 1996 -	Part 2: Measuring systems	EN 60060-2 - A11	1994 - 1998
IEC 61000-4-4	1995	Electromagnetic compatibility (EMC) Part 4-4: Testing and measurement techniques - Electrical fast transient/burst immunity test	EN 61000-4-4	1995

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