IEEE Std 1122-1998
(Revision of
IEEE Std 1122-1987)

IEEE Standard for Digital Recorders for Measurements in High-Voltage Impulse Tests

Sponsor

Power Systems Instrumentation and Measurement Committee
of the
IEEE Power Engineering Society

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Abstract: This standard defines the terms specifically related to the digital recorders used for monitoring high-voltage and high-current impulse tests, specifies the necessary performance characteristics for such digital recorders to ensure their compliance with the requirements for high-voltage and high-current impulse tests, and describes the tests and procedures that are necessary to show that these performance characteristics are within the specified limits.
Keywords: digital oscilloscope, digital recorder, digitizer, high-impulse current, high-impulse voltage, impulse tests

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Introduction

(This introduction is not part of IEEE Std 1122-1998, IEEE Standard for Digital Recorders for Measurements in High-Voltage Impulse Tests.)

The first edition of this standard was published in 1987. The International Electrotechnical Commission (IEC) published an equivalent standard in 1991, IEC 1083-1, *Digital recorders for measurements in high-voltage impulse tests—Part 1: Requirements for digital recorders.* From the outset there has been close liaison between the two working groups and it was agreed that each working group would try to provide its parent organization with documents that were substantially and technically the same. Liaison has been maintained with Technical Committee 10 (TC 10) of the IEEE Instrumentation and Measurement Society, Waveform Measurement and Analysis. This edition of the standard incorporates comments and the responses to questions that have been received by the working group since 1987.

This standard states the performance requirements for an impulse digitizer and the tests necessary to verify that these performance requirements have been met. When an impulse digitizer is used and maintained in accordance with this standard it will meet the accuracy requirements specified in IEEE Std 4-1995.

This standard was developed by the P1122 Working Group of the Digital Techniques in Electrical Measurements Subcommittee of the Power Systems Instrumentation and Measurement Committee of the IEEE Power Engineering Society.

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Contents

IEEE Standard for Digital Recorders for Measurements in High-Voltage Impulse Tests

1. Scope

This standard is applicable to digital recorders and digital oscilloscopes used for measurements during tests with high-impulse voltages and high-impulse currents. It covers the measuring characteristics and calibrations required to meet the measuring accuracy specified in IEEE Std 4-1995 and IEEE Std C57.98-1993 [B10].[1]

The characteristics of general-purpose digital recorders are covered in IEEE Std 1057-1994 [B9]. General methods of pulse measurement are covered in IEC 60469-1 (1987-12) [B4] and IEC 60469-2 (1987-12) [B5].

This standard

a) Defines the terms specifically related to the digital recorders used for monitoring high-voltage and high-current impulse tests;
b) Specifies the necessary performance characteristics for such digital recorders to ensure their compliance with the requirements for high-voltage and high-current impulse tests;
c) Describes the tests and procedures that are necessary to show that these performance characteristics are within the specified limits.

2. References

This standard shall be used in conjunction with the following publication:

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.[2]

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[1]The numbers in brackets correspond to those of the bibliography in Annex A.
[2]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

3. Definitions

3.1 actual resolution (r_a): The logarithm to base 2 of the [(maximum value used, v_{max}, minus the value corresponding to the baseline, v_b)/(the standard deviation of the noise, σ_n times $\sqrt{12}$)].

$$r_a = \log_2\left(\frac{v_{max} - v_b}{\sigma_n \times \sqrt{12}}\right)$$

NOTE—The rated resolution is the maximum resolution that could be achieved when measuring an impulse whose peak-value is equal to the full-scale range and when there is no reduction in the effective resolution caused by non-ideal behavior of the digital recorder. Reductions in resolution caused by using less than full-scale deflection can be quantified (e.g., an 8-bit recorder has a rated resolution of 1 in 256). The resolution used to record an impulse is approximately 1 in (maximum value minus minimum value). For a (maximum minus minimum) value of 198 the number of bits is reduced to 7.63 (0.37 lost bits) while for a value of 98 the number of bits is equivalent to 6.61 (1.39 lost bits). The resolution is also reduced by noise and the total reduction in resolution gives an actual resolution which is the logarithm to base 2 of the [(maximum value minus minimum value)/(the standard deviation of the noise times $\sqrt{12}$)]; see equation 97 of IEEE Std 1057-1994 [B9].

3.2 automatically processed data: The data available from the digitizer when some processing function cannot be avoided.

3.3 average code bin width (W_o): The product of the full-scale value and the rated resolution.

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

3.4 code bin width of code k (W_k): The range of input voltage allocated to code k (see Figure 1).

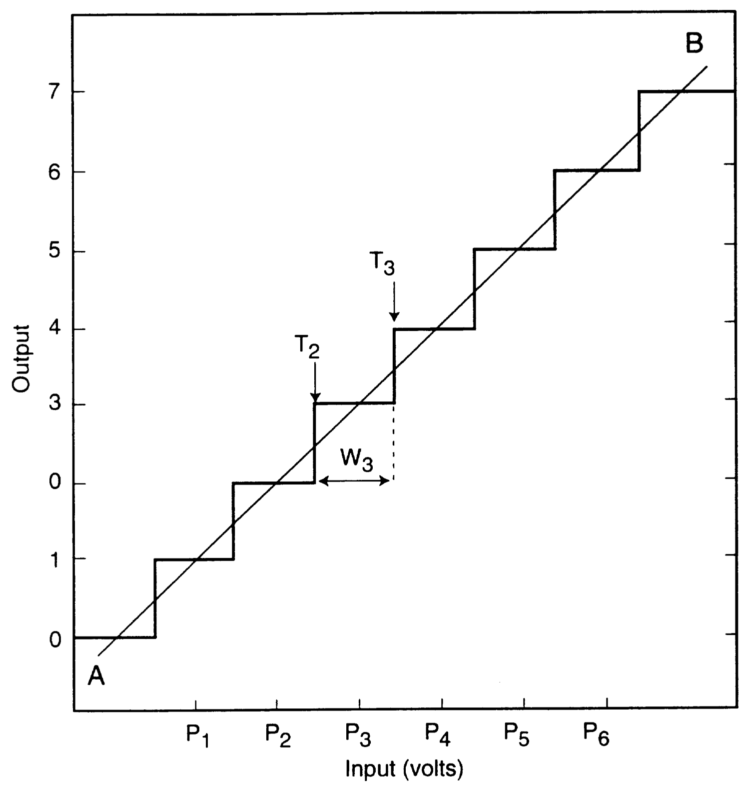

**Figure 1—Quantization characteristic of an ideal 3-bit digitizer—
Code transition thresholds (T_2 and T_3), a code bin width (W_3=W_o), nominal voltage (P_i) of each code and the straight line joining the mid-points of the code bins**

3.5 code k: An integer between 1 and 2^N (or between 0 and 2^{N-1}) where N is the number of bits.

3.6 differential nonlinearity (DNL): The difference between a measured code bin width and the average code bin width, divided by the average code bin width (see Figure 2).

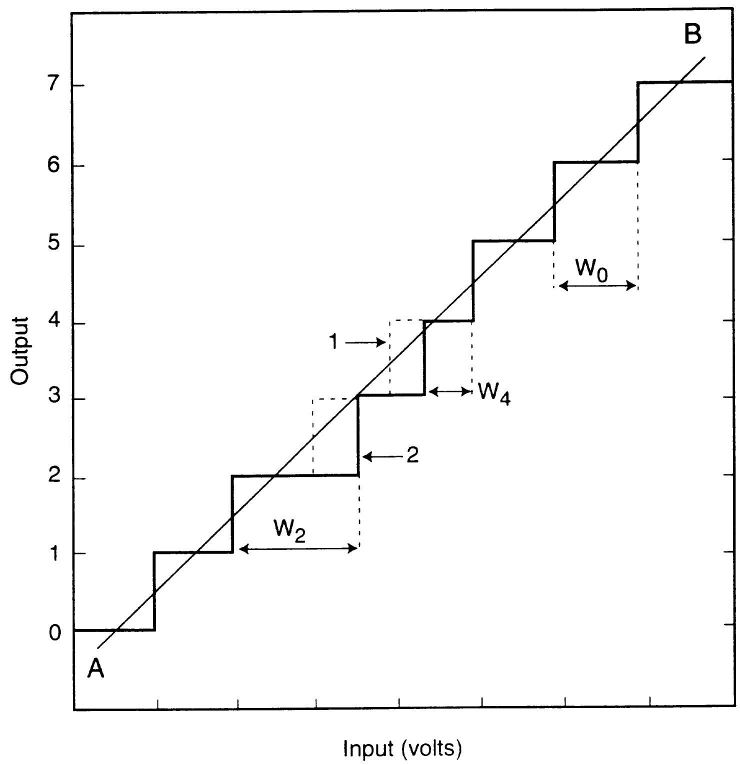

**Figure 2—Differential nonlinearity (DNL) for direct voltage—
Curve I, quantization characteristic of an ideal 3-bit digitizer; Curve II, quantization characteristic of a 3-bit digitizer with levels 2, 3, and 4 showing large DNL**

3.7 digital recorder for measurements in high-voltage impulse tests (impulse digitizer): An instrument that can make a temporary digital record of a scaled high-voltage or high-current impulse and can convert this temporary digital record to a permanent record (either analog or digital).

NOTE—An impulse digitizer contains an analog-to-digital converter, memory, and a timing circuit (a high-frequency clock and/or an analog sweep). It may be equipped with attenuators, amplifiers, display, output interface ports, and/or a controller. It has a permanent recording device (e.g., disc drive, digital cassette recorder, bubble memory, plotter, printer, and/or camera). It is protected against electromagnetic interference.

3.8 full-scale value (D_{fs}): The largest value of the actuating electrical quantity that can be indicated on the scale or, in the case of instruments having their zero between the ends of the scale, the full-scale value is the arithmetic sum of the values of the actuating electrical quantity corresponding to the two ends of the scale.

NOTE—For an impulse digitizer, the full-scale value is given by the minimum voltage that produces a change in the output corresponding to 2^N.

3.9 integral nonlinearity of the time-base: The difference between a known time interval and its measured value determined from the record as the product of the sample interval and the corresponding number (not necessarily integer) of samples.

3.10 notation: For raw data, each sample in the record of samples is denoted A_i where i gives the position of the sample in the record and A_i represents the value. [These values may be available as integers (e.g,. 231), values scaled by the instrument scale factor (e.g., 8.34 V), values scaled by the instrument scale factor including attenuators (e.g., 2.12 kV), or values scaled by the scale factor of the measuring system (e.g., 1.05 MV or 2.37 kA)]. The entire record of raw data is denoted by ***A***. Processed records are denoted by ***B***, ***C***, ***D***, etc.

3.11 offset: The output for zero input.

3.12 operating range: The range of input voltage for which the digital recorder can be used within the uncertainty limits given in this standard.

NOTE—The limits of the operating range are chosen by the user and verified by the performance tests specified in this standard. An example of an operating range is the range of inputs from 80% of D_{fs} to 100% of D_{fs}.

3.13 output of an impulse digitizer: The digital code allocated to the value of the input voltage at the instant of sampling.

3.14 oversampling: The sampling rate is greater than twice the highest significant frequency in the impulse.

NOTE—With oversampling, it may be possible to take the mean value of several consecutive samples to provide a more accurate estimate of the relevant amplitude (e.g., peak value).

3.15 quantization characteristic: The characteristic showing the relationship between the output of the impulse digitizer and the direct voltage input that produces this output (see Figure 1).

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

3.16 quantization error: The difference between the input voltage divided by the scale factor and the nearest digital code.

3.17 rated resolution (r): The reciprocal of two to the power of the number of bits (N):

$$r = 1/(2^N - 1)$$

3.18 raw data: Original record of sampled and quantized information obtained when a digital recorder converts an analog signal into digital form. This information may be made available in binary, octal, hexadecimal, or decimal 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 classed as raw data.

NOTE—Raw data are available from many digitizers but not all.

3.19 record length: The total number of samples that are stored in one record.

3.20 sampling interval variation: The experimental standard deviation of the time intervals between adjacent instants of sampling.

3.21 sampling rate: The number of samples taken per unit of time.

NOTE—The sampling rate is expressed in samples per second to distinguish it more clearly from quantities such as the analog bandwidth or the frequency of an analog input signal, which are expressed in hertz.

3.22 scale factor: The factor by which the output, corrected for offset, is multiplied in order to determine the measured value of the input quantity.

— Static scale factor (F_s): The scale factor for an input of direct voltage.
— AC scale factor (F_{ac}): The scale factor for an input of alternating voltage.
— Impulse scale factor (F_i): The scale factor for an input pulse similar in shape to the relevant standard impulse (see 6.2.5 and 8.1).

NOTE—The scale factor includes the ratio of any built-in attenuator and is determined by appropriate calibration.

3.23 static integral nonlinearity (I_s): The difference between corresponding points on the measured quantization characteristic and on the quantization characteristic calculated using the static scale factor (see Figure 3).

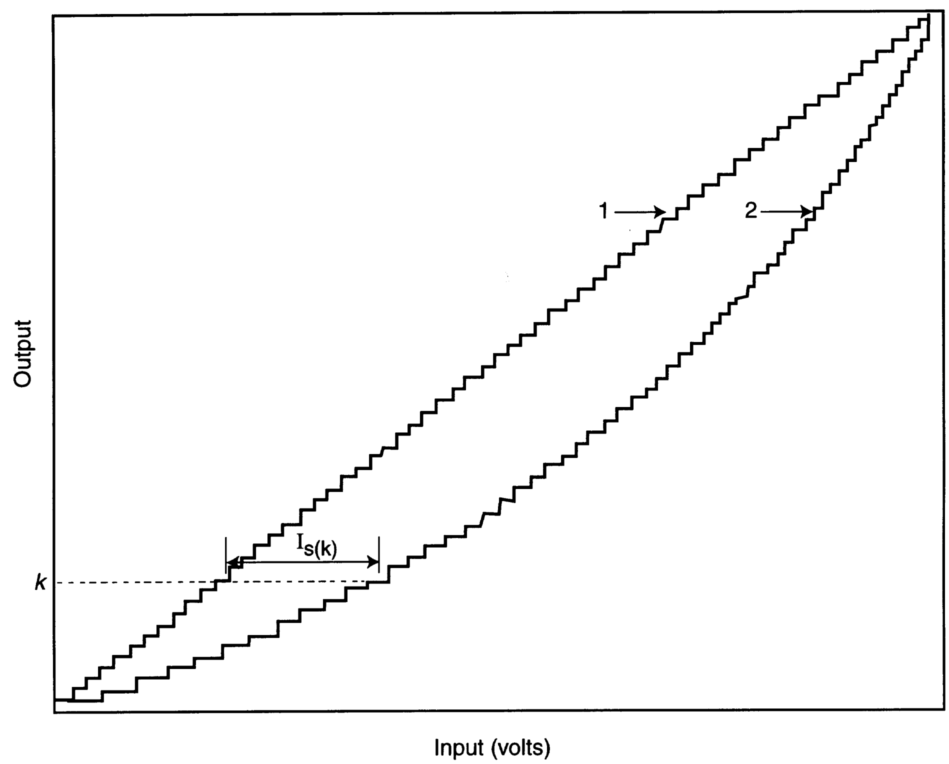

Figure 3—Static integral nonlinearity (I_s)—
Curve I, quantization characteristic of an ideal 6-bit digitizer [calculated using the static scale factor (F_s)]; Curve II, quantization characteristic of a very nonlinear 6-bit digitizer that has the same static scale factor (F_s)

3.24 warm-up time: The time interval from when the impulse digitizer is first switched on to when the instrument meets all the requirements.

NOTE—The warm-up time may be specified for reference conditions and may be considerably longer under adverse operating conditions.

4. Conditions of use

4.1 Range of operating conditions

The range of operating conditions under which the instrument should operate satisfactorily and should meet the accuracy requirements shall be stated in the record of performance. The ranges of ambient temperature, ambient relative humidity, and supply voltage (voltage and frequency) shall be listed.

NOTE—The supply voltage may have transient overvoltages superimposed on it; suitable precautions should be taken to prevent these from affecting the operation of the instrument.

4.2 Reference conditions

The reference conditions are those under which the instrument was calibrated; they shall be listed in the record of performance.

5. Analysis of the impulse waveform

This analysis is based on IEC 60469-1 (1987-12) [B4] and IEC 60469-2 (1987-12) [B5].

5.1 General

The analysis of the impulse waveform requires the sequential determination of the following:

a) Base magnitude and top magnitude;
b) Pulse amplitude;
c) Proximal (30%), mesial (50%), and distal (90%) lines and points;
d) Magnitudes of all other waveform characteristics as computed differences between line and point pairs.

5.2 Equivalent oscillogram method

A procedure for obtaining accurate measurements, which is equivalent to that approved in IEC 60469-2 (1987-12) [B5], is given below.

The calibration shall consist of three records obtained with the same sweep time and the same setting of the attenuator. These records should be plotted (see Figure 4), displayed, or printed.

— Record 1: The record of the impulse.
— Record 2: The record of a calibration pulse whose peak value is smaller than that of Record 1.
— Record 3: The record of a calibration pulse whose peak value is larger than that of Record 1.

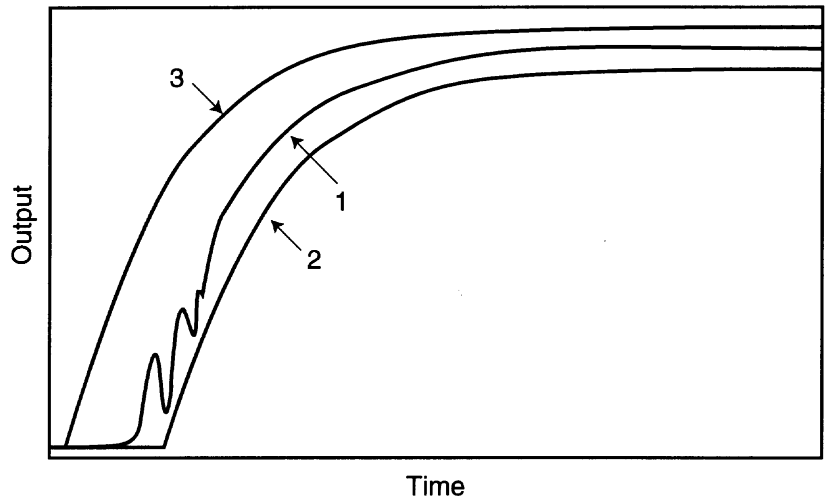

Figure 4—The equivalent oscillogram method applied to the first 3 μs of a full lightning impulse. Curve 1 is the recorded impulse. The calibration pulses, curves 2 and 3, are offset in time for clarity.

5.3 Procedures for reading digital records

These procedures exploit some of the advantages of digital records and apply to records of smooth impulses or to the mean curves drawn through impulses with oscillations.

5.3.1 Reading using a cursor

This procedure allows direct access to the digital record (time and amplitude), but the operator still uses judgment in evaluating the parameters.

5.3.2 Reading using numeric procedures

The reading accuracy can be increased using numeric procedures. Simple procedures for determination of base magnitude, top magnitude, and pulse amplitude are described because the determination of all other pulse waveform characteristics proceeds directly from these determinations.

a) Determination of the base magnitude as an average of several samples (no less than ten) of the initial flat part of the record that precedes the impulse;
b) Determination of the top magnitude of smooth full lightning impulses as the highest sample recorded;
c) Determination of pulse amplitude as the difference between the top magnitude and the base magnitude.

NOTE—More sophisticated procedures can be used to give further improvements in the reading accuracy. The IEC document on testing software is IEC 61083-2 (1996-07) [B7].

6. Accuracy requirements for impulse measurements

6.1 Limits on overall uncertainty

The overall uncertainty of the impulse digitizer shall be within

a) ±2.0% in the impulse peak voltage (current) measurement; and
b) ±4.0% in the measurement of the time parameters (front time, time to chopping, etc.) of the impulse.

Impulse digitizers shall meet these requirements without any signal processing of the raw data record for each voltage and time scale to be used in high-voltage tests. It is necessary to verify that the overall uncertainties meet the requirements of 6.1 by a performance test made according to 8.1 or 8.2.

If these requirements are met, then signal processing is permitted to enhance the reading accuracy. However, the raw data shall be retained for comparison with the processed data.

Digital recorders that automatically process data without option are not covered by this standard.

6.2 Limits on individual uncertainties

In order to stay within the limits given in 6.1, the limits for individual uncertainties given in 6.2 should usually be met. In some cases, one or more of these limits may be exceeded provided the permitted overall uncertainty is not exceeded. However, even when all the limits in this subclause are met, it is necessary to verify that the overall uncertainties meet the requirements of 6.1 by a performance test made according to 8.1 or 8.2.

NOTE—It is assumed that the sources of uncertainty considered in this standard have a random character and can be regarded as independent.

6.2.1 Sampling rate

The sampling rate shall be not less than $30/T_x$ samples/s where T_x is the time interval to be measured [e.g., when the front time (T_1) is to be determined then $T_x = 0.6\ T_1$ not T_1].

NOTE—For full lightning impulses, the permitted range of front times (±30% or from about 0.8 μs to about 1.6 μs) requires a sampling rate of at least 60 million samples/s (corresponding to the lower limit of T_x of 0.5 μs). However, if the range of front times is restricted to slower values, a slower sampling rate may be adequate (see Table 1).

To measure front oscillations, the sampling rate shall be not less than $4f_{max}$ where f_{max} is the maximum frequency that can occur in the test circuit.

NOTE—In the worst case, a sampling rate of $4f_{max}$ could lead to a measured value of the amplitude of an oscillation which is low by 0.3 of 5% of the peak value of the impulse (< 2%).

The minimum permitted sampling rate is given by the higher of the values determined from these requirements. Some examples are given in Table 1.

6.2.2 Limit on actual resolution

An actual resolution of 1% of the peak value is required for tests where only the impulse parameters are to be evaluated.

NOTE—For tests that require comparison of records, an actual resolution of 0.3% of the peak value is recommended unless the relevant Technical Committee has specified the actual resolution required or has specified a test that demonstrates the resolution is adequate [e.g., the shorted turn test (see IEEE Std C57.98-1993 [B10])].

Table 1—Examples of minimum sampling rates

Parameter to be evaluated	Nominal value	Value to be measured	Minimum required sample rate (million samples/s)
Front time	1000 ns	600 ns	50
Front time	1250 ns	750 ns	40
Front time	2000 ns	1200 ns	25
Time to peak	0.250 ms	0.250 ms	0.12
Maximum possible frequency	5 MHz	5 MHz	20
Maximum possible frequency	25 MHz	25 MHz	100

6.2.3 Accuracy of the reading process

Usually the parameters of impulses will be determined by processing the digital record; however, it is also acceptable to make a hard copy of the display of the impulse and calibration records and read this hard copy (e.g., a direct plot or a photograph of a display). In this case, the uncertainty caused by the method of reading the hard copy shall be less than ±1% of the read parameter.

6.2.4 Nonlinearity

6.2.4.1 Nonlinearity of amplitude

The static integral nonlinearity shall be within ±0.5% of D_{fs}.

The differential nonlinearity (DNL) shall be within ±0.8.

NOTE—When DNL is within ±0.8, all code bin widths, W_k, are within the range (1 ± 0.8) of the average code bin width, W_o, that is:

$$0.2\ W_o \leq W_k \leq 1.8\ W_o$$

In general, the differential nonlinearity varies from one code to another and is a function of the rate of change of the input signal. The DNL of each code, measured according to 7.1, shall lie within the specified limits.

6.2.4.2 Nonlinearity of time base

The integral nonlinearity of the time base shall be within ±2% of T_x, where T_x is the time interval to be measured. If the integral nonlinearity is between ±2% and ±0.5% of T_x, the time base shall be calibrated for each record. If the integral nonlinearity is within ±0.5% of T_x, only periodic calibration is needed.

The sampling interval uncertainty (the experimental standard deviation) shall be less than one-sixth of the sampling interval.

NOTE—This requirement is equivalent to requiring that the samples are taken at monotonically increasing times.

6.2.5 Time variation of the impulse scale factor

The variation of the impulse scale factor with time shall be less than ±1% from T_L to T_u. For double-exponential impulses, T_L shall be half the front time and T_u shall be twice the time to half-value. For rectangular impulses, T_L shall be half the nominal time when the impulse first reaches the 90% level and T_u shall be twice the nominal time when the impulse drops below the 90% level.

6.2.6 Rise time (t_r)

The rise time shall not be greater than $1/(2\pi f_{max})$. Furthermore, t_r shall be less than 0.03 T_C, where T_C is the shortest time to chopping which is to be measured (see IEEE Std 4-1995).

6.2.7 Internal noise level

The internal noise level as measured in 7.2 (the experimental standard deviation) shall be less than 0.5% D_{fs}.

NOTE—To achieve the actual resolutions recommended in some of the tests that require comparison of records, lower values of the internal noise may be needed (see 6.2.2).

6.2.8 Limits of interference

The maximum amplitude of any deflection from the base magnitude in the interference check (7.4) shall be less than 1% of the amplitude of the expected deflection for the impulse measurement. Greater values can be permitted if the interference occurs only in a time interval where it does not affect the accuracy of the measurement (i.e., before the 30% point).

6.2.9 Ripple from the dc power supply

The effects of any ripple from the dc power supply on the output of the impulse digitizer shall be less than ±0.5% D_{fs} for measurements of the waveform parameters and should be less than ±0.1% D_{fs} for comparative measurements.

6.2.10 Record length

The record length shall be sufficiently long to allow the required parameter (e.g., T_2 or T_P) to be evaluated, allowing for the selected mode of operation. Specific record lengths should be specified by the relevant Technical Committee.

NOTE—This requirement may be met by several modes of operation. For example,

> If only one sampling rate is used, then the record should be sufficiently long to meet the requirements of 6.2.1 (e.g., to measure a time to half-value of 60 µs at a sample rate of 60 million samples/s, a record length of more than 3600 words is needed).
>
> If two sampling rates are used within one record, the front of the impulse may be sampled at a rate that satisfies 6.2.1 and the tail may be sampled at a slower rate provided this rate at least gives equivalent time resolution to that provided by conventional oscilloscopes (e.g., 1200 words taken at 100 million samples/s followed by 800 words taken at 10 million samples/s is adequate for most full lightning impulse tests).
>
> If two successive records are used, then one may be taken at a sampling rate that satisfies 6.2.1 and the other may be taken at a slower rate provided this rate at least gives equivalent time resolution to that provided by conventional oscilloscopes (e.g., a record of 1000 words taken at 100 million samples/s followed by another record of 1000 words taken at 10 million samples/s). This mode is not acceptable for some tests.

Explicit requirements for the time and amplitude resolution needed to detect dielectric failures should be specified by the relevant Technical Committee.

6.3 Input impedance

Depending on the type of measuring device used (e.g., resistor dividers, capacitor dividers, etc.), the input impedance of the impulse digitizer should match the impedance of the coaxial cable or be greater than or equal to 1 MΩ with not more than 50 pF in parallel.

7. Acceptance tests

Acceptance tests shall be performed on each new impulse digitizer and after any major repair.

7.1 Differential nonlinearity (impulse conditions)

A symmetrical triangular wave of slope *S* whose amplitude is within ±5% of 95% of the full-scale value shall be applied to the input of the digital recorder (it is not necessary to test external, passive attenuators for differential nonlinearity). *S* shall be not less than $D_{fs}/(0.4\ T_x)$. The frequency of the triangular wave shall not be harmonically related to the sampling frequency. A record shall be stored and a histogram of the occurrence of every digital level shall be calculated. This shall be repeated *M* times and the cumulative histogram shall be calculated. *M* shall be large enough so that the average value of the occurrences in the cumulative histogram is not less than 100. This procedure will usually produce a histogram with large peaks on each side of an approximately uniform distribution. The analysis is restricted to this approximately uniform part. However, this uniform part shall correspond to at least 80% D_{fs}. The deviation of each point from the mean value over this approximately uniform part divided by this mean value is an adequate approximation of the DNL.

NOTE —Any nonlinearity in the input will contribute to the measured DNL. However, because of the large limits on DNL, it may be possible to use an approximate triangular wave or to use a sinusoid with the peaks clipped, provided the clipped portion is not included in the analysis.

7.2 Internal noise level

A direct voltage within the range of the impulse digitizer shall be applied. Enough records shall be taken to acquire at least 1000 samples. The standard deviation of these samples is an adequate approximation of the internal noise level.

7.3 Rise time

A step with a rise time that is short compared to the nominal rise time of the impulse digitizer shall be applied. The amplitude of the applied step shall be between 90% D_{fs} and 100% D_{fs}. The rise time shall be taken as the time from when the response crosses 10% of the settling level to when it crosses 90% of the settling level.

7.4 Interference test

This check is made to ensure adequate immunity to interference of the impulse digitizer in a given measuring circuit under given operating conditions. During this interference check, the measuring circuit (grounding, routing of measuring cable, control cables, and power cables) and the high-voltage circuit (position of the impulse generator, front capacitor, chopping devices, voltage divider) shall be as close as possible to the high-voltage test conditions, but the test object need not be included. The measuring cable shall be either short-circuited or terminated by its characteristic impedance at the input end (whichever best represents test conditions) and grounded in the same way as for the normal measurement. Care should be taken that the impulse digitizer is triggered at the appropriate time.

The generator is first charged to produce the test impulse and then fired. A record is taken and evaluated. The test shall be performed with each type of impulse that is to be used in the tests.

7.5 Ripple

A direct voltage within the measuring range of the impulse digitizer shall be applied. A record at a sufficiently slow sample rate to span one cycle of power frequency shall be taken. The record may be filtered to remove high-frequency noise. The amplitude of the ripple is taken as half the peak-to-peak variation of the filtered record. An alternative test, used when the digitizer does not have a slow enough sample rate to span one cycle of power frequency, is as follows: A large number (not less than 200) records of about 100 µs duration shall be taken. These records should be taken randomly relative to power frequency. The mean value of each record shall be taken. The amplitude of ripple is taken as half the peak-to-peak variation of the averages.

7.6 Integral nonlinearity

7.6.1 Amplitude

Values of the scale factor (either static or impulse) of the digital recorder shall be measured at the minimum and maximum voltages of the operating range and at three approximately equally-spaced voltages between these extremes. Each of these five values shall be within ±1% of its mean value.

7.6.2 Time-base

Values of the time scale factor shall be measured at approximately 20%, 40%, 60%, 80%, and 100% of the sweep. Each of these five values shall be within ±1% of its mean value.

8. Performance tests

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

The impulse scale factor shall be measured and the time scale shall be checked by the reference method according to 8.1. Alternatively the tests in 8.2 may be used. These performance tests shall be made on all voltage and time scales that are to be used for recording high-voltage impulses. All calibration equipment shall be traceable, either directly or indirectly, to international or national standards.

8.1 Pulse calibration

The requirements on values and limits on their variation with time for a standard pulse calibrator are given in Table 2. The long-term variation (drift) is the experimental standard deviation of the mean of the values determined in calibrations of the pulse calibrator repeated at regular intervals (about 1 year). The short-term variation is the experimental standard deviation determined from 20 repeated measurements made in a short time (about 15 min or less).

Wave shapes are chosen from those given in Table 2, according to the type of impulse to be measured. The peak value and time parameters of the applied calibration pulse shall be within the limits given in Table 2 and the actual values shall be entered in the record of performance. At least 20 pulses shall be recorded.

Table 2—Requirements for a standard pulse calibrator

Impulse type	Parameter being measured	Range for calibration	Long-term variation (%)	Short-term variation (%)
Full and tail-chopped lightning	Front time	0.8–0.9 µs	< ± 2	< ± 0.2
Full and tail-chopped lightning	Time to half-value	50–60 µs	< ± 2	< ± 0.5
Front-chopped lightning	Time to chopping	0.5–0.6 µs	< ± 2	< ± 1
Switching	Time to peak	200–300 µs	< ± 2	< ± 0.2
Switching	Time to half-value	2500–4000 µs	< ± 2	< ± 0.2
Rectangular	Rise time	0.7–0.8 T_r	< ± 2	< ± 0.2
Rectangular	Duration (T_D)	1.1–1.2 T_D	< ± 2	< ± 0.2
All impulses except front-chopped	Peak value	0.8–1.0 D_{fs}	< ± 0.5	< ± 0.1
Front-chopped	Peak value	0.8–1.0 D_{fs}	< ± 1.0	< ± 0.2

The peak values of these pulses shall be evaluated. All peak values shall be within ±1% of the mean value. The quotient of the input peak value in volts and the mean recorded peak value is taken as the impulse scale factor.

The time parameters of these pulses shall be evaluated. All values of each time parameter shall be within ±2% of the mean value for that parameter. If a single sampling rate is used, the quotient of the input value of each parameter and the mean recorded value of that parameter is taken as the time scale factor. If two sampling rates are used within one record, then the mean values of parameters that are evaluated using both sample rates shall be within ±2% of the input value.

The constancy of the impulse scale factor shall be checked by taking the step response of the impulse digitizer and verifying that it does not vary by more than ±1% from T_L to T_u.

8.2 Alternative method

The tests of 8.2.1 and 8.2.2 may be performed in lieu of 8.1.

8.2.1 Step calibration

A known direct voltage, V_c (±0.1%), in the range 0.8 D_{fs} ± 20%, shall be applied to the input of the impulse digitizer and then the input terminal shall be shorted to ground by an appropriate switching device (e.g., a mercury-wetted relay). The resulting transition to zero level is recorded and the recorded step is evaluated as the difference between the output before the transition and the output at each sample after the transition D(t) (see Figure 5). The quotient, $F_i(t)$, of V_c and D(t) at each sample after the transition is taken as the value of the response at that sample. $F_i(t)$ shall not vary by more than ±1% from T_L to T_u (see 6.2.5). The average value of $F_i(t)$ from T_L to T_u shall be taken as the impulse scale factor (F_i). A mean value of F_i shall be determined from 20 records of the step.

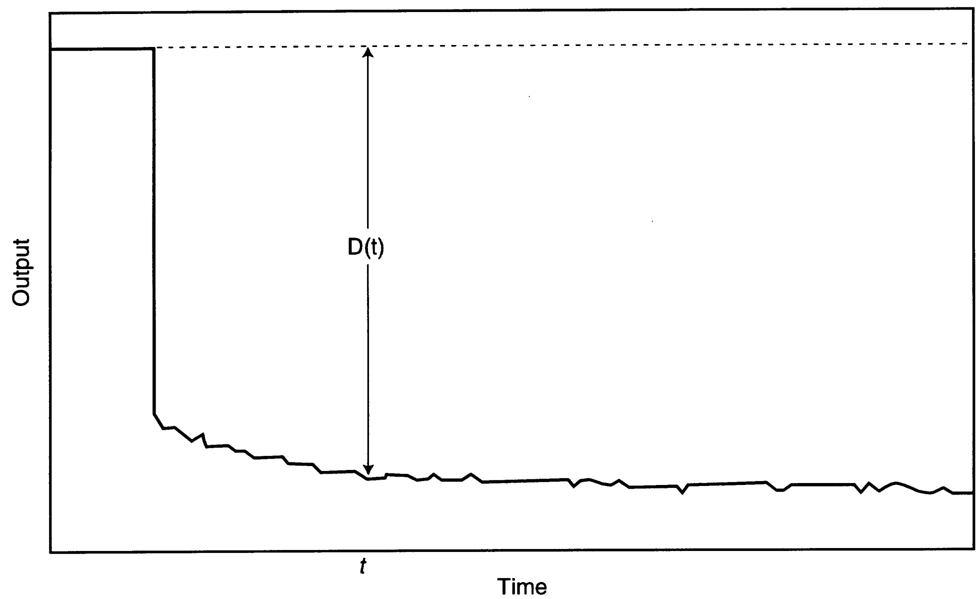

Figure 5—Step response of an impulse digitizer illustrating the definition of the difference D(t)

8.2.2 Time calibration

The output from a time mark generator, or a high-frequency oscillator, shall be applied to the input of the digitizer and a record shall be taken. The accuracy and stability of the calibrator shall be within ±0.1%. The frequency shall be chosen such that sufficient time marks, or cycles, shall be recorded to verify the requirements of 6.2.4.2.

NOTE—This test is adequate to establish that the time base of the instrument meets the requirements of 7.1. However, some digitizers have very precise clock-controlled sampling that can be utilized in some applications; verification of such precise sampling is beyond the scope of this standard and reference should be made to IEEE Std 1057-1994 [B9].

9. Performance checks

9.1 General

Performance checks shall be made at short intervals based on the record of performance. It is recommended that performance checks should be made at the beginning of each daily period of use (i.e., after the warm-up time and before the impulse digitizer is switched off).

The performance checks may be made according to 9.2 or 9.3.

If the performance checks reveal instability of the impulse digitizer, then the cause of the instability shall be investigated and a performance test shall be made.

9.2 Pulse calibration

It is recommended that pulse calibration as described in 8.1 be used as the sole performance check of the impulse digitizer. With this method, both amplitude and time measurements can be verified directly.

9.3 Alternative check

The tests in 8.2.1 and 8.2.2 can be used to verify amplitude and time measurements. If it is shown that the static and impulse scale factors are equal, direct voltage calibration may be used in place of the test in 8.2.1.

10. Record of performance

The record of performance shall include the following information:

a) Nominal characteristics
   1) Rated resolution
   2) Range of sampling rates and/or sweep times
   3) Maximum record lengths
   4) Memory management features
   5) Value and duration of the maximum input voltage
   6) Warm-up time
   7) Method of reading the output used to obtain the record of performance
   8) Range of operating conditions
   9) Range of reference conditions
b) Results of routine tests
   1) Integral nonlinearity
   2) Differential nonlinearity
   3) Sampling interval uncertainty
   4) Rise time
   5) Record of the internal noise test
   6) Record of the ripple test
   7) Record of the interference check
c) Results of performance tests
   1) Each static scale factor (if measured)
   2) Each impulse scale factor
   3) Each time scale factor
d) Results of performance check
   1) Date and time of each performance check
   2) Result: pass/fail (if fail, record of action taken)

Annex A

(informative)

Bibliography

[B1] IEC 60060-1 (1989-11) High-voltage test techniques. Part 1: General definitions and test requirements.[3]

[B2] IEC 60060-2 (1994-11) High-voltage test techniques. Part 2: Measuring systems.

[B3] IEC 60060-2-am1 (1996-03), Amendment No. 1 to IEC 60060-2.

[B4] IEC 60469-1 (1987-12), Pulse techniques and apparatus. Part 1: Pulse terms and definitions.

[B5] IEC 60469-2 (1987-12), Pulse techniques and apparatus. Part 2: Pulse measurement and analysis, general considerations.

[B6] IEC 60790 (1984-12), Oscilloscopes and peak voltmeters for impulse tests.

[B7] IEC 61083-2 (1996-07), Digital recorders for measurements in high-voltage impulse tests—Part 2: Evaluation of software used for the determination of the parameters of impulse waveforms.

[B8] IEEE Std 522-1992, IEEE Guide for Testing Turn-to-Turn Insulation on Form-Wound Stator Coils for Alternating Current Rotating Electric Machines.

[B9] IEEE Std 1057-1994, IEEE Standard for Digitizing Waveform Recorders.

[B10] IEEE Std C57.98-1993, IEEE Guide for Transformer Impulse Tests.

[3]IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.