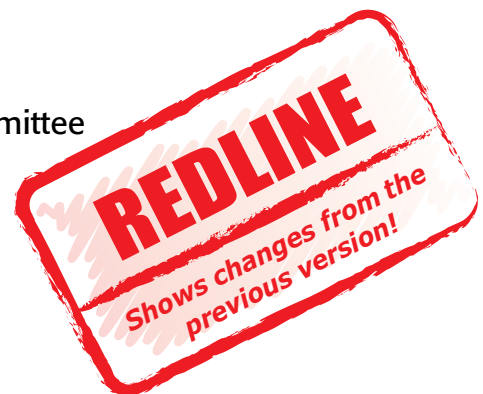


IEEE Standard for High-Voltage Testing Techniques

IEEE Power and Energy Society

Sponsored by the
Power System Instrumentation and Measurements Committee



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USA

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IEEE Standard for High-Voltage Testing Techniques

Sponsor

Power System Instrumentation and Measurements Committee
of the
IEEE Power and Energy Society

Approved 6 March 2013

IEEE-SA Standards Board

Abstract: Standard methods and basic techniques for high-voltage testing applicable to all types of apparatus for alternating voltages, direct voltages, lightning impulse voltages, switching impulse voltages, and impulse currents are established in this standard. Sections that deal with alternating voltage, direct voltage, and impulse testing are combined in this revision to organize the technical content for ease of use. In addition, the concept of measurement uncertainty in evaluation of high-voltage and high-current tests is introduced in this version.

Keywords: atmospheric corrections, high-current testing, high-voltage measurements, high-voltage testing, IEEE 4TM, impulse currents, impulse voltages, testing

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Introduction

This introduction is not part of IEEE Std 4-2013, IEEE Standard for High-Voltage Testing Techniques.

The current revision of this standard is the eighth edition of this document as a separate standard. The subject had been addressed in the earliest standardization report of the American Institute of Electrical Engineers (AIEE) in 1889 and had been substantially elaborated upon in the subsequent reports issued from 1902 to 1933. When it was decided, in 1922, to reorganize the AIEE's standards into separate sections, the measurement of test voltages became one of the first subjects to be designated for a separate publication. The first edition was published in 1928.

This standard establishes standard methods and basic techniques for high-voltage testing. The standard is applicable to all types of apparatus for alternating voltages, direct voltages, lightning impulse voltages, switching impulse voltages, and impulse currents.

The following standards have been used to prepare this document:

IEC 60052, Recommendations for voltage measurement by means of standard air gaps.

IEC 60060-1, High-voltage test techniques—Part 1: General definitions and test requirements.

IEC 60060-2, High-voltage test techniques—Part 2: Measuring systems.

IEC 60060-3, High-voltage test techniques—Part 3: Definitions and requirements for on-site testing.

IEC 60270, Partial discharge measurements.

IEC 60507, Artificial pollution tests on high-voltage insulators to be used on a.c. systems.

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

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

IEC 61245, Artificial pollution tests on high-voltage insulators to be used on d.c. systems.

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

ISO/IEC Guide 98-3, Uncertainty of measurement—Part 3: Guide to the expression of uncertainty in measurements (GUM).

For ease of use, this revision organizes the technical content in such a way as to combine sections that deal with alternating voltage, direct voltage, and impulse voltage testing. In addition, this version introduces the concept of measurement uncertainty in evaluation of high-voltage and high-current tests.

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1. Overview

1.1 Scope

This standard is applicable to:

- Dielectric tests with direct voltages
- Dielectric tests with alternating voltages
- Dielectric tests with impulse voltages
- Tests with impulse currents
- Tests with combinations of the above
- Capacitance and dielectric loss measurements

This standard is applicable only to tests on equipment with a rated voltage above 1000 V.

Procedures are given for applying correction factors to convert test data to standard atmospheric conditions.

This standard also specifies procedures for testing equipment when external insulation of the test object is to be subjected to dry, wet, or contaminated conditions.

1.2 Purpose

The purpose of this standard is to:

- Define terms of general applicability
- Present general requirements regarding test equipment and procedures
- Describe methods for evaluation of test results

1.3 Application

The methods of measurement and testing techniques described in this standard are generally applicable to all types of apparatus. Alternative test procedures may be required or permitted by the ~~appropriate~~[relevant](#) apparatus committee standards.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in the text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI/IEEE C2 National Electrical Safety Code (NESC).

ANSI/IEEE Std 510™-1983, IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing.

IEC 60270, High-Voltage Test Techniques—Partial discharge measurements.

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

NFPA 70E—Standard for Electrical Safety in the Workplace

~~This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.~~

¹IEEE Standards Dictionary Online subscription is available at:

http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

~~ANSI C39.1-1981 (Reaff. 1992), American National Standard Requirements for Electrical Analog Indicating Instruments.¹~~

~~IEEE Std 1122-1987, IEEE Standard for Digital Recorders for Measurement in High Voltage Impulse Tests (ANSI)²~~

~~IEEE Std C57.113-1991, IEEE Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.~~

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹

accuracy: The degree of agreement between a measured value and the true value.

approved measuring system: A measuring system that is shown to comply with one or more of the sets of requirements described in this standard by:

- an initial acceptance test
- successive performance checks and performance tests
- inclusion of the results of these tests in the record of performance²

² The system is approved only for the arrangements and operating conditions included in its record of performance.

¹~~ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.~~

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.~~

assured disruptive discharge voltage: The prospective value of the test voltage that causes disruptive discharge under specified conditions.

~~3.3 chopped lightning impulse: A prospective full lightning impulse during which any type of discharge causes a rapid collapse of the voltage.~~

conventional deviation of the disruptive discharge voltage (z): The difference between the 50% and 16% disruptive discharge voltages.

NOTE— It is often expressed in per unit or percentage value referred to the 50% disruptive discharge voltage.

dielectric loss factor: The factor by which the product of a sinusoidal alternating voltage applied to a dielectric and the component of the resulting current having the same period as the voltage have to be multiplied in order to obtain the power dissipated in the dielectric.

discharge: The passage of electricity through gaseous, liquid, or solid insulation.

disruptive discharge: A discharge that completely bridges the insulation under test, reducing the voltage between the electrodes practically to zero. Syn: electrical breakdown.

disruptive discharge probability (p): The probability that one application of a prospective voltage of a given shape and type will cause a disruptive discharge.

disruptive discharge voltage: The voltage causing the disruptive discharge for tests with direct voltage, alternating voltage, and impulse voltage chopped at or after the peak; the voltage at the instant when the disruptive discharge occurs for impulses chopped on the front.

error: The difference between the measured value of a quantity and the true value of that quantity under specified conditions.

external insulation: The air insulation and the exposed surface of the solid insulation of a piece of equipment, which are subject to both electrical stress and the effects of atmospheric and other conditions such as contamination, humidity, vermin, etc.

fifty percent disruptive discharge voltage (V_{50}): The prospective value of the test voltage that has a 50% probability of producing a disruptive discharge.

flashover: A disruptive discharge over the surface of a solid insulation in a gas or liquid.

~~3.13 full lightning impulse: A lightning impulse not interrupted by any type of discharge.~~

impulse: An intentionally applied transient voltage or current that rises rapidly to a peak value and then falls more slowly to zero.

~~3.16 instant of chopping: The instant when the initial discontinuity appears.~~

internal insulation: Insulation comprising solid, liquid, or gaseous elements, which are protected from the effects of atmospheric and other external conditions such as contamination, humidity, vermin, etc.

~~3.18 lightning impulse: An impulse with front duration up to a few tens of microseconds.~~

nondisruptive discharge: A discharge between intermediate electrodes or conductors in which the voltage across the terminal electrodes is not reduced to practically zero.

nonself-restoring insulation: Insulation that loses its insulating properties or does not recover them completely after a disruptive discharge.

nonsustained disruptive discharge: A momentary disruptive discharge.

~~3.22 overshoot: The value by which a lightning impulse exceeds the defined crest value.~~

partial discharge: A discharge that does not completely bridge the insulation between electrodes.

~~See: IEEE Std C57.113-1991.³~~

~~3.24 peak value of alternating voltage: The maximum value, disregarding small high-frequency oscillations (greater than 10 kHz) such as those arising from partial discharges.~~

~~3.25 peak value of impulse voltages: The maximum value of impulses that are smooth double exponential waves without overshoot.~~

p -percent disruptive discharge voltage (V_p) : The prospective value of the test voltage that has a p -percent probability of producing a disruptive discharge.

~~3.27 precision: The discrepancy among individual measurements.~~

prospective characteristics of a test voltage causing disruptive discharge: The characteristics of a test voltage that would have been obtained if no disruptive discharge had occurred.

puncture: A disruptive discharge through solid insulation.

random error: The result of a measurement minus the mean that would result from an infinite number of measurements of the same measurand carried out under repeatable conditions. ~~Errors that have unknown magnitudes and directions and that vary with each measurement.~~

NOTE 1—Random error is equal to error minus systematic error.

NOTE 2—Because only a finite number of measurements can be made, it is possible to determine only an estimate of random error.

record of performance of a measuring system: A detailed record, established by the user, describing the system and containing evidence that the requirements given in this standard have been met. This evidence shall include the results of the initial acceptance test and the schedule and results of each subsequent performance test and performance check.

reference measuring system: A measuring system having sufficient accuracy and stability for use in the approval of other systems when making simultaneous comparative measurements with specific types of waveforms and ranges of voltage.

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

~~**response (C):** The output, as a function of time or frequency, when a step input voltage or current is applied to the system.~~

response time (T): A quantity that is indicative of the speed with which a system responds to changing voltages or currents.

~~**3.33 root-mean-square (rms) value of alternating voltage:** The square root of the mean value of the square of the voltage values during a complete cycle.~~

scale factor of a measuring system: The factor by which the output indication is multiplied to determine the measured value of the input quantity or function.

self-restoring insulation: Insulation that completely recovers its insulating properties after a disruptive discharge.

sparkover: A disruptive discharge between electrodes in a gas or liquid.

standard deviation of the disruptive discharge voltage of a test object (s): A measure of the dispersion of the disruptive discharge voltage estimated by:

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (V_i - V_a)^2}$$

where

V_i is the i^{th} measured disruptive discharge voltage

V_a is the arithmetic mean of the disruptive discharge voltages (in most cases it is identical to V_{50})

n is the number of observations (discharges)

NOTE 1—It can also be evaluated by the difference between the 50% and 16% disruptive discharge voltages (or between the 84% and 50% disruptive discharge voltages). It is often expressed in per unit or percentage value referred to the 50% disruptive discharge voltage.

NOTE 2—For successive disruptive discharge tests, the standard deviation s is defined by the above formula. For multiple level up-and-down tests, it is defined by the difference of the quantiles. The methods are equivalent because, between $p = 16\%$ and $p = 84\%$, all probability distribution functions are nearly equal.

~~3.37 standard chopped lightning impulse: A standard lightning impulse chopped by an external gap after 2–5 ps.~~

~~3.38 standard lightning impulse: A full lightning impulse having a virtual front time of 1–2 ps and a virtual time to half value of 50 ps.~~

step response $g(t)$: The normalized output as a function of time t when the input is a voltage or current step.

surge: A transient voltage or current, which ~~usually~~ rises rapidly to a peak value and then falls more slowly to zero, occurring in electrical equipment or networks in service.

~~3.41 switching impulse: An impulse with a front duration of some tens to thousands of microseconds.~~

systematic error: The mean that would result from an infinite number of measurements of the same measurand carried out under repeatable conditions minus a true value of the measured ~~Errors where the magnitudes and directions are constant throughout the calibration~~

NOTE 1—Systematic error is equal to error minus random error.

NOTE 2—Like true value, systematic error and its causes cannot be completely known.

transfer function $H(f)$: The quantity $Y(f)$ divided by $X(f)$, where $Y(f)$ and $X(f)$ are the frequency domain representations of the output and input signals respectively.

type A evaluation of uncertainty: A method of evaluation of uncertainty by the statistical analysis of a series of observations.

type B evaluation of uncertainty: A method of evaluation of uncertainty by means other than the statistical analysis of a series of observations.

uncertainty: An estimated limit based on an evaluation of the various sources of error.

undershoot: The peak value of an impulse voltage or current that passes through zero in the opposite polarity of the initial peak.

~~3.46 value of the test voltage for alternating voltage: The peak value divided by the square root of 2, or the rms value as defined by the appropriate apparatus standard.~~

~~3.47 value of the test voltage for lightning impulse voltage:~~ The peak value when the impulse is without overshoot or oscillations. See clause 7 for further explanation.

~~3.48 virtual front time of a lightning impulse (T_f):~~ The time interval between the instants when a smooth impulse is 30% and 90% of the peak value multiplied by 1.67. See clause 7 for further explanation.

~~3.49 virtual origin (O_f):~~ The intersection with the time axis of a straight line drawn as a tangent to the steepest portion of the impulse or response curve. See 7.1.4 and 13.4.6.1 for further explanation.

~~3.50 virtual time to half value (T_2):~~ The time interval between the virtual origin and the instant on the tail when the voltage has decreased to half of the peak value.

~~3.51 voltage at the instant of chopping:~~ The voltage at the instant of the initial discontinuity.

voltage ratio of a voltage divider: The factor by which the output voltage is multiplied to determine the measured value of the input voltage.

withstand probability (q): The probability that one application of a prospective voltage of a given shape and type will not cause a disruptive discharge.

withstand voltage: The prospective value of the test voltage that equipment is capable of withstanding when tested under specified conditions.

4. Safety Awareness

WARNING

For all tests involving hazardous voltage levels, special attention shall be paid to ensure the safety of all personnel. Personnel safety is of utmost importance during all testing procedures. All equipment tests shall be performed on de-energized and isolated systems. Appropriate safety practices shall be followed. Where applicable, the safety practices shall include, but not be limited to, the following requirements:

- 1) Applicable user safety operating procedures.
- 2) ANSI/IEEE Std 510-1983, IEEE Recommended Practices for Safety in High-Voltage and High-Power Testing.
- 3) ANSI/IEEE C2 National Electrical Safety Code (NESC).
- 4) NFPA 70E—Standard for Electrical Safety in the Workplace.
- 5) Applicable national, state and local safety operating procedures.
- 6) Protection of utility and customer property.

5. General requirements for high-voltage tests and measurements

5.1 Normal environmental conditions

For high-voltage testing, in addition to a clean and dry environment, the following conditions are considered normal:

Temperature: 10 °C to 40 °C

Relative humidity: less than 95% non-condensing

Altitude: less than 1000 m

High-voltage tests and measurements performed in other than normal conditions may require special equipment and considerations.

5.2 Arrangement of the test object

5.2.1 General arrangement

The electrical discharge characteristics of a test object may be affected by its general arrangement. For example, its clearance from other energized or grounded structures, its height above ground level, and the arrangement of the high-voltage lead may affect the ~~flashover~~disruptive discharge voltage. For this reason, the general arrangement should be specified by the ~~appropriate~~relevant apparatus standard.

5.2.2 Clearances

A clearance to nearby structures equal to or greater than 1.5 times the length of the shortest possible discharge path on the test object usually makes proximity effects negligible.

In wet or contamination tests, or whenever the voltage distribution along the test object and the electric field around its energized electrode are sufficiently independent of external influences, smaller clearances may be acceptable, provided that discharges do not occur to nearby structures.

For positive polarity switching impulses, conservative ~~values of~~ clearances may be obtained from the relationship between the critical ~~flashover~~ sparkover voltages of rod-to-plane gaps, and the gap spacing:

$$V_{50} = \frac{3400}{(1 + \frac{8}{d})} \quad (1)$$

where

V_{50} is the critical ~~flashover~~ sparkover voltage (in kilovolts)

d is the gap spacing (in meters)

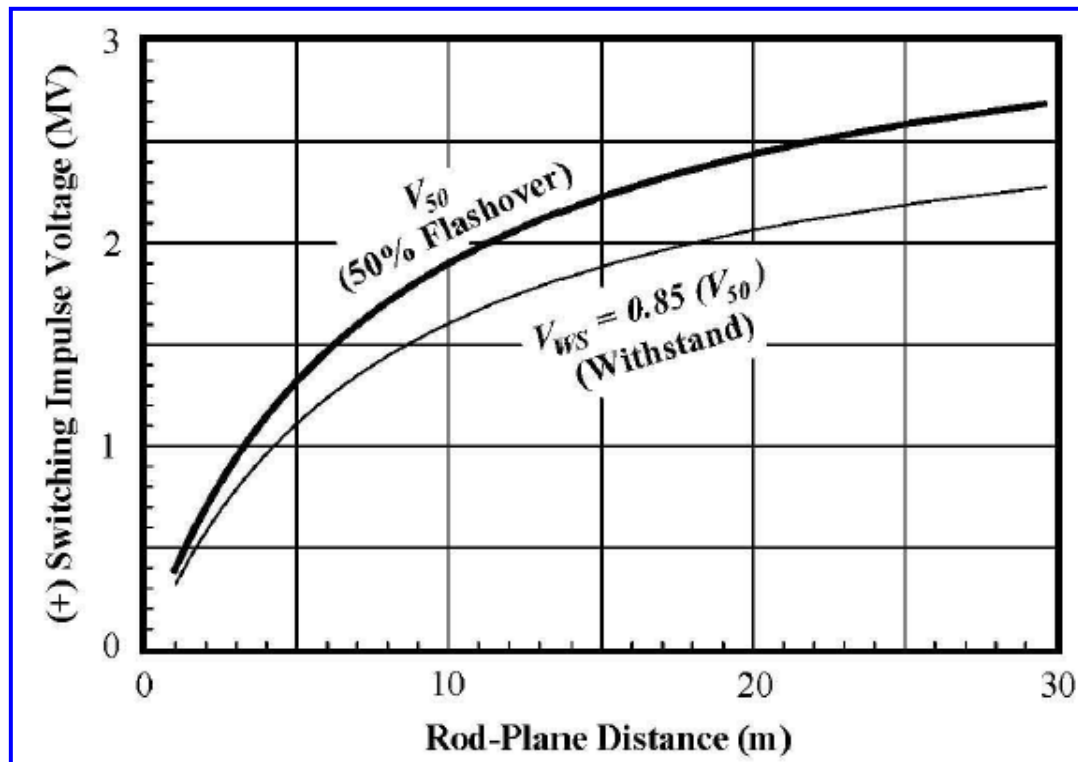
If the standard deviation of the assumed normal probability distribution is taken as 5% of V_{50} , the withstand voltage at three standard deviations below the 50% level is given by:

$$V_{WS} = 0.85 \times V_{50} \quad (2)$$

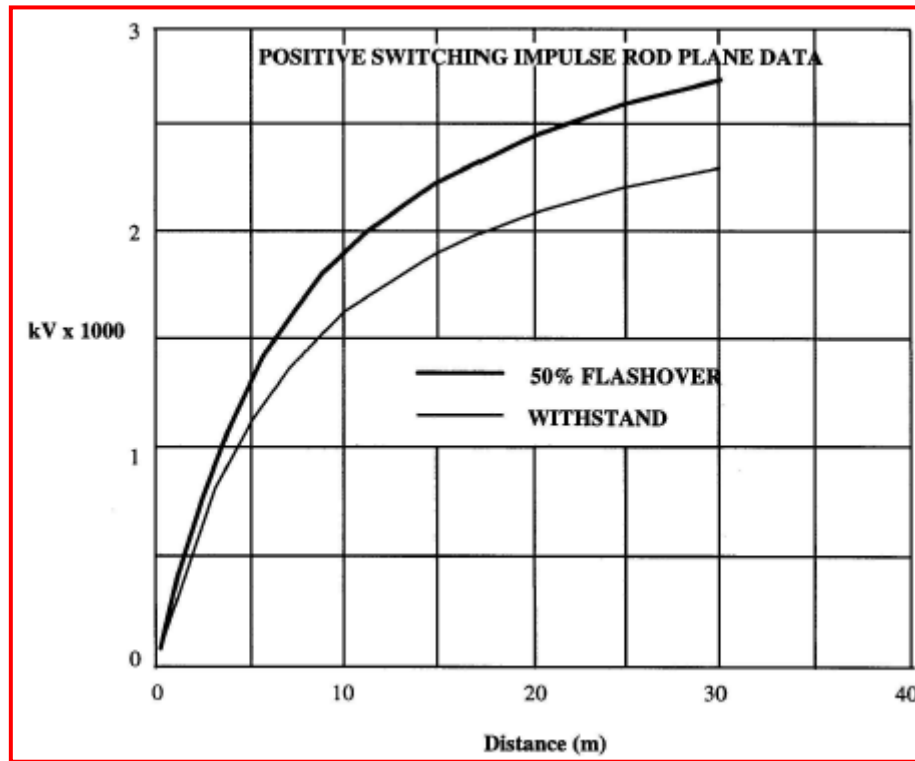
Where

V_{WS} is the withstand voltage corresponding to a ~~flashover~~ sparkover probability of 0.16%

Equation (1) and Equation (2) may then be used to determine the appropriate ~~gap spacing~~ clearance to withstand a given voltage level. Alternatively, the curves given in Figure 1 may be used.



[\(New\)](#)



(Deleted)

Figure 1— Voltage versus distance for rod-plane gap

5.3 Grounding requirements for high-voltage tests

There are normally several points in the test circuit that are interconnected and connected to the ground terminal of the test object. It is important that the impedance to ground and the impedance between such points in the test circuit be kept low to minimize potential differences during breakdowns. This can be accomplished through the use of single-point grounding, through the use of large nonmagnetic metal sheets between the ground terminals of the various components of the circuit, or by making short ground connections to a large metal sheet or mesh either on, or built into, the floor of the test area.

Normal practice is to locate the single-point ground of the test circuit at the base of the high-voltage divider, or the point of voltage measurement.

5.4 Use of properly dimensioned interconnections and electrodes

The position and dimensions of the interconnecting leads and electrodes used in the high-voltage test circuit may influence the performance of the measuring system or the results of the test.

- a) For alternating and direct voltage tests, a conductor diameter of 2.5 cm (1 in) per 100 kV test voltage is usually adequate.
- b) For all negative polarity impulses, and positive polarity lightning impulses below 1000 kV, small diameter conductors (wires) can be used.
- c) For positive polarity impulses above 1000kV, larger diameter conductors are usually required to control streamer discharges.
- d) For positive polarity switching impulses, conductor diameters should be chosen to limit the surface electric field strength to less than 15 kV/cm (38 kV/in).

5.5 Susceptibility to noise: instrumentation shielding

5.5.1 General

The shielding of general-purpose instruments may not be adequate for use in high-voltage laboratories. 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.

5.5.1 Precautions

5.5.1.1 Electromagnetic shielding

Interference due to electromagnetic fields penetrating directly 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 insures conductivity across permanent and mobile joints. This metal enclosure may be a shielded control room or an instrument enclosure. In most cases, the Faraday cage should be solidly grounded at a single point.

5.5.1.2 Reduction of conducted interference from the supply line

Conducted interference of the mains supply can be reduced by inserting a filter (effective in the range from some tens of kilohertz to some tens of megahertz). Another means of reducing conducted interference is to use an isolating transformer with low inter-winding capacitance between the instrument and the mains supply, or, for even better noise attenuation, an electrostatic shield between the windings.

5.5.1.3 Reduction of interference on the signal line

Interference due to current flowing in the shield of the measuring cable may be reduced by adequate grounding at the voltage divider side, by using tri-axial 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 ground returns can also reduce interference.

Interference due to potential difference, 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.

Interference may also be reduced in measurements by using optical transmission systems, provided that the converters at each end are well shielded, and not sensitive to temperature effects.

5.6 Classification of measuring systems

High-voltage measuring systems are classified in terms of their overall uncertainty. There are two basic classifications of measuring systems identified by this standard. These are:

a) Approved measuring systems.

b) Reference measuring systems.

The uncertainty requirements for each class of measuring system are summarized in Table 1, and are further discussed in 5.6.1 and 5.6.2.

**Table 1 — Basic uncertainty requirements by
measuring system classification**

<u>Measured Quantity</u>	<u>Approved measuring system</u>	<u>Reference measuring system</u>
<u>Direct voltage (arithmetic mean value)</u>	<u>$\pm 3\%$</u>	<u>$\pm 1\%$</u>
<u>Alternating voltage [peak or root mean square (rms) value 1]</u>	<u>$\pm 3\%$</u>	<u>$\pm 1\%$</u>
<u>Impulse voltage peak (peak value for full or tail- chopped impulses)</u>	<u>$\pm 3\%$</u>	<u>$\pm 1\%$ (see Note, below)</u>
<u>Impulse voltage time parameters (front time and time to half-value)</u>	<u>$\pm 10\%$</u>	<u>$\pm 5\%$</u>

NOTE—When measuring front-chopped impulses with a reference measuring system, the overall uncertainty requirement for peak value measurement is relaxed to $\pm 3\%$, per 5.6.2.1.3.

5.6.1 Approved measuring systems

Approved measuring systems as defined and described in Clause 3, Clause 6, Clause 7, Clause 8, and Clause 9 shall be used for making routine high-voltage measurements.

5.6.1.1 Requirements for approved measuring systems

5.6.1.1.1 Alternating voltage

An approved measuring system shall be capable of measuring the peak or root mean square (rms) value of an alternating voltage with an overall uncertainty of not more than $\pm 3\%$ in its range of use. More detailed information on approved measuring systems for alternating voltage may be found in 6.3.

5.6.1.1.2 Direct voltage

An approved measuring system shall be capable of direct voltage measurement with an overall uncertainty of not more than $\pm 3\%$ in its range of use. More detailed information on approved measuring systems for direct voltage may be found in 7.3.

5.6.1.1.3 Lightning and switching impulse voltage

An approved measuring system shall be capable of full and tail-chopped impulse voltage measurement with an overall uncertainty of not more than $\pm 3\%$ for peak voltage, and not more than $\pm 10\%$ for time parameters, in its range of use. More detailed information on approved measuring systems for impulse voltage may be found in 8.3.

5.6.2 Reference measuring systems

Reference measuring systems as defined in Clause 3 and Clause 5 are normally used to calibrate approved measuring systems. Reference measuring systems may be used for making routine high-voltage measurements if it is shown through appropriate performance tests and performance checks that such use does not affect their performance.

5.6.2.1 Requirements for reference measuring systems

5.6.2.1.1 Alternating voltage

A reference measuring system shall be capable of measuring the peak or rms value of an alternating voltage with an overall uncertainty of not more than $\pm 1\%$ in its range of use.

5.6.2.1.2 Direct voltage

A reference measuring system shall be capable of direct voltage measurement with an overall uncertainty of not more than $\pm 1\%$ in its range of use.

5.6.2.1.3 Lightning and switching impulse voltage

A reference measuring system shall be capable of full impulse voltage measurement with an overall uncertainty of not more than $\pm 1\%$ of peak voltage for full and tail-chopped impulses, not more than $\pm 3\%$ of peak voltage for front-chopped impulses, and not more than $\pm 5\%$ for time parameters, in its range of use.

5.6.2.2 Calibration of reference measuring systems

The compliance of a reference measuring system with the relevant requirements given in 5.6.2.1 of this standard shall be shown by the test outlined in 5.6.2.2.1. Alternatively the test outlined in 5.6.2.2.2 may be used.

5.6.2.2.1 Reference method: comparative measurement

The satisfactory performance of a reference measuring system shall be shown by making simultaneous comparative measurements of appropriate wave shapes with a suitable standard measuring system with overall uncertainty traceable through national or international comparisons.

5.6.2.2.2 Alternative method for impulse voltages: measurement of scale factor and evaluation of step response parameters

The scale factor of a reference measuring system shall be established for one impulse voltage shape by making simultaneous comparative measurements with a suitable standard measuring system with overall uncertainty traceable through national or international comparisons.

The step response parameters shall then be evaluated according to Annex B and shall satisfy the parameters specified in 8.7 of this standard.

5.7 Procedures for qualification and use of measuring systems

5.7.1 General principles

Approved measuring systems are required to undergo an acceptance test followed by performance tests and performance checks throughout their service lives. These performance tests and checks shall prove that the measuring system can measure the intended test voltages and currents within the uncertainties specified in this document, and that these uncertainties are traceable to national and international standards.

The following are necessary:

- a) Acceptance test on the system or system components.
- b) Performance tests on the system (periodic, see 5.7.2).
- c) Performance checks on the system (periodic, see 5.7.3).

The flowchart shown in Figure 2 outlines the process by which an approved measuring system shall be qualified and maintained.

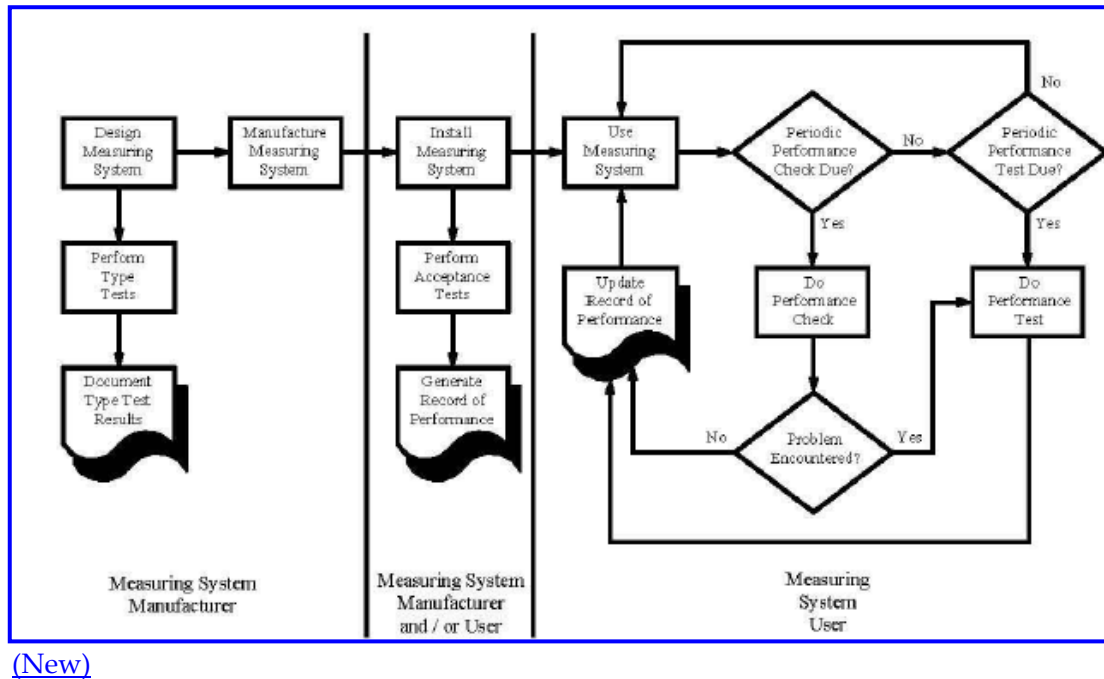


Figure 2—Qualification and maintenance of an approved measuring system

A major requirement for converting devices, transmission systems, and measuring instruments used in measuring systems is stability within their specified range of operating conditions so that the scale factor of the measuring system remains constant over long periods. The scale factor is determined in the performance tests.

Test facilities shall use the tests given in this document to qualify their measuring system(s). Alternatively, any test facility may choose to have the performance tests made by a traceable calibration laboratory.

Calibrations performed by an ISO/TEC 17025 accredited laboratory for the quantities calibrated and reported under the accreditation are considered traceable to national and international standards. If other calibration laboratories are chosen, it is the responsibility of the user to ensure that calibrations are performed by competent personnel using suitable reference measuring systems and procedures, and that proper traceability of the reference equipment has been ensured.

5.7.2 Schedule of performance tests

To maintain the quality of a measuring system, its scale factor(s) shall be determined by the performance tests repeated periodically as required in the record of performance. It is recommended that the performance tests should be repeated annually, or as required based on historical data.

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

When performance tests are required because a performance check shows that the scale factor has changed significantly, the cause of this change shall be investigated before the performance tests are made.

5.7.3 Need for performance checks

Performance checks should be performed by the user at regular intervals to assist in assuring continued stability of the measuring system.

If the performance check results in a discrepancy from the expected results, a performance test shall be performed.

5.7.4 Requirements for the record of performance

All approved measuring systems require that a record of performance be generated and maintained to document the accuracy and stability of the system. The required content of the record of performance for the various measurement systems covered by this standard is specified in the respective clauses.

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

The record of performance shall be comprised of at least the following chapters:

- a) General description of the measuring system.
- b) Results of acceptance test on the converting device, transmission system(s) and measuring instruments).
- c) Results of routine test(s) on the measuring system, when performed.
- d) Results of consecutive performance tests on the measuring system.
- e) Results of consecutive performance checks on the measuring system (optional).

NOTE—In general, a description is given for the measuring system, including main data and capabilities of the measuring system, such as the rated voltage or current, waveform(s), range of clearances, operating time, or maximum rate of voltage applications. For many measuring systems, information on the transmission system and grounding arrangements are important. When needed, a description is also given of the components of the measuring system, including, for example, the measuring instrument type and identification.

5.7.4.1 Exceptions

In the case of apparatus or equipment manufactured before the date of issue of this standard, if the evidence required in some part(s) of the acceptance test is not available, then performance tests and checks made in accordance with earlier versions of this standard are deemed to be adequate, provided they show that the scale factor is stable. The results of these previous checks shall also be entered in the record of performance.

If equipment manufactured before the date of issue of this standard is repaired, it is recommended that an acceptance test be conducted and included in the record of performance.

Approved measuring systems comprised of several pieces of equipment used interchangeably may be covered by a single record of performance including all possible combinations, with the least amount of duplication possible. Specifically, each converting device shall be covered individually, but transmission systems and instruments may be covered generically so that a range of cable lengths or similar instruments that meet the requirements of the relevant apparatus standard may be indicated.

5.7.5 Uncertainty

A measuring system qualified under this document shall be evaluated for the uncertainties that are related to the measurement. Guidance on determining uncertainty contributions that need to be considered, and on their combination, is given in 5.7.6.8 and Annex D.

It is emphasized that *uncertainty* is the envelope of the difference between the measured value and the true value. This should be distinguished from *tolerance*, which is the permitted difference between the specified value and the measured value.

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

A high-voltage or high-current measuring system is generally comprised of the following:

- a) A converting device (e.g., a voltage divider, high-voltage measuring impedance, or shunt).
- b) The leads required for connecting this device into the test circuit.
- c) A measuring cable, together with any attenuating, terminating, and adapting impedances or networks.
- d) The indicating or recording instrumentation.

Measuring systems that utilize only some of the above components, or those that are based on different principles may be acceptable. All measuring systems shall meet the requirements of this standard in order to be accepted.

The scale factor of the measuring system is determined by calibration according to the specified performance tests. For an impulse measuring system, the performance tests also show that its dynamic performance is adequate for the specified measurements and that the level of any disturbance is less than the specified limits. The equipment calibration should preferably be performed by comparison with a reference measuring system. If a measuring system is sensitive to proximity effects, the scale factor shall be measured for each condition of use. Each set of clearances or range of clearances shall be entered in the record of performance.

The input voltage or current used for calibration should be of the same type, frequency, or waveform as the quantity to be measured. The preferred calibration method for determining the scale factor of a measuring system is comparison with a reference measuring system at the maximum measured voltage or current. However, as reference-measuring systems are not always available at the highest voltages or currents, the comparison may be made at levels as low as 20% of the maximum measured quantity, provided that linearity is proven over the range of use.

Alternatively, the scale factor may be determined by measuring the scale factor of each component, usually at low voltage, and taking the product of the scale factors of the components (see 5.7.6.1.2), provided that the linearity has been proven over the range of use. When determining the system scale factor using low-voltage methods, the impedance of any measuring instrument used must be considered to allow for loading effects.

All equipment used in establishing the scale factor(s) of measuring systems and all instruments used in measuring systems shall have traceable calibration(s). The conditions under which the calibration has been performed shall be included in the record of performance. Whether the scale factor is determined by the reference method or an alternative method, the uncertainty must be evaluated (see 5.7.6.8 and Annex D).

5.7.6.1 Calibration - determination of the scale factor

The preferred method to determine the scale factor for a complete measuring system is by comparison with a reference measuring system. The scale factor of a measuring system can also be obtained as the product of the scale factors of its components.

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

The reference method is the preferred calibration method. A reference measuring system of sufficient rated measuring voltage or current shall be connected in parallel with the measuring system to be calibrated. Simultaneous readings shall be taken on both systems. The value of the input quantity obtained for each measurement by the reference measuring system is divided by the corresponding reading of the instrument in the system under test to obtain a value F_i of its scale factor. The procedure is repeated x times at each of $L=5$ levels (minimum and maximum of the operating range and three approximately equally spaced levels) to obtain the mean value F_m of the scale factor of the system under test:

$$F_m = \frac{1}{xL} \sum_{i=1}^{xL} F_i \quad (3)$$

The mean value F_m is taken as the scale factor. If the reference measuring system does not allow a calibration up to the rated measuring voltage or current of the system under calibration, a linearity test has to be added (see 5.7.6.2) to show that the scale factor is applicable over the full operating voltage or current range. The standard deviation of the individual values is given by:

$$s = \sqrt{\frac{1}{xL-1} \sum_{i=1}^{xL} (F_i - F_m)^2} \quad (4)$$

This results in the type A standard uncertainty of the comparison.

$$u_A = \frac{s}{\sqrt{xL}} \quad (5)$$

The uncertainty of the reference measuring system and the type B uncertainty contributions described in Annex D should be considered in the evaluation of the uncertainty of the calibration.

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

NOTE 2—A rounded value F_0 may be taken as the scale factor if the difference between F_0 and F_m is introduced as an uncertainty contribution of type B.

NOTE 3—For measurement of direct and alternating voltages, independent readings may be obtained either by applying the test voltage and taking x readings, or by applying the test voltage x times and taking a reading each time. For impulses, x impulses are applied.

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

5.7.6.1.2 Calibration of components (alternative method)

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

- a) By comparison with a reference component (e.g., a voltage divider with a reference voltage divider).
- b) Simultaneous measurements of its input and output quantities.
- c) A bridge method.
- d) Calculation based on measured impedances.

Further tests on measuring systems, transmission systems (other than cables), and measuring instruments shall be made in accordance with tests described in 5.7.6.2, 5.7.6.3, 5.7.6.4, 5.7.6.5, 5.7.6.6, 5.7.6.7, 5.7.6.8, and 5.7.6.9.

The scale factor of the measuring system shall be determined as the product of the scale factors of its converting device, its transmission system, any secondary attenuator, and its measuring instrument. For the converting device and the transmission system or their combination, the scale factor shall be measured by one of the methods given in 5.7.6.1. The scale factor of an impulse measuring instrument is determined according to IEC 61083-1 (listed in Clause 2).

5.7.6.2 Linearity test

This test is intended to provide an extension of the validity of the scale factor from the maximum level at which a calibration has been carried out, over the full range of use. The output of the measuring system shall be compared with a device or system that is linear over the full range of use.

The ratio of readings between the measuring system and the comparison device or system shall be established for five voltages, ranging from the maximum operating voltage down to the voltage at which the scale factor has been determined.

Evaluation of linearity is based on the maximum deviation of the ratios R_i from the mean R_m of the five ratios of the measured voltage to the corresponding voltage of the comparison device. The maximum deviation is taken as a type B estimate of the standard uncertainty related to constancy of scale factor:

$$u_{B1} = \frac{1}{\sqrt{3}} \max_{i=1}^5 \left| \frac{R_i}{R_m} - 1 \right| \quad (6)$$

Methods for determining linearity are given in Clause 6, Clause 7, Clause 8, and Clause 9 for each type of measuring system.

5.7.6.3 Dynamic behavior

The response of a component or a measuring system shall be determined in conditions representative of its use, particularly clearances to grounded and energized structures. Either the amplitude/frequency response (director alternating voltages) or the scale factors and time parameters at the limits of the range of use shall be measured.

The maximum deviation of the scale factor over the frequency range of use delivers a type B estimate of the standard uncertainty related to the dynamic behavior:

$$u_{B2} = \frac{1}{\sqrt{3}} \max_{i=1}^5 \left| \frac{F_i}{F_m} - 1 \right| \quad (7)$$

Where

F_i are the individual ratios

F_m is the mean ratio for parameters within the range of use

One method to determine dynamic behavior is to apply a sinusoidal input of known amplitude, usually at low level, and measure the output. This measurement is repeated for an appropriate range of frequencies. The deviations of the scale factor are evaluated according to the above formula.

Another method to determine dynamic behavior is to apply a unit step input, and record the output response. See Annex B for more information on this method.

5.7.6.4 Short term stability test

The maximum operating voltage or current shall be applied to the device continuously (or, in the case of impulses, at the maximum rate) for a period appropriate to the anticipated use. The scale factor shall be measured before and immediately after (within 10 minutes) the application of the voltage or current.

The result of the test may be the change of scale factor from which the standard uncertainty contribution is estimated as a type B estimate:

$$u_{B3} = \frac{1}{\sqrt{3}} \left| \frac{F_{after}}{F_{before}} - 1 \right| \quad (8)$$

where

F_{before} and F_{after} are the respective scale factors before and after the short-term stability test

5.7.6.5 Long term stability

The long-term stability characteristics may be taken from manufacturer's data or be demonstrated by successive performance tests.

The result of the estimation delivers a standard uncertainty contribution, which is estimated as a type B estimate:

$$u_{B4} = \frac{1}{\sqrt{3}} \left| \frac{F_{next}}{F_{previous}} - 1 \right| \quad (9)$$

where

$F_{previous}$ and F_{next} are the respective scale factors of two successive performance tests