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American National Standard

for power systems – insulation coordination

ANSI C92.1-1982

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C92.1-1982
Revision of
ANSI C92.1-1971

American National Standard for Power Systems — Insulation Coordination

Secretariat

Institute of Electrical and Electronics Engineers
National Electrical Manufacturers Association

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American National Standards Institute, Inc

American National Standard

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Foreword

(This Foreword is not a part of American National Standard C92.1-1982.)

This standard is a major revision of the previous standard, ANSI C92.1-1971, and presents the process of insulation coordination. Two discrete areas are addressed: self-restoring and non-self-restoring insulation. The statistical procedure of insulation coordination is applicable only for self-restoring insulations.

The basic lightning impulse insulation levels (BIL) and the basic switching impulse insulation levels (BSL) for self-restoring insulations are statistically defined as the crest value of a lightning or switching impulse test voltage at which the insulation exhibits a 90% withstand probability (or a 10% flashover probability). The distribution of lightning or switching overvoltages is defined by a single value that is the crest value of an overvoltage having a 2% probability of being exceeded. The statistical or probabilistic method for insulation coordination allows for insulation failures to occur and attempts to quantify the probability of an insulation flashover. This method statistically compares the voltage stresses on the insulation with the strength of the insulation.

The conventional method for insulation coordination presently required for non-self-restoring insulations consists of comparing the conventional BIL or BSL with the maximum lightning or switching overvoltage. The probability of a flashover is not calculated using the conventional method.

For purposes of insulation coordination, maximum system voltages above 1 kV are divided into three voltage classes:

Medium Voltage. Greater than 1 kV and equal or less than 72.5 kV.
High Voltage. Greater than 72.5 kV and equal to or less than 242 kV.
Extra-High and Ultra-High Voltage. Greater than 242 kV.

This standard, although applicable to the three voltage classes, places primary emphasis on voltages greater than 242 kV. For the purposes of insulation coordination, extra-high and ultra-high voltages are considered one class. Work on the medium and high voltage classes is now in progress in cooperation with the equipment committees and, upon completion, this standard will be revised.

This standard applies only to phase-to-ground insulation except for some definitions. Future revisions will treat phase-to-phase insulation and also the area of the lightning chopped wave insulation strength.

In the development of this standard, IEC Publication 71-1, Insulation Coordination, Part 1: Terms, Definitions, Principles, and Rules, 1976, was used as the primary guide. The major differences between this standard and the IEC standard are as follows:

(1) Maximum system voltages of 550 and 800 kV are used instead of 525 and 765 kV

(2) Values of BILs and BSLs of 825 and 900 kV are used instead of 850 and 950 kV

(3) Values of BILs or BSLs above 1800 kV increase in increments of 125 kV, whereas in the IEC standard, increments of 150 kV are used

(4) The terms BIL and BSL are maintained in this standard, whereas the IEC standard uses the term rated lightning (or switching) impulse withstand voltage

(5) In this standard, the specific combination of values of BIL and BSL for an apparatus is not specified. In the IEC standard, a specific set of values of BIL are tied to each value of BSL

Suggestions for improvement and revision of this standard will be welcome. They should be sent to the National Electrical Manufacturers Association, 2101 L Street, NW, Suite 300, Washington, D.C. 20037.

This standard was processed and approved for submittal to ANSI by American National Standards Committee on Insulation Coordination, C92. Committee approval of the standard does not necessarily imply that all committee members voted for its approval. At the time it approved this standard, the C92 Committee had the following members:

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American National Standard for Power Systems — Insulation Coordination

1. Scope and Purpose

1.1 Scope. This standard applies to equipment for three-phase alternating-current systems having a system voltage above 1 kV nominal and, except for some definitions, includes only phase-to-ground insulation.

1.2 Purpose. The object of this standard is to guide the preparation of specifications for insulation of the various items of equipment in a given installation. For the tests prescribed in this standard, the values of the basic lightning impulse insulation levels (BILs) and the basic switching impulse insulation levels (BSLs) shall be chosen from the preferred values of this standard. Each standards developer shall be responsible for specifying the BILs, BSLs, and test procedures suitable for its equipment, incorporating the content of this standard, where practical.

2. Related Standards

This standard is intended to be used in conjunction with the following American National Standards (see Section 8):

American National Standard Preferred Voltage Ratings for Alternating-Current Electrical Systems and Equipment Operating at Voltages Above 230 Kilovolts Nominal, ANSI C92.2-1981

American National Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers, ANSI/IEEE C57.12.00-1980

American National Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and Guide for Short-Circuit Testing of Distribution and Power Transformers, ANSI/IEEE C57.12.90-1980

American National Standard for Surge Arresters for AC Power Circuits, ANSI/IEEE C62.1-1981

American National Standard Techniques for High Voltage Testing, ANSI/IEEE 4-1978

3. Definitions

3.1 System Voltage. A root mean square phase-to-phase power frequency voltage on a three-phase alternating current electrical system (see ANSI C92.2-1981).

3.2 Maximum System Voltage (V_m). The highest root mean square phase-to-phase voltage that occurs on the system under normal operating conditions, and the highest root mean square phase-to-phase voltage for which equipment and other system components are designed for satisfactory continuous operation without de-rating of any kind. (This voltage generally provides a per unit base voltage for insulation coordination studies, and for the application of surge arresters. When defining maximum system voltage, voltage transients and temporary overvoltages caused by abnormal system conditions such as faults, load rejection, etc, are excluded. However, voltage transients and temporary overvoltages may affect equipment operating performance and are considered in equipment application.) (See ANSI C92.2-1981.)

3.3 Nominal System Voltage. The system voltage by which the system may be designated and to which certain operating characteristics of the system are related. (The nominal system voltage is near the voltage level at which the system normally operates and provides a per-unit base voltage for the purpose of system studies, such as load flows. To allow for operating contingencies, systems generally operate at voltage levels about 5% to 10% below the maximum system voltage for which the system components are designed.) (See ANSI C92.2-1981.)

3.4 Extra-High Voltage (EHV). A maximum system voltage that is greater than 242 kilovolts but less than 1000 kilovolts (see ANSI C92.2-1981).

3.5 Ultra-High Voltage (UHV). A maximum system voltage that is equal to or greater than 1000 kilovolts (see ANSI C92.2-1981).

3.6 Insulation Coordination. The process of bringing the insulation strengths of electrical equipment into the proper relationship with expected overvoltages and with the characteristics of surge protective devices.

3.7 External Insulation. The distances in open air and across the surfaces of the solid insulation of equipment in contact with open air that are subjected to dielectric stresses and to the effects of atmospheric and other external conditions such as contamination, humidity, animals, etc.

3.8 Internal Insulation. The internal solid, liquid, or gaseous parts of the insulation of equipment that are protected by the equipment enclosure from the effects of atmospheric and other conditions such as contamination, humidity, animals, etc.

3.9 Indoor External Insulation. External insulation that is designed to operate inside buildings or other protective enclosures and consequently is not exposed to the weather.

3.10 Outdoor External Insulation. External insulation that is designed to operate outside buildings or other protective enclosures and consequently is exposed to the weather.

3.11 Self-Restoring Insulation. Insulation that completely recovers insulating properties after a disruptive discharge. This type of insulation is generally, but not necessarily, external insulation.

3.12 Non-Self-Restoring Insulation. Insulation that loses insulating properties or does not recover completely after a disruptive discharge. This type of insulation is generally, but not necessarily, internal insulation.

3.13 Design Test (Type Test). Tests made by the manufacturer to determine the adequacy of the design of a particular type, style, or model of equipment or its component parts to meet its assigned ratings and to operate satisfactorily under normal service conditions or under special conditions, if specified. Design tests may also be used to demonstrate compliance with applicable standards of the industry.

NOTE: Design tests are made on representative apparatus or prototypes to verify the validity of design analysis and calculation methods and to substantiate the ratings assigned to all other apparatus of basically the same design. These tests are not intended to be used as normal production tests. The applicable portion of these design tests may also be used to evaluate modifications of a previous design and to ensure that performance has not been adversely affected. Test data from previous similar designs may be used for current designs, where appropriate. Once made, the tests need not be repeated unless the design is changed so as to modify performance.

3.14 Routine Tests (Production Tests). Tests made for quality control by the manufacturer on every device or on representative samples, or on parts or materials as required to verify, during production, that the product meets the design specifications and applicable standards.

NOTE: Certain quality assurance tests on identified critical parts of repetitive high-production devices may be tested on a planned statistical sampling basis.

3.15 Ungrounded Neutral System. A system in which the neutral is not connected to ground except through potential-indicating or -measuring devices or other very-high-impedance devices.

3.16 Resonant Grounded System (System Grounded Through an Arc-Suppression Coil). A system grounded through a reactor, the reactance being such that during a single phase-to-ground fault, the power frequency inductive current passed by this reactor essentially neutralizes the power-frequency capacitive component of the ground-fault current.

NOTE: With resonant grounding of a system, the net current in the fault is limited to such an extent that an arc fault in air would be self-extinguishing.

3.17 Grounded Neutral System. A system in which the neutral is connected to ground, either solidly or through a resistance or reactance of sufficiently low value to reduce temporary and transient overvoltages and to improve the conditions for selective ground-fault protection.

3.18 Ground-Fault Factor. For a given system configuration, the ratio of the highest root mean square phase-to-ground power-frequency voltage on a sound phase during a fault-to-ground (affecting one or more phases at any point) to the root mean square phase-to-ground power-frequency voltage that would be obtained at a selected location on a three-phase system without the fault.

NOTES:

(1) This factor is a numerical ratio ($\geqslant 1$) and characterizes, in general terms, the grounding conditions of a system as viewed from the selected location, independent of the actual operating value of the voltage at that location.

(2) Ground-fault factors for three-phase systems are calculated from the phase-sequence impedance components as viewed from the selected location. For machines, the subtransient reactance is used.

(3) If, for all system configurations, the zero-sequence reactance is less than three times the positive-sequence reactance, and if zero-sequence resistance does not exceed the positive-sequence reactance, the ground-fault factor will generally not exceed 1.3.

(4) ANSI/IEEE C62.1-1981 defines a "Coefficient of Grounding." This coefficient can be obtained by dividing the ground-fault factor by $\sqrt{3}$.

3.19 Overvoltage. Any time-dependent voltage between one phase and ground or between phases with a crest value or values exceeding the corresponding crest value $V_m \sqrt{2}/\sqrt{3}$, or $V_m \sqrt{2}$ respectively (see 3.2).

NOTE: Overvoltages are transient phenomena. A general distinction may be made between highly damped overvoltages of relatively short duration (see 3.22 and 3.23) and undamped or only slightly damped overvoltages of relatively long duration (see 3.26). The transition between these two groups cannot be clearly defined.

3.20 Phase-to-Ground Per Unit Overvoltage. The ratio of the crest values of a phase-to-ground overvoltage per unit and of the phase-to-ground voltage corresponding to the maximum system voltage (i.e., $V_m\sqrt{2}/\sqrt{3}$).[1]

3.21 Phase-to-Phase Per Unit Overvoltage. The ratio of the crest values of a phase-to-phase overvoltage per unit and of the phase-to-ground voltage corresponding to the maximum system voltage (i.e., $V_m\sqrt{2}/\sqrt{3}$).[1]

3.22 Lightning Overvoltage. A phase-to-ground or a phase-to-phase overvoltage[2] at a given location on a system due to one specific lightning discharge or other cause, the shape of which can be regarded, for the purpose of insulation coordination, as similar to that of the standard lightning impulse. Such overvoltages are usually unidirectional and of very short duration.

3.23 Switching Overvoltage. A phase-to-ground or a phase-to-phase overvoltage[2] at a given location on a system due to one specific switching operation, fault, or other cause, the shape of which can be regarded, for the purpose of insulation coordination, as similar to that of the standard switching impulse. Such overvoltages are usually highly damped and of short duration.

3.24 Statistical Lightning (or Switching) Overvoltage (E_2). Lightning (or switching) overvoltage as a result of an event of one specific type on the system (lightning discharge, line energization, reclosing, fault occurrence, etc), with a crest value that has a 2% probability of being exceeded.

3.25 Conventional Maximum Lightning (or Switching) Overvoltage. The crest value of a lightning (or switching) overvoltage that is adopted as the maximum overvoltage in the conventional procedure of insulation coordination (see 4.5.3).

3.26 Temporary Overvoltage. An oscillatory phase-to-ground or phase-to-phase overvoltage at a specific system location that is of relatively long duration and that is undamped or only slightly damped.

Temporary overvoltages usually originate from switching operations, faults, load rejection, and nonlinearities (ferro-resonance effects, harmonics) and are characterized by amplitude, oscillation frequencies, total duration, or decrement.

3.27 Withstand Voltage. The voltage that electrical equipment is capable of withstanding without failure or disruptive discharge when tested under specified conditions.

3.28 Standard Lightning Impulse. A full impulse[3] having a front time of 1.2 microseconds and a time-to-half-value of 50 microseconds. It is described as a 1.2/50 impulse (see ANSI/IEEE 4-1978).

3.29 Standard Switching Impulse. A full impulse[3] having a front time of 250 microseconds and a time-to-half-value of 2500 microseconds. It is described as a 250/2500 impulse (see ANSI/IEEE 4-1978).

3.30 Basic Lightning Impulse Insulation Level. The electrical strength of insulation expressed in terms of the crest value of a standard lightning impulse. The basic lightning impulse insulation level (BIL) may be either a statistical BIL or a conventional BIL, defined as follows:

3.30.1 Statistical BIL. Applicable specifically to self-restoring insulations.[4] The crest value of a standard lightning impulse for which the insulation exhibits a 90% probability of withstand (or a 10% probability of failure) under specified conditions.

3.30.2 Conventional BIL. Applicable specifically to non-self-restoring insulations.[4] The crest value of a standard lightning impulse for which the insulation shall not exhibit disruptive discharge when subjected to a specific number of applications of this impulse under specified conditions.

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[1] The per unit overvoltages defined in 3.20 and 3.21 for the purpose of insulation coordination studies are referenced to the crest value of the phase-to-ground voltage corresponding to the maximum system voltage. When overvoltages are measured in various conditions during tests on a system or an equivalent model, these overvoltages may be referred to the phase-to-ground voltage immediately prior to the overvoltage. In such cases, the term "overvoltage factor" should be used for the ratio. Since the overvoltages are not always proportional to the system voltage, it is necessary to state the overvoltage factor as well as all conditions of the test.

[2] For the purpose of insulation coordination, lightning and switching overvoltages are classified according to shape and duration, regardless of origin. Although considerable deviations from the standard shapes occur on actual systems, such overvoltages are defined by classification and crest (peak) value in this standard.

[3] It is recognized that some apparatus standards (e.g., transformers) may use a modified wave shape when practical test considerations or particular dielectric strength characteristics make such modification imperative.

[4] Depending on the type of insulation and conforming to the requirements of the standards developer, dielectric tests are made to verify that both the statistical BIL or BSL and the conventional BIL or BSL are equal to or higher than the BIL or BSL.

3.31 Basic Switching Impulse Insulation Level. The electrical strength of insulation expressed in terms of the crest value of a standard switching impulse. The basic switching impulse insulation level (BSL) may be either a statistical BSL or a conventional BSL, defined as follows:

3.31.1 Statistical BSL. Applicable specifically to self-restoring insulations.[4] The crest value of a standard switching impulse for which the insulation exhibits a 90% probability of withstand (or a 10% probability of failure) under specified conditions.

3.31.2 Conventional BSL. Applicable specifically to non-self-restoring insulations.[4] The crest value of a standard switching impulse for which the insulation does not exhibit disruptive discharge when subjected to a specific number of applications of this impulse under specified conditions.

3.32 Special Switching Impulses. The impulses to be used if the standard switching impulse does not give the desired test information are 100/2500 and 500/2500. Oscillatory impulses and those impulses defined by their time above 90% as specified in ANSI/IEEE C57.12.90-1980 for transformer testing are also in this category.

3.33 Critical Flashover Voltage. Applicable specifically to self-restoring insulations. The crest value of an impulse that, under specified conditions, causes critical flashover through the surrounding medium on 50% of the applications.

3.34 Critical Switching Impulse Wave Front. Applicable specifically to self-restoring insulations. The wave front of a switching impulse that, when applied to an insulation, produces a minimum value of critical flashover.

3.35 Rated Short-Duration or Long-Duration Low-Frequency Withstand Voltage. The prescribed root mean square value of a sinusoidal low-frequency voltage that equipment shall withstand during tests made under specified conditions and for a specified time.

3.36 Statistical Safety Factor. The ratio of the statistical BIL or BSL to the corresponding statistical lightning overvoltage, E_2.

3.37 Conventional Safety Factor. The ratio of a conventional BIL or BSL to the corresponding maximum overvoltage.

3.38 Lightning Impulse Protective Level of a Surge Protective Device. The highest crest value of lightning impulse voltage that may occur across the terminals of the protective device under prescribed conditions.

NOTE: The lightning impulse protective levels are given numerically by the maximums of the following quantities:
(1) Front-of-wave impulse sparkover voltage
(2) 1.2/50 impulse sparkover voltage
(3) Discharge voltage at a given discharge current

3.39 Switching Impulse Protective Levels of a Surge Protective Device. The highest value of switching impulse voltage that may appear across the terminals of a protective device under prescribed conditions.

NOTE: The switching impulse protective levels are given numerically by the maximums of the following quantities:
(1) Switching impulse discharge voltage
(2) Switching impulse sparkover voltage

3.40 Protective Ratio. The ratio of the insulation strength of the protected equipment to the protective level of the surge protective device.

3.41 Protective Margin. The value of the protective ratio (PR) minus one, expressed in percent, (PR − 1)/100.

4. Basic Principles of Insulation Coordination

4.1 Voltage Stresses Affecting Insulation. The following classes of dielectric stresses may be impressed on equipment during system operation:

(1) Power frequency voltages under normal operating conditions, i.e., not exceeding the maximum system voltage
(2) Temporary overvoltages
(3) Switching overvoltages
(4) Lightning overvoltages

For a specific voltage stresss, the behavior of internal insulation may be influenced by the degree of aging and internal contamination. External insulation may be influenced by the degree of atmospheric contamination.

4.2 Ranges of Maximum System Voltages. The standard values of maximum system voltages are divided into three voltage classes:

(1) *Medium Voltage.* Greater than 1 kV and equal to or less than 72.5 kV
(2) *High Voltage.* Greater than 72.5 kV and equal to or less than 242 kV
(3) *Extra-High and Ultra-High Voltages.* Greater than 242 kV

For purposes of insulation coordination, extra-high and ultra-high voltages are considered one class.

4.3 Dielectric Tests

4.3.1 Types of Dielectric Tests. The following types of dielectric tests are considered in this standard:

(1) Short-duration low-frequency tests
(2) Long-duration low-frequency tests

(3) Switching impulse tests
(4) Lightning impulse tests

Switching and lightning impulse tests may be either withstand tests, with a suitable number of voltage impulses at the specified BIL or BSL applied to the insulation, or critical flashover tests in which the ability of the insulation to withstand impulses at the rated BIL and BSL are inferred from the measurement of the critical flashover voltage. The critical flashover tests are only applicable to self-restoring insulation.

Short-duration low-frequency tests are withstand tests and values are not presently specified in this standard. Preferred BILs and BSLs are included in this standard. Guidance for long-duration low-frequency tests is presented in 4.4.

4.3.2 Selection of Dielectric Tests for the Medium and High Voltage Classes. The performance under lightning overvoltages shall be established by lightning impulse tests. The performance under system frequency operating voltages shall be established by short-duration low-frequency tests. The low-frequency tests also provide a measure of performance for temporary overvoltages. Power transformers, however, require special consideration since higher frequency temporary overvoltages may excite natural frequencies of oscillation within the windings to produce greater than turns ratio voltage between parts. Also, the short-duration low-frequency tests generally provide a measure of performance for switching overvoltages.

4.3.3 Selection of Dielectric Tests for the Extra-High and Ultra-High Voltage Class. The performance under lightning overvoltages shall be established by lightning impulse tests.

The performance under switching overvoltages shall be established by switching impulse tests.

The performance under system frequency operating voltages shall be established by short-duration and/or long-duration low-frequency tests. The low-frequency tests also provide a measure of performance for temporary overvoltages. Power transformers, however, require special consideration since higher frequency temporary overvoltages may excite natural frequencies of oscillation within the windings to provide greater than turns ratio voltage between parts.

NOTE: In the past, the values of the traditional short-duration low-frequency withstand test voltages in this range have been of sufficient magnitude to account for some effects of switching overvoltages and temporary overvoltages. With the introduction of switching impulse tests for equipment for systems with maximum system voltages in the extra-high and ultra-high voltage class and the availability of tests specific to corona or partial discharges, the values of the low-frequency test voltages may be reduced, and defined to be more representative of normal operating voltages and temporary overvoltages only. The low-frequency tests presently prescribed by the standards developers will apply.

4.4 Coordination for Voltages Under Normal Operating Conditions and for Temporary Overvoltages. Long-duration low-frequency tests that demonstrate the behavior of equipment with respect to the aging of internal insulation or contamination of external insulation should be prescribed by the standards developers. The following are general guidelines.

In specifying tests representative of stresses under normal operating conditions and temporary overvoltages, it should be assumed that:

(1) For normal operating conditions, the insulation shall withstand permanent operation at the maximum system voltage.

(2) Low-frequency tests to verify the ability to withstand surface contamination should be conducted at the appropriate voltage (i.e., either $V_m/\sqrt{3}$, or V_m if a system may operate for extended periods with a phase grounded) (see 3.2).

(3) Temporary phase-to-ground crest overvoltages in the extra-high and ultra-high voltage class will not normally exceed 1.5 per unit, and the duration will not normally exceed one second on each occasion. Special consideration may be required when system conditions are more severe or when temporary overvoltages have oscillation frequencies above system frequency.

(4) Low-frequency tests are intended to verify, as far as practical, that no significant deterioration of the insulation will occur due to partial discharges (corona) during the expected service life of equipment and that, in the most severe conditions, the insulation is not susceptible to thermal instability. These tests should be performed at a voltage above $V_m/\sqrt{3}$ phase-to-ground (see 3.2) and for a duration appropriate to the system conditions. All insulation components should be stressed in the same proportions as would occur in service.

All recommendations for test voltages, as well as test procedures and test conditions, should be defined by the standards developers.

4.5 Coordination for Lightning and Switching Overvoltages. In the extra-high and ultra-high voltage class, coordination for lightning and switching overvoltages are essentially independent.

Insulation coordination assumes that the magnitude of the overvoltages (for reasonable system contingencies) at the equipment location are known. Concurrently, the electrical insulation characteristics of the equipment and protective characteristics of applicable surge protective devices are also assumed to be known. In some instances, experience on comparable systems may be used in the rationalization of both the system overvoltages and equipment insulation characteristics.

The insulation strength of equipment for lightning and switching stresses should be chosen on the basis of the predicted overvoltages. A statistical or a conventional procedure may be used.

4.5.1 Choice of Procedure. The need for thorough studies of system overvoltages, as well as the need to conduct tests based on the application of a rather high number of impulses, set practical limits on the use of the statistical procedure of insulation coordination.

A statistical approach is particularly applicable when there is economic incentive for reduction of insulation strength, especially when switching overvoltages are a problem. The statistical procedure is primarily appropriate to the extra-high and ultra-high voltage class and is not normally applied to the medium-voltage and high-voltage classes.

In all voltage classes, when the equipment insulation is essentially non-self-restoring, only a small number of impulse applications (for instance, three for each test condition as specified in 7.4.4) can often be acceptable to establish the withstand strength. At the present state of the art, it is impossible to consider failure probability as a design variable subject to quantitative control. Thus, the use of the statistical procedure is presently restricted to self-restoring insulations.

4.5.2 Statistical Procedure. The statistical procedure allows for insulation failures to occur, and the procedure attempts to quantify the risk of failure.

A rigorous determination of the probability or risk of failure for a given category of overvoltage requires that both the overvoltage stresses and the equipment insulation strength be described in terms of their respective frequency distributions.

In a simplified form of this procedure, assumptions are made on the general characteristics of the probability distributions (e.g., normal frequency distribution and standard deviation) that permit the representation of each distribution by a single value of voltage corresponding to a specific value of probability. Such values of voltages are designated as the statistical overvoltage, E_2 (see 3.24), in the case of the overvoltage probability distribution, and as the statistical BIL or BSL (see 3.30 and 3.31) in the case of the insulation strength probability distribution. The statistical BIL or BSL is so defined that the probability of failure is 10% or the probability of withstand is 90%. The statistical lightning or switching overvoltage is so defined that this voltage value, E_2, has a 2% probability of being exceeded.

Insulation coordination for a given category of overvoltages, in this simplified statistical context, consists of the selection of a margin, characterized by the statistical safety factor, between the statistical BIL or BSL and the statistical overvoltage, E_2, that will result in a probability of failure (capable of numerical expression) deemed to be acceptable relative to system reliability and cost.

The minimum acceptable values of the statistical BIL or BSL voltages have thus been determined.

4.5.3 Conventional Procedure. In this procedure, the criterion of insulation coordination for lightning or switching overvoltages is the margin between the maximum overvoltage to be expected at the equipment location and the conventional BIL and BSL.

This margin determines a safety factor that should not be less than an adequate value based upon experience.

5. Preferred Values of BIL for Equipment in the Medium Voltage and High Voltage Classes

5.1 General. This section specifies the preferred value of BIL for medium voltage and high voltage classes. The value for short-duration or long-duration power frequency tests shall be established by the standards developer.

5.2 Preferred BILs. The preferred values of BIL for the medium voltage and high voltage classes shall be chosen from the following list. These values are expressed in terms of the kilovolt crest value of the standard lightning impulse.[5]

10	110	550
20	125	650
30	150	750
45	200	825
60	250	900
75	350	975
95	450	1050

6. Standard BILs and BSLs for Equipment in the Extra-High and Ultra-High Voltage Class

6.1 General

6.1.1 This section specifies BILs and BSLs for the standard values of the maximum system voltages in the extra-high voltage and ultra-high voltage class. These values are the same for both the statistical and the conventional BILs and BSLs.

[5] The tabulated values do not apply to lightning impulse chopped wave tests.

Table 1
Preferred BILs and BSLs for $V_m > 242$ kV

1	2	3	4	5
Maximum System Voltage V_m (rms) (kV)	Base for per unit Values $V_m \frac{\sqrt{2}}{\sqrt{3}}$ (crest) (kV)	BSL (p.u.)	BSL (kV)	BIL (kV)
				825
362	296	2.53	750	900
		2.79	825*	1050
		3.04	900	1175
		3.55	1050	1300
550	449	2.17	975	1175
		2.34	1050	1300
		2.62	1175*	1425
		2.90	1300	1550
		3.17	1425	1675
				1800
800	653	1.99	1300	1675
		2.18	1425	1800
		2.37	1500*	1925
		2.57	1675	2050
				2175
				2300
1200	980	†		†

*Various values of BIL and BSL may be used in combination as appropriate to specific apparatus or system elements.

†These values are not presently specified.

6.1.2 The values of preferred BILs and BSLs shall be chosen from the following list. These levels are expressed in terms of the kilovolt crest value of the standard impulse.[6, 7]

650	1425	2300
750	1550	2425
825	1675	2550
900	1800	2675
975	1925	2800
1050[8]	2050	2925
1175	2175	3050
1300		

A standards developer may determine that a fixed relationship between BIL and BSL is appropriate for a specific equipment. The BIL shall then be chosen from the list; and the associated BSL, as determined by the relationship, may differ from the values in the list.

6.1.3 Specific combinations of BILs and BSLs are not specified for each maximum system voltage. BILs and BSLs from the groups in Table 1 shall be used, except when BILs and BSLs other than those given in Table 1 are technically and economically justifiable due to the design of the system or the methods chosen for the control of lightning or switching overvoltages.

6.1.4 Several BILs and BSLs may exist in the same system, appropriate to installations situated in different locations or to various equipments situated in the same installation.

6.2 Preferred BILs and BSLs for Maximum System Voltages Above 242 kV. Table 1 lists combinations of maximum system voltages and the two components, BIL and BSL.

In Column 3, the per unit value of the BSL of Column 4 is indicated for convenience of comparison with expected per unit switching overvoltages.

6.3 BILs and BSLs for Protected and Unprotected Equipment. The BIL and BSL ranges associated with a particular maximum system voltage shown in Table 1

[6] Electrical equipment that has been tested using a switching impulse wave shape that produces more severe stresses on the insulation than are produced by the standard switching impulse wave shape need not be retested.

[7] The tabulated values do not apply to chopped wave tests.

[8] If particular apparatus standards require the use of nonpreferred BILs or BSLs above 1050 kV, it is recommended that intermediate values be obtained by adding 60 kV to the next lower preferred value.

are applicable to the equipment whether it is protected by a surge arrester or not.

6.3.1 Protected Equipment. For equipment protected against overvoltages by surge arresters, the BIL and BSL ranges were selected based on the following criteria:

(1) Expected values of temporary overvoltages

(2) Characteristics of applicable surge arresters

(3) Adequate margins between the protective levels of the surge arrester and the BIL and BSL of the equipment

6.3.2 Unprotected Equipment. For equipment not protected by surge arresters, the BIL and BSL ranges were selected based on the following criteria:

(1) Acceptable probability of failure based on the overvoltages occurring at the equipment location

(2) For switching overvoltages, the degree of overvoltage control obtained through surge control in the switching devices, design of the system, etc

7. General Test Procedure

7.1 General. This section specifies lightning impulse tests, switching impulse tests, and low-frequency withstand tests as defined by ANSI/IEEE 4-1978. The purpose of these tests is to verify that an equipment complies with the BILs, BSLs, and short-duration low-frequency withstand voltages. Other tests may be specified by the standards developer.

For each type of test and each type of equipment, the methods of detecting insulation failures and the criteria of failure of the insulation during the tests shall be the responsibility of the standards developer.

7.2 BIL and BSL Tests. The BIL and BSL shall be determined by tests using the prospective crest value of standard lightning and switching impulses of positive and negative polarities. External insulation tests should be referenced to standard atmospheric conditions, and for wet tests, to standard conditions as defined in ANSI/IEEE 4-1978. The standards developers specify different impulse shapes if necessary to establish the lowest withstand of a particular apparatus, or if the standard impulse shape cannot be achieved for a particular test object with presently available test equipment.

Two types of impulse tests should be used: the statistical tests (see 4.5.2 and 7.3) and the conventional test (see 4.5.3 and 7.4). The choice for application to particular apparatus shall be the responsibility of the standards developers within the general guidelines set forth in this standard.

7.3 Statistical BIL and BSL Tests

7.3.1 As required for the particular apparatus being tested, one or more of three test procedures shall be used for tests on self-restoring insulation in accordance with ANSI/IEEE 4-1978. These tests are also applicable to chopped wave tests.

7.3.1.1 Impulse Withstand Test. This test is made by applying fifteen impulses having crest magnitude equal to the BIL or BSL. The requirements of the test are satisfied if no more than two disruptive discharges occur.

7.3.1.2 3 × 3 Impulse Withstand Test. This test is made by applying three impulses having crest magnitudes equal to the BIL or BSL. If no impulse causes a disruptive discharge, the requirements of the test are satisfied. If more than one disruptive discharge occurs, the apparatus is considered to have failed the test. If one disruptive discharge occurs, three additional impulses shall be applied. If no disruptive discharge occurs, the requirements of the test are satisfied.

7.3.1.3 Critical Flashover Test. This test is made at voltages above the BIL or BSL using a procedure and the number of impulses that will establish the critical flashover of the insulation with acceptable accuracy. There are a number of procedures available, and any of these may be used, providing that the accuracy of the determination is within one-half of the standard deviation with a confidence level of 95%.

The critical flashover shall not be less than $1/(1-1.3\sigma)$ times the BIL or BSL, where σ is the standard deviation of the disruptive discharge voltage in per unit of critical flashover.[9] Unless otherwise recommended by the standards developer, the following values will be assumed for air insulation:

lightning impulse tests: $\sigma = 0.03$

switching impulse tests: $\sigma = 0.06$

7.3.2 Lightning and switching impulse tests shall be made as design tests.

7.3.3 Lightning impulse tests shall be made with the equipment dry for both indoor and outdoor equipment.

7.3.4 For indoor equipment, and for outdoor internal equipment insulation, switching impulse tests shall be made with the equipment dry. Wet and dry tests shall be made for outdoor external equipment insulation. For the latter, however, if it is known which condition, wet or dry, gives the lower disruptive discharge voltage, it is sufficient to test with that condition.

7.3.5 The equipment shall be tested by applying standard lightning and switching impulses of positive

[9] This value of critical flashover corresponds for the impulse voltage to the reference withstand probability (90%) in a Gaussian distribution.

and negative polarities, except if it is known which polarity will give the lower disruptive discharge voltage, in which case, it is sufficient to test with that polarity.

7.4 Conventional BIL and BSL Tests

7.4.1 This test restricts the number of impulses to avoid possible damage to non-self-restoring insulation.

7.4.2 The conventional BILs and BSLs are verified by lightning and switching impulse withstand tests in which the test voltage applied shall be equal to the BIL or BSL.

7.4.3 Lightning and switching impulses shall be of the standard shapes and of positive or negative polarity, or both. The polarity or polarities to be used shall be specified by the standards developer.

7.4.4 If not otherwise specified by the standards developer, the withstand test shall be performed by applying three impulses for each polarity required. The requirements of the test shall be satisfied if no indication of failure is found, using the methods of detection specified by the standards developer.

7.4.5 BIL and BSL tests shall be made as design tests. They may also be specified as routine tests by the standards developer.

NOTE: If a chopped wave lightning impulse withstand test is considered, the specification for such tests is the responsibility of the standards developer.

7.5 Low-Frequency Voltage Withstand Tests

7.5.1 The low-frequency test voltage shall be specified as the root mean square value of the voltage which the insulation shall be capable of withstanding for the specified time duration. The wave shape should be as close to sinusoidal as possible. If the test voltage is nonsinusoidal, the crest value divided by $\sqrt{2}$ is defined as the test voltage.

7.5.2 The dry low-frequency withstand test shall be made as a routine test, except where otherwise specified by the standards developer.

7.5.3 The wet low-frequency test (to ground) applicable to external outdoor insulation shall be made as a design test.

NOTE: Low-frequency tests include induced voltage tests on transformers. Such tests are usually made with test voltage frequencies up to a few hundred Hz. (See ANSI/IEEE C57.12.00-1979.)

8. Revision of American National Standards Referred to in This Document

When the American National Standards referred to in this document are superseded by a revision approved by the American National Standards Institute, Inc, the revision shall apply.

American National Standards

The standard in this booklet is one of more than 10,000 standards approved to date by the American National Standards Institute.

The Standards Institute provides the machinery for creating voluntary standards. It serves to eliminate duplication of standards activities and to weld conflicting standards into single, nationally accepted standards under the designation "American National Standards."

Each standard represents general agreement among maker, seller, and user groups as to the best current practice with regard to some specific problem. Thus the completed standards cut across the whole fabric of production, distribution, and consumption of goods and services. American National Standards, by reason of Institute procedures, reflect a national consensus of manufacturers, consumers, and scientific, technical, and professional organizations, and governmental agencies. The completed standards are used widely by industry and commerce and often by municipal, state, and federal governments.

The Standards Institute, under whose auspices this work is being done, is the United States clearinghouse and coordinating body for voluntary standards activity on the national level. It is a federation of trade associations, technical societies, professional groups, and consumer organizations. Some 1000 companies are affiliated with the Institute as company members.

The American National Standards Institute is the United States member of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). Through these channels U.S. standards interests make their positions felt on the international level. American National Standards are on file in the libraries of the national standards bodies of more than 60 countries.

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