

Recognized as an
American National Standard (ANSI)

IEEE Std C57.16-1996
(Revision of ANSI C57.16-1958)

IEEE Standard Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors

Sponsor

**Transformers Committee
of the
IEEE Power Engineering Society**

Approved 10 December 1996

IEEE Standards Board

Approved 7 May 1997

American National Standards Institute

Abstract: Series-Connected dry-type air-core single-phase and three-phase outdoor or indoor reactors of distribution and transmission voltage class that are connected in the power system to control power flow under steady-state conditions and/or limit fault current under short-circuit conditions are covered. Dry-Type air-core reactors covered by this standard are self-cooled by natural air convection. With some restrictions, other reactors, including filter reactors, shunt capacitor reactors (used with shunt capacitor banks), and discharge current limiting reactors (used with series capacitor banks), are also covered.

Keywords: air-core reactors, discharge current-limiting reactors, dry-type air-core reactors, dry-type reactors, filter reactors, harmonic filters, reactors, series capacitor bank applications, series-connected reactors, series reactor applications, shunt capacitor bank applications, shunt capacitor reactors

The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

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ISBN 1-55937-881-6

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Introduction

(This introduction is not part of IEEE Std C57.16-1996, IEEE Standard Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors.)

The work to revise ANSI C57.16-1958, Standard Requirements, Terminology and Test Code for Current Limiting Reactors, was carried out by the Dry-Type Reactor Working Group, reporting to the Dry-Type Transformers Subcommittee of the IEEE Transformers Committee. There were several important objectives for the revision, which led to the current document.

- a) The scope was broadened to reflect the current usage of ANSI C57.16-1958. Thus the title was changed to incorporate the words “series-connected reactors” instead of “current-limiting reactors.”
- b) It has been common practice in the industry to use ANSI C57.16-1958 in the specification and testing of filter reactors, shunt capacitor reactors, and discharge current-limiting reactors for series capacitor banks. Thus several new normative annexes were added to more appropriately and accurately accommodate this need.
- c) ANSI C57.16-1958 covered both oil-immersed and dry-type reactors. Based on a formal vote in the Performance Characteristics Subcommittee and a voice vote of the Transformers Committee, no interest was raised in continuing the inclusion of oil-immersed reactors in the standard. Therefore, this revision of ANSI C57.16-1958 is a dry-type standard only in order to reflect the present and future needs of purchasers (“end users”) and manufacturers.

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IEEE Standard Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors

1. Overview

1.1 Scope

This standard applies to *series-connected* dry-type air-core single-phase and three-phase outdoor or indoor reactors of distribution and transmission voltage class that are connected in the power system to control power flow under steady-state conditions and/or limit fault current under short-circuit conditions. Dry-type air-core reactors covered by this standard are self-cooled by natural air convection.

With some restrictions, this standard is applicable to filter reactors, shunt capacitor reactors (used with shunt capacitor banks), and discharge current-limiting reactors (used with series capacitor banks). Annexes A, B, and C are included to provide guidance.

This standard does not apply to devices such as

- a) Shunt reactors (see IEEE Std C57.21-1990, IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 500 kVA),
- b) Arc suppression coils,
- c) Neutral grounding devices [see IEEE Std 32-1972 (Reaff 1990), IEEE Standard Requirements, Terminology, and Test Procedures for Neutral Grounding Devices],
- d) Line resonant reactors,
- e) High-Voltage direct current (HVDC) smoothing reactors,
- f) Forced cooled reactors, and
- g) Line traps and radio interference (RI) filter reactors (ANSI C93.3-1995).

1.2 Purpose

The existing ANSI C57.16-1958, which is still in use by the industry, is out of date and has been withdrawn as an IEEE standard. It has now been revised to reflect modern product technology, to describe up-to-date test methods, and to present application requirements for series reactors.

2. References

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

ANSI C29.9-1983 (Reaff 1996), American National Standard—Wet-Process Porcelain Insulators (Apparatus, Post Type).¹

ANSI C37.06-1987 (Reaff 1994), American National Standard—Preferred Rating and Related Required Capabilities for AC High Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

ANSI C37.12-1991, American National Standard—Specification Guide for AC High-Voltage Circuit Breakers Based on a Symmetrical Current Basis.²

ANSI C84.1-1989, American National Standard—Voltage Ratings for Electric Power Systems and Equipment (60 Hz).

ANSI C93.3-1995, American National Standard—Requirements for Power-line Carrier Line Traps.³

ANSI S1.4-1983, American National Standard—Specification for Sound Level M (includes supplement ANSI S1.4a-1985).

ANSI S1.11-1986 (Reaff 1993), American National Standard—Specifications for Octave-Band and Fractional Octave-Band Analog and Digital Filters.

IEC 143-1-1992, Series capacitors for power systems—Part 1: General—Performance, testing and rating—Safety requirements—Guide for installation.⁴

IEC 143-2-1994, Series capacitors for power systems—Part 2: Protective equipment for series capacitor banks.

IEC 722-1982, Guide to the lightning impulse and switching impulse testing of power transformers and reactors. Appendix A, Principles for wave shape control.

IEC 943-1989, Guide for the specification of permissible temperature and temperature rise for parts of electrical equipment, in particular for terminals.

IEEE Std 1-1986 (Reaff 1992), IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation (ANSI).

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing (ANSI).

IEEE Std 18-1992, IEEE Standard for Shunt Power Capacitors (ANSI).

IEEE Std 100-1996, IEEE Standard Dictionary of Electrical and Electronics Terms.

¹IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

²ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

³As this standard goes to press, ANSI C93.3-1995 is approved but not yet published. Contact the American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA, for more information.

⁴IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute.

IEEE Std 315-1975 (Reaff 1993), Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters) (ANSI).

IEEE Std 693-1984 (Reaff 1991), IEEE Recommended Practices for Seismic Design of Substations (ANSI).

IEEE Std 824-1994, IEEE Standard for Series Capacitors in Power Systems (ANSI).

IEEE Std C57.12.80-1978 (Reaff 1992), IEEE Standard Terminology for Power and Distribution Transformers (ANSI).

IEEE Std C57.12.90-1993, IEEE Test Code for Liquid-Immersed Distribution, Power and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers (ANSI).

IEEE Std C57.21-1990 (Reaff 1995), IEEE Standard Requirements, Terminology and Test Code For Shunt Reactors Rated Over 500 kVA (ANSI).

IEEE Std C57.98-1994, IEEE Guide for Transformer Impulse Tests (ANSI).

IEEE Std C62.1-1989 (Reaff 1994), IEEE Standard for Gapped Silicon-Carbide Surge Arresters for AC Power Circuits (ANSI).

IEEE Std C62.2-1989 (Reaff 1994), IEEE Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating-Current Systems (ANSI).

IEEE Std C62.11-1993, IEEE Standard for Metal-Oxide Surge Arresters for Alternating Current Power Circuits (ANSI).

IEEE Std C62.22-1991, IEEE Guide for the Application of Metal Oxide Surge Arresters for Alternating Current Systems (ANSI).

NEMA 107-1988 (Reaff 1993), Methods of Measurement of Radio Influence Voltage (RIV) of High-Voltage Apparatus.⁵

3. Definitions

All definitions, except as specifically covered in this standard, shall be in accordance with IEEE Std 100-1996. For the convenience of the user, definitions are organized by category.

3.1 Types of dry-type air-core series reactors

3.1.1 air-core reactor: A reactor that does not include a magnetic core or magnetic shield.

3.1.2 indoor reactor: A reactor that, because of its construction, must be protected from the weather.

3.1.3 outdoor reactor: A reactor of weatherproof construction.

3.1.4 three-phase dry-type air-core reactor: A reactor made up of single-phase devices that are stacked and magnetically coupled. Depending on the application, the self-inductance may be modified to compensate for mutual coupling effects.

⁵NEMA publications are available from the National Electrical Manufacturers Association, 1300 N. 17th St., Ste. 1847, Rosslyn, VA 22209, USA.

3.2 Series reactor applications

3.2.1 bus tie reactor: A current-limiting reactor for connection between two different buses or two sections of the same bus for the purpose of limiting and localizing the disturbance due to a fault in either bus.

3.2.2 current-limiting reactor: A reactor connected in series with the phase conductors for limiting the current that can flow in a circuit under short-circuit conditions, or under other operating conditions, such as capacitor switching, motor starting, synchronizing, arc stabilization, etc.

3.2.3 duplex current-limiting reactor: A center-tapped reactor used in two circuit branches fed by a common circuit and wound in such a way as to employ negative coupling under normal operating conditions to reduce circuit impedance and positive coupling under fault conditions to increase circuit impedance.

3.2.4 feeder reactor: A current-limiting reactor connected in series with a feeder circuit, for the purpose of limiting and localizing the disturbance due to faults on the feeder.

3.2.5 high-voltage power flow control reactor: A transmission class reactor connected in series with the transmission system in order to optimize power flow by altering the line reactance.

3.2.6 insertion reactor: A reactor that is connected momentarily across the open contacts of a circuit-interrupting device for synchronizing and/or switching transient suppression purposes.

3.2.7 load balancing reactor: A series-connected reactor used to correct the division of current between parallel-connected transformers or circuits that have unequal impedance voltages under steady-state and short-circuit conditions.

3.2.8 motor starting reactor: A current-limiting reactor used to limit the starting current of a machine.

3.3 Rating

3.3.1 rating of a series reactor: The current that a series reactor can carry at its specified reactance together with any other defining characteristics, such as system voltage, basic impulse level (BIL), short-circuit current (thermal and mechanical) duty, and frequency.

3.4 Current

3.4.1 continuous current: The maximum constant root-mean-square (rms) power-frequency current that can be carried continuously without causing further measurable increase in temperature rise under prescribed conditions of test, and within the limitations of established standards.

3.4.2 mechanical short-circuit rating: The maximum asymmetrical (peak) fault current that the reactor is capable of withstanding with no loss of electrical or mechanical integrity.

3.4.3 rated current: The root-mean-square (rms) power-frequency current in amperes that can be carried for the duty specified, at rated frequency without exceeding the specified temperature limits, and within the limitations of established standards.

3.4.4 rated short-time overcurrent: The root-mean-square (rms) power-frequency current, of magnitude greater than the continuous current rating, that can be carried for a specified period of time and, depending on the ambient temperature, that may result in defined loss of the reactor's service life.

3.4.5 thermal short-circuit rating: The maximum steady-state short-circuit root-mean-square (rms) current that can be carried for a specified time, the reactor being approximately at rated temperature rise and maximum ambient at the time the load is applied, without exceeding the specified temperature limits, and within the limitations of established standards.

3.5 Duty

3.5.1 continuous duty: A requirement of service that demands operation at a substantially constant current for an extended period of time.

3.5.2 duty: A requirement of service that defines the degree of regularity of the current through the reactor.

3.5.3 intermittent duty: A requirement of service that demands operation for alternate periods of current loading and rest, such alternate intervals being definitely specified.

3.5.4 periodic duty: A type of intermittent duty in which the current loading conditions are regularly recurrent.

3.5.5 short-time duty: A requirement of service that demands operation at a substantially constant current for a short and definitely specified time.

3.5.6 varying duty: A requirement of service that demands operation at intermittent current loading, and for periods of time, both of which may be subject to wide variation.

3.6 Voltage

3.6.1 nominal voltage (of a system): A nominal value assigned to a system or circuit of a given voltage class for the purpose of convenient designation.

NOTE—The term *nominal voltage* designates the line-to-line voltage, as distinguished from the *line-to-neutral* voltage. It applies to all parts of the system or circuit.

3.6.2 rated system voltage: The voltage of a series reactor to which operational and performance characteristics are referred. It corresponds to the nominal line-to-line or phase-to-phase system voltage of the circuit on which the reactor is intended to be used.

3.6.3 voltage to ground: The voltage between any live conductor of a circuit and the earth.

NOTE—Where safety considerations are involved, the voltage to ground that may occur in an ungrounded circuit is usually the highest voltage normally existing between the conductors of the circuit, but in special circumstances higher voltages may occur.

3.7 Losses, impedance, and system frequency

3.7.1 Losses

3.7.1.1 “effective” resistance: The value of resistance of a series reactor obtained by dividing the total losses, as defined in 3.7.1.2 losses, items a), b), and c), by the current squared at power frequency. *Synonym:* ac resistance.

3.7.1.2 losses: Those losses that are incident to the carrying of current. They include

- a) The resistance and eddy-current loss in the winding due to load current.
- b) Losses caused by circulating current in parallel windings.

- c) Stray losses caused by magnetic flux in other metallic parts of the reactor, in the reactor support structure, and in the reactor enclosure when the support structure and the enclosure are supplied as an integral part of the reactor installation.

NOTE—The losses produced by magnetic flux in adjacent apparatus or material not an integral part of the reactor or its enclosure (if supplied) are not included.

3.7.2 Impedance

3.7.2.1 impedance: The phasor sum of the reactance and effective resistance, expressed in ohms.

3.7.2.2 impedance voltage drop: The product of the rated ohms' impedance and the rated current of a series reactor.

3.7.2.3 per-unit reactance: On a rated current base, a dimensionless quantity obtained by referencing the magnitude of the reactance to the rated system line-to-neutral voltage divided by the rated current of the reactor.

NOTE—Per-Unit reactance can also be defined on an arbitrary megavoltampere (MVA) base.

3.7.2.4 rated inductance: The total installed inductance at a specified frequency. It may consist of mutual as well as self-inductance components.

3.7.2.5 rated reactance: The product of rated inductance and rated angular frequency that provides the required reduction in fault current or other desired modification to power circuit characteristics.

3.7.2.6 reactance: The product of the inductance in henries and the angular frequency of the system.

3.7.2.7 reactance voltage drop: The component of voltage drop in quadrature with the current.

3.7.2.8 resistance voltage drop: The component of voltage drop in phase with the current.

4. General requirements

4.1 Service conditions

4.1.1 Usual service conditions

Series reactors conforming to this standard shall be suitable for operation at standard rating provided that the site-related conditions in the following subclauses are met.

4.1.1.1 Ambient temperature

Ambient temperature is the temperature of the air surrounding the reactor. For the purposes of this standard, it is assumed that the temperature of the cooling air (ambient temperature) does not exceed 40 °C and the average temperature of the cooling air for any 24 h period does not exceed 30 °C.⁶

4.1.1.2 Environmental and application related service conditions

Reactors for outdoor application must be designed for conditions such as rain, freezing rain (ice), snow, fog and ultraviolet (UV) ray exposure. The purchaser should, in the specification, attempt to quantify or qualify envi-

⁶It is recommended that the average temperature of the cooling air be calculated by averaging 24 consecutive hourly readings. When the outdoor air is the cooling medium, the average of the maximum and minimum daily temperature may be used. The value that is obtained in this manner is usually slightly higher than the true daily average.

ronmental conditions, including type and level of pollution. The reactor should also be designed to withstand, without damage or loss of service life, mechanical loads such as electromagnetic forces during short-circuit, wind loading, and stresses caused by thermal expansion and contraction due to ambient temperature and current loading variations. Wind speed data, including gust factors, should be specified by the purchaser. In the case of indoor application, the purchaser should specify the type and level of pollution from the environment and the indoor ambient temperature range.

4.1.1.3 Altitude

The altitude does not exceed 1000 m (3300 ft).

4.1.2 Unusual service conditions and other conditions that may affect design and application

Unusual service conditions may require that particular consideration be given to the construction or operation of the equipment, and these should be brought to the attention of those responsible for the specification, manufacture, application, and operation of the equipment. Among such unusual conditions are the following:

- a) Application at higher ambient temperatures or at higher altitudes than specified in 4.1.1.
NOTE—Standard equipment may be applied at higher ambient temperatures, or at higher altitudes than specified, but the performance will be affected.
- b) Restriction of air flow to the reactor that could affect its self-cooling by natural air convection.
- c) Exposure to damaging fumes or vapors; farm fertilizers and weed sprays; excessive dust, abrasive or magnetic dust; explosive mixtures of dust or gases; steam, excessive moisture, or dripping water; salt air or spray, etc.
- d) Exposure to abnormal vibration, shock, or tilting.
- e) Exposure to temperatures below -40°C .
- f) Exposure to unusual transportation or storage conditions.
- g) Unusual space limitations.
- h) Operating duty, difficulty of maintenance, abnormal harmonic content, unbalanced voltage, special insulation requirement, etc.
- i) Unusual operating requirements, such as might result from the absence of surge-arrester protection, lack of magnetic shielding, etc.

NOTE—If a series reactor is not fully shielded magnetically, consideration should be given to its location relative to other apparatus and to metallic structures, in order to minimize heating effects of stray fields at normal current and reaction forces under short circuit. The manufacturer can evaluate the suitability of an installation if provided with details of the surrounding structure.

- j) Operation of system with one phase conductor grounded.

NOTE—This should be considered as an emergency operating condition, and the duration should be limited to the time reasonably required to isolate the fault.

4.2 Insulation

4.2.1 Insulation between turns

Dry-type air-core series reactors have no magnetic core, therefore the primary internal insulation is solely the winding turn-to-turn insulation system. In the case of open-style dry-type reactor designs, the insulation between turns is provided by air and the materials utilized to separate the turns. In the case of dry-type reac-

tors with fully encapsulated windings, the insulation between turns is usually a solid dielectric material. The material utilized to encapsulate such a reactor is primarily employed to provide environmental protection and mechanical strength. In selecting appropriate materials to be utilized as turns insulation on the conductors, it is necessary to evaluate dielectric properties, mechanical properties, and multifactor aging characteristics under operating conditions. Encapsulation materials are evaluated in a similar fashion. Amount, type, and method of application of materials employed are a function of manufacturing considerations, specification requirements, service (application) requirements, and site or environmental conditions.

4.2.2 Insulation between terminals

The distance between input and output terminals, the winding length, the electrode configuration of the winding ends, and the dielectric properties of the winding surface must be such that the reactor can withstand the steady-state operating voltages, short-time, and transient overvoltages applied between the terminals.

4.2.3 Insulation to ground and between phases

The support insulators provide the primary insulation to ground and, if applicable, between phases of a dry-type air-core series reactor. These are selected based on system voltage considerations, special transient overvoltage requirements, and site environmental conditions (i.e., pollution, altitude, etc.).

4.3 Operation at altitudes in excess of 1000 m (3300 ft)

Standard equipment may be applied in locations having an altitude in excess of 1000 m (3300 ft), but the dielectric strength of air-insulated parts and the current-carrying capacity will be reduced. For instance, the effect of decreased air density due to high altitude is to decrease the flashover voltage for a given distance. See IEEE Std 4-1995⁷ for use of a correction factor with sphere gaps.

4.3.1 Dielectric strength of air-insulated parts

The dielectric strength at greater than 1000 m (3300 ft) of air-insulated parts of a given insulation class should be multiplied by the proper altitude correction factor, as given in Table 1, to obtain the dielectric strength at the required altitude. For example, the dielectric strength of a series reactor that depends in whole or in part upon air for its insulation decreases as the altitude increases.

4.3.2 Operation at rated current

It is recognized as good practice to use reactors of standard temperature rise at rated current at altitudes greater than 1000 m (3300 ft) provided the average temperature of the cooling air does not exceed the values in Table 2 for the respective altitudes. Standard temperature limits will not be exceeded.

4.3.3 Operation at less than rated current

It is recommended that when reactors of standard temperature rise in standard ambient temperatures are used at altitudes greater than 1000 m (3300 ft), that the current to be carried is reduced below rating by 0.3% for each 100 m (330 ft) that the altitude is above 1000 m. If this is done, the standard temperature rise will not be exceeded.

⁷Information about references can be found in Clause 2.

**Table 1—Dielectric strength correction factors
for altitudes greater than 1000 m (3300 ft)**

Altitude		Altitude correction factor for dielectric strength
m	ft	
1000	3300	1.00
1200	4000	0.98
1500	5000	0.95
1800	6000	0.92
2100	7000	0.89
2400	8000	0.86
2700	9000	0.83
3000	10 000	0.80
3600	12 000	0.75
4200	14 000	0.70
4500	15 000	0.67

NOTE—An altitude of 4500 m (15 000 ft) is considered a maximum for standard reactors.

**Table 2—Maximum allowable 24 h average temperature of cooling air
to permit a dry-type air-core series reactor to carry rated current**

Insulation index (°C)	Altitude (°C)			
	1000 m (3300 ft)	2000 m (6600 ft)	3000 m (9900 ft)	4000 m (13 200 ft)
105	30	27	24	21
130	30	26	22	18
155	30	24	18	12
180	30	23	16	9
220	30	22	15	7

NOTE—Recommended calculation of average temperature is described in Footnote 6 (see page 7).

5. Rating

5.1 Basis of rating

The rating of a series reactor shall include the following:

- Reactance (in ohms or percent)
- Voltage drop
- System voltage
- Continuous current
- Mechanical and thermal short-circuit current
- Number of phases
- Frequency
- Basic insulation level (BIL)

5.2 System frequency

The reference system frequency for series reactors used in this standard in North America is 60 Hz.

NOTE—As this standard is used outside North America, 50 Hz may be the operating frequency. In this case, calculations will have to be modified accordingly.

5.3 Reactance rating

Most currently available dry-type air-core series reactors are custom designed; thus the end user should specify the exact reactance required.

5.3.1 Reactance voltage drop

The reactance voltage drop of a series reactor at its rated current is obtained by multiplying the rated reactance by the rated current.

5.4 Voltage rating

Custom-designed dry-type air-core series reactors are available for any system voltage rating including the standard ones listed in Table 5 (see also Clause 9).

5.5 Continuous current rating

5.5.1 Specification of current rating

Currently available custom-designed dry-type air-core series reactors allow the end user to specify the exact current rating required, including special duty cycles.

NOTE—If harmonic current content is significant, it should be taken into consideration in arriving at the continuous current rating of the series reactor.

5.6 Short-Circuit current rating

5.6.1 Mechanical and thermal short-circuit current rating

Series (current-limiting) reactors shall have a thermal and mechanical short-circuit current rating. The thermal and mechanical short-circuit rating shall be specified by the purchaser. Typically, the short-circuit rating is determined from the calculated current when any type of fault occurs at the load side terminals with a minimum of 105% of rated system voltage present as measured at the supply side terminals of the reactor. Anticipated system voltages of greater than 105% should be specified and accounted for, as operation of reactors at a higher system voltage than that used for the short-circuit calculation will impose a severe short-circuit duty that may be beyond the mechanical strength of the reactor. It should also be emphasized that system impedance should be considered in arriving at the short-circuit rating of the current-limiting reactor in order to achieve an economic design that fully meets all system requirements. The mechanical short-circuit current rating is based on the worst-case assumption of a simultaneous three-phase fault and the resulting offset peak current. The degree of offset is a function of system damping. The magnitude of the thermal short-circuit current rating is obtained from system fault calculations and the duration is a function of system operating policy including number of “autorecloses” of the breaker, etc. Some useful formulas and a sample calculation follow.

Reference formulas include

$$X_L = \frac{(V_s)^2}{MVA} \quad (1)$$

$$X_R = (V_s)^2 \left(\frac{1}{MVA_A} - \frac{1}{MVA_B} \right) \quad (2)$$

$$X_R = \frac{V_s}{\sqrt{3}} \left(\frac{1}{I_{SCA}} - \frac{1}{I_{SCB}} \right) \quad (3)$$

$$I_{SC} = \frac{MVA}{\sqrt{3} \cdot V_s}, I_{SC} = \frac{V_s}{\sqrt{3}} \cdot \frac{1}{X_L} \quad (4)$$

NOTE—The Equation for X_L is correct only for the special case where the system resistance R is zero. In actual systems R is finite. However, the system resistance can be ignored if the R/X ratio is small enough. For an R/X ratio of 0.05 (about the middle of Table 7) the error is about 0.1%.

where

MVA is the three-phase symmetrical system fault level in megavoltamperes,

MVA_B is the three-phase symmetrical system fault level on the source side of a series reactor,

MVA_A is the three-phase symmetrical system fault level on the load side of a series reactor,

X_L is the total, per-phase, system equivalent series reactance, in ohms,

X_R is the reactance of series reactor in ohms,

V_s is the system line-to-line rms voltage in kilovolts,

I_{SC} is the rms short-circuit current in kiloamperes,

I_{SCB} is the per-phase, system fault current, in kiloamperes, excluding the use of a series reactor, and

I_{SCA} is the per-phase, system fault current, in kiloamperes, including the use of a series reactor.

A sample calculation is as follows:

- a) Rated system voltage is equal to 13.8 kV,
- b) Fault level is equal to 100 MVA at 105% of rated system voltage,
- c) Reduce fault level to 50 MVA at 105% of rated system voltage.

The existing system series reactance is

$$X_L = \frac{(13.8 \cdot 1.05)^2}{100} = 2.10 \, \Omega \quad (5)$$

The total series reactance required to limit fault level to 50 MVA and accounting for a nominal operating overvoltage of 105% is

$$X_L = \frac{(13.8 \cdot 1.05)^2}{50} = 4.20 \, \Omega \quad (6)$$

Therefore, the required value of the series reactor reactance is

$$X_R = 4.20 - 2.1 = 2.10 \, \Omega \quad (7)$$

The symmetrical rms fault-current rating of the reactor is

$$I_{SCA} = \frac{(13.8 \cdot 1.05)}{\sqrt{3}} \cdot \frac{1}{4.2} = 2.0 \text{ kA} \quad (8)$$

5.6.2 Short-Circuit mechanical stresses

Under short-circuit conditions, the electromagnetic forces and associated stresses in the windings and ancillary components of dry-type air-core reactors can reach values tens to hundreds of times those seen under steady-state operating conditions. Forces and stresses are proportional to the square of the magnitude of the current. Windings are subjected to simultaneous hoop and compressive forces. Input and output current-carrying bus or cable (including the terminals to which they are attached) must withstand vectorial loads that vary with the spatially changing pattern of the dry-type air-core reactor's magnetic field. The reactor's mechanical clamping structure and support elements are exposed to direct acting forces (if they carry current) as well as reaction forces.

5.6.3 Mechanical short-circuit current rating

The mechanical short-circuit current rating shall be expressed as maximum crest asymmetrical amperes. The maximum crest of an asymmetrical current shall be determined by the purchaser through system knowledge and the use of Equation (9). If not specified by the purchaser, the maximum crest asymmetrical current should be considered as 2.55 times the rms symmetrical current ($I_{pk} = 2.55 \cdot I_{rms}$).

The mechanical short-circuit current rating shall be verified by a design test and/or calculation. The method of calculation is to be agreed upon by the manufacturer and the purchaser.

5.6.4 Thermal short-circuit current rating

Series (current-limiting) reactors shall have a thermal short-circuit current rating of magnitude based on the rms symmetrical fault current as specified in 5.6.1. The duration should be specified by the purchaser and should typically take into consideration system protection practices such as breaker interrupting time, breaker autoreclose sequence, etc.

The thermal short-circuit current rating shall be expressed in rms symmetrical amperes.

Typical values for the duration of the thermal short-circuit current rating are 1, 2, or 3 s. The actual required duration should be specified by the purchaser. If not specified by the purchaser, the duration of the thermal short-circuit current should be considered to be 3 s.

NOTE—Duration of short-circuit current can impact the cost of a current-limiting reactor; therefore, it is in the purchaser's best interest to specify a realistic value of time.

The thermal short-circuit current rating shall be verified by a design test and/or calculation. The calculation method is found in 11.7.

5.6.5 Enclosures

When reactors are used in enclosures, a number of precautions should be observed. For fiberglass enclosures, large metallic auxiliary parts (e.g., ventilation screens) should be grounded so as to avoid shorted loops that could be subject to heavy current flow and damaging forces under short-circuit conditions. Metal enclosures should be designed using the principles of sectionalization and isolation in order to avoid overheating under steady-state operating conditions and permanent distortion, excessive temperature, or sparking under short-circuit conditions.

NOTE—The design of enclosures for use with air-core series reactors requires extensive engineering expertise and proper coordination with the reactor design. It is therefore recommended that the design of enclosures be left to the reactor manufacturer. Manufacture of the enclosures should also be left to the reactor manufacturer unless design details are supplied.

6. Tests

6.1 Routine, design, and other tests for series reactors

Tests for dry-type series reactors are listed in Table 3.

Table 3—Routine, design, and other tests for dry-type series reactors

Test	When performed	Test classification		
		Routine	Design	Other
Resistance measurement	The dc resistance measurement shall be made on all units.	X		
Impedance measurement	The impedance measurement shall be made on all units.	X		
Total loss measurement	Total losses should be measured on all counts.	X		
Temperature rise test	This test is performed on one unit out of a number of units of the same design.		X	
Applied voltage test	The applied voltage test shall be made only on support insulators when specified.			X
Radio influence voltage (RIV) test	This test is performed for nominal system voltages 230 kV and above only when specified.			X
Turn-to-Turn test	This test is performed for nominal system voltages of 34.5 kV and below.	X		
Lightning impulse test —Nominal system voltage greater than 34.5 kV —Nominal system voltage at or below 34.5 kV	The lightning impulse test should be performed on all units. The lightning impulse test should be performed only when specified.	X		X
Switching impulse test	The switching surge test shall be made on the support structure (insulators) of series reactors rated 115 kV or above only when specified.			X
Chopped-Wave impulse test	The chopped-wave impulse test shall be made on series reactors only when specified.			X
Audible sound test	Units shall be tested only when specified.			X
Seismic verification test	The seismic verification test shall be made on series reactors only when specified.			X
Short-Circuit test			X	

6.1.1 Routine tests

A routine test is a test made on each and every unit of a specific design and is primarily a verification of quality. Routine tests shall be made on all series reactors in accordance with the requirements of Table 3.

6.1.2 Design tests

A design test (also referred to as a type test) is a test carried out on a single unit of a specific design and is primarily a verification of the ability to meet in-service application requirements. Design tests shall be made on all series reactors in accordance with the requirements of Table 3.

6.1.3 Other tests

A test designated as “other” is a test performed on one or all units of a specific design if requested by the purchaser. It is usually requested to demonstrate conformance to special application requirements as opposed to the more general application requirements covered by design tests. When specified (as individual tests), “other” special tests, as listed in Table 3, shall be made on series reactors.

6.2 Where tests are to be made

All tests are to be made at the manufacturer’s plant, a recognized independent test laboratory, or other suitable facility unless specified otherwise.

6.3 Test sequence

The listing of tests shown in Table 3 does not necessarily indicate the sequence in which the tests shall be made. All tests are defined and shall be made in accordance with Clause 11.

6.4 Test procedures

The test procedures of this standard describe accepted methods used in making the tests and specify the tests that will demonstrate performance to rating. They do not preclude the use of other equivalent or more effective methods of demonstrating ratings based on agreement between manufacturer and purchaser.

7. Losses and impedance

7.1 Losses

7.1.1 Tolerance on losses

A tolerance on losses is utilized for two purposes: first, for commercial evaluation, and second, to provide the basis of a quality check.

7.1.1.1 Tolerance on losses for commercial evaluation

As energy costs increase, losses become a more significant component of total operating cost and, as such, may be evaluated by the purchaser. Therefore, compliance to guaranteed losses becomes part of the commercial contract. A tolerance on losses, to account, for instance, for measurement tolerances etc., may be part of the contractual agreement. Additionally, the contract may specify such guarantee criteria as maximum loss per unit, average loss for all units, total “package” losses, etc. In any case, this is purely a commercial matter between the purchaser and the manufacturer.

The only warning that should be stressed is that if a unit exceeds guaranteed loss, aside from the commercial implications (which are a matter between the manufacturer and the purchaser), it is essential to demonstrate that temperature rise limits for the insulation system employed are not exceeded.

7.1.1.2 Tolerance on losses as the basis of a quality check

The losses on any individual reactor unit shall not differ from the average loss of all units of the same design by more than 6%. For single-phase units, the average loss shall be calculated by using the measured losses on each individual unit. For three-phase stacked reactors, the average loss for each phase shall be calculated

by using the per-phase losses measured on a three-phase basis on each individual coil of a three-phase stacked reactor. For three-phase stacked reactors, the 6% tolerance on losses applies to units of the same phase.

If any of the individual units exceeds this tolerance, the manufacturer shall initiate an investigation in order to find the cause of this deviation. In order for acceptance to be considered, the manufacturer shall demonstrate to the purchaser, by either calculation and/or test, that the deviation will not impair the ability of the unit to meet the other requirements of this standard, including the temperature rise limits.

7.2 Impedance

7.2.1 Tolerance on impedance

Tolerances on impedance apply over a current range from zero to full short-circuit rating.

7.2.2 Impedance of a single-phase reactor

The impedance of a single-phase reactor, or of the minimum tap of a single-phase reactor having more than one impedance rating, shall not vary more than +7% or -3% from its guaranteed value. The impedance for all other connections shall not vary more than +10% or -3% from the guaranteed value.

7.2.3 Self-Impedance of a three-phase reactor

The self-impedance of each phase of a three-phase reactor, or of the minimum tap of a three-phase reactor having more than one impedance rating, shall not vary more than +7% or -3% from its guaranteed value. The self-impedance for all other connections shall not vary more than +10% or -3% from the guaranteed value.

7.2.4 Voltage drop

The voltage drop across each phase of a three-phase reactor, or of the minimum tap of a three-phase reactor having more than one rated voltage drop, with balanced three-phase rated current, shall be not more than 14% above or 3% below the guaranteed value. The voltage drop for all other connections shall be not more than 16% above or 3% below the guaranteed value.

7.2.5 Compensation for mutual impedance

When three-phase reactors are specified to be compensated for mutual impedance to provide balanced three-phase voltage drops, the minimum self-impedance of any phase shall be not less than 75% of the guaranteed value. Usually power systems are designed such that single-phase short-circuit currents are lower than three-phase short-circuit currents. However, it should be recognized that single line-to-ground faults on a system with a grounded neutral may result in fault currents in the lowest self-impedance phase higher than the three-phase fault currents. If no system impedance is considered, fault currents in the lowest self-impedance phase can be as high as 1.33 times the three-phase fault currents.

7.3 Impedance and losses test

Since dry-type air-core reactors have no iron core, the impedance and losses may be measured at any value of current and the losses corrected to rated current. For temperature correction, refer to 11.4.2.

If a wattmeter is used to determine losses, then impedance can be calculated by measuring simultaneous current and voltage and dividing the voltage by the current. Bridge methods allow the simultaneous measurement of reactance (inductance) and effective resistance, from which impedance and losses can be calculated.

8. Temperature rise

8.1 Considerations in establishing limits of temperature rise

8.1.1 Life of insulating materials

The life of insulating materials commonly used in dry-type series reactors depends largely upon the temperatures to which they are subjected and the duration of such temperatures.

Since the actual temperature is the sum of the ambient temperature and the winding temperature rise, it is apparent that the ambient temperature very largely influences the life of insulating materials used in dry-type series reactors.

Other factors upon which the life of insulating materials depend are as follows:

- a) Dielectric stress and associated effects
- b) Vibration or varying mechanical stress
- c) Repeated expansions and contractions
- d) Exposure to moisture, contaminants, etc.
- e) Overloading (current) of the device

8.1.2 Insulating materials

Currently, a wide range of conductor insulating materials are available. Most materials utilized today are polymers, which tend to be available in tape form, enamels or varnishes, and extrudable format. Selection of a conductor insulation material may be a function of thermal requirements, voltage requirements, mechanical requirements, or other service considerations. Because materials can exhibit different performance capabilities under various operating conditions, individual materials or combination of materials can be used in reactors of different temperature classes depending on the end application. It is for this reason that materials are no longer defined as Class B, F, or H, and are now assigned temperature indices. Each temperature index assigned to a material carries the implied descriptors of temperature, number of serviceable hours at that temperature, and end of life criteria. In general terms, an insulating material can be assigned more than one specific temperature index depending on the end of life criteria and performance characteristics desired. Therefore, because materials can exhibit different performance capabilities under various construction formats and operating conditions, the classification of a dry-type reactor as being of a particular temperature class does not imply that each individual material used in its construction is of the same thermal capability. The assignment of the temperature index of the insulation system and of the associated "hot spot" temperature rise is the responsibility of the reactor manufacturer. Only experience or adequate acceptance tests provide a basis for defining the temperature limits for the insulation system.

8.1.3 Thermal rating of materials and systems

Individual insulation and encapsulation materials may be assigned a temperature index based on maintenance of a certain performance characteristic for a specified number of hours at a specified temperature. However, in the case of dry-type air-core series reactors, it is not the performance characteristics of the constituent materials by themselves that is of interest; it is the performance of the system. Therefore, in designing dry-type air-core reactors for appropriate service life, it is not sufficient just to know the capabilities of the constituent materials; it is the performance of the system of materials that is critical.

Although performance at temperature is one of the main evaluating criteria for materials, multifactor aging effects also need to be considered, especially for the overall system. The assessment of what the important interactive aging mechanisms are is really in the jurisdiction of the manufacturer. Interactive aging mecha-

nisms that might have to be considered are temperature, electrical stress, thermal shock, mechanical load cycling, and environmental criteria.

Multifactor aging studies to establish the long-term performance of insulation materials are usually carried out based on principles in IEEE Std 1-1986.

8.1.4 Limits of temperature rise and duty of current-limiting reactors

Because series reactors are used in series with other equipment on the power system, the current through the reactor usually varies as the connected load changes. Therefore, series reactors do not operate at full rated current for much of their life.

Similar series-connected equipment (i.e., power line carrier wave traps; see ANSI C93.3-1995) typically have higher allowable winding temperature rise values due to variation in duty. Conversely, shunt reactors inherently have a very high continuous duty, with their current varying only with the applied voltage. Therefore, they have lower maximum winding temperature rise limits (see IEEE Std C57.21-1990) than series-connected equipment, since the winding will be at maximum design temperature rise for most of its connected lifetime.

Therefore, duty was also a major factor in arriving at the temperature rise limits in Table 4 of this standard.

8.1.5 Experience factor in establishing temperature rise limits for dry-type air-core series reactors

Although knowledge of the thermal capabilities of the constituent materials in a dry-type-air-core series reactor can provide a basis for establishing the allowable temperature rise limit for the reactor, service experience is also a significant determiner. This was an important criterion in arriving at the temperature rise limits in Table 4 of this standard. For this reason, the average temperature rise limits and hot spot temperature rise limits in Table 4 were arrived at both from the point of view of the temperature index of the insulation system and also from the application experience (including duty) and service history obtained from the application of reactors designed to identical temperature rise limits in the previous edition of this standard (ANSI C57.16-1958).

8.2 Limits of temperature rise

8.2.1 Standard limits of temperature rise

The standard limits of temperature rise of series reactors shall be as given in Table 4. Specifically, series reactors shall be so designed that the hottest-spot conductor temperature rise above the ambient temperature when operated at rated current will not exceed the values given in Table 4.

8.2.2 Enclosed reactor

When a dry-type air-core reactor is enclosed, external parts that can be touched shall not exceed a 30 °C temperature rise.

8.2.3 Temperature rise of reactor parts

The temperature rise above the ambient temperature of reactor parts in contact with the insulation or encapsulation material, when operated at rated current, shall not exceed the values given in Table 4. The temperature rise limit shall be based on the specific insulation temperature index of the insulation and encapsulation materials; whichever is in contact with the metallic part. For procedures in determining temperature rise, see 11.5.

**Table 4—Limits of temperature rise for continuously rated
dry-type air-core series reactors**

Item	Insulation temperature index (°C)	Average winding temperature rise by resistance (°C)	Hottest-spot winding temperature rise (°C)
1	105	55	85
	130	80	110
	155	100	135
	180	115	160
	220	140	200
2	Metallic parts in contact with or adjacent to the insulation shall not attain a temperature in excess of that allowed for the hottest spot of the windings adjacent to that insulation.		
3	Metallic parts other than those covered in item 2 shall not attain excessive temperature rises.		

NOTES

1—Temperature rise is rise above ambient in degrees Celsius.

2—A reactor with a specified temperature rise shall have an insulation temperature index that has been proven by experience or testing.

3—The insulation temperature index in Table 4 is supplied as a reference and is based on the preferred temperature index for insulation materials as defined in IEEE Std 1-1986. It should be noted that the preferred temperature index is the lowest value in a number range (of temperatures) into which insulation materials can be placed. This ensures an element of conservatism in the thermal performance of an insulation system and thus constitutes part of the experience factor in assigning temperature rise limits.

4—The above average temperature rises and hot spot temperature rises are maximum upper limits. Hottest-spot winding temperature rise limits are based on the accepted experience that series reactors are subject to significant variation in duty. The reference ambient temperature is considered to be a 20 °C annual average ambient temperature in conjunction with the capability to operate in a 40 °C maximum ambient when the 24 h average is 30 °C. Specified temperature limits may be lower due to such service considerations as high average ambient temperature conditions, prolonged exposure to high ambients, indoor vs. outdoor service, high continuous duty (limited “load cycling”), and loading profile (specified overloads).

5—The average winding temperature rise limits are based on the attempt to achieve a fixed 40% differential between hot spot rise and average rise. However, it should not be construed that the difference between maximum hot spot rise and average rise is a hot spot allowance. There are so many design variables involved that it is not possible to arrive at a meaningful single value. Nevertheless, it should be stressed that the intent is that neither the average winding rise nor the hottest spot winding rise should be exceeded. Since it is hot spot temperature rise that determines the life of a reactor, based on agreement between the manufacturer and purchaser, the average temperature rise can be safely exceeded for some reactor designs provided the hot spot rise limit is respected and verified.

6—Consideration should be given to specifying reduced temperature rise limits for reactors utilized on generator lines, interties, etc. In these types of applications, equipment is usually fully loaded most of the time, as opposed to more usual applications where equipment is loaded based on varying duty (“load cycled”).

8.2.4 Temperature rise of terminals

The temperature rise of a dry-type air-core series reactor's terminals furnished by the reactor manufacturer for connection to the user's circuits shall, in general, not exceed 60 °C. Service experience has demonstrated the validity of this guideline. However, if appropriate, a choice of terminal plating material, contact aids, bolting technique, etc., can make higher terminal operating temperatures possible. If more information is required regarding terminal operating temperatures, surface contact preparation, electrical contact aids, plating materials, etc., then [B1], [B2], [B3], and [B6] can be consulted.

NOTE—It should be recognized that the terminals of reactors, of necessity, come at the ends of the winding where the flux density may be almost as high as it is inside the coil. Therefore, it is important, especially for high-current reactor units, to use appropriate connectors, preferably those that present a streamlined geometry to the magnetic field. It is also critical to ensure that the dimensions and the direction of approach of the user's conductors are such as to not increase the eddy losses; otherwise, the temperature rise of the connection may be greatly increased. If the user's conductor insulation is limited to a lower temperature rise than that allowed for the reactor terminal, a section of bare conductor that will radiate sufficient heat to provide the desired temperature differential should be inserted by the user.

8.3 Temperature rise tests

8.3.1 Test methodology

This test shall be made by passing rated current through the reactor until the temperature rise becomes constant, and then determining the hottest-spot temperature rise, where practicable, together with the average winding temperature rise. The temperature rise tests shall be made in a room that is essentially draft-free.

NOTES

1—When the available test power does not permit making the test at rated current, then the manufacturer shall demonstrate to the user that reduced current testing produces sufficiently accurate results when extrapolated to rated current level. The manufacturer shall notify the user of reduced current level testing during the proposal stage.

2—For higher current rated units, knowledge of in-service terminal temperature rise may be of importance. In this case, consideration should be given to performing the temperature rise test with the actual connectors to be used in service, especially if they differ from those recommended by the manufacturer. If the connectors are not supplied by the manufacturer, the end user should supply them. It is important to ensure that conditions for such a test truly reflect in-service operating conditions, or erroneous results may be obtained. Test conditions must be agreed to by manufacturer and end user.

8.3.2 Hottest-Spot determination

The hottest-spot temperature rise for dry-type series reactors shall be determined by thermometer where the use of thermocouples poses a hazard due to high voltage.

8.3.3 Ambient temperature

Ambient temperature is the temperature of the air surrounding the reactor.

8.3.4 Methods of temperature determination

8.3.4.1 Thermometer method of temperature determination

The thermometer method consists of determining the temperature by mercury or alcohol thermometers, by resistance thermometers, or by thermocouples, any of these instruments being applied to the hottest part of the apparatus accessible to mercury or alcohol thermometers.

8.3.4.2 Resistance method of temperature determination

The resistance method consists of the determination of the temperature by comparison of the resistance of a winding at the temperature to be determined, with the resistance at a known temperature.

9. Insulation levels and dielectric tests

9.1 Impulse insulation levels

The standard impulse insulation levels for series reactors are given in Table 5, column 5. These values are expressed in terms of the crest value of a $1.2 \times 50 \mu\text{s}$ full wave.

Table 5—Insulation test levels for dry-type air-core series reactors

Nominal system voltage (kV)	Applied voltage test (kV) rms	Turn-to-Turn overvoltage		BIL and full wave (kV) crest	Chopped-Wave (kV) crest	Time to flashover (μs)	Switching impulse (kV) crest
		Indoor (kV) rms	Outdoor (kV) rms				
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
1.2	10	10	13	45	50	1.25	—
2.5	19	19	25	60	66	1.5	—
5.0	26	26	35	75	83	1.6	—
8.7	36	36	48	95	105	1.8	—
15.0	50	50	67	110	120	2.0	—
25.0	70	70	93	150	165	3.0	—
34.5	95	95	127	200	220	3.0	—
46.0	120	—	—	250	275	3.0	—
69.0	120	—	—	250	275	3.0	—
	175	—	—	350	385	3.0	—
115.0	175	—	—	350	385	3.0	280
	—	—	—	450	495	3.0	375
	280	—	—	550	605	3.0	460
138.0	—	—	—	450	495	3.0	375
	280	—	—	550	605	3.0	460
	335	—	—	650	715	3.0	540
161.0	280	—	—	550	605	3.0	460
	335	—	—	650	715	3.0	540
	385	—	—	750	825	3.0	620
230.0	335	—	—	650	715	3.0	540
	385	—	—	750	825	3.0	620
	—	—	—	825	905	3.0	685
	465	—	—	900	990	3.0	745
	545	—	—	1050	1155	3.0	870
345.0	465	—	—	900	990	3.0	745
	545	—	—	1050	1155	3.0	870
	—	—	—	1175	1290	3.0	975

Table 5—Insulation test levels for dry-type air-core series reactors (continued)

Nominal system voltage (kV)	Applied voltage test (kV) rms	Turn-to-Turn overvoltage		BIL and full wave (kV) crest	Chopped-Wave (kV) crest	Time to flashover (μs)	Switching impulse (kV) crest
		Indoor (kV) rms	Outdoor (kV) rms				
Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8
500.0	610	—	—	1300	1430	3.0	1080
	680	—	—	1425	1550	3.0	1180
	710	—	—	1550	1705	3.0	1290
	—	—	—	1675	1845	3.0	1390
765.0	810	—	—	1800	1980	3.0	1500
	—	—	—	1925	2120	3.0	1600
	940	—	—	2050	2255	3.0	1700
NOTES 1—The nominal system voltage values given above are used merely as reference numbers and do not necessarily imply a relation to operating voltages. 2—The applied voltage test on dry-type air-core series reactors is a high-voltage test on the insulators. 3—For some BIL levels associated with a particular system voltage, no low-frequency test voltage is specified as insulators are not manufactured to that BIL rating. 4—For system voltages greater than 34.5 kV, the turn-to-turn test is not applicable and a full-wave impulse test is to be performed as a routine test. 5—In the case of series reactors, the BIL across the coil may be different than the BIL across the support insulators (to ground). The purchaser shall specify if the BIL across the coil is to be at a reduced level. Such a decision will be based on factors such as knowledge of the system characteristics and protection practices. Reduced BIL levels shall be selected from the standard values in Table 5. 6—In the case of dry-type air-core series reactors, switching impulse insulation levels apply only to the support insulators for 115 kV system voltages and above. 7—In the case of dry-type air-core series reactors employed in a three-phase stack configuration, interphase insulators may have a higher BIL rating than those at the base of the stack that only provide phase-to-ground insulation.							

9.2 Dielectric test levels

Standard impulse and low-frequency dielectric tests for series reactors shall be as given in Table 5.

9.3 Dielectric tests

9.3.1 Dielectric tests

Dielectric tests are tests that consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy against breakdown of insulating materials and spacing under normal conditions.

9.3.2 Turn-to-Turn overvoltage test

The turn-to-turn test for dry-type air-core series reactors shall be made by applying between the terminals of each winding a series of high-frequency, exponentially decaying sinusoidal voltages. The test sequence shall

consist of a reduced sinusoidal voltage discharge followed by 7200 sinusoidal voltage discharges with a first peak voltage at least equal to $\sqrt{2}$ times the rms values specified in Table 5, columns 3 or 4. The duration of the test is not to exceed 60 s.

9.3.3 Impulse tests

For dry-type air-core series reactors, a lightning impulse test shall be made on each terminal of the reactor by applying a reduced wave and three full waves, all of positive polarity with crest voltage as specified in Table 5, column 5.

A chopped wave impulse test shall be made on each terminal of the reactor, when specified, by applying one reduced full wave, one full wave, one reduced chopped wave, two chopped waves, followed by two full waves (preferably within 10 min after the last chopped wave), with crest voltage as specified in columns 6 and 5 of Table 5 and time to chop as specified in column 7 of Table 5.

A switching impulse test shall be made, when specified, on the complete support assembly, including insulators, for system voltages 115 kV and higher. The test voltage is of positive polarity. The test should include one reduced and 15 full waves, with crest voltage as specified in Table 5, column 8. Two disruptive discharges (flashovers) are allowed. The purpose of this test is to assess the effect of the geometry of the reactor and ancillary elements of the support structure on the switching impulse withstand of the support insulators. Consideration can be given to performing this test under wet conditions as specified in IEEE Std 4-1995.

9.3.4 Applied voltage test

For dry-type air-core series reactors an applied voltage test shall be made, when specified, on the reactor's supporting structure, including insulators. For system voltages 230 kV and above, consideration should be given to performing the test under simulated wet conditions. Test values are those indicated in Table 5, column 2.

9.3.5 Radio influence voltage (RIV) test

The RIV test is only required for series reactors operating at system voltages 230 kV and higher and is carried out at power frequency according to NEMA 107-1988. The radio influence voltage of a series reactor shall not exceed the maximum RIV value stated in Table 6, when the series reactor is applied at the stated maximum system voltage. The RIV test should be performed on the reactor and its support structure, if available. The main sources of radio noise are the auxiliary metallic components of the reactor, such as the end electrodes, terminals, insulator mounting brackets, etc.

Table 6—Radio influence voltage

System voltage (kV) ^a		Radio influence test voltage (kV) ^b	Maximum radio influence voltage (μV) ^c
Maximum	Nominal		
242	230	140	250
362	345	209	250
550	500	317	500
800	765	462	750

^a The maximum and nominal system voltages are from ANSI C84.1-1995, Electric Power Systems and Equipment—Voltage Ratings (60 Hertz).

^b The radio influence test voltage is the line-to-ground value of the maximum system voltage.