



IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 500 kVA

IEEE Power Engineering Society

Sponsored by the
Transformers Committee



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IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 500 kVA

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

Approved 27 March 2008

IEEE-SA Standards Board

Abstract: All oil-immersed or dry-type, single-phase or three-phase, outdoor or indoor shunt reactors rated over 500 kVA are covered. Terminology and general requirements are stated, and the basis for rating shunt reactors is set forth. Routine, design, and other tests are described, and methods for performing them are given. Losses and impedance, temperature rise, dielectric tests, and insulation levels are covered. Construction requirements for oil-immersed reactors and construction and installation requirements for dry-type reactors are presented. This standard also covers thyristor-controlled shunt reactors used in static var compensators.

Keywords: dielectric tests, dry-type shunt reactor, oil-immersed shunt reactor

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Introduction

This introduction is not part of IEEE Std C57.21-2008, IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 500 kVA.

IEEE Std C57.21 was first published in 1971. It was subsequently revised in 1981 and 1990 and reaffirmed in 1995 and 2004. The current revision process has focused on the following:

- a) Annex A (normative) has been added to cover the specific requirements for dry-type air-core thyristor-controlled shunt reactors, which are an important component of static var compensator systems. Specific clauses, subclauses, tables, etc., in the main body of IEEE Std C57.21-2008 are referenced regarding specification and test code. Other aspects of specification and test code are covered in Annex A.
- b) Annex B (informative) has been added to provide background information on dielectric stresses imposed on shunt reactors during switching. The objective of Annex B is to provide guidance regarding the application and design of shunt reactors, especially in consideration of the significant switching duty and the associated repetitive dielectric stresses. As a consequence of the switching stresses seen by shunt reactors, reduced BIL (basic lightning-impulse insulation levels), which is common practice for power transformers, are no longer recommended and are not included in Table 5. Formal input regarding the content of this annex was requested of the IEEE Switchgear Committee and was provided. Input was also received from members of IEC MT32 on Inductive Load Switching.
- c) Table 5A and Table 5B in the previous version (IEEE Std C57.21-1990) have been combined into one table as Table 5 (insulation levels of shunt reactors). Separate tables for dry-type and oil-immersed shunt reactors were not deemed necessary as test levels are network-dependent and are independent of shunt reactor technology. Maximum system voltage is introduced to be consistent with terminology in the IEC reactor standard (see IEC 60076-6:2007 [B18]).^a

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^a The numbers in brackets correspond to those of the bibliography in Annex D.

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1. Overview

1.1 Scope

This standard applies to all oil-immersed or dry-type, single-phase or three-phase, outdoor or indoor shunt reactors rated over 500 kVA. [This standard also applies to thyristor-controlled shunt reactors used in static var compensators \(SVCs\).](#)

This standard does not apply to other devices such as the following:

- a) Shunt reactors, 500 kVA and smaller
- b) Current-limiting reactors (see IEEE Std C57.16™-1996¹)
- c) Arc-suppression coils
- d) Neutral-grounding devices (see IEEE Std 32™-1972)
- e) Saturable reactors
- f) Line-resonant reactors
- g) Filter reactors

¹ [Information on references can be found in Clause 2.](#)

1.2 Purpose

This standard specifies the requirements, terminology, and test code for oil-immersed and dry-type shunt reactors rated over 500 kVA and for thyristor-controlled shunt reactors used in SVCs.

2. Normative references

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

~~[2] ANSI C63.2-1987, American National Standard for Instrumentation—Electromagnetic Noise and Field Strength, 10 kHz to 40 GHz—Specifications.³~~

~~[3] ANSI C84.1-1989, Voltage Ratings for Electric Power Systems and Equipment (60 Hz). [4]~~

ANSI S1.4-1983 (Reaff 2006), American National Standard Specification for Sound Level Meters.²

ANSI S1.11-2004, Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters.

ANSI/ASME B1.20.1-1983 (Reaff 2001), Pipe Threads, General Purpose (Inch).

ANSI/CGA V-1-2005, Compressed Gas Cylinder Valve Outlet and Inlet Connections.

ASTM A167-~~90~~, ~~Specification for 1999~~ (Reaff 2004), Standard Specification for Stainless and Heat-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip.^{4,5}

~~[9] ASTM D117-89, Guide to Test Methods and Specifications for Electrical Insulating Oils of Petroleum Origin.~~

IEEE Std 1™-2000 (Reaff 2005), IEEE Recommended Practice—General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.^{4,5}

~~[10] IEC 722 (1982), Guide to the Lightning Impulse and Switching Impulse Testing of Power Transformers and Reactors, Appendix A, “Principles for Wave Shape Control”.⁵~~

~~[11] IEEE C57.12.80-1978 (Reaf 1986), IEEE Standard Terminology for Power and Distribution Transformers (ANSI).⁶ [12]~~

IEEE Std 4™-1995, IEEE Standard Techniques for High-Voltage Testing.

~~IEEE C57.13-1978 (Reaf 1986)~~Std 32™-1972 (Reaff 1990), IEEE Standard Requirements, Terminology, and Test Procedures for Instrument Transformers (ANSI). [13] IEEE C57.98-1986, IEEE Guide for Transformer Impulse Tests (ANSI). Neutral Grounding Devices.

²This standard has been withdrawn by ANSI. Copies can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, USA.

³ANSI publications are available from ANSI.

⁴ASTM publications are available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103-1187, USA.

⁵IEC publications are available from the International Electrotechnical Commission, 3 rue de Varembe, Case Postale 131, CH 1211, Genève 20,

Switzerland/Suisse. IEC publications are also available in the United States from ANSI.⁶

[IEEE Std 315™-1975 \(Reaff 1993\), IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams \(Including Reference Designation Letters\).](#)

[IEEE Std 693™-2005, IEEE Recommended Practice for Seismic Design of Substations.](#)

[IEEE Std 1277™-2002, IEEE Standard General Requirements and Test Code for Dry-Type and Oil-Immersed Smoothing Reactors for DC Power Transmission.](#)

[IEEE Std C37.015™-1993 \(Reaff 2006\), IEEE Application Guide for Shunt Reactor Switching. IEEE](#)

[Std C37.109™-2006, IEEE Guide for the Protection of Shunt Reactors.](#)

[IEEE Std C57.12.00™-2006, IEEE Standard for Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.](#)

² ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

³ ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

⁴ IEEE publications are available from the Institute of Electrical and Electronics Engineers, ~~Service Center~~, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

~~IEEE C57.113-1988, IEEE Trial-Use Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors (ANSI).~~

~~[16] IEEE C62.1-1989, IEEE Standard for Gapped Silicon-Carbide Surge Arresters for AC Power Circuits.~~

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[IEEE Std C57.12.80™-2002, IEEE Standard Terminology for Power and Distribution Transformers.](#)

[IEEE Std C57.12.90™-2006, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.](#)

[IEEE Std C57.13™-1993 \(Reaff 2003\), IEEE Standard Requirements for Instrument Transformers.](#)

[IEEE Std C57.16™-1996 \(Reaff 2001\), IEEE Standard Requirements, Terminology and Test Code for Dry- Type Air-Core Series-Connected Reactors.](#)

[IEEE Std C57.19.00™-2004, IEEE Standard General Requirements and Test Procedures for Power Apparatus Bushings.](#)

[IEEE Std C57.19.01™-2000 \(Reaff 2005\), IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.](#)

[IEEE Std C57.98™-1993 \(Reaff 1999\), IEEE Guide for Transformer Impulse Tests.](#)

[IEEE Std C57.106™-2006, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.](#)

[IEEE Std C57.113™-1991 \(Reaff 2002\), IEEE Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors.](#)

[IEEE Std C62.11™-2005, IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits \(>1 kV\). IEEE Std C62.22™-1997, IEEE Guide for the Application of ~~Gapped Silicon-Carbide~~ Metal-Oxide Surge Arresters for Alternating-Current Systems.](#)

~~[18] IEEE C62.11-1987, IEEE Standard for Metal Oxide Surge Arresters for AC Power Circuits (ANSI).~~

~~[19] IEEE Std 1-1986, IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation (ANSI).~~

~~[20] IEEE Std 4-1978, IEEE Standard Techniques for High Voltage Testing (ANSI).~~

~~[21] IEEE Std 21-1976, IEEE General Requirements and Test Procedures for Outdoor Apparatus Bushings (ANSI).~~

~~[22] IEEE Std 32-1972 (Reaff 1984), IEEE Requirements, Terminology, and Test Procedures for Neutral Grounding Devices (ANSI).~~

~~[23] IEEE Std 100-1988, IEEE Standard Dictionary of Electrical and Electronics Terms 4th ed. (ANSI).~~

~~[24] IEEE Std 315-1975 (Reaff 1988), IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams (CSA Z99-1975) (ANSI).~~

~~[25] IEEE Std 344-1987, IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations (ANSI).~~

~~[26] IEEE Std 454-1973 (Reaff 1979), IEEE Recommended Practice for the Detection and Measurement of Partial Discharges (Corona) During Dielectric Test (ANSI).⁸~~

~~[27] Bruckel, W. "Measurement Connection for Testing High Voltage Reactors (in German)." *Messen und Prüfen/Automatik*, Nov. 1976.~~

~~[28] Craig, S. and Kayser, H. "Iron loss Measurements by AC Bridge and Calorimeter." *Journal, Institution of Electrical Engineers*, vol. 95, p. 2, 1948, pp. 205-216.~~

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~~[30] Deutsch, F. "Measuring the Active Power Losses of Large Reactors." *Brown Boveri Review*, vol. 47, Apr. 1960, pp. 268-278.~~

~~[31] Erb, W. and Kraaij, D. J. "Design and Testing of Reactors for 735 kV." *Brown Boveri Review*, vol. 52, Nov./Dec. 1965, pp. 864-875.~~

~~[32] Foley, A. H. A. "Self Balancing Transformer Core Loss Bridge." *AIEE Transactions*, vol. 76, pt. 1, 1957, pp. 567-573.~~

⁷This standard has been withdrawn by ANSI.

⁸This standard has been withdrawn by IEEE. Copies can be obtained from the IEEE Standards Department.

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- [35] Heroines, R. T. and Graham, D. C. "Measurement of Self Cooled Transformer Sound Levels in Relatively High Ambients." *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-89, Sept./Oct. 1970, pp. 1657-1662.
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- [38] Moore, W. J. M. and Raftis, F. A. "Measurement of Shunt Reactor Loss at High Voltage with an Alternating Current Comparator Bridge." *IEEE Transactions on Power Apparatus and Systems*, vol. PAS 92, no. 2, Mar./Apr. 1973, pp. 662-667.
- [39] Petersons, O. A. "Transformer Ratio Arm Bridge for Measuring Large Capacitors Above 100 Volts." *IEEE Transactions on Power Apparatus and Systems*, vol. PAS 87, May 1968, pp. 1354-1361.

3. Definitions

For the purposes of this document, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms* [B19]⁶ should be referenced for terms not defined in this clause.

3.1 Shunt reactor

3.1.1 reactor: A device used for introducing impedance into an electric circuit, the principal element of which is inductive reactance.

3.1.2 shunt reactor: A reactor intended for connection in shunt to an electric system for the purpose of drawing inductive current.

NOTE—The normal use for shunt reactors is to compensate for capacitive currents from transmission lines, cables, or shunt capacitors. The need for shunt reactors is most apparent during light loads.⁷

⁶The numbers in brackets correspond to those of the bibliography in Annex D.

⁷Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

4. General requirements

4.1 Service conditions

4.1.1 Usual temperature and altitude service conditions

A shunt reactor conforming to this standard shall be suitable for operation at its rated kVA and voltage, provided that

- a) 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.⁸
- b) The altitude does not exceed 1000 m (3300 ft).
- c) The top liquid temperature of an oil-immersed shunt reactor (when operating) shall not be lower than –20 °C. Starting temperatures below –20 °C are not considered as usual service conditions.

4.1.2 Usual voltage conditions

Shunt reactors conforming to this standard shall be capable of operating continuously at [maximum operating voltage \(line-to-ground voltage associated with maximum system voltage\)](#), and with the increased current due to this overvoltage, without exceeding the rated temperature rise.

4.1.3 Usual installation conditions

The [installation](#) arrangement for single-phase shunt reactors without magnetic-field shielding and connected in three-phase banks shall be as [specified](#) by those responsible for the design and application of the shunt reactors.

[For reactors without magnetic field shielding, the](#) spacing between reactors of a three-phase bank and between reactor banks is one determinant of the mutual reactance between adjacent phases and banks, and thus, also of the rated kVA.

⁹~~It 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.~~

4.1.4 Unusual temperature and altitude service conditions

A shunt reactor may be applied at higher ambient temperatures or at higher altitudes than specified in 4.1.1, but its performance ~~may~~[will](#) be affected. [Typically, if not taken into consideration in the design, unusual service conditions can impact the ability of the shunt reactor to operate at nominal/rated and maximum voltage.](#) Special consideration should be given to these applications.

4.1.5 Other unusual service conditions

Where unusual conditions other than those discussed in 4.1.4 exist, they should be brought to the attention of those responsible for the design and application of the shunt reactor. Examples of some of these conditions are as follows:

- a) Damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, excessive moisture or dripping water, etc.
- b) Abnormal vibration, shocks, tilting [or seismic conditions \(see 10.10 regarding seismic performance verification\)](#)

⁸ [It 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.](#)

- c) Excessively high or low ambient temperatures
- d) Unusual transportation or storage conditions
- e) Unusual space limitations
- f) Unusual duty, frequency of operation, difficulty of maintenance, poor waveform, unbalanced voltage, special insulation requirements, etc.
- g) Unusual voltage conditions that may exist during periods of light system loading or unterminated or open transmission lines during which time significant voltage rises may occur. (See 4.1.2 for usual voltage conditions.)
- h) Unusual operating requirements that might result from the absence of surge protection or the proximity to magnetic material or structures.⁹

4.1.6 Environmental aspects

[The environmental conditions shall be stated clearly in the inquiry, e.g. degree of salt contamination or humidity, location of site if in the tropics or close to the sea, installation in desert areas or in heavy pollution areas such as steel mills. The environmental aspects shall be considered in the design, for example, in selecting materials and dimensioning of surface and turn-to-turn stresses of dry-type air-core shunt reactors, to ensure safe operation during the expected lifetime of the reactor. IEC/TR 60815:1986 \(see supporting published material \[1\] of A.9\) is a useful reference document as it contains a table listing ESDD \(equivalent salt deposition density\) levels versus site descriptors.](#)

[In addition, other environmental conditions such as actual maximum and average ambient temperatures at the site \(versus standard weather bureau data\), seismic requirements, wind loads, etc., should be included in the reactor specification. IEEE Std 693-2005 provides information regarding seismic design/qualification requirements.](#)

4.2 Effect of air density on flashover voltage

4.2.1 General

The effect of decreased air density due to high altitude is to decrease the flashover voltage for a given distance. See IEEE Std 4- 1995 for use of a correction factor with sphere gaps.

Table 1—Dielectric Strength Correction Factors for Altitudes Greater than 1000 m (3300 ft)

Altitude		Altitude Correction Factor for Dielectric Strength
(meters)	(feet)	
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	10000	0.80
3600	12000	0.75
4200	14000	0.70
4500	15000	0.67

NOTE — An altitude of 4500 m is considered a maximum for reactors conforming to this standard.

¹⁰ ~~If a shunt reactor is not shielded magnetically, to minimize heating effects due to stray fields, consideration should be given to its location relative to other apparatus and metallic structures, including reinforced concrete.~~

4.2.2 Insulation

The dielectric strength of a shunt reactor that depends in whole or in part upon air for its insulation decreases as the altitude increases. The insulation level at 1000 m (3300 ft) multiplied by the correction factor from Table 1 shall be not less than the required insulation level at the required altitude.

4.3 Frequency

The reference system frequency used in this standard for shunt reactors is 60 Hz.

~~Unless otherwise specified, shunt reactors shall be designed for operation at a frequency of 60 Hz.~~

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

⁹ If a shunt reactor is not shielded magnetically, to minimize heating effects due to stray fields, consideration should be given to its location relative to other apparatus and metallic structures, including reinforced concrete.

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

<u>Altitude</u>		<u>Altitude correction factor for dielectric strength</u>
<u>(m)</u>	<u>(ft)</u>	
<u><1000</u>	<u><3 300</u>	<u>1.00</u>
<u>1200</u>	<u>4 000</u>	<u>0.98</u>
<u>1500</u>	<u>5 000</u>	<u>0.95</u>
<u>1800</u>	<u>6 000</u>	<u>0.92</u>
<u>2100</u>	<u>7 000</u>	<u>0.89</u>
<u>2400</u>	<u>8 000</u>	<u>0.86</u>
<u>2700</u>	<u>9 000</u>	<u>0.83</u>
<u>3000</u>	<u>10 000</u>	<u>0.80</u>
<u>3600</u>	<u>12 000</u>	<u>0.75</u>
<u>4200</u>	<u>14 000</u>	<u>0.70</u>
<u>4500</u>	<u>15 000</u>	<u>0.67</u>
<u>NOTE—An altitude of 4500 m (15 000 ft) is considered a maximum for reactors conforming to this standard.</u>		

4.4 Effect of altitude on temperature rise

4.4.1 General

The effect of decreased air density due to high altitude is to increase the temperature rise of a shunt reactor that is dependent upon air for the dissipation of its heat losses.

4.4.2 Operation at rated kVA

A shunt reactor can be operated at rated kVA at altitudes greater than 1000 m (3300 ft) without exceeding temperature limits, provided that the average temperature of the cooling air does not exceed the values of Table 2 for the respective altitudes.

4.5 Classes of Shunt Reactors

4.5.1 Dry-Type Air-Cooled

~~Dry type, self-cooled (class AA).~~

4.5.2 Oil-Immersed Air-Cooled

~~Oil-immersed, self-cooled (class OA).~~

4.6 Dielectric Strength of Oil

**Table 2—Maximum allowable 24 h average temperature of
cooling air for carrying rated kVA**

<u>Method of cooling apparatus</u>	<u>Altitude</u>			
	<u><1000 m (3300 ft)</u>	<u>2000 m (6600 ft)</u>	<u>3000 m (9900 ft)</u>	<u>4000 m (13 200 ft)</u>
<u>Oil-immersed, self-cooled</u>	<u>30 °C</u>	<u>28 °C</u>	<u>25 °C</u>	<u>23 °C</u>
<u>Dry-type, self-cooled</u>				
<u>55 °C rise</u>	<u>30 °C</u>	<u>27 °C</u>	<u>24 °C</u>	<u>21 °C</u>
<u>80 °C rise</u>	<u>30 °C</u>	<u>26 °C</u>	<u>22 °C</u>	<u>18 °C</u>
<u>100 °C rise</u>	<u>30 °C</u>	<u>24 °C</u>	<u>18 °C</u>	<u>12 °C</u>
<u>125 °C rise</u>	<u>30 °C</u>	<u>23 °C</u>	<u>16 °C</u>	<u>9 °C</u>
<u>150 °C rise</u>	<u>30 °C</u>	<u>22 °C</u>	<u>15 °C</u>	<u>7 °C</u>
<u>NOTE—Recommended calculation of average temperature is described in 4.1.1.</u>				

4.5 Electrical properties of insulating oil

The oil used in new shunt reactors shall meet or exceed the requirements listed in IEEE Std C57.106-2006, including the dielectric strength of a sample of insulating oil taken from a new shunt reactor, which shall not be less than the minimum kV values listed in Table 2 or Table 3 ~~or 4 in IEEE C57.106-1977 [14]~~ of that standard.

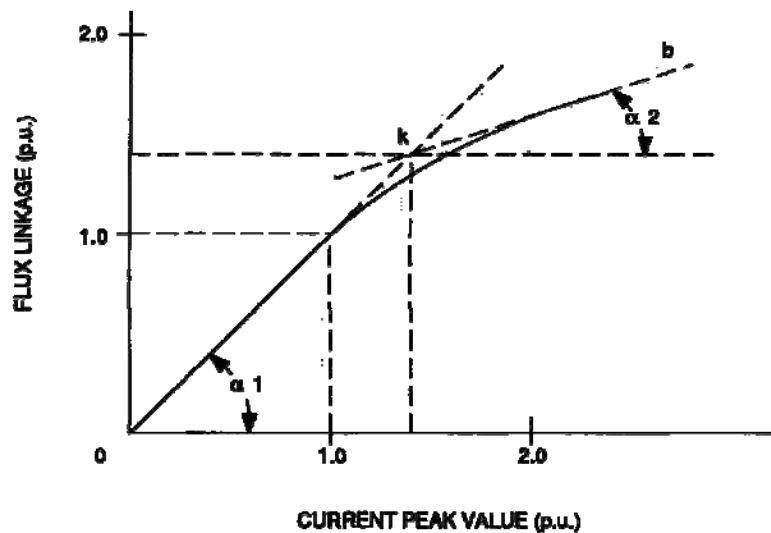
4.6 Magnetic characteristics

Shunt reactors may be identified, with regard to their magnetic characteristics, as linear, non-linear, or saturated. Most oil-immersed shunt reactors have a nonlinear magnetic characteristic where the normal operation is in the unsaturated portion of the curve. (See Figure 1.)

~~5. Basis for Rating Shunt Reactors~~

~~(See Section 12 for other requirements which may be specified for some applications).~~

~~5. kVA Ratings~~



$\alpha 1$ = slope angle of the characteristic in nonsaturated area
 $\alpha 2$ = slope angle of the characteristic in saturated area
 k = saturation knee point, intersection of two straight lines a and b

NOTE—If the magnetic characteristic curve cannot be extended into the saturation region to determine the knee of the curve at rated frequency, then conventional coordinates, which are rms voltage and current measurements, are adequate (see 10.9).

Figure 1—Nonlinear magnetic characteristics for shunt reactors

5. Basis for rating shunt reactors

See Clause 11 and Clause 12 for other requirements that may be specified for some applications.

5.1 kVA ratings

The kVA or MVA rating for shunt reactors is the apparent power for which the shunt reactors are designed, and is based on rated voltage (line-to-ground voltage associated with nominal system voltage). Shunt reactors shall also have the capability of continuous operation at ~~105% of rated voltage~~ maximum operating voltage (line-to-ground voltage associated with maximum system voltage) without exceeding the temperature-rise limits specified in Table 3.

5.2 Terms in Which Rating is Expressed

Table 3—Limits of temperature rise for continuously rated shunt reactors

<u>Item</u>	<u>Type of shunt reactor</u>	<u>Insulation temperature class</u>	<u>Average winding temperature rise by resistance (°C)</u>	<u>Hottest-spot winding temperature rise (°C)</u>
<u>1</u>	<u>Oil-immersed</u>	<u>—</u>	<u>65</u>	<u>80</u>
	<u>Dry-type</u>	<u>105</u>	<u>55</u>	<u>65</u>
		<u>130</u>	<u>80</u>	<u>90</u>
		<u>155</u>	<u>100</u>	<u>115</u>
		<u>180</u>	<u>125</u>	<u>140</u>
		<u>220</u>	<u>150</u>	<u>180</u>
<u>2</u>	<u>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.</u>			
<u>3</u>	<u>Metallic parts other than those covered in Item 2 shall not attain excessive temperature rises.</u>			
<u>4</u>	<u>An oil-immersed shunt reactor shall have an oil-preservation system. The temperature rise of the insulating liquid in such a shunt reactor should not exceed 65 °C when measured near the top of the tank.</u>			

NOTE 1—A shunt reactor with specified temperature rise shall have an insulation temperature index that has been proven by experience or testing.

NOTE 2—The insulation temperature class in this table is supplied as a reference, and is based on the “preferred temperature index” for insulation materials as defined in IEEE Std 1-2000.

NOTE 3—The maximum hot-spot temperature rise limits in this table are based on continuous operation in a 30 °C daily average ambient with a 40 °C maximum.

If the actual average annual ambient temperature is lower, or the equipment sees cyclical loading (such as the case for thyristor-controlled reactors), or the service duty is short term or seasonal, then consideration can be given to increasing the allowable hottest-spot winding-temperature rise limit.

5.2 Terms in which rating is expressed

The rating of a shunt reactor shall be expressed in the following terms:

- Rated voltage
- Maximum operating voltage
- Rated kVA
- Rated current
- Rated frequency
- Basic lightning-impulse insulation level (BIL)
- Number of phases
- Oil and/or winding-temperature rise
- Method of cooling
- Delta or star connection (three-phase shunt reactor)

Table 2—Maximum Allowable 24-h Average Temperature of Cooling Air for Carrying Rated kVA

NOTE—Magnetic characteristics are not deemed to be a basis for rating. However, magnetic linearity for oil-immersed shunt reactors employing a magnetic circuit may be important regarding switching considerations. However, it is beyond the scope of this standard to define desired magnetic characteristics. The end user should define such characteristics in their specification as required.

Table 3—Limits of Temperature Rise for Continuously Rated Shunt Reactors

Item	Type of Shunt Reactor	Insulation Temperature Class	Average Winding Temperature Rise by Resistance ²	Hottest Spot Winding Temperature Rise, °C
1	Oil-immersed	—	65	80
	Dry-type	105	55	65
		130	80	90
		155	100	115
		180	125	140
		220	150	180

~~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.

~~4~~ An oil-immersed shunt reactor shall have an oil-preservation system. The temperature rise of the insulating liquid in such a shunt reactor should not exceed 65 °C when measured near the top of the tank.

NOTES:

~~1~~ A shunt reactor with specified temperature rise shall have an insulation temperature index that has been proven by experience or testing.

~~2~~ The insulation temperature index in Table 3 is supplied as a reference, and is based on the “Preferred Temperature

Index” for insulation materials as defined in IEEE Std 1-1986

6. Tests

6.1 General

Unless otherwise specified, the tests described in 6.2 shall be made prior to delivery.

6.2 Types of tests

6.2.1 Routine, design, and other tests for shunt reactors

Types of tests for oil-immersed shunt reactors are listed in Table 4.A. Types of tests for dry-type shunt reactors are listed in Table 4.B. Definitions of these various tests are included in IEEE Std C57.12.80-2002. The listing of tests shown in Table 4.A and Table 4.B 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 10.

6.1.1.1

~~Routine tests shall be made on all shunt reactors in accordance with the requirements of Table 4.A and 4.B, as applicable.~~

6.1.1.2

~~Design tests shall be made on shunt reactors in accordance with the requirements of Tables 4.A and 4.B.~~

6.2.1.1 Routine tests for shunt reactors

Routine tests shall be made on all shunt reactors ~~as listed in~~ accordance with the requirements of Table 4.A and Table 4.B, as applicable.

6.2.1.2 Design tests for shunt reactors

Design tests shall be made on shunt reactors in accordance with the requirements of Table 4.A and Table 4.B.

6.2.1.3 Other tests for shunt reactors

When specified (as individual tests), other tests shall be made on shunt reactors as listed in Table 4.A and Table 4.B. “Other” tests may be routine or design, as required or specified.

7. Losses and impedance

7.1 Total losses

7.1.1 Loss measurement conditions

The total losses of a shunt reactor shall be determined at rated voltage and rated frequency. If available test power is insufficient for testing at rated voltage, then the manufacturer shall demonstrate to the user that reduced-voltage testing produces sufficiently accurate results when extrapolated to the rated voltage level. The manufacturer shall notify the user of reduced-voltage testing during the proposal stages.

7.1.2 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.

Table 4.A—Routine, design, and other tests for oil-immersed shunt reactors

Tests	Test classification		
	Routine	Design	Other
Resistance measurements..... The dc resistance measurements shall be made on the full winding.	X		
Impedance measurements The impedance measurements shall be made on the assembled shunt reactor.	X		
Total loss measurements	X		
Temperature tests Temperature test or tests shall be made on one unit when one or more units of a given rating are produced by one manufacturer at the same time. These tests may be omitted, however, when a record of a temperature test, made in accordance with this standard, on a duplicate or essentially duplicate unit is available.		X	
Insulation power factor tests	X		
Applied-voltage tests The applied-voltage tests shall be determined by the BIL of the neutral end of the Y-connected shunt reactor.	X		
Low-frequency overvoltage tests	X		
Lightning-impulse tests: Nominal system voltage of 115 kV or above Nominal system voltage below 115 kV (only when specified) Neutrals of reactors for nominal system voltage above 115 kV (only when specified)	X		X X
Switching impulse tests: Nominal system voltage of 345 kV or above Nominal system voltage below 345 kV (only when specified)	X		X
Audible-sound tests: Shunt reactors rated 50 MVA, three-phase (16.67 MVA, single-phase) or above, or nominal system voltage of 115 kV or above (routine test performed with the unit cold and design test performed with the unit at close to operating temperature) Shunt reactors rated below 50 MVA, three-phase (16.67 MVA, single-phase), or nominal system voltage below 115 kV (only when specified)	X	X	X
Vibration tests: Shunt reactors rated 50 MVA, three-phase (16.67 MVA, single-phase) or above, or nominal system voltage of 115 kV or above			X
Determination of magnetic characteristics (linearity): Shunt reactors rated below 50 MVA, three-phase (16.67 MVA, single-phase), or nominal system voltage below 115 kV (only when specified) Shunt reactors rated 50 MVA, three-phase (16.67 MVA, single phase) or above, or nominal system voltage of 115 kV or above.		X	X
Mechanical tests..... Mechanical tests shall be made to verify the pressure requirements for maximum operating pressures and full vacuum filling.		X	

Table 4.B—Routine, design, and other tests for dry-type shunt reactors

Tests	Test classification		
	Routine	Design	Other
Resistance measurements..... The dc resistance measurements shall be made on the full winding.	X		
Impedance measurements The impedance measurements shall be made on the full winding.	X		
Total loss measurements When specified, a total loss test may be performed on one unit of an order of identical units to measure total losses at rated voltage or at maximum voltage levels attainable with laboratory facilities.	X		
Temperature tests Temperature test or tests shall be made on one unit when one or more units of a given rating are produced by one manufacturer at the same time. These tests may be omitted, however, when a record of a temperature test, made in accordance with this standard, on a duplicate or essentially duplicate unit is available.		X	
Applied-voltage tests The applied-voltage tests shall be made only on support insulators when specified.			X
Turn-to-turn test This test is performed for nominal system voltages of 34.5 kV and below.	X		
Lightning-impulse tests: Nominal system voltage greater than 34.5 kV..... Nominal system voltage at or below 34.5 kV (only when specified)	X		X
Switching impulse tests..... Switching surge tests shall be made on shunt reactors rated 115 kV or above (only when specified).			X
Audible-sound tests..... The audible-sound-level test is a design test for dry-type shunt reactors only when a maximum noise limit is specified.			X
Vibration tests			X

7.1.2.1 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.

7.1.2.2 Tolerance on losses as a basis of a quality check

Unless otherwise specified the total losses of a shunt reactor, demonstrated by tests and corrected to the rated MVA base, shall not exceed the specified total losses by more than 6%. Failure to meet this loss tolerance shall not warrant immediate rejection but shall lead to consultation between purchaser and manufacturer. The manufacturer shall initiate an investigation in order to determine 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.

7.1.3 Stray losses

In the application of dry-type shunt reactors, due to the presence of an external magnetic field, there will be losses in any adjacent metallic structures. The magnitude of these losses is a function of the proximity, type of material, and geometric considerations.

7.2 Impedance

7.2.1 Tolerance

The tolerance for shunt reactor impedance at rated voltage shall be within $\pm 2.5\%$ of the specified value.

NOTE—In the case of nonlinear shunt reactors, for conditions above rated voltage, it may be necessary to define impedance characteristics to prevent resonant overvoltages. Such characteristics should be specified by the user.

7.2.2 Tolerance between phases

In the case of a three-phase shunt reactor or a bank made of three single-phase shunt reactors, the maximum deviation of impedance in any one phase shall be within $\pm 2\%$ of the average impedance of the three phases.¹⁰

7.2.3 Zero-sequence impedance

When specified, the zero-sequence impedance of oil-immersed iron-core shunt reactors shall be determined at rated frequency as measured between the line terminals connected together and its neutral terminal. It is expressed in ohms per phase. For three-phase shunt reactors, the zero-sequence impedance is three times the impedance measured as indicated. The applied voltage should not exceed one-third of rated line-to-neutral voltage, nor should the neutral current exceed the rated phase current.

8. Temperature rise

8.1 Life of insulating materials

The life of insulating materials commonly used in shunt 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 shunt 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 air, moisture, etc.

¹⁰ For dry-type shunt reactors without magnetic-field shielding, this tolerance applies only when units are arranged in an equilateral triangle configuration and isolated from any external magnetic influences.

8.2 Conditions under which temperature limits apply

Temperature limits shall not be exceeded when a shunt reactor is operated at ~~105% of the rated~~[maximum operating](#) voltage.

8.3 Limits of temperature rise for continuous ratings

8.3.1 Limits of observable temperature rise¹¹

The temperature rise above the ambient temperature of shunt reactors and parts in contact with the insulation or encapsulation material, when operated at ~~105% of rated~~[maximum operating](#) voltage, shall not exceed the values given in Table 3. For procedures for determining temperature rise, see 10.5.

8.3.2 Limits of hottest-spot temperature rise

Shunt reactors shall be designed so that the hottest-spot conductor temperature rise above the ambient temperature, when operated at ~~105% of rated~~[maximum operating](#) voltage, will not exceed the values given in Table 3.

9. Dielectric tests and insulation levels

9.1 Dielectric tests

9.1.1 General

[In this current revision, a number of significant changes were made to dielectric tests and includes the following:](#)

- ~~1) For oil-immersed shunt reactors, low-frequency tests shall consist of an applied voltage test and a one-hour low-frequency overvoltage test. For dry-type shunt reactors, tests shall consist of an applied voltage test, a turn-to-turn over voltage test, or both.~~
- ~~2) Impulse tests, if performed, shall be made on each line terminal.~~
- ~~3) The impulse test on the neutral of a shunt reactor shall be made only when specified for oil-immersed units. If the insulation level of the neutral bushing is different from that of the neutral end of the winding, the impulse test voltage shall be for whichever insulation level is lower.~~
- ~~4) Switching-impulse tests shall be performed in accordance with Table 4.A or Table 4.B.~~
- a) [In this revision, Table 5.A and Table 5.B of IEEE Std C57.21-1990 have been merged into one table, Table 5, for shunt reactors used in effectively grounded systems. Test levels are network-dependent and thus should be applicable to all technologies, e.g., dry-type or oil-immersed. Higher insulation levels may be required for shunt reactors used in non-effectively grounded systems. In such cases, specific standardized levels cannot be given because the required insulation levels depend on surge arrester protective levels and protection strategy. For such applications, the rated insulation levels shall be determined by system studies.](#)

~~The low-frequency overvoltage test for shunt reactors shall consist of a one-hour low-frequency test from Table 5.A, column 5. This voltage shall be applied across the winding with the neutral solidly grounded. Partial discharge measurements shall be made during the one-hour test.~~

- ~~2) Three single-phase one-hour tests may be substituted for a three-phase test. Care taken to avoid overheating three-leg reactors or reactors without a magnetic return path during single-phase overvoltage tests. Note~~

~~that, under these conditions, it is generally impractical to verify internal phase-to-phase insulation withstand strength during a three phase test. It is therefore recommended that the manufacturer shall demonstrate the adequacy of the phase-to-phase insulation structure by achieving a minimum of 1.5 times line-to-neutral test voltage between line terminals during the one hour test~~

9.1.3.2 Overvoltage Tests for Dry-Type Shunt Reactors

- b) In Table 5, the nominal system voltage and maximum system voltage are included.
- ~~4) *Applied Voltage Test.* The applied voltage test is a high voltage test for the support insulators only~~
- c) In Table 5, BIL values are based on the highest values associated with each nominal/maximum system voltage. For shunt reactor applications, the highest BIL values are used since shunt reactors are frequently (several times a day) switched on and off. This change essentially precludes the use of reduced BIL levels for shunt reactors. Annex B (informative) provides background information on the dielectric stresses imposed on shunt reactors during switching and is a basis for the elimination of reduced BILs.
- d) For oil-immersed shunt reactors, low-frequency tests shall consist of an applied-voltage test and a low-frequency overvoltage test. For dry-type shunt reactors, an applied-voltage test is carried out on the support insulators only and only when specified. A high-frequency overvoltage test or turn- to-turn test is a routine test for dry-type shunt reactors; nominal system voltage 34.5 kV and lower.
- e) Impulse tests, if performed, shall be made on each line terminal.

¹¹ See 4.4 for the effect of altitudes on temperature rise.

- f) The impulse test on the neutral of a shunt reactor shall be made only when specified for oil-immersed units. If the insulation level of the neutral bushing is different from that of the neutral end of the winding, the impulse-test voltage shall be for whichever insulation level is lower.
- g) Switching impulse tests shall be performed in accordance with Table 5.
- h) Insulation power factor tests are only required for oil-immersed shunt reactors. Insulation power factor tests on dry-type air-core shunt reactors would be very difficult to measure and interpret, since the insulation between the windings and ground is provided by the support insulators and insulation resistance is essentially the surface resistance of the support insulators.
- i) Consideration can be given to performing the dielectric tests for oil-immersed shunt reactors in the following order: switching impulse test, lightning impulse test, overvoltage test with partial discharge. However, it is most important to perform the overvoltage test with partial discharge measurement as the last dielectric test.

9.1.2 Applied-voltage test

9.1.2.1 Oil-immersed shunt reactors

For oil-immersed shunt reactors, the applied voltage test is a test of the insulation to ground and the applied voltage is in accordance with Table 5, Column 10.

9.1.2.2 Reduced insulation at the neutral

For an oil-immersed shunt reactor with reduced insulation at the neutral, the applied-voltage test shall be in accordance with Table 5, based upon the insulation level of the neutral end.

9.1.3 Overvoltage tests

9.1.3.1 Low-frequency overvoltage test for oil-immersed shunt reactors

The low-frequency overvoltage test for oil-immersed shunt reactors is based on the maximum system voltage as follows:

- a) The low-frequency overvoltage test for oil-immersed shunt reactors of maximum system voltage of 48.3 kV and less shall consist of a 7200 cycle overvoltage test from Table 5, Column 7. This voltage shall be applied across the winding with the neutral solidly grounded. No partial discharge measurements are required.
- b) The low-frequency overvoltage test for oil-immersed shunt reactors of maximum system voltage of 72.5 kV and higher shall consist of an enhancement test level from Table 5, Column 9, for 7200 cycles without partial discharge measurement directly followed, without reducing the applied voltage below the 1 h test level, by a 1 h low-frequency test from Table 5, Column 8. This voltage shall be applied across the winding with the neutral solidly grounded. Partial discharge measurements shall be made during the 1 h test.

9.1.3.2 Overvoltage tests for dry-type shunt reactors

- a) Applied-voltage test. The applied-voltage test is a high-voltage test of the support insulators only.
- b) Turn-to-turn overvoltage test. The turn-to-turn test for dry-type shunt reactors (nominal system voltage 34.5 kV and below) shall be made by applying between the terminals of each winding a train of high-frequency, exponentially decaying, sinusoidal voltages with a first-peak voltage at least equal to the values as specified in Table 5, Column 11.

NOTE—The rationale for performing the turn-to-turn test in lieu of the impulse test as a routine test on dry-type air-core shunt reactors is that the rise time to the first peak is the same order of magnitude as the front time for the impulse test. Also, the test duration is longer (1 min/7200 overvoltages) and failure detection is simpler.

9.1.4 Lightning-impulse test

The lightning-impulse test shall include reduced full-wave, chopped-wave, and full-wave tests. Front-of-wave tests may also be included when specified.

9.1.5 Insulation power factor test

Insulation power factor is the ratio of the power dissipated in the insulation, in watts, to the product of the effective voltage and current, in voltamperes, when tested under a sinusoidal voltage and prescribed conditions. It is recorded during factory tests to permit a comparison with the power factor measured in the field.

9.2 Dielectric tests for line terminals

9.2.1 Line terminal BIL

The BIL chosen for each line terminal shall be such that the lightning-impulse, chopped-wave-impulse, and switching impulse insulation levels include a suitable margin in excess of the dielectric stresses to which the terminal will be subjected in actual service. For information on surge arrester characteristics and application, refer to IEEE Std C62.11-2005 and IEEE Std C62.22-1997.

9.2.2 BIL and insulation test levels

The basic impulse insulation levels and insulation test levels are given in Table 5 for oil-immersed shunt reactors and for dry-type shunt reactors.

9.2.3 Y-connected shunt reactors

Oil-immersed and dry-type shunt reactors designed for Y connection only shall be assigned insulation levels for both line and neutral terminals.

9.2.4 Switching impulse test

When required, as indicated in Table 4.A and Table 4.B, switching impulse tests shall be performed on oil-immersed and dry-type shunt reactors. A switching impulse test may be desired to demonstrate the switching-surge insulation strength at the line terminals of the shunt reactor. A switching impulse test consists of applying to each phase, from the line terminal to ground, a switching-impulse voltage transient defined in Clause 10. The transients shall have a minimum crest value in accordance with Table 5.

NOTE—The required standard wave shape across the winding (e.g., $> 100 \mu\text{s}$ / $> 200 \mu\text{s}$ / $> 1000 \mu\text{s}$) can be difficult to achieve, especially the time to the first zero crossing. A shorter wave shape may be accepted if the optimum impulse generator configuration is used (use of parallel stages). The manufacturer should state at the bid stage if a deviation in required wave shape is expected.

~~When specified, oil immersed shunt reactors shall be designed to withstand the front of wave impulse insulation levels given in Table 5.A.~~

- ~~2) Turn-to-Turn Overvoltage Test. The turn-to-turn test for dry type shunt reactors shall be made by applying between the terminals of each winding a train of high frequency, exponentially decaying, sinusoidal voltages with a first peak voltage at least equal to the~~
~~4.~~

9.1.4 Lightning-Impulse Test

~~2 times the rms values as specified in Table 5.B, columns 3 or~~

~~The lightning impulse test shall include reduced full-wave, chopped-wave, and full-wave tests. Front-of-wave tests shall also be included when specified.~~

9.1.5 Insulation Power Factor Test

~~Insulation power factor is the ratio of the power dissipated in the insulation, in watts, to the product of the effective voltage and current, in voltamperes, when tested under a sinusoidal voltage and prescribed conditions. It is recorded during factory tests to permit a comparison with the power factor measured in the field.~~

9.2 Dielectric Tests for Line Terminals

~~The BIL chosen for each line terminal shall be such that the lightning impulse, chopped-wave impulse, and switching impulse insulation levels include a suitable margin in excess of the dielectric stresses to which the terminal will be subjected in actual service. For information on surge arrester characteristics and application, refer to IEEE C62.11-1987 [18] and IEEE C62.2-1987 [17].~~

9.2.2

The basic impulse insulation levels and insulation test levels are given in Table 5.A for oil immersed shunt reactors, and in Table 5.B for dry type shunt reactors.

9.3 Basic Lightning Impulse Insulation Levels and Insulation Test Levels for Neutral Terminal

Table 5—Insulation levels for shunt reactors (for use on effectively grounded systems)

Maximum system voltage (See Note 1)	Nominal system voltage (See Note 2)	BIL (See Note 3)	Chopped-wave level (See Note 4)	Minimum time to voltage chopping (See Note 11)	Switching impulse level (BSL) (See Note 5)	Low-frequency overvoltage test (phase-to-ground) 7200 cycles without partial discharge measurement (See Note 6)	Low-frequency overvoltage test (phase-to-ground) (See Note 7)		Applied voltage test (See Note 8)	Turn-to-turn overvoltage (See Note 9)
							One-hour level with partial discharge measurement	Enhancement level for 7200 cycles without partial discharge measurement		
kV rms Column 1	kV rms Column 2	kV crest Column 3	kV crest Column 4	μ s Column 5	kV crest Column 6	kV rms Column 7	kV rms Column 8	kV rms Column 9	kV rms Column 10	kV peak. Column 11
1.3	1.2	45	50	1.25	—	1.7	—	—	10	41
2.6	2.5	60	66	1.5	—	4.3	—	—	15	54
5.2	5.0	75	83	1.6	—	8.0	—	—	19	68
9.1	8.7	95	105	1.8	—	13	—	—	26	86
15.8	15	110	120	2.0	—	18	—	—	34	99
26.3	25	150	165	3.0	—	30	—	—	50	135
36.2	34.5	200	220	3.0	—	44	—	—	70	180
48.3	46	250	275	3.0	—	56	—	—	95	—
72.5	69	350	385	3.0	—	—	65	71	140	—
121	115	550	605	3.0	460	—	105	118	230	—
145	138	650	715	3.0	540	—	125	142	275	—
169	161	750	825	3.0	620	—	145	165	325	—
242	230	900	990	3.0	745	—	210	249	395	—
362	345	1175	1295	3.0	975	—	315	355	520	—
550	500	1550	1705	3.0	1290	—	475	540	—	—
800	765	1950	2145	3.0	1550	—	750	—	—	—
800	765	2050	2255	3.0	1700	—	750	—	—	—

NOTE 1—The maximum system voltage values given in Column 1 are the voltages for which shunt reactors can be continuously operated without exceeding the allowable average and hot-spot temperature rise limits and audible sound limit. For tertiary-connected shunt reactors at 69 kV and below, the maximum tertiary voltage (Column 1) is 105% of nominal/rated unless otherwise specified.

Table 5—Insulation levels for shunt reactors (for use on effectively grounded systems) (continued)

NOTE 2—The nominal system voltage values given in Column 2 are used merely as reference numbers and do not necessarily imply a relation to operating voltages.
NOTE 3—Because shunt reactors may be frequently (several times a day) switched on and off, the use of reduced BIL levels is not recommended. For dry-type reactors having a maximum system voltage less than 48.3 kV, the preferred method for testing the insulation between terminals is the turn-to-turn test. See Column 11.
NOTE 4—Chopped-wave test levels (Column 4) are $1.10 \times \text{BIL}$.
NOTE 5—Unless otherwise indicated, BSL values (Column 6) are equal to $0.83 \times \text{BIL}$. Because shunt reactors may be frequently (several times a day) switched on and off, the use of reduced BSL levels is not recommended. This is a change from IEEE Std C57.21-1990.
NOTE 6—The low-frequency overvoltage test (phase-to-ground) is applicable only to oil-immersed shunt reactors having a maximum system voltage less than 72.5 kV. The test voltage (Column 7) is approximately equal to 2.0 times the maximum system phase-to-ground voltage.
NOTE 7—The low-frequency overvoltage test is applicable only to oil-immersed shunt reactors having a maximum system voltage of 72.5 kV and above. Unless otherwise indicated, the 1 h test voltage is equal to 1.5 times and the enhancement test voltage (Column 8 or Column 9) is equal to 1.7 times the maximum system phase-to-ground voltage. The enhancement test is carried out directly prior the 1 h test. If the enhancement test level cannot be achieved in the manufacturer's test facility because the power demand is too high, this limitation/exception has to be stated by the manufacturer at bid stage. In this case, the test should be carried out at as high a level of enhancement as possible or the enhancement test may be omitted by agreement between purchaser and manufacturer at the time of order.
NOTE 8—The applied voltage test as performed on dry-type air-core shunt reactors is a high-voltage test of the support insulators. The test level should be chosen according to the BIL level specified for the reactor terminal having the lowest BIL. The applied voltage test levels for dry-type shunt reactors are the same as for oil-immersed shunt reactors since they are applied interchangeably.
NOTE 9—The turn-to-turn test is not applicable for reactors having a nominal system voltage greater than 34.5 kV. For dry-type reactors having a nominal system voltage equal to or lower than 34.5 kV, the turn-to-turn test is the preferred method for testing the insulation across the winding. The voltages are expressed in terms of peak voltage because it is more applicable to the type of wave shape (decaying sinusoidal wave shape). All voltages are equal to $0.9 \times \text{BIL}$ value since this is a test performed in lieu of the lightning impulse. Because the wave shape is in between switching surge and lightning impulse, a de-rating factor of 0.9 is appropriate. See Column 9. A lightning impulse test according to Column 3 may be performed as an alternative.
NOTE 10—For systems having a non-effectively grounded neutral (isolated or grounded through a high impedance value), the rated insulation levels should be determined by using classic insulation coordination studies and depends on the protective level of the surge arresters installed across the shunt reactor. Insulation and test values should be agreed upon between manufacturer and user.
NOTE 11—Spark gaps and other suitable means for voltage chopping may be used to carry out a chopped-wave impulse.
NOTE 12—Front-of-wave levels have not been listed in the revision of this standard since very few end users request this test.
NOTE 13—Historically, some of the BIL and BSL values included in previous editions of standards, such as IEEE Std C57.21-1990, were very high, especially for 765 kV reactors. Instead of 2050 kV (BIL) and 1700 kV (BSL), 1950 kV (BIL) and 1550 (BSL) are recommended and included. The low-frequency overvoltage test with partial discharge measurement for 765 kV reactors has been changed to 750 kV rms for 1 h. This change is based on the very good service experience of shunt reactors tested in this manner. For instance, using 1950 kV BIL, 1524 kV (BSL), and 650 kV rms, for the 1 h test level, service experience was, in some cases, unsatisfactory.

Table 5—Insulation levels for shunt reactors (for use on effectively grounded systems) (continued)

NOTE 14—If an end user is employing shunt reactors at a maximum system voltage not included in this table, then the end user should specify both the maximum system voltage and nominal system voltage. This applies to directly connected and tertiary-connected shunt reactors. The various test voltage levels should also be specified; possibly using extrapolation from values listed in this table.
NOTE 15—In IEEE Std C57.21-1990, shunt reactors were required to be able to operate at voltages 5% higher than the nominal system voltage without exceeding the temperature rise limits. If the end user wishes to utilize this rating practice, he should so stipulate in the specification that maximum operating voltage is based on 105% of nominal system voltages.
NOTE 16—In the application of shunt reactors at voltages 69 kV and below, they are usually connected to a transformer tertiary. Transformer tertiary voltages, as such, do not have to necessarily conform to typical distribution voltage standard values. Therefore, care must be taken in specifying maximum operating voltage levels corresponding to nominal system voltage values. The maximum voltage on a transformer tertiary is impacted by the maximum voltage on the primary (transmission voltage) and by transformer characteristics. Tertiary voltages do not necessarily follow typical values for distribution systems. Tertiary-connected shunt reactors may operate at distribution voltage levels but they are part of the transmission system and defining parameters must be selected accordingly.
NOTE 17—One test level is listed for the overvoltage test on 800 kV shunt reactors. The service experience of some utilities with 800 kV shunt reactors showed that an overvoltage test at 1.5 p.u. was not enough to verify the insulation system; the number of service failures was way too high. At a test level of 750 kV, service experience was far better and failure rates were similar to those for lower rated voltages.
NOTE 18—The Working Group decided not to include an enhancement level for 800 kV reactors since very few labs are able to perform the test at the required voltage level since about 30% more reactive power compensation is required. For instance one of Hydro Quebec's normal 800 kV reactor ratings is 110 MVA (single-phase) and even IREQ cannot perform the test at the required voltage level. Past experience with 800 kV shunt reactors showed good service experience when tested without enhancement. If the test was carried out, an enhancement voltage of 850 kV (as is done for 800 kV power transformers) should be specified. However, purchasers should be aware that this new requirement will require substantial changes for test laboratories and primarily involves the addition of substantial power factor compensation capacitor banks.

9.3 Basic lightning-impulse insulation levels and insulation test levels for neutral terminals

The neutral terminal of a winding that is designed for Y connection only may have an insulation level lower than that for the line terminal(s) in accordance with 9.3.1, 9.3.2, and 9.3.3.

9.3.1 Specified BIL

When specified, the neutral shall be designed for a specific BIL in addition to the low-frequency test.

~~Table 5.B—Insulation Test Levels for Dry-Type Shunt Reactors~~

9.3.2 Y-connected oil-immersed shunt reactors

Oil-immersed shunt reactors designed for Y connection only, with the neutral brought out and solidly grounded directly or through a current transformer, shall have an insulation level at the neutral not less than 110 kV BIL.

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 low-frequency test on dry-type shunt reactors is essentially a high-voltage test on the insulators.~~
- ~~3—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.~~

9.3.3 Insulation level of neutral end of winding

The insulation level of the neutral end of the winding may differ from the insulation level of the neutral bushing for which provision is made in the shunt reactor tank. In this case, the dielectric tests on the neutral shall be determined by the insulation level of the neutral end of the winding, or the insulation level of the neutral bushing, whichever is lower. Neutral BIL shall not, in any case, be lower than 110 kV.

The windings of single-phase or three-phase shunt reactors designed for Y operation shall be capable of withstanding the applied-voltage test corresponding to the insulation test level of the line end for those cases where the neutral is insulated to withstand the low-frequency test voltage assigned to the line terminal(s). The windings (or insulators, in the case of dry-type shunt reactors) shall also be capable of withstanding a low-frequency overvoltage test at a voltage in accordance with the low-frequency test values, specified in Table 5 for the nominal system voltage of the line end. The line end shall be capable of withstanding full-wave, chopped-wave, and, if specified, front-of-wave impulse tests corresponding to its nominal system voltage.