

American National Standard

**requirements, terminology, and
test code for shunt reactors
over 500 kVA**

ANSI/IEEE C57.21-1981



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An American National Standard

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

1. Scope

1.1 This standard applies to all oil-immersed or dry-type, single-phase or three-phase outdoor or indoor shunt reactors rated 501 kVA and larger.

1.2 This standard does not apply to other devices such as:

- (1) Shunt reactors, 500 kVA and smaller
- (2) Current-limiting reactors (see ANSI C57.16-1958 (R 1971) [2]¹)
- (3) Arc suppression coils
- (4) Neutral grounding devices (see IEEE Std 32-1972 (R 1978) [16])
- (5) Saturable reactors
- (6) Line resonant reactors
- (7) Filter reactors

2. Terminology

All definitions, except as specifically covered in this standard, shall be in accordance with ANSI/IEEE Std 100-1977 [13].

2.1 Shunt Reactor

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

2.1.2 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, cable, or shunt capacitors. The need for shunt reactors is most apparent at light load.

¹ The numbers in brackets correspond to the references listed in Section 3 of this standard.

2.2 Rating

2.2.1 Rated kVA (of a Shunt Reactor). The apparent power at rated voltage for which the shunt reactor is designed.

2.2.2 Rated Current (of a Shunt Reactor). Derived from the rated voltage and rated kVA.

2.2.3 Rated Voltage (of a Shunt Reactor). The voltage to which operating and performance characteristics are referred.

2.3 Insulation

2.3.1 Oil-Immersed Shunt Reactor. One in which the coils and magnetic circuit are immersed in an insulating oil.

2.3.2 Dry-Type Shunt Reactor. One in which the coils and magnetic circuit are neither impregnated with an insulating fluid nor immersed in an insulating oil.

2.4 Losses and Impedance

2.4.1 Total Losses (of a Shunt Reactor). The sum of the conductor loss, magnetic circuit loss, cooling loss, shielding loss, and any other stray losses in the shunt reactor.

2.4.2 Impedance (of a Shunt Reactor). The phasor sum of the reactance and resistance, expressed in ohms per phase, it may be derived from the rated kVA and rated voltage.

2.5 Construction

2.5.1 Indoor Shunt Reactor. One which, because of its construction, must be protected from the weather.

2.5.2 Outdoor Shunt Reactor. One of weather-resistant construction.

2.6 Methods of Cooling

2.6.1 Dry-Type Air-Cooled Shunt Reactors

2.6.1.1 Dry-Type Self-Cooled Shunt Reactor (Class AA). A dry-type shunt reactor which is cooled by the natural circulation of the cooling air.

2.6.2 Oil-Immersed Air-Cooled Shunt Reactors

2.6.2.1 Oil-Immersed Self-Cooled Shunt Reactor (Class OA). An oil-immersed shunt reactor which is cooled by natural circulation of the cooling air over the cooling surface.

2.6.2.2 Oil-Immersed Forced-Air-Cooled Shunt Reactor (Class OFA). An oil-immersed shunt reactor which is cooled by forced circulation of the cooling air over the cooling surface.

2.6.3 Oil-Immersed Water-Cooled Shunt Reactor (Class OW). An oil-immersed shunt reactor which is cooled by the natural circulation of the cooling oil over the water-cooled surface.

2.6.4 Oil-Immersed Forced-Oil-Cooled Shunt Reactors

2.6.4.1 Oil-Immersed Forced-Oil-Cooled with Forced-Air Cooler Shunt Reactor (Class FOA). An oil-immersed shunt reactor cooled by the forced circulation of oil through external oil-to-air heat-exchanger equipment utilizing forced circulation of air over its cooling surface.

2.6.4.2 Oil-Immersed Forced-Oil-Cooled with Forced-Water Cooler Shunt Reactor (Class FOW). An oil-immersed shunt reactor cooled by the forced circulation of the oil through external oil-to-water heat-exchanger equipment utilizing forced circulation of water over its cooling surface.

3. References

- [1] ANSI B2.1-1968, Pipe Threads (Except Dryseal).²
- [2] ANSI C57.16-1958 (R1971), Requirements, Terminology, and Test Code for Current-Limiting Reactors.
- [3] ANSI C84.1-1977, Voltage Ratings for Electric Power Systems and Equipment (60 Hz), including supplement ANSI C84.1a-1980.
- [4] ANSI S1.4-1971 (R1976), Specification for Sound Level Meters.
- [5] ANSI S1.11-1966 (R1976), Specifications for Octave, Half-Octave, and Third-Octave Band Filter Sets.
- [6] ANSI/ASTM D117-80, Methods of Testing Electrical Insulating Oils.
- [7] ANSI/CGA V-1-1977, Compressed Gas Cylinder Valve Outlet and Inlet Connections.
- [8] ASTM A167-63, Specification for Corrosion-Resistant Chromium-Nickel Steel Plate, Sheet and Strip.³
- [9] ANSI/IEEE C57.12.80-1978, Terminology for Power and Distribution Transformers.
- [10] ANSI/IEEE C57.13-1978, Requirements for Instrument Transformers.
- [11] ANSI/IEEE C57.98-1968, Guide for Transformer Impulse Tests.
- [12] ANSI/IEEE Std 21-1976, General Requirements and Test Procedures for Outdoor Apparatus Bushings.
- [13] ANSI/IEEE Std 100-1977, Dictionary of Electrical and Electronics Terms.
- [14] ANSI/IEEE Std 315-1975, Graphic Symbols for Electrical and Electronics Diagrams.
- [15] IEEE Std 4-1978, Techniques for High-Voltage Testing.
- [16] IEEE Std 32-1972 (R1978) Requirements, Terminology, and Test Procedure for Neutral Grounding Devices.
- [17] HEMMES, 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.
- [18] FOLEY, A.H.A Self-Balancing Transformer Core Loss Bridge. *AIEE Transactions*, vol 76, p 1, 1957, pp 567-573.
- [19] CRAIG, S. and KAYSER, H. Iron-Loss Measurements by A C Bridge and Calorimeter. *Journal, Institution of Electrical Engineers*, vol 95, p 2, 1948, pp 205-216.

² ANSI documents are available from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

³ ASTM documents are available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa 19103

- [20] DEUTSCH, F. Measuring the Active Power Losses of Large Reactors. *Brown Boveri Review*, vol 47, Apr 1960, pp 268–278.
- [21] 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.
- [22] GRUNDMARK, B. High-Voltage Shunt Reactors—Trends in Design and Testing. Paper 12-03, *International Conference on Large High Tension Electric Systems (CIGRE)*, 23rd session, 1970.
- [23] KUSTERS, N.L., and PETERSONS, O. A Transformer-Ratio-Arm Bridge for High Voltage Capacitance Measurements. *IEEE Transactions (Communications and Electronics)*, vol 69, Nov 1963, pp 606–611.
- [24] 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.
- [25] DEBOURG, H., JENKINS, R. S., SLETENMARK, I., TENGSTRAND, C. A., and WEBSTER, C. A. Calorimetric Loss Measurement on Alternators and Reactors. Paper 119, *International Conference on Large High Tension Electric Systems (CIGRE)*, 20th session, 1964.
- [26] 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.
- [27] MOORE, W.J.M., LOVE, G., and RAFTIS, F.A. Measurement of Short-Circuit Load Losses in Large Three-Phase Power Transformers, Using an Alternating Current Comparator Bridge. *IEEE Transactions on Power Apparatus and Systems*, vol PAS-94, no 6 Nov/Dec 1975, pp 2074–2076.
- [28] HAGUE, B. *Alternating Current Bridge Methods*. London: Pitman and Sons, 1957.
- [29] BRUCKEL, W. Measurement Connection for Testing High Voltage Reactors (in German). *Messen und Prüfen/Automatik*, Nov 1976.

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 provided that:

(1) If air cooled, the temperature of the cooling air (ambient temperature) does not exceed 40 °C and average temperature of the cooling air for any 24 h period does not exceed 30 °C.⁴

(2) If water cooled, the temperature of the cooling water (ambient temperature) does not exceed 30 °C and the average temperature of the cooling water for any 24 h period does not exceed 25 °C.

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

4.1.2 Usual Voltage and Installation Conditions. The usual voltage and installation conditions for shunt reactors conforming to this standard shall be as follows:

(1) Shunt reactors shall be capable of operating continuously at 5% above rated voltage, and with the increased current due to this overvoltage, without exceeding the limiting temperature rise.

(2) 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 reactor.

NOTE: 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.

4.1.3 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 be affected and special consideration should be given to these applications.

4.1.4 Other Unusual Service Conditions. Where unusual conditions other than those discussed in 4.1.3 exist, they should be brought to the attention of those responsible for the

⁴ 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.

design and application of the shunt reactor. Examples of some of these conditions are:

- (1) Damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, excessive moisture or dripping water, etc
- (2) Abnormal vibration, shocks, or tilting
- (3) Excessively high or low ambient temperatures
- (4) Unusual transportation or storage conditions
- (5) Unusual space limitations
- (6) Unusual duty, frequency of operation, difficulty of maintenance, poor wave form, unbalanced voltage, special insulation requirements, etc
- (7) Unusual voltage conditions, such as 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 (1) for usual voltage conditions.
- (8) Unusual operating requirements, such as might result from the absence of surge protection or the proximity to magnetic material or structures.⁵

4.2 Effect of Air Density on Sparkover Voltage

4.2.1 General. The effect of decreased air density due to high altitude is to decrease the sparkover voltage for a given sparkover distance. See IEEE Std 4-1978 [15] for use of a correction factor with sphere gaps.

4.2.2 Insulation. The dielectric strength of a shunt reactor which 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. Unless otherwise specified, shunt reactors shall be designed for operation at a frequency of 60 Hz.

⁵If 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 to metallic structures including reinforced concrete.

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

Altitude (meters)	Altitude (feet)	Altitude Correction Factor for Dielectric Strength
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

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

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 which 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

- (1) Dry-type, self-cooled (class AA)

4.5.2 Oil-Immersed Air Cooled

- (1) Oil-immersed self-cooled (class OA)
- (2) Oil-immersed forced-air-cooled (class OFA)

4.5.3 Oil-Immersed Water-Cooled (Class OW)

4.5.4 Oil-Immersed Forced-Oil-Cooled

- (1) Oil-immersed, forced-oil-cooled with forced-air cooler (class FOA)
- (2) Oil-immersed, forced-oil-cooled with forced-water cooler (class FOW)

4.6 Dielectric Strength of Oil. The dielectric strength of a sample of insulating oil taken from a new shunt reactor shall not be less than 26 kV, when measured in accordance with ANSI/ASTM D117-80 [6].

Table 2
Maximum Allowable Average Temperature* of Cooling Air for Carrying Rated kVA

Method of Cooling Apparatus	1000 m (3300 Ft)	2000 m (6600 Ft)	3000 m (9900 Ft)	4000 m (13 200 Ft)
Degrees C				
Oil-immersed self-cooled	30	28	25	23
Oil-immersed forced-air-cooled	30	26	23	20
Oil-immersed forced-oil-cooled with oil-to-air cooler	30	26	23	20
Dry-type self-cooled				
(1) 55°C rise	30	27	24	21
(2) 80°C rise	30	26	22	18
(3) 150°C rise	30	22	15	7
Dry-type forced-air-cooled				
(1) 55°C rise	30	24	19	14
(2) 80°C rise	30	22	14	6
(3) 150°C rise	30	15	0	-15

*Recommended calculation of average temperature is described in 4.1.1(1), footnote 4.

5. Basis for Rating Shunt Reactors

(See sections 11–13 for other requirements which may be specified for some applications)

5.1 kVA Ratings. The kVA rating for shunt reactors is the apparent power for which the shunt reactors are designed and is based on rated voltage. Shunt reactors shall also have

Table 3
Limits of Temperature Rise for Continuously Rated Shunt Reactors

Item	Type of Shunt Reactor*	Winding Temperature Rise by Resistance, °C	Hottest-Spot Winding Temperature Rise, °C
1	55 °C Rise Oil-Immersed 65 °C Rise Oil-Immersed 80 °C Rise Dry-Type	55 65 80	65 80 110
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	Where a 55 °C rise shunt reactor is provided with sealed-tank, conservator, gas-oil seal, or inert-gas-pressure systems, the temperature rise of the insulating oil shall not exceed 55 °C when measured near the top of the main shunt reactor tank. The temperature rise of insulating oil in a shunt reactor not provided with one of the oil preservation systems listed above shall not exceed 50 °C when measured near the top of the main shunt reactor tank.		
5	A shunt reactor that has a limiting winding temperature rise of 65 °C shall have an oil preservation system. The temperature rise of the insulating oil in such a shunt reactor shall not exceed 65 °C when measured near the top of the main shunt reactor tank.		

*A shunt reactor with specified temperature rise shall have an insulation system which has been proven by experience, general acceptance or accepted test.

the capability of continuous operation at 105% of rated voltage without exceeding the temperature rise limits specified in Table 3.

5.2 Terms in which Rating Is Expressed.

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

- (1) Rated voltage
- (2) Rated kVA
- (3) Rated current
- (4) Rated frequency
- (5) Basic impulse insulation level
- (6) Number of phases
- (7) Temperature rise
- (8) Method of cooling

6. Insulation Classes and Dielectric Tests

6.1 Insulation Classes and Dielectric Tests for Line Terminals

6.1.1 The line terminals of a winding shall be assigned a basic impulse insulation level and an insulation class to indicate the factory dielectric test that these terminals are capable of withstanding.

6.1.2 The basic impulse insulation levels and insulation classes are those given in Table 4 for oil-immersed shunt reactors and in Table 5 for dry-type shunt reactors.

6.1.3 Shunt reactors designed for Y connection only with neutral brought out through a bushing shall be assigned insulation classes for both line and neutral terminals.

The neutral may have a lower insulation class than the line (see 6.2).

6.1.4 When specified, oil-immersed shunt reactors shall be designed to withstand the front-of-wave impulse insulation levels given in Table 6.

6.1.5 When specified, switching surge tests shall be performed on oil-immersed shunt reactors. A switching surge test may be

desired to demonstrate the switching surge insulation strength at the line terminals of the shunt reactor. A switching surge test consists of applying to each phase from the line terminal to ground a switching surge voltage transient defined in Section 13. The transient shall have a minimum crest value in accordance with Table 7.

6.2 Basic Impulse Insulation Levels and Insulation Classes for Neutral Terminals

6.2.1 The neutral terminal of a winding which is designed for Y connection only may have an insulation class lower than that for the line terminal as indicated in 5.2.1 and 5.2.2.

6.2.2 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 class at the neutral not less than that specified in column (2) of Table 8.

6.2.3 The insulation class of the neutral end of the winding may differ from the insulation class 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 whichever is lower; the insulation class of the neutral end of the winding or the insulation class of the neutral bushing.

The windings of single-phase or three-phase shunt reactors designed for Y operation shall be capable of withstanding the applied-potential test corresponding to the insulation class of the line end for those cases where the neutral is insulated to withstand the low-frequency test voltage assigned to the line terminals. The windings also shall be capable of withstanding a turn-to-turn potential test at a voltage in accordance with the low-frequency test values specified in Table 4 or 5 for the insulation class of the line end. The line end shall be capable of withstanding full-wave, chopped-wave, and, when specified, front-of-wave impulse tests corresponding to its insulation class.

Table 4
Insulation Classes and Dielectric Tests
for Oil-Immersed Shunt Reactors
when Specified

Insulation Class	Low-Frequency Test	BIL and Full Wave	Chopped Wave	
(kV)	(kV)	Crest (kV)	Crest (kV)	Minimum Time to Flashover, (μ s)
(1)	(2)	(3)	(4)	(5)
15	34	110	130	2
18	40	125	145	2.25
25	50	150	175	3
34.5	70	200	230	3
46	95	250	290	3
60	120	300	345	3
69	140	350	400	3
92	185	450	520	3
115	230	550	630	3
138	275	650	750	3
161	325	750	865	3
180	360	825	950	3
196	395	900	1035	3
215	430	975	1120	3
230	460	1050	1210	3
260	520	1175	1350	3
287	575	1300	1500	3
315	630	1425	1640	3
345	690	1550	1780	3
375	750	1675	1925	3
400	800	1800	2070	3
430	860	1925	2220	3
460	920	2050	2360	3
490	980	2175	2500	3
520	1040	2300	2650	3
545	1090	2425	2800	3

NOTES: (1) Y-connected shunt reactors for operation with neutral solidly grounded or grounded through an impednace may have reduced insulation at the neutral as specified in 6.2.

(2) The insulation class values given above are used merely as reference numbers and do not necessarily imply a relation to specific operating voltages.

Table 5
Insulation classes and Dielectric Tests
for Dry-type Shunt Reactors

Insulation Class (kV)	Low-Frequency Test (kV)	Turn-to-Turn Potential		BIL and Full Wave Crest (kV)	Chopped Wave	
		Indoor (kV)	Outdoor (kV)		Crest (kV)	Minimum Time to Flashover (μ s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.2	10	10	13	45	54	1.25
2.5	19	19	25	60	69	1.5
5.0	26	26	35	75	88	1.6
8.7	36	36	48	95	110	1.8
15.0	50	50	67	110	130	2
25.0	70	70	93	150	175	3
34.5	95	95	127	200	230	3

NOTE: The insulation class values given above are used merely as reference numbers and do not necessarily imply a relation to operating voltages.

Table 6
Basic Impulse Insulation Level and Front-
of-Wave Tests for Oil-Immersed Shunt
Reactors when Specified

Insulation Class (kV)	Basic Impulse Insulation Level (kV)	Minimum Crest Voltage (kV)	Specific Time to Sparkover (μ s)
(1)	(2)	(3)	(4)
15	110	195	0.5
25	150	260	0.5
34.5	200	345	0.5
46	250	435	0.5
60	300	510	0.51
69	350	580	0.58
92	450	710	0.71
115	550	825	0.825
138	650	960	0.96
161	750	1070	1.07
180	825	1150	1.15
196	900	1240	1.24
230	1050	1400	1.40
260	1175	1530	1.53

NOTES: (1) Above 260 kV insulation class, the chopped wave and the front of wave approach the same rate of rise, and therefore, only the chopped waves shall be applied.

(2) The insulation class values given are used merely as reference numbers and do not necessarily imply a relation to specific operating voltages.

Table 7
Basic Impulse Insulation Level
and Switching Surge Tests
for Oil-Immersed Shunt Reactors
when Specified

Insulation Class (kV)	Basic Impulse Insulation Level (kV)	Switching Surge Test (kV crest)
(1)	(2)	(3)
92	450	375
115	550	460
138	650	540
161	750	620
180	825	685
196	900	745
215	975	810
230	1050	870
260	1175	975
287	1300	1080
315	1425	1180
345	1550	1290
375	1675	1390
400	1800	1500
430	1925	1600
460	2050	1700
490	2175	1800
520	2300	1900
545	2425	2010

NOTE: The insulation class values given are used merely as reference numbers and do not necessarily imply a relation to specific operating voltages.

Table 8
Minimum Insulation Class at Neutral
for Oil-Immersed Shunt Reactors
when Specified

Insulation Class at Line Terminals of Winding (kV*)	Grounded Solidly or Through Current Transformer (kV)
(1)	(2)
15	8.7
25	8.7
34.5	8.7
46	15
69	15

*For higher line terminal insulation classes the insulation class at the neutral shall be specified to conform with service requirements, but in no case shall be less than 15 kV.

NOTE: The insulation class values given are used merely as reference numbers and do not necessarily imply a relation to specific operating voltages.

7. Losses and Impedance

7.1 Total Losses

7.1.1 The total losses of a shunt reactor shall be determined at rated voltage and rated frequency.

7.1.2 Tolerance on Losses. The losses of a shunt reactor, represented by test of shunt reactors or a shunt reactor on a given order, when corrected to the rated current base, shall be equal to or less than the specified loss.

7.2 Impedance

7.2.1 The tolerance for shunt reactor impedance at rated voltage shall be within $\pm 5\%$ of the specified value.

NOTE: For conditions above rated voltage, it may be necessary to define impedance characteristics to prevent resonant over-voltages. Such characteristics should be specified by those responsible for the design and application of the shunt reactors.

7.2.2 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 2% of the average impedance of the three phases.⁶

⁶ 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. Temperature Rise

8.1 Life of Insulating Materials. The life of insulating materials commonly used in shunt reactors depends very largely upon the temperatures to which they are subjected and the duration of such temperatures.

For shunt reactors, since the actual temperature is the sum of the ambient temperature and the temperature rise, it is apparent that the ambient temperature very largely influences the life of insulating materials.

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

- (1) Electric stress and associated effects
- (2) Vibration or varying mechanical stress
- (3) Repeated expansions and contractions
- (4) Exposure to air, moisture, etc

8.2 Conditions under which Temperature Limits Apply. Temperature limits shall not be exceeded when a shunt reactor is operating where the maximum continuous operating voltage at the reactor does not exceed 105% of the rated voltage.

8.3 Limits of Temperature Rise for Continuous Ratings

8.3.1 Limits of Observable Temperature Rise.⁷ The temperature rise above the ambient temperature of shunt reactors or parts thereof, when tested at 105% of rated voltage, shall not exceed the values given in Table 3. For procedures in determining temperature rise, see 13.5. These temperatures are based on the use of a nonmetallic flake pigment paint finish.

8.3.2 Limits of Hottest-Spot Temperature Rise. Shunt reactors shall be so designed that the hottest spot conductor temperature rise above the ambient temperature when tested at 105% of rated voltage will not exceed the values given in Table 3.

⁷ For the effect of altitudes on temperature rise, see 4.4.

9. Tests

Unless otherwise specified, tests shall be made at the factory only.

9.1 Kinds of Tests

9.1.1 Routine Tests. The following routine tests shall be made on all shunt reactors, except as specifically stated below. The numbers shown do not necessarily indicate the sequence in which the tests shall be made. All tests are defined and shall be made in accordance with Section 13.

9.1.1.1 Resistance Measurement. The resistance measurement shall be made on the full winding.

9.1.1.2 Impedance Measurement. The impedance measurement shall be made on the assembled shunt reactor.

9.1.1.3 Total Loss Measurement. Loss measurements shall be made on at least one unit when one or more units of a given rating are produced by one manufacturer at the same time, and the losses for other units may be calculated from resistance measurements.

9.1.1.4 Temperature Tests. A 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, except that these tests shall be omitted when a record of a temperature test, made in accordance with this standard, on a duplicate or essentially duplicate unit is available.

9.1.1.5 Applied-Potential Tests

9.1.1.6 Turn-to-Turn Potential Tests

9.1.2 Other Tests

9.1.2.1 Insulation Power Factor Tests. Insulation power factor tests shall be made only when specified.

9.1.2.2 Switching Surge Tests. Switching surge tests shall be made only when specified, or as may otherwise be required in 9.2.3.1(4).

9.1.2.3 Front-of-Wave Tests. Front-of-wave tests shall be made only when specified.

9.1.2.4 Impulse Tests. Impulse tests shall be made only when specified.

9.1.2.5 Audible Sound Tests. Audible sound tests shall be made only when specified. While tests at the factory are preferred, tests at the installation site shall be acceptable in cases where the manufacturer's power supply is inadequate.

9.1.2.6 Vibration Tests. Vibration tests shall be made only when specified. While tests at the factory are preferred, tests at the installation site shall be acceptable in cases where the manufacturer's power supply is adequate.

9.2 Dielectric Tests

9.2.1 General

(1) Low-frequency tests shall consist of an applied-potential test, a turn-to-turn potential test, or both.

(2) Impulse tests shall be made only when required and then only on the windings specified.

(3) The impulse test on the neutral of a shunt reactor shall be made only when specified. If the insulation class of the neutral bushing for which provision is made is different from the insulation class of the neutral end of the winding, the impulse test voltage shall be for whichever insulation class is lower.

Table 9
Minimum Phase-to-Phase Tests
for Oil-Immersed
Three-Phase Shunt Reactors

Nominal System Voltage*	Minimum Low-Frequency Phase-to-Phase Test Voltage** (kV)
(1)	(2)
25	42
34.5	57
46	76
60	99
69	115
92	155
115	185
138	230
161	275
230	395
287.5	460
345	575
500	825
700	1155

*For nominal system voltages not in the table, use a test voltage not less than 1.65 times the nominal system voltage.

** The low-frequency test requirement between phases shall not be lower than the test requirement from line-to-ground.