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

Sponsor

Transformer Committee
of the
IEEE Power Engineering Society

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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.

Keywords: Dielectric test, dry-type shunt reactors, oil-immersed shunt reactor

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Foreword

(This Foreword is not a part of IEEE C57.21-1990, IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 500 kVA.)

The Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 501 kVA, C57.21, was first issued as a separate standard in 1971. The next revision was completed in 1981. The present revision was started in 1980 by the Standards Subcommittee, chaired by Leonard R. Smith, approved by the C57 Subcommittee in 1981, and completed within the IEEE Transformer Committee. This included work on the dielectric tests by the Task Force on Revisions of Dielectric Tests of Shunt Reactors, chaired by W. N. Kennedy, and the Task Force on Dry-Type Reactors chaired by R. F. Dudley. The work was correlated by the Working Group on Shunt Reactors, chaired by J. W. McGill, which reports to the Performance Characteristics Subcommittee.

The present standard represents the agreement of those involved in reactor design, construction testing, and usage based on the present state-of-the-art for shunt reactors.

At the time this document was published, it was under consideration for approval as an American National Standard. The Accredited Standards Committee on Transformers, Regulators, and Reactors, C57, had the following members at the time this document was sent to letter ballot:

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The final conditions for approval of this standard were met on August 13, 1990. This standard was conditionally approved by the IEEE Standards Board on May 31, 1990 with the following membership:

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CLAUSE	PAGE
1. Scope	1
2. Terminology	1
2.1 Shunt Reactor	1
2.2 Rating of a Shunt Reactor	2
2.3 Insulation	2
2.4 Losses and Impedance	2
2.5 Construction	2
2.6 Methods of Cooling	3
3. References	3
4. General Requirements	5
4.1 Service Conditions	5
4.2 Effect of air Density on Flashover Voltage	6
4.3 Frequency	7
4.4 Effect of Altitude on Temperature Rise	7
4.5 Classes of Shunt Reactors	7
4.6 Dielectric Strength of Oil	7
4.7 Magnetic Characteristics	7
5. Basis for Rating Shunt Reactors	7
5.1 kVA Ratings	8
5.2 Terms in Which Rating is Expressed	8
6. Tests	10
6.1 Types of Tests	10
7. Losses and Impedance	12
7.1 Total Losses	12
7.2 Impedance	13
8. Temperature Rise	13
8.1 Life of Insulating Materials	13
8.2 Conditions Under Which Temperature Limits Apply	14
8.3 Limits of Temperature Rise for Continuous Ratings	14
9. Dielectric Tests and Insulation Levels	14
9.1 Dielectric Tests	14
9.2 Dielectric Tests for Line Terminals	15
9.3 Basic Lightning-Impulse Insulation Levels and Insulation Test Levels for Neutral Terminals	16

CLAUSE	PAGE
10. Test Code	20
10.1 General	20
10.2 Resistance Measurements	21
10.3 General Dielectric Tests.....	22
10.4 Losses and Impedance	33
10.5 Temperature-Rise Tests	39
10.6 Audible-Sound-Level Test.....	44
10.7 Vibration Tests on Oil-Immersed Shunt Reactors	51
10.8 Vibration Tests on Dry-Type Shunt Reactors	52
10.9 Magnetic Characteristic Measurements	53
10.10 Seismic Performance Verification on Oil-Immersed and Dry-Type Shunt Reactors.....	53
11. Construction for Oil-Immersed Shunt Reactors.....	53
11.1 Bushings.....	53
11.2 Bushing-Type Current Transformers	53
11.3 Accessories.....	54
11.4 Terminal Markings.....	60
11.5 Oil Preservation.....	60
11.6 Oil-Preservation Systems	60
11.7 Tanks.....	61
11.8 Shunt Reactor Finish.....	62
11.9 Other Equipment Accessories	62
12. Construction and Installation of Dry-Type Shunt Reactors.....	63
12.1 General Description	63
12.2 Safety	63
12.3 Magnetic Clearances	63
12.4 Connections.....	64
12.5 Installed Sound Level.....	64
12.6 Concrete Foundations	65
12.7 Switching — Circuit Breakers	65
12.8 Protection Practices for Air-Core Shunt Reactors	65
Annex (Informative) Appendix to Dielectric Tests Including Information on Wave Shape Control.....	66

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

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 does not apply to other devices such as

- 1) Shunt reactors, 500 kVA and smaller
- 2) Current-limiting reactors (see ANSI C57.16-1958 [1]¹)
- 3) Arc-suppression coils
- 4) Neutral-grounding devices (see IEEE Std 32-1972 [22])
- 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 IEEE Std 100-1984 [23].

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.

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

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, cables, or shunt capacitors. The need for shunt reactors is most apparent at light loads.

2.2 Rating of a Shunt Reactor

2.2.1 Rated kVA

The apparent power at rated voltage for which the shunt reactor is designed.

2.2.2 Rated Current

Derived from the rated voltage and rated kVA.

2.2.3 Rated Voltage

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 are neither impregnated with an insulating fluid nor immersed in an insulating oil.

2.4 Losses and Impedance

2.4.1 Total Losses

For an oil-immersed shunt reactor, the sum of the conductor I^2R loss, magnetic circuit loss, shielding loss, and all other stray losses in the shunt reactor.

For dry-type shunt reactors, the total losses shall be taken as the sum of the conductor I^2R loss, the conductor eddy loss, and the stray loss in the windings and manufacturer supplied framework, but not including stray (eddy) losses in the user supplied support structure, surrounding structures (bus supports etc.), or mounting pad (rebar).

2.4.2 Impedance

The phasor sum of the reactance and effective resistance, expressed in ohms per phase. The impedance may be derived from the rated kVA and rated voltage.

2.5 Construction

2.5.1 Indoor Shunt Reactor

One that, 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 Self-Cooled Shunt Reactor (Class AA)

A dry-type shunt reactor that is cooled by the natural circulation of the cooling air.

2.6.2 Oil-Immersed Self-Cooled Shunt Reactor (Class OA)

An oil-immersed shunt reactor that is cooled by natural circulation of the cooling air over the cooling surface.

3. References

- [1] ANSI C57.16-1958 (Reaf 1971), Requirements, Terminology, and Test Code for Current-Limiting Reactors.²
- [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, Specification for Sound Level Meters.
- [5] ANSI S1.11-1986, Specifications for OctaveBand and Fractional Octave-Band Analog and Digital Filters.
- [6] ANSI/ASME B1.20.1-1983, Pipe Threads, General Purpose.
- [7] ANSI/CGA V-1-1987, Compressed Gas Cylinder Valve Outlet and Inlet Connections.
- [8] ASTM A167-90, Specification for Stainless and Heat Resisting Chromium-Nickel Steel Plate, Sheet, and Strip.⁴
- [9] ASTM D117-89, Guide to Test Methods and Specifications for Electrical Insulating Oils of Petroleum Origin.
- [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 C57.13-1978 (Reaf 1986), IEEE Standard Requirements for Instrument Transformers (ANSI).
- [13] IEEE C57.98-1986, IEEE Guide for Transformer Impulse Tests (ANSI).

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.

⁶IEEE publications are available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, Piscataway, NJ 08855-1331, USA.

- [14] IEEE C57.106-1977, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.⁷
- [15] 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.
- [17] IEEE C62.2-1987, IEEE Guide for the Application of Gapped Silicon-Carbide Surge Arresters for Alternating Current Systems (ANSI).
- [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 (Reaf 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 (Reaf 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 (Reaf 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 Pruefen/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.
- [29] Debourg, H., Jenkins, R. S., Slettenmark, I., Tengstrand, C.A., and Wester, C.E. "Calorimetric Loss Measurement on Alternators and Reactors." Paper 119, International Conference on Large High Tension Electric Systems (CIGRE), 20th session, 1964.
- [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.

[33] 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.

[34] Hague, B. *Alternating Current Bridge Methods*. London: Pitman and Sons, 1957.

[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.

[36] Kusters, N. L. and Petersons, O. A. "Transformer-Ratio-Arm Bridge for High Voltage Capacitance Measurements." *IEEE Transactions on Communications and Electronics*, vol. 69, Nov. 1963, pp. 606-611.

[37] 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.

[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.

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

- 1) 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.⁹
- 2) The altitude does not exceed 1000 m (3300 ft).
- 3) 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 5% above rated 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.

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.

⁹It 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 be affected. 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

- 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 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.)
- 8) Unusual operating requirements that might result from the absence of surge protection or the proximity to magnetic material or structures¹⁰

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 4-1978 [20] 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.

¹⁰If 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 i 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.

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

The dielectric strength of a sample of insulating oil taken from a new shunt reactor shall not be less than the minimum kV values listed on Table 3 or 4 in IEEE C57.106-1977 [14].

4.7 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 non-linear magnetic characteristic where the normal operation is in the unsaturated portion of the curve. (See Fig 1.)

5. Basis for Rating Shunt Reactors

(See Section 12 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 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 lightning-impulse insulation level
- 6) Number of phases
- 7) Oil and/or winding-temperature rise
- 8) Method of cooling

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

Method of Cooling Apparatus	Altitude			
	1000 m (3300 ft)	2000 m (6600 ft)	3000 m (9900 ft)	4000 m (13 200 ft)
Oil-immersed, self-cooled	30 °C	28 °C	25 °C	23 °C
Dry-type, self-cooled				
55 °C rise	30 °C	27 °C	24 °C	21 °C
80 °C rise	30 °C	26 °C	22 °C	18 °C
100 °C rise	30 °C	24 °C	18 °C	12 °C
125 °C rise	30 °C	23 °C	16 °C	9 °C
150 °C rise	30 °C	22 °C	15 °C	7 °C

NOTE — Recommended calculation of average temperature is described in 4.1.1.

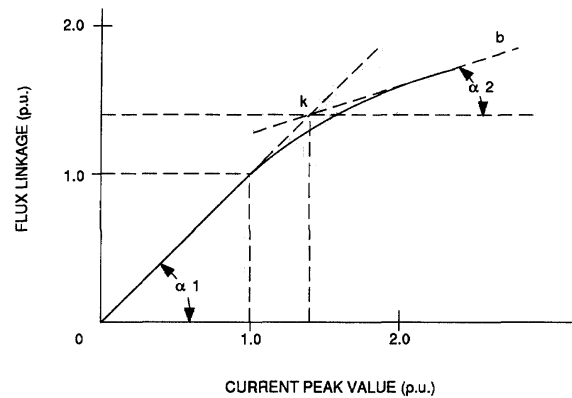
Table 3—Limits of Temperature Rise for Continuously-Rated Shunt Reactors

Item	Type of Shunt Reactor	Insulation Temperature Class	Average Winding Temperature Rise by Resistance °	Hottest-Spot Winding Temperature Rise, °C
1	Oil-immersed Dry-type	—	65	80
		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 [19].
- 3 — The maximum hot spot temperature rise limits in Table 3 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.



$\alpha 1$ = 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

6. Tests

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

6.1 Types of Tests

6.1.1 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 C57.12.80-1978 [11].

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.

6.1.1.3

When specified (as individual tests), other tests shall be made on shunt reactors as listed in Table 4.A and 4.B.

6.1.1.4

The listing of tests shown on Table 4.A and 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 Section 10.

Table 4.A—Routine, Design, and Other Tests for Oil-Immersed Shunt Reactors

Tests	Test Classification		
	Routine	Design	Other
Resistance Measurements.....	X		
The dc resistance measurements shall be made on the full winding.			
Impedance Measurements.....	X		
The impedance measurements shall be made on the assembled shunt reactor.			
Total Loss Measurements.....	X		
Temperature Tests.....		X	
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 shall 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.			
Insulation Power Factor Tests.....	X		
Applied-Voltage Tests.....	X		
The applied-voltage tests shall be determined by the BIL of the neutral end of the Y connected shunt reactor.			
Low-Frequency Overvoltage Tests.....	X		
Lightning-Impulse Tests:			
Nominal system voltage of 115 kV or above.....	X		
Nominal system voltage below 115 kV (only when specified).....			X
Neutrals of reactors for nominal system voltage above 115 kV (only when specified).....			X
Switching-Impulse Tests:			
Nominal system voltage of 345 kV or above.....	X		
Nominal system voltage below 345 kV (only when specified).....			X
Front-of-Wave Test (only when specified).....			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.....	X		
Shunt reactors rated below 50 mVA, three phase (16.67 mVA, single-phase), or nominal system voltage below 115 kV (only when specified).....			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		
Shunt reactors rated below 50 mVA, three phase (16.67 mVA, single-phase), or nominal system voltage below 115 kV (only when specified).....			X
Mechanical Tests.....	X		
Mechanical tests shall be made to verify the pressure requirements for maximum operating pressures and full vacuum filling.			

Table 4.B—Routine, Design, and Other Tests for Dry-Type Shunt Reactors

Tests	Test Classification		
	Routine	Design	Other
Resistance Measurements.....	X		
The dc resistance measurements shall be made on the full winding.			
Impedance Measurements.....	X		
The impedance measurements shall be made on the full winding.			
Total Loss Measurements.....	X		
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.			
Temperature Tests.....		X	
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 shall 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.			
Applied-Voltage Tests.....			X
The applied-voltage tests shall be made only on support insulators when specified.			
Turn-to-Turn Test.....	X		
This test is performed for nominal system voltages of 34.5 kV and below.			
Lightning-Impulse Tests:			
Nominal system voltage greater than 34.5 kV.....	X		
Nominal system voltage at or below 34.5 kV (only when specified).....			X
Switching-Impulse Tests.....			X
Switching surge tests shall be made on shunt reactors rated 115 kV or above (only when specified).			
Audible-Sound Tests.....			X
(Only when specified)			
Vibration Tests.....			X

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. If available test power is insufficient for testing at rated voltage, then the manufacturer must 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

The total losses of one shunt reactor, demonstrated by tests and corrected to the rated current base, shall not exceed the specified losses by more than 6%. On multiple-unit orders, the average value shall be used for guarantee purposes, unless otherwise specified by the user. In this case, the average total losses shall be equal to or less than the specified loss.

7.1.3

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

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

NOTE — In the case of non-linear 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

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.¹¹

7.2.3

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

- 1) Dielectric stress and associated effects

¹¹For 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.

- 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 operated at 105% of the rated voltage.

8.3 Limits of Temperature Rise for Continuous Ratings

8.3.1 Limits of Observable Temperature Rise¹²

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 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 voltage, will not exceed the values given in Table 3.

9. Dielectric Tests and Insulation Levels

9.1 Dielectric Tests

9.1.1 General

- 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.
- 5) Insulation power factor tests are only required for oil-immersed shunt reactors. Insulation power factor tests on dry-type air-core reactors would be very difficult to measure and interpret, since the insulation between the windings and ground is essentially the resistance of the support insulators.

9.1.2 Applied-Voltage Test

9.1.2.1

For a shunt reactor with reduced insulation at the neutral, the applied-voltage test shall be in accordance with Table 5.A or Table 5.B, based upon the insulation level of the neutral end.

¹²See 4.4 for the effect of altitudes on temperature rise.

9.1.3 Overvoltage Tests

9.1.3.1 Low-Frequency Overvoltage Test for Oil-Immersed Shunt Reactors

- 1) 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 should be 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 with-stand 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

- 1) *Applied-Voltage Test.* The applied-voltage test is a high-voltage test for the support insulators only.
- 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 $\sqrt{2}$ times the rms values as specified in Table 5.B, columns 3 or 4.

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 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

9.2.1

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.

9.2.3

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

When required, as indicated in Table 4.A and 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 Section 10. The transients shall have a minimum crest value in accordance with Tables 5.A and 5.B.

9.2.5

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

9.3 Basic Lightning-Impulse Insulation Levels and Insulation Test Levels for Neutral Terminals

9.3.1

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 the following sections.

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