



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

IEEE Power and Energy Society

Developed by the
Transformers Committee

IEEE Std C57.21™-2021
(Revision of IEEE Std C57.21-2008)



STANDARDS

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

Developed by

Transformers Committee
of the
IEEE Power and Energy Society

Approved 9 May 2021

IEEE SA Standards Board

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Abstract: All liquid-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 liquid-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, IEEE C57.21™, liquid-immersed shunt reactor

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Introduction

This introduction is not part of IEEE Std C57.21™-2021, 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, 1990, and 2008.

The standard issued in 1971 was the first standalone standard for shunt reactors. Ten years later in 1981, through a coordinated effort of several task forces, the standard was again updated. The resulting standard represented the agreement of all those involved in reactor design, construction, testing, and usage, and was based on the state-of-the-art for shunt reactors at that time.

In 2008, a new revision of the standard was developed and in addition to style, format, and general content updates, several key changes and additions were made including the following:

- a) Dry-type air-core thyristor-controlled shunt reactors were added. This included the addition of [Annex A](#) (normative) to cover the specific requirements these reactors, as well as modifications to the main body text.
- b) Information on dielectric stresses imposed on shunt reactors during switching was added with a new [Annex B](#) (informative) providing background. As a consequence of the switching stresses seen by shunt reactors, reduced basic lightning-impulse insulation levels (BIL), which is common practice for power transformers, were no longer recommended and were not included in [Table 5](#). Input for this annex was coordinated with the IEEE Switchgear Committee and with members of IEC MT32 on Inductive Load Switching.
- c) [Table 5A](#) and [Table 5B](#) were combined into one table as [Table 5](#) (insulation levels of shunt reactors). [Table 6](#) and its notes were changed.
- d) Maximum system voltages were introduced to be consistent with terminology in the IEC reactor standard (see IEC 60076-6:2007 [\[B25\]¹](#)).

The current revision has been updated to current IEEE style and has been revised to be in conformance with the improvements made in the latest versions of IEEE Std C57.12.00™ and IEEE Std C57.12.90™.

A major update to this revision has been the addition of variable shunt reactors. Changes were made throughout the standard to include this technology. In addition, an [Annex D](#) (informative) was added to provide background information on variable shunt reactors with on-load tap-changers.

Finally, [Annex E](#), the bibliography, has been updated.

¹The numbers in brackets correspond to those of the bibliography in [Annex E](#).

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1. Overview

1.1 Scope

This standard applies to all ~~liquid 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^{TM2-1996⁺})
- c) Arc-suppression coils ([see IEEE Std C57.32TM](#))
- d) Neutral-grounding devices (see IEEE Std [C57.32TM-1972](#))

²⁺Information on references can be found in Clause 2.

- e) Saturable reactors
- f) Line-resonant reactors
- g) Filter reactors

1.2 Purpose

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

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{3, 4}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

³The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁴The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

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.

ANSI/[ASA S1.4–2014/Part 1/IEC 61672:1:2013](#) ~~1983 (Reaff 2006)~~, American National Standard [Electroacoustics— Specification for](#) Sound Level Meters—[Part 1: Specifications \(a Nationally Adopted International Standard\)](#).^{5 2}

ANSI/[ASA S1.11–2016/Part 2/IEC 61260-2:2016](#) ~~2004~~, [American National Standard Electroacoustics— Specification for](#) Octave-band and Fractional-octave-band ~~Analog and Digital~~ Filters—[Part 2: Pattern-evaluation Tests \(Nationally Adopted International Standard\)](#).

[ANSI/ASA S1.11–2016/Part 3/IEC 61260-3:2016](#), [American National Standard Electroacoustics— Octave-band and Fractional-octave-band Filters—Part 3: Periodic Tests \(Nationally Adopted International Standard\)](#).

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

ASTM [A240/A240M-18](#) ~~A167-1999 (Reaff 2004)~~, Standard Specification for ~~Stainless and Heat-Resisting~~ [Chromium and](#) Chromium-Nickel [Stainless](#) Steel Plate, Sheet, and Strip [for Pressure Vessels and for General Applications](#).^{6 3}

~~ANSI/CGA V-1–2013~~ ~~2005~~, [Standard for](#) Compressed Gas Cylinder Valve Outlet and Inlet Connections.

^{5 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/>).

^{6 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/>).

IEEE Std 1TM-~~2000 (Reaff 2005)~~, IEEE Recommended Practice—General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation. ^{7,8} ~~4,5~~

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

~~IEEE Std 32TM-1972 (Reaff 1990), IEEE Standard Requirements, Terminology, and Test Procedures for Neutral Grounding Devices.~~

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

IEEE Std 693TM-~~2005~~, IEEE Recommended Practice for Seismic Design of Substations.

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

IEEE Std C37.015TM-~~1993 (Reaff 2006)~~, IEEE Application Guide for Shunt Reactor Switching.

IEEE Std C37.109TM-~~2006~~, IEEE Guide for the Protection of Shunt Reactors.

IEEE Std C57.12.00TM-~~2006~~, IEEE Standard for Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.80TM-~~2002~~, IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90TM-~~2006~~, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

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

IEEE Std C57.19.00TM~~-2004~~, IEEE Standard General Requirements and Test Procedures for Power Apparatus Bushings.

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

IEEE Std C57.98TM~~-1993 (Reaff 1999)~~, IEEE Guide for Transformer Impulse Tests.

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

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

[IEEE Std C57.131TM, IEEE Standard Requirements for Tap Changers.](#)

IEEE Std C62.11TM~~-2005~~, IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>.1 kV).

IEEE Std C62.22TM~~-1997~~, IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The ~~Authoritative Dictionary of IEEE Standards~~ [Dictionary Online](#) ~~Terms [B19]⁶~~ should be [consulted](#) ~~referenced~~ for terms not defined in this clause.⁹

⁹[IEEE Standards Dictionary Online](http://dictionary.ieee.org) is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

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

3.1 Shunt reactor

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

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

variable shunt reactor (VSR): A shunt reactor where the inductive reactance is dynamically variable. Typically insulating liquid-immersed with an on load tap-changer (OLTC).

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.¹⁰ 

3.2 Rating of a shunt reactor

maximum operating voltage: The maximum line-to-ground voltage or phase-to-phase voltage associated with maximum system voltage. Unless otherwise specified, the maximum operating voltage shall be taken to be 105% of rated voltage.

maximum system voltage: The highest rms phase-to-phase voltage that occurs on the system under normal operating conditions and also corresponds to the highest rms phase-to-phase or phase-to-ground voltage for which the shunt reactor is to be designed and operated without exceeding temperature limits. Dielectric test levels are based on this voltage.

rated current: Derived from the rated voltage, rated frequency, and rated kVA (kilovolt-amperes).

rated kVA: The apparent power at rated voltage and rated frequency for which the shunt reactor is designed.

¹⁰ —Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

rated voltage: The voltage to which operating and performance characteristics of shunt reactors are referred; the associated phase-to-phase or phase-to-ground voltage is used for calculation depending on the shunt reactor system connection.

3.3 Insulation

dry-type shunt reactor: A shunt reactor in which the coils are neither impregnated with an insulating ~~liquid fluid~~ nor immersed in an insulating ~~liquid oil~~. The insulating medium for the windings is a solid dielectric and/or air. The insulation to ground is provided by porcelain or polymeric insulators.

liquid-immersed shunt reactor: A shunt reactor in which the core and coils are immersed in an insulating liquid.

oil-immersed shunt reactor: A shunt reactor in which the ~~core and~~ coils ~~and magnetic circuit~~ are immersed in ~~transformer or impregnated with an insulating~~ oil.

3.4 Losses and impedance

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.

total losses: For a liquid ~~an oil~~-immersed shunt reactor, the total losses shall be taken as the sum of the conductor I^2R loss, the conductor eddy 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).

3.5 Construction

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

outdoor shunt reactor: A reactor of weather-resistant design and construction.

3.6 Methods of cooling

Shunt reactors shall be identified according to the cooling method employed. For liquid-immersed shunt reactors, this identification is expressed by a four-letter code as described below. For dry-type reactors, the identification is expressed similarly to that for [liquid oil](#)-immersed shunt reactors, but by considering only the third and fourth letters of the four-letter code as used for liquid-immersed shunt reactors. These designations are consistent with IEEE Std C57.12.00 [TM-2015 2006](#) and IEC 60076-2: [2011 1997](#) [[B22 B14](#)].

first letter: Internal cooling medium in contact with the windings (applicable only to liquid-immersed shunt reactors):

- O ~~mineral oil or synthetic~~ Insulating liquid with fire point $\leq 300\text{ }^{\circ}\text{C}$ ([see ASTM D92 \[B5\]](#))
- K Insulating liquid with fire point $> 300\text{ }^{\circ}\text{C}$
- L Insulating liquid with no measurable fire point

second letter: Circulation mechanism for internal cooling medium (applicable only to liquid-immersed shunt reactors):

- N Natural convective flow through cooling equipment and in windings
- F Forced circulation through cooling equipment (i.e., coolant pumps), natural convective flow in windings (also called non-[directed](#) flow)

- D Forced circulation through cooling equipment, directed from the cooling equipment into at least the main windings ([also called direct flow](#))

third letter: External cooling medium:

- A Air
- W Water (not applicable to dry-type reactors)

fourth letter: Circulation mechanism for external cooling medium:

- N Natural convection
- F Forced circulation [fans (air cooling), pumps (water cooling)]

dry-type shunt reactors: Dry-type shunt reactors are generally cooled by the natural circulation of the cooling air (class AN). Forced air circulation may also be used.

liquid-immersed shunt reactors: Liquid-immersed shunt reactors are generally cooled by natural circulation of the cooling [liquid](#) ~~mineral-oil~~ within the winding section and natural circulation of the cooling air over the external cooling surface (radiators, class ONAN). ~~Other insulating liquids and/or~~ Forced liquid circulation and/or forced air or water cooling may also be employed if specified.

NOTE—IEEE Std C57.12.00-~~2006~~ can be consulted as a reference.

4. Service conditions

4.1 Usual ~~temperature and altitude~~ service conditions

4.1.1 General ~~requirements~~

A shunt reactor conforming to this standard shall be suitable for operation at its rated kVA and voltage, under the following usual conditions. ~~provided that~~

4.1.2 Temperatures

4.1.2.1 Cooling air temperature limits

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. ¹¹ §

4.1.2.2 Liquid temperature limits

The top liquid temperature of a liquid ~~an oil~~-immersed shunt reactor (when operating) shall not be lower than -20 °C. For mineral oil-filled shunt reactors, starting temperatures below -20 °C are not considered as usual service conditions.

4.1.3 Altitude

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

¹¹ §-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 Supply ~~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.

4.1.5 Frequency

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

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

4.1.6 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.

4.2 Loading at other than rated conditions

Loading of shunt reactors is a function of the voltage applied. The effect of any voltage variation on the life of oil-filled shunt reactor can be assessed using guidance contained in IEEE Std C57.91™ [B33], for the insulation system. IEEE Std C57.91 does not apply to dry-type shunt reactors or those with alternate liquids. Shunt reactor loading conditions are discussed in Clause 8 for loading at other-than-rated conditions including the following:

- a) Ambient temperatures higher or lower than the basis of rating
- b) Short-time loading in excess of nameplate kVA with normal life expectancy

- c) [Loading that results in reduced life expectancy](#)

4.3 Unusual service conditions

4.3.1 General

[Conditions other than those described in 4.1 are considered unusual service conditions and, when prevalent, should be brought to the attention of those responsible for the design and application of the apparatus. Examples of some of these conditions are listed in 4.3.4.](#)

4.3.2 Unusual temperature and altitude service conditions

A shunt reactor may be applied at higher ambient temperatures or at higher altitudes than specified in [4.1.2 and 4.1.3](#) ~~4.1.1~~, but its performance 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.

4.3.3 Insulation at high altitude

4.3.3.1 General

[The dielectric strength of a reactor that depends in whole or in part on air for insulation decreases as the altitude increases due to the effect of decreased air density. When specified, reactors shall be designed with larger air spacing between terminals using the correction factors of Table 1 to obtain adequate air dielectric strength at altitudes above 1000 m \(3300 ft\).](#)

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

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

NOTE 1—An altitude of 4500 m (15 000 ft) is considered a maximum for reactors conforming to this standard.
NOTE 2—In case testing is performed at 1500 m and installation will be at 1200 m, then dielectric test voltage needs to be multiplied by a factor of 0.95/0.98.

(New)

Altitude		Altitude correction factor for dielectric strength
(m)	(ft)	
≤1000	≤3 300	1.00
1200	4 000	0.98
1500	5 000	0.95
1800	6 000	0.92
2100	7 000	0.89
2400	8 000	0.86
2700	9 000	0.83
3000	10 000	0.80
3600	12 000	0.75
4200	14 000	0.70
4500	15 000	0.67

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

(Deleted)

4.3.3.2 Insulation level

The minimum insulation necessary at the required altitude can be obtained by dividing the standard insulation level at 1000 m (3300 ft) by the appropriate correction factor from Table 1.

4.3.3.3 Bushings

Bushings with additional length or arcing distance shall be furnished when necessary for operation above 1000 m (3300 ft).

4.3.4 Other unusual service conditions

Where unusual conditions other than those discussed in [4.1.6](#) ~~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)
- 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 un-terminated or open transmission lines during which time significant voltage rises may occur. (See [4.1.4](#) ~~4.2~~ 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. ¹² ^a

4.3.5 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 [help](#) ensure [proper](#) ~~safe~~ operation during the expected lifetime of the reactor. [Subclause A.9 of IEC/TS TR 60815-1:2008 \[B27\], IEC TS 60815-2:2008 \[B28\], and IEC TS 60815-3:2008 \[B29\] are 1986 \(see supporting published material \[1\] of A.9\) is a](#) useful reference documents as [they](#) ~~it~~ contain ~~s~~^a tables listing ~~ESDD~~ (equivalent salt deposition density ([ESDD](#))) 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 693TM-~~2005~~ provides information regarding seismic design/qualification requirements.

4.4 Effect of air density on flashover voltage

4.4.1 General

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

¹² ^aIf 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.

4.4.2 Insulation

The dielectric strength of a shunt reactor that depends in whole or in part ~~on~~ ~~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.

4.5 Effect of altitude on temperature ~~rise~~

4.5.1 General

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

4.5.2 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.

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)
Liquid-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 4.1.2.				

(New)

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.				

(Deleted)

4.6 Electrical properties of the insulating liquid oil

4.6.1 Electrical properties of mineral oil

New, unused mineral oil shall meet the requirements of ASTM D3487.

The mineral oil used in new shunt reactors shall meet or exceed the requirements listed in IEEE Std C57.106TM -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 of that standard.

4.6.2 Electrical properties of other insulating liquids

The insulating liquid used in new shunt reactors shall meet or exceed the following requirements.

- Less-flammable hydrocarbon fluid. New, unused less-flammable hydrocarbon fluid shall meet the requirements of ASTM D5222 [B8].
- Silicone insulating fluid. New, unused silicone insulating fluid shall meet the requirements of ASTM D2225 [B7].

- c) [Natural ester insulating liquid. New, unused natural ester insulating liquid shall meet the requirements of ASTM D6871 \[B9\].](#)

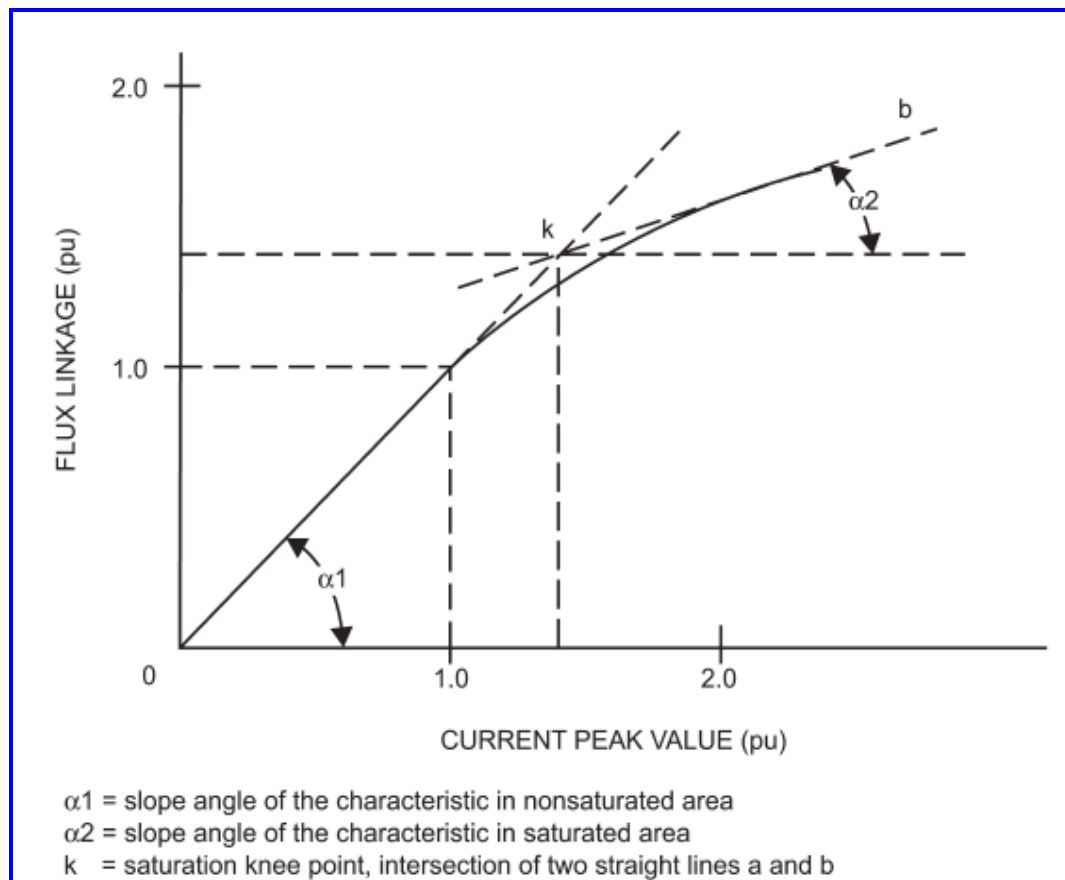
4.7 Magnetic characteristics

Shunt reactors may be identified, with regard to their magnetic characteristics, as linear, nonlinear, or saturated. Most [liquid oil](#)-immersed shunt reactors have a nonlinear magnetic characteristic where the normal operation is in the [nonsaturated](#) ~~unsaturated~~ portion of the curve- (See Figure 1-) [represented by slope \$\alpha_1\$](#) .

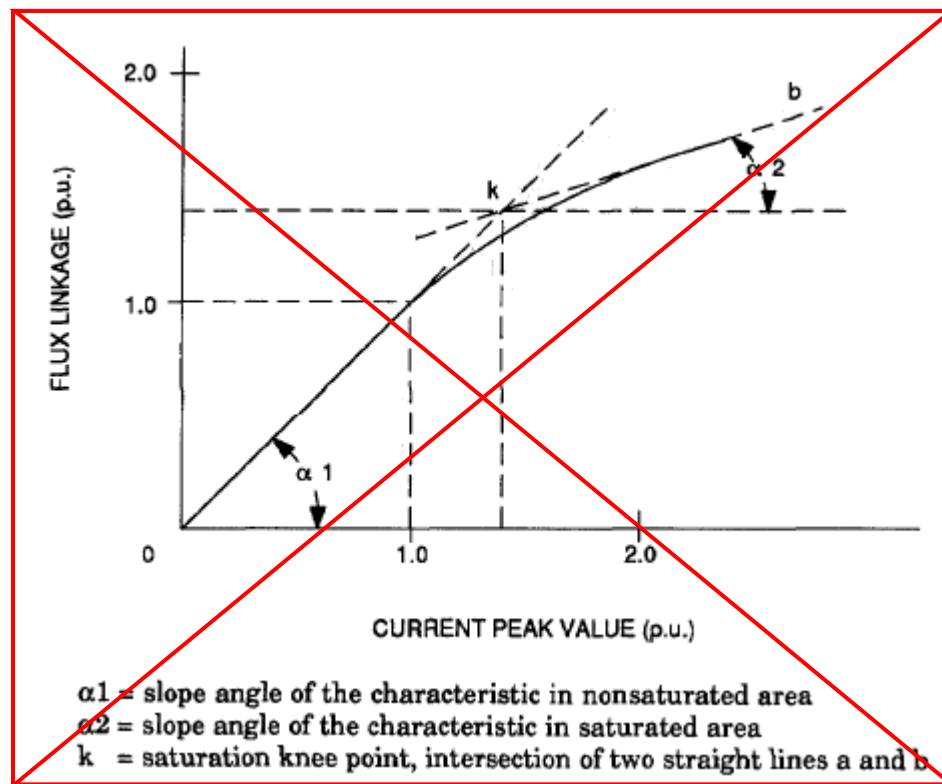
5. Basis for rating shunt reactors

5.1 General

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



(New)



(Deleted)

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 ([see 10.9](#))

5.2 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 maximum operating voltage (line-to-ground voltage associated with maximum system voltage) without exceeding the temperature-rise limits specified in Table 3.

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 (°C)	Hottest-spot winding temperature rise (°C)
1	Liquid-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 liquid-immersed shunt reactor shall have an liquid-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.			
5	A shunt reactor with specified temperature rise shall have an insulation temperature index that has been proven by experience or testing.			
NOTE 1—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 2—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 detects 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.				

(New)

Item	Type of shunt reactor	Insulation temperature class	Average winding temperature rise by resistance (°C)	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.			
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.				

(Deleted)

5.3 Terms in which rating is expressed

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

- a) Rated voltage
- b) Maximum operating voltage
- c) Rated kVA
- d) Rated current
- e) Rated frequency
- f) Basic lightning-impulse insulation level (BIL)
- g) Number of phases
- h) [Liquid oil](#) and/or winding-temperature rise
- i) Method of cooling
- j) Delta or star connection (three-phase shunt reactor)

NOTE—Magnetic characteristics are not deemed to be a basis for rating. However, magnetic linearity for [liquid 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.

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~~

6.2.1.1 General

Types of tests for liquid ~~oil~~-immersed shunt reactors are listed in Table 4.~~A~~. Types of tests for dry-type shunt reactors are listed in Table 5 ~~4.B~~. Definitions of these various tests are included in IEEE Std C57.12.80TM ~~-2002~~. The listing of tests shown in Table 4.~~A~~ and Table 5 ~~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.

6.2.1.2 Routine tests~~for shunt reactors~~

Routine tests shall be made on all shunt reactors in accordance with the requirements of Table 4.~~A~~ and Table 5 ~~4.B~~, as applicable.

6.2.1.3 Design tests~~for shunt reactors~~

Design tests shall be made on shunt reactors in accordance with the requirements of Table 4.~~A~~ and Table 5 ~~4.B~~.

6.2.1.4 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 5 ~~4.B~~. “Other” tests may be routine or design, as required or specified.

Table 4—Routine, design, and other tests for liquid ~~oil~~-immersed shunt reactors¹³

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 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.			
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.			

Table continues

(New)

¹³When these tests are performed on variable shunt reactors, see 10.1.1 for additional requirements.

Table 4—Routine, design, and other tests for liquid-immersed shunt reactors (continued)

Tests	Test classification		
	Routine	Design	Other
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
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)	X	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		
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)			X
Shunt reactors rated 50 MVA, three-phase (16.67 MVA, single-phase) or above, or nominal system voltage of 115 kV or above.		X	
Mechanical tests			
Mechanical tests shall be made to verify the pressure requirements for maximum operating pressures and full vacuum filling.		X	

(New)

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.....	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
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	

(Deleted)

Table 5—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 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.			
Applied-voltage tests			X
The applied-voltage tests shall be made only on support insulators when specified.			

(New)

Table 5—Routine, design, and other tests for dry-type shunt reactors

(continued)

Tests	Test classification		
	Routine	Design	Other
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
The audible-sound-level test is a design test for dry-type shunt reactors only when a maximum noise limit is specified.			
Vibration tests			X

(New)

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

(Deleted)

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.

Note that loss measurement for air-core dry-type reactors may be performed with low voltage and current (small signal) after the linearity of the reactor has been established.

7.1.2 Tolerance on losses

7.1.2.1 General

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

7.1.2.2 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.

7.1.2.3 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.¹⁴ ~~10~~

7.2.3 Zero-sequence impedance

When specified, the zero-sequence impedance of ~~liquid 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 depends^s are as follows:

- a) Dielectric stress and associated effects
- b) Vibration or varying mechanical stress

¹⁴ ~~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.

- c) Repeated expansions and contractions
- d) 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 maximum operating voltage.

8.3 Limits of temperature rise for continuous ratings

8.3.1 Limits of observable temperature rise¹⁵ ~~14~~

The temperature rise above the ambient temperature of shunt reactors and parts in contact with the insulation or encapsulation material, when operated at 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 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, no a-number-of significant changes were made to dielectric tests and insulation levels provided in IEEE Std C57.21–2008; only the table number was changed to conform to IEEE embedded macros. ~~includes the following:~~

¹⁵ ~~14~~–See 4.4 for the effect of altitudes on temperature rise.

- 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.~~
- b) ~~In Table 5, the nominal system voltage and maximum system voltage are included.~~
- 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.~~
- 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 Liquid ~~Oil~~-immersed shunt reactors

For liquid ~~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 6 ~~5~~, Column 10.

9.1.2.2 Reduced insulation at the neutral

For an liquid ~~oil~~-immersed shunt reactor with reduced insulation at the neutral, the applied-voltage test shall be in accordance with Table 6 ~~5~~, based upon the insulation level of the neutral end.

9.1.3 Overvoltage tests

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

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