

# IEEE Standard for Requirements, Terminology, and Test Procedures for Neutral Grounding Devices

IEEE Power and Energy Society

Sponsored by the  
Transformers Committee

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USA

**IEEE Std C57.32™-2015**  
(Revision of  
IEEE Std 32™-1972)

# **IEEE Standard for Requirements, Terminology, and Test Procedures for Neutral Grounding Devices**

Sponsor

**Transformers Committee**  
of the  
**IEEE Power and Energy Society**

Approved 5 December 2015

**IEEE-SA Standards Board**

**Abstract:** This standard applies to devices used for the purpose of controlling the ground current or the potentials to ground of an alternating current system. These devices are: grounding transformers, ground-fault neutralizers, resistors, reactors, or combinations of these.

**Keywords:** arc-suppression reactors, ground fault neutralizers, grounding transformers, IEEE C57.32™, neutral grounding devices, reactors, resistors

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## Introduction

This introduction is not part of IEEE Std C57.32-2015, IEEE Standard for Requirements, Terminology, and Test Procedures for Neutral Grounding Devices.

Historically this standard developed from AIEE Standard 32, 1947. The standard was substantially revised to become IEEE Std 32™ in 1972 and was reaffirmed in 1978, 1984, and 1990.

This standard is a revision of IEEE Std 32-1972, to which many changes have been made. The Standard 32 was originally developed by the Neutral Grounding Subcommittee of the Surge Protective Devices Committee of the IEEE Power Engineering Society. In 2003, the responsibility for upkeep and maintenance of this standard was transferred to the Performance Characteristics Subcommittee of the Transformers Committee of the IEEE Power and Energy Society.

This version is being published under a new number, C57.32, and has been completely revised to bring it in line with the current technology. Each grounding device now has its own section with all requirements and test methods included. Old test methods that were developed in the 1930s and 1940s have lost their relevance over time. Conservative calculation methods were lost in history and did not correlate to modern practices. To maintain a link to the old methods for now, Annex A is a copy of the old test code and is provided solely for reference purposes.

Note that capacitors have been removed from this standard. They had traditionally been used on occasion for front of wave surges. They are rarely used today. The use of capacitors has evolved into blocking devices in the neutral of transformers to block Geomagnetically Induced Currents (GIC) from Geomagnetic Disturbances (GMD). The IEEE Capacitor Subcommittee of the Transmission and Distribution Committee of PES has a task force that is handling this topic.

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# IEEE Standard for Requirements, Terminology, and Test Procedures for Neutral Grounding Devices

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## 1. Overview

### 1.1 Scope

This standard applies to devices used for the purpose of controlling the ground current or the potentials to ground of an alternating current system. These devices are: grounding transformers, ground-fault neutralizers, resistors, reactors, or combinations of these devices.

### 1.2 General considerations

The voltage, current, and insulation ratings for such devices shall consider their operation during normal and faulted system conditions. See also the IEEE C62.92™ series of guides [B29], [B30], [B31], [B32], and [B33] for additional information.<sup>1,2,3</sup>

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<sup>3</sup> The numbers in brackets correspond to those of the bibliography in Annex B.

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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.

Accredited Standards Committee C2-2012, National Electrical Safety Code® (NESC®).<sup>4</sup>

ANSI/NEMA C29.8, Wet-Process Porcelain Insulators—Apparatus, Cap and Pin Type.<sup>5</sup>

ANSI/NEMA C29.9, Wet Process Porcelain Insulators—Apparatus, Post Type.

ANSI/NEMA C29.10, Wet Process Porcelain Insulators—Indoor Apparatus Type.

ASTM D1816, Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes.<sup>6</sup>

IEC 60076-5, Power Transformers—Part 5: Ability to withstand short-circuit, Edition 3.0, 2006-02.<sup>7</sup>

IEC 60076-6, Power Transformers—Part 6: Reactors, Edition 1.0, 2007-12.

IEEE Std 1™, IEEE Recommended Practice-General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation.

IEEE Std 693™, IEEE Recommended Practices for Seismic Design of Substations.

IEEE Std C37.30.1™, IEEE Standard Requirements for AC High-Voltage Air Switches Rated Above 1000 V.

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

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

IEEE Std C57.12.91™, IEEE Standard Test Code for Dry-type Distribution and Power Transformers.

IEEE Std C57.16™, IEEE Standard for Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors.

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

IEEE Std C57.19.01™, IEEE Standard Performance Characteristics and Dimensions for Outdoor Apparatus Bushings.

IEEE Std C57.91™, IEEE Guide for Loading Mineral Oil-Immersed Transformers and Step-Voltage Regulators.

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<sup>4</sup> The NESC is available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

<sup>5</sup> ANSI/NEMA publications are available from the National Electrical Manufacturers Association (<http://www.nema.org>).

<sup>6</sup> ASTM publications are available from the American Society for Testing and Materials (<http://www.astm.org>).

<sup>7</sup> IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch>). IEC publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org>).

IEEE Std C57.96™, IEEE Guide for Loading Dry-Type Distribution and Power Transformers.

IEEE Std C57.106™, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.

IEEE Std C57.110™, IEEE Recommended Practice for Establishing Liquid-Filled and Dry-Type Power and Distribution Transformer Capability When Supplying Nonsinusoidal Load Currents.

IEEE Std C57.111™, IEEE Guide for Acceptance of Silicone Insulating Fluid and Its Maintenance in Transformers.

IEEE Std C57.121™, IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers.

IEEE Std C57.147™, IEEE Guide for Acceptance and Maintenance of Natural Ester Fluids in Transformers.

### 3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.<sup>8</sup>

**acceptance test:** A test to demonstrate the degree of compliance of a device with purchaser's requirements.

**extended-time rating (of a grounding device):** A rated time in which the period of time is greater than the time required for the temperature rise to become constant but is limited to a specified average number of days operation per year.

**ground current:** The current flowing in the earth or in a grounding connection.

**ground end (of a neutral grounding device):** The end or terminal that is grounded directly or through another device.

**ground-fault neutralizer:** An electromagnetic device grounded through such values of reactance that, during a fault between one of the phases of the power system and earth, the rated-frequency current flowing in the grounding reactances and the rated-frequency capacitance current moving between the unfaulted phases and earth are substantially equal. *Syn:* **arc-suppression reactor.**

**grounded circuit:** A circuit in which one conductor or point (usually the neutral conductor or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through a grounding device.

**grounding transformer:** A transformer intended primarily to provide a neutral point for grounding purposes. *Syn:* **neutral grounding transformer.**

**insulating materials, thermal classification:** For the purpose of establishing temperature limits, insulating materials should be classified as described in the latest revision of IEEE Std C57.12.80™.

NOTE—For information on IEEE Std C57.12.80 [B26], please see Annex B.

**iron-core:** Having a magnetic core.

<sup>8</sup>IEEE Standards Dictionary Online subscription is available at: <http://ieeexplore.ieee.org/xpls/dictionary.jsp>.

**losses (of a grounding device):** The  $I^2R$  loss in the windings, core loss (where applicable), dielectric loss, loss due to stray magnetic fluxes in windings and other metallic parts of the device, and, in cases involving parallel windings, losses due to circulating currents. The losses as here defined do not include any losses produced by the device in adjacent apparatus or materials not a part of the device. Losses will normally be considered at the rated continuous current, but in some cases may be required at other current ratings (if more than one rating is specified) or at no load, as for grounding transformers.

**neutral grounding wave trap:** A neutral grounding device comprising a combination of inductance and capacitance designed to offer a very high impedance to a specified frequency or frequencies. The inductances used in neutral grounding wave traps should meet the same requirements as neutral grounding reactors.

**outdoor:** Equipment with weatherproof construction suitable for operation in specified exposed environment.

**reactor (neutral grounding):** A single-phase reactor for connection in the neutral for the purpose of limiting and neutralizing disturbances due to ground faults.

**resonant grounded:** A resonant grounded system is one in which the capacitance current is tuned or neutralized by a neutral reactor or similar device.

**short-time rating (of a grounding device):** A rated time of ten minutes or less.

## 4. Grounding reactors

### 4.1 General description

All parts of dry-type air-core neutral grounding reactors are “live,” unlike liquid-immersed reactors and transformers where the tank is grounded. The only external “live” parts of a liquid-immersed reactor or transformer are the bushings.

Dry-type air-core neutral grounding reactors do not have an iron core. Therefore, the magnetic field is not constrained and will occupy the space around the dry-type air-core reactor. Although the magnetic field reduces in strength with increase in distance from the reactor, the presence of this field should be taken into consideration for the installation of dry-type air-core units. The extent to which care has to be taken is largely a function of the continuous kVA rating and is lower for low kVA units. Since neutral grounding reactors usually have small continuous current ratings, magnetic clearances are normally smaller than electrical clearances.

In 4.2, 4.3, 4.4, and 4.5, applications related construction details and installation considerations will be discussed in order to provide guidance to the purchaser of dry-type air-core neutral grounding reactors.

### 4.2 Safety

Since dry-type air-core neutral grounding reactors are not enclosed in a grounded tank, parts above the base support insulators must be treated as “live.” Therefore, in order to help meet personnel safety requirements, the reactor shall be installed with clearances established by National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2-2012).<sup>9</sup> For transmission voltage class and distribution voltage class

<sup>9</sup> Information on normative references can be found in Clause 2.

equipment, standard methods of improving personnel clearance are the use of fencing and special support structures. In many cases, both methods are employed simultaneously. Distribution voltage class neutral grounding reactors are also installed in cells fabricated from standard building materials or vendor supplied enclosures.

### 4.3 Clearances: electrical, ventilation, and magnetic

The clearance requirements are of three types: electrical, ventilation, and magnetic.

As the normal dry-type air-core neutral grounding reactor has exposed live parts at essentially all points on its outer surface, provision must be made for electrical clearance from the reactor surface to nearby grounded surfaces and to other adjacent energized conductors. Standard electrical clearances to live parts are adequate. No special precautions over and above normal substation practices are required.

Ventilation clearance requirements may vary somewhat depending on the reactor manufacturer. For instance, in the case of reactors employing vertical cooling ducts, provision must be made for the unimpeded entrance and exit of cooling air at the bottom and top of the cooling ducts, respectively. In some cases baffles are required for establishing sufficient cooling convection through the reactor ducts during conditions of consistent crosswinds. Generally, the ventilation clearance will be less than the magnetic clearance requirements and, as such, it will not prove to be a limiting factor when installing the unit. Irrespective of this fact, it is still important to recognize that there is a requirement for sufficient ventilation and the blockage of the cooling ducts with any foreign material, metallic or non-metallic, or interference with normal convective airflow must be avoided.

Magnetic clearance requirements arise since dry-type air-core reactors have no iron core to capture the magnetic field. However, since continuous kVA ratings and hence continuous stray magnetic fields of neutral grounding reactors are relatively small, electrical clearances are usually greater than magnetic clearances. Nevertheless, during conditions when reactors carry thermal and mechanical peak currents, induced forces in large metallic objects or closed electrical loops near the reactors should be evaluated. Information regarding recommended magnetic clearances can usually be obtained from the equipment manufacturer and is often supplied on reactor outline drawings.

Neutral grounding reactors may also be mounted directly on transformer tanks. In this case, possible elevated ambient temperatures and the magnetic clearance required to the transformer tank need to be taken into consideration in the reactor design. Therefore, it is important that the reactor specification includes details regarding the reactor mounting site on the transformer tank, tank dimensions, and expected ambient temperature range at the location where the reactor is to be installed.

### 4.4 Mechanical considerations

Depending on the scope of supply, special attention should be given, by either the manufacturer or purchaser, to the interactive electromagnetic forces between the reactor and current carrying auxiliary parts (such as buswork) and between the reactor and bus or cable connections to the reactor. Support structure and bracing elements must be designed to resist the resultant loads.

As standard practice, unless otherwise specified, peak wind loads and seismic loads or other specified loading are typically assumed to act on a non-coincidental basis.

Reactors should be designed to facilitate lifting and should be provided with lifting eyes or similar devices to allow safe and rapid installation. Lifting and handling instructions should be clear and readily available.

## 4.5 Concrete foundation and mounting

Foundation and mounting requirements are a function of the rating (hence the mass of the reactor) and the dimensions of the supporting structure. To design the foundation, the design engineer will need the anchor bolt layout and an overall outline showing device dimensions and the centers of gravity. The foundation must consider wind, ice, and seismic loading along with the specific soil conditions. Most neutral grounding reactors can be mounted with no special precautions other than clearance considerations.

## 4.6 Service conditions

Service conditions shall be in accordance with 4.1 of IEEE Std C57.16-2011.

## 4.7 Basis for rating

### 4.7.1 Conditions

Ratings for neutral grounding reactors are based on standard operating conditions and shall include the following:

- a) Service (indoor or outdoor)
- b) Current
- c) Voltage
- d) Frequency
- e) Time
- f) Basic impulse insulation level (BIL) and insulation class
- g) Circuit voltage of system

### 4.7.2 Rated current

#### 4.7.2.1 Rated thermal current

Unless otherwise specified, the basis for this rating shall be the thermal current. This will be the current through the neutral grounding reactor during a worst-case ground-fault condition.

Implicit in the thermal current rating is an associated continuous current that, unless otherwise specified, shall bear the following relationship to the thermal current rating as shown in Table 1.

**Table 1—Continuous duty in percent of thermal current rating for neutral grounding reactors**

| Rated time    | Continuous duty in percent of thermal current rating (%) |
|---------------|----------------------------------------------------------|
| 10 s          | 3                                                        |
| 1 min         | 7                                                        |
| 10 min        | 30                                                       |
| Extended time | 30                                                       |

Where there is a third harmonic component of current, it shall not exceed 15% of the rated continuous duty current (see IEEE Std C57.110).

#### 4.7.2.2 Short-circuit current—asymmetrical

Neutral grounding reactors shall be able to withstand, without mechanical failure, forces associated with the asymmetrical peak current. This peak current shall be determined from Equation (1):

$$I_C = KI_T \quad (1)$$

where

- $I_C$  is the crest of the initial offset current, peak asymmetrical
- $K$  is the appropriate multiplier obtained from Table 2 or calculated with Equation (2)
- $I_T$  is the thermal current rating, rms symmetrical

$$K = \left\{ 1 + e^{-\left(\phi + \frac{\pi}{2}\right)\frac{r}{x}} \sin \phi \right\} \sqrt{2} \quad (2)$$

where

- $\phi$  is the arc tan ( $x/r$ ), (radians)
- $e$  is the base of natural logarithm
- $x/r$  is the ratio of ohms reactance to ohms resistance in the system when the short-circuit occurs

When sequence impedances for the system are not specified, the ratio  $x/r$  shall be taken to be the ratio of ohms reactance to ohms resistance in the winding of the neutral grounding reactor through which the current flows. When the system to which the neutral grounding reactor is connected has an  $x/r$  ratio at that point which is greater than 10, the ohmic values of sequence impedances should be specified. When specified, the manufacturer shall combine them with the  $X$  and  $R$  of the neutral grounding reactor to determine the value of  $K$  to be used in calculating  $I_C$ .

When neutral grounding reactors are located on or near generator or motor buses, sub-transient impedances shall be utilized in calculating system  $x/r$  ratios.

$K$  can be calculated using Equation (2); however, it is important to note that the expression for  $K$  is an approximation. The tabulated values for  $K$  given in Table 2 are calculated from this approximation and are accurate to within 0.7% of the values calculated by exact methods.

**Table 2—Values of  $K$  for Equation (2) for neutral grounding reactors**

| $r/x$ | $x/r$   | $K$   |
|-------|---------|-------|
| 0.001 | 1000.00 | 2.824 |
| 0.002 | 500.00  | 2.820 |
| 0.003 | 333.00  | 2.815 |
| 0.004 | 250.00  | 2.811 |
| 0.005 | 200.00  | 2.806 |
| 0.006 | 167.00  | 2.802 |
| 0.007 | 143.00  | 2.798 |
| 0.008 | 125.00  | 2.793 |
| 0.009 | 111.00  | 2.789 |
| 0.010 | 100.00  | 2.785 |
| 0.020 | 50.00   | 2.743 |
| 0.030 | 33.30   | 2.702 |
| 0.040 | 25.00   | 2.662 |
| 0.050 | 20.00   | 2.624 |
| 0.060 | 16.70   | 2.588 |
| 0.070 | 14.30   | 2.552 |
| 0.080 | 12.50   | 2.518 |
| 0.090 | 11.10   | 2.484 |
| 0.100 | 10.00   | 2.452 |
| 0.200 | 5.00    | 2.184 |
| 0.300 | 3.33    | 1.990 |
| 0.400 | 2.50    | 1.849 |
| 0.500 | 2.00    | 1.746 |
| 0.600 | 1.67    | 1.669 |
| 0.700 | 1.43    | 1.611 |
| 0.800 | 1.25    | 1.568 |
| 0.900 | 1.11    | 1.534 |
| 1.000 | 1.00    | 1.509 |

#### 4.7.2.3 Maximum mechanical stress of neutral grounding reactors for short-circuit conditions

For determination of maximum mechanical stresses, the initial thermal current shall be assumed to be offset. In a system with zero damping the maximum crest value of the short-circuit current is two times the crest value of the rms symmetrical thermal current. However, in reality the value is lower due to system damping effects.

The first cycle asymmetrical peak current that the reactor is required to withstand shall be specified by the purchaser or based on knowledge of system damping, and can be determined as described in 4.7.2.2. If not

specified by the purchaser, the maximum asymmetrical crest value of short-circuit current should be considered to be 2.55 times the rms symmetrical current. The 2.55 value for the asymmetry factor  $K$  is based on a dc offset of 1.8 versus the theoretical maximum value of 2.0, i.e.,  $K = 1.8 \times \sqrt{2} = 2.55$ .

#### 4.7.3 Rated voltage

The rated voltage shall be taken as the product of the rated thermal current and the impedance of the neutral grounding reactor at rated frequency and at 30 °C.

A neutral grounding reactor consisting of tapped sections or sections connected in series may have a rated voltage for each section determined from the impedance and the rated thermal current of the section as above.

#### 4.7.4 Rated frequency

The rated frequency shall be the fundamental power frequency.

#### 4.7.5 Rated time

Rated time for the duration of the rated thermal current shall be 10 seconds, 1 minute, 10 minutes, extended time, or another duration as specified. Extended-time operation shall not exceed an average of 90 days per year.

### 4.8 Insulation levels

#### 4.8.1 Insulation classes

All apparatus covered by this standard shall be assigned basic impulse insulation levels (BIL) and/or insulation class designations.

**Table 3—Insulation classes for neutral grounding reactors**

| Insulation class                             |                                     |                |
|----------------------------------------------|-------------------------------------|----------------|
| System insulation class <sup>a</sup><br>(kV) | Fault voltage criteria <sup>b</sup> |                |
| Class<br>Column 1                            | kV<br>Column 2                      | kV<br>Column 3 |
| 1.2                                          | 1.2                                 | 1.2            |
| 2.5                                          | 2.5                                 | 2.5            |
| 5.0                                          | 5.0                                 | 5.0            |
| 8.7                                          | 8.7                                 | 8.7            |
| 15.0                                         | 8.7                                 | 8.7            |
| 23.0                                         | 15.0                                | 8.7            |
| 34.5                                         | 25.0                                | 8.7            |
| 46.0                                         | 34.5                                | 15.0           |
| 69.0                                         | 46.0                                | 15.0           |
| 115.0                                        | 69.0                                | 15.0           |
| 138.0                                        | 92.0                                | 15.0           |
| 161.0                                        | 92.0                                | 15.0           |
| 230.0                                        | 138.0                               | 15.0           |

NOTE 1—Once the insulation class value has been determined, the same value of rated system voltage can be identified in Table 4. From this table the appropriate dielectric test voltages can be chosen.<sup>10</sup>

NOTE 2—For system voltages above 230 kV, fault voltage criteria have not been established for determining appropriate reduced insulation classes.

<sup>a</sup>Where the insulation class for the terminal of a reactor is specified to be the system insulation class, the nominal system insulation level shall apply except that reduced BIL may be used where appropriate.

<sup>b</sup>When the fault voltage criterion applies, the maximum rms voltage that may exist between the terminal and ground, under fault conditions, is determined. If this fault voltage is less than or equal to the value in Column 2 but is greater than the value in Column 3 corresponding to the system insulation class in Column 1, the system insulation class at the terminal in question shall be the value in Column 2. If the fault voltage is less than or equal to the value in Column 3, the system insulation class at the terminal in question shall be the value in Column 3. If the fault voltage exceeds the value in Column 2 the system insulation class at the terminal in question shall be the value in Column 1.

The line end and ground end insulation levels shall be selected from Table 3 on the basis of fault voltage criteria, Column 2 and Column 3.

Insulation levels for dry-type air core neutral grounding reactors are provided in Table 4. The nominal system voltage values in Table 4 are used as reference numbers and do not imply relation to operating voltages.

For system voltages greater than 34.5 kV, the turn to turn test is not applicable and a full wave impulse test is to be performed as a routine test.

In the case of neutral grounding reactors the BIL across the coil may be different than the BIL across the support insulators (to ground). The purchaser shall specify if the BIL across the coil or support insulators is to be at a reduced level. Such a decision should be based on factors such as knowledge of the system characteristics and protection practices. Reduced BIL levels shall be selected from the standard values in Table 4.

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

**Table 4—Insulation test levels for neutral grounding reactors**

| Column 1<br>Rated system<br>voltage<br>(kV) <sup>a</sup> | Column 2<br>BIL and full<br>wave test <sup>b,g</sup><br>(kV peak) | Column 3<br>Chopped –<br>wave test <sup>c</sup><br>(kV peak) | Column 4<br>Time to<br>chopping<br>(μs) | Column 5<br>Switching<br>impulse test <sup>d</sup><br>(kV peak) | Column 6<br>Turn-to-turn<br>test voltage <sup>e</sup><br>(kV peak) | Column 7<br>Power frequency<br>withstand test <sup>f</sup><br>(kV rms) |
|----------------------------------------------------------|-------------------------------------------------------------------|--------------------------------------------------------------|-----------------------------------------|-----------------------------------------------------------------|--------------------------------------------------------------------|------------------------------------------------------------------------|
| 1.2                                                      | 30                                                                | 33                                                           | 1.0                                     | —                                                               | 25                                                                 | 10                                                                     |
|                                                          | 45                                                                | 50                                                           | 1.5                                     | —                                                               | 38                                                                 | 10                                                                     |
| 2.5                                                      | 45                                                                | 50                                                           | 1.5                                     | —                                                               | 38                                                                 | 15                                                                     |
|                                                          | 60                                                                | 66                                                           | 1.5                                     | —                                                               | 51                                                                 | 15                                                                     |
| 5.0                                                      | 60                                                                | 66                                                           | 1.5                                     | —                                                               | 51                                                                 | 19                                                                     |
|                                                          | 75                                                                | 83                                                           | 1.5                                     | —                                                               | 64                                                                 | 19                                                                     |
| 8.7                                                      | 75                                                                | 83                                                           | 1.5                                     | —                                                               | 64                                                                 | 26                                                                     |
|                                                          | 95                                                                | 105                                                          | 1.8                                     | —                                                               | 81                                                                 | 26                                                                     |
| 15                                                       | 95                                                                | 105                                                          | 1.8                                     | —                                                               | 81                                                                 | 34                                                                     |
|                                                          | 110                                                               | 120                                                          | 2.0                                     | —                                                               | 94                                                                 | 34                                                                     |
| 25                                                       | 150                                                               | 165                                                          | 3.0                                     | —                                                               | 128                                                                | 50                                                                     |
| 34.5                                                     | 200                                                               | 220                                                          | 3.0                                     | —                                                               | 170                                                                | 70                                                                     |
| 46                                                       | 200                                                               | 220                                                          | 3.0                                     | —                                                               | —                                                                  | 95                                                                     |
|                                                          | 250                                                               | 275                                                          | 3.0                                     | —                                                               | —                                                                  | 95                                                                     |
| 69                                                       | 250                                                               | 275                                                          | 3.0                                     | —                                                               | —                                                                  | 140                                                                    |
|                                                          | 350                                                               | 385                                                          | 3.0                                     | —                                                               | —                                                                  | 140                                                                    |
| 115                                                      | 350                                                               | 385                                                          | 3.0                                     | 291                                                             | —                                                                  | 173                                                                    |
|                                                          | 450                                                               | 495                                                          | 3.0                                     | 375                                                             | —                                                                  | 173                                                                    |
|                                                          | 550                                                               | 605                                                          | 3.0                                     | 450                                                             | —                                                                  | 173                                                                    |
| 138                                                      | 450                                                               | 495                                                          | 3.0                                     | 375                                                             | —                                                                  | 207                                                                    |
|                                                          | 550                                                               | 605                                                          | 3.0                                     | 460                                                             | —                                                                  | 207                                                                    |
|                                                          | 650                                                               | 715                                                          | 3.0                                     | 540                                                             | —                                                                  | 207                                                                    |
| 161                                                      | 550                                                               | 605                                                          | 3.0                                     | 460                                                             | —                                                                  | 242                                                                    |
|                                                          | 650                                                               | 715                                                          | 3.0                                     | 540                                                             | —                                                                  | 242                                                                    |
|                                                          | 750                                                               | 825                                                          | 3.0                                     | 620                                                             | —                                                                  | 242                                                                    |
|                                                          | 825                                                               | 900                                                          | 3.0                                     | 685                                                             | —                                                                  | 242                                                                    |
| 230                                                      | 750                                                               | 825                                                          | 3.0                                     | 620                                                             | —                                                                  | 345                                                                    |
|                                                          | 825                                                               | 900                                                          | 3.0                                     | 685                                                             | —                                                                  | 345                                                                    |
|                                                          | 900                                                               | 990                                                          | 3.0                                     | 745                                                             | —                                                                  | 345                                                                    |
| 345                                                      | 1050                                                              | 1155                                                         | 3.0                                     | 870                                                             | —                                                                  | 518                                                                    |
|                                                          | 1175                                                              | 1290                                                         | 3.0                                     | 975                                                             | —                                                                  | 518                                                                    |
| 500                                                      | 1425                                                              | 1570                                                         | 3.0                                     | 1180                                                            | —                                                                  | 750                                                                    |
|                                                          | 1550                                                              | 1705                                                         | 3.0                                     | 1290                                                            | —                                                                  | 750                                                                    |
|                                                          | 1675                                                              | 1845                                                         | 3.0                                     | 1390                                                            | —                                                                  | 750                                                                    |
| 735                                                      | 1950                                                              | 2145                                                         | 3.0                                     | 1550                                                            | —                                                                  | 830                                                                    |
| 765                                                      | 2050                                                              | 2255                                                         | 3.0                                     | 1700                                                            | —                                                                  | 880                                                                    |

<sup>a</sup>A reduced insulation level may be applied across reactor terminals if the reactor is adequately protected by a surge arrester. This could be an economical engineering solution for some neutral grounding reactors. For such cases, the insulation level across the reactor shall be one of the above standardized levels and shall be at least 1.25 times the  $8 \times 20 \mu\text{s}$ , 10 kA protective level of the surge arresters connected between terminals.

<sup>b</sup>Alternate BIL test values are provided for each value of rated system voltage to reflect current practices by various users.

<sup>c</sup>Chopped-wave test level is defined as  $1.1 \times \text{BIL test level}$ ; including the appropriate “round off.”

<sup>d</sup>Switching impulse test is applicable to the support insulator only and are defined for nominal system voltages 230 kV and higher.

<sup>e</sup>Turn-to-turn test levels are defined for BIL equal to or less than 200 kV. Turn-to-turn test levels are defined to be approximately 90% of the rated BIL across reactor terminals. For BIL voltages greater than 200 kV, the turn-to-turn test is not applicable and a full-wave impulse test is to be performed as a routine test. Although the WG considered extending the turn-to-turn test up to BIL equal to or less than 550 kV, it was decided not to include test values in Table 4 as fully commercialized test equipment was not readily available or fully proven. However, the option remains to employ a turn-to-turn test at higher BILs based on a crest voltage of approximately 85% of BIL. Performance of the turn-to-turn test in lieu of the impulse test would be based on the availability of test equipment and agreement between the manufacturer and the purchaser.

<sup>f</sup>Power frequency withstand test is applicable to the support insulator only.

<sup>g</sup>For reactors installed indoors the purchaser may specify a reduced BIL.

## 4.8.2 Impulse insulation levels

The standard impulse insulation levels for neutral grounding reactors are given in Table 4, Column 2. These values are expressed in terms of the crest value of a  $1.2 \times 50$  microsecond full wave.

## 4.9 Limiting temperature rises

### 4.9.1 Temperature limitations at rated continuous current

The inherent continuous current capability for a given rated thermal current is given in 4.7.2.1, Table 1.

Table 5 provides average and hottest-spot temperature rises for various insulation systems for the designed continuous current rating of a neutral grounding reactor.

**Table 5—Limits of temperature rise at continuous rated current for neutral grounding reactors**

| Item | Insulation materials, thermal classification <sup>b, c</sup> (°C)                                                                                                                       | Average winding temperature rise by resistance <sup>a, d, e</sup> (°C) | Hottest-point winding temperature rise <sup>a, d</sup> (°C) |
|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|-------------------------------------------------------------|
| 1    | 105                                                                                                                                                                                     | 55                                                                     | 85                                                          |
|      | 130                                                                                                                                                                                     | 80                                                                     | 110                                                         |
|      | 155                                                                                                                                                                                     | 100                                                                    | 135                                                         |
|      | 180                                                                                                                                                                                     | 115                                                                    | 160                                                         |
|      | 220                                                                                                                                                                                     | 140                                                                    | 200                                                         |
| 2    | Metallic parts in contact with or adjacent to the insulation shall not attain a temperature in excess of that allowed for the hottest spot of the windings adjacent to that insulation. |                                                                        |                                                             |
| 3    | Metallic parts other than those covered in Item 2 shall not attain excessive temperature rises.                                                                                         |                                                                        |                                                             |

<sup>a</sup>Temperature rise is rise above ambient in degrees Celsius.

<sup>b</sup>A reactor with a specified temperature rise shall have an insulation temperature index that has been proven by experience or testing.

<sup>c</sup>The insulation temperature index in Table 5 is supplied as a reference and is based on the preferred temperature index for insulation materials as defined in IEEE Std 1-2000. It should be noted that the preferred temperature index is the lowest value in a number range (of temperatures) into which insulation materials can be placed. This results in an element of conservatism in the thermal performance of an insulation system and thus constitutes part of the experience factors in assigning temperature rise limits.

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

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

#### 4.9.2 Temperature limitations under short-circuit conditions

The temperature, as calculated by methods given in IEEE Std C57.16-2011, 11.7, of the conductor material in the windings of reactors under the short-circuit conditions specified in 4.7.2 shall not exceed the limiting values given in Table 6.

**Table 6—Limiting temperature for rated short-time current for neutral grounding reactors**

| Insulation temperature index (°C) | Actual limiting temperature (°C) |
|-----------------------------------|----------------------------------|
| 105                               | 205                              |
| 130                               | 285                              |
| 155                               | 315                              |
| 180                               | 350                              |
| 220                               | 400                              |

The limiting temperatures in Table 6 are upper bounds based on the known capabilities of available materials. The actual limit used on design must be modified based on the winding insulation and encapsulation materials utilized.

#### 4.10 Routine, design, and other tests for neutral grounding reactors

Routine, design, and other tests for neutral grounding reactors are listed in Table 7.

General test information is provided in 4.10 to 4.16. Further details regarding reactor testing may be obtained in IEEE Std C57.16-2011.

**Table 7—Routine, design, and other tests for neutral grounding reactors**

| Tests:                                                                                                                                         | Test classification |        |       |
|------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|--------|-------|
|                                                                                                                                                | Routine             | Design | Other |
| Resistance measurement: The dc resistance measurement shall be made on the full winding.                                                       | X                   |        |       |
| Impedance measurement: The impedance measurement shall be made on the full winding.                                                            | X                   |        |       |
| Total loss measurement: Total losses to be measured on all units.                                                                              | X                   |        |       |
| Temperature rise test: This test is performed on one unit out of a number of units of the same design.                                         |                     | X      |       |
| Power frequency withstand test: The power frequency withstand test 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 test:<br>— Nominal system voltage greater than 34.5 kV.<br>— Nominal system voltage at or below 34.5 kV only when specified. | X                   |        | X     |
| Chopped wave impulse test: The chopped wave impulse test shall be made only when specified.                                                    |                     |        | X     |
| Seismic verification test: Test performed only when specified.                                                                                 |                     |        | X     |
| Short circuit test: Test performed only when specified.                                                                                        |                     |        | X     |

## 4.11 Dielectric tests

Dielectric tests apply a higher than rated voltage for a specified time to determine the adequacy of insulating materials and spacing with respect to the specified insulation levels.

### 4.11.1 Turn-to-turn overvoltage test

The turn-to-turn test for dry-type air-core neutral grounding reactors shall be made by applying between the terminals of each winding a series of high frequency, exponentially decaying sinusoidal voltages. The test sequence shall consist of a reduced sinusoidal voltage discharge followed by 7200 sinusoidal voltage discharges with a first peak voltage at least equal to the values specified in Column 6 of Table 4. The duration of the test is not to exceed 60 s.

Further details regarding the turn to turn overvoltage test are provided in 11.3.5 of IEEE Std C57.16-2011.

### 4.11.2 Impulse tests

For dry-type air-core neutral grounding reactors a lightning impulse test shall be made on each terminal of the reactor by applying a reduced wave and three full waves, all of positive polarity with crest voltages as specified in Table 4, Column 2.

A chopped wave impulse test shall be made on each terminal of the reactor, when specified, by applying one reduced full wave, one full wave, two chopped waves, followed by two full waves (preferably within ten minutes after the last chopped wave), with crest voltage as shown in Table 4, Column 3 and time to chopping as shown in Table 4, Column 4.

A reduced BIL may be specified to be applied at the reactor ground terminal.

Further details regarding the impulse test are provided in 11.3.6 of IEEE Std C57.16-2011.

### 4.11.3 Power frequency withstand voltage test

For dry-type air-core neutral grounding reactors, a power frequency withstand test shall be made, when specified, on the reactor's supporting structure, including insulators. Test values are those indicated in Column 7 of Table 4. This test shall be made at the test voltage corresponding to the insulation class assigned to the ground end.

Further details regarding the power frequency withstand voltage test (applied-voltage test) are provided in 11.3.3 of IEEE Std C57.16-2011.

## 4.12 Temperature rise test

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

When the available test power does not permit making the test at rated current, then the manufacturer shall demonstrate to the purchaser that reduced current testing produces sufficiently accurate results when