A-09-03
A-39-13

IEEE STD 32-1972
25 March 1988

ADOPTION NOTICE

This non-Government document was adopted on 25 March 1988 and is approved for use by the DOD. The indicated industry group has furnished the clearance required by existing regulations. Copies of the document are stocked by DOD Single Stock Point, Naval Publications and Forms Center, Philadelphia, PA 19120, for issue to DOD activities only. Contractors and industry groups must obtain copies from IEEE, 345 E. 47th Street New York, NY 10017.

Title of Document: IEEE Standard Requirements for Terminology, and Test Procedure for Neutral Grounding Devices

Date of Specific Issue Adopted: March 21, 1972

Releasing Industry Group: Institute of Electrical and Electronics Engineers, Inc.

Custodians:
Army - ME
Navy - YD

Military Coordinating Activity:
Navy - YD

(Project 6110-0307)

Review Activity:
DLA - GS

AMSC N/A

FSC 6110

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

THIS DOCUMENT CONTAINS 1 PAGES.

144-00-022

IEEE Standard
Requirements, Terminology, and Test Procedure for Neutral Grounding Devices

September 20, 1972

THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, Inc.

IEEE
Std 32-1972

IEEE Standard
Requirements, Terminology, and Test Procedure for Neutral Grounding Devices

Sponsor

Surge Protective Devices Committee of the IEEE Power Engineering Society

Approved March 21, 1972

IEEE Standards Committee

Foreword

This standard is a revision of AIEE Standard 32, 1947, to which many changes and additions have been made.

This standard was developed by the Neutral Grounding Subcommittee of the Surge Protective Devices Committee of the IEEE Power Engineering Society. The membership of the Subcommittee is as follows:

N. Stadtfeld, Jr, *Chairman*

G. G. Auer
L. B. Crann
G. S. Haralampu
P. F. Hargreaves
D. W. Jackson
I. B. Johnson
J. L. Koepfinger
F. R. Licini
J. A. McKinley
D. E. Orten
W. J. Vandergrift

G. G. Auer was Chairman of the Subcommittee during the bulk of the period of preparation of this issue. Others who took part are as follows:

E. W. Boehne
G. D. Breuer
L. V. Devine
J. B. Hays
C. C. Jones
J. C. Russ
L. E. Sauer

When the Surge Protective Devices Committee of the IEEE Power Engineering Society reviewed and approved this document, it had the following membership:

A. G. Yost, ***Chairman***

I. B. Johnson, ***Vice Chairman*** **W. R. Ossman,** ***Secretary***

D. L. Andrews
S. A. Annestrand
J. J. Archambault
G. G. Auer
R. D. Ball
G. A. Baril
F. G. Berg
E. W. Bochne
P. W. Bogner
G. D. Breuer
L. B. Crann
W. H. Eason
H. E. Foelker
G. L. Gaibrois
R. S. Gens
G. S. Haralampu
A. R. Hileman
D. W. Jackson
S. S. Kershaw, Jr
J. L. Koepfinger
F. R. Licini
H. Linck
D. J. Melvold
B. D. Miller
V. B. Nolan
J. D. M. Phelps
R. W. Powell
W. S. Price
R. E. Seabrook
J. W. Simpson
N. Stadtfeld, Jr
M. W. Stoddart
H. L. Thwaites
A. C. Westrom

Contents

SECTION		PAGE
1.	General	7
1.1	Scope	7
1.2	Service Conditions	7
1.3	Operation at Altitudes in Excess of 1000 Meters (3300 Feet)	7
2.	Basis for Rating	8
2.1	Conditions	8
2.2	Rated Current	8
2.3	Rated Voltage	8
2.4	Rated Frequency	9
2.5	Rated Time	9
3.	Insulation Classes and Dielectric Withstand Levels	9
3.1	Basic Impulse Insulation Levels and Insulation Classes	9
3.2	Dielectric Withstand Test Levels	10
3.3	Protective Devices	10
4.	Temperature Limitations	10
4.1	Limits	10
4.2	Steady-State Temperature Rises	10
4.3	Rated-Time Temperature Rises	10
5.	Tests	10
5.1	Routine Tests	10
5.2	Dielectric Tests	14
5.3	Losses and Impedance	15
6.	Construction	16
6.1	Bushings, Insulators, and Oil	16
6.2	Nameplates	16
6.3	Tanks and Enclosures	16
7.	Reactors	16
7.1	Insulation Levels	16
7.2	Dielectric Tests	16
8.	Ground-Fault Neutralizers	17
8.1	Insulation Levels	17
8.2	Dielectric Tests	17
9.	Grounding Transformers	17
9.1	Insulation Levels	17
9.2	Dielectric Tests	17
10.	Resistors	18
10.1	Resistor Element	18
10.2	Insulation Levels	18
10.3	Dielectric Tests	19
11.	Capacitors	19
11.1	Insulation Levels	19
11.2	Dielectric Tests	19
12.	Combination Devices	19
12.1	Insulation Levels	19
12.2	Dielectric Tests	19

SECTION PAGE

13. Definitions and Terminology 19

14. Test Code 24
 14.1 Resistance Measurements 24
 14.2 Dielectric Tests 25
 14.3 Impedance and Loss Measurements 28
 14.4 Temperature-Rise Tests 30
 14.5 Temperature-Rise Calculations 33

TABLES

Table 1 Dielectric Strength Correction Factors for Standard Devices at Altitudes Greater Than 1000 Meters (3300 Feet) 8

Table 2 Maximum Allowable Average Temperature, Degrees Celsius of Cooling Air for Carrying Rated Current 8

Table 3 Value of K for Eq 1 9

Table 4 Insulation Classes for Neutral Grounding Devices 9

Table 5 Dielectric Test Voltage and Time to Test-Gap Flashover 11

Table 6 Limiting Temperature Rises Above Ambient for Current-Carrying Parts- Neutral Devices 12

Table 7 Time Factor Multiplier M for Use in Equation in Table 6 14

Table 8 Limits of Top Oil Temperature Rise 14

Table 9 Classes of Insulating Materials 22

Table 10 Metric and English Thermal Calculation Nomenclature 34

FIGURES

Fig 1 Connections for the Drop-of-Potential Method of Resistance Measurement 25

Fig 2 Connections for Impedance Voltage and Impedance Loss Tests 29

IEEE Standard Requirements, Terminology, and Test Procedure for Neutral Grounding Devices

1. General

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, capacitors, or combinations of these.

1.2 Service Conditions.

1.2.1 ***Usual Temperature and Altitude Service Conditions.*** Devices conforming to this standard shall be suitable for operation at their ratings provided that:

(1) The temperature of the cooling air (ambient temperature) does not exceed 40°C and the average temperature of the cooling air for any 24-hour period does not exceed 30°C.

NOTE: 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 temperatures may be used. The value which is obtained in this manner is usually slightly higher than the true daily average but not by more than ½°C.

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

1.2.2 ***Unusual Temperature and Altitude Service Conditions.*** Devices conforming to this standard may be applied to higher ambient temperatures or at higher altitudes than specified in 1.2.1, but their performance will be affected and special consideration should be given to these applications.

1.2.3 ***Other Unusual Service Conditions.*** Where unusual conditions other than those discussed in 1.2.2 exist, they should be brought to the attention of those responsible for the design and application of the equipment. Examples of such conditions are:

(1) Exposure to damaging fumes, radiation, or vapors; excessive abrasive or magnetic dust; explosive mixtures of dust, vapors, or gases; steam, excessive moisture, dripping water, fog or spray; salt or acid; etc.

(2) Abnormal vibration, shock, or tilting from earthquakes or other causes.

(3) Unusual transportation or storage conditions.

(4) Unusual space limitations.

(5) Abnormal operating duty, frequency of operation, difficulty of maintenance, poor waveform, excessive unbalance voltage, special insulation requirements, lack of normal lightning arrester protection, unusual magnetic shielding problems, harmonics in excess of or other than those expressed in Note of Section 2.2.

NOTE: Unless an air-core reactor is fully shielded magnetically, consideration should be given to its location relative to other apparatus and to metallic structures which may suffer overheating due to stray fields and mechanical damage under fault conditions.

(6) System having a ratio of reactance to resistance *X/R* greater than 10. See Section 2.2.

1.3 Operation at Altitudes in Excess of 3300 ft (1000 m). Standard devices may be applied in locations having an altitude in excess of 3300 ft (1000 m), but the dielectric strength of air-insulated parts and the current-carrying capacity will be affected.

1.3.1 ***Insulation.*** The dielectric strength of air-insulated parts of a given insulation class at or above 3300 ft (1000 m) should be multiplied by the proper correction factor, as given in Table 1, to obtain the dielectric strength at the required altitude.

An altitude of 15 000 ft (4500 m) is considered a maximum for standard devices.

1.3.2 ***Operation at Rated Current.*** Devices with standard temperature rise may be used at rated current at altitudes greater than 3300 ft (1000 m) provided the average temperature of the cooling air does not exceed the values in Table 2 for the respective altitudes. Under these conditions, standard temperature limits will not be exceeded.

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

Altitude meters	Altitude feet	Factor for Correction
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	9900	0.80
3600	12 000	0.75
4200	14 000	0.70
4500	15 000	0.67

2. Basis for Rating

2.1 Conditions. Ratings for devices are based on standard operating conditions and shall include the following:

(1) Current
(2) Voltage
(3) Frequency
(4) Basic Impulse Insulation Level (BIL) and Insulation Class
(5) Circuit Voltage of System
(6) Service (Indoor or Outdoor)
(7) Time

2.2 Rated Current. Unless otherwise specified, the basis for this rating shall be the thermal current. This will be the current through the neutral device during a ground-fault condition at the device location.

Implicit in the thermal current rating is an associated continuous current which, unless otherwise specified, shall bear the following relationship to the thermal current rating:

Rated Time of Device	Continuous Duty Current in Percent of Thermal Current Rating: Reactors, Ground-Fault Neutralizers, and Transformers Used For Grounding	Continuous Duty Current in Percent of Thermal Current Rating: Resistors
10 s	3	0
1 min	7	0
10 min	30	0
Extended Time	30	0

NOTE: Where there is a third harmonic component of current, it shall not exceed 15 percent of the rated continuous duty current.

Devices shall be able to withstand, without mechanical failure, forces associated with the crest of the offset current wave, assuming subtransient reactance fault conditions. This current crest, for devices other than resistors, shall be determined from the following equation:

$$I_c = KI_T \qquad \text{(Eq 1)}$$

where

I_c = Crest of the initial offset current
K = Multiplier from Table 3
I_T = Thermal current rating

2.3 Rated Voltage (see definition in Section 13). The rated voltage except for certain resistors (see 10.1.1) and grounding transformers

Table 2
Maximum Allowable Average Temperature,* Degrees Celsius of Cooling Air for Carrying Rated Current

Methods of Cooling Apparatus	3300 ft (1000 m)	6600 ft (2000 m)	9900 ft (3000 m)	13 200 ft (4000 m)
Oil-Immersed Self-Cooled	30	28	25	23
Dry-Type Self-Cooled				
55 °C rise	30	27	24	21
80 °C rise	30	26	22	18
150 °C rise	30	22	15	7
Resistors	30	3	—14	—25

*For recommended calculation of average temperature, see Note in 1.2.1.

Table 3
Value of *K* for Eq 1

X/R	*K*	*X/R*	*K*	*X/R*	*K*
1000	3.390	28	3.215	13	3.026
250	3.379	24	3.186	12	3.000
100	3.342	20	3.148	11	2.970
65	3.312	18	3.121	10 or less	2.940
45	3.278	16	3.089		
34	3.245	15	3.070		

NOTE:

$$K = 1.2 \left\{1 + \exp\left[-\pi (R/X)\right]\right\} \sqrt{2}$$

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 (dc) in the winding of the device through which the current flows.

When the system to which the neutral device 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 device to determine the value of K to be used in calculating I_c. The 1.2 factor is based on use of transient reactance in calculating thermal current.

(see 9.2.3), shall be taken as the product of the rated thermal current and the impedance of the device at rated frequency and at 25 °C.

A device 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.

2.4 Rated Frequency (see definition in Section 13). The rated frequency shall be the fundamental, except that for some devices such as neutral wave traps, the rating may include additional harmonic frequencies which the device is designed to control.

2.5 Rated Time (see definition in Section 13). Rated time shall be 10 seconds, 1 minute, 10 minutes, and extended time. Extended-time operation shall not exceed an average of 90 days per year.

3. Insulation Classes and Dielectric Withstand Levels

3.1 Basic Impulse Insulation Levels and Insulation Classes (see definition in Section 13). All apparatus covered by this standard shall be assigned BIL (basic impulse insulation levels) and/or insulation class designations.

Table 4
Insulation Classes for Neutral Grounding Devices

Insulation Class			
System Insulation Class, kV (See Note 1)		Fault Voltage Criteria (See Note 2)	
Column 1	Column 2	Column 3	Column 4
Class	BIL	kV	kV
1.2	45	1.2	1.2
2.5	60	2.5	2.5
5.0	75	5.0	5.0
8.7	95	8.7	8.7
15.0	110	8.7	8.7
23.0	150	15.0	8.7
34.5	200	25.0	8.7
46.0	250	34.5	15.0
69.0	350	46.0	15.0
92.0	450	69.0	15.0
115.0	550	69.0	15.0
138.0	650	92.0	15.0
161.0	750	92.0	15.0
180.0	825	115.0	15.0
196.0	900	115.0	15.0
230.0	1050	138.0	15.0

NOTE 1: Where the insulation class for the terminal of a device is specified to be the system insulation class, the nominal system insulation level shall apply except that reduced BIL may be used where appropriate.

NOTE 2: 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 falls between the values in columns 3 and 4 corresponding to the system insulation class in column 1, the system insulation class at the terminal in question shall be the value in column 3 which equals or is next higher than the maximum fault voltage. If the fault voltage is less than the value in column 4, the system insulation class at the terminal in question shall be the value in column 4. If the fault voltage exceeds the value in column 3 the system insulation class at the terminal in question shall be the value in column 1.

Specific instructions for selecting the BIL and insulation class, and associated dielectric tests for a particular device, are covered in the section of the standard which is set aside for the device in question.

Reactors	Section 7
Ground-Fault Neutralizers	Section 8
Grounding Transformers	Section 9
Resistors	Section 10
Capacitors	Section 11
Combination Devices	Section 12

Basic impulse insulation levels and insulation class designations used with grounding devices are given in Table 4.

The two ends of the winding of a neutral device may be assigned different insulation levels.

3.2 Dielectric Withstand Test Levels. Applied-potential, induced-potential, and impulse test withstand levels are those given in Table 5. For duration and frequency of test, see 14.2.2.

3.3 Protective Devices. Suitable protective devices shall be provided whenever necessary to hold transient overvoltages at the terminals of a device to values within the limits set by the selected insulation levels.

4. Temperature Limitations

4.1 Limits. Steady-state and rated-time temperature rises for current-carrying parts, determined under standard operating conditions, shall not exceed the limits established in Table 6.

Top oil temperature rises determined under standard operating conditions shall not exceed the limits established in Table 8.

Parts, other than current-carrying parts, in contact with or adjacent to insulation or oil, shall not attain temperature rises in excess of those allowed for current-carrying parts. Other parts shall not attain temperatures that will be injurious to structures, or personnel, or produce excessive smoke or toxic fumes.

4.2 Steady-State Temperature Rises (see definition in Section 13). The steady-state average winding temperature rise shall be determined by routine test (see Section 5.1).

The steady-state hot-spot winding temperature rise T_{HS} shall be determined by design test.

4.3 Rated-Time Temperature Rises (see definition in Section 13).

4.3.1 ***Ten-Second and One-Minute Ratings.*** The rated-time temperature rise of 10-second and 1-minute devices is an average winding rise (except resistors, for which it is a hot-spot rise).

The rated-time temperature rise of 10-second and 1-minute devices shall be taken as the sum of the steady-state rise determined as in 4.2 and the additional rise caused by the flow of rated thermal current (or, for certain resistors, the application of rated voltage) for rated time, determined by calculation, using Eq 11 (for resistors, Eq 17).

4.3.2 ***Ten-Minute Ratings.*** The rated-time temperature rise of 10-minute devices is an average winding rise (except resistors, for which it is a hot-spot rise).

The rated-time temperature rise of 10-minute devices shall be taken as the winding rise above ambient resulting from the flow of rated thermal current (or, for certain resistors, the application of rated voltage) for 10 minutes starting with an initial temperature rise equal to the steady-state rise of the device.

The rated-time temperature rise of 10-minute devices shall be determined by routine test (Section 5.1).

4.3.3 ***Extended-Time Ratings*** (see definition in Section 13). The rated-time temperature rise of extended-time devices is an average winding rise (except resistors, for which it is a hot-spot rise).

The rated-time temperature rise of extended-time devices shall be taken as the ultimate rise above ambient resulting from the continued flow of rated thermal current (or, for certain resistors, the continued application of rated voltage).

The rated-time temperature rise of extended-time devices shall be determined by routine test (Section 5.1).

5. Tests

Unless otherwise specified, tests shall be made at the manufacturer's facilities.

5.1 Routine Tests (see definitions in Section 13). The following routine tests shall be made on all devices where feasible, except as covered in the section of the standard which is set aside for the device in question. The numbers shown do not necessarily indicate the sequence in which the tests shall be made. All tests shall be made in accordance with Section 14, Test Code.

(1) Resistance measurements of all windings on the rated voltage connection and taps or sections of each device

(2) Voltage measurements on the rated voltage connection and on all tap connections

(3) Polarity and phase relation tests on the rated voltage connection

Table 5
Dielectric Test Voltage and Time to Test-Gap Flashover

Insul-ation Class	Grounding Transformers, Ground-Fault Neutralizers & Reactors*														Resistors†	Capacitors		
	Impulse Tests							Applied Potential			Induced Potential				Applied Potential	Applied Potential		Induced Potential
	Chopped Wave*				Full Wave						Excluding Reactors	Reactors						
	Oil	Dry	Minimum Time to Flashover		Oil	Dry (Excluding Reactors)	Dry Reactors	Oil	Dry (Excluding Reactors)	Dry Reactors		Oil	Dry			Out-door	In-door	
			Oil	Dry									Out-door	In-door				
kV rms	kV crest		Microseconds		kV crest			kV rms			kV rms	kV crest	kV rms		kV rms	kV rms		kV rms
Col. 1	Column 2				Column 3			Column 4			Column 5				Column 6	Column 7		Column 8
1.2	54	10	1.5	1.0	45	10	45	10	4	10	Two Times Rated Voltage	45	13	10	5	10	5	Two Times Rated Voltage
2.5	69	20	1.5	1.0	60	20	60	15	10	19		60	25	19	7.5	15	10	
5.0	88	25	1.6	1.0	75	25	75	19	12	26		75	35	26	13.5	19	15	
8.7	110	35	1.8	1.0	95	35	95	26	19	36		95	48	36	22	26	22	
15	130	50	2.0	1.25	110	50	110	34	31	50		110	67	50	36	34	28	
18	145	-	2.25		125	-	125	40	40	-		125	-	-	-	40		
25	175	75	3		150	75	150	50	50	70		150	93	70	60	50		
34.5	230	105	3		200	105	200	70	70	95		200	127	95	80	70		
46	290	140	3		250	140	250	95	95			250				95		
60	345	-	3		300	-	300	120	120			300				120		
69	400	215	3		350	215	350	140	140			350				140		
92	520		3		450		450	185				450				185		
115	630		3		550		550	230				550				230		
138	750		3		650		650	275				650				275		
161	865		3		750		750	325				750				325		
180	950		3		825		825	360				825				360		
196	1035		3		900		900	395				900				395		
215	1120		3		975		975	430				975				430		
230	1210		3		1050		1050	460				1050				460		

*Dry-type reactors do not receive chopped-wave impulse test.
†For resistors made in sections, see 10.3.2.

Table 6
Limiting Temperature Rises Above 30°C Ambient for Current Carrying Parts—Neutral Devices*†

Column 1	Column 2	Column 3		Column 4		Column 5		Column 6		Column 7	
		55°C Oil-Immersed		55°C Dry-Type		80°C Dry-Type		150°C Dry-Type		Resistors	
										Temperature Rise, °C	
		Temperature Rise °C	Time Factor‡ seconds	Temperature Rise °C	Time Factor‡ seconds	Temperature Rise °C	Time Factor‡ seconds	Temperature Rise °C	Time Factor‡ seconds	Stainless Steel #	Cast Grid #
Steady State for Continuous Current Ratings	Steady State (Hot-Spot) Section 4.2	65		65		110		180		385	385
	Steady State (Average) Section 4.2	55		55		80		150		—	—
Rated Time for Thermal Current Ratings (rated voltage for certain resistors)	Extended-Time (Average) Section 4.3.3	75		75		110		200		610	385
	Ten-Minute (Average) Section 4.3.2	125		125		185		275		610	460
	Less than 10 Minutes (Average) Section 4.3.1	120	22 500	120	103 000	160	143 000	250	98 400	760	510
		125	15 000	130	53 300	170	86 700	260	63 000		
		130	9 000	140	30 000	180	53 700	270	41 000		
		135	6 700	150	16 700	190	33 300	280	26 600		
		140	4 300	160	9 330	200	21 000	290	18 000		
		145	3 000	170	5 330	210	13 700	300	12 000		
		150	2 100	180	3 330	220	9 170	310	8 340		
		155	1 500	190	2 000	230	6 170	320	5 670		
		160	1 030	200	1 270	240	4 170	330	4 000		
		165	733	210	767	250	2 830	340	2 800		
		170	517	220	500	260	1 970	350	1 968		
		180	270	230	333	280	967	360	1 434		
		190	143	240	257	300	500	380	750		
		200	77	250	150	320	277	400	406		
		210	40	260	103	340	157	420	243		
		220	25	270	73	360	94	440	140		
		230	15	280	50	380	61	460	84		
		240	8.8	300	26	400	34	480	51		
		250	5.3	320	14	420	22	500	32.4		
		260	3.3	340	7.7	440	14	520	20.5		

Notes to Table 6:

*The values in this table are based on the thermal aging characteristics of the insulation. Devices built to these thermal limits will have normal insulation life.

Other factors may limit temperature rises in specific designs. For example:

(1) The reduction in the mechanical strength and increase in elongation of copper at temperatures above 300°C and aluminum above 350°C.

(2) Gas evolution from insulation and oil adjacent to hot conductors.

(3) Auto-ignition of insulation or oil.

†No limits have been established for capacitors.

‡The time factor of a device for use in determining the limit of temperature rise shall be calculated as follows:

$$f = \frac{C\theta_1 M \text{ seconds}}{P}$$

$\theta_1 = 1.182\,\theta_2 - \theta_3$ for 55°C oil-immersed devices

$= 1.182\,\theta_2$ for 55°C dry-type devices

$= 1.373\,\theta_2$ for 80°C dry-type devices

$= 1.200\,\theta_2$ for 150°C dry-type devices

where

θ_1 = Steady-state hot-spot temperature rise at continuous current rating either above top oil temperature for oil-immersed equipment or above the ambient air temperature for dry-type equipment.

θ_2 = Average winding rise over ambient for rated continuous current under standard operating conditions

θ_3 = Top oil rise over ambient for rated continuous current under standard operating conditions

P = Specific power (watts per unit mass of conductor material)

C = Specific thermal capacitance (joules per degree Celsius unit mass) of conductor material and its associated insulation, as calculated in Eqs 13 and 14

M = Multiplier from Table 7.

NOTE: The values of both C and P shall be taken at the temperature corresponding to θ_1 and standard ambient conditions.

#The temperature rise limits for extended time, ten-minute or less rated resistors are hot-spot values.

Table 7
Time Factor Multiplier *M* for Use in Equation in Table 6

Oil-Immersed		Dry-Type					
55°C Rise		55°C Rise		80°C Rise		150°C Rise	
Steady-State Average Winding Rise	Multiplier *M*	Steady-State Average Winding Rise	Multiplier *M*	Steady-State Average Winding Rise	Multiplier *M*	Steady-State Average Winding Rise	Multiplier *M*
55	1.0	55	1.0	80	1.0	150	1.0
54	0.13	54	0.15	79	0.18	149	0.21
53	0.074	53	0.088	78	0.098	148	0.12
52	0.053	52	0.066	77	0.069	147	0.085
51	0.043	51	0.052	76	0.056	146	0.067
50	0.037	50	0.045	75	0.047	145	0.056
48	0.031	49	0.040	74	0.041	144	0.049
46	0.026	48	0.036	73	0.037	142	0.040
44	0.024	46	0.031	72	0.034	140	0.034
40	0.022	44	0.027	70	0.030	138	0.031
35	0.021	42	0.025	68	0.027	136	0.028
<30	0.020	40	0.024	66	0.025	134	0.026
		35	0.022	64	0.024	132	0.025
		30	0.021	62	0.023	130	0.024
		<25	0.020	60	0.022	128	0.023
				55	0.021	124	0.022
				<50	0.020	120	0.021
						<115	0.020

Table 8
Limits of Top Oil Temperature Rise

	Conservator or Inert Gas Cushion	No Conservator or Inert Gas Cushion
Steady-State	55°C	50°C
Extended-Time	55°C	50°C
Short-Time	60°C	55°C

(4) Excitation loss at rated voltage on the rated voltage connection

(5) Excitation current at rated voltage on the rated voltage connection

(6) Impedance voltage and power at rated current on rated connection of each device and the tap connections of one unit only of a given design

(7) Temperature test or tests shall be made on a device only if no record of a temperature test, made in accordance with these standards, on a duplicate or essentially duplicate design, is available

NOTE: This standard provides for using values calculated from tests at reduced currents.

(8) Dielectric tests

5.2 Dielectric Tests (see definition in Section 13). Dielectric tests shall consist of impulse tests (when required), followed by low-frequency applied-potential tests and induced-potential tests.

5.2.1 *Impulse Tests* (see definition in Section 13). The impulse test wave is a 1.2 × 50 microsecond wave, as described in Section 14.

(1) *Reduced Full-Wave Test.* For this test, the applied voltage wave shall have a crest value of 50 to 70 percent of the full-wave value given in Table 5.

(2) *Chopped-Wave Test.* For this test, the applied voltage wave shall have a crest voltage and time to flashover in accordance with Table 5. The chopped wave shall be obtained by flashover of an external rod gap.

(3) *Full-Wave Test.* For this test, the applied voltage wave shall have a crest value in accordance with Table 5.

The impulse test on a line terminal consists of one application of a reduced voltage full wave, two applications of a chopped wave, followed by one application of a full wave. Either, but not both, positive or negative waves may be used. Waves of negative polarity for oil-immersed devices and of positive polarity for dry-type or compound-filled devices are recommended. If, in testing oil-immersed devices, the atmospheric conditions at the time of test are such that the bushings will not withstand the specified polarity wave, then a wave of the opposite polarity may be used.

The impulse test on the neutral of a device, when brought out through a bushing, will consist of one reduced full wave and two full waves having a crest voltage for the insulation class of the neutral, provided the size of the neutral bushing pemits. This test on the netural will be made only when specifically called for.

If the insulation class of the highest voltage neutral bushing for which provision is made is different from the insulation class of the neutral end of the winding, the impulse test voltage will be for whichever insulation class is lower.

When applied directly to the neutral, the test waves shall be 1.2 × 50 microsecond waves. When induced in the neutral by the application of 1.2 × 50 microsecond waves to other terminals, the wave shape shall be that resulting from the characteristics of the winding. If the neutral ends of windings are specified for alternate or future connection as line terminals, standard tests shall be applied to the neutral as outlined above.

The foregoing paragraphs also apply to the terminals of the series devices to be located in the neutral. If the series windings have taps, tests should be made with maximum turns in the windings.

For impulse tests on devices of very low impedance, see Section 14.

When devices covered by this standard are to be assembled in a common tank and interconnected, the complete assembly shall be tested as a unit at 100 percent of the lowest test voltage required by any of the components.

5.2.2 *Applied-Potential Test* (See definition in Section 13). For devices designed so that either terminal of a winding can be used as the line terminal, the applied-potential test shall be made by applying between each winding and all other windings connected to ground a low-frequency voltage from an external source in accordance with Table 5.

For devices with reduced insulation at the neutral, the applied-potential test shall be made by applying between the winding and all other windings connected to ground a low-frequency voltage from an external source, in accordance with Table 5 based upon the insulation class of the neutral end.

All other dielectric circuits and metal parts shall be grounded during the test.

The duration of the applied-potential test shall be one minute.

5.2.3 *Induced-Potential Test* (see definition in Section 13). The induced-potential test for devices which receive the full standard applied-potential test shall be made by applying between the terminals of one winding a voltage of twice the normal voltage developed in the winding, unless this will produce a voltage between the terminals of any winding higher than the low-frequency test voltage specified in Table 5. In this case, the induced voltage developed between terminals of any winding shall be limited to the specified low-frequency test voltage for that winding.

If test conditions are such that the induced-potential test, if made as described in the previous paragraph, would not produce the voltage required therein between adjacent three-phase line terminals, the test shall be modified to produce this voltage.

For devices with reduced insulation at the neutral, when neither the applied-potential nor the induced-potential tests, if made as described above, would produce between line terminals and ground (not necessarily between line terminal and neutral) the low-frequency test voltage specified in Table 5, corresponding to the insulation class of the line end, then the induced-potential test shall be modified to produce this voltage.

The induced-potential test shall be applied for 7200 cycles if the frequency is 120 Hz or more. The duration shall be 60 seconds for frequencies less than 120 Hz.

5.3 Losses and Impedance. Excitation losses and exciting current shall be determined from the rated voltage and frequency on a sine-wave basis unless a different form is inherent in the operation of the apparatus.

Load losses shall be determined for rated voltage, or current, or both, and frequency, and shall be corrected to a reference temperature of 75°C.

6. Construction

6.1 Bushings, Insulators, and Oil. Bushings shall comply with IEEE Std 21-1964, Requirements and Test Code for Outdoor Apparatus Bushings (ANSI C76.1-1964 (R 1970)).

Insulator units shall comply with IEEE Std 324-1971, Definitions and Requirements for High-Voltage Air Switches, Insulators, and Bus Supports (ANSI C37.30-1970).

The dielectric strength of insulating oils when shipped shall be 30 kV minimum as measured by the standard methods of testing electrical insulating oils. See American National Standard Method of Testing Electrical Insulating Oils, C59.2-1970.

6.2 Nameplates. Nameplates of devices designed primarily as grounding devices shall have as a minimum amount of information the following:

1. Name of manufacturer
2. Serial number
3. Name of device
4. Type designation (if any)
5. Impedance (except resistors)
6. Number of phases
7. Temperature coefficient of resistance and resistance at 25°C (for resistors only)
8. Rated current

NOTES: (1) Initial value of current for neutral grounding resistors rated on constant voltage.
(2) When a neutral grounding device has more than one current-time rating, each rating shall appear on the nameplate.

9. Rated frequency
10. Rated time
11. Rated voltage
12. BIL of "line"
13. Indoor or outdoor service
14. Weight
15. Volume of oil
16. Instruction book number or equivalent

The nameplate shall be affixed to each device by the manufacturer. Unless otherwise specified, it shall be made of corrosion-resistant materials. On devices with one or more taps not brought out of the case, a diagram shall be included.

6.3 Tanks and Enclosures. Tanks where applicable shall be designed to withstand without permanent deformation a pressure 25 percent greater than the maximum operating pressures resulting from the system of insulation preservation or ventilation used. For tanks, the maximum operating pressures (positive and negative) for which the tank is designed shall be indicated on the rating plate.

Bolted or welded main cover construction shall be considered as alternate standards.

A pigment paint shall be used when surfaces are painted.

Tanks shall be designed for vacuum filling in the field on all current-limiting devices with 350 BIL or higher and all rated 2000 kVA equivalent or higher of any insulation level.

7. Reactors

7.1 Insulation Levels. The line end and ground end insulation levels shall be selected from Table 4 on the basis of fault voltage criteria, Columns 3 and 4.

7.2 Dielectric Tests. Dielectric test withstand levels shall be those listed in Table 5 for applicable insulation class, as follows:

Impulse chopped-wave test (oil-type only)	Column 2
Impulse full-wave test	Column 3
Applied-potential test	Column 4
Induced-potential test	Column 5

7.2.1 ***Impulse Tests.*** Reactors shall be designed to withstand impulse tests, but the impulse tests are required only when specified.

7.2.2 ***Applied-Potential Tests.*** Applied-potential tests are required. They shall be made at the test voltage corresponding to the insulation class assigned to the ground end if it is lower than the insulation class assigned to the line end. The external ground connection is removed for this test. If the ground end bushing is not capable of withstanding this test voltage, it is to be disconnected, and, if necessary, special insulation is to be provided for test purposes.

7.2.3 ***Induced-Potential Tests.*** Induced-potential tests are required. The ground end shall be connected to ground for this test. When taps are provided, the test shall be made on the tap which produces the highest voltage per turn in the winding and also on the connections having the greatest number of turns, but the voltage to ground at the line end shall not exceed the specified test voltage.

For dry-type reactors a voltage of suitable frequency having a crest value equal to the crest value of the voltage listed in Column 5, Table 5, shall be applied between the terminals of each winding.

For oil-immersed reactors, each line end and each ground end of the winding shall be tested by applying to the terminal one 50-percent, followed by two 100-percent full waves of the value given in Column 5, Table 5, for the voltage class in Column 1 corresponding to the voltage class of the winding being tested.

8. Ground-Fault Neutralizers

8.1 Insulation Levels. The line end and ground end insulation levels shall be selected from Table 4 on the basis of fault voltage criteria, Columns 3 and 4.

8.2 Dielectric Tests. Dielectric test withstand levels shall be those listed in Table 5 for applicable insulation class, as follows:

Impulse chopped-wave test	Column 2
Impulse full-wave test	Column 3
Applied-potential test	Column 4
Induced-potential test	Column 5

8.2.1 ***Impulse Tests.*** Ground-fault neutralizers shall be designed to withstand impulse tests, but the impulse tests are required only when specified.

8.2.2 ***Applied-Potential Tests.*** Applied-potential tests are required. They shall be made at the test voltage corresponding to the insulation class assigned to the ground end if it is lower than the insulation class assigned to the line end. The external ground connection is removed for this test. If the ground end bushing is not capable of withstanding this test voltage, it is to be disconnected, and, if necessary, special insulation is to be provided for test purposes.

8.2.3 ***Induced-Potential Tests.*** Induced-potential tests are required. The ground end shall be connected to ground for this test. When taps are provided, the test shall be made on the tap which produces the highest voltage per turn in the winding and also on the connections having the greatest number of turns, but the voltage to ground at the line end shall not exceed the specified test voltage.

9. Grounding Transformers

9.1 Insulation Levels. The line end and ground end insulation levels shall be selected from Table 4 on the following basis:

	Line End	Ground End
Disconnectable from Ground	System Insulation Class Columns 1 and 2	System Insulation Class Columns 1 and 2
Permanently Grounded	System Insulation Class Columns 1 and 2	Fault Voltage Criteria Columns 3 and 4

9.2 Dielectric Tests. Dielectric test withstand levels shall be those listed in Table 5 for the applicable insulation class, as follows:

Impulse chopped-wave test	Column 2
Impulse full-wave test	Column 3
Applied-potential test	Column 4
Induced-potential test	Column 5

9.2.1 ***Impulse Tests.*** Grounding transformers shall be designed to withstand impulse tests, but the impulse tests are required only when specified.

9.2.2 ***Applied-Potential Tests.*** Applied-potential tests are required. They shall be made at the test voltage corresponding to the insulation class assigned to the ground end if it is lower than the insulation class assigned to the line end. The external ground connection is removed for this test. If the ground end bushing is not capable of withstanding this test voltage, it is to be disconnected and, if necessary, special insulation is to be provided for test purposes.

9.2.3 ***Induced-Potential Tests.*** Induced-potential tests are required. The ground end shall be connected to ground for this test. When taps are provided, the test shall be made on the tap which produces the highest voltage per turn in the winding and also on the connections having the greatest number of turns, but the voltage to ground at the line end shall not exceed the specified test voltage.

The rated voltage of a grounding transformer is the maximum line-to-line voltage at which it is designed to operate continuously.

10. Resistors

10.1 Resistor Element. A resistor element is the conducting unit which functions to limit the current flow to a predetermined value.

The element material shall possess a balanced combination of properties, uniformity of resistance, and mechanical stability over the intended operating temperature range, without any injurious effects to the elements and its associated insulation.

10.1.1 *Rated Voltage* (see definition in Section 13). Since the active material used in resistors has an appreciable temperature coefficient, the resistance is materially changed during the time of operation causing the voltage to increase or the current to decrease. When the product of the fault current and resistance at 25° C exceeds 80 percent of the line-to-neutral voltage of the circuit, the resistor shall be rated for constant voltage and the rated voltage shall be taken equal to the line-to-neutral voltage.

10.1.2 *Temperature Coefficient of Resistance.*

(1) The conductor element resistance changes to some extent with temperature. The change may be calculated from the temperature coefficient of resistivity.

$$a = \frac{R_2 - R_1}{R_1\ (\theta_2 - \theta_1)} \qquad \text{(Eq 2)}$$

$$R_2 = R_1\ [1 + a\ (\theta_2 - \theta_1)] \qquad \text{(Eq 3)}$$

R_1 and R_2 are resistances in ohms at temperatures θ_1 and θ_2 in degrees Celsius, respectively, and a is the temperature coefficient of resistance.

(2) Where special temperature coefficient is required, such data are to be brought to the attention of those responsible for the design of an unusual service condition.

10.1.3 *Conductor Connections.* All conductor terminations shall be bolted, welded, or brazed. Low-melting alloys used to join connectors which would be adversely affected by the resistor operating temperatures shall not be used. All conductor terminations must be mechanically secure to provide continuous electrical continuity.

10.1.4 *Resistance Test.* Overall resistance shall be measured to determine that the resistance is within the design value. Unless the application requires close resistance tolerance, the dc resistance shall not vary more than ± 10 percent from the guaranteed value.

10.2 Insulation Levels. The line end and ground end insulation levels shall be selected from Table 4 on the basis of fault voltage criteria, Columns 3 and 4.

10.3 Dielectric Tests. Dielectric test withstand levels shall be those listed in Table 5, Column 6.

10.3.1 *Impulse Tests.* Impulse tests are not required for resistors.

10.3.2 *Applied-Potential Tests.* Applied-potential tests are required. They shall be made by applying between terminals and ground for the complete device, or between terminals of each unit and its own individual frame, the specified voltage from a suitable external source. When specifications do not require that such a resistor be completely assembled at the factory, it shall be permissible for the manufacturer to waive the applied voltage test of the complete device, substituting the applied-potential test of each section, supplemented by insulation d a which will show that the complete resis or will meet the insulation requirements of service and would pass the applied-potential test when assembled.

In many cases resistors are made in sections insulated from each other and from ground by standard apparatus insulators whose insulation value has been established. Each section may consist of one or more frames or unit assemblies of resistance material supported on a suitable framework. In such cases each frame or unit assembly shall receive an applied-potential test. The voltage applied from the terminals of each assembly to its own frame shall be twice the rated voltage of the section of which the frame is a part plus 1000 V when rated 600 V or less, or 2.25 times the rated value plus 2000 V when rated over 600 V.

10.3.3 *Induced-Potential Tests.* Induced-potential tests (except as may be incidental to any required temperature test) are not required for resistors.

11. Capacitors

11.1 Insulation Levels. The line end and ground end insulation levels shall be selected from Table 4 on the basis of fault voltage criteria, Columns 3 and 4.

11.2 Dielectric Tests. Dielectric test withstand levels shall be those listed in Table 5, Columns 7 and 8.

11.2.1 *Impulse Tests.* Impulse tests are not required for capacitors.

11.2.2 *Applied-Potential Tests.* Applied-potential tests (terminal-to-case) are required for all neutral grounding capacitors, except those having one terminal permanently grounded inside the case (the case being solidly grounded under operating conditions). Capacitors designed for operation with one terminal permanently grounded outside of the case may have the ground connection removed for this test.

11.2.3 *Induced-Potential Tests.* Induced-potential tests (terminal-to-terminal) are required on all neutral grounding capacitors. The induced test voltages shall be two times the rated voltage of the capacitor. If a capacitor has two or more voltage ratings, the test voltage shall be based on the highest voltage rating.

12. Combination Devices

Combination devices are any combination of devices of Sections 7 through 11, including distribution transformers, with resistance, inductance, or capacitance, or combination of two or more of these elements connected in their low-voltage winding or the delta of such low-voltage windings.

12.1 Insulation Levels. The line end and ground end insulation levels shall be selected from Table 4 on the following basis:

	Line End	Ground End
Disconnectable from Ground	System Insulation Class Columns 1 and 2	System Insulation Class Columns 1 and 2
Permanently Grounded	System Insulation Class Columns 1 and 2	Fault Voltage Criteria Columns 3 and 4

12.2 Dielectric Tests. Dielectric test withstand levels shall be those listed in Table 5 for the applicable insulation class, as follows:

Impulse chopped-wave test	Column 2
Impulse full-wave test	Column 3
Applied-potential test	Columns 4, 6, and 7
Induced-potential test	Columns 5 and 8

12.2.1 *Impulse Tests.* Combination devices shall be designed to withstand impulse tests, but the impulse tests are required only when specified. Components not requiring impulse tests shall be disconnected or suitably protected.

12.2.2 *Applied-Potential Tests.* Applied-potential tests are required. They shall be made by applying between terminals and ground for the complete device, or between terminals of each unit and its own individual frame, the specified voltage from a suitable external source. When specifications do not require that such a device be completely assembled at the factory, it shall be permissible for the manufacturer to waive the applied-potential test of the complete device, substituting the applied-potential test of each section, supplemented by insulation data which will show that the complete device will meet the insulation requirements of service and would pass the applied-potential test when assembled.

12.2.3 *Induced-Potential Tests.* Induced-potential tests shall be made as required for each component part but not on the whole.

13. Definitions and Terminology

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

ambient temperature. The temperature of the medium such as air, water, or earth into which the heat of the equipment is dissipated.

NOTES: (1) For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate neighborhood of the equipment.

(2) For air- or gas-cooled equipment with forced ventilation or secondary water cooling, the ambient temperature is taken as that of the ingoing air or cooling gas.

(3) For self-ventilated enclosed (including oil-immersed) equipment considered as a complete unit, the ambient temperature is the average temperature of the air outside of the enclosure in the immediate neighborhood of the equipment.

applied-potential test. A dielectric test in which the test voltage is a low-frequency alternating voltage from an external source applied between conducting parts, and between conducting parts and ground.

askarel. A synthetic nonflammable insulating liquid, that, when decomposed by an electric arc, evolves only nonflammable gaseous mixtures.

basic impulse insulation level (BIL). A reference impulse insulation strength expressed in terms of the crest value of the withstand voltage of a standard full impulse voltage wave.

chopped wave. A voltage impulse that is terminated intentionally by sparkover of a gap.

compound-filled (for a grounding device). Having the windings encased in an insulating fluid that becomes solid or remains slightly plastic, at normal operating temperatures.

conservator system or expansion tank system. A method of oil preservation in which the oil in the main tank is sealed from the atmosphere, over the temperature range specified, by means of an auxiliary tank partly filled with oil and connected to the completely filled main tank.

critical impulse flashover voltage. The crest value of the impulse wave that, under specified conditions, causes flashover through the surrounding medium on 50 percent of the applications.

design test. A test made by the manufacturer to obtain data for design application.

dielectric tests. Tests that consist of the application of a voltage, higher than the rated voltage, for a specified time to prove compliance with the required voltage class of the device.

disconnectable device. A grounding device that can be disconnected from ground by the operation of a disconnecting switch, circuit breaker, or other switching device.

dry-type (for a grounding device). Having the windings immersed in an insulating gas.

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.

gas-oil sealed system. A method of oil preservation in which the interior of the tank is sealed from the atmosphere over the temperature range specified, by means of an auxiliary tank or tanks, to form a gas-oil seal operating on the manometer principle.

ground. A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body, of a relatively large extent, that serves in place of the earth. It is used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential, on conductors connected to it, and for conducting ground current to and from the earth (or the conducting body).

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

grounded. Connected to earth or to some extended conducting body that serves instead of the earth, whether the connection is intentional or accidental.

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.

grounded concentric wiring system. A grounded wiring system in which the external (outer) conductor is solidly grounded and completely surrounds the internal (inner) conductor throughout its length. The external conductor is usually uninsulated.

grounded conductor. A conductor that is intentionally grounded, either solidly or through a current-limiting device.

grounded parts. Parts that are intentionally connected to ground.

grounded system. A system of conductors in which at least one conductor or point (usually the neutral conductor or neutral point of transformer or generator windings) is intentionally grounded, either solidly or through a current-limiting device.

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

ground-fault neutralizer. A grounding device that provides an inductive component of current in a ground fault that is substantially equal to and therefore neutralizes the rated-frequency capacitive component of the ground-fault current, thus rendering the system resonant grounded.

ground-fault neutralizer grounded. Reactance grounded through such values of reactance that, during a fault between one of the conductors and earth, the rated-frequency current flowing in the grounding reactances and the rated-frequency capacitance current flowing between the unfaulted conductors and earth shall be substantially equal. In the fault, these two components of fault current will be substantially 180 degrees out of phase.

NOTE: When a system is ground-fault neutralizer grounded, it is expected that the quadrature component of the rated-frequency single-phase-to-ground fault current will be so small that an arc fault in air will be self-extinguishing.

grounding device. An impedance device used to connect conductors of an electric system to ground for the purpose of controlling the ground current or voltage to ground.

NOTE: The grounding device may consist of a grounding transformer or a neutral grounding device, or a combination of these. Protective devices, such as lightning arresters, may also be included as an integral part of the device.

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

NOTE: It may be provided with a delta winding in which resistors or reactors may be connected.

impedance grounded. Grounded through impedance.

NOTE: The components of the impedance need not be at the same location.

impedance voltage. Comprises an effective resistance component corresponding to the impedance losses, and a reactance component corresponding to the flux linkages of the winding.

impulse flashover voltage. The crest voltage of an impulse causing a complete disruptive discharge through the air between electrodes of a test specimen.

impulse tests. Dielectric tests in which the voltage applied is an impulse voltage of specified wave shape. The wave shape of an impulse test wave is the graph of the wave as a function of time or distance.

NOTE: It is customary in practice to express the wave shape by a combination of two numbers, the first part of which represents the wave front and the second the time between the beginning of the impulse and the instant at which one-half crest value is reached on the wave tail, both values being expressed in microseconds, such as a 1.2 x 50 microsecond wave.

impulse withstand voltage. The crest value of an applied impulse voltage which does not cause a flashover, puncture, or disruptive discharge on the test specimen.

induced-potential test. A dielectric test in which the test voltage is an alternating voltage of suitable frequency, applied or induced between the terminals.

inert gas-pressure system. A method of oil preservation in which the interior of the tank is sealed from the atmosphere, over the temperature range specified, by means of a positive pressure of inert gas maintained from a separate inert-gas source and reducing-valve system.

inhibited oil. Mineral transformer oil to which a synthetic oxidation inhibitor has been added.

insulation class (of a grounding device). A number that defines the insulation levels of the device.

insulating materials, classification. See Table 9.

line end (of a neutral grounding device). The end or terminal of the device that is connected to the line circuit directly or through another device.

Table 9
Classification of Insulating Materials

Class 105°C (Class A)	Materials or combinations of materials such as cotton, silk, and paper when suitably impregnated or coated or when immersed in a dielectric liquid such as oil. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to be capable of operation at 105°C.
Class 130°C (Class B)	Materials or combinations of materials such as mica, glass, fiber, asbestos, etc, with suitable bonding substances. Other materials or combinations of materials, not necessarily inorganic, may be included in this class if by experience or accepted tests they can be shown to be capable of operation at 130°C.
Class 220°C	Materials or combinations of materials which by experience or accepted tests can be shown to be capable of operation at 220°C.
Class Over 220°C (Class C)	Insulation that consists entirely of mica, porcelain, glass, quartz, and similar inorganic materials. Other materials or combinations of materials may be included in this class if by experience or accepted tests they can be shown to be capable of operation at temperatures over 220°C.

NOTES: (1) Insulation is considered to be "impregnated" when a suitable substance provides a bond between components of the structure and also a degree of filling and surface covering sufficient to give adequate performance under the extremes of temperature, surface contamination (moisture, dirt, etc), and mechanical stress expected in service. The impregnant must not flow or deteriorate enough at operating temperature so as to seriously affect performance in service.

(2) The electrical and mechanical properties of the insulation must not be impaired by the prolonged application of the limiting insulation temperature permitted for the specific insulation class. The word "impaired" is here used in the sense of causing any change which could disqualify the insulating material for continuously performing its intended function, whether creepage spacing, mechanical support, or dielectric barrier action.

(3) In the above definitions, the words "accepted test" are intended to refer to recognized test procedures established for the thermal evaluation of materials by themselves or in simple combinations. Experience or test data, used in classifying insulating materials, are distinct from the experience based on test data derived for the use of materials in complete insulation systems. The thermal endurance of complete systems may be determined by test procedures specified by the cognizant technical committees. A material that is classified as suitable for a given temperature may be found suitable for a different temperature, either higher or lower, by an insulation system test procedure. For example, it has been found that some materials suitable for operation at one temperature in air may be suitable for a higher temperature when used in a system operated in an inert-gas atmosphere.

(4) It is important to recognize that other characteristics, in addition to thermal endurance, such as mechanical strength, moisture resistance, and corona endurance, are required in varying degrees in different applications for the successful use of insulating materials.

(5) The rate of thermal degradation of materials is influenced by environmental and other factors. The thermal characteristics of a material may be radically altered by exposure to nuclear radiation and by various processing techniques. Because of these many factors, realistic temperature classifications for insulating materials should be based on information obtained from field experience and from thermal aging tests. They cannot be based on composition alone.

losses (of a grounding device). The I^2R loss in the windings, core loss, 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.

NOTES: (1) 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.

(2) Losses will normally be considered at the rated thermal 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. The losses may be given at 25°C or 75°C.

mechanical limit. The rated maximum instantaneous value of current, in amperes, that the device will withstand without mechanical failure.

minimum impulse flashover voltage. The crest value of the lowest voltage impulse at a given wave shape and polarity that causes flashover.

neutral grounding device. A grounding device used to connect the neutral point of a system of electric conductors to earth.

NOTE: The device may consist of a resistance, inductance, or capacitance element, or a combination of them.

neutral grounding capacitor. A neutral grounding device, the principal element of which is capacitance.

neutral grounding impedor. A neutral grounding device comprising an assembly of at least two of the elements, resistance, inductance, or capacitance.

neutral grounding reactor. A neutral grounding device, the principal element of which is inductive reactance.

neutral grounding resistor. A neutral grounding device, the principal element of which is resistance.

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.

NOTE: The inductances used in neutral grounding wave traps should meet the same requirements as neutral grounding reactors.

oil. Includes synthetic insulating liquids as well as mineral transformer oil.

oil-immersed (for a grounding device). Means that the windings are immersed in an insulating oil.

permanently grounded device. A grounding device designed to be permanently connected to ground, either solidly or through current transformers and/or another grounding device.

rated continuous current. The current expressed in amperes, root mean square, that the device can carry continuously under specified service conditions without exceeding the allowable temperature rise.

rated current (of a neutral device) (current rating). The rated thermal current of a neutral device.

rated frequency (of a grounding device). The frequency of the alternating current for which a device is designed.

rated thermal current. The rms neutral current in amperes which the device is rated to carry under standard operating conditions for rated time without exceeding temperature limits.

rated time (time rating). The time during which the device will carry its rated thermal current (or, for certain resistors, withstand its rated voltage) under standard operating conditions, without exceeding the limitations established by these standards.

rated-time temperature rise (for a grounding device). The maximum temperature rise above ambient attained by the winding of a device as the result of the flow of rated thermal current (or, for certain resistors, the maintenance of rated voltage across the terminals) under standard operating conditions, for rated time and with a starting temperature equal to the steady-state temperature. It may be expressed as an average or a hot-spot winding rise.

rated voltage. The rms voltage, at rated frequency, which may be impressed between the terminals of the device under standard operating conditions for rated time (continuously for grounding transformers) without exceeding the limitations established by these standards.

reactance grounded. Grounded through impedance, the principal element of which is reactance.

NOTE: The reactance may be inserted either directly, in the connection to ground, or indirectly by increasing the reactance of the ground return circuit. The latter may be done by intentionally increasing the zero-sequence reactance of apparatus connected to ground, or by omitting some of the possible connections from apparatus neutrals to ground.

resistance grounded. Grounded through impedance, the principal element of which is resistance.

NOTE: The resistance may be inserted either directly, in the connection to the ground, or indirectly, as, for example, in the secondary of a transformer, the primary of which is connected between neutral and ground, or in series with the delta-connected secondary of a wye-delta grounding transformer.

resistance method of temperature determination. The determination of the temperature by comparison of the resistance of a winding at the temperature to be determined, with the resistance at known temperature.

routine test. A test made for quality control by the manufacturer on every device, on representative samples, or on parts or materials as required to verify during production that the product meets the design specifications.

sealed tank system. A method of oil preservation in which the interior of the tank is sealed from the atmosphere and in which the gas plus the oil volume remains constant over the temperature range.

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

solidly grounded. Grounded through an adequate ground connection in which no impedance has been inserted intentionally.

NOTE: Adequate as used here means suitable for the purpose intended.

starting temperature (for a grounding device). The winding temperature at the start of the flow of thermal current.

steady-state temperature rise (for a grounding device). The maximum temperature rise above ambient which will be attained by the winding of a device as the result of the flow of rated continuous current under standard operating conditions. It may be expressed as an average or a hot-spot winding rise.

tap. An available connection which permits changing the active portion of the device in the circuit.

thermal current rating. For resistors whose rating is based on constant voltage, the initial rms symmetrical value of the current that will flow when rated voltage is applied.

thermometer method of temperature determination. The determination of the temperature by mercury, alcohol, resistance, or thermocouple thermometers, any of these instruments being applied to the hottest accessible part of the device.

ungrounded. Without an intentional connection to ground except through potential indicating of measuring devices or other very-high-impedance devices.

uninhibited oil. Mineral transformer oil to which no synthetic oxidation inhibitor has been added.

voltage to ground. The voltage between any live conductor of a circuit and the earth.

NOTE: Where safety considerations are involved, the voltage to ground that may occur in an ungrounded circuit is usually the highest voltage normally existing between the conductors of the circuit, but in special circumstances higher voltages may occur.

14. Test Code

The usual program of testing a neutral grounding device includes some or all of the following tests:

(1) Resistance measurements
(2) Dielectric tests
(3) Impedance and loss measurements
(4) Temperature-rise tests

14.1 Resistance Measurements

14.1.1 ***Necessity for Resistance Measurements.*** Resistance measurements are of fundamental importance for two purposes:

(1) For the calculation of the conductor I^2R loss

(2) For the calculation of winding temperatures at the end of a temperature test

14.1.2 ***Determination of Cold Temperature.*** The cold temperature of the winding shall be determined as accurately as possible when measuring the cold resistance. The following precautions shall be observed:

14.1.2.1 *General.* Cold resistance measurements shall not be taken on a device when it is located in drafts or when it is located in a room in which the temperature is fluctuating rapidly.

14.1.2.2 *Windings Out of Oil.* The temperature of the windings shall be recorded as the average of several thermocouples or thermometers inserted between the winding sections, with extreme care used to see that their junctions or bulbs are as nearly as possible in actual contact with the windings. It should not be assumed that the windings are at the same temperature as the surrounding air.

14.1.2.3 *Windings Immersed in Oil.* The temperature of the windings shall be assumed to be the same as the temperature of the oil, provided the device has been under oil with no current in its winding from 3 to 8 hours before the cold resistance is measured, depending upon the size of the device.

14.1.3 ***Drop-of-Potential Method.*** The drop-of-potential method is generally more convenient than the bridge method for measurements made in the field.

In all cases, greater accuracy may be obtained by the use of potentiometers for the measurement of both current and voltage although the setup may be rather cumbersome.

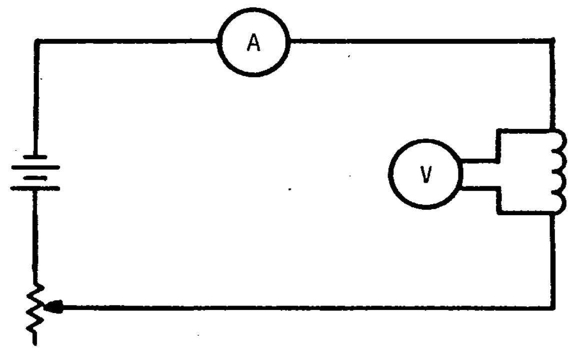

Fig 1
Connections for the Drop-of-Potential Method of Resistance Measurement

Measurement is made with direct current, and simultaneous readings of current and voltage are taken using the connections of Fig. 1. The required resistance is calculated from the readings in accordance with Ohm's law.

In order to minimize errors of observation, the measuring instruments insofar as possible shall have such ranges as will give reasonably large deflections.

The voltmeter leads shall be connected as closely as possible to the terminals of the winding to be measured. This is to avoid including in the reading the resistances of current-carrying leads and their contacts and of extra lengths of leads.

To avoid dangerous induced voltages, a rheostat should be used to reduce the current to less than ½ percent of rated winding current before opening the circuit. Also, to protect the voltmeter from injury by off-scale deflections, it should be disconnected before switching the current on or off.

If the drop of potential is less than 1 V, a potentiometer or millivoltmeter shall be used.

Readings shall not be taken until after the current and voltage have reached steady-state values.

Readings shall be taken with not less than four values of a current when deflecting instruments are used. The average of the resistances calculated from these measurements shall be considered to be the resistance of the circuit.

The current used shall not exceed 15 percent of the rated continuous current of the winding whose resistance is to be measured. Larger values may cause inaccuracy by heating the winding and thereby changing its temperature and resistance.

14.1.4 *Bridge Methods.* Bridge methods are generally preferred because of their accuracy and convenience, since they may be employed for the measurement of resistances up to 10 000 ohms. The rheostat should always be turned to minimum current before opening the circuit.

Bridge methods are especially recommended for all measurements that are to be used in connection with temperature-rise determination.

14.2 Dielectric Tests

14.2.1 *Test Procedure.* Unless otherwise specified, dielectric tests shall be made in accordance with IEEE Std 4-1968, Techniques for Dielectric Tests (ANSI C68.1-1968).

NOTE: Where a sphere gap is used to measure voltage, IEEE Std 4-1968 provides for reduction of the series resistance when the test frequency exceeds 1 kHz. The resistance should be in an inverse ratio to the frequency, which for current-limiting reactors means the sphere gap resistance must be short-circuited.

14.2.1.1 *Factory Dielectric Tests.* The purpose of dielectric tests in the factory is to check the insulation and workmanship, and, when required, to demonstrate that the device has been designed to withstand the insulation tests required by the purchase specifications.

Impulse tests, when required, shall precede the low-frequency tests.

Dielectric tests should preferably be made at the temperature assumed under normal operation or at the temperature attained under the conditions of commercial test.

14.2.1.2 *Insulation Resistance.* The insulation resistance of machinery is of doubtful significance as compared with the dielectric strength. It is subject to wide variation with temperature, humidity, and cleanliness of the parts. When the insulation resistance falls below prescribed values, it can, in most cases of good design and where no defect exists, be brought up to the required standard by cleaning and drying the machine. The insulation resistance, therefore, may afford a useful indication as to whether the machine is in suitable condition for application of the dielectric test.

The insulation-resistance test shall be made with all circuits of equal voltage above ground connected together. Circuits or groups of circuits of different voltage above ground shall be tested separately.

14.2.1.3 *Periodic Dielectric Tests in the Field.* It is recognized that dielectric tests impose a severe stress on the insulation, and if applied frequently will hasten breakdown or may cause breakdown, the stress imposed, of course, being the more severe the higher the value of the applied voltage. Hence, practice in this matter has varied widely among operating companies, and the advisability of periodic testing may be questionable.

It is recommended that field tests of insulation should not be in excess of 75 percent of the factory test voltage; that for old apparatus rebuilt in the field, tests should not be in excess of 75 percent of the factory test voltage; and that periodic insulation tests in the field should not be in excess of 65 percent of the factory test voltage. These recommendations relate to dielectric tests applied between windings and ground and to tests between turns.

Under some conditions, devices may be subjected to periodic insulation test using dc voltage. In such cases, the test dc voltage should not exceed the original factory test rms alternating voltage; for example, the factory test was 26 kV rms, then the routine test dc voltage should not exceed 26 kV.

Periodic dc tests should not be applied to devices of higher than 34.5 kV rating.

14.2.1.4 *Tests on Bushings.* When tests are required on bushings separately from the devices, the tests shall be made in accordance with IEEE Std 21-1964, Requirements and Test Code for Outdoor Apparatus Bushings (ANSI C76.1-1964 (R 1970)).

14.2.2 ***Applied-Potential Tests.*** The terminal ends and taps brought out of the case of the winding under test should all be joined together and to the line terminal of the testing transformer. The duration of these tests shall be 1 minute and of a value given in Table 5.

All other terminals and parts (including magnetic shield and tank) should be connected to ground and to the other terminal of the testing transformer.

The ground connections between the apparatus being tested and the testing transformer must be a substantial metallic circuit. All connections must make a good mechanical joint without forming sharp corners or points.

Small bare wire may be used in connecting the respective taps and line terminal together, but care must be taken to keep the wire on the high-voltage side well away from the ground.

The high-voltage lead from the testing transformer should preferably be at least 1/8 inch (3 mm) in overall diameter.

Neutral Capacitor Terminal-to-Case. The terminal-to-case applied-potential test shall be made by applying between terminal and case, with the case connected to ground, the specified alternating voltage.

Neutral Resistor. Tests shall be made by applying between terminals and ground, for the complete device, or between terminals of each unit and its own frame, for individual frames, the specified alternating voltage.

No appreciable resistance should be placed between the testing transformer and the device under test. It is permissible, however, to use reactive coils at or near the terminals of the testing transformer.

A sphere gap set at a voltage 10 percent or more in excess of the specified test voltage shall be connected during the applied-potential test.

For devices to be tested at 50 kV or less, it is permissible to depend on the ratio of the testing transformer to indicate the proper test voltage and also to omit the sphere gap, if the kVA equivalent parts are less than 100 for grounding transformers and ground-fault neutralizers or 500 for current-limiting reactors and other devices.

14.2.3 ***Induced-Potential Tests***

14.2.3.1 *Grounding Transformers and Ground-Fault Neutralizers.* As this test overexcites the device, the frequency of the applied potential should be high enough to prevent the exciting current of the device under test from exceeding about 30 percent of its rated-load current. Ordinarily, this requirement necessitates the use of a frequency of 120 Hz or more, when testing 60-Hz units.

When frequencies higher than 120 Hz are used, the severity of the test is abnormally increased, and for this reason the duration of the test should be reduced in accordance with the table given below.

Frequency in Hz	*Duration in seconds*
120 and less	60
180	40
240	30
360	20
400	18

To avoid switching surges, the voltage should be started at one-quarter or less of the full value and be brought up gradually to full value, within a period of 15 seconds.

After being held for the duration of time specified in the table above, it should be reduced gradually to one-quarter of the maximum value within a period of 5 seconds, at which time the circuit may be opened.

14.2.3.2 *Dry-Type Current-Limiting Reactors.* Because of the low impedance of current-limiting reactors, inducing voltage between turns will have to be done with a high frequency, well above the power frequency range.

This can be obtained by repeatedly charging a capacitor and discharging it into the reactor winding. The number of discharges should be sufficient to produce 7200 cycles of high frequency having crest values outlined in 7.2.3 except that testing time shall not exceed 60 seconds. If the available equipment cannot induce sufficient voltage in the reactor coil directly, then turns of insulated cable may be placed around the mid-section of the reactor as a primary of a Tesla coil and the capacitor discharged into it. Where a sphere gap is used to check, the current-limiting resistance normally in series with the spheres should be short-circuited. Detection shall be by noise, smoke, or spark discharge in the windings.

14.2.3.3 *Oil-Immersed Current-Limiting Reactors.* For oil-immersed reactors, each line terminal of each winding shall be induced-potential tested as outlined in 7.2.3.

14.2.3.4 *Neutral Capacitors.* The terminal-to-terminal induced-potential test shall be made by applying between the terminals of each unit the specified alternating voltage.

14.2.3.5 *Neutral Resistors.* No induced test required.

14.2.4 ***Standard Impulse Tests.*** The standard impulse test consists of applying, in the following order, one reduced full wave, two chopped waves, and one full wave.

14.2.4.1 *Reduced Full-Wave Test.* For this test, the applied voltage wave shall have a crest value between 50 and 70 percent of the full wave in accordance with 3.2. Crest voltages near the lower limit are preferable.

14.2.4.2 *Chopped-Wave Test.* For this test, the applied voltage wave shall be chopped by a suitable air gap. It shall have a crest voltage and time to flashover in accordance with 3.2.

To avoid recovery of insulation strength if failure has occurred during a previous impulse, the time interval between application of the last chopped wave and the final full wave should be minimized, and preferably should not exceed 5 minutes.

14.2.4.3 *Full-Wave Test.* For this test, the voltage wave shall have a crest value in accordance with 3.2, and no flashover of the bushing or test gap shall occur.

To avoid flashover of the bushing during adverse conditions of humidity and air density, the bushing flashover may be increased by appropriate means.

In general, the tests shall be applied to each terminal one at a time.

All impulses applied to a device shall be recorded by a cathode-ray oscillograph if their crest voltage exceeds 40 percent of the crest of the full wave in accordance with 3.2.

When reports require oscillograms, those of the first reduced full wave, the last two chopped waves, and the last full wave of voltages shall represent a record of the successful application of the impulse test to the device.

14.2.4.4 *Connections for Impulse Tests.* One terminal of the winding under test shall be grounded directly or through a small resistance if current measurements are to be made. Other terminals in the same winding not being tested or terminals in the windings of other phases may be protected by grounding or other appropriate means.

In some cases the inductance of the winding is so low that the desired impulse voltage magnitude and the duration to the 50-percent point on the tail of the wave cannot be obtained with available test equipment. Such low-inductance windings may be tested by inserting a resistor of not more than 500 Ω in the grounded end of the winding.

The secondaries of current transformers, either on bushings or permanently connected to the equipment being tested, shall be short-circuited and grounded. Any magnetic shielding or metallic housing shall be grounded for all impulse tests.

14.2.4.5 *Detection of Failure.* Because of the nature of impulse test failures, one of the most important matters is the detection of failure. There are a number of indications of insulation failure. Some of these are:

(1) Noise; presence of smoke or bubbles; failure of the gap or bushing to flash over, although the oscillogram indicates a chopped wave.

(2) Any difference between the reduced full wave and the final full wave detected by superimposing the two oscillograms or any difference between the two chopped waves from each other or from the full wave up to the time of flashover similarly detected. Such deviations may, however, be caused by conditions in the impulse test circuit external to the device and should be fully investigated.

(3) Measurement of the current in the grounded end of the winding tested. The current is measured by means of a cathode-ray oscillograph connected to a suitable shunt inserted between the normally grounded end of the winding and the grounded tank. Any deviation of current-wave shape obtained during the reduced full wave and full-wave tests indicates changes in impedance arising from insulation breakdown within the device, or changes in the impulse circuit external to the device, and the cause should be investigated.

14.2.4.6 *Wave to be Used for Impulse Tests.* A nominal 1.2 × 50 microsecond wave shall be used for impulse tests.

Either, but not both, positive or negative waves may be used.

Waves of negative polarity for oil-immersed apparatus and of positive polarity for dry-type or compound-filled apparatus are recommended and shall be used unless otherwise specified.

If in testing oil-immersed apparatus the atmospheric conditions at the time of test are such that the bushings will not withstand the specified polarity wave, then a wave of the opposite polarity may be used.

The time to crest on the front from virtual time zero to actual crest shall not exceed 2.5 microseconds, except for windings of large impulse capacitance (low-voltage high-apparent-power and some high-voltage high-apparent-power windings). To demonstrate that the large capacitance of the winding causes the long front, the impulse generator series resistance may be reduced, which should cause imposed oscillations. Only the inherent generator and lead inductances should be in the circuit.

For convenience in measurement, the time to crest may be considered as 1.67 times the actual time between points on the front of the wave at 30 percent and 90 percent of the crest value.

The time on the tail to the point of half-crest voltage of the applied wave shall be 50 microseconds from the virtual time zero.

The virtual time zero can be determined by locating points on the front of the wave at which the voltage is, respectively, 30 and 90 percent of the crest value and then drawing a straight line through these points. The intersection of this line with the time axis (zero-voltage line) is the virtual time zero.

If there are oscillations on the front of the wave, the 30 and 90 percent points should be determined from the average, smooth wave front sketched in through the oscillations.

The magnitude of the oscillations preferably should not exceed 10 percent of the applied voltage. (With superimposed oscillations of high magnitude, evaluation of wave crest is difficult, while if generator characteristics are such as to give a completely smooth wave it may be difficult to detect failures of small portions of the winding insulation by means of the cathode-ray oscillograph. If the impulse generator is sufficiently flexible, a good compromise is the use of generator constants such that the device impedance largely determines the length of the tail of the applied wave.)

14.3 Impedance and Loss Measurements. It is not practical to measure the resistive and reactive components of the impedance voltage separately, but after the total impedance loss and impedance voltage are measured, the components may be separated by calculation.

Resistance and reactance components of the impedance voltage are determined by the use of the following equations:

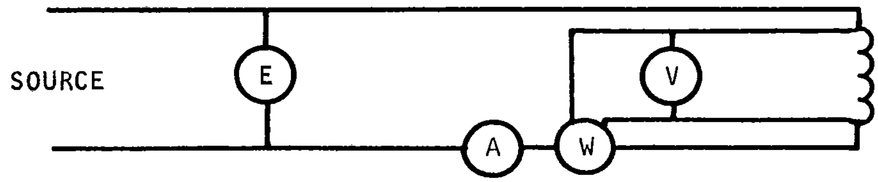

Fig 2
Connections for Impedance Voltage and Impedance Loss Tests

$$E_r = \frac{P}{I} \quad \text{(Eq 4)}$$

$$E_x = \sqrt{E^2 - E_r^2} \quad \text{(Eq 5)}$$

where

E = Potential impressed on winding
E_r = Component of E that is in phase with I
E_x = Component of E that is in quadrature with I
P = Power measured in impedance test of winding carrying current
I = Current in winding on which voltage is impressed

The I^2R component of the impedance loss increases with the temperature, the stray-loss component diminishes with the temperature, and, therefore, when it is desired to convert the impedance losses from one temperature to another, as for instance when calculating efficiency which calls for 75°C losses, the two components of the impedance loss are converted separately. Thus,

$$P_r' = P_r \frac{T + \theta'}{T + \theta} \quad \text{(Eq 6)}$$

$$P_s' = P_s \frac{T + \theta}{T + \theta'} \quad \text{(Eq 7)}$$

where

T = 234.5 for copper
T = 225 for aluminum

P_r' and P_s' are desired resistance and stray losses, respectively, at the specified temperature θ'; and P_r and P_s are measured resistance and stray losses at temperature θ.

14.3.1 ***Wattmeter Method.*** Voltage at rated frequency is applied and adjusted to circulate rated current in the winding (see Fig 2).

With current and frequency adjusted to the rated values as nearly as possible, simultaneous readings should be taken on the ammeter, voltmeter, wattmeter, and frequency meter. Because of the extremely low power factor, correction must be made for phase angle and losses of meters and metering transformers. Test current and potential leads should leave the winding terminals in a radial plane for a distance not less than one coil diameter when measuring coils in air.

In the case of reactors of the current-limiting type, when reactor windings are being measured outside of enclosures or shielded tanks, the measurement may be made at lower than rated current to minimize the effect of short-circuited loops of nearby magnetic materials that are not part of the reactor and would have a disproportionately larger current induced in them at rated current.

The temperature of the winding shall be taken immediately before and after the impedance measurements in a manner similar to that described in 14.1. The average shall be taken as the true temperature.

The I^2R loss of the winding is calculated from the resistance measurements (corrected to the temperature at which the impedance test was made) and the currents which were used in the impedance measurement. These I^2R losses subtracted from the impedance losses give the stray losses of the winding. When reactor windings are enclosed in shielded housings or tanks, part or all of which are magnetic material, part of the stray loss must be considered with the winding I^2R when correcting losses from measured temperature to other temperatures. Since this varies with proportions of design and type of shield, it will have to be approximated for each design but can be checked by measurement of loss at the start and finish of the temperature run.

Per-unit values of the resistance, reactance, and impedance voltage are obtained by dividing E, E_r, E_x in Eqs 4 and 5 by the rated voltage. Percentage values are obtained by multiplying per-unit values by 100.

Temperature correction shall be made as in Eqs 6 and 7. The stray-loss component of the impedance watts is obtained by subtracting from the latter the I^2R losses of the reactor.

14.3.2 *Bridge Method.* Bridges are frequently used and are generally more accurate than the wattmeter method.

14.4 Temperature-Rise Tests

14.4.1 ***Loading for Temperature-Rise Tests.*** Neutral grounding devices shall be tested under loading conditions that will give losses approximating, as nearly as possible, those obtained at rated frequency with rated current in the device. Units having taps for more than one rating shall be tested on the connection providing the highest losses. For devices rated less than 10 minutes, the loading shall be adjusted to obtain a steady-state rise approximating that listed in Table 6 for the class of insulation involved. The data so obtained shall be used to determine the degree of compliance with the short-time temperature requirements by calculation using the method of Section 14.5.1.

14.4.2 ***Determination of Average Measured Winding Temperature by the Hot-Resistance Method.*** The average measured temperature of the winding conductor may be determined by either of the following equations:

$$\theta = \frac{R}{R_0}(T + \theta_0) - T \qquad \text{(Eq 8)}$$

$$\theta = \frac{R - R_0}{R_0}(T + \theta_0) + \theta_0 \qquad \text{(Eq 9)}$$

where

T = 234.5 for copper
T = 225 for aluminum
θ = Temperature in degrees Celsius corresponding to hot resistance R
θ = Temperature in degrees Celsius corresponding to cold resistance R_0
R = Hot resistance (see Section 14.4.5)
R_0 = Cold resistance determined in accordance with the rules in this standard

The induction time for the measuring current to become stable should be noted during the cold-resistance measurements, in order to assure that sufficient time elapses for the induction effect to disappear before hot-resistance readings are taken.

When tests are made at an altitude not exceeding 3300 ft (1000 m) above sea level, no altitude correction shall be applied to the temperature rise.

When a device which is tested at an altitude less than 3300 ft (1000 m) is to be operated at an altitude in excess of that altitude, it shall be assumed that the observed temperature rise will increase in accordance with the following relation:

Increase in Temperature Rise

$$= \text{Observed Rise} \times \frac{(A - 1000)}{100} \; (F)$$

or

$$= \text{Observed Rise} \times \frac{(B - 3300)}{330} \; (F)$$

where A is the altitude in meters, B is the altitude in feet, and F is an empirical factor equal to 0.004 for oil-immersed self-cooled and 0.005 for dry-type self-cooled.

The observed rise in the foregoing equation is:

Top oil rise, or average oil rise, over the ambient temperature for oil-immersed self-cooled devices

Winding rise over the ambient temperature for dry-type self-cooled devices

The winding rise for oil-immersed devices over ambient at altitude A is the observed winding rise over ambient plus the calculated increase in temperature rise.

Devices shall be completely assembled and if oil-immersed they shall be filled to the proper level.

If the devices are equipped with thermal indicators, bushing-type current transformers, etc, such apparatus shall be assembled with the device.

The temperature-rise test shall be made in a room which is essentially free from drafts.

The temperature of the surrounding air (ambient temperature) shall be determined by at least three thermocouples, or thermometers, spaced uniformly around the devices under test. They should be located about one-half the height of the device, and at a distance of about 3 to 6 ft (1 to 2 m) from the device. They should be protected from drafts and abnormal heating. For dry-type reactors, they should be located one coil diameter from the coil at the level of the bottom of the coil.

To reduce to a minimum the errors due to time lag between the temperature of the devices and the variations in the ambient temperature, the thermocouples, or thermometers, shall be placed in suitable containers which shall have such proportions as will require not less than 2 hours for the indicated temperature within the container to change 6.3°C if suddenly placed in air which has a temperature 10°C higher, or lower, than the previous steady-state indicated temperature within the container.

The temperature rise of metal parts (other than the winding conductor) in contact with, or adjacent to, insulation, and of other metal parts, shall be determined by thermocouple or by thermometer.

Provision shall be made to measure the surface temperature of iron or alloy parts surrounding or adjacent to the outlet leads or terminals carrying large currents. Readings shall be taken at intervals or immediately after shutdown.

The determination of the temperature rise of metal parts within the case, other than winding conductors, is a design test and shall be made when so specified unless a record of this test made on a duplicate, or essentially duplicate, unit can be furnished. This test will not be made unless definitely specified because provision for the proper placement of the thermocouples and leads must frequently be made during the design of the devices. Comparison with other devices having metal parts of similar design and arrangement, but not necessarily having the same rating, will in many cases be adequate.

A thermocouple is the preferred method of measuring surface temperature. When used for this purpose on tanks or enclosures, the thermocouples should be soldered to a thin metal plate or foil approximately 1 in (25 mm) square. The plate is to be placed and held firmly and snugly against the surface. In either case, the thermocouple should be throughly insulated thermally from the surrounding medium.

It is permissible to shorten the time required for the test by the use of initial overloads, restricted cooling, or any other suitable method.

The temperature rise of the winding shall be determined by the resistance method, or by thermometer when so specified.

The ultimate temperature rise is considered to be reached when the temperature rise becomes constant; that is, when the temperature rise does not vary more than 2.5 percent during a period of 3 consecutive hours.

14.4.3 ***Temperature-Rise Tests — Oil-Immersed Devices.*** The top oil temperature shall be measured by a thermocouple or alcohol thermometer immersed approximately 2 in (51 mm) below the top oil surface.

The average temperature of the oil shall be determined when it is to be used.

The average oil temperature is equal to the top oil temperature minus one-half the difference in temperature of the moving oil at the top and the bottom of the cooling means, as determined by suitable measurements.

For devices with external cooling means, this temperature difference may be closely approximated by careful determination of the temperature on the external surfaces of the oil inlet and oil outlet of the cooling means by the use of thermocouples.

The ambient temperature shall be taken as that of the surrounding air which should be not less than 10°C or more than 40°C.

No corrections for variations of ambient temperature within this range shall be applied.

Temperature tests may be made with ambient temperature outside the range specified, if suitable and agreed upon correction factors are available.

14.4.4 ***Temperature-Rise Tests — Dry-Type Devices.*** When the ambient air temperature is other than 30°C, a correction shall be applied to the temperature rise of the winding by multiplying it by the correction factor K which is given by the ratio

$$K = \frac{T + 30}{T + \theta} \qquad \text{(Eq 10)}$$

where
T = 234.5 for copper
T = 225 for aluminum
θ = Ambient air temperature, °C

When the temperature-rise tests by thermometer are required, it is important that the coil thermometers be properly placed in the air ducts in such a manner as to indicate the winding temperature and yet not restrict the ventilation. This may be accomplished by means of grooved sticks of dry wood or some other kind of insulating material slightly larger than the thermometer bulbs.

When the thermometers are used for measuring temperature of apparatus other than oil-immersed, the bulbs shall be covered by felt pads cemented to the equipment. When pads interfere with ventilation, as in ventilating ducts between coils, grooved wooden sticks may be used.

Dimensions of felt pads for use with large apparatus should be approximately 1.5 in by 2 in by 0.125 in (40 mm by 50 mm by 3 mm).

When the temperature rise has become constant, the test voltage and current should be removed and the blowers, if used, shut off. Immediately thereafter, the coil thermometers and any other temperature-indicating devices should be read continually in rotation until the temperature begins to fall. If any of the thermometer temperatures are higher than those observed during the run, the highest temperature should be recorded as the final thermometer temperature.

The temperature rise of the device above the specified ambient temperature, when tested or calculated in accordance with the rating, shall not exceed values given in Table 6.

For times of one minute or less the temperature rise shall be determined in accordance with Section 4.3.1.

For a time of 10 minutes and greater, Sections 4.3.2 and 4.3.3, the temperature rise is the limiting observable temperature rise using the methods of measurement as follows:

Resistance method for grounding transformers, ground-fault neutralizers, and reactors

Thermometer method and radiation thermometer method for resistors

When the rated voltage of a resistor is equal to the line-to-neutral voltage of the circuit, the specified temperature limits are based upon the application of line-to-neutral voltage at rated frequency to the resistor for a time equal to the rated time, the current being allowed to decrease during the rated time.

NOTE: This assumes there will be sufficient additional impedance in the circuit to keep the current at the start of the test from exceeding the mechanical current rating when the product of the rated current and the resistance at the starting temperature is less than 83⅓ percent of the line-to-neutral voltage.

14.4.5 *Correction Back to Shutdown*

14.4.5.1 *Empirical Method.* The empirical method utilizes correction factors which represent average results from usual commercial designs. This method is not to be used for forced-oil-cooled devices, nor for those designs which deviate considerably from usual commercial proportions. In such cases, the cooling curve method should be used (Section 14.4.5.2).

Take one hot-resistance reading on each winding, record the time after shutdown, and determine the corresponding temperature rise.

When the conductor loss of oil-immersed equipment does not exceed 7 W/lb (15 W/kg) for copper or 12 W/lb (26 W/kg) for aluminum, an arbitrary correction of 1°C per minute may be used.

The conductor loss in watts per pound in a winding shall be taken as the sum of the calculated I^2R and eddy-current loss at a temperature equal to the rated temperature rise plus 20°C divided by the weight of the active conductor in pounds.

14.4.5.2 *Cooling Curve Method.* Take a series of at least four, preferably more, readings on one phase of each winding, and record the time after shutdown for each reading.

The readings should be time spaced to assure accurate extrapolation back to shutdown.

The overall reading time should exceed 4 minutes and may extend considerably beyond.

The first reading on each winding should be taken as quickly as possible after shutdown, but not before the measuring current has become stable, and must be taken within 4 minutes.

Plot the resistance time data on suitable coordinate paper, and extrapolate the curve back to instant of shutdown.

The resistance value so obtained shall be used to calculate the average winding temperature at instant of shutdown.

The resistance time curve obtained on one phase may be used to determine the correction back to shutdown for the other phases provided the first reading on each of the other windings has been taken within 4 minutes after shutdown.

If necessary the temperature test may be resumed so that the first readings on any windings may be completed within the required 4 minutes.

14.5 Temperature-Rise Calculations

14.5.1 *Thermal Short-Time Capability Calculations for Reactors, Ground-Fault Neutralizers, and Transformers Used for Grounding.* The increase in winding temperature θ_f during short-time conditions shall be estimated on the basis of all heat stored in the conductor material and its associated turn insulation.

The thermal capability of the conductor material shall be taken as the average of the values at the starting and finishing temperatures.

All temperatures are in degrees Celsius.

The increase in winding temperature θ_f which will occur during a specified short time t shall be calculated by the following equation:

$$\theta_f = (T + \theta_s)\,[(1 + e)\,m + 0.6\,m^2] \qquad \text{(Eq 11)}$$

where

$m = at$

$$a = \frac{W_s}{C_{av}}\,\frac{1}{T + \theta_s} = \frac{W_r}{C_{av}\,(T + 75)} \qquad \text{(Eq 12)}$$

t = Time, in seconds

T = 234.5 for copper

T = 225 for aluminum

θ_f = Increase in winding temperature during time t (not to be greater than the difference between starting temperature θ_s and the limiting temperature during short-circuit conditions given in Table 7)

θ_s = Starting temperature—reference ambient temperature (30°C) plus steady-state hottest-spot temperature rise above reference ambient temperature at continuous current rating, using

(1) measured hottest-spot temperature rise, if tested

(2) standard hottest-spot limiting temperature rise, if not temperature tested

W_s = Short-circuit resistance loss at starting temperature θ_s, watts per kilogram or pound of conductor material

W_r = Short-circuit resistance loss at 75°C, watts per kilogram or pound of conductor material

e = Per-unit eddy-current loss, based on resistance loss at the starting temperature

$$e = (e_{75})\left[\frac{T + 75}{T + \theta_s}\right]^2$$

e_{75} = Per-unit eddy-current loss, based on resistance loss at 75°C

C_{av} = Average specific thermal capacity in Joules per degree Celsius, per kilogram or pound of conductor material and its associated turn insulation over the range of increase in winding temperature.

NOTE: Equation 11 is an approximate formula and its use should be restricted to values of m = 0.6 or less. The exact equation is:

$$\theta_f = (T + \theta_s)\left[\sqrt{\epsilon^{2m} + e\,(\epsilon^{2m} - 1)} \;-1\right]$$

ϵ = 2.7183 = base of the natural logarithms

The thermal capacity C_x at any temperature θ_x below 500°C may be closely estimated from the following empirical equations:

Metric $$C_x = 384 + 0.099\,\theta_x + 243\,\frac{A_i}{A_c}$$ per kilogram of copper

(Eq 13)

English $$C_x = 174 + 0.045\,\theta_x + 110\,\frac{A_i}{A_c}$$ per pound of copper

Metric $$C_x = 893 + 0.441\,\theta_x + 794\,\frac{A_i}{A_c}$$ per kilogram of aluminum

(Eq 14)

English $$C_x = 405 + 0.200\,\theta_x + 360\,\frac{A_i}{A_c}$$ per pound of aluminum

where

A_i = Cross-sectional area of insulation

A_c = Cross-sectional area of conductor

Table 10
Respective Metric and English System
Nomenclature for Eqs 15 and 16

Symbol and Identity		Metric	English
θ	Final temperature rise	°C	°F
θ_1	Initial temperature rise	°C	°F
θ_0	Initial temperature	°C = θ_1 + 30	°F = θ_1 + 86
a_0	Temperature coefficient of resistance, change in resistance per degree, at initial temperature,	°C	°F
δ	Density of material	$\frac{g}{cm^3}$	$\frac{lb}{in^3}$
$*C$	Effective integrated specific heat	$\frac{Cal}{g \cdot °C}$	$\frac{Btu}{lb \cdot °F}$
J_0	Initial current density	$\frac{A}{cm^2}$	$\frac{A}{in^2}$
r_0	Resistivity at initial temperature	$\frac{\Omega}{cm^3}$	$\frac{\Omega}{in^3}$
t	Time	s	s
$\log_{10}{}^{-1} = \text{antilog}_{10}\, x = 10^x$			

*For cast iron, over the range of temperature covered by this standard, C shall be taken as 0.130.

14.5.2 ***Thermal Capability Calculation for Neutral Resistors***

14.5.2.1 *Respective Metric and English System Equations for Temperature Rise and Current Density, When Current is Constant.* The eddy-current loss may usually be ignored due to the high-resistance materials used in neutral resistors.

The temperature rise when the current is held constant, and all heat is assumed to be stored in the active material, shall be computed by the following equations, where all quantities have been defined in Table 10.

Metric

$$\theta = \frac{1}{a_0}\left[\log_{10}^{-1}\left(\frac{0.104\, a_0\, r_0\, t\, J_0^2}{C\delta}\right) - 1\right] + \theta_1 \qquad \text{(Eq 15)}$$

English

$$\theta = \frac{1}{a_0}\left[\log_{10}^{-1}\left(\frac{a_0\, r_0\, t\, J_0^2}{2430C\delta}\right) - 1\right] + \theta_1$$

For design purposes, it is more convenient to insert the desired temperature rise and derive the current density which will produce the desired temperature rise. Thus

Metric

$$J_0 = \sqrt{\frac{9.62C\delta \log_{10}\,[1 + a_0\,(\theta - \theta_1)]}{a_0 r_0 t}}$$

English (Eq 16)

$$J_0 = \sqrt{\frac{2430C\delta \log_{10}\,[1 + a_0\,(\theta - \theta_1)]}{a_0 r_0 t}}$$

NOTE: Equations 15 and 16 apply only when the temperature coefficient of resistance a_0 is substantially constant over the temperature range used, and must not be used for materials for which the coefficient varies greatly.

14.5.2.2 *Respective Metric and English System Equations for Temperature Rise and Current Density, When Voltage is Constant.* For some resistors (see 10.1.1) temperature rise is computed on the basis that constant voltage is maintained between the terminals, the current being allowed to decrease as the resistance increases with temperature. The temperature rise, with all heat stored in the active material and with constant voltage, shall be computed by the following equations where all quantities have been defined in Table 10.

Metric

$$\theta = \frac{1}{a_0}\left(-1 + \sqrt{1 + \frac{0.478\, J_0^2\, r_0 a_0 t}{C\delta}}\right) + \theta_1$$

(Eq 17)

English

$$\theta = \frac{1}{a_0}\left(-1 + \sqrt{1 + \frac{1.898 \times 10^{-3}\, J_0^2\, r_0 a_0 t}{C\delta}}\right) + \theta_1$$

For design purposes, it is more convenient to insert the desired temperature rise and derive the current density that will produce the temperature rise with the voltage maintained. Thus,

Metric

$$J_0 = \sqrt{\frac{4.18 C\delta}{r_0 t}\left[\theta - \theta_1 + a_0 \frac{(\theta - \theta_1)^2}{2}\right]}$$

(Eq 18)

English

$$J_0 = \sqrt{\frac{1054 C\delta}{r_0 t}\left[\theta - \theta_1 + a_0 \frac{(\theta - \theta_1)^2}{2}\right]}$$

NOTE: Equation 18 applies only when the temperature coefficient of resistance a_0 is substantially constant over the temperature range used, and must not be used for materials for which the coefficient varies greatly.