

An American National Standard

**IEEE Standard Requirements,
Terminology, and Test Code for
Step-Voltage and Induction-Voltage
Regulators**

Sponsor
**Transformers Committee
of the
IEEE Power Engineering Society**

Secretariat

**Institute of Electrical and Electronics Engineers
National Electrical Manufacturers Association**

Approved June 19, 1986
Reaffirmed May 1, 1992

Institute of Electrical and Electronics Engineers

Approved March 18, 1987
Reaffirmed December 2, 1992

American National Standards Institute

Copyright 1988 by

**The Institute of Electrical and Electronics Engineers, Inc
345 East 47th Street, New York, NY 10017, USA**

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the Technical Committees of the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE which have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least once every five years for revision or reaffirmation. When a document is more than five years old, and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason IEEE and the members of its technical committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE Standards Board
345 East 47th Street
New York, NY 10017
USA

IEEE Standards documents are adopted by the Institute of Electrical and Electronics Engineers without regard to whether their adoption may involve patents on articles, materials, or processes. Such adoption does not assume any liability to any patent owner, nor does it assume any obligation whatever to parties adopting the standards documents.

Foreword

(This Foreword is not a part of ANSI/IEEE C57.15-1986, IEEE Standard Requirements, Terminology, and Test Code for Step-Voltage and Induction-Voltage Regulators.)

Although step-voltage and induction-voltage regulators are specifically excluded from the provisions of ANSI/IEEE C57.12.00-1980 (IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers), it is clear that the similarity of the products makes it desirable to maintain many equivalent requirements for the two products. Thus, the original underlying objective of this revision was to bring the standard into conformity with more recently revised transformer standards, especially ANSI/IEEE C57.12.00-1980 and ANSI/IEEE C57.12.90-1980. Changes equivalent to those incorporated in the reference standards since 1968 have generally been included in this publication.

A second significant change relates to the control system of the regulator. Earlier issues had control requirements interspersed throughout the standard. A new Section 9 is composed as a stand-alone treatment of the control. New considerations pertaining to tests for control accuracy and surge withstand capability are included in that section.

A third newly treated topic is the explicit recognition of two basic configuration options available to the designer and the effect of choosing either option on the regulator losses. The basic alternatives have been defined as Type A and Type B regulators.

The reader will note, and perhaps question, the lack of recognition of 65°C rise liquid-immersed voltage regulators in this standard. Voltage regulators rated for 65°C rise have been available for some time where a sealed tank construction is utilized to preserve the integrity of the liquid dielectric. One philosophy is that a vented tank should be provided for voltage regulators because of the gases produced by arcing in routine operation. A vented system operated at 65°C rise would result in increased sludging and deterioration of the liquid dielectric over that experienced at 55°C rise. Very considerable discussion by the Working Group resulted in the consensus to continue the 55°C rise rating (only) for the liquid-immersed type of regulator.

The American National Standards Institute document is a voluntary consensus standard. Its use may become mandatory only when required by a duly constituted legal authority, or when specified in a contractual relationship. To meet specialized needs and to allow innovation, specific changes are permissible when mutually determined by the user and the producer, provided such changes do not violate existing laws, and are considered technically adequate for the function intended.

When this standard is used on a mandatory basis, the words “shall” and “must” indicate mandatory requirements; and the words “should” or “may” refer to matters that are recommended or permissive, but not mandatory.

The Accredited Standards Committee C57 had the following membership when it reviewed and approved this document:

The Working Group that prepared this standard had the following membership:

J. H. Harlow, *Chair*

R. W. Beckwith
W. F. Sheehan

E. C. Edwards
W. E. Wrenn

K. A. Mennerich
A. C. Wurdack

The Accredited Standards Committee C57 had the following membership when it reviewed and approved this document:

Roger Ensign, Chair
L. S. McCormick, Vice Chair
C. H. White, Secretary

<i>Organization Represented</i>	<i>Name of Representative</i>
Electric Light and Power.....	W. Cole (<i>Delegation Chairman</i>)
	G. Gunnels
	P. Orehek
	D. Soffrin (<i>Alt</i>)
	J. Sullivan (<i>Alt</i>)
	A. Velazquez
Institute of Electrical and Electronics Engineers	J. Bonucchi
	O. Compton (<i>Delegation Chairman</i>)
	J. Dutton
	R. Ensign
	F. Huber, Jr (<i>Alt</i>)
	L. McCormick
	W. Neiswander
	H. Smith (<i>Alt</i>)
	B. Stanleigh
	H. Tucker
National Electrical Manufacturers Association	P. Cacalloro (<i>Alt</i>)
	P. Dewever (<i>Alt</i>)
	J. Douglas
	W. Kendall
	K. Linsley (<i>Delegation Chairman</i>)
	G. Mayall
	W. McNutt
	J. Nay (<i>Alt</i>)
	T. Reback
	D. Strang (<i>Alt</i>)
	R. Uptegraff, Jr
Testing Laboratory Group	W. O'Grady
	R. Seelbach
Tennessee Valley Authority.....	L. Smith
US Department of the Navy	H. Stickley
US Department of Energy	D. Torgerson
US Department of the Interior	F. Cook, Sr
US Department of Agriculture REA	J. Arnold, Jr
American National Standards Institute	C. Zegers

The following persons were on the balloting committee that approved this document for submission to the IEEE Standards Board:

L. C. Aicher	D. A. Gillies	R. E. Minkwitz
H. E. Gabel	C. K. Miller	S. J. Antalis
S. P. Mehta	R. Allustiari	R. L. Grubb
D. J. Allan	A. W. Goldman	C. E. Mitchell
C. M. Gardam	C. Millian	E. H. Arjeski
N. J. Melton	R. J. Alton	G. Gunnels
B. F. Allen	W. F. Griffard	H. R. Moore

J. C. Arnold
G. Hall
H. J. Moser
R. Bancroft
J. H. Harlow
R. J. Musil
P. L. Bellaschi
T. K. Hawkins
W. H. Mutschler
S. Bennon
F. W. Heinrichs
E. T. Norton
J. J. Bergeron
J. J. Herrera
R. A. Olsson
J. V. Bonucchi
K. R. Highton
H. A. Pearce
J. D. Borst
P. J. Hoefler
D. Perco
G. H. Bowers
C. C. Honey
D. A. Roach
F. J. Brutt
C. Hurty
L. J. Savio
D. J. Cash
G. W. Iliff
R. L. Schmid
E. E. Chatter
R. G. Jacobsen
B. E. Smith

E. Chitwood
E. T. Jauch
L. R. Smith
O. R. Compton
D. C. Johnson
W. W. Stein
F. W. Cook
C. P. Kappeler
L. R. Stensland
J. L. Corkran
O. Keller
R. B. Stetson
D. W. Crofts
J. J. Kelly
F. R. Stockum
M. G. Daniels
R. C. Kieren
A. L. Tanton
R. C. Degeneff
A. D. Kline
R. C. Thomas
D. H. Douglas
W. Lampe
F. W. Thomason
J. D. Douglass
R. E. Liebich
J. A. Thompson
J. C. Dutton
H. F. Light
T. P. Traub
J. K. Easley
T. G. Lipscomb
D. E. Truax

J. A. Ebert
R. Little
R. E. Uptegraff
E. C. Edwards
L. W. Long
R. A. Veitch
R. L. Ensign
R. I. Lowe
L. B. Wagenaar
C. G. Evans
M. L. Manning
J. W. Walton
P. P. Falkowski
H. B. Margolis
S. A. Wiencek
W. R. Farber
J. W. Matthews
R. J. Whearty
H. G. Fischer
L. S. McCormick
A. Wilks
J. A. Forster
J. W. McGill
W. E. Wrenn
S. L. Foster
C. J. McMillen
A. C. Wurdack
M. Frydman
W. J. McNutt
D. A. Yannucci
G. G. McCrae

When the IEEE Standards Board approved this standard on June 19, 1986, it had the following membership:

John E. May, *Chair*
Irving Kolodny, *Vice Chair*
Sava I. Sherr, *Secretary*

James H. Beall
Jack Kinn
Robert E. Rountree
Fletcher J. Buckley
Joseph L. Koepfinger*
Martha Sloan
Paul G. Cummings
Edward Lohse
Oley Wanaselja

Donald C. Fleckenstein
Lawrence V. McCall
J. Richard Weger
Jay Forster
Donald T. Michael*
William B. Wilkens
Daniel L. Goldberg
Marco W. Migliaro
Helen M. Wood

Kenneth D. Hendrix
Stanley Owens
Charles J. Wylie
Irvin N. Howell
John P. Riganati
Donald W. Zipse
Frank L. Rose

*Member emeritus

CLAUSE	PAGE
1. Scope	1
1.1	1
1.2	1
1.3	1
1.4	1
2. Terminology	2
2.1 General	2
2.2 Transformers and Regulators	2
2.3 Rating	4
2.4 Insulation	4
2.5 Losses, Excitation Current, and Impedance Voltage	5
2.6 Testing	5
2.7 Construction	6
2.8 Polarity and Angular Displacement	7
2.9 Methods of Tank Construction	7
3. References	8
4. Service Conditions	9
4.1 Usual Service Conditions	9
4.2 Loading at Other Than Rated Conditions	10
4.3 Unusual Service Conditions	10
4.4 Frequency	12
5. Rating Data	12
5.1 Cooling Classes of Regulators	12
5.2 Ratings in kVA	13
5.3 Operating Voltage Limits	13
5.4 Supplementary Continuous-Current Ratings	17
5.5 Voltage Supply Ratios	19
5.6 Insulation Levels	19
5.7 Losses	20
5.8 Short-Circuit Requirements	20
5.9 Tests	21
6. Construction	22
6.1 Bushings	22
6.2 Terminal Markings	23
6.3 Diagram of Connections	23
6.4 Nameplates	25
6.5 Tank Grounding Provisions	26
6.6 Components and Accessories	27

CLAUSE	PAGE
7. Other Requirements	28
7.1 Other Supplementary Current Ratings.....	29
7.2 Other Short-Circuit Capability	29
7.3 Other Components and Accessories	29
8. Test Code	30
8.1 Resistance Measurements	30
8.2 Polarity Test	33
8.3 Ratio Tests.....	34
8.4 No-Load Losses and Excitation Current	36
8.5 Impedance and Load Losses	43
8.6 Dielectric Tests	46
8.7 Temperature Rise	56
8.8 Short-Circuit Tests	62
8.9 Calculated Data	65
9. Control System.....	67
9.1 General	67
9.2 Requirements	67
9.3 Construction	69
9.4 Test Code	70
Annex A (Informative) Unusual Temperature and Altitude Conditions	73
Annex B (Informative) Minimum Information to be Included in Certified Test Data	75
Annex C (Informative) Variable Transformers	76

An American National Standard

IEEE Standard Requirements, Terminology, and Test Code for Step-Voltage and Induction-Voltage Regulators

1. Scope

1.1

This standard is intended as a basis for the establishment of performance, limited electrical and mechanical interchangeability, and safety requirements of equipment described; and for assistance in the proper selection of such equipment.

1.2

This standard describes electrical, mechanical, and safety requirements of step-voltage and induction-voltage regulators, single-phase and three-phase, oil-filled and dry-type, not exceeding 2500 kVA of regulation for three-phase units, or not exceeding 833 kVA of regulation for single-phase units.

1.3

This standard does not apply to load tap-changing transformers.

1.4

When this document is used on a mandatory basis, the words “shall” and “must” indicate mandatory requirements; and the words “should” or “may” refer to matters that are recommended or permissive, but not mandatory.

NOTE — The Foreword of this voluntary consensus standard describes the circumstances in which the document may be used on a mandatory basis.

2. Terminology

2.1 General

2.1.1 Nominal System Voltage

A nominal value assigned to a system or circuit of a given voltage for the purpose of convenient designation. Note: The term *nominal voltage* designates the *line-to-line* voltage, as distinguished from the *line-to-neutral* voltage. It applies to all parts of the system or circuit.

2.1.2 Rated Voltage (of Equipment)

The voltage to which operating and performance characteristics are referred.

2.1.3 Primary Circuit

The primary circuit, in reference to a voltage regulator, is the circuit on the input side of the regulator.

2.1.4 Regulated Circuit

The regulated circuit, in reference to a voltage regulator, is the circuit on the output side of the regulator, where it is desired to control the voltage, or the phase relation, or both. Note: The voltage may be held constant at any selected point on the regulated circuit.

2.2 Transformers and Regulators

2.2.1 Autotransformer

An autotransformer is a transformer in which part of one winding is common to both the primary and the secondary circuits associated with that winding.

- 1) *Common, or Shunt, Winding of an Autotransformer.* That part of the autotransformer winding that is common to both the primary and secondary circuits.
- 2) *Series Winding of an Autotransformer.* That portion of the autotransformer winding that is not common to both the primary and secondary circuits, but is connected in series between the input and output circuits.

2.2.2 Voltage Regulator (Transformer Type)

An induction device having one or more windings in shunt with and excited from the primary circuits, and having one or more windings in series between the primary circuits and the regulated circuit, all suitably adapted and arranged for the control of the voltage, or of the phase angle, or of both, of the regulated circuit.

- 1) *Induction- Voltage Regulator.* A regulator having a primary winding in shunt and a secondary winding in series with a circuit for gradually adjusting the voltage or the phase relation, or both, of the circuit by changing the relative position of the exciting and series windings of the regulator.
- 2) *Step-Voltage Regulator.* A voltage regulator in which the voltage and (or) phase angle of the regulated circuit are controlled in steps by means of taps without interrupting the load.
 - a) *Type A Step-Voltage Regulator.* A step-voltage regulator in which the primary circuit is connected directly to the shunt winding of the regulator. The series winding is connected to the shunt winding and, in turn, via taps, to the regulated circuit, per Fig 1. In a Type A step-voltage regulator the core excitation varies because the shunt winding is connected across the primary circuit.

- b) *Type B Step-Voltage Regulator.* A step-voltage regulator in which the primary circuit is connected, via taps, to the series winding of the regulator. The series winding is connected to the shunt winding, which is connected directly to the regulated circuit, per Fig 2. In a Type B step-voltage regulator the core excitation is constant because the shunt winding is connected across the regulated circuit.

2.2.3 Voltage Regulating Relay

A voltage sensitive device that is used on an automatically operated voltage regulator to control the voltage of the regulated circuit.

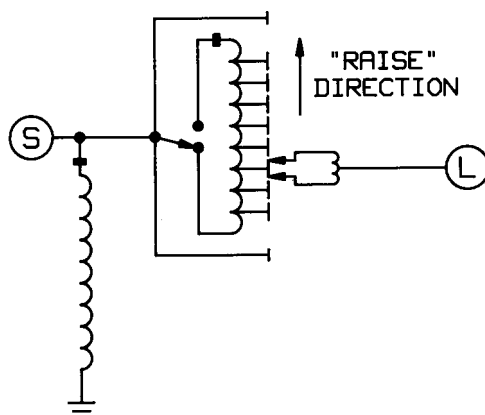


Figure 1—Schematic Diagram; Single-Phase, Type A Step-Voltage Regulator

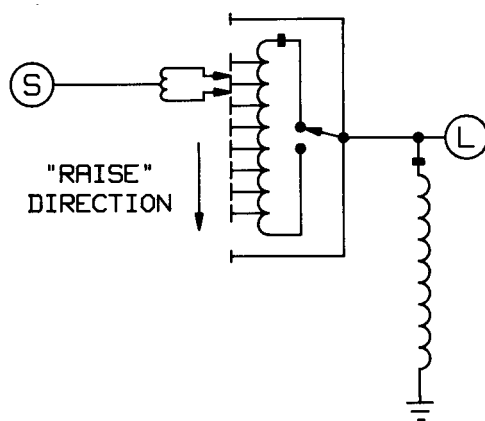


Figure 2—Schematic Diagram; Single-Phase, Type B Step-Voltage Regulator

2.2.4 Line-Drop Compensator

A device that causes the voltage regulating relay to vary the output voltage an amount that compensates for the impedance voltage drop in the circuit between the regulator and a predetermined location on the circuit (sometimes referred to as the *load center*).

2.2.5 Tap

A connection brought out of a winding at some point between its extremities to permit the changing of the voltage ratio.

2.3 Rating

2.3.1 Rating in kVA of a Voltage Regulator

The rating in kilovolt-amperes (kVA) of a single-phase voltage regulator is the product of the rated continuous load amperes and the rated “raise” or “lower” range of regulation in kilovolts (kV).

If the rated range and lower range of regulation are unequal, the larger shall be used in determining the rating in kVA.

The rating in kVA of a three-phase voltage regulator is the product of the rated load amperes and the rated range of regulation in kilovolts multiplied by 1.732.

2.3.2 Rated Voltage of a Winding

The rated voltage of a winding is the voltage to which operating and performance characteristics are referred.

2.3.3 Rated Voltage of a Step-Voltage or Induction-Voltage Regulator

The voltage for which the regulator is designed and on which performance characteristics are based.

2.3.4 Rated Voltage of the Series Winding of a Step-Voltage or Induction-Voltage Regulator

The voltage between terminals of the series winding, with rated voltage applied to the regulator, when the regulator is in the position that results in maximum voltage change and is delivering rated output at 80% lagging power factor.

2.3.5 Rated Range of Regulation of a Voltage Regulator

The amount that the regulator will raise or lower its rated voltage. *Note:* The rated range may be expressed in per unit, or in percent, of rated voltage; or it may be expressed in kilovolts.

2.4 Insulation

2.4.1 Liquid-Immersed Regulator

A liquid-immersed regulator is one in which the core and coils are immersed in an insulating liquid.

2.4.2 Dry-Type Regulator

A regulator in which the core, coils, and other components are cooled and insulated by air or a gas.

2.4.3 Liquid

The term “liquid” includes synthetic liquids as well as mineral transformer oil. *Note:* Some synthetic fluids may not be suitable for use in the arcing environment of a step-volt-age regulator.

2.5 Losses, Excitation Current, and Impedance Voltage

2.5.1 Total Losses

The total losses of a regulator are the sum of the no-load losses and the load losses. *Note:* Power required for cooling fans, oil pumps, space heaters, and other ancillary equipment is not included in the total loss. When specified, loss data on such ancillary equipment shall be furnished.

2.5.2 No-Load (Excitation) Losses

Those losses that are incident to the excitation of the regulator. No-load (excitation) losses include core loss, dielectric loss, conductor loss in the winding due to exciting current, and conductor loss due to circulating current in parallel windings. These losses change with the excitation voltage.

2.5.3 Excitation Current

The current that maintains the excitation of the regulator. *Note:* It may be expressed in amperes, per unit, or percent of the rated current of the regulator.

2.5.4 Load Losses of a Regulator

Those losses that are incident to the carrying of the load. *Note:* Load losses include I^2R loss in the windings due to load current, stray loss due to stray fluxes in the windings, core clamps, etc.

2.5.5 Impedance Voltage of a Regulator

The voltage required to circulate rated current through one winding of the regulator when another winding is short circuited, with the respective windings connected as for a rated voltage operation. *Note:* It is usually referred to the series winding, and then expressed in per unit, or percent, of the rated voltage of the regulator.

- 1) *Resistance Drop.*¹ The component of the impedance voltage in phase with the current.
- 2) *Reactance Drop.*² The component of the impedance voltage in quadrature with the current.
- 3) *Impedance Drop.*³ The phasor sum of the resistance voltage drop and the reactance voltage drop.

2.6 Testing

2.6.1 Dielectric Tests

Tests that consist of the application of a voltage higher than the rated voltage for a specified time for the purpose of determining the adequacy of insulating materials against breakdown, and spacing under normal conditions.

2.6.2 Ambient Temperature

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

¹For regulators, the resistance drop, the reactance drop, and the impedance drop are respectively the sum of the primary and secondary drops reduced to the same terms. They are usually expressed in per unit or percent, of the rated voltage of the regulator. Since they differ at different operating positions of the regulator, two values of impedance shall be considered in practice to be the tap positions that result in the minimum and the maximum impedance.

²See footnote 1.

³See footnote 1.

2.6.3 Thermometer Method of Temperature Determination

This method consists of the determination of the temperature by thermocouple or suitable thermometer, the instrument being applied to the hottest accessible part of the equipment.

2.6.4 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 a known temperature.

2.7 Construction

2.7.1 Indoor Regulator

A regulator that, because of its construction, must be protected from the weather.

2.7.2 Outdoor Regulator

A regulator designed for use outside of buildings.

2.7.3 Pole-Type Regulator

A regulator that is designed for mounting on a pole or similar structure.

2.7.4 Station-Type Regulator

A regulator designed for ground-type installations in stations or substations.

2.7.5 Dry-Type Air-Cooled Regulators

- 1) *Dry-Type Self-Cooled (Class AA)*. A regulator that is cooled by the natural circulation of air.
- 2) *Dry-Type Forced-Air-Cooled (Class AFA)*. A regulator that is cooled by the forced circulation of air through the core and coils.
- 3) *Dry-Type Self-Cooled Forced-Air-Cooled (Class AA/FA)*. A regulator that is cooled at the self-cooled rating by natural circulation of air through the core and coils and cooled at the forced-air-cooled rating by the forced circulation of air through the core and coils.

2.7.6 Liquid-Immersed Air-Cooled Regulators

- 1) *Liquid-Immersed Self-Cooled (Class OA)*. A regulator having its core and coil immersed in liquid and cooled by the natural circulation of air over the cooling surfaces.
- 2) *Liquid-Immersed Self-Cooled/ Forced-Air-Cooled (Class OA/FA and OA/FA/FA)*. A regulator having its core and coils immersed in liquid and having a self-cooled rating with cooling obtained by the natural circulation of air over the cooling surface and a forced-air-cooled rating with cooling obtained by the forced circulation of air over this same cooling surface.

2.7.7 Liquid-Immersed Air-Cooled / Forced-Liquid-Cooled Regulators

- 1) *Liquid Immersed Self-Cooled / Forced-Air-Cooled/Forced-Liquid-Cooled (Class OA/FA/FOA)*. A regulator having its core and coils immersed in liquid and having a self-cooled rating with cooling obtained by the natural circulation of air over the cooling surface; a forced-air-cooled rating with cooling obtained by the forced circulation of air over this same air cooling surface, and a forced-liquid-cooled rating with cooling obtained by the forced circulation of liquid over the core and coils and adjacent to this same cooling surface over which the cooling air is being forced-circulated.

2.7.8 Liquid-Immersed Water-Cooled Regulators (Class OW)

A regulator having its core and coils immersed in liquid and cooled by the natural circulation of the liquid over the water-cooled surface.

- 1) *Liquid-Immersed-Water-Cooled/Self-Cooled (Class OW/A)*. A regulator having its core and coils immersed in liquid and having a water-cooled rating with cooling obtained by the natural circulation of liquid over the water-cooled surface, and a self-cooled rating with cooling obtained by the natural circulation of air over the air-cooled surface.

2.8 Polarity and Angular Displacement

2.8.1 Polarity

The polarity of a regulator is intrinsic in its design. Polarity is correct if the regulator boosts the voltage in the “raise” range and bucks the voltage in the “lower” range. *Note:* The relative polarity of the shunt winding and the series windings of a step-voltage regulator will differ in the boost and buck modes between Type A and Type B regulators.

The relative instantaneous polarity of the main transformer windings, instrument transformer(s), and utility winding(s), as applicable, will be designated by an appropriate polarity mark on the diagram of connection on the nameplate, in accordance with 6.3.

2.8.2 Angular Displacement of Polyphase Regulator

The angular displacement is the time angle, expressed in degrees, between the line-to-neutral voltage of the reference identified source voltage terminal S_1 and the line-to-neutral voltage of the corresponding identified load voltage terminal L_1 .

The connection and arrangement of terminal markings for three-phase regulators in a wye connection has an angular displacement of zero degrees.

The connection and arrangement of terminal markings for three-phase regulators in a delta connection has an angular displacement of zero degrees when the regulator is on the neutral tap position. When the regulator is on a tap position other than neutral, the angular displacement will be other than zero degrees. *Note:* The angular displacement with the regulator connected in delta will be less than $\pm 5^\circ$ for a $\pm 10\%$ range of regulation.

2.9 Methods of Tank Construction

The following are accepted techniques for tank construction as it relates to oil-gas space systems.

2.9.1 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.

2.9.2 Gas-Oil Sealed System

An oil preservation system 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.

2.9.3 Inert Gas Pressure System

A system 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.

2.9.4 Conservator, or Expansion Tank, System

An oil preservation system 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.

2.9.5 Nonsealed System

A system in which a tank or compartment is vented to the atmosphere usually with two breather openings to permit circulation of air across the gas space above the oil. Circulation can be made unidirectional when a pipe is extended up through the oil and is heated by the oil to induce movement of air drawn from the outside into the gas space and across the oil to a breather on top.

3. References

When the following ANSI standards and guides referred to in this standard are superseded by a revision approved by the American National Standards Institute, the latest revision shall apply.

The following publications shall be used in conjunction with this standard:

- [1] ANSI C57.12.20-1981, American National Standard Requirements for Overhead-Type Distribution Transformers, 500 kVA and Smaller: High-Voltage 67 000 Volts and Below; Low-Voltage, 15 000 Volts and Below.⁴
- [2] ANSI C57.12.30-1977, American National Standard Requirements for Load-Tap-Changing Transformers 230 000 Volts and Below, 3750/4687 through 60 000/80 000/100 000 kVA, Three-Phase.
- [3] ANSI C84.1-1982, American National Standard Voltage Ratings for Electric Power Systems and Equipment (60 Hz).
- [4] ANSI/IEEE C37.90-1978, IEEE Standard Relays and Relay Systems Associated with Electric Power Apparatus.⁵
- [5] ANSI/IEEE C57.12.00-1980, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.
- [6] ANSI/IEEE C57.12.80-1978, IEEE Standard Terminology for Power and Distribution Transformers.
- [7] ANSI/IEEE C57.12.90-1980, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers and IEEE Guide for Short-Circuit Testing of Distribution and Power Transformers.
- [8] ANSI/IEEE C57.12.91-1979, IEEE Standard Test Code for Dry-Type Distribution and Power Transformers.
- [9] ANSI/IEEE C57.13-1978, IEEE Standard Requirements for Instrument Transformers.

⁴ANSI publications are available from the Sales Department of the American National Standards Institute, 1430 Broadway, New York, NY 10018.

⁵ANSI/IEEE publications can be obtained from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018, or from the Institute of Electrical and Electronics Engineers, Service Center, Piscataway, NJ 08854.

- [10] ANSI/IEEE C57.91-1981, IEEE Guide for Loading Mineral-Oil-Immersed Overhead and Pad-Mounted Distribution Transformers Rated 500 kVA and Less with 65°C or 55°C Average Winding Rise.
- [11] ANSI/IEEE C57.95-1984, IEEE Guide for Loading Liquid-Immersed, Step-Voltage and Induction-Voltage Regulators.
- [12] ANSI/IEEE C57.98-1986, IEEE Guide for Transformer Impulse Tests (Appendix to C57.21.90-1980).
- [13] ANSI/IEEE C57.104-1978, IEEE Guide for the Detection and Determination of Generated Gases in Oil-Immersed Transformers and their Relation to the Serviceability of the Equipment.
- [14] ANSI/IEEE C57.106-1977, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment.
- [15] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.
- [16] ANSI/IEEE Std 21-1976, IEEE Requirements and Test Procedures for Outdoor Apparatus Bushings.
- [17] ANSI/IEEE Std 24-1984, IEEE Standard Electrical, Dimensional, and Related Requirements for Outdoor Apparatus Bushings.
- [18] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronic Terms.
- [19] ANSI/IEEE Std 315-1975, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams.
- [20] ASTM D117-1987, Guide to Test Methods and Specifications for Electrical Insulating Oils of Petroleum Origin.⁶
- [21] ASTM D3487-82A, Specifications for Mineral Insulating Oil Used in Electrical Apparatus.

4. Service Conditions

4.1 Usual Service Conditions

Apparatus conforming to this standard shall be suitable for operation at rated kilovolt-amperes under the following usual service conditions.

4.1.1 Temperature

- 1) If air-cooled, 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.
- 2) If water-cooled, the temperature of the cooling water (ambient temperature) does not exceed 30°C, and the average temperature of the cooling water for any 24-hour period does not exceed 25°C. Minimum water temperature shall not be lower than 1°C, unless the cooling water includes antifreeze suitable for –20°C operation.
- 3) The top-liquid temperature of the regulator (when operating) shall not be lower than –20°C. Starting temperatures below –20°C are not considered as usual service conditions.

⁶ASTM publications are available from the Sales Department of the American Society for Testing and Materials, 1916 Race St, Philadelphia, PA 19103.

4.1.2 Altitude

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

4.1.3 Supply Voltage

The supply voltage wave shape shall be approximately sinusoidal, and the phase voltages supplying a poly-phase regulator shall be approximately equal in magnitude and time displacement.

4.1.4 Load Current

The load current shall be approximately sinusoidal. The harmonic factor shall not exceed 0.05 per unit. *Note:* “Harmonic factor” is defined in ANSI/IEEE C57.12.80-1978 [6].

4.1.5 Outdoor Operation

Unless otherwise specified, regulators shall be suitable for outdoor operation.

4.1.6 Tank or Enclosure Finish

Temperature limits and tests shall be based on the use of a nonmetallic pigment surface paint finish. *Note:* Metallic flake paints, such as aluminum, zinc, etc, have properties that increase the temperature rise of regulators, except in direct sunlight.

4.2 Loading at Other Than Rated Conditions

ANSI/IEEE C57.95-1984 [11] provides guidance for loading at other than rated conditions including:

- 1) Ambient temperatures higher or lower than the basis of rating
- 2) Short-time loading in excess of nameplate kVA with normal life expectancy
- 3) Loading that results in reduced life expectancy

NOTE — The guides mentioned above are not standards. They provide the best known general information for loading of regulators under various conditions based on typical winding insulation systems and are based upon the best engineering information available at the time of preparation. The guides discuss “limitations” of ancillary components other than windings that may limit the capability of regulators. When specified ancillary components and other construction features (cables, bushings, tap changers, oil expansion space, etc) shall be supplied such that they in themselves will not limit the loading to less than the capability of the windings.

4.3 Unusual Service Conditions

Conditions other than those described in 4.1 are considered unusual service and when present should be brought to the attention of those responsible for the design and application of the apparatus. Examples of some of these conditions are discussed in the following.

4.3.1 Unusual Temperature and Altitude Conditions

Regulators may be used at higher or lower ambient temperatures or at higher altitudes than specified in 4.1, but special consideration must be given to these applications. Appendix A and ANSI/IEEE C57.95-1984 [11] provide information on recommended practices.

4.3.2 Insulation at High Altitude

The dielectric strength of regulators that depend in whole or in part upon air for insulation decreases as the altitude increases due to the effect of decreased air density. When specified, regulators shall be designed with larger air spacings using the correction factors of Table 1 to obtain adequate air dielectric strength at altitudes above 3300 ft (1000 m).

- 1) The insulation level at 3300 ft (1000 m) multiplied by the correction factor from Table 1 must be not less than the required insulation level at the required altitude.
- 2) Bushings with additional length of creep distance shall be furnished when necessary for operation above 3300 ft (1000 m).

4.3.3 Other Unusual Service Conditions:

- 1) Damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, excessive moisture or dripping water, etc
- 2) Abnormal vibration, tilting, shock, or seismic conditions
- 3) Ambient temperatures outside of normal range
- 4) Unusual transportation or storage conditions
- 5) Unusual space limitations
- 6) Unusual maintenance problems
- 7) Unusual duty or frequency of operation, impact loading
- 8) Unbalanced alternating-current (ac) voltages, or departure of ac systems voltages from a substantially sinusoidal wave form
- 9) Loads involving abnormal harmonic currents such as those that may result where appreciable load currents are controlled by solidstate or similar devices; such harmonic currents may cause excessive losses and abnormal heating
- 10) Specified loading conditions (kVA outputs and power factors) associated with multi-winding transformers or autotransformers
- 11) Excitation exceeding either 110% rated voltage or 110% rated V/Hz
- 12) Planned short circuits as a part of regulator operating or relaying practice
- 13) Unusual short-circuit application conditions differing from those described as "usual" in 5.8
- 14) Unusual voltage conditions, including transient overvoltages, resonance, switching surges, etc, that may require special consideration in insulation design
- 15) Unusually strong magnetic fields
NOTE — Solar magnetic disturbances may result in the flow of telluric currents in regulator neutrals
- 16) Unusually high nuclear radiation
- 17) Parallel operation
NOTE — While parallel operation is not unusual, it is desirable that users advise the manufacturer if paralleling with other regulators is planned, and the characteristics of the transformers or reactors so involved
- 18) Direct current circulating within the regulator

4.3.3.1

The voltage regulating relay, depending on its construction, may be sensitive to altitude considerations. The manufacturer should be consulted where applications exceed 6600 ft (2000 m).

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

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

NOTE — Altitude of 15 000 ft is considered a maximum for standard regulators.

4.4 Frequency

Unless otherwise specified, regulators shall be designed for operation at a frequency of 60 Hz.

5. Rating Data

5.1 Cooling Classes of Regulators

5.1.1 Dry-Type Air-Cooled

- 1) Dry-Type Self-Cooled (Class AA)
- 2) Dry-Type Forced-Air-Cooled (Class AFA)
- 3) Dry-Type Self-Cooled / Forced-Air-Cooled (Class AA / FA)

5.1.2 Liquid-Immersed Air-Cooled

- 1) Liquid-Immersed Self-Cooled (Class OA)
- 2) Liquid-Immersed Self-Cooled / Forced-Air-Cooled (Class OA / FA)

5.1.3 Liquid-Immersed Water-Cooled

- 1) Liquid- Immersed Water- Cooled (Class OW)
- 2) Liquid- Immersed Water- Cooled / Self-Cooled (Class OW / A)

5.2 Ratings in kVA

Ratings in kVA for induction-type or step-type regulators are continuous and based on not exceeding the temperature limits covered in Table 2.

Ratings in kVA covered by this standard shall be expressed in the terms given in 5.2.1 and as specified in 5.2.2.

5.2.1 Terms in Which Rating is Expressed

The rating of a regulator of either the induction-type or step-type shall be expressed in the following terms:

- 1) kVA
- 2) Number of phases
- 3) Frequency
- 4) Voltage
- 5) Current
- 6) Voltage range in percent (raise and lower)

Regulators shall be approximately compensated for their internal regulation to provide the specified voltage range at rating in kVA and with an 80% lagging power factor load.

5.2.2 Preferred kVA Ratings

Preferred ratings of step-voltage regulators shall be based on operation at a frequency of 60 Hz and a voltage range of 10% raise and 10% lower, as given in Tables 3 and 4.

5.2.3 Supplementary kVA Ratings

In addition to their normal ratings, as defined in 5.2.2 regulators shall deliver rated kVA output without exceeding the specified temperature rise at the operating voltage given in Table 5.

5.3 Operating Voltage Limits

Regulators including their controls shall be suitable for operation within the following limits of voltage provided that the rated load current is not exceeded.

- 1) A minimum input voltage of 97.75 V times the ratio of voltage transformer
- 2) A maximum input voltage at rated load amperes of 1.05 times the rated input voltage of the regulator or 137.5 V times the ratio of voltage transformer, whichever is less
- 3) A maximum input voltage at no load of 1.10 times the rated input voltage of the regulator or 137.5 V times the ratio of voltage transformer, whichever is less
- 4) A minimum output voltage of 103.5 V times the ratio of voltage transformer
- 5) A maximum output voltage of 1.1 times the rated voltage of the regulator or 137.5 V times the ratio of voltage transformer whichever is less
- 6) The output voltage obtainable with a given input voltage is limited also by the regulator voltage range

Typical examples of the application of these rules to some common ratings of regulators are given in Table 6.

Table 2—Limits of Temperature Rise

Item	Type of Apparatus*	Winding Temperature Rise by Resistance, °C	Hottest-Spot Winding Temperature Rise, °C
(1)	55°C Rise Liquid-Immersed	55	65
	55°C Rise Dry-Type	55	65
	80°C Rise Dry-Type	80	110
	150°C Rise Dry-Type	150	180
(2)	Metallic parts in contact with or adjacent to the insulation shall not attain a temperature in excess of that allowed for the hottest spot of the windings adjacent to that insulation.		
(3)	Metallic parts other than those covered in Item (2) not attain excessive temperature rises.		
(4)	Where regulator is provided with sealed-tank, conservator, gas-oil-seal, or inert-gas-pressure systems, the temperature rise of the insulating oil shall not exceed 55°C when measured near the surface of the oil. The temperature rise of insulating oil in regulator not provided with the oil preservation systems listed above shall not exceed 50 °C when measured near the exposed surface of the oil.		

NOTE — In the context of Item 1, dry-type apparatus is understood to refer to induction-voltage regulators.

*Apparatus with specified temperature rise shall have an insulation system that has been proven by experience, general acceptance or accepted test.

Table 3—Preferred Ratings for Oil-Immersed Step-Voltage Regulators (Single-Phase)

Nominal System Voltage	BIL (kV)	kVA	Line Amperes
2400 / 4160Y	60	50	200
		75	300
		100	400
		125	500
		167	668
		250	1000
		333	1332
4800 / 8320Y	75	50	100
		75	150
		100	200
		125	250
		167	334
		250	500
		333	668
7620 / 13 200Y	95	38.1	50
		57.2	75
		76.2	100
		114.3	150
		167	219
		250	328
		333	438
		416	546
		509	668
		667	875
		833	1093
13 800	95	69	50
		138	100
		207	150
		276	200
		414	300
		552	400
14 400 / 24 940Y	150*	72	50
		144	100
		216	150
		288	200
		333	231
		432	300
		576	400
		667	463
19 920 / 34 500Y	150*	833	578
		100	50
		200	100
		333	167
		400	201
		667	334
		833	418

*Low-frequency test voltage 50 kV by induced test with neutral grounded.

Table 4—Preferred Ratings for Oil-Immersed Step-Voltage Regulators (Three-Phase)

Nominal System Voltage	BIL (kV)	Self-Cooled		Self-Cooled/Forced Cooled	
		kVA	Line Amperes	kVA	Lines Amperes
2400	45	500	1155	625	1443
		750	1732	937	2165
		1000	2309	1250	2887
2400 / 4160Y	60	500	667	937	833
		750	1000	1250	1250
		1000	1334		1667
4800	60	500	577	625	721
		750	866	937	1082
		1000	1155	1250	1443
7620 / 13200Y	95	500	219	625	274
		750	328	938	410
		1000	437	1250	546
		1500	656	2000	874
		2000	874	2667	1166
7970 / 13800Y	95	500	209	625	261
		750	313	937	391
		1000	418	1250	523
		1500	628	2000	837
		2000	837	2667	1116
		2500	1046	3333	1394
14400 / 24940Y	150	500	125.5	625	156.8
		750	188.3	937	235.4
		1000	251	1250	314
		1500	377	2000	502
		2000	502	2667	669
		2500	628	3333	837
19920 / 34500Y	150	500	83.7	625	104.6
		750	125.5	937	156.8
		1000	167	1250	209
		1500	251	2000	335
		2000	335	2667	447
		2500	418	3333	557
26560 / 46000Y	250	500	62.8	625	78.5
		750	94.1	937	117.6
		1000	126	1250	157
		1500	188	2000	251
		2000	251	2667	335
		2500	314	3333	419
39840 / 69000Y	350	500	41.8	625	52.5
		750	62.8	937	78.5
		1000	83.7	1250	105
		1500	126	2000	167
		2000	167	2667	223
		2500	209	3333	278

Table 5—Supplementary Ratings for Regulators

Rated Voltage	Operating Voltage
Single-Phase: 7620	7200
Three-Phase: 2500	2400
4330	4160
5000	4800
8660	8320
13 200	12 470
13 800	13 200

5.4 Supplementary Continuous-Current Ratings

Single-phase step-voltage regulators up to 19.9 kV, inclusive, rated 668 A and below shall have the following continuous-current ratings

or 668 A, whichever is less, on intermediate ranges of steps:

Range of Voltage Regulation (Percent)	Continuous- Current Rating (Percent)
10.0	100
8.75	110
7.5	120
6.25	135
5.0	160

Three-phase step-voltage regulators up to 13.8 kV, inclusive, rated 668 A and below have the following current ratings or 668 A, whichever is less, on intermediate ranges of steps:

Range of Voltage Regulation (Percent)	Continuous- Current Rating (Percent)
10.0	100
8.75	108
7.5	115
6.25	120
5.0	130

Table 6—Typical Examples of Operating Voltage Limits Including All Operating Voltage Tolerances

Nominal System Voltage	Regulator Voltage Rating (V)		Voltage Supply Ratio*	Input Voltage (V)			Output Voltage (V)	
	Single-Phase	Three-Phase		Min	Max at Rated-Load Amperes	Max at No-Load	Min	Max at Rated Load Amperes or at No-Load
2400	2500	2500	20	1955	2625	2750	2070	2750
2400/4160Y	2500	—	20	1955	2625	2750	2070	2750
2400/4160Y	—	4330	34.6	3380	4550	4760	3580	4760
4800	5000	5000	40	3910	5250	5500	4140	5500
7200	7620	—	60	5870	8000	8250	6210	8250
7200	—	8660	60	5870	8250	8250	6210	8250
4800/8320Y	5000	—	40	3910	5250	5500	4140	5500
8320	—	8660	69.3	6775	9090	8525	7170	9525
12 470	13 800	13 800	104	10 170	14 300	14 300	10 760	14 300
7200/12 470Y	7620	—	60	5870	8000	8250	6210	8250
7200/12 470Y	—	13 800	104	10 170	14 300	14 300	10 760	14 300
7620/13 200Y	7620	—	63.5	6210	8000	8380	6570	8380
7620/13 200Y	7620	—	66.3	6480	8000	8380	6860	8380
7620/13 200Y	—	13 800	110	10 750	13 860	14 520	11 400	14 520
7960/13 800Y	—	13 800	115	11 240	14 490	15 180	11 900	15 180
7960/13 800Y	7960	—	66.3	6480	8360	8760	6860	8760
13 200	13 800	13 800	110	10 750	14 490	15 125	11 400	15 840
14 400	13 800	13 800	120	11 730	14 490	15 180	12 420	15 180
14 400/24 940Y	14 400	—	120	11 730	15 120	15 840	12 420	15 840
19 920/34 500Y	19 920	—	166	16 230	20 920	21 910	17 180	21 910
14 400/24 940Y	—	24 940	208	20 330	26 190	27 435	21 530	27 435
19 920/34 500Y	—	34 500	287.5	28 100	36 225	37 950	29 760	37 950
26 560/46 000Y	—	46 000	373.3	36 490	48 300	50 600	38 640	50 600
39 840/69 000Y	—	69 000	575	56 210	72 450	75 900	59 510	75 900

*Where the listed potential ratio is not provided, an additional auxiliary transformer may be required.

NOTE — Example values are derived using procedures of 5.3.