

Recognized as an
American National Standard (ANSI)

IEEE Std C57.15-1999
(Revision of
IEEE Std C57.15-1986)

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

Sponsor

Transformers Committee
of the
IEEE Power Engineering Society

Approved 16 September 1999

IEEE-SA Standards Board

Abstract: Electrical, mechanical, and safety requirements of oil-filled, single- and three-phase voltage regulators not exceeding regulation of 2500 kVA (for three-phase units) or 833 kVA (for single-phase units) are covered.

Keywords: electrical, mechanical, safety, step-voltage regulators, test code

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Copyright © 2000 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 13 April 2000. Printed in the United States of America.

Print: ISBN 0-7381-1833-8 SH94799
PDF: ISBN 0-7381-1834-6 SS94799

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 IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) 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 that 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 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 societies and Standards Coordinating 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-SA Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Note: Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (978) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Introduction

(This introduction is not part of IEEE Std C57.15-1999, IEEE Standard Requirements, Terminology, and Test Code for Step-Voltage Regulators.)

The working group has undertaken the task to update this standard to

- a) Reflect the latest revisions of IEEE Std C57.12.00 and IEEE Std C57.12.90.
- b) Permit the winding temperature rise to increase from 55 °C to 65 °C for selected regulator (sealed) designs.
- c) Adapt the new IEEE approved format to ensure compatibility with the latest ISO and IEC standards.
- d) Eliminate references to induction voltage and dry-type regulators.
- e) Revise the list of standard sizes.

The working group membership for the preparation of this standard was as follows:

Craig A. Colopy, *Co-Chair*
Tom Diamantis, *Co-Chair*

Sam Aguirre
Glenn Andersen
Wallace Binder
Jerry H. Bishop
Kevin Edwards

Robert Grunert
Ken Hanus
James Harlow
Ron Jordan
Mark Loveless

Sam Michael
Tom Pekarek
Jerry Rowe
Ron Stahara
Ralph D. Wakeam

The following members of the balloting committee voted on this standard:

Sam Aguirre
David Aho
Glenn Andersen
Donald E. Ballard
Ron L. Barker
Mike Barnes
A. Bartek
Martin Baur
Edward A. Bertolini
Wallace Binder
Jerry H. Bishop
Alain Bolliger
Alvaro Cancino
Craig A. Colopy
Jerry L. Corkran
Tom Diamantis
Dieter Dohnal
Carlos Gaytan
Harry D. Gianakouros
Robert Grunert
N. Wayne Hansen
James Harlow
Theodore J. Hauptert
William R. Henning

Keith R. Highton
Philip J. Hopkinson
Bert R. Hughes
Rowland I. James
Gene Kallaur
Egon Koenig
Donald L. Lowe
William A. Maguire
K. T. Massouda
John W. Matthews
Nigel P. McQuin
Charles Patrick McShane
Joe Melanson
Sam Michael
C. Kent Miller
R. E. Minkwitz Sr.
Daniel H. Mulkey
Paul E. Orehek
Gerald A. Paiva
B. K. Patel
Sanjay Y. Patel
Wesley F. Patterson
Paulette A. Payne

Larry C. Pearson
Linden W. Pierce
Paul. Pillitteri
R. Leon Plaster
John R. Rossetti
Subhas Sarkar
Vic Shenoy
Hyeong Jin Sim
Kenneth R. Skinger
Leonard R. Smith
James E. Smith
James E. Smith
Steven L. Snyder
Craig L. Stiegemeier
Ron W. Stoner
Richard E. Sullivan
James A. Thompson
Thomas P. Traub
Subhash C. Tuli
Joseph J. Vaschak
Robert A. Veitch
Barry H. Ward
Christopher Wickersham
B. Scott Wilson

When the IEEE-SA Standards Board approved this standard on 16 September 1999, it had the following membership:

Richard J. Holleman, *Chair*
Donald N. Heirman, *Vice Chair*
Judith Gorman, *Secretary*

Satish K. Aggarwal
Dennis Bodson
Mark D. Bowman
James T. Carlo
Gary R. Engmann
Harold E. Epstein
Jay Forster*
Ruben D. Garzon

James H. Gurney
Lowell G. Johnson
Robert J. Kennelly
E. G. "Al" Kiener
Joseph L. Koepfinger*
L. Bruce McClung
Daleep C. Mohla
Robert F. Munzner

Louis-François Pau
Ronald C. Petersen
Gerald H. Peterson
John B. Posey
Gary S. Robinson
Akio Tojo
Hans E. Weinrich
Donald W. Zipse

*Member Emeritus

Also included is the following nonvoting IEEE-SA Standards Board liaison:

Robert E. Hebner

Greg Kohn
IEEE Standards Project Editor

Contents

1.	Overview.....	1
1.1	Scope.....	1
1.2	Purpose.....	1
1.3	Word usage	1
2.	References.....	1
3.	Definitions.....	2
4.	Service conditions.....	7
4.1	Usual service conditions	7
4.2	Loading at other than rated conditions.....	7
4.3	Unusual service conditions	8
4.4	Frequency.....	9
5.	Rating data	10
5.1	Cooling classes of regulators	10
5.2	Ratings in kVA	10
5.3	Operating voltage limits.....	11
5.4	Supplementary continuous-current ratings	11
5.5	Voltage supply ratios	11
5.6	Insulation levels	14
5.7	Losses.....	14
5.8	Short-circuit requirements	17
5.9	Tests	18
6.	Construction.....	19
6.1	Bushings.....	19
6.2	Terminal markings	19
6.3	Diagram of connections	21
6.4	Nameplates.....	21
6.5	Tank construction.....	22
6.6	Tank grounding provisions	22
6.7	Components and accessories.....	22
7.	Other requirements.....	23
7.1	Other supplementary continuous-current ratings.....	23
7.2	Other short-circuit capability	24
7.3	Other components and accessories	24
8.	Test code	25
8.1	Resistance measurements.....	25
8.2	Polarity test	28
8.3	Ratio tests.....	29
8.4	No-load losses and excitation current.....	31

8.5	Impedance and load losses	36
8.6	Dielectric tests	41
8.7	Temperature rise	52
8.8	Short-circuit tests	58
8.9	Data	62
9.	Control systems	65
9.1	General	65
9.2	Control device construction	65
9.3	Control system requirements	66
9.4	Tests	68
Annex A (informative) Unusual temperature and altitude conditions		71
Annex B (informative) Bushing and field dielectric tests		73
Annex C (informative) Bibliography		74

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

1. Overview

1.1 Scope

This standard describes electrical, mechanical, and safety requirements of oil-filled, single- and three-phase step-voltage regulators not exceeding a regulation of 2500 kVA (for three-phase units) or 833 kVA (for single-phase units). This standard does not apply to load tap-changing transformers.

1.2 Purpose

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

1.3 Word usage

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

2. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ANSI C57.12.20-1997, American National Standard for Transformers—Standard for Overhead Type Distribution Transformers, 500 kVA and Smaller: High Voltage, 34 500 Volts and Below; Low Voltage, 7970/13 800 Y Volts and Below.¹

¹ANSI C57.12.20-1997 is available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

ANSI C84.1-1995, American National Standard Voltage Ratings (60 Hz) for Electric Power Systems and Equipment.²

IEEE Std 4-1995, IEEE Standard Techniques for High-Voltage Testing.³

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

IEEE Std C37.90.1-1989 (Reaff 1994), IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems.

IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.12.80-1978 (Reaff 1992), IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90-1999, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.

IEEE Std C57.13-1993, IEEE Standard Requirements for Instrument Transformers.

IEEE Std C57.19.00-1991 (Reaff 1997), IEEE Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings.

IEEE Std C57.95-1984 (Reaff 1991), IEEE Guide for Loading Liquid-Immersed, Step-Voltage and Induction-Voltage Regulators (withdrawn).⁴

IEEE Std C57.98-1993, IEEE Guide for Transformer Impulse Tests.

IEEE Std C57.106-1991, IEEE Guide for Acceptance and Maintenance of Insulating Oil in Equipment (withdrawn).⁵

3. Definitions

For the purposes of this standard, the following terms and definitions apply. IEEE Std C57.12.80-1978⁶ and The IEEE Standards Dictionary of Electrical and Electronics Terms [B7]⁷ should be referenced for terms not defined in this clause.

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

3.2 angular displacement of polyphase regulator: (A) 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

²ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁴IEEE Std C57.95-1984 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (<http://www.global.ihs.com/>).

⁵IEEE Std C57.106-1991 has been withdrawn; however, copies can be obtained from Global Engineering.

⁶Information on references can be found in Clause 2.

⁷The numbers in brackets correspond to those of the bibliography in Annex C.

of the corresponding identified load voltage terminal L_1 . **(B)** The connection and arrangement of terminal markings for three-phase regulators in a wye connection has an angular displacement of zero degrees. **(C)** 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. The angular displacement with the regulator connected in delta will be less than $\pm 5^\circ$ for a $\pm 10\%$ range of regulation.

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

3.4 common winding: That part of the autotransformer winding that is common to both the primary and secondary circuits. *Syn:* **shunt winding.**

3.5 conservator 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 ancillary tank partly filled with oil and connected to the completely filled main tank. *Syn:* **expansion tank system.**

3.6 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 for spacing under normal conditions.

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

3.8 excitation losses: *See:* **no-load losses.**

3.9 expansion tank system: *See:* **conservator system.**

3.10 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 ancillary tank or tanks to form a gas-oil seal operating on the manometer principle.

3.11 impedance voltage drop: The phasor sum of the resistance voltage drop and the reactance voltage drop. For 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. Neutral position has the minimum amount of impedance.

3.12 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. Impedance voltage is usually referred to the series winding, and then that voltage is expressed in per unit, or percent, of the rated voltage of the regulator.

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

3.14 line-drop compensator: A device that causes the voltage regulating device 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).

3.15 liquid: Refers to both synthetic fluids and mineral transformer oil.

NOTE—Some synthetic fluids may be unsuitable for use in the arcing environment of a step-voltage regulator.

3.16 liquid-immersed regulator: A regulator in which the core and coils are immersed in an insulating liquid.

3.17 liquid-immersed self-cooled (Class ONAN): A regulator having its core and coil immersed in a liquid and cooled by the natural circulation of air over the cooling surfaces.

3.18 liquid-immersed self-cooled/forced-air-cooled (Classes ONAN/ONAF and ONAN/ONAF/ONAF): 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.

3.19 liquid-immersed self-cooled/forced-air-cooled/forced-liquid-cooled (Class ONAN/ONAF/OFAF): 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.

3.20 liquid-immersed water-cooled (Class ONWF): A regulator having its core and coils immersed in a liquid and cooled by the natural circulation of the liquid over the water-cooled surface.

3.21 liquid-immersed water-cooled/self-cooled (Class ONWF/ONAN): 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.

3.22 load losses of a regulator: Those losses that are incident to the carrying of the load. Load losses include I^2R loss in the windings due to load current, stray loss due to stray fluxes in the windings, core clamps, and so forth.

3.23 no-load losses: Those losses that are incident to the excitation of the regulator. No-load 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. *Syn:* **excitation losses.**

3.24 nominal system voltage: A nominal value assigned to a system or circuit of a given voltage for the purpose of convenient designation. 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.

3.25 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 of the tank.

3.26 outdoor regulator: A regulator designed for use outside of buildings.

3.27 polarity: (A) 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. 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. **(B)** 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 of IEEE Std C57.15-1999.

3.28 pole-type regulator: A regulator that is designed for mounting on a pole or similar structure.

3.29 primary circuit: The circuit on the input side of the regulator.

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

3.31 rated voltage (of equipment): The voltage to which operating and performance characteristics are referred.

3.32 rated voltage of a step-voltage regulator: The voltage for which the regulator is designed and on which performance characteristics are based.

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

3.34 rated voltage of the series winding of a step-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.

3.35 rating in kVA of a voltage regulator: (A) The rating that is the product of the rated load amperes and the rated “raise” or “lower” range of regulation in kilovolts (kV). If the rated raise and lower range of regulation are unequal, the larger shall be used in determining the rating in kVA. (B) 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.

3.36 reactance voltage drop: The component of the impedance voltage in quadrature with the current.

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

3.38 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.

3.39 resistance voltage drop: The component of the impedance voltage in phase with the current.

3.40 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 volume plus the oil volume remains constant. The regulator shall remain effectively sealed for top oil temperature range of -5°C to 105°C , continuous, and under the operating conditions described in IEEE Std C57.95-1984.

3.41 series winding: 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.

3.42 shunt winding: *See: common winding.*

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

3.44 step-voltage regulator (transformer type): An induction device having one or more windings in shunt with, and excited from, the primary circuit, and having one or more windings in series between the primary

circuit 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 in steps by means of taps without interrupting the load.

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

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

3.47 total losses: Those losses that are the sum of the no-load losses and the load losses. 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.

3.48 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 Figure 1. In a Type A step-voltage regulator, the core excitation varies because the shunt winding is connected across the primary circuit.

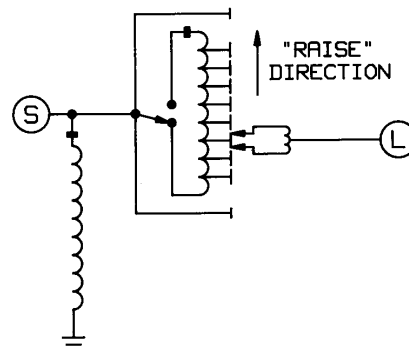


Figure 1—Schematic diagram of single-phase, Type A step-voltage regulator

3.49 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 Figure 2. In a Type B step-voltage regulator, the core excitation is constant because the shunt winding is connected across the regulated circuit.

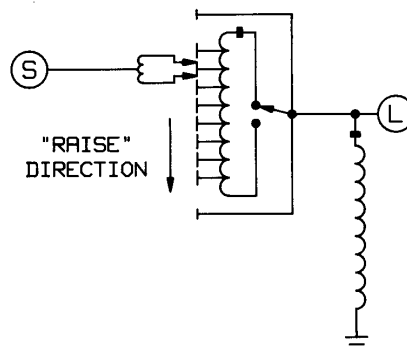


Figure 2—Schematic diagram of single-phase, Type B step-voltage regulator

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

4. Service conditions

4.1 Usual service conditions

Apparatus conforming to this standard shall be suitable for operation at rated kilovolt-amperes under the service conditions given in 4.1.1 through 4.1.6.

4.1.1 Temperature

- a) 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 h period does not exceed 30 °C.
- b) 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 h period does not exceed 25 °C. (Minimum water temperature shall not be lower than 1 °C, unless the cooling water includes anti-freeze suitable for –20 °C operation.)
- c) 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.)

4.1.2 Altitude

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

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. *Harmonic factor* is defined IEEE Std C57.12.80-1978.

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, and so forth, have properties that increase the temperature rise of regulators, except in direct sunlight.

4.2 Loading at other than rated conditions

IEEE Std C57.95-1984 provides guidance for loading at other than rated conditions including

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

NOTE—IEEE Std C57.95-1984 is a guide rather than a standard. It provides the best known general information for the loading of regulators under various conditions based on typical winding insulation systems, and is based upon the best engineering information available at the time of preparation. The guide discusses 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 4.3.1 through 4.3.3.

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. Annex A and IEEE Std C57.95-1984 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 a larger air spacing, using the correction factors of Table 1, to obtain adequate air dielectric strength at altitudes above 1000 m (3300 ft).

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

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

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

4.3.3 Other unusual service conditions

Other unusual service conditions include the following:

- a) Damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, excessive moisture or dripping water, etc.
- b) Abnormal vibration, tilting, shock, or seismic conditions.
- c) Ambient temperatures outside of normal range.
- d) Unusual transportation or storage conditions.
- e) Unusual space limitations.
- f) Unusual maintenance problems.
- g) Unusual duty or frequency of operation, impact loading.
- h) Unbalanced alternating-current (ac) voltages or departure of ac systems voltages from a substantially sinusoidal wave form.
- i) Loads involving abnormal harmonic currents, such as those that may result where appreciable load currents are controlled by solid-state or similar devices; such harmonic currents may cause excessive losses and abnormal heating.
- j) Specified loading conditions (kVA outputs and power factors) associated with multiwinding transformers or autotransformers.
- k) Excitation exceeding either 110% rated voltage or 110% rated V/Hz.
- l) Planned short circuits as a part of regulator operating or relaying practice.
- m) Unusual short-circuit application conditions differing from those described as usual in 5.8.
- n) Unusual voltage conditions, including transient overvoltages, resonance, switching surges, etc., that may require special consideration in insulation design.
- o) Unusually strong magnetic fields.

NOTE—Solar magnetic disturbances may result in the flow of telluric currents in regulator neutrals.

- p) Unusually high nuclear radiation.
- q) 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.

- r) Direct current circulating within the regulator.

4.3.3.1 Voltage regulating device

The voltage regulating device, depending on its construction, may be sensitive to altitude considerations. The manufacturer should be consulted where applications exceed 2000 m (6600 ft). Altitude of 4500 m (15 000 ft) is considered a maximum for standard regulators. Dielectric strength correction factors for altitudes greater than 1000 m (3300 ft) are shown in Table 1.

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 Liquid-immersed air-cooled

- a) Liquid-immersed self-cooled (Class ONAN)
- b) Liquid-immersed self-cooled/forced-air-cooled (Class ONAN/ONAF)

5.1.2 Liquid-immersed water-cooled

- a) Liquid-immersed water-cooled (Class ONWF)
- b) Liquid-immersed water-cooled/self-cooled (Class ONWF/ONAN)

5.2 Ratings in kVA

Ratings (in kVA) for step-voltage 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.

Table 2—Limits of temperature rise

Item	Type of apparatus ^a	Winding temperature rise by resistance (°C)	Hottest-spot winding temperature rise (°C)
1	55 °C rise liquid immersed (vented or sealed tank)	55	65
	65 °C rise liquid immersed (sealed tank)	65	80
2	Metallic parts in contact with or adjacent to the insulation shall not attain a temperature in excess of that allowed for the hottest spot of the windings adjacent to that insulation.		
3	Metallic parts other than those covered in item 2 shall not attain excessive temperature rises.		
4	Where a regulator is provided with a sealed-tank, conservator, or gas-oil-seal system, the temperature rise of the insulating oil shall not exceed 55 °C (55 °C rise unit) or 65 °C (65 °C rise unit) 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.		

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

5.2.1 Terms in which rating is expressed

The rating of a step-voltage regulator shall be expressed in the following terms:

- a) kVA
- b) Number of phases
- c) Frequency
- d) Voltage
- e) Current
- f) 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 Table 3 and Table 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. Voltage regulators with multitapped voltage transformers may be operated at nominal system voltages below the maximum rated voltage, and may deliver rated line amperes without exceeding the temperature limits of Table 2.

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:

- a) A minimum input voltage of 97.75 V times the ratio of voltage transformer.
- b) 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.
- c) 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.
- d) A minimum output voltage of 103.5 V times the ratio of voltage transformer.
- e) 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.
- f) 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 8.

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 continuous-current ratings or 668 A, whichever is less, on intermediate ranges of steps as shown in Table 6.

Three-phase step-voltage regulators up to 13.8 kV, inclusive, rated 668 A and below, have the following continuous-current ratings or 668 A, whichever is less, on intermediate ranges of steps as shown in Table 7.

5.5 Voltage supply ratios

Values of voltage supply ratios are given in Table 9. When a voltage supply ratio is specified that is not a preferred value shown in Table 9, an ancillary transformer may be furnished in the unit or control to modify the preferred ratio.

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
		416	1665
4800/8320Y	75	50	100
		75	150
		100	200
		125	250
		167	334
		250	500
		333	668
		416	833
7620/13 200Y	95	38.1	50
		57.2	75
		76.2	100
		114.3	150
		167	219
		250	328
		333	438
		416	546
		500	656
		667	875
		833	1093
13 800	95	69	50
		138	100
		207	150
		276	200
		414	300
		552	400
14 400/24 940Y	150 ^a	72	50
		144	100
		216	150
		288	200
		333	231
		432	300
		576	400
		667	463
		833	578
19 920/34 500Y	150	100	50
		200	100
		333	167
		400	201
		667	334
		833	418

^aLow-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	Line amperes
2400	45	500 750 1000	1155 1732 2309	625 937 1250	1443 2165 2887
2400/4160Y	60	500 750 1000	667 1000 1334	625 937 1250	833 1250 1667
4800	60	500 750 1000	577 866 1155	625 937 1250	721 1082 1443
7620/13 200Y	95	500 750 1000 1500 2000	219 328 437 656 874	625 938 1250 2000 2667	274 410 546 874 1166
7970/13 800Y	95	500 750 1000 1500 2000 2500	209 313 418 628 837 1046	625 937 1250 2000 2667 3333	261 391 523 837 1116 1394
14 400/24 940Y	150	500 750 1000 1500 2000 2500	125.5 188.3 251 377 502 628	625 937 1250 2000 2667 3333	156.8 235.4 314 502 669 837
19 920/34 500Y	150	500 750 1000 1500 2000 2500	83.7 125.5 167 251 335 418	625 937 1250 2000 2667 3333	104.5 156.8 209 335 447 557
26 560/46 000Y	250	500 750 1000 1500 2000 2500	62.8 94.1 126 188 251 314	625 937 1250 2000 2667 3333	78.5 117.6 157 251 335 419
39 840/69 000Y	350	500 750 1000 1500 2000 2500	41.8 62.8 83.7 126 167 209	625 937 1250 2000 2667 3333	52.5 78.5 105 167 223 278

Table 5—Supplementary voltage ratings for regulators

Number of phases	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

Table 6—Supplementary continuous-current ratings for single-phase regulators

Range of voltage regulation (%)	Continuous-current rating (%)
10.0	100
8.75	110
7.5	120
6.25	135
5.0	160

Table 7—Supplementary continuous-current ratings for three-phase regulators

Range of voltage regulation (%)	Continuous-current rating (%)
10.0	100
8.75	108
7.5	115
6.25	120
5.0	130

5.6 Insulation levels

Regulators shall be designed to provide coordinated low-frequency and lightning impulse insulation levels on line terminals, and low-frequency insulation levels on neutral terminals. The identity of a set of coordinated levels shall be its basic impulse insulation level (BIL), as shown in Table 10.

NOTE—When single-phase regulators are connected in wye, the neutral of the regulator bank shall be connected to the neutral of the system. A delta connection of the regulators is commonly recommended when the system is three-wire ungrounded.

5.7 Losses

The losses specified by the manufacturer shall be the no-load (excitation) and total losses, as defined in 3.23 and 3.47, respectively.

Table 8—Typical examples of operating voltage limits including all operating voltage tolerances

Nominal system voltage	Regulator voltage rating (V)		Voltage supply ratio ^a	Input voltage (V)			Output voltage (V)	
	Single-phase	Three-phase		Minimum	Maximum at rated-load amperes	Maximum at no-load	Minimum	Maximum at rated-load amperes or at no-load
2400 2400 / 4160Y 2400 / 4160Y	2500 2500 —	2500 — 4330	20 20 34.6	1955 1955 3380	2625 2625 4550	2750 2750 4760	2070 2070 3580	2750 2750 4760
4800 7200 7200 4800 / 8320Y 8320	5000 7620 — 5000 —	5000 — 8660 — 8660	40 60 60 40 69.3	3910 5870 5870 3910 6775	5250 8000 8250 5250 9090	5500 8250 8250 5500 9525	4140 6210 6210 4140 7170	5500 8250 8250 5500 9525
12 470 7200 / 12 470Y 7200 / 12 470Y	13 800 7620 —	13 800 — 13 800	104 60 104	10 170 5870 10 170	14 300 8000 14 300	14 300 8250 14 300	10 760 6210 10 760	14 300 8250 14 300
7620 / 13 200Y 7620 / 13 200Y 7620 / 13 200Y 7960 / 13 800Y 7960 / 13 800Y	7620 7620 — — 7690	— — 13 200 13 800 —	63.5 66.3 110 115 66.3	6210 6480 10 750 11 240 6480	8000 8000 13 860 14 490 8360	8380 8380 14 520 15 180 8760	6570 6860 11 400 11 900 6860	8380 8380 14 520 15 180 8760
13 200 14 400	13 800 13 800	13 800 12 800	110 120	10 750 11 730	14 490 14 490	15 125 15 180	11 400 12 420	15 125 15 180
14 400 / 24 940Y 19 920 / 34 500Y	14 400 19 920	— —	120 166	11 730 16 230	15 120 20 920	15 840 21 910	12 420 17 180	15 840 21 910
14 400 / 24 940Y 19 920 / 34 500Y	— —	24 940 34 500	208 287.5	20 330 28 100	26 190 36 225	27 435 37 950	21 530 29 760	27 435 37 950
26 560 / 46 000Y 39 840 / 69 000Y	— —	46 000 69 000	373.3 575	36 490 56 210	48 300 72 450	50 600 75 900	38 640 59 510	50 600 75 900

^aWhere the listed potential ratio is provided, an additional ancillary transformer may be required.

NOTE—Example values are derived using procedures of 5.3.

Table 9—Values of voltage supply ratios

Voltage rating of regulator		Values of voltage supply ratios
Single-phase	Three-phase	
2500	2500	20, 20.8
—	4330	34.6, 36.1
5000	5000	40, 41.7
7620	—	60, 63.5
7690	—	66.3
—	8660	69.3, 72.2
—	13 200	110, 104
13 800	13 800	115, 110
14 400	—	120
19 920	—	166
—	24 940	208
—	34 500	287.5
—	46 000	383.3
—	69 000	575

Table 10—Interrelationships of dielectric insulation levels for regulators used on systems with BIL ratings of 350 kV and below

BIL kV	Low-frequency voltage insulation level (kV rms)	Impulse levels		
		Full wave	Chopped wave	
		(kV crest)	(kV crest)	Minimum time to flashover (μs)
45	15	45	54	1.5
60	19	60	69	1.5
75	26	75	88	1.6
95	34	95	110	1.8
150	50	150	175	3.0
200	70	200	230	3.0
250	95	250	290	3.0
350	140	350	400	3.0

5.7.1 Total losses

The total losses of a regulator shall be the sum of the no-load (excitation) and load losses.

5.7.2 Tolerance for losses

Unless otherwise specified, the losses represented by a test of a regulator shall be subject to the following tolerances: the no-load losses of a regulator shall not exceed the specified no-load losses by more than 10%, and the total losses of a regulator shall not exceed the specified total losses by more than 6%. Failure to meet the loss tolerances shall not warrant immediate rejection but lead to consultation between purchaser and manufacturer about further investigation of possible causes and the consequences of the higher losses.

NOTE—Since losses will differ at different operating positions of the regulator, care must be exercised in the consideration of tap position with losses. Some styles of step-voltage regulators will exhibit appreciable change in load loss when boosting versus bucking, or will exhibit appreciable change in no-load loss on alternate tap positions. See 5.7.3.

5.7.3 Determination of losses and excitation current

No-load (excitation) losses and exciting current shall be determined for 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, current, and frequency and shall be corrected to a reference temperature equal to the sum of the limiting (rated) winding temperature rise by resistance from Table 2 plus 20 °C.

Since losses may be very different at different operating positions and with various design options, losses shall be considered in practice as the sum of no-load and load losses where

- a) No-load loss is the average of no-load loss in the neutral and next adjacent boost position with rated voltage applied to the shunt or series winding for regulators that do not include a series transformer.
NOTE—It will be apparent, in the case of a Type B step-voltage regulator that is on the next adjacent boost position, that the excitation voltage applied at the source terminal will be higher at the shunt winding. Care must be exercised to assure that rated excitation is present on the shunt winding; this may be accomplished by exciting the regulator from the load terminal.
- b) No-load loss is reported for neutral position, maximum boost position, and position adjacent to maximum boost position for regulators that include a series transformer.
- c) Load loss is the average load loss in both the maximum and adjacent-to-maximum buck positions, and the maximum and adjacent-to-maximum boost positions (that is, four positions) with rated current in the windings.

5.8 Short-circuit requirements

5.8.1 General

Step-voltage regulators shall be designed and constructed to withstand the mechanical and thermal stresses produced by external short circuits of 25 times the base rms symmetrical rated load current.

- a) The short-circuit current shall be assumed to be displaced from zero insofar as determining the mechanical stresses. The maximum peak value of the short-circuit current that the regulator is required to withstand is equal to 2.26 times the required rms symmetrical short-circuit current.
- b) The short-circuit current shall be assumed to be a duration of 2 s to determine the thermal stresses.

It is recognized that short-circuit withstand capability can be adversely affected by the cumulative effects of repeated mechanical and thermal over-stressing, as produced by short-circuits and loads above the name-

plate rating. Since means are not available to continuously monitor and quantitatively evaluate the degrading effects of such duty, short-circuit tests, when required, should be performed prior to placing the regulator in service. It is recommended that current-limiting reactors be installed, when necessary, to limit the short-circuit current to a maximum of 25 times the normal full-load current.

5.8.2 Mechanical capability demonstration

It is not the intent of this subclause that every regulator design be short-circuit tested to demonstrate adequate construction. When specified, tests of short-circuit mechanical capability shall be performed as described in 8.8.

5.8.3 Thermal capability of regulators for short-circuit conditions

The temperature of the conductor material in the windings of regulators under the short-circuit conditions specified in 5.8.1 item b), as calculated by methods described in 8.9.4, shall not exceed 250 °C for a copper conductor or 200 °C for an EC aluminum conductor. A maximum temperature of 250 °C shall be allowed for aluminum alloys that have resistance to annealing properties at 250 °C, equivalent to EC aluminum at 200 °C, or for application of EC aluminum where the characteristics of the fully annealed material satisfy the mechanical requirements. In setting these temperature limits, the following factors were considered:

- a) Gas generation from oil or solid insulation
- b) Conductor annealing
- c) Insulation aging

5.9 Tests

Except as specified in 5.9.1, 5.9.2, and Clause 8, tests shall be performed as specified in IEEE Std C57.12.00-1993 and in IEEE Std C57.12.90-1999. Tests are divided into two categories: routine and design. Routine tests are made for quality control by the manufacturer to verify during production that the product meets the design specifications. Design tests are made to determine the adequacy of the design of a particular type, style, or model of equipment or its component parts to meet its assigned rating under normal service conditions or under special conditions if specified.

5.9.1 Routine tests

The routine tests given in the following list shall be made on all regulators. The order of listing does not necessarily indicate the sequence in which the tests shall be made.

- a) Resistance measurements of all windings
- b) Ratio tests on all tap connections
- c) Polarity test
- d) No-load (excitation) loss at rated voltage and rated frequency
- e) Excitation current at rated voltage and rated frequency
- f) Impedance and load loss at rated current and rated frequency
- g) Lightning impulse tests specified in 8.6.3
- h) Applied-voltage tests
- i) Induced-voltage tests
- j) Insulation power factor tests
- k) Insulation resistance tests