BS IEC 60076-21:2011

Power transformers

Part 21: Standard requirements, terminology, and test code for step-voltage regulators

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National foreword

This British Standard is the UK implementation of IEC 60076-21:2011.

The UK participation in its preparation was entrusted to Technical Committee PEL/14, Power transformers.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Power transformers –
Part 21: Standard requirements, terminology, and test code for step-voltage regulators

INTERNATIONAL
ELECTROTECHNICAL
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Contents

1. Overview 1
1.1 Scope 1
1.2 Purpose 1
1.3 Word usage 1

2. Normative references 2

3. Definitions 3

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 voltage regulators 12
5.2 Ratings 13
5.3 Supplementary continuous-current ratings 17
5.4 Taps 18
5.5 Operating voltage limits 18
5.6 Voltage supply ratios 20
5.7 Insulation levels 20
5.8 Losses 21
5.9 Short-circuit requirements 22
5.10 Tests 23

6. Construction 24
6.1 Bushings 24
6.2 Terminal markings 25
6.3 Diagram of connections 26
6.4 Nameplates 26
6.5 Tank construction 27
6.6 Components and accessories 31

7. Other requirements 32
7.1 Other supplementary continuous-current ratings 32
7.2 Other components and accessories 32

8. Test code 33
8.1 Resistance measurements 34
8.2 Polarity test 36
8.3 Ratio tests 37
8.4 No-load losses and excitation current 40
8.5 Load losses and impedance voltage 45
8.6 Dielectric tests 51
8.7 Temperature-rise tests 64
8.8 Short-circuit tests 73
8.9 Calculated data 77

9. Control systems 81

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Documents
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Full document details: BS IEC 60076-21:2011

9.1 General 81
9.2 Control device construction 81
9.3 Control system requirements 82
9.4 Tests....83

Annex A (informative) Unusual temperature and altitude conditions 87

Annex B (informative) Field dielectric tests....89

Annex C (informative) Bibliography....90

Annex D (informative) IEEE List of Participants 92

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POWER TRANSFORMERS –

Part 21: Standard requirements, terminology, and test code for step-voltage regulators

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The text of this standard is based on the following documents:

IEEE Std	FDIS	Report on voting
C57.15-2009	14/688/FDIS	14/697/RVD

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

Sponsor

Transformers Committee
of the
IEEE Power & Energy Society

Approved 11 September 2009

IEEE-SA Standards Board

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Abstract: Description of design types, tables of 50 Hz and 60 Hz ratings, supplementary ratings, construction, and available accessories are provided. Methods for performing routine and design tests applicable to liquid-immersed single and three-phase step-voltage regulators are described. Winding resistance measurements, polarity tests, insulation power factor and resistance tests, ratio tests, no load loss and excitation current measurements, impedance and load loss measurements, dielectric tests, temperature tests, routine and design impulse tests, short-circuit tests, control tests, calculated data, and certified test data are covered.
Keywords: control, design tests, position indicator, routine tests, series transformer, tap changer, Type A, Type B, voltage regulator

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IEEE Introduction

This introduction is not part of IEEE Std C57.15-2009, 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 referenced documents IEEE Std C57.12.00™ [B13] and IEEE Std C57.12.90™ [B16], and eliminate references to these standards in this standard IEEE Std C57.15-2009 and duplicate applicable text. [1]

b) Adapt the new IEEE approved format to ensure compatibility with the latest ISO and IEC standards.

c) Include references to applicable IEC standards and keep IEEE standard references to a minimum. This assists in setting up document as a possible candidate for a dual logo (IEC/IEEE).

d) Update tables of preferred ratings; include 50 Hz ratings. Ratings of 2.4 kV (45 BIL), 46 kV (250 BIL), and 69 kV (350 BIL) have been removed from the three-phase 60 Hz voltage regulator rating Table 5 (Table 4 in 1999 edition) due to historical inactivity of requests from users for ratings.

e) Add bushing terminal connectors for current ratings of 669 A to 2000 A.

f) Clarify Type A and Type B designs and their resulting voltage regulation per extreme tap positions.

g) Review short-circuit requirements for distribution and substation applications and revise where applicable.

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[1] The numbers in brackets correspond to those of the bibliography in Annex C.

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Part 21: Standard requirements, terminology, and test code for step-voltage regulators

1. Overview

1.1 Scope

This standard describes electrical and mechanical requirements of liquid-immersed, single- and three-phase, step-voltage regulators, not exceeding a regulation of 3000 kVA (for three-phase units) or 1000 kVA (for single-phase units). This standard does not apply to load tap-changing power transformers.

1.2 Purpose

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

1.3 Word usage

When this standard is used on a mandatory basis, the word *shall* indicates mandatory requirements. The words should or ma*y* refer to matters that are recommended or permitted but not mandatory.

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2. Normative references

The following referenced documents are indispensable for the application of this standard (i.e., they must be understood and used; therefore, each referenced document is cited in text and its relationship to this standard is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

Where references to both IEC and IEEE standards are made, users shall specify the standard they require, and equipment shall be manufactured to meet that standard.

IEC 60068-2-1, Environmental testing—Part 2-1: Tests—Test A: Cold.[1]

IEC 60068-2-2, Environmental testing—Part 2-2: Tests—Test B: Dry heat.

IEC 60068-2-30, Environmental testing—Part 2-30: Tests—Test Db: Damp heat, cyclic (12 h + 12 h cycle).

IEC 60214-1, Tap-changers—Part 1: Performance requirements and test methods.

IEC 60255-5, Electrical Relays—Part 5: Insulation coordination for measuring relays and protection equipment—Requirements and tests.

IEC 60255-21-1, Electrical Relays—Part 21: Vibration, shock, bump and seismic tests on measuring relays and protection equipment—Section one: Vibration tests (sinusoidal).

IEC 60255-22-1, Measuring relays and protection equipment—Part 22-1: Electrical disturbance tests—1 MHz burst immunity tests.

IEC 60255-22-2, Measuring relays and protection equipment—Part 22-2: Electrical disturbance tests—Electrostatic discharge tests.

IEC 60255-22-3, Measuring relays and protection equipment—Part 22-3: Electrical disturbance tests—Radiated electromagnetic field immunity.

IEC 60255-22-4, Measuring relays and protection equipment—Part 22-4: Electrical disturbance tests—Electrical fast transient/burst immunity test.

IEC 60255-22-5, Measuring relays and protection equipment—Part 22-5: Electrical disturbance tests for measuring relays and protection equipment—Surge immunity test.

IEC 60255-22-6, Electrical relays—Part 22-6: Electrical disturbance tests for measuring relays and protection equipment—Immunity to conducted disturbances induced by radio frequency fields.

IEEE Std 4™, IEEE Standard Techniques for High-Voltage Testing.[2, 3]

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IEEE Std C37.90.1™, IEEE Standard Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus.

IEEE Std C37.90.2™, IEEE Standard for Withstand Capability of Relay Systems to Radiated Electromagnetic Interference from Transceivers.

IEEE Std C37.90.3™, IEEE Standard Electrostatic Discharge Tests for Protective Relays.

IEEE Std C57.12.31™, IEEE Standard for Pole-Mounted Equipment—Enclosure Integrity.

IEEE Std C57.91™, IEEE Guide for Loading Mineral-Oil-Immersed Transformers.

IEEE Std C57.98™, IEEE Guide for Transformer Impulse Tests.

IEEE Std C57.131™, IEEE Standard Requirements for Load Tap Changers.

3. Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards Dictionary: Glossary of Terms & Definitions* should be referenced for terms not defined in this clause.[4]

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

NOTE 1—For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate neighborhood of the equipment.[5]

NOTE 2—For air cooled equipment with forced ventilation, the ambient temperature is taken as that of the in-going air.

angular displacement of a three-phase voltage regulator or bank of three single-phase voltage regulators: (**A**) The time angle, expressed in degrees, between the line-to-neutral voltage of the reference source voltage terminal and the line-to-neutral voltage of the corresponding load voltage terminal. (**B**) The connection and arrangement of terminal markings for a three-phase voltage regulator or bank of three single-phase voltage regulators in a wye connection has an angular displacement of zero degrees. (**C**) The connection and arrangement of terminal markings for a three-phase voltage regulator or bank of three single-phase voltage regulators in a delta connection has an angular displacement of zero degrees when the voltage regulators are on the neutral tap position. When the voltage regulators are on a tap position other than neutral, the angular displacement will be other than zero degrees. The angular displacement with the voltage regulators connected in delta will be less than ±5° for a ±10% range of regulation.

autotransformer: A transformer in which at least two windings have a common section.

average winding temperature rise of a voltage regulator: The arithmetic difference between the average winding temperature of the hottest winding and the ambient temperature.

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

[4] *The IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at http://shop.ieee.org/.
[5] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

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current transformer: An instrument transformer intended to have its primary winding connected in series with the conductor carrying the current to be measured or controlled.

dielectric withstand voltage tests: Tests made to determine the ability of insulating materials and spacings to withstand specified overvoltages for a specified time without flashover or puncture.

NOTE—The purpose of the tests is to determine the adequacy against breakdown of insulating materials and spacings under normal or transient conditions.

excitation current: The current that flows in any winding used to excite the voltage regulator when all other windings are open-circuited. It is usually expressed in percent of the rated current of the voltage regulator.

impedance drop: The phasor sum of the resistance voltage drop and the reactance voltage drop.

NOTE—For voltage 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 determined from the load-loss measurements and are usually expressed in per unit or percent of the rated voltage of the voltage regulator. Since they differ at different operating positions of the voltage 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.

impedance voltage of a voltage regulator: The voltage required to circulate rated current through one winding of the voltage regulator when another winding is short-circuited, with the respective windings connected as for a rated voltage operation.

NOTE—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 voltage regulator.

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

liquid: Refers to synthetic fluid, natural ester-based fluid, and mineral oil.

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

liquid-immersed self-cooled (Class KNAN): A voltage regulator having its core and coil immersed in a liquid with fire point > 300 °C and cooled by the natural circulation of air over the cooling surfaces.

liquid-immersed self-cooled (Class ONAN): A voltage regulator having its core and coil immersed in a liquid with fire point ≤ 300 °C and cooled by the natural circulation of air over the cooling surfaces.

liquid-immersed self-cooled/forced-air-cooled (Classes KNAN/KNAF and KNAN/KNAF/KNAF): A voltage regulator having its core and coils immersed in liquid with fire point > 300 °C 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.

liquid-immersed self-cooled/forced-air-cooled (Classes ONAN/ONAF and ONAN/ONAF/ONAF): A voltage regulator having its core and coils immersed in liquid with fire point ≤ 300 °C 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.

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liquid-immersed self-cooled/forced-air-cooled/forced-liquid-cooled (Class KNAN/KNAF/KFAF): A voltage regulator having its core and coils immersed in liquid with fire point > 300 °C 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.

liquid-immersed self-cooled/forced-air-cooled/forced-liquid-cooled (Class ONAN/ONAF/OFAF): A voltage regulator having its core and coils immersed in liquid with fire point ≤ 300 °C 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.

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

liquid-immersed water-cooled (Class KNWF): A voltage regulator having its core and coils immersed in a liquid with fire point > 300 °C and cooled by the natural circulation of the liquid over the water-cooled surface.

liquid-immersed water-cooled (Class ONWF): A voltage regulator having its core and coils immersed in a liquid with fire point ≤ 300 °C and cooled by the natural circulation of the liquid over the water-cooled surface.

liquid-immersed water-cooled/self-cooled (Class KNWF/KNAN): A voltage regulator having its core and coils immersed in liquid with fire point > 300 °C 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.

liquid-immersed water-cooled/self-cooled (Class ONWF/ONAN): A voltage regulator having its core and coils immersed in liquid with fire point ≤ 300 °C 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.

load losses: Those losses that are incident to the carrying of a specified load. Load losses include I^2R loss in the current carrying parts (windings, leads, busbars, bushings), eddy losses in conductors due to eddy currents and circulating currents (if any) in parallel windings or in parallel winding strands, and stray loss induced by leakage flux in the tank, core clamps, or other structural parts.

load tap changer: A selector switch device, which may include current interrupting contactors, used to change voltage regulator taps with the voltage regulator energized and carrying full load.

no-load (excitation) losses: Those losses that are incident to the excitation of the voltage 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.

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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. The system voltage by which the system is designated and to which certain operating characteristics of the system are related. (The nominal voltage of a system is near the voltage level at which the system normally operates and provides a per-unit base voltage for system study purposes. To allow for operating contingencies, systems generally operate at voltage levels about 5% to 10% below the maximum system voltage for which system components are designed.)

platform mounted voltage regulator: A line voltage regulator that is designed for mounting on a platform and has a maximum weight limitation. This step-voltage regulator controls the voltage on the main feeder out of the substation or on laterals off of the main feeder. It is commonly referred to as a *distribution voltage regulator.*

polarity of a voltage regulator: (**A**) The polarity of a voltage regulator is intrinsic in its design. Polarity is correct if the voltage 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 voltage regulators. (**B**) The relative instantaneous polarity of the voltage regulator 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.

NOTE—The diagram of connection for **(B)** is in accordance with 6.3.

pole-type voltage regulator: A line voltage regulator that is designed for mounting on a pole and has a maximum weight limitation. This step-voltage regulator controls the voltage on the main feeder out of the substation or on laterals off of the main feeder. It is commonly referred to as a *distribution voltage regulator.*

primary circuit of a voltage regulator: The circuit on the input side of the voltage regulator.

rated range of regulation of a voltage regulator: The amount that the voltage 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.

rated voltage: The voltage to which operating and performance characteristics of apparatus and equipment are referred.

rated voltage of a step-voltage regulator: The voltage selected for the basis of performance specifications of a voltage regulator.

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

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 voltage regulator, when the voltage regulator is in the position that results in maximum voltage change and is delivering rated output at 80% lagging power factor.

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 square root of 3.

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

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reactor: An electromagnetic device, the primary purpose of which is to introduce inductive reactance into a circuit.

regulated circuit of a voltage regulator: The circuit on the output side of the voltage regulator, and in which it is desired to control the voltage.

NOTE—The voltage may be held constant at any selected point on the regulated circuit.

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

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.

series transformer: A transformer with a "series" winding and an "exciting" winding, in which the series winding is placed in a series relationship in a circuit to change voltage in that circuit as a result of input received from the exciting winding.

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.

shunt winding: *See:* **common winding.**

station-type voltage regulator: A voltage regulator designed for ground-type installations in substations. This voltage regulator is used for bus or individual feeder regulation. It is commonly referred to as a *substation voltage regulator.*

step-voltage regulator: A regulating autotransformer in which the voltage of the regulated circuit is controlled in steps by means of taps and without interrupting the load.

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

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

total losses of a regulator: The sum of the no-load and load losses, excluding losses due to accessories.

Type A step-voltage regulator: A step-voltage regulator in which the primary circuit is connected directly to the shunt winding of the voltage regulator. It is sometimes referred to as a *straight* design in the industry. The series winding is connected to the shunt winding and, in turn, via taps, to the regulated circuit. In a Type A step-voltage regulator, the core excitation varies because the shunt winding is connected across the unregulated primary circuit. The maximum range of regulation on the *raise* side equals the maximum range of regulation of the *lower* side with 10% being the nominal amount of regulation for the preferred kVA ratings.

NOTE—See Figure 1.

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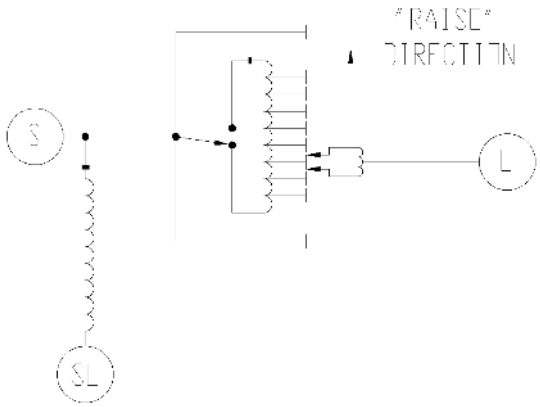

Figure 1—Schematic diagram of single-phase, Type A, step-voltage regulator

Type B step-voltage regulator: A step-voltage regulator in which the primary circuit is connected, via taps, to the series winding of the voltage regulator. It is sometimes referred to as an *inverted* design in the industry. The series winding is connected to the shunt winding, which is connected directly to the regulated circuit. In a Type B step-voltage regulator, the core excitation is constant because the shunt winding is connected across the regulated circuit. The maximum range of regulation of the *raise* side is higher than the maximum range of regulation of the *lower* side with 10% being the nominal amount of regulation of the raise side for the preferred kVA ratings.

NOTE—See Figure 2.

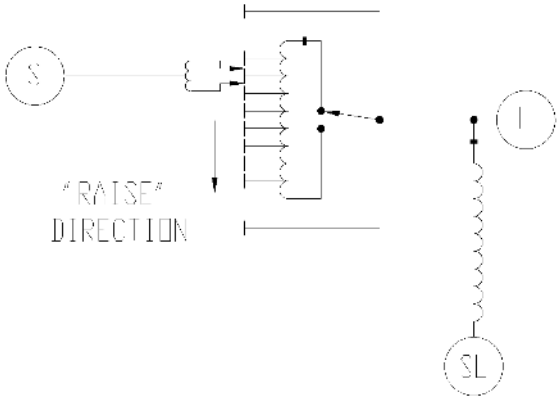

Figure 2—Schematic diagram of single-phase, Type B, step-voltage regulator

utility winding: That part of a voltage regulator coil that provides a voltage supply for the tap changer motor and/or the control, for a cooling fan or for a user's specified requirement.

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

voltage supply ratio: The ratio of the regulated line voltage to the control supply voltage.

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4. Service conditions

4.1 Usual service conditions

4.1.1 General

Voltage regulators conforming to this standard shall be suitable for operation at rated kilovoltamperes under the usual service conditions given in 4.1.2 through 4.1.7.

4.1.2 Temperature

4.1.2.1 Cooling air temperature limit

When 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.

4.1.2.2 Liquid temperature limit

The top-liquid temperature of the voltage regulator (when operating) shall not be lower than –20 °C. Liquid temperatures below –20 °C are not considered as usual service conditions.

4.1.2.3 Cooling water temperature limit

When 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 shall 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.

4.1.3 Altitude

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

4.1.4 Supply voltage

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

4.1.5 Load current

The load current shall be approximately sinusoidal. The harmonic factor shall not exceed 0.05 per unit.

4.1.6 Outdoor operation

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

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4.1.7 Tank or enclosure finish

Temperature limits and tests shall be based on the use of a nonmetallic pigment surface paint finish. It should be noted that metallic-flake paints, such as aluminum and zinc, have properties that increase the temperature rise of voltage regulators, except in direct sunlight. Unless otherwise specified, the tank finish shall conform to Light Gray Number 70, Munsell Notation 5BG 7.0/0.4. Finishing of voltage regulators shall meet requirements specified in IEEE Std C57.12.31.[6]

4.2 Loading at other than rated conditions

IEEE Std C57.91 provides guidance for loading at other than rated conditions including the following:

a) Ambient temperatures higher or lower than the basis of rating

b) Short-time loading in excess of nameplate kVA with normal life expectancy

c) Loading that results in reduced life expectancy

NOTE—IEEE Std C57.91 is a guide rather than a standard. It provides the best known general information for the loading of voltage 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 voltage regulators. When specified, ancillary components and other construction features (cables, bushings, tap changers, liquid 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 conditions and, when prevalent, should be brought to the attention of those responsible for the design and application of the voltage regulator. Examples of some of these conditions are discussed in 4.3.1 through 4.3.3.

4.3.1 Unusual temperature and altitude conditions

Voltage regulators may be used at higher or lower ambient temperatures or at higher altitudes than specified in 4.1, but special consideration should be given to these applications. Annex A and IEEE Std C57.91 provide information on recommended practices.

4.3.2 Insulation at high altitude

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

4.3.2.1 Insulation level

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

[6] Information on references can be found in Clause 2.

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

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

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

4.3.2.2 Bushings

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

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, or high current short duration loading.

h) Unbalanced alternating currents (ac), voltages, or departure of ac system voltages from a substantially sinusoidal waveform.

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, excessive tap changer contact wear, and abnormal heating.

j) Excitation exceeding either 110% rated voltage or 110% rated volts per Hertz.

k) Planned short circuits as a part of regular operating or relaying practice.

l) Unusual short-circuit application conditions differing from those described as usual in 5.9.1.

m) Unusual voltage conditions (transient overvoltages, resonance, switching surges, etc.), which may require special consideration in insulation design.

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n) Unusually strong magnetic fields. It should be noted that solar magnetic disturbances might result in the flow of telluric currents in voltage regulator neutrals.

o) Parallel operation. It should be noted that while parallel operation is not unusual, it is desirable that users advise the manufacturer if paralleling with other voltage regulators is planned, and the characteristics of the transformers or reactors so involved.

4.3.3.1 Control

The control, depending on its construction, may be sensitive to altitude considerations. The manufacturer should be consulted where applications exceed 2000 m (6600 ft). The control shall withstand an altitude of up to 3000 m (10 000 ft) without loss of control.

4.4 Frequency

Step-voltage regulators shall be designed for operation at a frequency of 60 Hz or 50 Hz as specified.

5. Rating data

5.1 Cooling classes of voltage regulators

Voltage regulators shall be identified according to the cooling method employed. For liquid-immersed voltage regulators, this identification is expressed by a four-letter code as described in 5.1.1 through 5.1.4.

5.1.1 Liquid-immersed (fire point ≤ 300 °C) air-cooled

Internal cooling medium in contact with the windings is insulating liquid with fire point ≤ 300 °C:

a) Liquid-immersed self-cooled (Class ONAN).

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

5.1.2 Liquid-immersed (fire point > 300 °C) air-cooled

Internal cooling medium in contact with the windings is insulating liquid with fire point > 300 °C:

a) Liquid-immersed self-cooled (Class KNAN).

b) Liquid-immersed self-cooled/forced-air-cooled (Class KNAN/KNAF).

5.1.3 Liquid-immersed (fire point ≤ 300 °C) water-cooled

Internal cooling medium in contact with the windings is insulating liquid with fire point ≤ 300 °C:

a) Liquid-immersed water-cooled (Class ONWF).

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

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5.1.4 Liquid-immersed (fire point > 300 °C) water-cooled

Internal cooling medium in contact with the windings is insulating liquid with fire point > 300 °C:

a) Liquid-immersed water-cooled (Class KNWF).

b) Liquid-immersed water-cooled/self-cooled (Class KNWF/KNAN).

5.2 Ratings

Ratings for step-voltage regulators are continuous and based on not exceeding the temperature limits covered in Table 3. Other winding rises may be recognized for unusual ambient conditions specified.

Ratings 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	55	65
	65 °C rise liquid immersed	65	80
(2)	Metallic parts in contact with current-carrying conductor insulation shall not attain a temperature rise in excess of the winding hottest-spot temperature rise.		
(3)	Metallic parts other than those described in item (2) shall not attain excessive temperature rises at maximum rated load.		
(4)	The temperature rise of the insulating fluid shall not exceed 55 °C (55 °C rise unit) or 65 °C (65 °C rise unit) when measured near the surface of the fluid.		

[a] Apparatus 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) Kilovoltampere (kVA)

b) Number of phases

c) Frequency

d) Voltage

e) Current

f) Voltage range in percent (raise and lower)

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

5.2.2 Preferred ratings

Preferred ratings of step-voltage regulators shall be based on operation at a frequency of 60 Hz or 50 Hz and nominal system voltages as given in Table 3, Table 4, Table 5, and Table 6.

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Table 3—Preferred ratings for liquid-immersed 60 Hz 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
		1000	1312
13 800	95	69	50
		138	100
		207	150
		276	200
		414	300
		552	400
		667	483
		833	604
		1000	725
14 400/24 940Y	150	72	50
		144	100
		288	200
		333	231
		432	300
		576	400
		667	463
		833	578
		1000	694
19 920/34 500Y	150	100	50
		200	100
		333	167
		400	201
		667	334
		833	418
		1000	502
34 500	200	173	50
		345	100
		518	150
		690	200

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Table 4—Preferred ratings for liquid-immersed 50 Hz step-voltage regulators (single phase)

Nominal system voltage	BIL (kV)	kVA	Line amperes
6600/11430Y	95	33	50
		66	100
		99	150
		132	200
		198	300
		264	400
		330	500
		396	600
		462	700
		528	800
11000	95	55	50
		110	100
		165	150
		220	200
		330	300
		440	400
		550	500
		660	600
		770	700
		880	800
15000/25980Y	150	75	50
		150	100
		225	150
		300	200
		450	300
		600	400
		750	500
		900	600
22000	150	110	50
		220	100
		330	150
		440	200
		660	300
		880	400
33000	170	165	50
		330	100
		495	150
		660	200

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Table 5—Preferred ratings for liquid-immersed 60 Hz step-voltage regulators (three phase)

Nominal system voltage	BIL (kV)	Self-cooled		Self-cooled/forced-cooled	
		kVA	Line amperes	kVA	Line amperes
2400/4160Y	60	500	667	625	833
		750	1000	937	1250
		1000	1334	1250	1667
4800	60	500	577	625	721
		750	866	937	1082
		1000	1155	1250	1443
7620/13 200Y	95	500	219	625	274
		750	328	937	410
		1000	437	1250	546
		1500	656	2000	874
		2000	874	2667	1166
		2500	1093	3333	1458
		3000	1312	4000	1750
7970/13 800Y	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
		3000	1255	4000	1673
14 400/24 940Y	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
		3000	694	4000	926
19 920/34 500Y	150	500	84	625	105
		750	125.5	937	156.8
		1000	167	1250	209
		1500	251	2000	335
		2000	335	2667	446
		2500	418	3333	557
		3000	502	4000	669

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Table 6—Preferred ratings for liquid-immersed 50 Hz step-voltage regulators (three phase)

Nominal system voltage	BIL (kV)	Self-cooled		Self-cooled/forced-cooled	
		kVA	Line amperes	kVA	Line amperes
6600/11430Y	95	500	253	625	316
		750	379	937	474
		1000	505	1250	631
		1500	758	2000	1010
11000	95	500	262	625	328
		750	394	937	492
		1000	525	1250	656
		1500	787	2000	1050
15000/25980Y	150	500	111	625	139
		750	167	937	208
		1000	222	1250	278
		1500	333	2000	444
		2000	444	2667	593
		2500	556	3333	741
22000	150	500	131	625	164
		750	197	937	246
		1000	262	1250	328
		1500	394	2000	525
33000	170	500	87	625	189
		750	131	937	164
		1000	175	1250	219

5.2.3 Supplementary voltage ratings

In addition to their rated voltage, as defined in 5.2.2, voltage regulators shall deliver rated kVA output without exceeding the specified temperature rise per Table 2 at the operating voltages given in Table 7.

Voltage regulators with multitapped voltage transformers and/or utility windings may be operated at voltages other than the rated voltage, as specified per the nameplate, and shall deliver rated line amperes without exceeding the temperature limits of Table 2 and as specified per the nameplate.

Table 7—Supplementary voltage ratings for 60 Hz voltage regulators

Number of phases	Rated voltage	Operating voltage
Single phase	7620	7200
	4330	4160
Three phase	5000	4800
	8660	8320
	13 200	12 470
	13 800	13 200

5.3 Supplementary continuous-current ratings

Single-phase step-voltage regulators rated up to 34.5 kV, inclusive, and rated 668 A and below shall have supplementary continuous-current ratings on intermediate ranges of steps as shown in Table 8. Maximum continuous current shall be 668 A.

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Table 8—Supplementary continuous-current ratings for single-phase voltage regulators

Range of voltage regulation (%)	Continuous-current rating (%)
10.00	100
8.75	110
7.50	120
6.25	135
5.00	160

Three-phase step-voltage regulators rated up to 13.8 kV, inclusive, and rated 668 A and below shall have supplementary continuous-current ratings on intermediate ranges of steps as shown in Table 9. Maximum continuous current shall be 668 A.

Table 9—Supplementary continuous-current ratings for three-phase voltage regulators

Range of voltage regulation (%)	Continuous-current rating (%)
10.00	100
8.75	108
7.50	115
6.25	120
5.00	130

5.4 Taps

Load tap changing equipment shall be furnished to provide approximately ±10 % automatic adjustment of the unregulated supply on the source side of the voltage regulator. This is to be done in approximately 0.625 percent steps, with sixteen steps above and sixteen steps below rated voltage.

5.5 Operating voltage limits

Voltage 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 voltage 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 voltage 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 1.10 times the rated voltage of the voltage 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 voltage regulator voltage range.

Typical examples of the application of these rules to some common ratings of voltage regulators are given in Table 10.

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Table 10 —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	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	9525	7170	9525
11000	11000	—	91.7	8960	11 550	12 100	9490	12 100
6600/11 430Y	6600	—	55	5380	6930	7260	5690	7260
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	—	13 200	110	10 750	13 860	14 520	11 400	14 520
7970/13 800Y	—	13 800	115	11 240	14 490	15 180	11 900	15 180
7970/13 800Y	7970	—	66.3	6480	8360	8760	6860	8760
13 200	13 800	13 800	110	10 750	14 490	15 125	11 400	15 125
14 400	13 800	13 800	120	11 730	14 490	15 180	12 420	15 180
22 000	22 000	—	183.3	17 920	23 100	24 200	18 975	24 200
14 400/24 940Y	14 400	—	120	11 730	15 120	15 840	12 420	15 840
15 000/25 980Y	15 000	—	120	11 730	15 750	16 500	12 420	16 500
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
33 000	33 000	—	275	26 880	34 650	36 300	28 460	36 300
19 920/34 500Y	—	34 500	287.5	28 100	36 225	37 950	29 760	37 950
34 500	34 500	—	287.5	28 100	36 225	37 950	29 760	37 950

NOTE—Example values are derived using procedures of 5.5.

[a]Where the listed voltage ratio is provided, an ancillary transformer may be required.

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5.6 Voltage supply ratios

Values of voltage supply ratios are given in Table 11. When a voltage supply ratio is specified that is not a preferred value shown in Table 11, an ancillary transformer may be furnished in the unit or control to modify the preferred ratio.

Table 11 —Values of voltage supply ratios

Voltage regulator rating (V)		Values of voltage supply ratios
Single phase	Three phase	
2500		20, 20.8
	4330	34.6, 36.1
5000	5000	40, 41.7
6600		55
7620		60, 63.5
7970		66.4
	8660	69.3, 72.2
11 000		91.7
	13 200	110, 104
13 800	13 800	115, 110
14 400		120
15 000		120
19 920		166
22 000		183.3
	24 940	208
33 000		275
34 500	34 500	287.5

5.7 Insulation levels

Voltage regulators shall be designed to provide coordinated applied-voltage and lightning impulse insulation levels on line terminals, and applied-voltage 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 12.

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

Table 12 —Interrelationships of dielectric insulation levels for voltage regulators used on systems with BIL ratings of 200 kV and below

BIL kV	Applied-voltage insulation level (kV rms)	Impulse levels		
		Full wave	Chopped wave	
		(kV crest)	(kV crest)	Min time to flashover (μs)
60	19	60	66	1.5
75	26	75	83	1.5
95	34	95	105	1.8
110	34	110	120	2.0
150	50	150	165	3.0
170	70	170	187	3.0
200	70	200	220	3.0

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