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IEEE Std C57.15™

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

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International Standard IEC 60076-21/IEEE Std C57.15-2017 has been prepared by IEC technical committee 14: Power transformers, in cooperation with the Transformers Committee of the IEEE Power and Energy Society[1], under the IEC/IEEE Dual Logo Agreement.

This publication is published as an IEC/IEEE Dual Logo standard. This second edition cancels and replaces IEC 60076-21, published in 2011, and IEEE Std C57.15-2009.

This edition includes the following significant technical changes with respect to IEC 60076-21:2011/IEEE Std C57.15-2009:

a) updated list of normative and bibliography IEC and IEEE references and their associated text;
b) updated tables of preferred ratings for inclusion of maximum system voltage (U_m), nominal system voltage and rated voltage (U_r);
c) inclusion of tables for optional fan-cooled ratings, external dielectric clearances and sound pressure levels;
d) revision of short-circuit requirements for distribution and substation voltage regulators;
e) inclusion of an universal interface between control enclosure and apparatus;
f) inclusion of tap-changer routine and type tests;
g) inclusion of audible sound pressure emissions test procedures;
h) inclusion of tank enclosure integrity type test procedures;
i) update of control environmental IEC reference test standard.

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

FDIS	Report on voting
14/974/FDIS	14/989/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

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A list of parts of the 60076 International Standard, published under the general title *Power transformers*, can be found on the IEC website.

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- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

[1] A list of IEEE participants can be found at the following URL: https://standards.ieee.org/standard/C57.15-2017.html

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POWER TRANSFORMERS –

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

1 Scope

This document describes electrical, mechanical and test requirements of liquid-immersed, single- and three-phase, 50 Hz and 60 Hz, self and forced-air cooled, distribution, overhead and substation, step-voltage regulators, 1 000 kVA (single-phase units) or 3 000 kVA (three-phase units) and smaller, 34 500 volts and below (2 400 V minimum) and their associated controls.

Requirements, references and definitions relevant to either IEC or IEEE contexts are given and their use is described in Clause 4.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

2.1 IEC references

IEC 60050-421, *International Electrotechnical Vocabulary – Chapter 421: Power transformers and reactors*

IEC 60060 (all parts), *High-voltage test techniques*

IEC 60076-2, *Power transformers – Part 2: Temperature rise for liquid-immersed transformers*

IEC 60255-1, *Measuring relays and protection equipment – Part 1: Common requirements*

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 60255-26, *Measuring relays and protection equipment – Part 26: Electromagnetic compatibility requirements*

IEC 60255-27, *Measuring relays and protection equipment – Part 27: Product safety requirements*

IEC 61672-1, *Electroacoustics – Sound level meters – Part 1: Specifications*

2.2 IEEE references

IEEE Std 4™, *IEEE Standard Techniques for High-Voltage Testing*

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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 C57.19.00™, *IEEE Standard General Requirements and Test Procedure for Outdoor Power Apparatus Bushings*

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

2.3 SAE references

SAE AS50151, *General specification for connectors, electrical, circular threaded, AN type*[2]

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-421 and the following apply.

ISO, IEC and IEEE maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp
- IEEE Standards Dictionary Online: available at http://ieeexplore.ieee.org/xpls/dictionary.jsp

3.1
ambient sound level
background noise level measured with the voltage regulator de-energized

3.2
ambient temperature
temperature of the medium, such as air, water, or earth, into which the heat of the equipment is dissipated

Note 1 to entry: For self-ventilated equipment, the ambient temperature is the average temperature of the air in the immediate neighbourhood of the equipment.

Note 2 to entry: For air-cooled equipment with forced ventilation, the ambient temperature is taken as that of the in-going air.

3.3
angular displacement
time angle, expressed in degrees, between the line-to-neutral voltage of the unregulated circuit and the line-to-neutral voltage of the corresponding regulated load circuit

[2] SAE (Society of Automotive Engineers) international publications are available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096, USA (http://sae.org/).

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Note 1 to entry: 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.

Note 2 to entry: 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 with all voltage regulators in the Neutral tap position and less than ±5° for all other positions with the maximum value occurring when all voltage regulators are on the same extreme tap position.

3.4
autotransformer
transformer in which at least two windings have a common section

3.5
average winding temperature-rise
arithmetic difference between the average winding temperature of the hottest winding and the ambient temperature

3.6
current transformer
instrument transformer intended to have its primary winding connected in series with the conductor carrying the current to be measured or controlled

3.7
diverter switch
switching device used in conjunction with a tap selector to carry, make and break currents in circuits that have already been selected

3.8
excitation current
current flowing in any winding used to excite the voltage regulator when all other windings are open-circuited

Note 1 to entry: Excitation current is usually expressed in percent of the rated current of the voltage regulator.

3.9
equalizer winding
winding on the same magnetic circuit (core) as the excitation and tap windings of a voltage regulator with approximately half the number of turns of each tap section

3.10
intrinsic polarity
polarity is correct if the voltage regulator boosts the voltage in the raise direction and bucks the voltage in the lower direction

Note 1 to entry: The relative polarity of the shunt and series windings of a step-voltage regulator differs in the boost and buck modes between Type A and Type B voltage regulators.

3.11
line-drop compensation
scheme causing the control to vary the regulated circuit voltage by an amount that compensates for the impedance voltage drop in the circuit between the voltage regulator and a predetermined location (sometimes referred to as the regulation point) on the circuit

3.12
liquid
synthetic fluid, natural ester-based fluid, and mineral oil

Note 1 to entry: Some liquids may be unsuitable for use in the arcing environment of a step-voltage regulator.

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3.13
liquid-immersed voltage regulator
voltage regulator having its cores and coils immersed in an insulating liquid

3.14
load loss
loss incident to the voltage regulator carrying a specified load

Note 1 to entry: Load loss includes I^2R loss in the current carrying parts (windings, leads, bus bars, bushings), eddy loss 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.

3.15
maximum system voltage
U_m
highest RMS phase-to-phase voltage in a three-phase system for which a voltage regulator winding is designed in respect of its insulation

3.16
no-load loss
loss incident to the excitation of the voltage regulator

Note 1 to entry: No-load loss includes core loss, dielectric loss, conductor loss in the winding due to excitation current, and conductor loss due to circulating current in parallel windings. The no-load loss changes with the excitation voltage.

3.17
nominal system voltage
nominal value assigned to a system or circuit of a given voltage for the purpose of convenient designation

Note 1 to entry: 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 designates the system to which certain operating characteristics are related.

Note 2 to entry: 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.

3.18
non-vacuum type on-load tap-changer
on-load tap-changer with contacts breaking and making the load and circulating currents with the arcing taking place in a liquid

3.19
on-load tap-changer
OLTC
device for selection of tap connections of a winding, suitable for operation while the voltage regulator is energized or on load

Note 1 to entry: This device can also be called a load tap-changer (LTC) but this is not the preferred usage.

3.20
rated range of regulation
amount the voltage regulator raises or lowers its rated voltage with the range being expressed in per unit, or in percent, of rated voltage, or expressed in kilovolts

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3.21
rated voltage
U_r
voltage to which operating and performance characteristics of apparatus and equipment are referred

3.22
rating in kVA
<single-phase voltage regulator> product of the rated load amperes and the rated range of regulation in kilovolts (kV)

3.23
rating in kVA
<three-phase voltage regulator> product of the rated load amperes, maximum rated range of regulation in kilovolts (kV), and the square root of 3

3.24
reactor
preventive autotransformer with the primary purpose of introducing inductive reactance into a circuit

Note 1 to entry: This definition is only valid for reactors used in combination with reactor-type OLTCs. All other reactors, such as short-circuit limiting reactors, are not covered by this definition.

3.25
regulated circuit
circuit on the output (load) side of the voltage regulator, and in which it is desired to control the voltage

Note 1 to entry: The voltage can be held constant at any selected point on the regulated circuit.

3.26
relative polarity
instantaneous polarity of the windings, instrument transformer(s), and utility winding(s), as applicable, designated by an appropriate polarity mark on the diagram of connection on the nameplate

Note 1 to entry: The diagram of connection is in accordance with 7.4.

3.27
series transformer
transformer with a series winding and an excitation 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 the regulated circuit received from the excitation winding

3.28
series winding
portion of the autotransformer not common to both the unregulated and regulated circuits, but connected in series between the circuits

3.29
selector switch
switching device capable of carrying, making and breaking current, combining the duties of a tap selector and a diverter switch

Note 1 to entry: Selector switches are sometimes called arcing tap switches.

Note 2 to entry: In non-vacuum type selector switches, the selection of tap connections (tap selector duty) and the diversion of the through-current (diverter switch duty) are carried out by the same contacts.

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Note 3 to entry: In vacuum type selector switches, the selection of tap connections (tap selector duty) and the diversion of the through-current (diverter switch duty) are carried out by different contacts.

3.30
shunt winding
portion of the autotransformer common to both the unregulated and regulated circuits

3.31
step-voltage regulator
regulating autotransformer in which the voltage of the regulated circuit is controlled in steps by means of taps and without interrupting the load

3.32
tap selector
device designed to carry, but not to make or break, current, used in conjunction with a diverter switch to select tap connections

3.33
Type A step-voltage regulator
step-voltage regulator in which the unregulated circuit is connected directly to the shunt winding of the voltage regulator with the series winding connected to the shunt winding and, in turn, via taps, to the regulated circuit

Note 1 to entry: Refer to Annex C for additional information on step-voltage regulator construction.

3.34
Type B step-voltage regulator
step-voltage regulator in which the unregulated circuit is connected, via taps, to the series winding of the voltage regulator with the series winding connected to the shunt winding, which is connected directly to the regulated circuit

Note 1 to entry: Refer to Annex C for additional information on step-voltage regulator construction.

3.35
unregulated circuit
circuit on the input (source) side of the voltage regulator

3.36
utility winding
winding in a voltage regulator coil providing a voltage supply for the on-load tap-changer motor and/or the control device, for a cooling fan or for a purchaser's specified requirement

3.37
vacuum type on-load tap-changer
on-load tap-changer where vacuum interrupters break and make the load and circulating currents

3.38
voltage supply ratio
ratio of the regulated circuit voltage to the control supply voltage

4 Use of normative references

This document can be used with either the IEC or IEEE normative references, but the references shall not be mixed. The purchaser shall include in the enquiry and order which normative references are to be used. If the choice of normative references is not specified,

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then IEC standards shall be used, except for step-voltage regulators intended for installation in North America where IEEE standards shall be used.

If only one alternative is given in a certain part of the document, i.e. only IEC reference(s) or only IEEE reference(s), then that/these reference(s) is/are valid independent of the choice of normative references.

5 Service conditions

5.1 Usual service conditions

5.1.1 General

Voltage regulators meeting the requirements of this document shall be suitable for operation at rated kVA under the following usual service conditions.

5.1.2 Temperature

5.1.2.1 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 shall not exceed 30 °C.

5.1.2.2 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.

5.1.3 Altitude

The altitude shall not exceed 1 000 m (3 300 ft).

5.1.4 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.

5.1.5 Load current

The load current shall be approximately sinusoidal. The harmonic factor shall not exceed 0,05 per unit.

5.1.6 Outdoor operation

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

5.1.7 Tank or enclosure finish

Temperature limits and tests shall be based on the use of a non-metallic pigment surface paint finish. It should be noted that metallic-flake paints, such as aluminium and zinc, have properties increasing 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.

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5.2 Loading at other than rated conditions

IEEE Std C57.91 or IEC 60076-7 [11][3] 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 resulting in reduced life expectancy.

NOTE IEEE Std C57.91 and IEC 60076-7 [11] are guides rather than standards. They provide the best known general information for the loading of voltage regulators under various conditions based on typical winding insulation systems, and are based upon the best engineering information available at the time of preparation. The guides discuss limitations of ancillary components other than windings, limiting the capability of voltage regulators.

5.3 Unusual service conditions

5.3.1 General

Conditions other than those described in 5.1 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 5.3.2 to 5.3.4.

5.3.2 Unusual temperature and altitude conditions

Voltage regulators may be used at higher or lower ambient temperatures or at higher altitudes than specified in 5.1, but special consideration should be given to these applications. Annex A of this document, IEEE Std C57.91, and IEC 60076-7 [11] provide information on recommended practices.

5.3.3 Insulation at high altitude

5.3.3.1 General

The dielectric strength of voltage regulators depends in whole or in part upon the external clearances. It 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 1 000 m (3 300 ft).

5.3.3.2 Insulation level

The minimum insulation necessary at the required altitude can be obtained by dividing the standard insulation level at 1 000 m (3 300 ft) by the appropriate correction factor from Table 1.

[3] Numbers in square brackets refer to the Bibliography.

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Table 1 – Dielectric strength correction factors for altitudes greater than 1 000 m (3 300 ft)

Altitude		Altitude correction factor for dielectric strength
(m)	(ft)	
1 000	3 300	1,00
1 200	4 000	0,98
1 500	5 000	0,95
1 800	6 000	0,92
2 100	7 000	0,89
2 400	8 000	0,86
2 700	9 000	0,83
3 000	10 000	0,80
3 600	12 000	0,75
4 200	14 000	0,70
4 500	15 000	0,67
NOTE An altitude of 4 500 m (15 000 ft) is considered a maximum for voltage regulators compliant with this document.		

5.3.3.3 Bushings

Bushings with additional strike distance or creep distance shall be furnished where necessary for operation above 1 000 m (3 300 ft).

NOTE It is not required for the BIL rating of bushings to be increased to match level of increased creep distance and strike distance.

5.3.4 Other unusual service conditions

5.3.4.1 General

Other unusual service conditions include the following:

a) damaging fumes or vapours, 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 resulting where appreciable load currents are controlled by solid-state or similar devices;

NOTE 1 Such harmonic currents can cause excessive loss, excessive on-load 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;

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l) unusual short-circuit application conditions differing from those described in 6.8.1;

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

n) unusually strong magnetic fields, for example, solar magnetic disturbances can result in the flow of telluric currents in voltage regulator neutrals;

o) parallel operation.

NOTE 2 IEEE Std C57.153 [27] is available as a guide for paralleling voltage regulators.

5.3.4.2 Control

The control, depending on its construction, may be sensitive to altitude considerations. The manufacturer should be consulted where applications exceed 2 000 m (6 600 ft). The control shall withstand an altitude of up to 3 000 m (10 000 ft) without loss of control.

6 Rating data

6.1 Cooling classes of voltage regulators

6.1.1 General

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 6.1.2 and 6.1.3.

6.1.2 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 ONAN);

b) liquid-immersed self-cooled/forced-air-cooled (class ONAN/ONAF).

6.1.3 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).

6.2 Ratings

6.2.1 General

Ratings for step-voltage regulators are continuous and based on not exceeding the temperature limits covered in Table 2. Ratings covered by this document shall be expressed in the terms given in 6.2.2 and as specified in 6.2.3.

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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 [b]	55	65
(2)	65 °C rise liquid immersed [c]	65	78
(3)	65 °C rise liquid immersed [d]	65	80
(4)	Metallic parts in contact with current-carrying conductor insulation shall not attain a temperature-rise in excess of the winding hottest-spot temperature-rise. The core hot spot temperature shall be limited to 130 °C for the condition of highest core over-excitation, rated load, and the maximum average daily ambient temperature for voltage regulators immersed in dielectric liquid. This is to avoid the problem of gas generation in the core caused by thermal breakdown of the thin liquid film between the core laminations. Under the same operating conditions, the core surface temperatures shall be limited by the temperature capability of the insulation materials in contact with the core surfaces.		
(5)	Metallic parts other than those described in item (4) shall not attain excessive temperature-rise at maximum rated load. Excessive temperature-rise shall be interpreted to mean a temperature-rise resulting in an operating temperature exceeding the temperature limits of the insulation material in contact with the metallic part.		
(6)	The top liquid temperature-rise of the insulating liquid shall not exceed 55 °C (55 °C rise unit) or 65 °C (65 °C rise unit) when measured near the surface of the liquid. (Item (1) and (3))		
(7)	The top liquid temperature-rise of the insulating liquid shall not exceed 60 °C (65 °C rise unit) when measured near the surface of the liquid. (Item (2))		

[a] Apparatus with specified temperature-rise shall have an insulation system proven to possess minimum aging characteristics by an established test.

[b] Apparatus with 30 °C average yearly external cooling air temperature as defined in 5.1.2.1, which may use thermally upgraded insulating paper.

[c] Apparatus with 20 °C average yearly external cooling air temperature as defined in IEC 60076-2.

[d] Apparatus with 30 °C average yearly external cooling air temperature as defined in 5.1.2.1, which utilizes thermally upgraded insulating paper.

6.2.2 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.

6.2.3 Preferred ratings

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

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Ratings of single-phase voltage regulators are dependent on the application of two (2) or three (3) voltage regulators applied to support a specific three-phase load. For example, three (3) single-phase voltage regulators rated 333 kVA connected in a wye configuration, support a 10 MVA load.

NOTE National practices can be different for preferred ratings.

Table 3 – Ratings for liquid-immersed 60 Hz step-voltage regulators (single-phase)

Maximum system voltage (U_m) (kV RMS)	Nominal system voltage (kV RMS)	Rated voltage (U_r) (V RMS)	BIL (kV)	Kilovoltamperes (kVA)	Line amperes (A)
6,9	5	2 500/4 330Y	60	50	200
				75	300
				100	400
				125	500
				167	668
				250	1 000
				333	1 332
				416	1 665
11	8,7	5 000/8 660Y	75	50	100
				75	150
				100	200
				125	250
				167	334
				250	500
				333	668
				416	833
17	15	7 620/13 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	1 093
				1 000	1 312
17	15	13 800	95	69	50
				138	100
				207	150
				276	200
				414	300
				552	400
				667	483
				833	604
				1 000	725

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Maximum system voltage (U_m) (kV RMS)	Nominal system voltage (kV RMS)	Rated voltage (U_r) (V RMS)	BIL (kV)	Kilovoltamperes (kVA)	Line amperes (A)
26	25	14 400/24 940Y	150	72	50
				144	100
				288	200
				333	231
				432	300
				576	400
				667	463
				833	578
				1 000	694
36	35	19 920/34 500Y	150	100	50
				200	100
				333	167
				400	201
				667	334
				833	418
				1 000	502
36	35	34 500	200	173	50
				345	100
				518	150
				690	200

Table 4 – Ratings for liquid-immersed 50 Hz step-voltage regulators (single-phase)

Maximum system voltage (U_m) (kV RMS)	Nominal system voltage (kV RMS)	Rated voltage (U_r) (V RMS)	BIL (kV)	Kilovoltamperes (kVA)	Line amperes (A)
7,2	6,6	6 600	75	33	50
				66	100
				99	150
				132	200
				198	300
				264	400
				330	500
				396	600
				462	700
				528	800

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Maximum system voltage (U_m) (kV RMS)	Nominal system voltage (kV RMS)	Rated voltage (U_r) (V RMS)	BIL (kV)	Kilovoltamperes (kVA)	Line amperes (A)
12	11	6 350/11 000Y	95	32	50
				64	100
				95	150
				127	200
				190	300
				254	400
				317	500
				381	600
				444	700
				508	800
12	11	11 000	95	55	50
				110	100
				165	150
				220	200
				330	300
				440	400
				550	500
				660	600
				770	700
				880	800
17,5	15	15 000	95	75	50
				150	100
				225	150
				300	200
				450	300
				600	400
				750	500
				900	600
24	22	22 000	150	110	50
				220	100
				330	150
				440	200
				660	300
				880	400
36	33	33 000	170	165	50
				330	100
				495	150
				660	200

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Table 5 – Ratings for liquid-immersed 60 Hz step-voltage regulators (three-phase)

Maximum system voltage (U_m)	Nominal system voltage	Rated voltage (U_r)	BIL	Self-cooled		Forced-cooled	
				Kilovoltamperes	Line amperes	Kilovoltamperes	Line amperes
(kV RMS)	(kV RMS)	(V RMS)	(kV)	(kVA)	(A)	(kVA)	(A)
6,9	5	2 500/4 330Y	60	500	667	625	833
				750	1 000	937	1 250
				1 000	1 334	1 250	1 667
11	8,7	5 000/8 660Y	75	500	577	625	721
				750	866	937	1 082
				1 000	1 155	1 250	1 443
17	15	7 620/13 200Y	95	500	219	625	274
				750	328	937	410
				1 000	437	1 250	546
				1 500	656	2 000	874
				2 000	874	2 667	1 166
				2 500	1 093	3 333	1 458
				3 000	1 312	4 000	1 750
17	15	7 970/13 800Y	95	500	209	625	261
				750	313	937	391
				1 000	418	1 250	523
				1 500	628	2 000	837
				2 000	837	2 667	1 116
				2 500	1 046	3 333	1 394
				3 000	1 255	4 000	1 673
26	25	14 400/24 940Y	150	500	125,5	625	156,8
				750	188,3	937	235,4
				1 000	251	1 250	314
				1 500	377	2 000	502
				2 000	502	2 667	669
				2 500	628	3 333	837
				3 000	694	4 000	926
36	34.5	19 920/34 500Y	150	500	84	625	105
				750	125,5	937	156,8
				1 000	167	1 250	209
				1 500	251	2 000	335
				2 000	335	2 667	446
				2 500	418	3 333	557
				3 000	502	4 000	669

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Table 6 – Ratings for liquid-immersed 50 Hz step-voltage regulators (three-phase)

Maximum system voltage (U_m) (kV RMS)	Nominal system voltage (kV RMS)	Rated voltage (U_r) (V RMS)	BIL (kV)	Self-cooled		Forced-cooled	
				Kilovoltamperes (kVA)	Line amperes (A)	Kilovoltamperes (kVA)	Line amperes (A)
7,2	6,6	6 600	75	500	253	625	316
				750	379	937	474
				1 000	505	1 250	631
				1 500	758	2 000	1 010
12	11	6 350/11 000Y	95	500	243	625	304
				750	364	937	456
				1 000	485	1250	607
				1 500	729	2 000	971
12	11	11 000	95	500	262	625	328
				750	394	937	492
				1 000	525	1 250	656
				1 500	787	2 000	1 050
17.5	15	15 000	95	500	111	625	139
				750	167	937	208
				1 000	222	1 250	278
				1 500	333	2 000	444
				2 000	444	2 667	593
				2 500	556	3 333	741
24	22	22 000	150	500	131	625	164
				750	197	937	246
				1 000	262	1250	328
				1 500	394	2 000	525
36	33	33 000	170	500	87	625	189
				750	131	937	164
				1 000	175	1 250	219

6.2.4 Supplementary voltage ratings

6.2.4.1 General

In addition to their rated voltage, as defined in 6.2.3, 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 multi-tapped 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

Rated voltage (V RMS)	**Operating voltage** (V RMS)
7 620/13 200Y	7 200/12 470Y
15 000	14 400

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6.2.4.2 Overexcitation

A voltage regulator shall be capable of continuous operation at rated load without damage under conditions of "over fluxing" where the value of voltage divided by frequency (V/Hz) exceeds the corresponding value at rated voltage and rated frequency by no more than 5 %, unless otherwise specified by the purchaser.

At no-load, voltage regulators shall be capable of continuous operation at V/Hz of 110 % of the rated V/Hz. At load current, X times the voltage regulator rated current (0 ≤ X ≤ 1), the over fluxing shall be limited in accordance with the following Equation (1):

$$\frac{U \times f_{\mathrm{r}}}{U_{\mathrm{r}} \times f} \times 100 \leq 110 - 5X \quad (\%) \tag{1}$$

where

U is the system voltage;

f is the system frequency;

U_{r} is the rated voltage of voltage regulator;

f_{r} is the rated frequency of voltage regulator.

If the voltage regulator is to be operated at V/Hz in excess of those stated above, this shall be identified by the purchaser in the enquiry.

6.3 Supplementary continuous-current ratings

6.3.1 General

Step-voltage regulators without a series transformer construction 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.

Table 8 – Supplementary continuous-current ratings

Range of voltage regulation (%)	**Continuous-current rating** (%)
10,00	100
8,75	110
7,50	120
6,25	135
5,00	160

6.3.2 Optional forced-air ratings

Optional forced-air ratings are given in Table 9.

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Table 9 – Forced-air ratings relationship

Class	Self-cooled ratings		Percent of self-cooled rating with auxiliary cooling
	Single-phase	Three-phase	
ONAN/ONAF KNAN/KNAF	333 kVA and below	1 000 kVA and below	125
ONAN/ONAF KNAN/KNAF	above 333 kVA	above 1 000 kVA	133 1/3

6.4 Taps

Load tap-changing apparatus and windings shall be furnished to provide automatic adjustment of the unregulated circuit voltage on the source side of the voltage regulator. This is to be done with sixteen steps above and sixteen steps below rated voltage. Maximum percent regulation in the Raise and Lower positions is based on the design, Type A or Type B. Minimum range of regulation in the Raise direction shall be 10 %. The output voltage obtainable with a given input voltage is limited by the voltage regulation ranges.

6.5 Voltage supply ratios

Values of voltage supply ratios are given in Table 10. When a voltage supply ratio is specified that is not a preferred value shown in Table 10, an ancillary transformer may be furnished within the apparatus or control to modify the ratio.

Table 10 – Values of voltage supply ratios

Voltage regulator rating (V RMS)	Values of voltage supply ratios
2 500	20, 20,8
5 000	40, 41,7
6 350	52,9
6 600	55
7 620	60, 63,5
7 970	66,4
11 000	91,7
13 800	115, 110
14 400	120
15 000	125, 120
19 920	166
22 000	183,3
33 000	275
34 500	287,5

6.6 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 11.

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When single-phase voltage regulators are connected in wye, it is recommended that the neutral ("SL" terminals) of the voltage regulator bank be connected to a grounded neutral of the system. A closed or open delta connection of the voltage regulators is recommended when the system is three-wire ungrounded with the "SL" terminals connected to live phases.

Table 11 – Interrelationships of dielectric insulation levels for voltage regulators

BIL kV	**Applied-voltage insulation level** (kV **RMS**)	**Impulse levels**		
		Full wave	**Chopped wave**	
		(kV crest)	(kV crest)	**Minimum 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

6.7 Losses

6.7.1 General

The losses specified by the manufacturer shall be the no-load (excitation) loss and load loss, as defined in Clause 3.

6.7.2 Total loss

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

6.7.3 Tolerance for losses

Unless otherwise specified, the losses represented by a test of a voltage regulator shall be subject to the following tolerances: the no-load loss of a voltage regulator shall not exceed the specified no-load loss by more than 10 %, and the total loss of a voltage regulator shall not exceed the specified total loss 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 differ at different operating positions of the voltage regulator, care is exercised in the consideration of tap position with losses. Some styles of step-voltage regulators exhibit appreciable change in load loss when boosting versus bucking, or exhibit appreciable change in no-load loss on alternate tap positions. See 6.7.4.

6.7.4 Determination of losses and excitation current

No-load (excitation) loss and excitation 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 loss 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.

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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 loss and load loss where:

a) No-load loss is the average of no-load loss in the Neutral position and the adjacent boost position with rated voltage applied to the shunt or series winding for voltage regulators not incorporating a series transformer construction.

NOTE It is apparent, in the case of a Type B step-voltage regulator in the adjacent boost position, the excitation voltage applied at the Source "S" terminal is higher at the shunt winding. Care is exercised to assure rated excitation is present on the shunt winding; this may be accomplished by exciting the voltage regulator from the Load "L" terminal.

b) No-load loss is reported for Neutral position, maximum boost position, and position adjacent-to-maximum boost position for voltage regulators incorporating a series transformer construction.

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.

6.8 Short-circuit requirements

6.8.1 General

Step-voltage regulators shall be designed and constructed to withstand the mechanical and thermal stresses produced by external short-circuits at a maximum value of 25 times the base RMS symmetrical rated load current to a maximum requirement of 16 kA.

a) The first-cycle asymmetrical peak current the voltage regulator is required to withstand shall be determined as shown in Equation (2) and Table 12. The test procedure for demonstrating this mechanical capability for duration of 250 ms is defined in 9.11.

$$I_{sc}\ \text{(peak asym)} = k \times I_{sc}\ \text{(RMS sym)} \tag{2}$$

Table 12 – Values of k

Base rated kVA	k	
	60 Hz	50 Hz
< 250 (single-phase) [c] < 750 (three-phase) [c]	2,26 [a]	2,19 [a]
≥ 250 (single-phase) ≥ 750 (three-phase)	2,60 [b]	2,55 [b]

[a] Value of the first-cycle asymmetrical peak current is based on an X/R ratio of 6 and 5, 60 Hz and 50 Hz, respectively, which are common for distribution circuits.

[b] Value of the first-cycle asymmetrical peak current is based on an X/R ratio of 17 and 14, 60 Hz and 50 Hz, respectively, which are common for substation circuits.

[c] Purchaser may specify the higher 2,60 or 2,55 factor for 60 Hz and 50 Hz ratings, respectively, for specific applications.

b) The short-circuit, thermal withstand capability, shall be based on a symmetrical current with a duration of 2 s calculated by methods described in 9.13.4 not to exceed the limiting temperatures of 6.8.3.

c) Larger kVA sizes with the same voltage rating should be considered if the available fault current exceeds the 25 times base rated current.

It is recognized that short-circuit withstand capability can be adversely affected by the cumulative effects of repeated mechanical and thermal overstressing, as produced by short-

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circuits and loads above the nameplate 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 voltage regulator in service.

Voltage regulator components such as leads, bushings, and on-load tap-changers carrying current continuously shall meet all the requirements of 6.8.1. On-load tap-changers are not required to change tap position coincident with a short-circuit condition.

It is recommended that current-limiting reactors be installed by the purchaser, when necessary, to limit the short-circuit current to a maximum of 25 times the base rated full-load current or 16 000 A, whichever is less.

NOTE Short-circuit limiting reactors are not covered by the definition in 3.24.

6.8.2 Mechanical capability demonstration

It is not the intent of 6.8.1 that every voltage regulator design have a short-circuit test to demonstrate adequate construction. When specified, tests of short-circuit mechanical capability shall be performed as described in 9.11.

6.8.3 Thermal capability of voltage regulators for short-circuit conditions

The temperature of the conductor material in the windings of voltage regulators under the short-circuit condition specified in 6.8.1, as calculated by methods described in 9.13.4, shall not exceed 250 °C for a copper conductor or 200 °C for an electrical conductor (EC) aluminium. A maximum temperature of 250 °C shall be allowed for aluminium alloys having resistance to annealing properties at 250 °C, equivalent to EC aluminium at 200 °C, or for application of EC aluminium 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 liquid or solid insulation;

b) conductor annealing;

c) insulation aging.

6.9 Sound pressure level for liquid-immersed voltage regulators

The sound pressure level produced by the voltage regulator under a no-load (excitation) condition should not exceed the values specified in Table 13 when measured in accordance with the requirements of 9.12.

Table 13 – Maximum no-load (excitation) sound pressure levels

kVA	Average sound pressure level (dB)
0 – 50	48
51 – 100	51
101 – 300	55
301 – 500	60
501 – 750	61
751 – 1 000	62
1 001 – 1 500	64
1 501 – 2 000	65
2 001 – 2 500	66
2 501 – 3 000	67

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6.10 Tests

6.10.1 General

Tests are divided into two categories: routine and type. Routine tests are made for quality control by the manufacturer to verify during production that the product meets the design specifications. Type tests are made to determine the adequacy of the design of a particular type, style, or model of equipment or its component parts. Design adequacy includes but is not limited to: meeting assigned ratings, operating satisfactorily under normal service conditions or under special conditions if specified, and compliance with appropriate standards of the industry. The sequence of routine and type tests can be performed in any order unless otherwise specified in this document.

6.10.2 Routine tests

Routine tests shall be made on all voltage regulators per the following list:

a) leak test;
b) operational test of voltage regulator including all devices. Controlled devices such as on-load tap-changers, position indicators, fans, etc., shall be operated for proper functioning;
c) resistance measurements of all windings (see 9.2);
d) polarity test (see 9.3);
e) ratio test (see 9.4);
f) no-load loss at rated voltage and rated frequency (see 9.5);
g) excitation current at rated voltage and rated frequency (see 9.5);
h) impedance and load loss at rated current and rated frequency (see 9.6);
i) lightning impulse test (see 9.7.3);
j) applied-voltage test (see 9.7.4);
k) induced-voltage test (see 9.7.5);
l) insulation power factor test (see 9.7.6);
m) insulation resistance test (see 9.7.7);
n) on-load tap-changer tests (see 9.8);
o) control system tests (see 9.9).

NOTE Listed tests are not in a required sequence.

6.10.3 Type tests

6.10.3.1 General

The type tests described in 6.10.3.2 to 6.10.3.5 shall be made on representative voltage regulators to substantiate the ratings assigned to all other voltage regulators of basically the same design. Type tests are not intended to be used as a part of normal production. The applicable portion of these type tests may also be used to evaluate modifications of a previous design and to assure the performance has not been adversely affected. Test data from previous similar designs may be used for current designs, where appropriate. Once made, the type tests need not be repeated unless the design is changed to modify performance.

6.10.3.2 Temperature-rise test

Temperature-rise test shall be carried out on one unit of a given rating produced by a manufacturer as a record that this design meets the temperature-rise requirement for a 55 °C or 65 °C winding rise rating. The temperature-rise test shall be carried out at the tap position

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producing the highest total loss at rated load current for the highest operating voltage per nameplate, supplementary voltage rating (see 6.2.4), and the 160 % or 668 A rating (see 6.3). When a voltage regulator is supplied with ancillary cooling equipment to provide higher kVA ratings, a temperature-rise test shall be carried out at those ratings also. The test shall be carried out in accordance with 9.10.

When specifications state a temperature-rise test may be omitted if there is thermal test data available for a thermal duplicate voltage regulator, then calculated data based upon the thermal test data may be submitted as thermal duplicate test data. A thermal duplicate is a voltage regulator whose thermal design characteristics are identical to a design previously tested, or whose differences in thermal characteristics are within agreed-upon variations, such that the thermal performance of the thermal duplicate voltage regulator shall meet the performance guarantees established by standards or specifications.

6.10.3.3 Lightning impulse test

A lightning impulse test shall be carried out on one unit of a given rating produced by a manufacturer for the purpose of demonstrating the adequacy of the insulating materials' breakdown and spacing under normal conditions. Test shall be carried out in accordance with 9.7.2. Impulse test is to be followed by the application of the low-frequency applied-voltage and induced-voltage tests.

6.10.3.4 Short-circuit test

A short-circuit test shall be carried out on one unit of a rating produced by a manufacturer for the purpose of demonstrating that the unit meets the mechanical requirements of 6.8.2. Where other ratings have the same design configuration, core and coil framing, and clamping as the unit tested, a short-circuit test is not required, and it is adequate to show by calculation the mechanical forces are equal or less than the unit tested. Test is to be carried out in accordance with 9.11.

6.10.3.5 Sound level test

A No-load (excitation) sound level test shall be carried out on one unit of a given rating produced by a manufacturer as a record that this design meets the sound level requirement for the specific power rating specified in Table 13. This test shall be performed by applying rated voltage directly to the excitation winding of the equipment at nominal frequency. The same circuit used for measuring no-load loss shall be adopted for this measurement. The test shall be performed with the voltage regulator fully assembled with all accessories. The test shall be performed at the tap position in which the reactor is energized at its maximum level. Voltage regulators incorporating a series transformer construction shall have their test performed at the tap position in which the reactor and series transformer deliver the maximum No-load (excitation) sound level. This test is to be carried out in accordance with 9.12.

7 Construction

7.1 Bushings

Voltage regulators shall be equipped with bushings having an insulation level not less than the winding terminal to which they are connected, unless otherwise specified.

Bushings for use in voltage regulators shall have impulse and applied-voltage insulation levels as listed in Table 14. Unless otherwise specified, the colour of the bushings shall conform to Light Gray Number 70, Munsell Notation 5BG7.0/0.4, as described in IEEE Std C57.12.31.

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Table 14 – Electrical characteristics of voltage regulator bushings

BIL (kV)	**Creep distance** (minimum) mm (in)	**Applied-voltage withstand**		**Impulse full-wave dry withstand** kV crest (1,2 × 50 µs)
		1 min dry (kV **RMS**)	**10 s wet** [a] (kV **RMS**)	
60	90 (3,5)	21	20	60
75	150 (6)	27	24	75
95	255 (10)	35	30	95
110	280 (11)	50	45	110
150	435 (17)	60	50	150
170	660 (26)	70	65	170
200	660 (26)	80	75	200

[a] Wet withstand values are based on water resistivity of 180 Ω·m (7 000 Ω·in) and precipitation rate of 0,085 mm/s (0,2 in/min).

7.2 External dielectric clearances

Table 15 establishes the required minimum external clearances between live parts of different phases and live parts to ground. In the formation of these clearances, it is recognized the bushing ends normally have rounded electrode shapes. It is also expected the conductor clamps are suitably shaped so they do not reduce the withstand strengths, and the arrangement of the incoming conductors does not reduce the effective clearances provided by the voltage regulator bushings. In other words, the clearances were established based upon electrostatic fields not usually being divergent.

Factory dielectric test conditions may require larger clearances than those defined in Table 15.

Table 15 – External dielectric clearances

BIL (kV)	**Minimum clearance between live parts and ground**		**Minimum clearance between live parts of different phases**	
	mm	in	mm	in
60	76	3	76	3
75	89	3,5	102	4
95	114	4,5	127	5
110	152	6	165	6,5
150	203	8	229	9
170	230	9	254	10
200	305	12	330	13

7.3 Terminal markings

Voltage regulator terminals connected to the regulated circuit (load) shall be designated by an "L", and those connected to the unregulated circuit (source) shall be designated by an "S". For example, in the case of a single-phase voltage regulator, the terminals shall be identified by "S", "L", and "SL". In the case of a three-phase voltage regulator, the terminals shall be identified S_1, S_2, S_3, L_1, L_2, L_3, and, if a neutral is provided, S_0L_0.

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Single-phase voltage regulators, when viewed from the top, shall have the "S" terminal on the left, followed in sequence in a clockwise direction by the "L" terminal and the common terminal "SL", as shown in Figure 1.

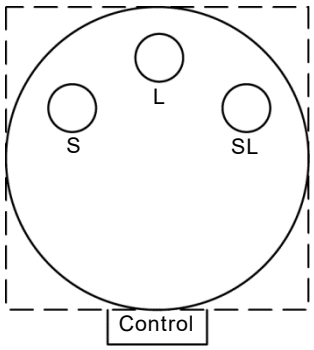
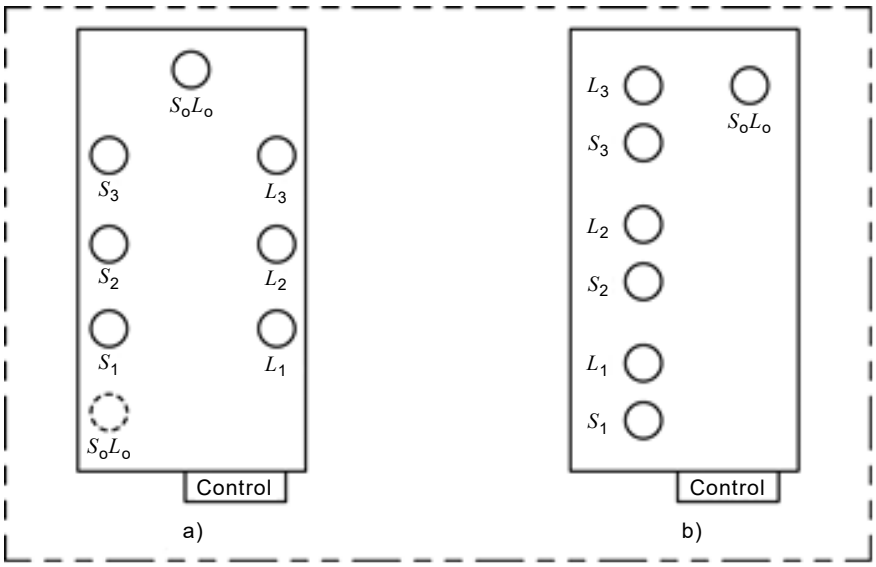


Figure 1 – Single-phase voltage regulators

For three-phase voltage regulators, when facing the voltage regulator on the unregulated circuit side (source), the S_1 terminal shall be in front on the right, and the L_1 terminal shall be directly behind the S_1 terminal, as shown in Figure 2(a), or the S_1 terminal shall be in front on the right, and the L_1 terminal shall be directly to the left of the S_1 terminal, as shown in Figure 2(b). The other terminals shall be located as shown in Figure 2.



NOTE The dotted circle in Figure 2(a) shows alternate location of neutral (S_0L_0) bushing.

Figure 2 – Three-phase voltage regulators with two arrangements of bushings

7.4 Diagram of connections

The manufacturer shall furnish, with each voltage regulator, complete diagrams showing the leads and internal connections and their markings, including polarity markings, and the voltages obtainable with the various connections. These diagrams shall be inscribed on and be part of the nameplate.

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Voltage transformers and current transformers shall be indicated on the nameplate. Polarity and electrical location shall be identified.

Any nonlinear devices, capacitors, or resistors installed on the winding assembly or on the on-load tap-changer shall be indicated on the nameplate.

7.5 Nameplates

Two durable metal nameplates shall be furnished with each voltage regulator and shall be affixed to the main tank and on the front of the control enclosure. Unless otherwise specified, they shall be of corrosion-resistant material. The nameplates shall show, at a minimum, the ratings and other essential operating data as specified below:

a) manufacturer's name;
b) type and form designation or the equivalent;
c) cooling class;
d) serial number;
e) month and year of manufacturing (not coded);
f) number of phases;
g) rated kVA;
h) rated current;
i) supplementary continuous-current ratings;
j) rated voltage;
k) voltage transformer ratio;
l) rated range of regulation;
m) rated frequency;
n) impulse level, full wave in kilovolts (kV);
o) untanking weight;
p) total weight;
q) insulating liquid type;
r) volume of insulating liquid (weight of insulating liquid when specified in place of volume);
s) conductor material;
t) average winding rise in degrees Celsius (°C);
u) diagrams as specified in 7.4;
v) installation and operating instructions reference;
w) symmetrical short-circuit withstand ampere rating with time duration;
x) asymmetrical short-circuit withstand, first peak ampere rating (when specified);
y) on-load tap-changer model number and maximum through-current rating;
z) tap-changer motor capacitor rating;
aa) ratio of load current to switched current (if series transformer construction is used).

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7.6 Tank construction

7.6.1 General

Voltage regulators shall have a sealed-tank liquid-preservation system. Sealed-tank construction is a construction in which the interior of the tank is sealed to prevent the introduction of external atmosphere into the tank. As a part of the normal operation, a device, as defined in 7.6.2, shall be provided to relieve excess pressure due to normal temperature variation of top liquid and/or due to on-load tap-changer operations. The voltage regulator shall remain effectively sealed for a top liquid temperature range of −20 °C to +110 °C for continuous operation at rated kilovoltamperes and under operating conditions as described in IEEE Std C57.91 and IEC 60076-7[11] without gaskets and O-rings seizing or deteriorating, for the life of the voltage regulator. Excess pressure may also build up slowly due to overloads, or high ambient temperatures, or external secondary faults, or internal incipient faults in the series or shunt windings. This excess pressure should result in an emission of only a negligible amount of liquid.

7.6.2 Pressure-relief valve

The replaceable pressure-relief valve shall be located on the tank above the 110 °C top liquid level, as determined by the manufacturer's calculation. The valve shall be located so it does not interfere with the use of support lugs and lifting lugs. It shall not be located in the quadrant of the tank that contains the control enclosure.

Exposed parts shall be of weather- and corrosion-resistant materials. Gaskets and O-rings shall withstand liquid vapour at 110 °C continuously and under operating conditions as described in IEEE Std C57.91 and IEC 60076-7[11], without seizing or deteriorating, for the life of the voltage regulator.

The valve shall have a pull ring for manually reducing pressure to atmospheric level using a standard hook stick, and shall be capable of withstanding a static pull force of 112 N (25 lbf) for 1 min without permanent deformation. The valve shall withstand for 1 min a static force of 445 N (100 lbf) applied normal to its longitudinal axis at the outermost extremity of the body. When specified, the venting port on the outward side of the valve-head seat shall be protected to prevent entry of dust, moisture, and insects before and after the valve has operated.

Venting and sealing characteristics shall be as follows:

a) venting pressure = 34,5 kPa (5 psig) ± 13 kPa (gauge) (2 psig);

b) resealing pressure = 6,9 kPa (gauge) (1 psig) minimum;

c) zero leakage from reseal pressure to −56 kPa (gauge) (−8 psig);

d) flow at 103 kPa (gauge) (15 psig) = 23,6 l/s [50 standard cubic feet per minute (SCFM)] minimum corrected for air pressure of 101 kPa (14,7 psi) (absolute) and air temperature of 21 °C.

7.6.3 Cover assembly

A cover assembly designed to relieve excessive pressure in the voltage regulator tank shall remain effectively sealed for overloads (IEEE Std C57.91 and IEC 60076-7[11]) and short-circuits (6.8 and IEC 60076-5[10]). The assembly shall relieve pressure at a minimum of 20 kPa (gauge) (3 psig) if designed to reseal, or at a minimum of 138 kPa (gauge) (20 psig) if designed for pressure relief without resealing. Such operation shall occur before other components of the tank are ruptured or displaced, and the cover shall remain in position. Manual means of venting the tank before removal of the cover shall be provided. The flow rate shall be at least equal to that of the pressure-relief device specified in 7.6.2.

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7.6.4 Sudden pressure relay

When specified, a sudden pressure relay with a seal-in circuit shall be provided for the indication of voltage regulator faults, and to minimize damage to equipment. The relay shall not actuate under normal voltage regulator operating pressures. The sudden pressure relay may be either a gas space mounted relay or an under liquid relay. Under liquid relays shall actuate under rapidly changing pressures of 10 kPa/s to 38 kPa/s (1,5 psi/s to 5,5 psi/s). The gas space mounted relays shall actuate with a pressure change of 3,5 kPa/s to 21 kPa/s (0,5 psi/s to 3,0 psi/s). These two types of relays shall have their seal-in circuits actuate within three cycles of the rated power frequency after the pressure relay operation.

The sudden pressure relay shall be able to withstand full vacuum or positive pressure of 103 kPa (15 psi) without damage.

7.6.5 Lifting lugs

The lifting lugs shall be permanently attached to and arranged on the tank to provide a balanced lift in a vertical direction for the completely assembled voltage regulator and shall be designed to provide a safety factor of five. The safety factor of five is the ratio of the ultimate stress to the working stress of the material used. The working stress is the maximum combined stress developed in the lifting lugs by the static load of the completely assembled voltage regulator. If the angle of the lifting means interferes with the cover, bushings, arresters or other components, a spreader bar should be provided by the purchaser.

7.6.6 Support lugs

Support lugs for pole mounting shall be provided for ratings 288 kVA and less, with rated line current of 668 A or less. Support lugs shall be designed to provide a safety factor of five when supported in a vertical plane from the top lug only. The safety factor of five shall be as defined for lifting lugs in 7.6.5. Interchangeable mounting to the maximum extent is accomplished by use of Type-B and Type-C support lugs designed in accordance with Figure 3 and Figure 4, respectively. An upper and a lower support lug shall be provided for direct-pole mounting. Type and spacing of support lugs used are dependent on the total weight and height of the voltage regulator.

NOTE 1 Support lug identification and descriptions come from IEEE Std C57.12.20™[19]. Owing to weight restrictions, Type-A support lug is not relevant to voltage regulators.

NOTE 2 Depending on the manufacturer, weights can be significantly different for the same rating. The purchaser is advised to verify the pole is suitable for the weight specified on the voltage regulator's nameplate.

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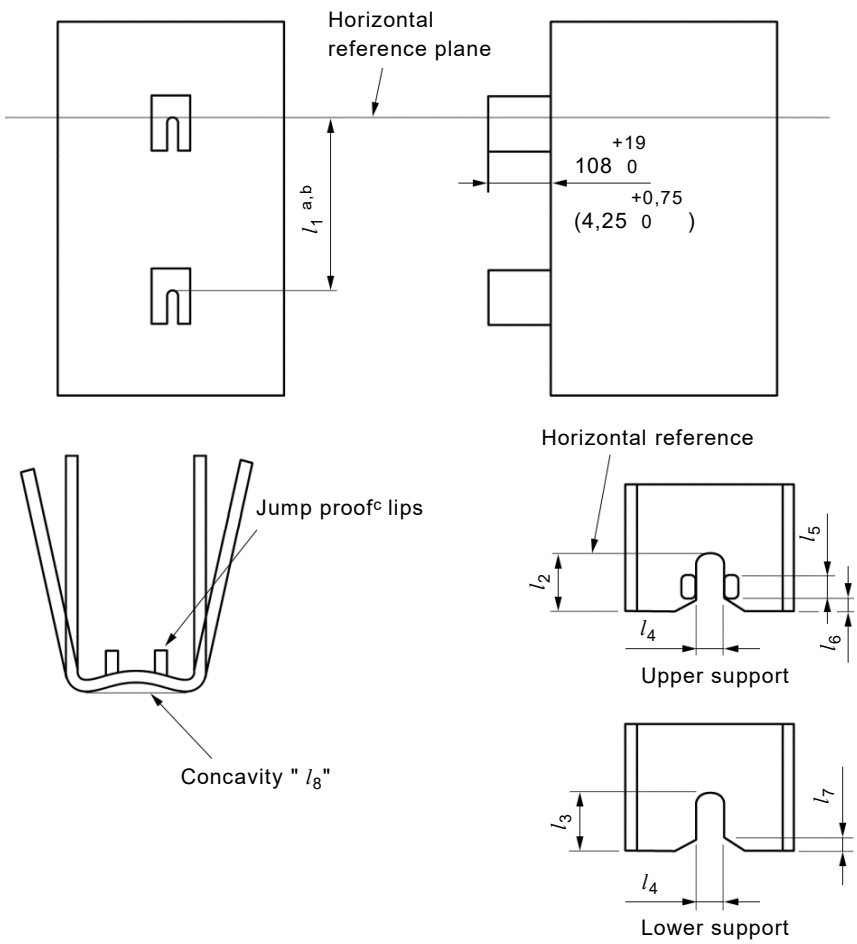
Dimensions in millimetres (dimensions in inches)



Dimensions[d]	Support lug B[e] mm (in)
l_2	44,5 (1,75)
l_3	63,5 (2,50)
l_4[f]	20,2 (0,80)
l_5	15,9 (0,63)
l_6	6,4 (0,25)
l_7	12,7 (0,50)
l_8	6,4 (0,25)

NOTE Unless otherwise noted, all dimensions have a tolerance of ±2 mm (0,063 in).

[a] "l_1" dimension is 590 mm (23,25 in) or 895 mm (35,25 in) depending on the tank height.

[b] Slots "l_1" dimension is spaced 20 mm (0,75 in) less than pole bolt spacing.

[c] Jump-proof lips are on upper support only.

[d] The dimensions shown shall be maintained to obtain a standard mounting and are not intended to show construction details except for slot dimensions.

[e] Type-B support lugs use 20 mm (0,75 in) bolts.

[f] Tolerance for slot dimension "l_4" shall be ±0,4 mm (±0,016 in).

Figure 3 – Type-B support lugs

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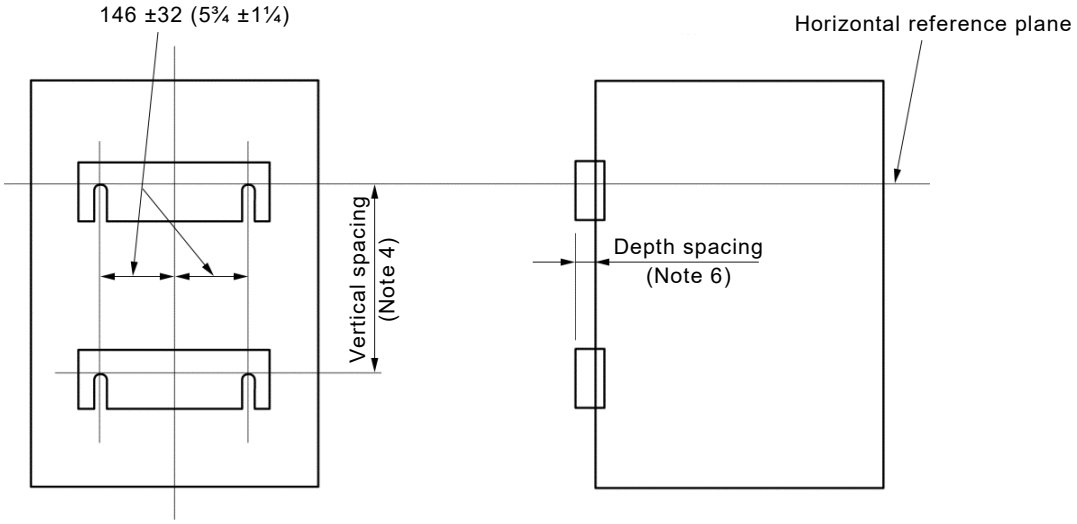
Dimensions in millimetres (dimensions in inches)



NOTE 1 Support lugs attached to voltage regulator have provisions for bolting on Type-C adapter plates for direct pole mounting.

NOTE 2 Slots can be vertical as well as horizontal and are suitable for 16 mm (0,625 in) bolts.

NOTE 3 Support lug faces are located in one plane.

NOTE 4 Vertical spacing is 914 mm (36 in).

NOTE 5 Type-C adapter plates for direct pole mounting and cluster mounting of voltage regulators are available from pole-line hardware manufacturers. If such adapter plates are to be used, it is suggested the purchaser contact the manufacturer for maximum loading capacities.

NOTE 6 Depth of support lugs is dependent on a manufacturer's design. Bushing profiles on top of cover are to be offset. Some manufacturers incorporate the design specifications of a Type-C adapter plate within their Type-C support lug design for ease of installation.

Figure 4 – Type-C support lugs

7.6.7 Substation bases

Bases for substation mounting shall be provided for 165 kVA and higher and shall be arranged for rolling or skidding in two directions: parallel to and right angles to one side of the voltage regulator. Voltage regulators with substation base and support lugs shall not have the base interfere with the mounting of the voltage regulator to the pole.

7.6.8 Tank grounding provisions

7.6.8.1 Maximum continuous rating less than 300 A

Tank grounding provisions shall consist, at a minimum, of one steel pad with a 0,5 in-13 NC tapped hole, 11 mm (0,44 in) deep and located near the bottom of the tank.

7.6.8.2 Maximum continuous rating 300 A or greater

Tank grounding provision shall consist, at a minimum, of one unpainted copper-faced steel or stainless-steel pad, 50 mm × 90 mm (2,0 in × 3,5 in), with two holes horizontally spaced on 44,5 mm (1,75 in) centres, tapped for 0,5 inch 13 NC thread and located near the bottom of the tank. Minimum thread depth of each hole shall be 13 mm (0,5 in). Minimum thickness of the copper facing, when used, shall be 0,4 mm (0,015 in).

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7.7 Components and accessories

7.7.1 Components for full automatic control and operation

a) Control system

b) Current and voltage transformers or the equivalent for supplying the control system

c) On-load tap-changer equipment consisting of a liquid-immersed arcing tap switch, a tap selector and an arcing switch, or a tap selector with vacuum switch or other current interrupting facility, and motor mechanism

d) Internal power supply for on-load tap-changer motor

e) Provision for disconnecting control power supply

f) Position indicator for the on-load tap-changer with maximum and minimum indicating hands and provision for resetting

   1) Adjustable range of regulation for the Raise and Lower ranges provided for supplementary current ratings per 6.3

   2) Mechanically actuated electric limit switches provided preventing travel beyond the maximum Raise and Lower positions

7.7.2 Accessories for single-phase step-voltage regulators

a) Combination drain and lower filter valve with sampling device

b) Fill plug located at the top of the tank above liquid level

c) Indicator for 25 °C liquid level

d) Bushing terminals shall be either clamp-type or threaded stud, depending on the nameplate line current ratings as shown in Table 16. The clamp-type terminals shall have at least the conductor range stated and shall be capable of accepting an aluminium or copper conductor. Spade terminals shall have a pad with a minimum dimension of 101,6 mm × 101,6 mm (4,0 in × 4,0 in), with four 14,2 mm (0,562 5 in) holes horizontally and vertically spaced on 44,5 mm (1,75 in) centres. Thicknesses of the pad are shown in Table 16. The purchaser has the responsibility of selecting the proper conductor size for use with the clamp-type or spade terminals. When selecting the conductor size, the purchaser should consider factors such as additional current carrying capability with reduced regulation (see 6.3), supplementary voltage ratings (see 6.2.4) and loading at other than rated conditions (see 5.2).

Table 16 – Bushing terminal applications

Nameplate line current rating (A)	**Conductor size range or 4-hole spade**
150 or less	8–4/0 AWG
151 to 300	2 AWG – 477 kCM
301 to 668	2 AWG – 800 kCM
669 to 1 200	1-1/8–12 UNF-2A with 4-hole spade – 9,5 mm (0,375 in) minimum thickness
1 201 to 2 000	1-1/2–12 UNF-2A with 4-hole spade – 12,7 mm (0,5 in) minimum thickness

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7.7.3 Accessories for three-phase step-voltage regulators

a) Combination drain and lower filter valve with sampling device

b) Fill plug located at the top of the tank

c) Indicator for 25 °C liquid level

d) Clamp-type terminals in accordance with single-phase criteria [see item d) in 7.7.2]

e) Provision for thermometer

f) Openings to permit inspection of core and coil and on-load tap-changer

8 Other requirements

8.1 General

Certain specific applications have voltage regulator requirements not covered in Clause 5 to Clause 7. Clause 8 comprises descriptions of the most frequently used requirements for such voltage regulators. They shall be provided only when specified in conjunction with the requirements of Clause 5 to Clause 7. Information in the following subclauses may be specified for some applications.

8.2 Other components and accessories

8.2.1 General

When specified, the other components and accessories listed in 8.2.2 and 8.2.3 may be provided.

8.2.2 Single- and three-phase voltage regulators

a) Control cabinet removable for remote control operation [up to 15 m (50 ft) from the voltage regulator]

b) Universal interface (see Clause 11)

c) Voltage transformer for source side sensing for reverse power flow mode of control

d) Control cabinet heater

e) Remote communication interfaces

f) 5 A secondary rating for current transformer

g) Surge arresters

h) Thermometer with or without alarm contacts

i) Oil level gauge with or without alarm contacts

j) Sight gauge for critical liquid level indication (decal required for designating level at middle of dial)

k) Tank and control enclosure ground connectors

l) Forced air cooling (ONAF or KNAF) with fan motors rated 120 V or 240 V, 50/60 Hz, single-phase, without centrifugal switch, and individually fused or otherwise thermally protected. In addition the following equipment shall be provided:

   1) fan control circuitry including relays and operation switch;

   2) mechanical arrangement and provisions for mounting fans;

   3) thermometer with alarm contacts.

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8.2.3 Three-phase voltage regulators

a) Hand operation crank for on-load tap-changer

b) On-load tap-changer compartment separate from the core and coil

c) Remote position indicator[4]

9 Test code

9.1 General

Although the figures with the following test procedures show conventional meters, adequate digital readout measuring devices and digital sampling techniques with computer calculations are considered to be satisfactory alternatives.

9.2 Resistance measurements

9.2.1 General

Resistance measurements are of fundamental importance for the following purposes:

a) calculation of the I^2R component of conductor loss;

b) calculation of winding temperatures at the end of a temperature-rise test;

c) as a quality control test of the manufacturing process;

d) as a base for assessing possible damage in the field.

9.2.2 Determination of cold temperature

9.2.2.1 General

The cold temperature of the winding shall be determined as accurately as possible when measuring the cold-resistance. Cold-resistance measurements shall be made on a voltage regulator only when the liquid or winding temperature is stable. The temperature is considered stable if the top liquid temperature does not vary by more than 2 °C in a 1 h period.

9.2.2.2 Voltage regulator windings immersed in insulating liquid

The temperature of the windings shall be assumed to be the same as the average temperature of the insulating liquid, provided:

a) the windings have been under insulating liquid without excitation and current for a minimum of 3 h before the cold-resistance is measured;

b) the temperature of the insulating liquid has stabilized, and the difference between top and bottom temperatures does not exceed 5 °C.

9.2.2.3 Voltage regulator windings out of insulating liquid

The temperature of the windings shall be recorded as the average of several thermometers or thermocouples inserted between the coils, with care used to see their measuring points are as nearly as possible in actual contact with the winding conductors. It should not be assumed the windings are at the same temperature as the surrounding air.

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[4] For Selsyn-type systems, care shall be exercised to assure that the conductor size is commensurate with the distance used.

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