



DPC: 16 / 30337130 DC

BSI Group Headquarters

389 Chiswick High Road London W4 4AL

Tel: +44 (0)20 8996 9000

Fax: +44 (0)20 8996 7400

www.bsigroup.com

Date: 19 October 2016

Origin: European

Latest date for receipt of comments: 15 November 2016

Project No. 2016/00159

Responsible committee: PEL/14 Power transformers

Interested committees:

Title: Draft BS EN 60076-57-15 Ed 1.0 Power transformers

Part 57-15: Standard requirements, terminology and test code for step-voltage regulators

Please notify the secretary if you are aware of any keywords that might assist in classifying or identifying the standard or if the content of this standard

- i) has any issues related to 3rd party IPR, patent or copyright
- ii) affects other national standard(s)
- iii) requires additional national guidance or information

**WARNING: THIS IS A DRAFT AND MUST NOT BE REGARDED OR USED AS A BRITISH STANDARD.
THIS DRAFT IS NOT CURRENT BEYOND 15 November 2016**

This draft is issued to allow comments from interested parties; all comments will be given consideration prior to publication. No acknowledgement will normally be sent. **See overleaf for information on the submission of comments.**

No copying is allowed, in any form, without prior written permission from BSI except as permitted under the Copyright, Designs and Patent Act 1988 or for circulation within a nominating organization for briefing purposes. Electronic circulation is limited to dissemination by e-mail within such an organization by committee members.

Further copies of this draft may be purchased from BSI Shop <http://shop.bsigroup.com> or from BSI Customer Services, Tel: +44(0) 20 8996 9001 or email cservices@bsigroup.com. British, International and foreign standards are also available from BSI Customer Services.

Information on the co-operating organizations represented on the committees referenced above may be obtained from <http://standardsdevelopment.bsigroup.com>

Responsible Committee Secretary: **Mr Roger G Tanfield (BSI)**
Direct tel: **020 8996 7218**
E-mail: roger.tanfield@bsigroup.com

Introduction

This draft standard is based on European discussions in which the UK has taken an active part. Your comments on this draft are welcome and will assist in the preparation of the consequent British Standard. Comment is particularly welcome on national, legislative or similar deviations that may be necessary.

Even if this draft standard is not approved by the UK, if it receives the necessary support in Europe, the UK will be obliged to publish the official English Language text unchanged as a British Standard and to withdraw any conflicting standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with reasons) or positive vote on this draft.

Submission of Comments

- The guidance given below is intended to ensure that all comments receive efficient and appropriate attention by the responsible BSI committee. **Annotated drafts are not acceptable and will be rejected.**
- All comments must be submitted, preferably electronically, to the Responsible Committee Secretary at the address given on the front cover. Comments should be compatible with version 6.0 or version 97 of Microsoft Word for Windows, if possible; otherwise comments in ASCII text format are acceptable. **Any comments not submitted electronically should still adhere to these format requirements.**
- All comments submitted should be presented as given in the example below. Further information on submitting comments and how to obtain a blank electronic version of a comment form are available from the BSI website at:
<http://drafts.bsigroup.com/>

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
------------------	-------------------------------

1	2	(3)	4	5	(6)	(7)
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/ Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



14/872/CD

COMMITTEE DRAFT (CD)

IEC/TC or SC: 14	Project number IEC/IEE 60076-57-15 Ed.1	
Title of TC/SC: Power transformers	Date of circulation 2016-09-30	Closing date for comments 2016-11-25
Also of interest to the following committees	Supersedes document 14/845/CD and 14/855A/CC/	
Proposed horizontal standard ☐ Other TC/SCs are requested to indicate their interest, if any, in this CD to the TC/SC secretary		
Functions concerned: ☐ Safety ☐ EMC ☐ Environment ☐ Quality assurance		
Secretary: M Maghar	THIS DOCUMENT IS STILL UNDER STUDY AND SUBJECT TO CHANGE. IT SHOULD NOT BE USED FOR REFERENCE PURPOSES. RECIPIENTS OF THIS DOCUMENT ARE INVITED TO SUBMIT, WITH THEIR COMMENTS, NOTIFICATION OF ANY RELEVANT PATENT RIGHTS OF WHICH THEY ARE AWARE AND TO PROVIDE SUPPORTING DOCUMENTATION.	

Title:

Power transformers - Part 57-15: Standard requirements, terminology, and test code for step-voltage regulators

Introductory note

/

Copyright © 2016 International Electrotechnical Commission, IEC. All rights reserved. It is permitted to download this electronic file, to make a copy and to print out the content for the sole purpose of preparing National Committee positions. You may not copy or "mirror" the file or printed version of the document, or any part of it, for any other purpose without permission in writing from IEC.

CONTENTS

1	Scope	8
2	Normative references	8
3	Terms and definitions	9
4	Service conditions	14
4.1	Usual service conditions	14
4.1.1	General	14
4.1.2	Temperature	14
4.1.3	Altitude	14
4.1.4	Supply voltage	14
4.1.5	Load current	14
4.1.6	Outdoor operation	14
4.1.7	Tank or enclosure finish	14
4.2	Loading at other than rated conditions	14
4.3	Unusual service conditions	15
4.3.1	Unusual temperature and altitude conditions	15
4.3.2	Insulation at high altitude	15
4.3.3	Other unusual service conditions	16
5	Rating Data	16
5.1	Cooling classes of voltage regulators	16
5.1.1	Liquid-immersed (fire point $\leq 300\text{ }^{\circ}\text{C}$) air-cooled	16
5.1.2	Liquid-immersed (fire point $> 300\text{ }^{\circ}\text{C}$) air-cooled	16
5.1.3	Liquid-immersed (fire point $\leq 300\text{ }^{\circ}\text{C}$) water-cooled	17
5.1.4	Liquid-immersed (fire point $> 300\text{ }^{\circ}\text{C}$) water-cooled	17
5.2	Ratings	17
5.2.1	Terms in which rating is expressed	17
5.2.2	Preferred ratings	18
5.2.3	Supplementary voltage ratings	23
5.3	Supplementary continuous-current ratings	24
5.3.1	Preferred optional forced-air ratings	24
5.4	Taps	24
5.5	Voltage supply ratios	25
5.6	Insulation levels	25
5.7	Losses	26
5.7.1	Total loss	26
5.7.2	Tolerance for losses	26
5.7.3	Determination of losses and excitation current	26
5.8	Short-circuit requirements	27
5.8.1	General	27
5.8.2	Mechanical capability demonstration	28
5.8.3	Thermal capability of voltage regulators for short-circuit conditions	28
5.9	Sound levels for liquid-immersed voltage regulators	28
5.10	Tests	28
5.10.1	Routine tests	28
5.10.2	Design tests	29
6	Construction	30

6.1	Bushings	30
6.2	External dielectric clearances	31
6.3	Terminal markings	31
6.3.1	Terminal markings for step-voltage regulators	31
6.4	Diagram of connections	32
6.5	Nameplates	32
6.6	Tank construction	33
6.6.1	Pressure-relief valve	33
6.6.2	Cover assembly	33
6.6.3	Sudden pressure relay	34
6.6.4	Lifting lugs	34
6.6.5	Support lugs	34
6.6.6	Moving facilities	36
6.6.7	Tank grounding provisions	36
6.7	Components and accessories	36
6.7.1	Components for full automatic control and operation	36
6.7.2	Accessories for single-phase step-voltage regulators	37
6.7.3	Accessories for three-phase step-voltage regulators	37
7	Other requirements	37
7.1	Other supplementary continuous-current ratings	38
7.2	Other components and accessories	38
7.2.1	For single- and three-phase voltage regulators	38
7.2.2	In addition for three-phase voltage regulators	38
8	Test code	39
8.1	Resistance measurements	39
8.1.1	Determination of cold temperature	39
8.1.2	Conversion of resistance measurements	40
8.1.3	Resistance measurement methods	40
8.2	Polarity test	41
8.2.1	Polarity by inductive kick	41
8.2.2	Polarity by ratio meter	42
8.3	Ratio tests	42
8.3.1	General	42
8.3.2	Tolerance for ratio	42
8.3.3	Ratio test methods	43
8.4	No-load loss and excitation current	44
8.4.1	General	44
8.4.2	No-load loss test	45
8.4.3	Waveform correction of no-load loss	46
8.4.4	Test methods for three-phase voltage regulators	47
8.4.5	Determination of excitation (no-load) current	47
8.4.6	Measurements	48
8.4.7	Correction of loss measurement due to metering phase-angle errors	48
8.5	Load loss and impedance voltage	49
8.5.1	General	49
8.5.2	Factors affecting the values of load loss and impedance voltage	50
8.5.3	Tests for measuring load loss and impedance voltage	50
8.5.4	Calculation of load loss and impedance voltage from test data	52

8.6	Dielectric tests	55
8.6.1	General	55
8.6.2	Design lightning impulse test procedures	55
8.6.3	Routine lightning impulse test procedures	60
8.6.4	Low-frequency tests	62
8.6.5	Applied-voltage tests	62
8.6.6	Induced-voltage tests	62
8.6.7	Insulation power factor tests	63
8.6.8	Insulation resistance tests	64
8.7	Temperature-rise tests	65
8.7.1	Test methods	66
8.7.2	Resistance measurements	69
8.7.3	Temperature measurements	69
8.7.4	Correction of temperature-rise test results	72
8.8	Short-circuit test	74
8.8.1	General	74
8.8.2	Test connections	74
8.8.3	Test requirements	74
8.8.4	Test procedure	75
8.8.5	Proof of satisfactory performance	76
8.9	Determination of sound level	77
8.9.1	General	77
8.9.2	Instrumentation	78
8.9.3	Test conditions	78
8.9.4	Microphone positions	79
8.9.5	Sound level measurements	80
8.9.6	Determination of sound level of a voltage regulator	84
8.9.7	Presentation of results	85
8.10	Enclosure integrity test	87
8.10.1	Enclosure integrity	87
8.10.2	Design test for fault current capability of voltage regulators.	87
8.11	Calculated data	89
8.11.1	Reference temperature	89
8.11.2	Loss and excitation current	89
8.11.3	Efficiency	89
8.11.4	Calculation of winding temperature during a short-circuit	89
8.11.5	Certified test data	91
9	On-load tap-changer	92
9.1	General	92
9.2	Routine tests	92
9.2.1	On-load tap-changer tests	92
9.2.2	Mechanical tests	92
9.2.3	Auxiliary circuits insulation test	93
9.3	Design tests	93
9.3.1	Temperature-rise of contacts test	93
9.3.2	Switching tests	93
9.3.3	Short-circuit test	95
9.3.4	Reactor test	95
9.3.5	Mechanical test	95

9.3.6	Dielectric tests	96
10	Control Systems	97
10.1	General.....	97
10.2	Control device construction	97
10.2.1	Setpoint adjustment ranges	97
10.2.2	Components and accessories	97
10.3	Universal interface (when specified).....	98
10.3.1	Connection between control enclosure and apparatus liquid-immersed container	98
10.3.2	Universal interface connectors.....	98
10.4	Control system requirements.....	101
10.4.1	Accuracy.....	101
10.5	Tests.....	102
10.5.1	Design tests.....	102
10.5.2	Routine tests	106
Annex A (informative)	Unusual temperature and altitude conditions	107
A.1	Unusual temperatures and altitude service conditions	107
A.2	Effects of altitude on temperature-rise.....	107
A.3	Operation at rated kVA.....	107
A.4	Operation at less than rated kVA.....	107
Annex B (informative)	Field dielectric tests	108
B.1	Tests on bushings.....	108
B.2	Dielectric tests in the field	108
Annex C (informative)	Step-voltage regulator construction	109
C.1	Type A	109
C.2	Type B	109
C.3	Series transformer	110
C.4	Reactor circuit.....	110
C.5	Equalizer winding.....	111
Annex D (informative)	Bypass off Neutral.....	113
Annex E (informative)	Overloading of step-voltage regulators	116
Annex F (informative)	Power capacitor and distributed generation compatibility	120
F.1	Power capacitor application issues	120
F.1.1	Power circuit for consideration.....	120
F.1.2	Voltage regulator incorporating line-drop compensation (LDC) in the control	120
F.1.3	Voltage regulator incorporating line current compensation (LCC) in the control	123
F.2	Distributed generation application issues	123
F.2.1	Control operation with power reversal recognition	123
F.2.2	Power circuit for consideration.....	124
F.2.3	Distributed generator alternatives	125
F.2.4	P-Q summary.....	125
F.2.5	Example system with distribution generation (DG)	125
F.2.6	Expanded example, distributed generation mode	126
F.2.7	Caveats	127
F.2.8	Conclusions	127
Bibliography		128

Figure 1 – Schematic diagram of single-phase, Type A, step-voltage regulator	13
Figure 2 – Schematic diagram of single-phase, Type B, step-voltage regulator	13
Figure 3 – Single-phase voltage regulators	31
Figure 4 – Three-phase voltage regulators	32
Figure 5 – Support lugs B	35
Figure 6 – Support lugs C	36
Figure 7 – Connections for voltmeter-ammeter method of resistance measurement	40
Figure 8 – Voltage regulator connected for polarity testing; voltage regulator in Neutral position	42
Figure 9 – Voltmeter arranged to read the difference between the two output side voltages	44
Figure 10 – Voltmeters arranged to read the two series winding voltages	44
Figure 11 – Basic circuit of ratio meter	44
Figure 12 – Connection for no-load loss test of single-phase voltage regulator without instrument transformers	46
Figure 13 – Connections for no-load loss test of a single-phase voltage regulator with instrument transformers	46
Figure 14 – Three-phase voltage regulator connections for no-load loss and excitation current test using three-wattmeter method	48
Figure 15 – Single-phase voltage regulator connections for load loss and impedance voltage test without instrument transformers	51
Figure 16 – Single-phase voltage regulator connections for load loss and impedance voltage test with instrument transformers	52
Figure 17 – Three-phase voltage regulator connections for load loss and impedance voltage test using the three-wattmeter method	52
Figure 18 – Example of loading back method: Single phase	67
Figure 19 – Example of loading back method: three-phase	68
Figure 20 – Microphone location for measuring audible sound from voltage regulator	80
Figure 21 – Sound reflection correction factor “K” calculated per Equation (29)	83
Figure 22 – Measurements using the sound pressure method	86
Figure 23 – Measurements using the sound intensity method	87
Figure 24 – Connector Specification	99
Figure 25 – Socket/Pin detail for connector	100
Figure 26 – Universal interface locations	101
Figure C.1 – Type A	109
Figure C.2 – Type B	110
Figure C.3 – Example of a series transformer circuit	110
Figure C.4 – Equalizer (balance) and reactor circuitry– bridging (even) tap position	111
Figure C.5 – Equalizer (balance) winding and reactor circuitry – bridging (odd) tap position	111
Figure D.1 – “Bypass off Neutral” power circuit	113
Figure D.2 – Example of “Bypass off Neutral” symmetrical current pattern of Type A design	115
Figure D.3 – Example of “Bypass off Neutral” symmetrical current pattern of Type B design	115

Figure E.1 – Example of overload capability by tap position	117
Figure E.2 – Example of Type A load loss vs tap position	117
Figure E.3 – Example of Type B load loss vs tap position	118
Figure F.1 – Power distribution substation and representative distribution feeder.....	120
Figure F.2 – Power distribution system with distributed generation	124
Figure F.3 – P-Q diagram quadrant relationships	125
Table 1 – Dielectric strength correction factors for altitudes greater than 1000 m (3300 ft).....	15
Table 2 – Limits of temperature rise	17
Table 3 – Preferred ratings for liquid-immersed 60 Hz step-voltage regulators (single-phase)	19
Table 4 – Preferred ratings for liquid-immersed 50 Hz step-voltage regulators (single-phase)	21
Table 5 – Preferred ratings for liquid-immersed 60 Hz step-voltage regulators (three-phase)	22
Table 6 – Preferred ratings for liquid-immersed 50 Hz step-voltage regulators (three-phase)	23
Table 7 – Supplementary voltage ratings for 60 and 50Hz voltage regulators	23
Table 8 – Supplementary continuous-current ratings for single-phase voltage regulators	24
Table 9 – Supplementary continuous-current ratings for three-phase voltage regulators	24
Table 10 – Forced-air ratings relationship	24
Table 11 – Values of voltage supply ratios	25
Table 12 – Interrelationships of dielectric insulation levels for voltage regulators used on systems with BIL ratings of 200 kV and below	26
Table 13 – Values of K.....	27
Table 14 – Maximum noise levels	28
Table 15 – Electrical characteristics of voltage regulator bushings (kV)	30
Table 16 – External dielectric clearances	31
Table 17 – Bushing terminal applications	37
Table 18 – Other supplementary continuous-current ratings for three-phase voltage regulators.....	38
Table 19 – Requirements for phase-angle error correction	49
Table 20 – Measurements to be made in insulation power factor tests	64
Table 21 – Ambient sound corrections	81
Table 22 – Approximate values of the average acoustic absorption coefficient.....	82
Table 23 – Socket pin identification for connector	100
Table 24 – Voltage-level values for select line-drop compensation settings.....	103
Table 25 – Control supply voltage	105
Table A.1 – Maximum allowable average temperature of cooling air for rated kVA ^a	107
Table A.2 – Rated kVA correction factors for altitudes greater than 1000 m (3300 ft)	107
Table F.1 – Relevant system voltages and currents with capacitor location	122
Table F.2 – Voltage regulator with insignificant distributed generation (DG).....	126

Power transformers –

Part 57.15: Standard Requirements, Terminology, and Test Code for Step-Voltage Regulators

1 Scope

This part of IEC 60076 describes electrical, mechanical and test requirements of liquid-immersed, single- and three-phase, 50 and 60 Hz, self and forced-air cooled distribution overhead and substation step-voltage regulators, 1000 kVA (single-phase units) or 3000 kVA (three-phase units) and smaller, 34,500 Volts and below (2400 Volts minimum) and their associated controls.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

IEC 60050-421, International electrotechnical vocabulary, Chapter 421: Power transformers and reactors¹

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

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

IEEE 4TM, Standard techniques for high-voltage testing^{2,3}

IEEE C37.90.1TM, Standard surge withstand capability (SWC) tests for relays and relay systems associated with electric power apparatus

IEEE C37.90.2TM, Standard for withstand capability of relay systems to radiated electromagnetic interference from transceivers

IEEE C37.90.3TM, Standard electrostatic discharge tests for protective relays

IEEE C57.12.31TM, Standard for pole-mounted equipment—Enclosure integrity

IEEE C57.91TM, Guide for loading mineral-oil-immersed transformers

SAE AS50151, General specification for connectors, electrical, circular threaded, AN type⁴

¹ IEC publications are available from the Central Office of the International Electrotechnical Commission, 3, rue de Varembe, P.O. Box 131, CH-1211, Geneva 20, Switzerland (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

² IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

³ The IEEE standards or products referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in The *IEEE Standards Dictionary Online* and IEC 60050-421, *International Electrotechnical Vocabulary*, and the following apply.⁵

3.1

ambient sound level

background noise level measured at a test facility or at the substation without the voltage regulator 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.⁶

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 reference source voltage terminal and the line-to-neutral voltage of the corresponding load voltage terminal

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 $\pm 5^\circ$ 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

Note to entry The purpose of the tests is to determine the adequacy against breakdown of insulating material and spacing under normal or transient conditions.

3.7

diverter switch

switching device used in conjunction with a tap selector to carry, make and break currents in circuits which 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

⁴ SAE (Society of Automotive Engineers) international publications are available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096, USA (<http://sae.org/>).

⁵ *IEEE Standards Dictionary Online* subscription is available at:
<http://ieeexplore.ieee.org/xpls/dictionary.jsp>.

⁶ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

Note 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 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 resulting in the control varying the output voltage by an amount compensating for the impedance voltage drop in the circuit between the voltage regulator and a predetermined location (sometimes referred to as the load centre) on the circuit

3.12

liquid

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

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

3.13

liquid-immersed voltage regulator

a 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 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 to entry No-load loss includes core loss, dielectric loss, conductor loss in the winding due to exciting 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 current with the arcing taking place in a liquid

3.19

on-load tap-changer

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

3.20

primary circuit

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

3.21

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

3.22

rated voltage (U_r)

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

3.23

rated voltage of the series winding

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

3.24

rating in kVA

product of the rated load amperes and the rated *raise* or *lower* range of regulation in kilovolts (kV) for a single-phase voltage regulator with a three-phase voltage regulator having an additional multiplier of a square root of 3

Note 1 to entry If the rated *raise* and *lower* range of regulation are unequal, the larger shall be used in determining the rating in kVA.

3.25

reactor

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

3.26

regulated circuit

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

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

3.27

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 to entry The diagram of connection is in accordance with subclause 6.4

3.28

series transformer

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

3.29

series winding

portion of the autotransformer not common to both the primary and secondary circuits, but connected in series between the input and output circuits

3.30**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.

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.

3.31**shunt winding**

portion of the autotransformer common to both the primary and secondary circuits

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**

connection brought out of a winding at some point between its extremities, to permit changing the turns ratio of a transformer

3.33**tap selector**

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

3.34**total loss**

sum of the no-load and load losses of a voltage regulator, excluding loss due to its accessories

3.35**Type A step-voltage regulator**

step-voltage regulator in which the primary 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 It is sometimes referred to as a *straight* design in the industry.

Note 2 to entry The core excitation varies due to the shunt winding being 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 3 to entry See Figure 1.

Note 4 to entry Refer to Annex C for additional information on step-voltage regulator construction.

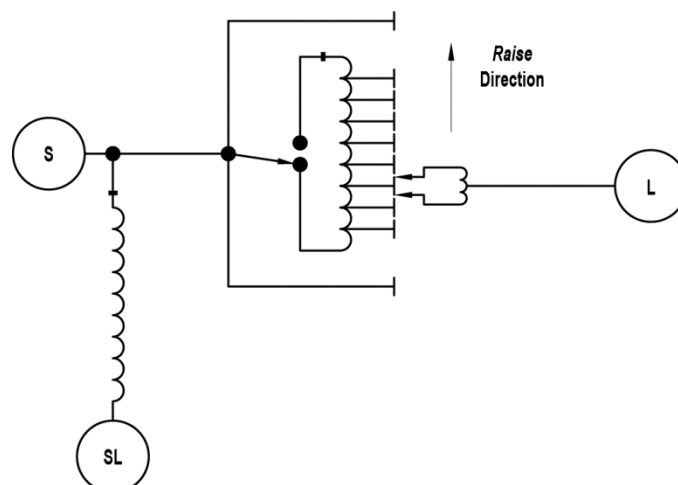


Figure 1 – Schematic diagram of single-phase, Type A, step-voltage regulator

3.36

Type B step-voltage regulator

step-voltage regulator in which the primary 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 It is sometimes referred to as an *inverted* design in the industry.

Note 2 to entry The core excitation is constant due to the shunt winding being 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 the stated nominal amount of regulation referred to the *raise* side for the preferred kVA ratings.

Note 3 to entry See Figure 2.

Note 4 to entry Refer to Annex C for additional information on step-voltage regulator construction.

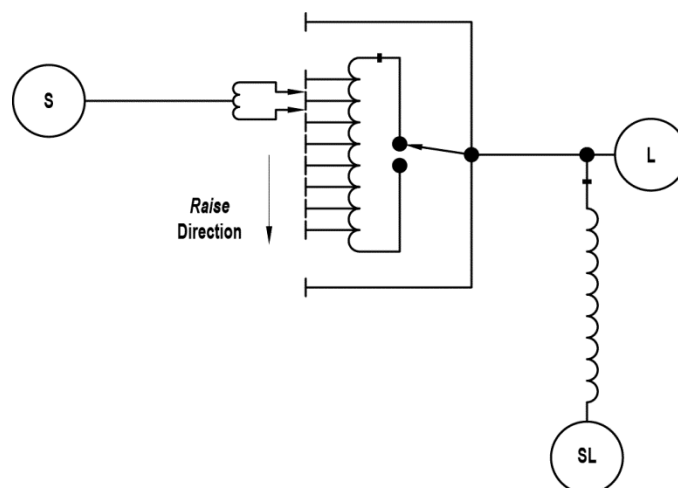


Figure 2 – Schematic diagram of single-phase, Type B, step-voltage regulator

3.37

utility winding

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

3.38

vacuum type on-load tap-changer

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

3.39**voltage supply ratio**

ratio of the regulated line voltage to the control supply voltage

4 Service conditions**4.1 Usual service conditions****4.1.1 General**

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

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 shall 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) shall 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, which is 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.

4.1.7 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 match up with Light Gray Number 70, Munsell Notation 5BG 7.0/0.4. Finishing of voltage regulators shall meet requirements specified in IEEE C57.12.31.⁷

4.2 Loading at other than rated conditions

IEEE C57.91 or IEC 60076-7[B11] provides guidance for loading at other than rated conditions including the following:

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

⁷ Information on references can be found in Clause 2.

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

c) Loading resulting in reduced life expectancy

Note to entry IEEE C57.91 and IEC 60076-7[B11] 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. When specified, ancillary components and other construction features (cables, bushings, tap-changers, liquid expansion space, etc.), shall be supplied, not limiting 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, IEEE C57.91 and IEC 60076-7[B11] provide information on recommended practices.

4.3.2 Insulation at high altitude

The dielectric strength of voltage regulators depending 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.

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 to entry An altitude of 4500 m (15 000 ft.) is considered a maximum for voltage regulators compliant with 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.).

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

4.3.3 Other unusual service conditions

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 to entry Such harmonic currents may 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
 - l) Unusual short-circuit application conditions differing from those described in 5.8.1
 - 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 might result in the flow of telluric currents in voltage regulator neutrals
 - o) Parallel operation

Note to entry IEEE standard, C57.153 [B29] is available as a guide for paralleling voltage regulators.

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.

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)

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 2. 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 ^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 Section 4.1.2.1, 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 Section 4.1.2.1, which utilizes thermally upgraded insulating paper.			

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 rated voltages as given in Table 3, Table 4, Table 5, and Table 6.

Power ratings of single-phase voltage regulators are dependent on the application of 2 or 3 voltage regulators applied to support a specific three-phase load. For example three 333 kVA single-phase voltage regulators connected in a Wye configuration support a 10 MVA load

Note to entry National practices may be different for preferred ratings

A voltage regulator shall be capable of continuous operation at rated power without potential 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 a V/Hz of 110% of the rated V/Hz. At current, S times the voltage regulator rated current ($0 \leq S \leq 1$), the over fluxing shall be limited in accordance with the following Equation (1):

$$\frac{U \times f_r}{U_r \times f} \times 100 \leq 110 - 5S \quad (\%) \quad (1)$$

where

U is System voltage

f is System frequency

U_r is rated voltage of voltage regulator

f_r is 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.

Table 3 – Preferred 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) (Volts rms)	BIL (kV)	Kilovoltamperes (kVA)	Line amperes (A)
6.9	5	2500/4330Y	60	50 75 100 125 167 250 333 416	200 300 400 500 668 1000 1332 1665
11	8.7	5000/8660Y	75	50 75 100 125 167 250 333 416	100 150 200 250 334 500 668 833
17	15	7620/13 200Y	95	38.1 57.2 76.2 114.3 167 250 333 416 500 667 833 1000	50 75 100 150 219 328 438 546 656 875 1093 1312
17	15	13 800	95	69 138 207 276 414 552 667 833 1000	50 100 150 200 300 400 483 604 725
26	25	14 400/24 940Y	150	72 144 288 333 432 576 667 833 1000	50 100 200 231 300 400 463 578 694
36	35	19 920/34 500Y	150	100 200 333 400 667 833 1000	50 100 167 201 334 418 502
36	35	34 500	200	173 345 518 690	50 100 150 200

Table 4 – Preferred 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) (Volts rms)	BIL (kV)	Kilovoltamperes (kVA)	Line amperes (A)
7.2	6.6	6600	75	33 66 99 132 198 264 330 396 462 528	50 100 150 200 300 400 500 600 700 800
12	11	6350/11 000Y	95	32 64 95 127 190 254 317 381 444 508	50 100 150 200 300 400 500 600 700 800
12	11	11000	95	55 110 165 220 330 440 550 660 770 880	50 100 150 200 300 400 500 600 700 800
17.5	15	15000	95	75 150 225 300 450 600 750 900	50 100 150 200 300 400 500 600
24	22	22000	150	110 220 330 440 660 880	50 100 150 200 300 400
36	33	33000	170	165 330 495 660	50 100 150 200

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

Maximum system voltage (U _m) (kV rms)	Nominal system voltage (kV rms)	Rated voltage (U _r) (Volts rms)	BIL (kV)	Self-cooled		Forced-cooled	
				Kilovoltamperes (kVA)	Line amperes (A)	Kilovoltamperes (kVA)	Line amperes (A)
6.9	5	2500/4330Y	60	500	667	625	833
				750	1000	937	1250
				1000	1334	1250	1667
11	8.7	5000/8660Y	75	500	577	625	721
				750	866	937	1082
				1000	1155	1250	1443
17	15	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
17	15	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
26	25	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
36	34.5	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

Table 6 – Preferred 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) (Volts rms)	BIL (kV)	Self-cooled		Forced-cooled	
				Kilovoltamperes (kVA)	Line amperes (A)	Kilovoltamperes (kVA)	Line amperes (A)
7.2	6.6	6600	75	500	253	625	316
				750	379	937	474
				1000	505	1250	631
				1500	758	2000	1010
12	11	6350/11000Y	95	500	243	625	304
				750	364	937	456
				1000	485	1250	607
				1500	729	2000	971
12	11	11000	95	500	262	625	328
				750	394	937	492
				1000	525	1250	656
				1500	787	2000	1050
17.5	15	15000	95	500	111	625	139
				750	167	937	208
				1000	222	1250	278
				1500	333	2000	444
				2000	444	2667	593
				2500	556	3333	741
24	22	22000	150	500	131	625	164
				750	197	937	246
				1000	262	1250	328
				1500	394	2000	525
36	33	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 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 for 60 and 50Hz voltage regulators

Number of phases	Rated voltage	Operating voltage
Single-phase	6600	6350
	7620	7200
	15 000	14 400
Three-phase	5000	4800
	13 200	12 470
	13 800	13 200

5.3 Supplementary continuous-current ratings

Single-phase step-voltage regulators without a series transformer 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 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 without series transformers 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

Note to Entry Purchaser may specify a higher maximum continuous-current based on the tap-changer's maximum continuous-current rating for those voltage regulators having a base current rating greater than 418 amps but less than the tap-changer maximum continuous-current rating. The higher maximum supplementary continuous-current rating shall be agreed upon by purchaser and manufacturer.

5.3.1 Preferred optional forced-air ratings

Preferred optional forced-air ratings are given in Table 10.

Table 10 – 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	1000 kVA and below	125
ONAN/ONAF KNAN/KNAF	above 333 kVA	above 1000 kVA	133 1/3

5.4 Taps

Load tap-changing apparatus and windings shall be furnished to provide automatic adjustment of the unregulated supply 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.

5.5 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
5000	5000	40, 41.7
6350		52.9
6600		55
7620		60, 63.5
7970		66.4
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

5.6 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 12.

Note to entry 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

5.7 Losses

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

5.7.1 Total loss

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

5.7.2 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 to entry Since losses differ at different operating positions of the voltage regulator, care must be 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 5.7.3.

5.7.3 Determination of losses and excitation current

No-load (excitation) loss and exciting current shall be determined for the rated voltage and frequency on a sine-wave basis, unless a different form is inherent in the operation of the apparatus.

Load 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.

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:

- 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.

Note to entry 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 terminal is higher at the shunt winding. Care shall be exercised to assure rated excitation is present on the shunt winding; this may be accomplished by exciting the voltage regulator from the Load terminal.

- 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.

- c) Load loss is the average load loss in both the *maximum* and *adjacent-to-maximum buck* positions, and the *maximum* and *adjacent-to-maximum boost* positions (that is, four positions) with rated current in the windings.

5.8 Short-circuit requirements

5.8.1 General

Step-voltage regulators shall be designed and constructed to withstand the mechanical and thermal stresses produced by external short-circuits 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 13.

$$I_{sc} (peak asym) = K \times I_{sc} (rms sym) \quad (2)$$

Table 13 – Values of K

Rated voltage	Base rated kVA	K	
		60 Hz	50 Hz
2500	< 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
5000 through 22000	< 300 (single-phase) ^c < 1000 (three-phase) ^c	2.26	2.19
	≥ 300 (single-phase) ≥ 1000 (three-phase)	2.60	2.55
33000 through 34500	≥ 165 (single-and three-phase)	2.60	2.55
^a Value of the first-cycle asymmetrical peak current is based on an X/R ratio of 6 and 5, 60 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 and 50 Hz, respectively, which are common for substation circuits. ^c Purchaser may specify the higher 2.60 or 2.55 factor for 60 and 50 Hz ratings, respectively, for specific applications			

- b) The short-circuit thermal withstand capability shall be based on a duration of 2 s calculated by methods described in 8.11.4 not to exceed the limiting temperatures of 5.8.3.

It is recognized short-circuit withstand capability can be adversely affected by the cumulative effects of repeated mechanical and thermal overstressing, as produced by short-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 test, 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 5.8.1. On-load tap-changers are not required to change tap position coincident with a short-circuit condition.

It is recommended current-limiting reactors be installed by the purchaser, where 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 1 to entry A Larger kVA sizes for the same voltage rating should be considered if the available fault current exceeds the 25 times base rated current.

Note 2 to entry Purchaser may specify a larger short-circuit withstand value due to unique system parameters. A common request seen is for a short-circuit withstand of 40 times the base rated load current or 20 000 A, whichever is less.

is less. Application, limitations, design, short-circuit design test and resulting cost are to be agreed upon by the purchaser and the manufacturer.

5.8.2 Mechanical capability demonstration

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

5.8.3 Thermal capability of 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 5.8.1, as calculated by methods described in 8.11.4, 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

5.9 Sound levels for liquid-immersed voltage regulators

The sound level produced by the voltage regulator under a no-load (excitation) condition should not exceed the values specified in Table 14 when measured in accordance with the requirements of Section 8.9.

Note to entry The manufacturer should be consulted for sound levels of voltage regulators incorporating a series transformer in their design.

Table 14 – Maximum no-load (excitation) sound levels

Kilovoltampere rating	Average sound level (dB)
0 - 50	48
51 - 100	51
101 - 300	55
301 - 500	60
501 - 750	61
751 - 1000	62
1001-1500	64
1501-2000	65
2001-2500	66
2501-3000	67

5.10 Tests

Tests are divided into two categories: routine and design. Routine tests are made for quality control by the manufacturer to verify during production the product meets the design specifications. Design tests are made to determine the adequacy of the design of a particular type, style, or model of equipment or its component parts. 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.

5.10.1 Routine tests

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

- a) Resistance measurements of all windings (see 8.1)
- b) Polarity test (see 8.2)
- c) Ratio test on all tap connections (see 8.3)
- d) Operational test of all devices. Controlled devices such as on-load tap-changers, position indicators, fans, pumps, etc., shall be operated for proper functioning
- e) Leak test
- f) No-load loss at rated voltage and rated frequency (see 8.4)
- g) Excitation current at rated voltage and rated frequency (see 8.4)
- h) Impedance and load loss at rated current and rated frequency (see 8.5)
- i) Lightning impulse test (see 8.6.3)
- j) Applied-voltage test (see 8.6.5)
- k) Induced-voltage test (see 8.6.6)
- l) Insulation power factor test (see 8.6.7)
- m) Insulation resistance test (see 8.6.8)
- n) On-load tap-changer test (see 9.2)

5.10.2 Design tests

The design tests described in 5.10.2.1 through 5.10.2.5 shall be made on representative voltage regulators to substantiate the ratings assigned to all other voltage regulators of basically the same design. Design tests are not intended to be used as a part of normal production. The applicable portion of these design 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 tests need not be repeated unless the design is changed to modify performance.

5.10.2.1 Temperature-rise test

Temperature-rise design test shall be made on one unit of a given rating produced by a manufacturer as a record this design meets the temperature-rise requirement for a 55 °C or 65 °C winding rise rating. Temperature-rise test shall be made at the tap position producing the highest total loss at rated load current for the highest operating voltage per nameplate, supplementary voltage rating (see 5.2.3), and the 160% or 668 A rating (see 5.3). When a voltage regulator is supplied with ancillary cooling equipment to provide higher kVA ratings, a temperature-rise test shall be made at those ratings also. Test shall be made in accordance with 8.7.

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.

5.10.2.2 Lightning impulse test

Design lightning impulse test shall be made on one unit of a given rating produced by a manufacturer for the purpose of demonstrating the adequacy of insulating materials breakdown and spacing under normal conditions. Test shall be made in accordance with 8.6.2. Impulse test is to be followed by the application of the low-frequency applied-voltage and induced-voltage tests.

5.10.2.3 Short-circuit test

A short-circuit test shall be made on one unit of a rating produced by a manufacturer for the purpose of demonstrating the unit meets the mechanical requirements of 5.8.2. 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 made in accordance with 8.8.

5.10.2.4 Sound level test

A sound level test shall be made on one unit of a given rating produced by a manufacturer as a record this design meets the sound level requirement for the specific power rating specified in Table 14 of Section 5.9. The 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 the maximum level. Voltage regulators incorporating a series transformer shall have their test performed at the tap position in which the reactor and series transformer deliver the maximum sound level. Tests are to be made in accordance with 8.9.

5.10.2.5 Enclosure integrity test

Enclosure integrity test for the purpose of demonstrating mechanical force withstand requirements shall be made on a voltage regulator having the following base ratings, 22,000 volts and below, 450 kVA and below, and 668 A and below. Where other ratings have the same tank and cover configuration, a test is not required, and it is satisfactory to show by calculation the mechanical forces are equal or less than the unit tested. Tests are to be made in accordance with 8.10.

Note to entry The enclosure integrity test establishes minimum mechanical force withstand requirements however it does not establish requirements for withstanding an abnormal fault condition such as bypassing a voltage regulator off of the *Neutral* position while energized.

6 Construction

6.1 Bushings

Voltage regulators shall be equipped with bushings with 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 15. Unless otherwise specified, the colour of the bushings shall match Light Gray Number 70, Munsell Notation 5BG7.0/0.4, as described in IEEE C57.12.31.

Table 15 – Electrical characteristics of voltage regulator bushings (kV)

Voltage regulator 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 (7000 Ω·in) and precipitation rate of 0.085 mm/s (0.2 in/min).

6.2 External dielectric clearances

Table 16 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 16..

Table 16 – 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
200	305	12	330	13

6.3 Terminal markings

6.3.1 Terminal markings for step-voltage regulators

Voltage regulator terminals connected to the load shall be designated by an L , and those connected to the 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 .

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 3.

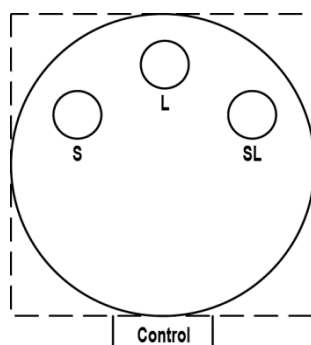


Figure 3 – Single-phase voltage regulators

For three-phase voltage regulators, when facing the voltage regulator on the source side, 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 4(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 4(b). The other terminals shall be located as shown in Figure 4.

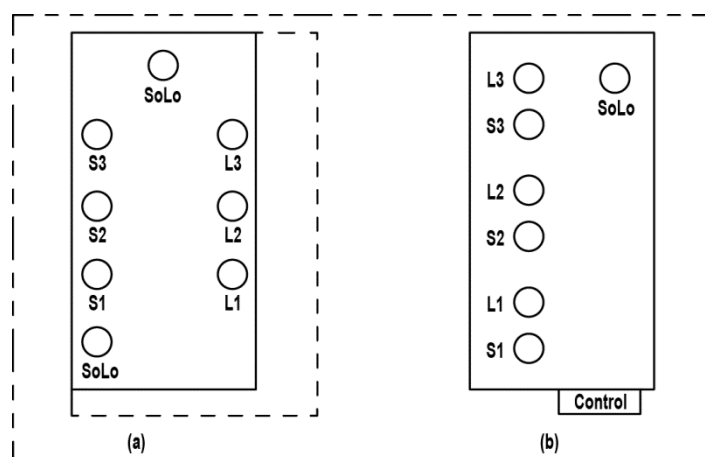


Figure 4 – Three-phase voltage regulators

Note to entry The dotted line in Figure 4 shows the location of the control compartment and the tap-changing under load equipment. The dotted circle shows alternate location of neutral bushing.

6.4 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.

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.

6.5 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 cabinet. 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 as follows:

- 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
- s) Conductor material
- t) Average winding rise in degrees Celsius (°C)
- u) Diagrams as specified in 6.4
- v) Installation and operating instructions reference
- w) Symmetrical short-circuit withstand ampere rating with time duration
- x) On-load tap-changer model number
- y) Tap-changer motor capacitor rating
- z) Ratio of load current to switched current (if series transformer is present)

6.6 Tank construction

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 6.6.1, shall be provided to relieve excess pressure due to normal temperature variation of top oil and/or due to on-load tap-changer operation. 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 C57.91 and IEC 60076-7[B11] 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.

6.6.1 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 device.

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 C57.91 and IEC 60076-7[B11], 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 (gage) (2 psig)
- b) Resealing pressure = 6.9 kPa (gage) (1 psig) minimum
- c) Zero leakage from reseal pressure to –56 kPa (gage) (–8 psig)
- d) Flow at 103 kPa (gage) (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

6.6.2 Cover assembly

A cover assembly designed to relieve excessive pressure in the voltage regulator tank shall remain effectively sealed for overloads (IEEE C57.91 and IEC 60076-7[B11] and short-circuits (Section 5.8 and IEC 60076-5[B10])). The assembly shall relieve pressure at a minimum of 20 kPa (gage) (3 psig) if designed to reseal, or at a minimum of 138 kPa (gage) (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 6.6.1.

6.6.3 Sudden pressure relay

When specified, a sudden pressure relay shall be provided for the indication of voltage regulator faults, and to minimize potential 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 actuate within three cycles of the rated power frequency.

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

6.6.4 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.

6.6.5 Support lugs

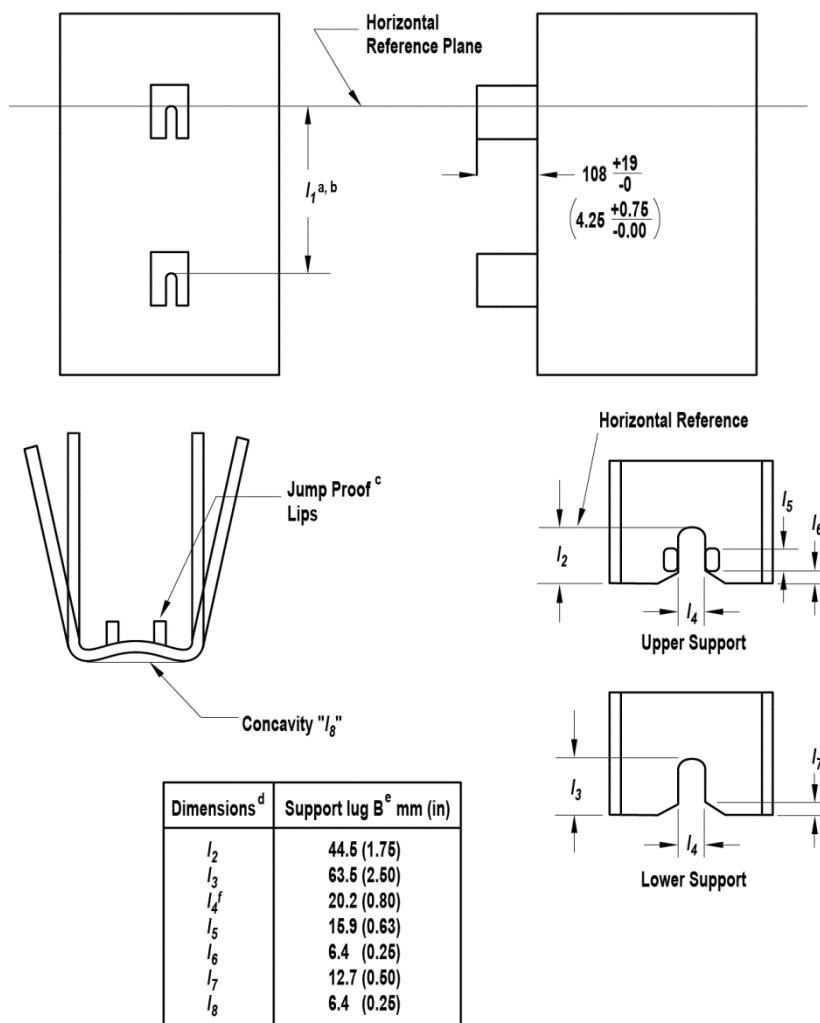
Support lugs for pole mounting shall be provided for ratings 288 kVA and less, with rated line current of 668 A or less. Support lugs shall be designed to provide a safety factor of five when supported in a vertical plane from the top lug only. The safety factor of five shall be as defined for lifting lugs in 6.6.4. Interchangeable mounting to the maximum extent is accomplished by use of Type-B and Type-C support lugs designed in accordance with Figure 5 and Figure 6, 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 to entry Support lug identification and descriptions come from IEEE C57.12.20™[B20].⁸ Due to weight restrictions Type-A support lug is not relevant to voltage regulators.

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

NOTE 3 to entry Some ratings as a standard, depending on manufacturer, have a substation base along with the support lugs for pole mounting. The substation base shall not interfere with the mounting of the voltage regulator to the pole.

⁸ The numbers in brackets correspond to those of the bibliography in Annex G.



Note to entry 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 spaced 20 mm (0.75 in) less than pole bolt spacing

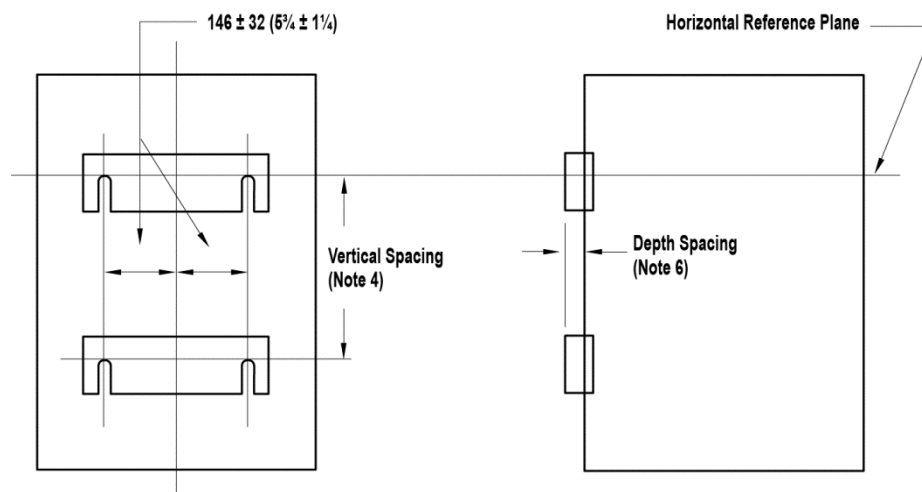
^c Jump-proof lips on upper support only

^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 "B" lugs use 20 mm (0.75 in) bolts

^f Tolerance for slot dimension " l_4 " shall be ± 0.4 mm (± 0.016 in)

Figure 5 – Support lugs B



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

Note 2 to entry Slots can be vertical as well as horizontal and shall be suitable for 16 mm (0.625 in) bolts.

Note 3 to entry Support lug faces shall be in one plane.

Note 4 to entry Vertical spacing shall be 914 mm (36 in).

Note 5 to entry 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 safe loading capacities.

Note 6 to entry Depth of support lugs is dependent on a manufacturers design. Bushing profiles on top of cover shall 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 6 – Support lugs C

6.6.6 Moving facilities

Substation voltage regulators shall be arranged for rolling in two directions: parallel to and right angles to one side of the voltage regulator. Bases for substation mounting shall be provided for 165 kVA and higher.

6.6.7 Tank grounding provisions

6.6.7.1 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.

6.6.7.2 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).

6.7 Components and accessories

6.7.1 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
- Adjustable range of regulation for the *Raise* and *Lower* ranges provided for supplementary current ratings per 5.3.
 - Mechanically actuated electric limit switches provided preventing travel beyond the maximum *Raise* and *Lower* positions

6.7.2 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 17. 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 (0.5625 in) holes horizontally and vertically spaced on 44.5 mm (1.75 in) centres. Thickness of the pad is shown in Table 17. 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 5.3), supplementary voltage ratings (see 5.2.3) and loading at other than rated conditions (see 4.2).

Table 17 – Bushing terminal applications

Nameplate line current rating (A)	Conductor size range or 4-hole spade
150 or less	#8–4/0
151 to 300	#2–477 kCM
301 to 668	#2–800 kCM
669 to 1200	1-1/8–12 UNF-2A with 4-hole spade—9.5 mm (0.375 in) minimum thickness
1201 to 2000	1-1/2–12 UNF-2A with 4-hole spade—12.7 mm (0.5 in) minimum thickness

6.7.3 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 6.7.2)
- e) Provision for thermometer
- f) Openings to permit inspection of core and coil and on-load tap-changer

7 Other requirements

Certain specific applications have voltage regulator requirements not covered in Clause 4, Clause 5, or Clause 6. Clause 7 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 4 through Clause 6. Information in the following subclauses may be specified for some applications.

7.1 Other supplementary continuous-current ratings

When specified, other supplementary continuous-current ratings, 668 A maximum, for three-phase voltage regulators without a series transformer, rated 13 200 V shall be provided as shown in Table 18 (see 5.3).

Table 18 – Other supplementary continuous-current ratings for three-phase voltage regulators

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

Note to entry Purchaser may specify a higher maximum continuous-current based on the tap-changer's maximum continuous-current rating for those voltage regulators having a base current rating greater than 418 amps but less than the tap-changer maximum continuous-current rating. The higher maximum supplementary continuous-current rating shall be agreed upon by purchaser and manufacturer.

7.2 Other components and accessories

When specified, the other components and accessories listed in 7.2.1 and 7.2.2 may be provided.

7.2.1 For 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 10.3)
- 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 -20 °C liquid level (decal required for designating level at middle of dial)
- k) Tank and control enclosure ground connectors
- l) Forced air cooling (ONAF or KNAF). When specified, fan motors shall be 120 or 240 volts, 50/60 Hz, single-phase, without centrifugal switch, and shall be 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. A thermometer with alarm contacts

7.2.2 In addition for three-phase voltage regulators

- a) Hand operation crank for on-load tap-changer
- b) On-load tap-changer in compartment separate from the core and coil