

Voltage Regulators

Functional Specification Guide

Pad-Mounted Single-Phase 32-Step Voltage Regulator with Communication-Ready Controls **PS225004EN**

1. Scope

- 1.1. This specification covers electrical, mechanical, and safety features and characteristics of outdoor, pad-mounted, single-phase, liquid-immersed, step-type voltage regulators. The voltage regulator must be completely self-contained and provide $\pm 10\%$ regulation in thirty-two (32) steps of approximately 5/8% each. In order to minimize losses, ensure long life, and provide required overload ability, forced air (ONAF) ratings are not acceptable for the nominal voltage regulator rating.

Table 1 Regulator Voltage Ratings and Corresponding Terminations				
Voltage	Current	kVA	Bushing	BIL
60 Hz Ratings				
2500	200	50	200 A well and 15 kV class insert	60
2500	300, 400	75, 100	600 A integral bushing	60
5000	100, 200	50, 100	200 A well and 15 kV class insert	75
5000	250, 334, 500	125, 167, 250	600 A integral bushing	75
7620	50, 75, 100, 150, 200	38, 57, 76, 114, 152	200 A well and 15 kV class insert	95
7620	328, 438, 548	250, 333, 416	600 A integral bushing	95
13800	50, 100, 150, 200	69, 138, 207, 276	200 A well and 15 kV class insert	95
13800	300, 362, 400, 483	414, 500, 552, 667	600 A integral bushing	95
14400	50, 100, 200	72, 144, 288	200 A well and 25 kV class insert	125*
14400	300, 347, 400, 463	432, 500, 576, 667	600 A integral bushing	125*
19920	50, 100, 167, 200	100, 200, 333, 400	600 A integral bushing	150
19920	250, 335	500, 667	600 A integral bushing	150
34500	50, 100, 150, 200	172.5, 345, 517.5, 690	600 A integral bushing	150
50 Hz Ratings				
6600	50, 100, 150, 200	33, 66, 99, 132	200 A well and 15 kV class insert	95
6600	300, 400, 500, 600	198, 264, 330, 396	600 A integral bushing	95
11000	50, 100, 150, 200	55, 110, 165, 220	200 A well and 15 kV class insert	95
11000	300, 400	330, 440	600 A integral bushing	95
15000	50, 100, 150, 200	75, 150, 225, 300	200 A well and 25 kV class insert	125*
15000	300	450	600 A integral bushing	125*
22000	50, 100, 150, 200	110, 220, 330, 440	600 A integral bushing	150
33000	50, 100, 150	165, 330, 495	600 A integral bushing	150
*The 125 kV BIL rating is only limited by the bushing; all internal connections are designed and constructed to 150 kV BIL. A 600 A, 150 BIL integral bushing is available as an option.				

2. Ratings

- 2.1. The regulators furnished under this specification shall be designed, manufactured, and tested in accordance with IEEE Std C57.15™-2009 standard. That standard shall be a part of this specification.
- 2.2. Regulator rating and operating voltage shall be as specified on the inquiry. Refer to Table 1 for the available ratings and corresponding terminations.

- 2.3. Regulators of the voltage ratings shown in Table 2 shall have internal tap settings for operation at the nominal system voltages listed. Unless otherwise noted in the specification, the units will be shipped factory-set at the "standard" taps as indicated by underlining in Table 2.
- 2.4. Regulators shall be rated and name-plated for 65 °C average winding rise.
- 2.5. Regulators shall be furnished with ANSI® Type II mineral oil per ASTM D-3487. The oil shall contain less than 1 part per million PCBs at time of manufacture, and this shall be so stated on the regulator nameplate. Envirotemp™ FR3™ type fluid shall be made available as an option.

3. Internal Construction

- 3.1. The tap-changing mechanism shall be of the Quik-Drive type and shall be completely liquid-immersed. The tap-changer, in the manual position, shall have the ability to operate from -16L to +16R in less than 10 seconds.
- 3.2. An electrical feedback circuit shall be incorporated with the tap-changer motor circuit and control to ensure accurate indication of tap position and number of operations. Accuracy is to be maintained for all dielectric fluids used with the voltage regulator.

Table 2 Regulator Voltage Ratings								
Voltage Rating	Standard Internal Tap Settings							
60 Hz								
2,500 V	2,500	<u>2,400</u>						
5,000 V	5,000	<u>4,800</u>	4,160	2,400				
7,620 V	8,000	7,970	7,620	<u>7,200</u>	6,930	4,800	4,160	2,400
13,800 V	<u>13,800</u>	13,200	12,470	12,000	7,970	7,620	7,200	6,930
14,400 V	<u>14,400</u>	13,800	13,200	12,000	7,970	7,620	7,200	6,930
19,920 V	<u>19,920</u>	17,200	16,000	15,242	14,400	7,970	7,620	7,200
34,500 V	<u>34,500</u>	19,920						
50 Hz								
6,600 V	6,930	<u>6,600</u>	6,350	6,000	5,500			
11,000 V	11,600	<u>11,000</u>	10,000	6,930	6,600	6,350	6,000	5,500
15,000 V	<u>15,000</u>	14,400	13,800	13,200	12,000	11,000	10,000	8,660
22,000 V	23,000	<u>22,000</u>	20,000	19,100	15,000	12,700	11,000	10,000
33,000 V	<u>33,000</u>	30,000	22,000	20,000	11,600	11,000	10,000	

- 3.3. The regulator main coil, reactor, and potential transformer shall include thermally upgraded insulation. A suitably patterned, epoxy-coated insulation paper shall be used in all windings. Prior to assembly of the main core and coil assembly, the windings are baked with sufficient mechanical pressure exerted on the sides of the coil winding to maximize a complete bonding of the insulation to improve its short-circuit current-withstand capabilities.
- 3.4. The regulator shall be supplied with a center-tapped reactor for the purpose of maintaining continuity while the tap-changer is changing position. The reactor shall be isolated from ground to provide protection from lightning and switching surges. Construction of the reactor shall be core-type, wherein windings occupy each of the two limbs in order to provide balanced windings, reduce leakage current, and minimize no-load losses.
- 3.5. Internal secondary wiring shall be color coded and labeled for easy identification.
- 3.6. All regulators shall be provided with an under-oil, metal oxide varistor (MOV) bypass arrester connected across the series winding. For units rated less than 22 kV, the series arrester shall be rated 3 kV. For units rated 22 kV or larger, the series arrester shall be rated 6 kV.

4. Standard External Features

- 4.1. The BIL rating of the bushings shall be compatible with the BIL of the regulator. Three bushings will be provided, and the SL bushing shall be externally grounded for grounded Wye systems. The bushing

designations (S, L, and SL) shall be permanently marked on the regulator adjacent to the bushings. The S, L, and SL bushings must be interchangeable with each other.

- 4.2. Regulators rated 548 A and below shall include an ADD-AMP type feature which will permit additional current-carrying capabilities at reduced regulation, as shown in Table 3, but not to exceed 6068 A. The ADD-AMP type adjustment shall be located inside the position-indicator faceplate to prevent inadvertent adjustment. In addition, a SOFT-ADD-AMP type feature shall be available that will allow for adjustment through the control keypad.

Table 3 ADD-AMP Feature Adjustments	
Regulation (%)	Current (%)
±10.0	100
±8.75	110
±7.5	120
±6.25	135
±5.0	160

- 4.3. Each regulator shall be provided with two laser-etched nameplates, one mounted on the control enclosure and the other mounted on the regulator tank. The nameplates shall have the manufacturer code and serial number bar-coded with "3 of 9" coding with a 0.25" minimum height.
- 4.4. The regulator shall be of a sealed-tank construction to permit operation at 65°C rise without increasing the oxidation rate of the oil. A pressure-relief device shall be supplied which vents at approximately 5 psig.
- 4.5. The external parts of the tank and cabinet shall be painted green, Munsell 7GY3.29/1.5, and meet the coating and security requirements of IEEE Std C57.12.28™-2005 standard. The inside of the tank, cabinet, and bottom of the cover shall also be primed and/or painted.
- 4.6. The operational (right-hand side) compartment shall be fully separated by a metal barrier from the system voltage (left-hand side) compartment to enhance operational safety conditions.
- 4.7. Located in the operational compartment shall be:
- 4.8. The control enclosure, mounted to the right-hand compartment door and connected to the internal circuitry of the voltage regulator with a multi-conductor neoprene 600 V, -50 °C to 105 °C cable. The cable shall be equipped with disconnect plugs at each end.
- 4.9. An electronic device to protect the internal CT from high voltages due to the control cable being disconnected while the voltage regulator is energized.
- 4.10. An oil-level sight gauge that indicates oil color and a magnetic oil-level gauge to indicate the oil level at 25 °C ambient.
- 4.11. A 1" drain valve with sampling device and a 1" upper filter press connection.
- 4.12. A corrosion-resistant tap-changer position indicator. The tap position indicator shall be polymer-constructed and mounted above the oil level. The tap position indicator shall be mounted inside the cabinet to minimize the incidence of damage.

5. Regulator Control

- 5.1. The control system of a voltage regulator shall have an overall system error not exceeding ±1%. The accuracy requirement is based on the combined performance of the control device and the voltage and current sensing apparatus. The voltage source accuracy shall be determined on a nominal secondary voltage base of 120 V and a burden of 10 VA. The current source accuracy shall be determined on a nominal 0.2 A secondary current and a burden of 3.5 VA.
- 5.2. The control shall operate in an operating environment temperature range of -40 °C to +65 °C. Control device components shall withstand a temperature range -40 °C to +85 °C without damage or loss of control.
- 5.3. The regulator control shall be mounted in a weather-resistant enclosure, which is capable of being padlocked, absent other appropriate security options. The control enclosure shall have an external 1/2" – 13 UNC stainless steel welded ground boss.

- 5.4. The control shall be hinge-mounted and designed for easy replacement. The control shall be constructed to provide direct interchangeability without removal of the control enclosure. Visible means shall be provided to de-energize the control and short the regulator's internal current transformer prior to control testing or removal.
- 5.5. All leads in the control enclosure shall be color coded and labeled for easy identification.
- 5.6. The terminal strips of the control back panel shall consist of clamp-style quick connectors for ease of access.
- 5.7. All printed circuit boards shall be conformal coated for fungi and moisture protection.
- 5.8. A ratio-correction transformer shall be provided inside the enclosure for easy access for fine voltage adjustment. Ratio-correction taps and the corresponding system voltage shall be clearly identified on the nameplates.

5.9. Multi-phase Operation

5.9.1. When specified, the regulator control shall be capable of operating two or three apparatuses. A multi-phase control shall include the following features:

- A single control for multiple regulators
- Capability of operating all tap changer types
- Front Panel Features (for each phase):
 - Independent Neutral Light
 - Independent manual control
 - Voltage test terminals
 - Auto/Remote-Off-Manual switch
 - Internal-Off-External power switch
 - Raise-Off-Lower control switch
 - Motor Fuse

5.10. Front Panel

5.10.1. The control front panel shall include the following features:

- A numeric keypad for quick, easy modification of existing control parameters.
- USB ports for programming and data retrieval capabilities via a USB drive and a USB-to-PC connection.
- A backlit LCD display, 4 lines by 20 characters each, for displaying relevant information. The display shall have an adjustment for contrast.
- Four user-selectable languages (English, Spanish, French, Portuguese), 3 user-selectable date formats (MM/DD/YYYY, DD/MM/YYYY, YYYY/MM/DD), and two user-selectable time formats (12 hour AM/PM, 24 hour).
- A six-digit electronic operations counter, which counts every tap change.
- A motor fuse, which is replaceable. Fuse size shall be clearly marked near the fuse holder. A spare fuse shall be included within the control enclosure.

5.10.2. The control front panel shall also include the following features:

5.10.2.1. Switches

- A three-position voltage source switch, labeled INTERNAL-OFF-EXTERNAL, which allows the control to be energized from the regulator's internal voltage supply or from an external source. The OFF position is provided to de-energize the control.
- A three-position, AUTO/REMOTE-OFF-MANUAL control switch, which allows for automatic/remote or manual/local operation of the voltage regulator. Monitoring of the control is available at all positions.
- A momentary three-position RAISE-OFF-LOWER control switch, which shall be active only when the adjacent control switch is in the MANUAL position.
- A position-indicator drag-hand reset switch.
- A supervisory ON-OFF switch which, in the OFF condition, inhibits tap-changer motor control and parameter changing via digital SCADA but allows for monitoring of the control data base via SCADA.

5.10.2.2. Terminals

- High-impedance voltmeter test terminals which monitor the load side voltage (L bushing) of the regulator. An automatic resetting fuse shall be provided to inhibit an accidental back feed loop in the voltage regulator by way of the voltmeter test terminals.
- External voltage source terminals to allow tap-changer and control operation from an external 120 Vac source. Ground terminal shall be clearly identified. An interlocking means shall be provided to inhibit energizing of the high-voltage bushings from the external source.
- Additional earth ground terminal for the front panel, prominently and clearly identified.

5.10.2.3. LED Indicators

- Dual neutral position LEDs that are actuated via the tap-changer to provide neutral position indication. These LEDs must be of the high-intensity type and easily readable in direct sunlight.
- LED indicators to indicate whether the voltage is inside or outside of the set voltage band and whether the voltage is high or low.
- LED indicators for Alarms, configurable via the interface software provided by the manufacturer.
- LED indicators for Warnings, configurable via the interface software provided by the manufacturer.
- LED indicator for a diagnostics test failure.
- Transmit and Receive LEDs for all communication ports located on the front panel of the control for user visibility.
- LED indicators to indicate whether the voltage is inside or outside the voltage limiter settings, when active, and whether the voltage is high or low.
- LED indicator to indicate activation of a Auto-tap-change-blocked condition.
- LED indicator to indicate activation of a reverse power flow mode.
- LED indicator to indicate activation of the voltage reduction feature.
- LED indicator for user-defined output of programmable I/O, configurable via the interface software.

5.10.2.4. Front-Panel Programming

- 5.10.2.4.1.** The control shall be microprocessor based, shall be accessible from the front panel via a combination structure using function codes and a scrollable nested menu, and shall have provisions for programming of the following parameters:
- Set voltage adjustable from 100.0 to 135.0 V in increments of 0.1 V.
 - Set voltage bandwidth adjustable from 1.0 to 6.0 V in increments of 0.1 V.
 - Time delay adjustable from 5 seconds to 180 seconds in 1-second increments.
 - Line-Drop Compensation, resistance and reactance settings, adjustable from -96.0 to +96.0 V in increments of 0.1 V. A means shall be provided to set the polarity.

5.10.2.5. Alarms

- 5.10.2.5.1.** The control shall allow for 20 user-configurable Status (binary) and 20 Data (analog) alarms. Alarms shall be able to turn on an LED viewed on the front panel, generate time-tagged Events or Profile snapshots, and be used as a programmable I/O input.

5.10.2.6. Digital Metering

- 5.10.2.6.1.** A digital metering package of Class 1 accuracy which shall provide the following information:
- Instantaneous values of load voltage, compensated voltage, current, power factor, kVA load, kW load, kvar load, voltage harmonics, and current harmonics. Voltage and current harmonics shall include, at a minimum, total harmonic distortion.
 - Demand values of load voltage, compensated voltage, current, kVA load, kW load, and kvar load. For each of these values, the present value, highest value since last reset, and lowest value since last reset shall be provided. Highest and lowest values shall be time and date tagged. Power factor at

maximum and minimum kVA load shall be provided. Metering values must be available for both forward and reverse power flow conditions.

- 5.10.2.6.2.** The metering data must be easily accessible at the control.
- 5.10.2.7. Data Acquisition**
- 5.10.2.7.1. Profiler**
- 5.10.2.7.1.1.** The control shall have a profiler that consists of up to 60 user-selectable metering values with configurable sample time intervals. It shall be capable of storing at least 40,000 data items.
- 5.10.2.7.2. Event Recorder**
- 5.10.2.7.2.1.** The control shall allow for time-tagged recording of user-definable Events. The last 50 Events shall be viewable through the LED display.
- 5.10.2.8. Control Communications**
- 5.10.2.8.1.** The voltage regulator control shall include the following features:
- USB drive, programming and data retrieval, capabilities. The control shall be capable of uploading or downloading parameters and data via a USB port without requiring the use of external computers or hand-held devices.
 - A front-panel USB port for temporary communications connection for upload or download of data and configuration.
 - Two permanent communications ports for use with communication accessories.
 - Protocols DNP 3 (Serial and Ethernet) and IEC 60870-5-(101)(104) resident in the control and user-configurable for all communication ports, with options of MODBUS, DATA 2179, IEC 61850.
 - DNP 3 protocol certified level 2 compliant.
 - The following communication card options shall be available: RS-232, Serial Fiber ST, RS-485, Ethernet Fiber ST, Ethernet Single-Mode LC, Ethernet Multi-Mode MTRJ, Ethernet ST, Ethernet SC, and Ethernet RJ-45.
- 5.10.2.9. SCADA**
- 5.10.2.9.1.** The control shall have provisions to allow remote override of regulator operation via discrete (analog) supervisory control. Terminals shall be provided on the back panel of the control enclosure as follows:
- For motor raise: Two terminals for normally-open, momentary-close contacts.
 - For motor lower: Two terminals for normally-open, momentary-close contacts.
 - For auto inhibit: Two terminals for normally-closed, latch-open contacts (120 Vac must be supplied to activate auto inhibit).
- 5.10.2.10. Configurable Logic**
- The control shall have Configurable Logic capabilities, which will allow the user to write logical equations to perform user-defined control and communication operations.
 - The control shall have three discrete 120 Vac inputs for discrete I/O interfacing. The user shall add an accessory option to add multiple I/Os.
- 5.10.2.11. Standard Control Features**
- 5.10.2.11.1. Tap Position Indication**
- 5.10.2.11.1.1.** A tap position indication capability, which tracks the movement of the tap-changer motor, shall provide the present tap position and the highest and lowest positions since last reset. The highest and lowest values shall be date and time tagged.
- 5.10.2.11.2. Voltage Limiting**

5.10.2.11.2.1. A voltage-limiting capability that prevents the regulator from making additional tap changes once the regulator output voltage meets a programmed upper- or lower-limit setting. If the source voltage should change, causing the regulator output voltage to exceed either limit, the control, after an initial programmable shorten-time delay, dependent on the voltage swing outside the voltage limit, shall have the tap-changer step the voltage to within the voltage-limiter setting.

5.10.2.11.3. Voltage Reduction

5.10.2.11.3.1. A configurable voltage reduction capability which consists of at least four distinct modes as follows:

5.10.2.11.3.2. Any Digital Remote discrete value, from 0.0 to 10.0 percent in 0.1% steps, can be applied and activated as an Analog value through SCADA communications.

5.10.2.11.3.3. Up to three voltage reduction values shall be able to be set locally at the control or remotely via a digital SCADA/communications system from 0.0 to 10.0 percent in 0.1% steps.

5.10.2.11.3.4. Remote voltage reduction shall allow any one of the three voltage reduction values to be activated remotely by applying 120 Vac to the appropriate discrete input points on the control (A 120 Vac whetting voltage shall be available at the discrete I/O terminal for this purpose) or by applying the appropriate input to the SCADA communications Output blocks .. Each of the three reduction values shall be independent of each other and shall be programmable from 0.0 to 10.0 percent.

5.10.2.11.3.5. Pulse-activated voltage reduction shall provide a programmable number of steps of reduction, from 0 to 10.0 percent in increments of 0.1 percent. Total allowable reduction shall be limited to 10.0 percent. Stepping shall be accomplished by momentarily applying 120 Vac to a contact provided on the back panel of the control enclosure. Immediate reset to 0 percent shall be accomplished by applying 120 Vac to a second terminal on the back panel.

5.10.2.11.4. Reverse Power Flow

5.10.2.11.4.1. A Reverse Power Flow Detector that automatically senses a power reversal and can provide indication that a power reversal is taking place. The regulator control shall incorporate separate forward and reverse control settings for voltage level, bandwidth, time delay, and line-drop compensation R and X. At a minimum, the following modes of reverse power operation shall be provided:

- Locked forward mode
- Locked reverse mode
- Reverse idle mode
- Bi-directional mode
- Bias Bi-directional mode
- Neutral idle mode
- Cogeneration mode
- Reactive bi-directional mode

5.10.2.11.5. Source Voltage Calculation

5.10.2.11.5.1. A configuration point which, when turned on, will calculate the source voltage, based on tap position, regulator type, and internal impedance. The regulator types are either Type A or Type B per IEEE Std C57.15™-2009 standard. The calculated source voltage will enable reverse power flow operation without the use of a source-side potential transformer.

5.10.2.11.6. Leader/Follower Scheme

5.10.2.11.6.1. Control scheme designed to keep two or three voltage regulators on the same mechanical tap position. When utilized with single phase controls, the scheme will use a fiber optic intelligence loop between the phases to provide the communications necessary to initialize a tap change and provide positive feedback in maintaining equal tap positions. When utilized in a multi-phase control, no fiber optic loop or communications cards shall be necessary.

5.10.2.11.7. Max Deviation Scheme

5.10.2.11.7.1. Control scheme designed to keep two or three regulators in a predetermined moving tap position window. This feature will limit the maximum number of tap positions the regulators can differ. When active, this mode constrains the regulator tap positions to a user defined maximum deviation. When utilized with single phase controls, the scheme will use a fiber optic intelligence loop between the phases to provide the communications necessary. When utilized in a multi-phase control, no fiber optic loop or communications cards shall be necessary.

5.10.3. Tap-Changer Diagnostics and Maintenance**5.10.3.1. Duty Cycle Monitor**

5.10.3.1.1. The control shall have a "Duty Cycle Monitor" that will calculate the life used for all contacts of the tap-changer based upon actual service conditions and the individual regulator design.

5.10.3.2. PMT Preventive Maintenance Tapping

5.10.3.2.1. The control shall be able to perform PMT preventive maintenance tapping, which is the ability for the control to exercise the tap-changer based upon user-defined conditions on a routine basis to prevent the build-up of carbon deposits on the contacts (contact coking). Two modes shall be available allowing for various degrees of configurability and the ability to exercise all stationary and moveable contacts.

5.10.3.3. TIME-ON-TAP Feature

5.10.3.3.1. The control shall have a TIME-ON-TAP feature that provides specific information about the amount of time that the regulator has spent on each tap position.

6. Available Options**6.1.** Available options include:

- A bypass switch module which mounts inside the secure cabinet and allows the regulator to be removed from service without interrupting the continuity of the system (400 A ratings and below, grounded wye systems only).
- A source-side voltage supply to provide control accuracy of $\pm 1\%$ (ANSI[®] Class 1) under reverse power flow conditions.
- A thermostatically controlled heater assembly for maintaining the temperature of the control enclosure between 29 °C (85 °F) and 38 °C (100 °F).
- Fiber-optic/RS-232 communications interface board for use in SCADA communications.
- RS-485/RS-232 communications interface board for use in SCADA communications.
- Under-oil surge arresters for the Load and Source bushings.
- Thermometer with or without alarm contacts.
- Oil-level gauge with or without alarm contacts.
- Pressure and Vacuum gauge.

- Stainless steel tank and cabinet.
- Envirotemp™ FR3™ type fluid.
- Tank and control enclosure ground connectors.
- Alternate top-coat color.
- Deeper cabinet.
- External tap-changer for PT taps.
- External stainless steel hardware.
- Stainless steel control enclosure.

7. Testing

7.1. Testing shall include the following:

- Ratio tests on all windings and tap connections.
- 1000 operations using external voltage supply.
- Operational test using rated voltage.
- Polarity test.
- Resistance measurements of all windings excluding control and tap-changer voltage supplies. Tapped windings shall have resistance measurements made at 16R, 15R, 15L and 16L.
- Insulation power factor test.
- Insulation resistance test.
- No-load loss and Excitation current at rated voltage and frequency. Measurements to be made at N and 1R positions for Type A and Type B designs.
- Load loss and Impedance at rated current and frequency. Measurements to be made at 16R, 15R, 15L, and 16L positions.
- Applied potential test.
- Induced potential test.
- Routine Lightning Impulse test.

8. Documentation

8.1. Information to submit at time of bid to include:

- Outline & nameplate drawings.

9. Shipping

9.1. Regulators are to be shipped "F.O.B. Destination." The destination shall be indicated either in the specification or in the order documentation.

10. Deviation from Specification

10.1. It is expected that any regulators supplied by the vendor will be in strict accordance with this specification unless appropriately noted with the original bid and agreed to by vendor in writing.

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