

# Substation and Overhead Single-Phase 32-Step Voltage Regulator with Communication-Ready Controls

## Technical Specifications

### Voltage Regulator

#### Introduction

This specification covers electrical, mechanical, and safety features and characteristics of outdoor, single-phase, fluid-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.

#### Ratings

The regulators furnished under this specification shall be designed, manufactured, and tested in accordance with IEEE Standard C57.15-1999™. That standard shall be a part of this specification.

Regulator rating and operating voltage shall be as specified on the inquiry.

Regulators of the voltage ratings shown in Table 1 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 1.

Regulators shall be rated and name-plated for 55/65°C average winding rise.

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.

**TABLE 1  
Regulator Voltage Ratings**

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

**Internal Construction**

The regulators shall be designed such that they can be partially or completely untanked for inspection and maintenance without disconnecting any internal electrical or mechanical connections. (External connections must be disconnected.) A military specification-style quick-disconnect circular connector shall be provided with a solid-state automatic current transformer shorting device.

The tap-changing mechanism shall be of the Quik-Drive™ type and shall be completely fluid-immersed. The tap-changer, in the manual position, shall have the ability to operate from -16L to +16R in less than 10 seconds.

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.

The regulator main coil, reactor, and potential transformer shall include thermally upgraded insulation to permit operation up to 65°C rise without loss of life to the insulating system. At 65°C rise, the regulator shall provide 12% extra current capacity over the base current rating. 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.

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.

Internal secondary wiring shall be color coded and labeled for easy identification.

**Standard External Features**

The BIL rating of the bushings shall be compatible with the BIL of the regulator, and all bushings 15 kV and above shall have a minimum creep distance of 18 inches. The bushing designations (S, L, and SL) shall be permanently marked on the regulator cover adjacent to the bushings. The S, L, and SL bushings must be interchangeable with each other.

For regulators rated 1200 A and below, each bushing shall include a threaded 1.125" - 12 UNF-2A stud. For regulators rated 1201 to 2000 A, each bushing shall include a 1.5" - 12UNF-2A stud. Connectors integral to the bushing are not acceptable. Refer to Table 2 for standard terminals.

Material of threaded studs and connectors shall be tinned plated bronze. Clamp-type, four-hole spade terminals shall be available as an option for all current ratings.

**TABLE 2  
Bushings Connectors**

<b>Current Rating</b>	<b>Terminals</b>
150 A and below:	Clamp-type terminals for #6 to 250 MCM Conductor
151 to 668 A:	Clamp-type terminals for #6 to 800 MCM Conductor
669 to 1200 A:	1.125" - 12 UNF-2A stud only
1201 to 2000 A:	1.5" - 12UNF-2A stud only

All regulators shall be provided with an external UltraSIL®, Heavy Duty, VariGAP®(MOV) type 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.

An oil sight gauge shall be provided that indicates oil color and oil level at 25°C ambient.

An external, corrosion-resistant position indicator shall indicate the tap-changer position. The position indicator shall be polymer constructed, mounted above the oil level, and slanted downward at a 45-degree angle for ease of reading when the regulator is mounted above ground level.

Regulators rated 668 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 668 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. An optional ADD-AMP feature maximum of 875 A shall be provided when specified for regulators rated 438–668 A.

**TABLE 3  
ADD-AMP Adjustments**

<b>Regulation (%)</b>	<b>Current (%)</b>
± 10.0	100
± 8.75	110
± 7.5	120
± 6.25	135
± 5.0	160

Stainless steel mounting bosses shall be provided for the addition of lightning arresters adjacent to the source (S), load (L), and source-load (SL) bushings. The bosses shall be fully welded around their circumference. Spot welding is not acceptable.

All regulators shall have a 1" drain valve with sampling device and a 1" upper filter press connection.

A hand-hole shall be provided on the cover of the regulator for inspection purposes and to access terminals used to reconnect the regulators for operation at large variations of system voltage.

Regulators rated 250 kVA and below shall be pole-mounted and provided with welded-on hanger brackets. Regulators rated 167 kVA and above shall be provided with a base suitable for securing them to a pad or elevating structure. All regulators must be capable of being secured to elevating structures.

Regulators with pole-mounting hanger brackets shall be provided with two stainless steel 1/2" –13 UNC welded ground bosses located diagonally opposite from each other. Regulators with substation base mounts shall have two stainless steel ground pads located diagonally opposite from each other. Each pad shall have two stainless steel 1/2" - 13UNC ground provisions. All grounding provisions are to be located near the base of the regulator.

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.

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.

The external parts of the tank and control enclosure shall be painted light gray, Munsell 5BG7.0/0.4, and meet the coating and security requirements of ANSI C57.12.28 and C57.12.31. The inside of the tank and bottom of the cover shall also be primed and/or painted.

An external electrical connection between the cover and tank shall be supplied to allow the cover-suspended internal assembly and tank to be grounded together to eliminate voltage differentials during energizing.

Thermometer provisions shall be provided for all substation voltage regulators.

A multi-conductor neoprene 600 V, –50°C to 105°C cable with disconnect plugs at each end shall provide the connection between the internal circuitry of the voltage regulator and the control.

An electronic device shall be provided to protect the internal CT from high voltages due to the control cable being disconnected or cut while the voltage regulator is energized.

## **Regulator Control**

### **Introduction**

The control shall have a functional temperature range of -40°C to +85°C.

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.

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.

All leads in the control enclosure shall be color coded and labeled for easy identification.

The terminal strips of the control back panel shall consist of clamp-style quick connectors for ease of access.

All printed circuit boards shall be conformal coated for fungi and moisture protection.

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.

### **Front Panel**

The control front panel shall include the following features:

- A numeric keypad for quick, easy modification of existing control parameters.
- A flash card port for programming and data retrieval capabilities via compact flash card.
- 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.
- An EIA-232 DB-9 port for temporary communications connection for upload or download of data.
- 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.

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The control front panel shall also include the following features:

### 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 two-position supervisory ON-OFF switch which, in the OFF position, inhibits tap-changer motor control and parameter changing via digital SCADA but allows for monitoring of the control data base via SCADA.

### 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 backfeed 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 ground terminal for the front panel, prominently and clearly identified.

### 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 tap-changer-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.

### Front-Panel Programming

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.

### Alarms

The control shall allow for over 15 user-configurable Status (binary) alarms and over 30 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.

### Digital Metering

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.

The metering data must be easily accessible at the control.

## **Data Acquisition**

### **Profiler**

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 1,000 data items.

### **Event Recorder**

The control shall allow for time-tagged recording of user-definable Events. The last 50 Events shall be viewable through the LED display.

### **Histograms**

The control shall store user-configurable data for Histograms (graphs that show voltage regulator performance at a glance).

## **Control Communications**

The voltage regulator control shall include the following features:

- Flash card, programming and data retrieval, capabilities. The control shall be capable of uploading or downloading parameters and data via a flash card port without requiring the use of external computers or hand-held devices.
- A front-panel EIA-232 DB-9 port for temporary communications connection for upload or download of data.
- Two permanent communications ports for use with communication accessories.
- Protocol DNP 3 and DATA 2179 resident in the control and user-configurable for all communication ports.
- DNP 3 protocol certified level 2 compliant.

## **SCADA**

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).

## **Programmable I/O**

The control shall have programmable I/O capabilities, which will allow the user to write logical equations to perform user-defined control and communication operations.

The control shall have four discrete 120 Vac inputs and four FORM-C discrete output contacts for discrete I/O interfacing.

## **Standard Control Features**

### **Tap Position Indication**

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.

### **Voltage Limiting**

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 fixed 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.

### **Voltage Reduction**

A configurable voltage reduction capability which consists of at least three distinct modes as follows:

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.

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. Each of the three reduction values shall be independent of each other and shall be programmable from 0.0 to 10.0 percent.

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.

### Reverse Power Flow

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
- Bidirectional mode
- Neutral idle mode
- Cogeneration mode
- Reactive bidirectional mode

### Source Voltage Calculation

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 standard C57.15. The calculated source voltage will enable reverse power flow operation without the use of a source-side potential transformer.

### Tap-Changer Diagnostics and Maintenance

#### Duty Cycle Monitor

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.

#### PMT™ Preventive Maintenance Tapping

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.

#### TIME-ON-TAP™ feature

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.

### Available Options

Available options include:

- Long-length cable to allow remote placement of the regulator control. Cable lengths shall be specified in 10-foot increments from 10 to 50 feet in length. Cables are of the quick-connect type and shall be factory installed. A disconnect plug is to be provided at the control enclosure and at the junction box located on the cover.
- Armored cable.
- Shielded cable.
- Adjustable galvanized-steel elevating structure for raising the regulator to meet specified live part-to-ground clearances.
- 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.
- 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.
- Rapid pressure-rise relay.
- Stainless steel tank and cover.
- Envirotemp FR3 type fluid.
- Tank and control enclosure ground connectors.
- Alternate top-coat color.
- External stainless steel hardware.
- Stainless steel control enclosure.
- Birdguards.
- 4-hole NEMA spade bushing connector.
- #2 - 1000 MCM bushing connector.

## **Testing**

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, N, 15R and 16R for Series Transformer 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.

## **Documentation**

Information to submit at time of bid to include:

- Outline & nameplate drawings

## **Shipping**

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

## **Deviation from Specification**

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.

## **Substation and Overhead Single-Phase 32-Step Voltage Regulators with Communication-Ready Controls**

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