

Voltage Regulators



**Intelligent Solutions.
Endless Possibilities.**

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**Helping Utilities Around the World
Provide the Ultimate in Power Quality**

Voltage Drop

An inherent system characteristic

An ideal electric power system would supply constant voltage at rated value for every piece of equipment. This is not practical due to voltage drop which is caused by current flowing through an impedance, such as a transformer (trafo), reactor, bus, overhead conductor, cable, etc.

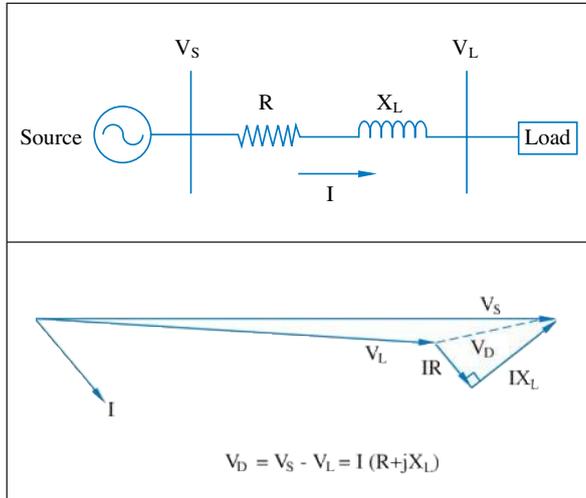


Figure 1: Voltage received by load (V_L) is lower than source voltage (V_S) due to voltage drop (V_D).

Voltage drop is a problem

Since power systems cannot deliver a constant voltage level, modern equipment is designed to tolerate a voltage variation within specific limits. When these limits are exceeded, either performance or equipment life is sacrificed. Examples include:

- Induction motors: Low voltage causes reduction in starting torque and increased full-load current and temperature. High voltage causes increased torque, increased starting current, and low power factor. All of these factors are critical to the performance and life of the motors.
- Incandescent lamps: Low voltage causes low light output. High voltage causes reduced lamp life.
- Fluorescent lamps: Low or high voltage causes low light output.
- Higher system losses: Voltage drop causes an increase in the current drawn by motors. This higher-than-necessary current must be transmitted through the system, increasing system losses and utility costs.

How it usually develops

MV distribution feeders are designed short enough and/or are “conservatively” loaded so that the voltage profile is kept within specific limits.

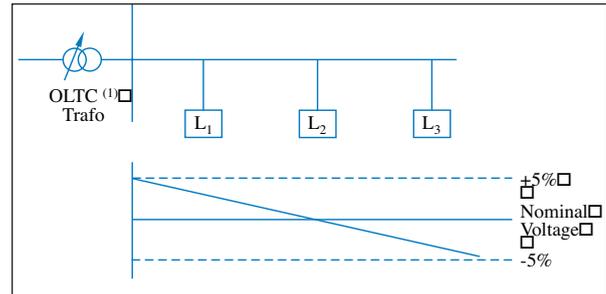


Figure 2: Properly-designed distribution feeder (1): On-load tap-changing power transformer.

However, an increase in load density in the vicinity of the feeder is usually the norm. To minimize the time and expense of serving the new load, the length of the feeder is usually extended. Hence, in most cases, the feeder develops an unacceptable voltage drop as shown in Figure 3.

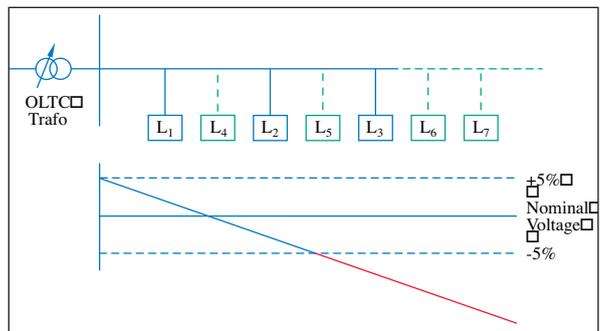


Figure 3: Increase of load density and feeder length results in an unacceptable voltage drop.

Possible solutions

Several alternatives have been adopted by utilities worldwide to counter voltage drop problems, such as:

- Reconnector existing feeders to lower the impedances and corresponding losses.
- Increase the system voltage by a factor of 2 or 3 to reduce the current and voltage drop.
- Construct new primary substations and feeders.

These solutions are difficult to justify due to high capital investment, high installation costs and long lead times, especially in cases of low power demand and dispersed load.

Shunt capacitors, installed along the feeders to correct poor power factor, will also improve the voltage (from the point of installation back towards the source). The voltage improvement obtained is in the range of 2-3%, usually not enough to correct most voltage problems.

To provide continuous regulating capability by either increasing or decreasing the voltage, a product was developed...the voltage regulator.

A voltage regulator installed after L_2 will receive a low (or high) voltage at its input and will adjust itself so that a specific voltage level is provided at its output. This keeps the voltage profile within acceptable limits for all load conditions.

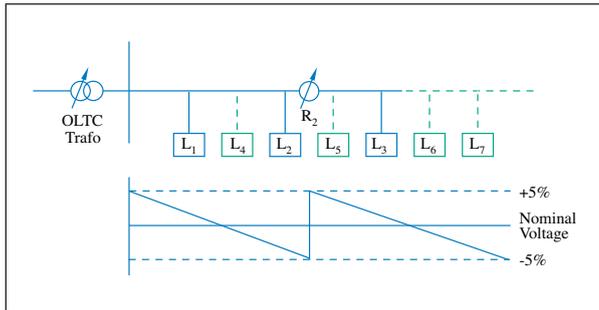


Figure 4: Voltage regulator solves voltage drop problem.

32-Step Voltage Regulator

What is it?

A voltage regulator is a tap-changing autotransformer with the ability to continuously monitor its output voltage and automatically adjust itself by changing taps until the desired voltage is obtained.

Two types of regulators are available: Three-phase units and single-phase units.

Due to their high cost and bulky design, three-phase units are rarely considered as an option.

Single-phase units, properly connected to the system, regulate the voltage of three-phase systems.

Single-phase regulators are now the dominant technology at most utilities around the world. Their low cost and small size permit an economical and easy installation. (Many ratings permit pole-mount installation.)

How it works

A single-phase regulator is represented by the autotransformer of Figure 5. When referring to a regulator, the low-voltage winding is called the “series winding” and the high-voltage winding the “shunt winding.”

By reversing the polarity of the series winding, the autotransformer can boost (increase) or buck (decrease) the output voltage with respect to the input voltage.

Polarity reversing is achieved via a reversing switch. An on-load tap-changer connects a variable number of turns of the series winding into the circuit, thereby allowing small increments of voltage change.

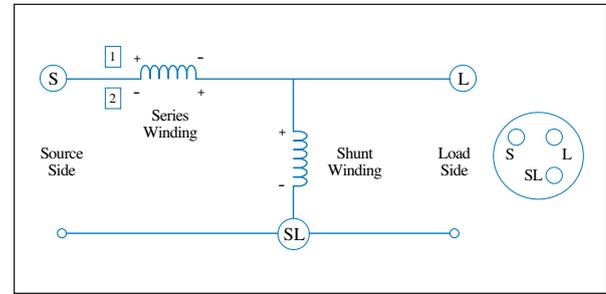


Figure 5: Autotransformer with series winding on input side.

Polarity 1: Step-Down Autotransformer

Polarity 2: Step-Up Autotransformer

Figure 6 shows a detailed schematic of a single-phase regulator. The combination of an 8-position tap-changer, a bridging reactor, and the reversing switch provide 32 steps (16 increase and 16 decrease) of approximately 5/8% each.

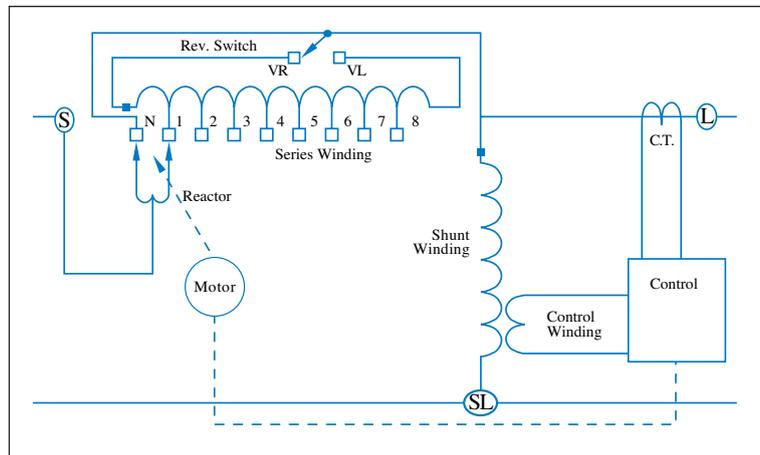


Figure 6: Schematic of a single-phase, 32-step voltage regulator.

How it is used

Two or three single-phase regulators banked together make it possible to regulate the voltage of a three-phase, three-wire system when connected according to these configurations:

- Open-Delta Connection (Figure 7): Maximum regulation is $\pm 10\%$ of input. Two single-phase regulators are used.
- Closed-Delta Connection (Figure 8): Maximum regulation is $\pm 15\%$ of input. Three single-phase regulators are used.

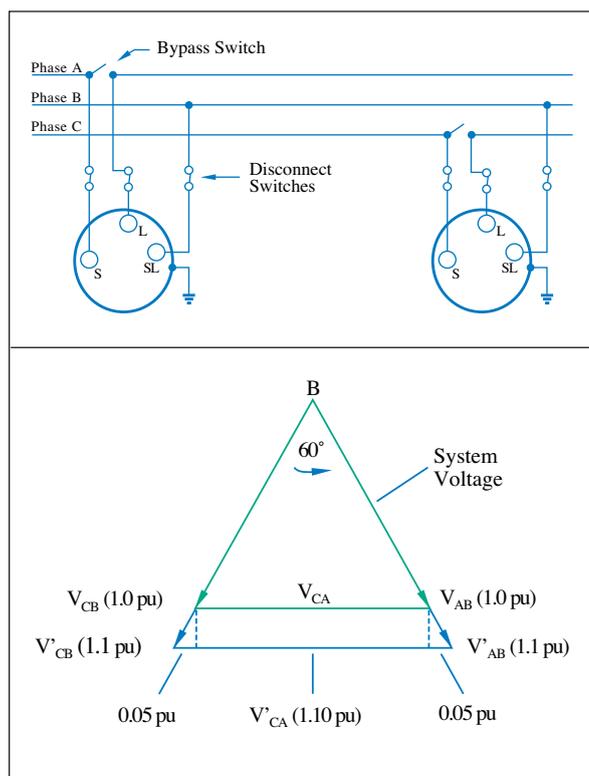


Figure 7: Two single-phase regulators control voltage on a three-phase, three-wire circuit.

The open-delta connection offers a voltage improvement of $\pm 10\%$ (± 0.1 on a per unit basis) in each of the phases containing the regulator and a $\pm 5\%$ improvement in the phase without a regulator. Since both regulators contribute $\pm 5\%$ voltage regulation to the third phase, all three phases are regulated to $\pm 10\%$, the units' maximum regulating range. Considering that only two regulators are required to provide three-phase regulation, the cost for the open-delta connection is very attractive.

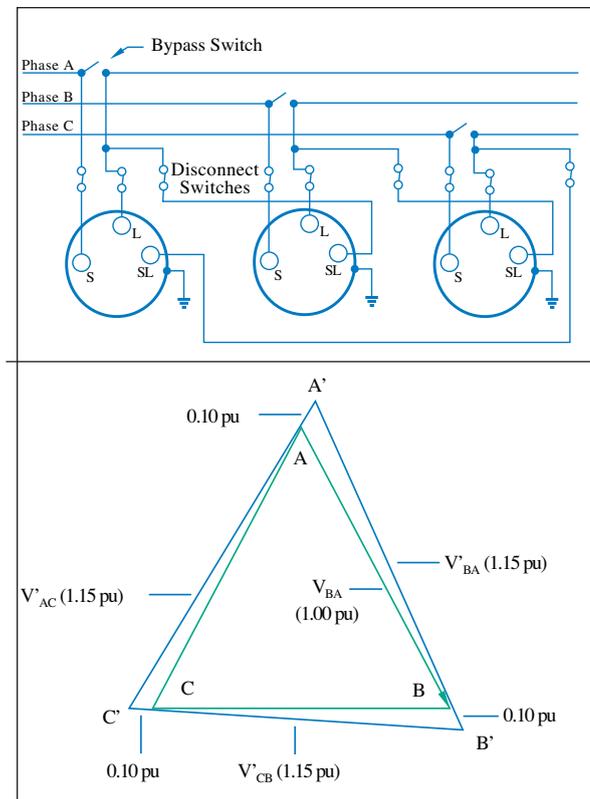


Figure 8: Three single-phase regulators control voltage on a three-phase, three-wire circuit.

The closed-delta connection results in a $\pm 10\%$ voltage regulation in the connected phase and a $\pm 5\%$ regulation in the adjacent phase. The overall effect is to increase the regulation range of all three phases to $\pm 15\%$. The additional cost of the closed-delta connection is justified if increased regulation is needed.

How ratings are selected

Two parameters are necessary to select a voltage regulator: Rated Voltage and Rated Current.

Rated Voltage: It must be equal to or higher than the system nominal voltage.

Rated Current: It must be equal to or higher than the maximum load current at the place that regulator is going to be installed.

Example: Nominal system voltage: 20 kV
Maximum load current at the point that regulator is going to be installed: 90 A

Regulator ratings will be:

Rated Voltage = 22 kV (≥ 20 kV)
Rated Current = 100 A (> 90 A)

Refer to the table on page 9 for the list of available 50 Hz ratings.

Where to Apply

On existing feeders with voltage drop problems

This is a common application of voltage regulators. They are installed before the point that the voltage drop problem starts under heavy load conditions.

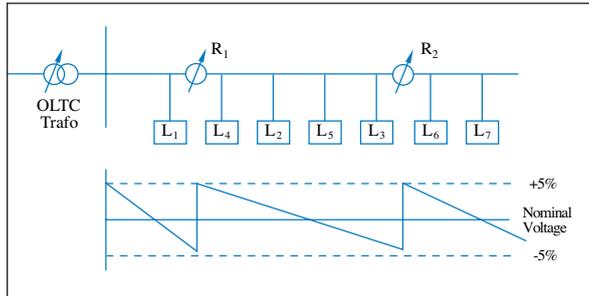


Figure 9: Regulator banks R_1 and R_2 are required to correct feeder voltage profile.

On important laterals

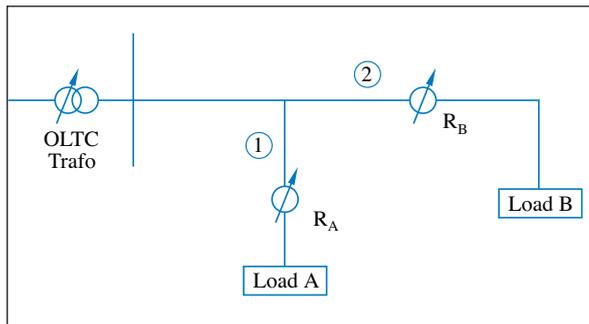


Figure 10: Regulator banks control important load voltages.

Important laterals from a main feeder can be effectively controlled with regulators. This is not possible with a single on-load tap-changing transformer for the following reasons:

- a. If branch (1) is short and branch (2) is long, the transformer has to be set for maximum boost to support Load B's voltage. Load A will experience an undesirable overvoltage. The solution is to install regulator bank R_B . Now, the transformer tap can be set to a lower value and the overvoltage can be avoided.
- b. If branch (2) is too long, regulator bank R_A might also be needed along with bank R_B —one to raise the voltage (R_B) and the other to lower the voltage (R_A).

To serve a remotely located load

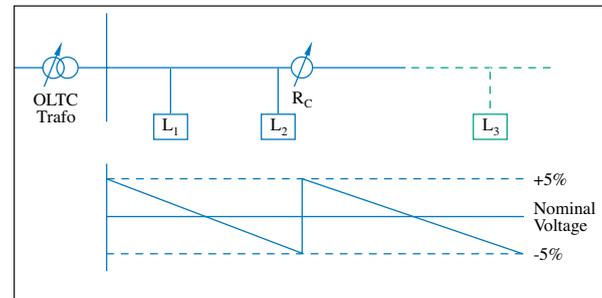


Figure 11: Regulator bank R_C makes it possible to extend the existing feeder to serve L_3 .

Dispersed, remotely located loads present another problem. The revenue from them does not justify the extension of the HV network or construction of a new primary substation. These types of loads can be economically and quickly served by extending the existing feeder and installing voltage regulators to correct for the voltage drop in the extension.

- 1 Bypass Arrester:** An MOV-type arrester protects the series winding from surges. An operator can easily verify that the arrester continues to protect the winding.
- 2 High-Profile Bushings:** An extra margin of protection is provided by high-profile bushings. All three bushings are identical.
- 3 Threaded-Stud Bushings:** Threaded-stud terminals provide high-ampacity junction to the connectors and easy connector change-out.
- 4 Pressure Relief:** All regulators are equipped with a pressure relief valve that automatically vents at 35 kPa (5 psig) to avoid pressure buildup. It has an insect shield, and is hot-stick operable.

- 5 Position Indicator:** The large, downward-angled position indicator shows the present and extreme raise and lower tap positions. Drag hands are resettable from the control.



Position Indicator

- Feature:** Adjustable internal microswitches allow for reduced range of regulation with resultant increase in ampacity.
- 6 Dual Nameplates:** Two identical nameplates are supplied on every regulator — one located on the control enclosure and one on the tank.
- 7 Pole-Mounting Brackets:** Lighter weight regulators have pole-mounting brackets. The style of bracket varies with regulator weight.
- 8 Drain Valve:** A brass drain valve with sampling device is standard on every regulator. This valve and the upper fill plug make sampling and oil filtration simple.
- 9 Liquid Sight Gauge:** This floating-ball gauge provides a simple, visible indication of the level and color of the insulating liquid.

Handhole: The covered handhole on all ratings provides access to terminal connections used for lower voltage operation. It also allows for limited inspection.



Convenient access



10 Sealed Tank: A sealed tank is used to prevent air from entering the regulator, thus reducing the oxidation rate of the insulating liquid.

Higher Temperature Rating: The 55/65°C temperature rise rating provides 12 percent more continuous capacity at 65°C rise without reduced regulation or loss of insulation life. This capability results from the use of thermally-upgraded paper and a sealed-tank design. This rating is shown on the nameplates.

11 Lifting Eyes: The entire cover-suspended internal assembly is lifted via these eyes.

12 Upper Filter Press Connection: Insulating liquid can be added and a filter press hose can be connected at this fitting.

13 Arrester Mounting Bosses: Line-to-ground arresters can be installed adjacent to all three bushings.

14 Lifting Lugs: These lugs are used to lift the entire unit.

15 Ground Bosses: Two diagonally opposite grounding bosses are located on the tank and one on the control enclosure.

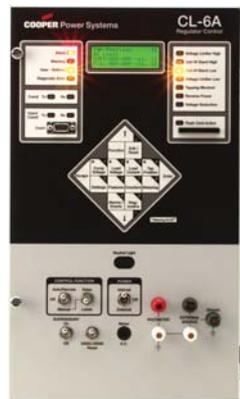
16 Mounting Provisions: Tanks without a rectangular base have four loops for attachment of the regulator to a shipping pallet, “H” platform or elevating structure.

17 Control Enclosure: The fully-gasketed and lockable enclosure has a screened vent at its base. With an optional long cable it can be located away from the regulator for operator convenience.

18 Junction Box: This box provides the oil-tight junction of the position indicator flex cable and internal control leads through the cover and the weather-tight junction of the control cable. A solid-state C.T. shorting device is located in the junction box.

19 Cable Fitting: Weather-tight military-type cable fitting allows for convenient cable disconnection.

20 Interchangeable Panels: Control panels can easily be replaced in the field, even with the regulator energized. To change out a panel, simply swing open the front panel, open one knife switch and close another (on the back panel), disconnect plug from the bottom terminal board, and lift the panel from its hinges.



CL-6-series panel



Maintaining Customer Voltage in an Expanding Network

Of the many ways to maintain the proper voltage in a MV system, the application of voltage regulators is often the best. Voltage drop is too significant to be cured by the lowering of transformer tap settings, and the use of capacitors for power factor correction, while contributing to voltage improvement, typically is not sufficient for total correction.

The use of voltage regulators is easier and less expensive than upgrading power lines, changing the system voltage, or adding a new primary substation.

Successfully used for more than 50 years, voltage regulators automatically adjust (regulate) high or low voltage input to a specific voltage level. The result is a voltage profile within defined limits for all loads at all times—reliable, quality electric power at minimum cost for both the utility and its customers.

Uncompromising Reliability, Quality and Service

The Cooper Power Systems voltage regulator product team is committed to providing products and services that meet or exceed your requirements.

Testing for Reliability



Prior to final assembly, every subassembly is individually tested. Then, in addition to receiving the electrical production tests normally associated with a transformer, each regulator receives an *operational test* which tests the tap-changer, position indicator, cable assembly, control, and control accessories.

Finally, Cooper Power Systems subjects every voltage regulator to an *impulse test* at rated BIL to assure conformance to strict design and manufacturing standards.

Local Support Worldwide

The Cooper Power Systems sales and service team starts with your local sales agent or Cooper Power Systems Sales Engineer. They assure that you get what you expect and that, if problems surface, resolution is accomplished quickly and fairly.

Engineers, located at the Cooper Power Systems international offices, support the field sales force, providing additional technical assistance.

Behind these two groups is the product service department. Service personnel provide spare parts, replacement parts for older model regulators, and upgrades of regulator controls.

Factory and Field Training Schools



The service department also offers regularly scheduled training programs in the application and maintenance of voltage regulators. Classes are conducted at the factory in Milwaukee, Wisconsin, USA.

Engineers also provide regulator training schools at utility locations.

Extensive Selection of Designs

Cooper Power Systems maintains a large selection of pre-engineered 50 Hz regulator designs in all voltage classes from 6600 V to 35000 V*. Minor modifications to the base designs usually can be made quickly without extending the shipment lead time.

*Note: An extensive list of pre-engineered 60 Hz designs is also available.

Cooper Power Systems: A World-Class Supplier of Electrical Equipment

Cooper Power Systems is a major manufacturer of medium- and high-voltage electrical equipment, components and systems that help bring electric power to homes, industries, businesses and institutions throughout the world. The company's products are used in substations, overhead, underground and in-plant medium-voltage distribution systems.

Products include distribution transformers, capacitors, voltage regulators, surge arresters, transformer components and protective equipment, molded rubber products, pole-line hardware, and engineering services. Cooper Power Systems has been providing electrical distribution solutions for the residential, commercial, industrial and utility markets for decades. Our rich history includes such well-known, respected brands as Edison®, McGraw-Edison®, RTE®, Kearney™, and Kyle®.

Cooper Power Systems is a division of Cooper Industries, Ltd., a global manufacturer of electrical products, tools and hardware. Incorporated in Bermuda, the Company's administrative headquarters are in Houston, Texas. Cooper has more than 28,000 employees serving more than 100 locations around the world and sells products to customers in more than 50 countries.

Cooper Power Systems invests millions of dollars annually on research and development at its Thomas A. Edison Technical Center. Analytical chemistry, electronic controls and apparatus development, materials research, and high-power/voltage testing are all part of Cooper Power Systems' commitment to bring you the finest electrical distribution products.



The services of the high-voltage and high-power laboratories at the Thomas A. Edison Technical Center are contracted for development work by Cooper Power Systems Product Groups as well as non-Cooper companies.



The Thomas A. Edison Technical Center Power Test Laboratories in Franksville, Wisconsin, has been accredited through the American Association for Laboratory Accreditation (A2LA Certificate Number 1457.01) since March of 2000. Our Quality system presently conforms to ISO 17025.

Standard Ratings of 50 Hertz Regulators



Two small or medium-size line regulators, connected open-delta, may be installed on a pole or on a platform (*top photo*). Three line regulators connected closed-delta typically are installed on a platform.

With the use of an optional long control cable, the control enclosures may be installed away from the regulators for operator convenience.

The largest ratings listed to the right are designed for use in medium-voltage primary substations (*lower photo*).

Voltage regulators can be used on systems with nominal voltages lower than the regulators' nominal rated voltage. For instance, a 22 kV regulator can be used on an 11 kV system. This change can be made at the factory or by utility personnel.

50 Hz Ratings			
Rated Voltage	Rated kVA*	Rated Load Current A*	
6600 (95 kV BIL)	33/37	50/56	1**
	66/74	100/112	1
	99/111	150/168	1
	132/148	200/224	2
	198/222	300/336	3
	264/296	400/448	3
	330/370	500/560	3
	396/444	600/672	3
11000 (95 kV BIL)	462/517	700/784	3
	55/62	50/56	1
	110/123	100/112	1
	165/185	150/168	1
	220/246	200/224	2
	330/370	300/336	3
	440/493	400/448	3
	550/616	500/560	3
15000 (150 kV BIL)	660/739	600/672	3
	75/84	50/56	1
	150/168	100/112	1
	225/252	150/168	2
	300/336	200/224	3
	450/504	300/336	3
22000 (150 kV BIL)	600/672	400/448	3
	750/840	500/560	3
	110/123	50/56	1
	220/246	100/112	2
	330/370	150/168	3
33000 (200 kV BIL)	440/493	200/224	3
	660/739	300/336	3
	880/986	400/448	3
	165/185	50/56	3
35000 (200 kV BIL)	330/370	100/112	3
	495/554	150/168	3
	660/739	200/224	3
35000 (200 kV BIL)	175/196	50/56	3
	350/392	100/112	3
	525/588	150/168	3
	700/784	200/224	3

* Notes: All ratings listed are for 55/65°C rise designs operating in an average ambient of 30°C. (Special designs available for average ambient of 40°C)

** Notes: 1-Pole Brackets
2-Pole Brackets & Substation Base
3-Substation Base

Nominal Rated Voltage – 50 Hz					
6600	11000	15000	22000	33000	35000
System Voltages Listed on Nameplate					
6930	11600	15000	23000		35000
6600	11000	14400	22000	33000	33000
6350	10000	13800	20000	30000	30000
6000	6930	13200	19100	22000	22000
5500	6600	12000	15000	20000	20000
	6350	11000	12700	11600	11600
	6000	10000	11000	11000	11000
	5500	8660	10000	10000	10000

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