



Substations - Volume VI: Voltage Regulators and Capacitors

An Online Continuing Education Course for Engineers

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Preface

This course is one of a series of thirteen courses on the design of electrical substations. The courses do not necessarily have to be taken in order and, for the most part, are stand-alone courses. The following is a brief description of each course.

Volume I, Design Parameters. Covers the general design considerations, documents and drawings related to designing a substation.

Volume II, Physical Layout. Covers the layout considerations, bus configurations, and electrical clearances.

Volume III, Conductors and Bus Design. Covers bare conductors, rigid and strain bus design.

Volume IV, Power Transformers. Covers the application and relevant specifications related to power transformers and mobile transformers.

Volume V, Circuit Interrupting Devices. Covers the specifications and application of power circuit breakers, metal-clad switchgear and electronic reclosers.

Volume VI, Voltage Regulators and Capacitors. Covers the general operation and specification of voltage regulators and capacitors.

Volume VII, Other Major Equipment. Covers switch, arrester, and instrument transformer specification and application.

Volume VIII, Site and Foundation Design. Covers general issues related to site design, foundation design and control house design.

Volume IX, Substation Structures. Covers the design of bus support structures and connectors.

Volume X, Grounding. Covers the design of the ground grid for safety and proper operation.

Volume XI, Protective Relaying. Covers relay types, schemes, and instrumentation.

Volume XII, Auxiliary Systems. Covers AC & DC systems, automation, and communications.

Volume XIII, Insulated Cable and Raceways. Covers the specifications and application of electrical cable.

Chapter 1: Substation Voltage Regulators

Both three-phase and single-phase voltage regulators are used in distribution substations to regulate the load-side voltage. Substation regulators are one of the primary means, along with load-tap-changing power transformers, shunt capacitors, and distribution line regulators, for maintaining a proper level of voltage at a customer's service entrance.

A very important function of substation voltage regulation is to correct for supply voltage variation. With the proper use of the control settings and line drop compensation, regulators can correct for load variations as well. A properly applied and controlled voltage regulator not only keeps the voltage at a customer's service entrance within approved limits but also minimizes the range of voltage swing between light and heavy load periods.



The substation regulators may be located on individual feeders or in the transformer secondary circuit for main bus regulation, such as shown in the photo above. Normally, the low-voltage substation bus will be regulated rather than the individual feeders. Individual feeder regulation can usually be justified only when there are extreme variations between individual distribution feeder peak load times. Very long or heavily loaded distribution feeders may require

supplemental regulators strategically located out on the line to maintain voltage levels within required limits.

Recommend voltage levels are given in ANSI Std. C84.1, “Voltage Ratings for Electric Power Systems and Equipment (60 Hz).” The American National Standards Institute, ANSI, defines acceptable voltage levels on an electric distribution system. According to ANSI, voltage levels should be within the following ranges shown in Table 1.

Table 1 Acceptable Voltage Levels (120 Volt base)		
Range	Minimum	Maximum
A	114	126
B	110	127

Range "A" is the normal service delivery range. Range "B" defines the limits in which service voltages may vary for limited time duration due to normal system operation. To the utility engineer, this means that the electric system should be designed for operation within the voltage range of 114 - 126 volts and once the voltage level falls into range "B" action should be taken immediately to bring the voltage back into range "A".

Operating an electric system on the low end of the voltage range may cause excessive current demand in motors, which generate additional heat and possibly limit the life of the motor. Incandescent lamps will operate fine at reduced voltage levels, but they will deliver less light output than they would operating at rated voltage. At higher voltages, motors will run cooler and operate more efficiently while incandescent lamps will deliver more light output and will have a shorter life span.

Customers typically will report equipment damage when voltage levels drop below 105 volts or above 130 volts.

Regulators should comply with ANSI Std. C57.15, “Requirements, Terminology, and Test Code for Step-Voltage and Induction-Voltage Regulators,” and ANSI Std. C57.95, “Guide for Loading Oil-Immersed Step-Voltage and Induction-Voltage Regulators.”

Types

There are two general types of voltage regulators, the *induction regulator* and the *step-type regulator*. Both types are available in single- or three-phase designs. The step-type regulator has by far the wider application in the electric distribution system. The step-voltage regulator has virtually replaced the induction-voltage regulator because it is lower in cost and equally reliable.

A *step-voltage regulator* is a regulator having one or more windings excited from the system circuit or a separate source and one or more windings connected in series with the system circuit for adjusting the voltage, or the phase angle, without interrupting the load. A step-type voltage regulator has a load-tap changing mechanism built into an integral transformer. Voltage is impressed on the primary winding, and the secondary winding will induce a voltage

An automatic reverse load tap changer can be used to subtractive voltage from the series winding or to add voltage. The series winding are connected to the load tap changer. The voltage change in equal steps.

The terminal design is:

- The terminal
- The terminal
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For three-phase regulators, the terminal designations are, and SOLO.

Several factors influence the choice of single-phase versus three-phase regulators. For smaller substation sizes, single-phase regulators are usually less expensive. They also do a better job of maintaining balanced phase voltages under conditions of unbalanced loading. Single-phase regulators are also more adaptable to line use because of the relative ease of pole mounting. Regulation by single-phase regulators also gives maximum reliability for the system because a regulator can be removed for maintenance or repair without the need to de-energize transformers or other regulators. Special switches are available to permit removing a regulator from service without interrupting the circuit.

In large distribution substations, the choice of three-phase regulators may be based on costs or on the availability of single-phase regulators of the required size. Three-phase regulators require somewhat less space than three single-phase regulators; however, this is not generally a major factor in selection.

Load-tap-changing power transformers (LTCs) are becoming more common in distribution substations. They consist essentially of a three-phase regulator built into a three-phase power transformer. The relative cost of this combination compared to a separate transformer and either three-phase or single-phase regulators varies depending on the size of the substation. Aside from the base cost of the equipment, the LTC method generally will result in a saving in space,

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