



# Substations - Volume IV: Power Transformers

An Online Continuing Education Course for Engineers

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**Credit: 3 Hours / 3 PDH / 3 CPD**

# Substation Design – Volume IV: Power Transformers

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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: Power Transformers

The primary function of a power transformer is to transform system voltage from one nominal level to another. The transformer has to be capable of carrying the power flow for its particular location in the system under various operating conditions and contingencies, such as line or transformer outages. The photo shown below is an example of three single-phase power transformers in a substation.



This course deals primarily with oil-filled power transformers with nominal primary voltage ratings of 230 kV and below and utilizing one of the following methods of cooling:

- Self-cooled (OA)
- Self-cooled and assisted by forced-air (OA/FA for one stage; OA/FA/FA for two stages)
- Self-cooled and assisted by forced-air and forced-oil (OA/FA/FOA or OA/FOA/FOA for two stages)

The type of cooling used is based on the requirements of the specifications, the size of the transformer, and the manufacturer's standard design. Meeting these specific requirements usually results in the power transformer's being the largest, heaviest, and most costly piece of equipment used in a substation.

Because of their great importance and complexity, power transformers require special care in their application, specification, and procurement. This is best accomplished by taking full advantage of applicable industry standards and guides of national organizations such as the American National Standards Institute (ANSI), Institute of Electrical and Electronic Engineers (IEEE), and National Electrical Manufacturers Association (NEMA), etc.

The following discussion highlights various aspects of power transformers and provides guidance and recommendations to assist cooperatives in obtaining the proper equipment for their systems.

## **Types**

Power transformers may be either autotransformers or multi-winding conventional transformers. A three-phase installation may consist of a three-phase unit or three single-phase units. The decision as to what type of transformer to purchase depends on such factors as initial installed cost, maintenance costs, operating cost, reliability, etc. Three-phase units have lower construction and maintenance costs and can be built to the same efficiency ratings as single-phase units. The initial cost of a three-phase transformer is usually approximately one-third less than four single-phase units. Additionally, the exposure of three-phase units to long outages can be minimized system-wide when a mobile substation or transformer is available for backup in case of failure.

The kVA ratings for various sizes of transformers are covered by the standards such as IEEE Std. C57.12.00, which defines the preferred continuous ratings for both single - and three-phase units. Transformers 10,000 kVA and below can accommodate one stage of cooling only, while transformers larger than 10,000 kVA can include up to two stages of cooling. Each stage of cooling increases the capacity of the transformer by a fixed percentage of the base (OA) rating. For three-phase transformers rated between 750 and 2,000 kVA, increasing the base level of cooling to forced air cooling will increase the continuous kVA capacity by 15 percent. For transformers rated 2500 kVA to 10,000 kVA, the increase is 25 percent. For transformers above 10,000 kVA, additional stages of cooling may be used to increase the continuous kVA rating of the transformer by 33 percent per stage. Transformers larger than those listed in the tables can be purchased and would normally be triple rated or would have provision for the future addition of two stages of cooling equipment to produce a triple rating.

