



Substations - Volume IX: Substation Structures

An Online Continuing Education Course for Engineers

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Substations – Volume IX: Substation Structures

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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: Structural Issues

Prior to the start of structure design, several factors should be evaluated that may affect the choice of material and member type selected for the structure. Factors influencing selection of material and member type include first cost, cost of erection, deflection characteristics, cost of maintenance, availability, resistance to corrosion and other deterioration, freedom from fire hazard, appearance, size of revenue-producing load served, and temporary or permanent nature of structure.

The American Society of Civil Engineers (ASCE) is a good resource for substation structural design issues including various structure types, loading criteria, deflection criteria, methods of structure analysis and design, and structure connection to foundations.

Materials

There are four basic materials used for substation structures:

- Steel
- Aluminum
- Concrete
- Wood

Steel is used for most substation structures. Its availability and good structural characteristics generally make it economically attractive. Steel, however, has to have adequate protection from the elements to prevent corrosion. Galvanizing and painting are two widely used finishes for steel substation structures. Because of the protective finish, steel substation structures should not be designed for field welding or field drilling for connections. Field welding is generally uneconomical and usually requires close control over the welding conditions.

ASTM A36 steel is the standard grade of steel used for most rolled-shape members in structural design. Member stresses are usually low, and weight saving is of little advantage. However, should large loads be encountered, coupled with the need for weight reduction, a high-strength steel should be considered such as for line support structures. Structural steel pipe and square tube sections are normally constructed of ASTM A53 Grade B and ASTM A501 steel, respectively.

Aluminum is sometimes used for substation structures where good corrosion-resistant properties are desired. It is about one-third the weight of steel. If aluminum is used, member types should be selected taking advantage of the optimum structural qualities of aluminum and avoiding the shapes in which aluminum members may be a problem. Deflection and torsion has to be

carefully reviewed when selecting member types in aluminum. Aluminum has a lower modulus of elasticity and modulus of elasticity in shear than steel; these properties are directly related to deflection and torsional rotation. See Table 1.

Table 1		
Comparison of Aluminum vs. Steel Properties		
Property	Aluminum	Steel
Modulus of Elasticity	10×10^6	29×10^6
Modulus of Elasticity - Shear	3.8×10^6	12×10^6

Structures designed for aluminum are constructed of Alloy 6061-T6 and should be designed, fabricated, and erected in accordance with the Aluminum Association's Specifications for Aluminum Structures.

Precast, prestressed concrete substation structures may be economical in coastal areas with high winds and a corrosive environment, and also when substations are located near the fabricator's plant. Special considerations are required for the foundation, erection, handling, and equipment mounting characteristics of the structure.

Wood may be used for substation structures. Members have to be treated with an appropriate preservative. Wood poles and members are usually readily available. Structural properties and size tolerances of wood are somewhat variable, and design considerations should take this into account. The life of a wood structure is shorter than for steel, aluminum, or concrete, and maintenance costs may be higher.

Economics is an important consideration when making a material and member type selection. The total cost over the life of the structure should be considered. This also includes the cost of fabrication and shipping, ease of erection, and cost of maintenance.

Functional Structure Types

There are essentially three types of substation structures as categorized from a structural design approach related to the function served in the substation.

Line Support Structures are used as line exit structures, internal strain bus structures, and line terminating structures. They consist basically of two high towers and a crossarm on which the line conductors are attached. They may be used as single-bay or multibay structures.

The major forces acting on these structures are the shield wire and conductor tensions and wind forces. Because of their large size and the magnitude of forces acting on them, these structures are usually highly stressed and require the most design effort.

Equipment Support Structures are commonly referred to as bus support structures, switch stands, lightning arrester stands, line trap supports, etc. In low-profile substation design, these structures are designed primarily as vertical cantilever beams with wind and short-circuit forces being the primary design forces. Deflection may control the design size of some structures and should be reviewed in all structures. Switch stands should be designed to be more rigid than bus supports or other structures because of the dynamic forces from the blade operation and the requirement that the structure must fit in the relatively small space of the saddle. Any appreciable deflection will prohibit this function.

Distribution Substation Structures are similar to a building frame. It may consist of one or two bays. It may vary in height from 20 to 40 feet or more. They support equipment. It usually will have line conductors and equipment. It usually will be designed for rigidity and flexibility in equipment. It is usually composed of box truss members.

Structure Member Types

Three types of structure members are used today. They are classified from their general components. The types are:

1. Lattice
2. Solid profile
3. Semi-solid profile

1. Lattice Structure

The *lattice structure* consists primarily of angle members forming the chords and lacing of a box truss acting as a beam or column. Depending on the function of the structure (i.e., bus support stand vs. line support structure), the design of the members may or may not be time-consuming and complex.

The lattice structure has been widely used for substation structures for many years. Its box truss beams and columns allow for an efficient use of material. Usually the lattice structure results in the least structure weight compared to other line support structures. It is also very stable and rigid. It is very easy to fabricate, galvanize, and ship. It requires a large amount of bolting and

