



**PDHonline Course E469 (4 PDH)**

# **Substation Design**

## **Volume II**

### **Physical Layout**



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Volume II  
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This series of courses are based on the “Design Guide for Rural Substations”, published by the Rural Utilities Service of the United States Department of Agriculture, RUS Bulletin 1724E-300, June 2001.

## 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

## Layout Considerations

This chapter presents general information concerning the design of the substation physical arrangement. It describes various types of substations, illustrates typical layouts, and presents guidelines to be used during detailed design. Information concerning insulation and electrical clearances are reviewed in the following chapters.

A careful analysis of basic parameters establishing the purposes and design criteria for the substation has to precede the detailed design. In addition, circuit quantities, configurations, and ratings; system and equipment protective relay schemes; the necessity for specialized equipment details of surge protection equipment; and requirements for direct stroke protection should be considered.

The power system as a whole has to be considered when deciding the substation switching scheme. Future system growth based on long-range forecasts may indicate the necessity for an economical, basic arrangement initially with possible future conversion to a more sophisticated scheme as the number of circuits increases. Important circuits may require additional protection or redundant supply. Equipment maintenance requirements may necessitate bypassing facilities to enable circuit operation during maintenance periods. Since the equipment that can be out of service for maintenance or during faults without sacrificing system operation depends on alternative supplies and duplication of circuits, the flexibility of the switching scheme is often one of the most important selection criteria. Large substations with many circuits handling great amounts of power need to have high degrees of both flexibility and reliability to continue service without interruption during the most undesirable conditions. Since flexibility and reliability are directly proportional to cost, the ultimate configuration has to be the result of a compromise.

Frequently, after initial substation construction, requirements change, and plans for the ultimate capabilities of the substation are altered. As a result, expansion of the substation facilities may deviate from the anticipated initial plan. To accommodate unforeseen future system modifications, consider the flexibility of the arrangement. Since a typical substation can be expected to continue in service indefinitely, maintaining maximum flexibility throughout each stage of expansion will ensure the least costly and most efficient use of the facilities during the service period.

To facilitate future expansion, the initial design should be arranged to accommodate long range needs. The site should be as large as practical to allow for future development. Large areas readily allow for changes in the basic substation configuration and switching scheme should future conditions so dictate. Leave at least one and preferably both ends of all major buses open or future expansion. When a basic initial arrangement is planned, placement of equipment should

take into account future expansion of the substation into a more complex, reliable, and flexible configuration. Frequently, additional switches, switch stands, and bus supports are installed initially to facilitate future expansion.

The profile of substation structures and equipment has become an increasingly important aspect to consider in substation layout. In the past, large lattice and box-type structures supporting overhead strain buses were commonly used. Most substations currently being designed and constructed use low-profile structures and rigid buswork, particularly for low-voltage distribution substations or in areas with natural environmental screening.

Low-profile construction generally uses lower structures with a minimum number of members for support. Larger pieces of equipment, such as power transformers and power circuit breakers, have become smaller over the years. Consequently, substations are considered less obtrusive overall. The height limitations causing the use of low-profile construction sometimes result in arrangements of increased area, particularly for the lower voltage levels. Generally, the advantages of easier equipment operation and maintenance as a result of reduced equipment sizes and effective locations make up for the expense of purchasing somewhat larger sites.

An effective method to improve substation appearance is to install circuits underground as they leave the substation. Low-profile construction using lower structures with fewer support members lends itself to the use of underground circuits. Installing underground circuits can similarly improve the appearance of substations with larger structures by reducing the size of some of the large supporting structures or eliminating them altogether.

Substation arrangements have to include adequate space for the installation and possible removal of large pieces of equipment such as power transformers and power circuit breakers. Buses, particularly in low-profile arrangements, even when at acceptable operating elevations, can block the removal of equipment. Consequently, it is important to consider equipment removal routes during the structure layout. Often the most desirable arrangement has the main buses at higher elevations than the buses and equipment in the substation bays. In this way, the main buses will not block the removal of equipment located in the substation interior. Removable bus sections can also be provided to permit movement of large equipment. This, however, requires bus de-energization during the procedure.

Bay spacing has to be carefully evaluated during layout to allow for removal of equipment. In multi-bay configurations, it is common to limit the number of bays to two before increasing the bay center-to-center spacing. This allows equipment to be removed from a bay to the side and provides additional space for moving the equipment between a bay and an adjacent bay.

## Distribution Substations

Distribution substations are usually characterized by voltages up to 230 kV on the primary side and on the low side the voltages are typically,

- ❖ 12.5Y/7.2 kV
- ❖ 13.2Y/7.6 kV
- ❖ 13.8Y/8.0 kV
- ❖ 24.9Y/14.4 kV
- ❖ 34.5Y/19.9 kV

In recent years, the trend has been toward increasing system voltages. It is becoming more common to eliminate the intermediate transmission substations and directly reduce the transmission voltages to primary distribution levels. The distribution substations discussed are generally limited to the traditional type characterized by simple bus arrangements and minimal equipment. However, the arrangements can be expanded for use in larger distribution substations with higher voltages.

### Basic Distribution Substation

Figure 1 is a one-line diagram for a simple distribution substation. Depending on the load being served, it is possible that initial construction may be limited to one distribution circuit. The sub-transmission circuit enters the substation through a primary disconnect switch used principally to isolate the substation from the sub-transmission system for maintenance or when replacement of substation equipment is required. It is usually of the three-pole, single-throw, group-operated type.

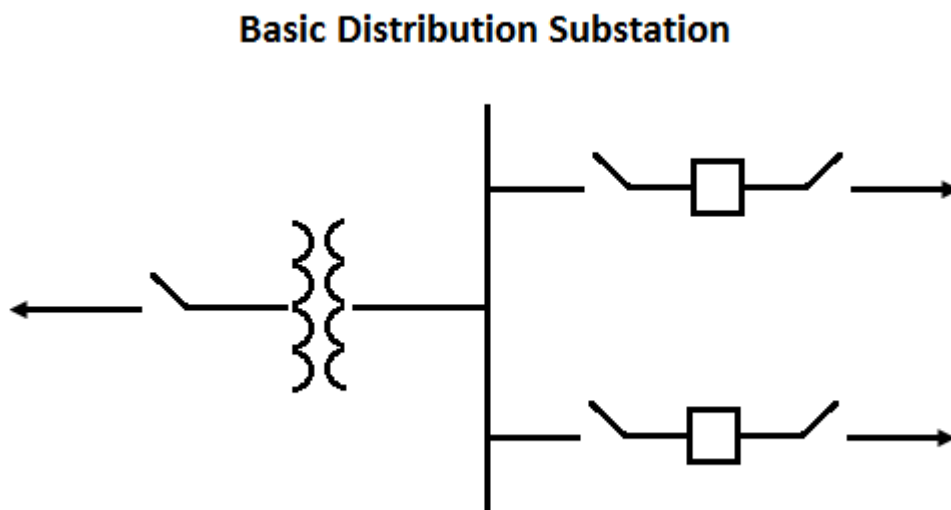


Figure 1

The power transformers commonly used in this application are two-winding type and may be single- or three-phase units. In new substations and when replacing transformers or increasing transformer capacity, the trend has been toward using three-phase transformers. In configurations using single-phase transformers, a fourth transformer may be added as a spare. Use of three-phase transformers results in a neater and less cluttered arrangement. However, since failure of a three-phase transformer means loss of the substation, the overall design layout should provide facilities for the rapid installation of a mobile transformer or a mobile substation.

The two primary distribution feeders of the substation illustrated in Figure 1 are protected by either power circuit breakers or automatic circuit reclosers. Disconnect switches on both the source and load sides permit isolation during maintenance or other periods when complete de-energization is required. The switches can be either single-pole, single-throw, hook stick-operated or three-pole, single-throw, group-operated, depending on the arrangement.

#### Transformer Primary Protective Devices

To prevent equipment damage from transformer or low-voltage bus faults, protective devices are generally provided on the primary side of the transformer. These devices may also serve as primary disconnects to enable isolation from the transmission system.

Several types of devices are available, including power fuses, circuit breakers, circuit switchers, and vacuum interrupters. Selection of the type of device is based on the voltage; short-circuit conditions, and transformer capacity.

#### Voltage Regulation

To maintain voltage at a uniform level, voltage regulation equipment is usually required in rural distribution substations. The voltage can be regulated by using either feeder or bus regulation. Feeder regulation may be used in multi-circuit distribution substations, where the circuits are very diverse in load characteristics. With feeder regulation, the voltage of each distribution circuit can be individually maintained to conform to the load characteristics. Bus regulation may be used in rural distribution substations where the distribution feeders have similar load characteristics. Bus voltage may be controlled by using power transformers with load tap changing mechanisms, single- or three-phase voltage regulators, or switched capacitor banks. To permit voltage regulator maintenance without feeder or bus de-energization, bypass facilities are provided as illustrated in Figure 2.

Voltage Regulator Bypass Arrangements

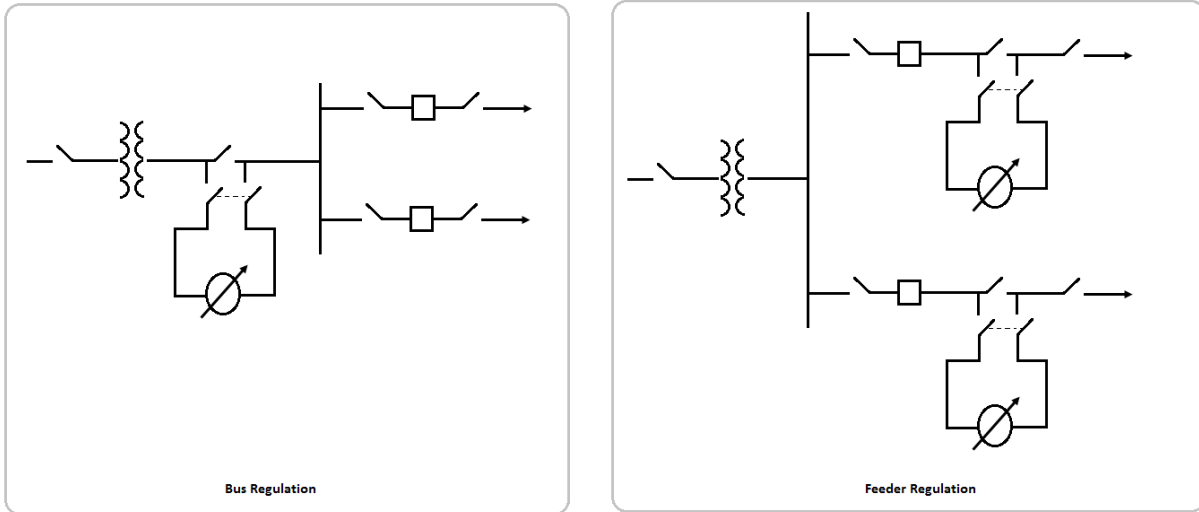


Figure 2

The switches normally used for regulator bypassing automatically combine all switching operations and perform them in the correct operating sequence. Each combined switch can usually be installed in the same space as one single-pole disconnect switch.

Circuit Breaker/Recloser Bypass Facilities

Bypass facilities permit circuit breaker or recloser maintenance or repair without circuit de-energization. The bypass switches usually consist of three independently operated hook stick switches, but a three-pole group-operated switch can also be used. In some applications, it may be desirable to combine some of the switches to facilitate installation. Figure 3 illustrates one possible configuration. This is in contrast to a circuit without a bypass arrangement as shown in Figure 4.

In this configuration, a tandem switch is used to combine the bypass switch and the load side disconnect switch onto a single switch base. The combined switch can be installed in nearly the same space as one single-pole disconnect switch. To provide circuit protection during bypassing, the bypass switch can be replaced by a fuse.



### Basic Distribution Substation

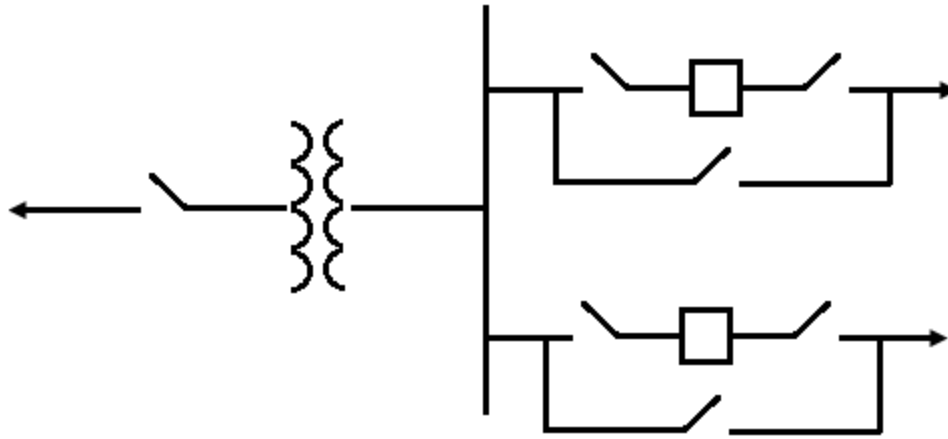


Figure 3

### Basic Distribution Substation

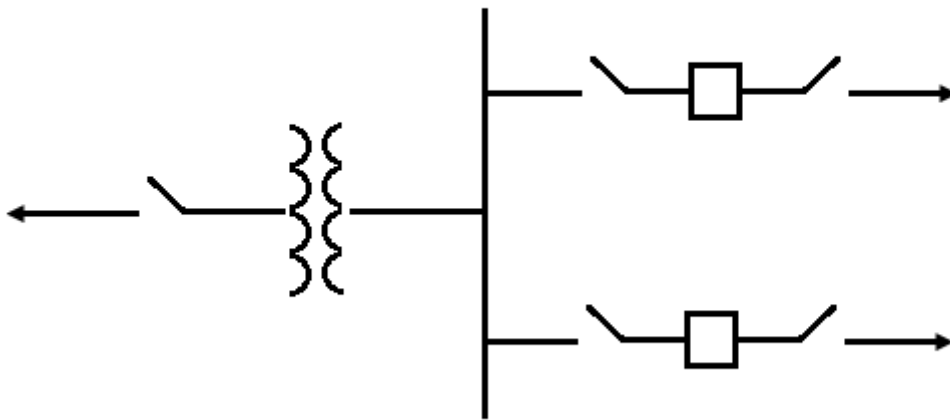


Figure 4

#### Surge Arresters

Transformers, regulators, and other substation equipment are particularly sensitive to transient overvoltages. For the highest degree of equipment protection, surge arresters should be installed as close as practical to the equipment being protected. In most instances, power transformers can be furnished with surge arrester mounting brackets to facilitate installation. Separate arrester stands can also be used, or the arresters can be installed on adjacent switching structures. For voltage regulator applications, the surge arresters are normally installed directly on the regulator tanks.

When power transformers are protected by fuses, it is recommended that transformer surge arresters be connected on the line side of the fuses, as close as practical to the power transformers. This will minimize the stress on the fuse and help avoid partial melting of the fuse link when the surge arrester responds to a transient overvoltage.

### Enclosed Equipment

In certain applications, particularly when space is at a premium, consider use of switchgear, unit substations, or partially enclosed equipment. *Switchgear* is a name commonly used in referring to groupings of switching equipment contained in metal enclosures. All circuit breakers, metering and control equipment, and interconnecting buswork are contained inside the enclosures.

A *unit substation* consists of switchgear electrically and mechanically connected to at least one power transformer. Various arrangements of power transformers and switchgear equipment are available to suit individual requirements.

Use of switchgear, unit substations, and other types of enclosed equipment eliminates the need for extensive field construction since most of the equipment is preassembled by the manufacturer or supplier. Depending on the configuration, the equipment may be shipped completely assembled or in sections to be connected together at the job site. Feeders are normally installed underground from the switchgear compartments.

Partial enclosure of some of the low-voltage distribution equipment can be implemented to improve the appearance of the substation. The equipment can be furnished in modular form to facilitate installation. Interconnections between modules are usually underground, although overhead bus duct is occasionally used.

### **Transmission Substations**

Transmission substations are usually characterized by primary and secondary voltages of 69 kV or higher. Since one transmission substation may supply several distribution substations and large loads, reliability of service and flexibility of operation are extremely important. Facilities normally allow equipment maintenance without circuit interruption. Multiple bus arrangements and extensive use of circuit breakers for switching provide added system flexibility.

### Basic Transmission Substation

Figure 5 is a one-line diagram for a basic transmission substation. Depending on system requirements, initial substation construction may be limited to one power transformer and one sub-transmission circuit.

### Basic Transmission Substation

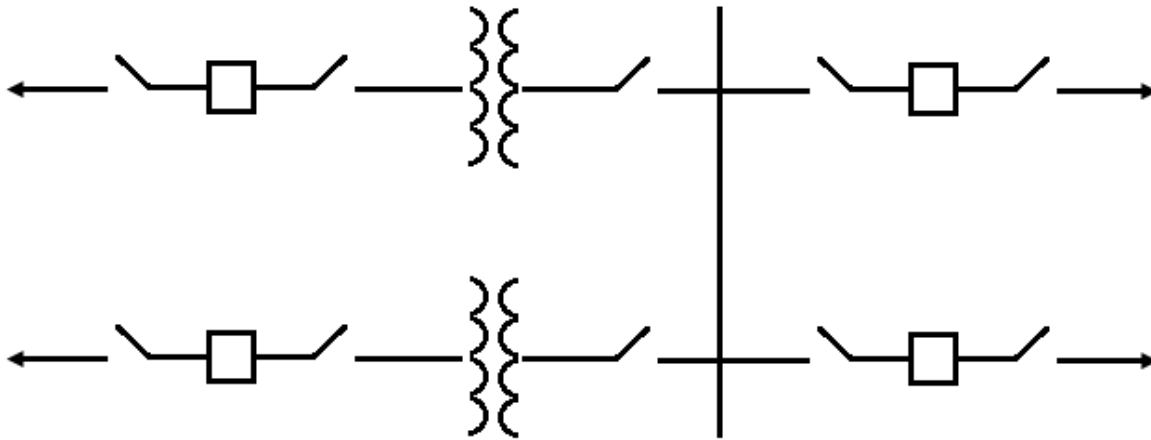


Figure 5

Power circuit breakers are included in the two transmission circuits to help prevent complete substation shutdown for line faults. The circuit breakers have disconnect switches on both source and load sides to permit isolation during maintenance or other periods requiring complete de-energization. These switches are normally of the three-pole, single-throw, group-operated type, mounted on separate stands.

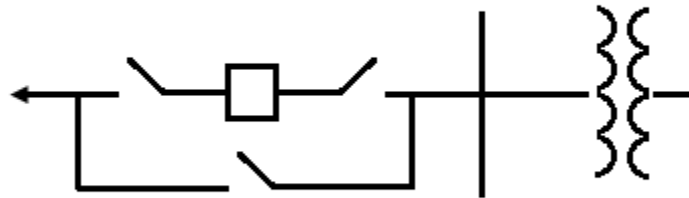
The power transformers commonly used are three-phase autotransformers, usually with tertiary windings. Three-phase two-winding transformers are used when phase relationships have to be sustained between the primary and the secondary systems. The disconnect switches on the low-voltage sides of the power transformers allow de-energization of one transformer while maintaining service to both low-voltage circuits from the other transformer.

The low-voltage or secondary section of the substation illustrated in Figure 5 consists of two sub-transmission feeders protected by power circuit breakers. Disconnect switches on both the source and load sides permit isolation during maintenance or other periods when complete de-energization is required. The switches are normally of the three-pole, single-throw, group-operated type, but can be of the single-pole, single-throw, and hook stick-operated type, depending on the voltage and arrangement. Hook stick-operated switches usually are not considered above 69 kV.

### Circuit Breaker Bypass Facilities

Bypass facilities can be provided for the power circuit breakers to permit maintenance without circuit de-energization. Figure 6 illustrates a typical arrangement.

#### **Typical Circuit Breaker Bypass Arrangement**



**Figure 6**

The bypass facilities normally consist of three independent three-pole, single-throw, group-operated switches. The circuit breaker disconnect switches may be of the single-pole, single-throw, hook stick-operated type, depending on system voltage and bus configuration.

In most cases bypassing circuit breakers removes normal relay protection since the circuit breaker current transformers are also removed from service. The overall protection scheme, have to be designed to provide for this situation. Fused bypass switches may be used for temporary feeder protection.

### Surge Arresters

Because of the desire for high reliability and the high cost of equipment replacement, surge arresters are installed in various positions in transmission substations. Since power transformers are particularly sensitive to overvoltages, they normally have arresters on each phase of both the primary and secondary. Also install arresters on each ungrounded phase of the tertiary winding when it is brought out to provide service.

The highest degree of equipment protection occurs with the surge arresters located as close as possible to the equipment to be protected. Power transformers can usually be furnished with arrester mounting brackets adjacent to the transformer bushings.

Occasionally, surge arresters or other surge protective equipment are located at the line entrances and exits. In these instances, it is best to locate the arresters or other protective equipment on the line side of the substation equipment to be protected to limit the lightning and switching surges

to acceptable levels as they enter the substation. Locating the arresters on the line side of the circuit breakers will also protect the gap in the breakers when in the open position.

### Carrier Equipment

Line traps, coupling capacitor voltage transformers, and associated accessories are used when relaying or communications systems dictate use of carrier equipment for signal transmission to remote terminals. Normally, the line traps and coupling capacitor voltage transformers are installed on separate stands located near the circuit entrance positions in the substations. In some instances, the two pieces of equipment may be mounted on a common structure or stand, depending on the arrangement. The particular relaying and communications schemes being used on the circuit will dictate the number of phases containing line traps and coupling capacitor voltage transformers.

### Voltage Transformers

Voltage transformers are used in conjunction with the circuit and equipment protection, synchronization, and metering schemes. They are normally mounted on individual or three-position stands. Depending on the bus configuration and the relaying schemes, the voltage transformers may be positioned near the circuit entrance positions or adjacent to the buses.

It is usually desirable to provide a method for disconnecting the voltage transformers. One possible method is to install the primary connections to the appropriate buses by using disconnectable clamps. In arrangements using voltage transformers at the circuit positions, they can be positioned to allow de-energization by opening the power circuit breaker and the line disconnect switches.

### Current Transformers

Current transformers used in both relaying and metering schemes can usually be located inside major equipment such as power circuit breakers and power transformers. These current transformers are normally multi-ratio bushing type and therefore do not require special mounting provisions. In some cases, separately mounted current transformers may be required, such as for revenue metering purposes. They are usually installed on individual stands and located as required.

### Grounding Switches

Manually operated grounding switches are frequently used to ground incoming circuits during maintenance or other out-of-service periods. These switches can be separately mounted or, as is usually the case, can be furnished as part of the circuit disconnect switches. The switches can then be interlocked in such a way as to prevent both from being closed simultaneously.

High-speed grounding switches are sometimes used in power transformer protection schemes to initiate tripping of remote circuit breakers during transformer faults. As with manually operated grounding switches, high-speed grounding switches can be separately mounted or can be furnished as part of group-operated disconnect switches. High-speed grounding switches are normally installed on one phase only. The use of high-speed grounding switches, while still in practice, is generally not preferred since its use subjects the system to more of a shock and potentially affects more customers on the system.

## Switching Stations

Switching stations do not change system voltage from one level to another and therefore do not contain power transformers. Switching stations usually operate at sub-transmission or transmission voltage levels. Depending on system voltage, the equipment types and characteristics used in switching stations are identical to those used in transmission stations.

### Basic Switching Substation

Figure 7 is a one-line diagram for a basic switching substation with three terminals.

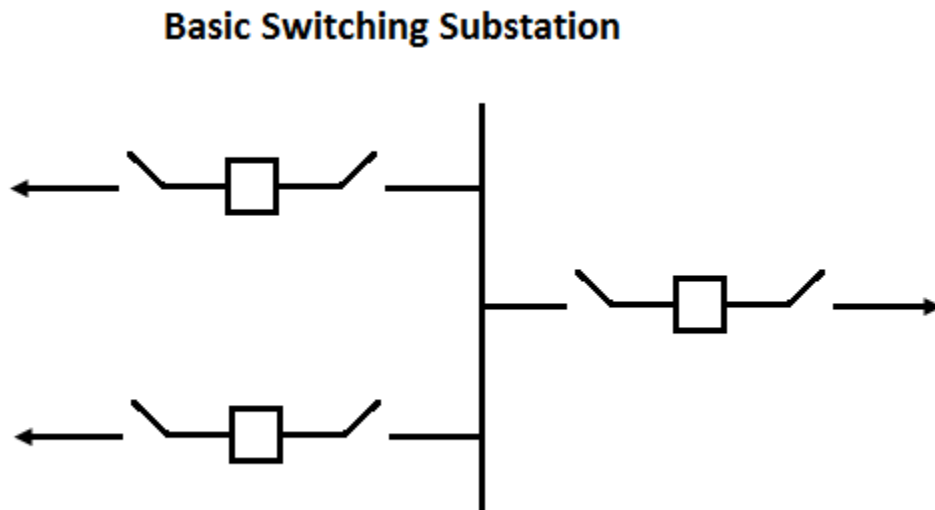


Figure 7

Power circuit breakers in the three circuits help prevent complete substation shutdown for line faults. The circuit breakers have disconnect switches on both source and load sides to permit isolation during maintenance or other periods requiring complete de-energization. Depending on station voltage and bus configuration, the switches may be of the three-pole, single-throw, group-operated type or of the single-pole, single-throw, hook stick-operated type. Hook stick-operated switches usually are not considered above 69 kV. Bypass facilities can be provided to allow circuit breaker maintenance without de-energizing the circuit.

### Surge Arresters

Surge arresters or other surge protection equipment may be installed either on the line positions or on the substation buses to protect against excessive lightning or switching surges.

A comparison of the costs of the surge protection equipment to the frequency and extent of possible equipment damage can be evaluated to determine the desirability of the protective equipment. Possible circuit or substation outages and equipment damage as a result of the unprotected surges should be considered. In general, if there is any question, surge arresters should be installed for equipment and circuit protection.

## Chapter 2

# Typical Bus Configurations

The typical bus configurations may be used for distribution, transmission, or switching substations at voltages up to 345 kV. Details will vary depending on the type and voltage of the substations. The physical size, type, and arrangement of major equipment, such as power transformers, power circuit breakers, and switches, may cause variance in the layouts to suit individual requirements. Portions of different layouts may be combined, as required, to achieve desired configurations.

It is important that the engineer's plans remain as flexible as possible during substation layout to allow for unforeseen difficulties as designs progress. Coordinate activities with the equipment manufacturers to ensure that each design detail reflects the actual equipment to be used.

### Single Bus

A *single bus configuration* consists of one main bus that is energized at all times and to which all circuits are connected. This arrangement is the simplest, but provides the least amount of system reliability. Bus faults or failure of circuit breakers to operate under fault conditions results in complete loss of the substation. The single bus configuration can be constructed by using either low- or high-profile structures. Figure 8 illustrates the single bus arrangement with low-profile structures and presents a neat, orderly plan. The high-profile design, shown in Figure 9, accomplishes the same purpose and may not require as large a site for a given system voltage.



Single Bus - Low Profile

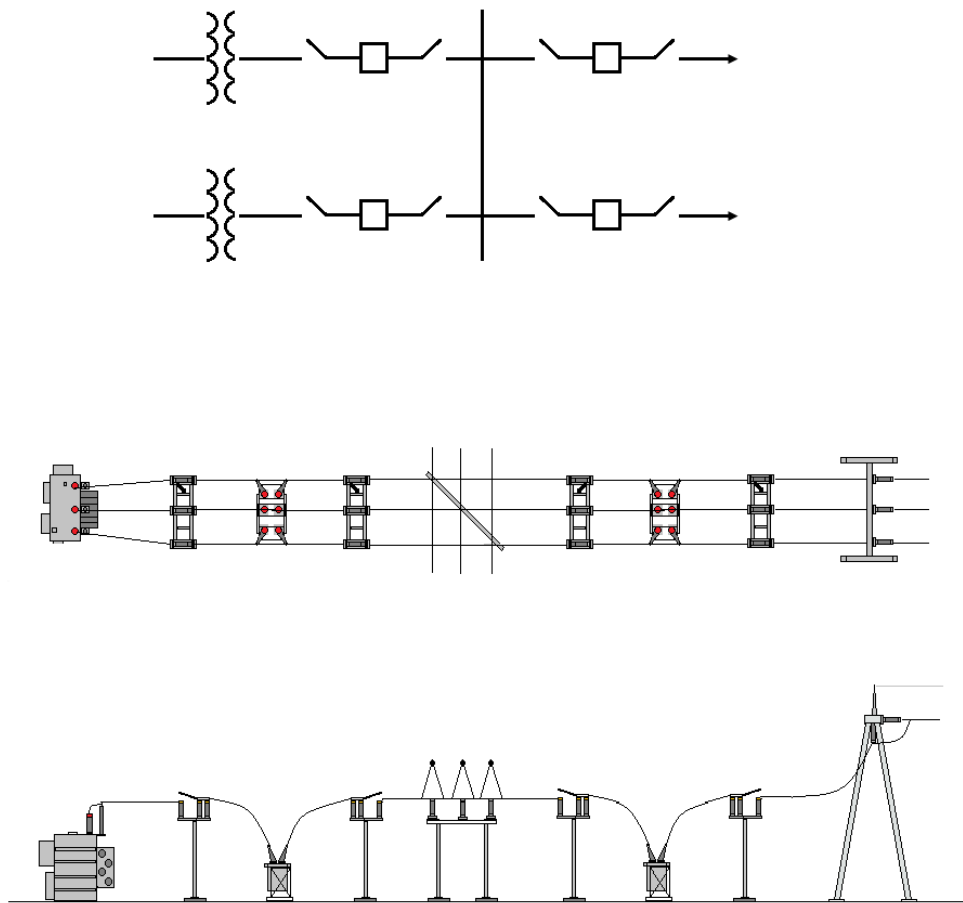


Figure 8

The single bus arrangement is not recommended without circuit breaker bypass facilities that permit circuit breaker maintenance while maintaining circuit operation. The *high-profile configuration* can easily be modified to provide this feature by installing group-operated switches and the associated buswork and connections in the positions shown in Figure 9. This arrangement, however, results in loss of overcurrent protection for the circuit except by remote circuit breakers during the bypassing operations. A fault occurring on the line with the breaker bypassed would result in complete substation shutdown. The low-profile arrangement does not allow for future addition of this type of bypassing equipment. Consequently, in both low-profile and some high-profile substations, the bypass facilities can be installed outside the substation.

Switches can be provided that, when closed, parallel two lines to enable one circuit breaker to be removed from service. The other breaker then protects both circuits. If this bypassing method is used, the equipment associated with both circuits, have to be capable of carrying the total load of both circuits. If the load is greater than the equipment capability, the load should be reduced. This method of circuit breaker bypassing may be more desirable in high-profile arrangements than that shown in Figure 8 for lines where frequent or lengthy equipment maintenance is expected.

The high-profile configuration shown in Figure 9 is generally limited to distribution and sub-transmission voltage levels. At transmission voltage levels, independent structures and strain bus interconnections are usually used.

Advantages:

- Lowest cost
- Small land area required
- Easily expandable
- Simple in concept and operation
- Relatively simple for the application of protective relaying

Disadvantages:

- High-profile arrangement equipped with circuit breaker bypass facilities does not provide for circuit protection when bypass facilities are being used inside the substation.
- A single bus arrangement has the lowest reliability.
- Failure of a circuit breaker or a bus fault causes loss of the entire substation.
- Maintenance switching can complicate and disable some of the protective relay scheme and overall relay coordination.
- Maintenance at the upper elevations of high-profile arrangements necessitates de-energization or protection of the lower equipment.

### Single Bus - High Profile

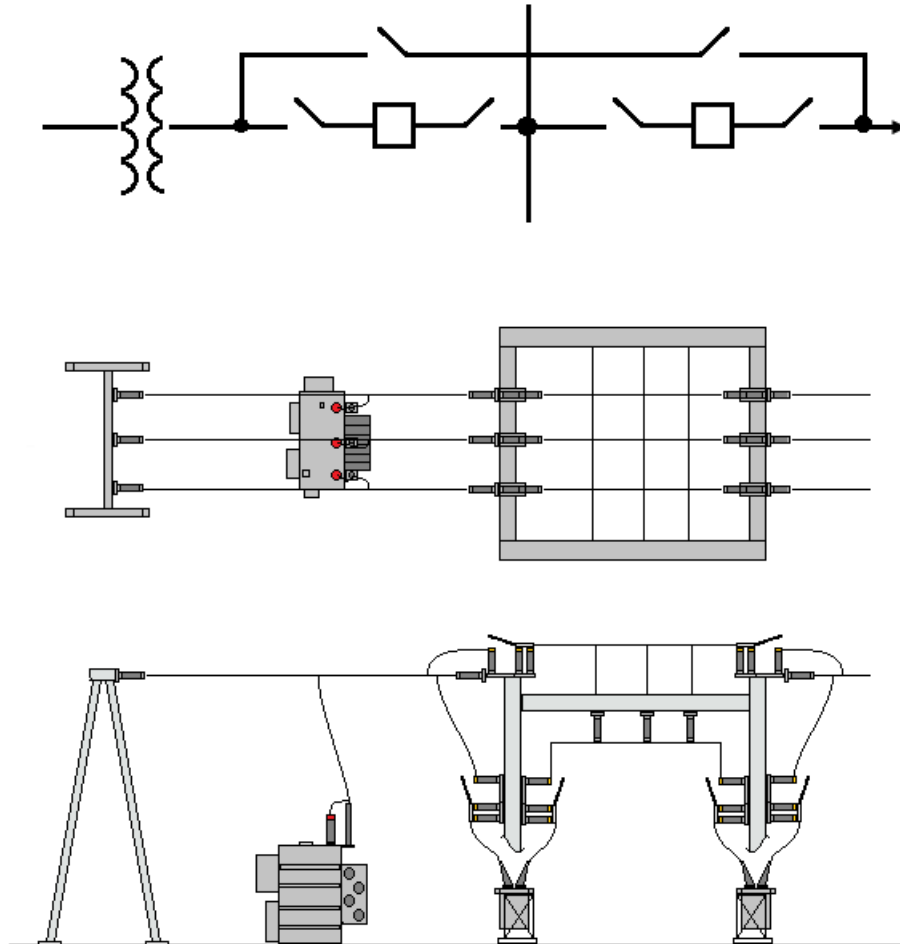


Figure 9

### Sectionalized Bus

An extension of the single bus configuration is the *sectionalized bus* arrangement shown in Figure 10. This arrangement is basically two or more single bus schemes, each tied together with bus sectionalizing breakers. The sectionalizing breakers may be operated normally open or closed, depending on system requirements. In this arrangement, a bus fault or breaker failure causes only the affected bus section to be removed from service and thus eliminates total substation shutdown. Usually, the fault can be isolated and non-faulted portions of the system restored to service easier and faster because of the increased flexibility of this arrangement.

### Sectionalized Bus

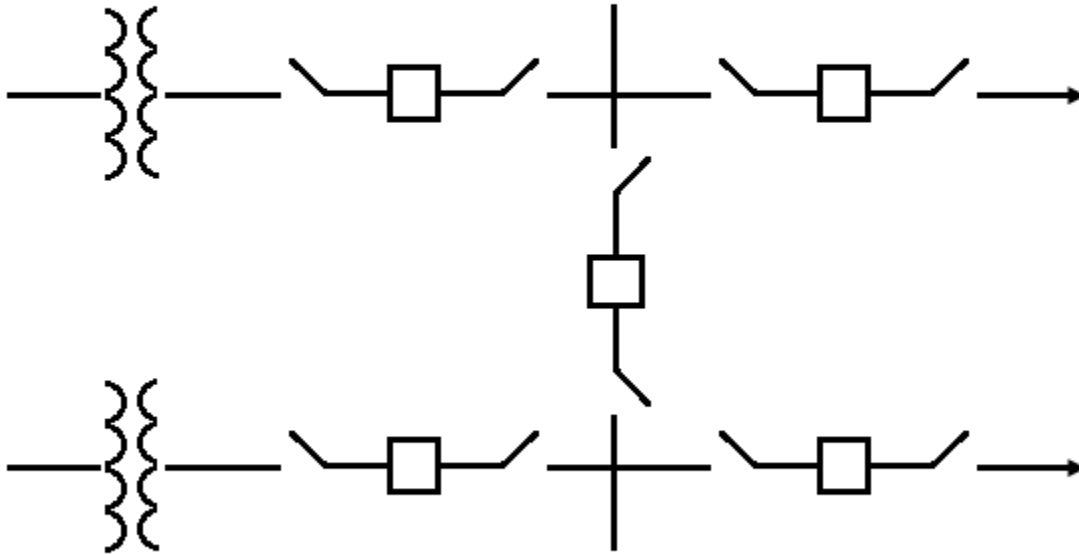


Figure 10

Physically, the equipment can be organized similar to that shown in Figures 8 and 9 for the single bus arrangement. The sectionalizing breakers and their associated isolation switches are located in line with the main bus. In the high-profile configuration, it is usually desirable to provide a separate bay for the sectionalizing breakers and switches to facilitate maintenance and removal.

The arrangement of lines and transformers in a sectionalized bus arrangement depends on system operating criteria. They should be arranged so as to prevent outage of lines or other circuits dependent on each other. This can be accomplished by positioning the interrelated circuits on different bus sections to eliminate concurrent shutdown. Perform a thorough analysis of all possible operational contingencies identifying any undesirable conditions preceding the final determination of circuit grouping.

Bypassing arrangements for the sectionalized bus configuration can be provided as explained for the single bus scheme.

**Advantages:**

- Flexible operation
- Higher reliability than single bus scheme
- Isolation of bus sections for maintenance
- Loss of only part of the substation for a breaker failure or a bus fault

**Disadvantages:**

- A sectionalized bus arrangement has a higher cost than a single bus scheme.
- Additional circuit breakers are required for sectionalizing.
- Sectionalizing may cause interruption of non-faulted circuits.

**Main and Transfer Bus**

A *main and transfer bus configuration* consists of two independent buses, one of which, the main bus, is normally energized. Under normal operating conditions, all incoming and outgoing circuits are fed from the main bus through their associated circuit breakers and switches. If it becomes necessary to remove a circuit breaker from service for maintenance or repairs, the integrity of circuit operation can be bus tie equipment. The bypass switch for the circuit breaker to be isolated is closed, the bus tie breaker and its isolation switches are closed, and the bypassed breaker and its isolation switches are opened to remove the breaker from service. The circuit is then protected by the bus tie breaker.

Figure 11 illustrates a main and transfer bus configuration in a low-profile arrangement. For comparison, Figure 12 shows the same switching scheme with high-profile box-type structures. With the box-type structure arrangement, two circuit positions can be accommodated per equipment bay. However, with the low-profile arrangement, each circuit requires its own bay and, as a result, somewhat more land area may be required. When the low-profile configuration is used, equipment bays should be limited in width to a maximum of two bays before the bay-to-bay centerline spacing is increased to accommodate circuit breaker maintenance and removal. Without the additional space these tasks can become very difficult.

The high-profile, box-type structure arrangement shown in Figure 12 can accommodate multiple circuits in a relatively small area. The configuration is particularly suitable in environmentally shielded or otherwise isolated locations, where only a limited substation site is available. This arrangement is generally limited to distribution and sub-transmission voltage levels. At transmission voltage levels, independent structures and strain bus interconnections can be used.

**Advantages:**

- Accommodation of circuit breaker maintenance while maintaining service and line protection

- Reasonable in cost
- Fairly small land area
- Easily expandable

Disadvantages:

- An additional circuit breaker is required for bus tie.
- Since the bus tie breaker, have to be able to be substituted for any line breaker, its associated relaying may be somewhat complicated.
- Failure of a circuit breaker or a bus fault causes loss of the entire substation.
- Somewhat complicated switching is required to remove a circuit breaker from service for maintenance.

Main & Transfer Bus - Low Profile

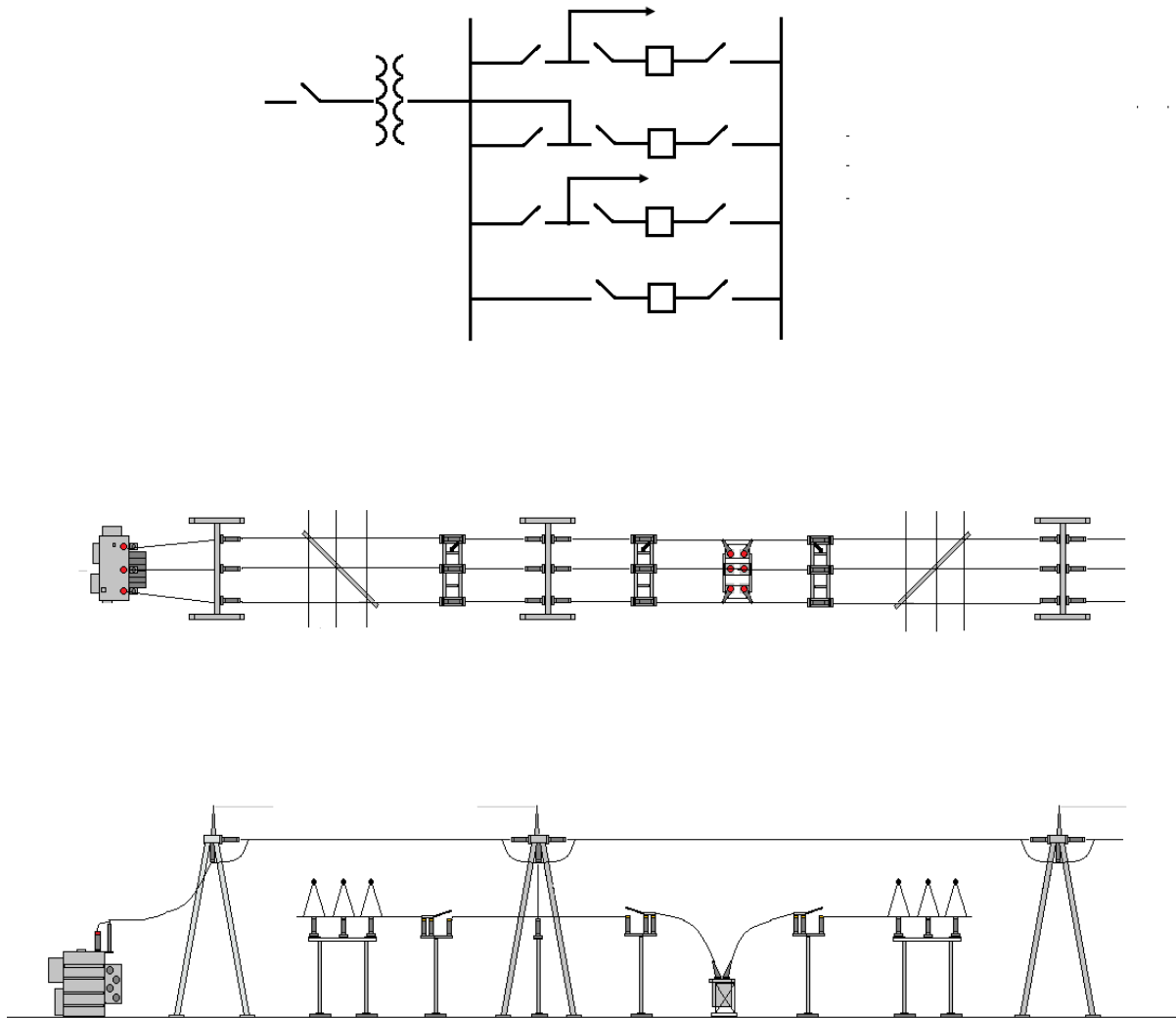


Figure 11

### Main & Transfer Bus - High Profile

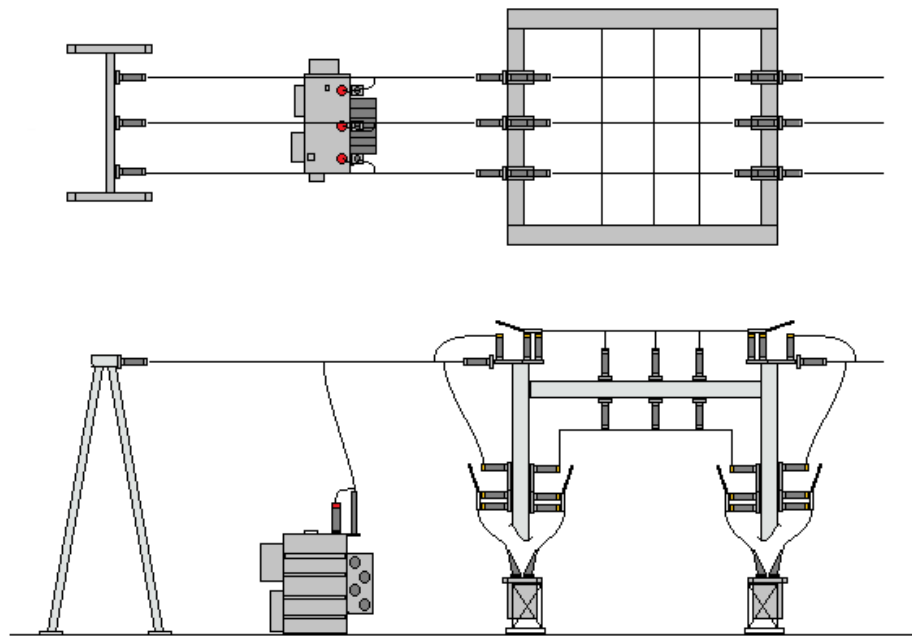
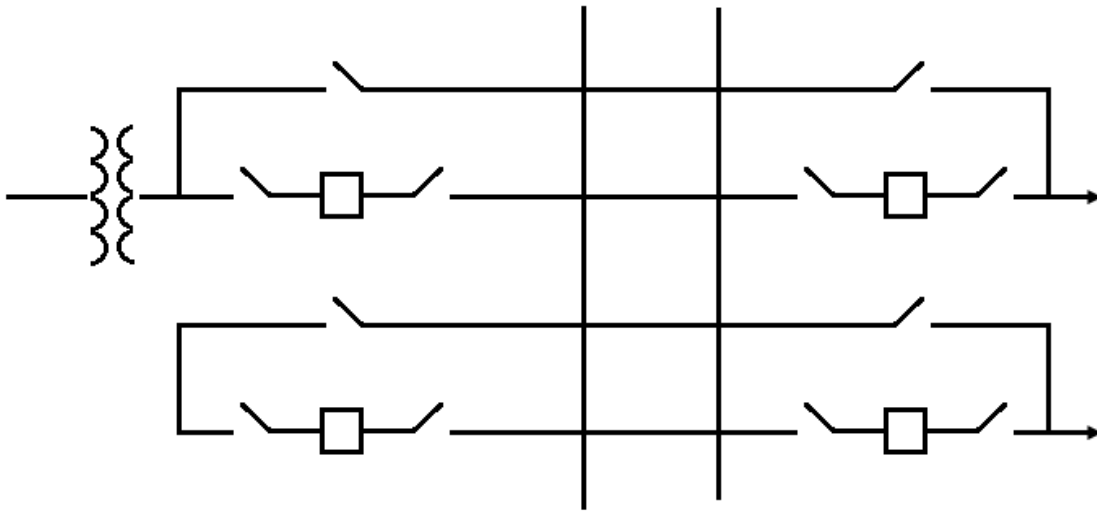


Figure 12



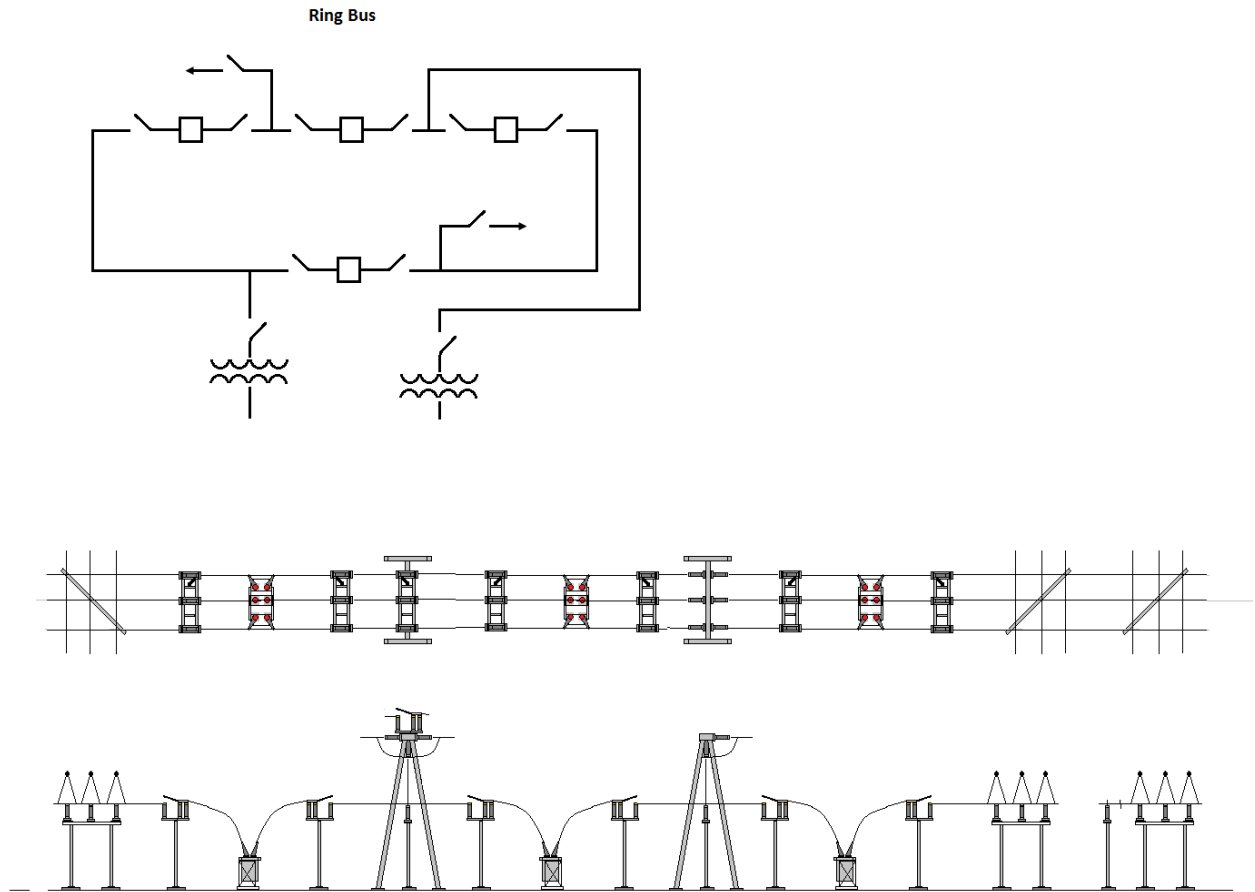
## Ring Bus

A *ring bus configuration* is an extension of the sectionalized bus arrangement and is accomplished by interconnecting the two open ends of the buses through another sectionalizing breaker. This results in a closed loop or ring with each bus section separated by a circuit breaker. For maximum reliability and operational flexibility, each section should supply only one circuit.

In this arrangement, as with the sectionalized bus configuration, only limited bus sections and circuits are removed from service because of line or bus faults or circuit breaker failure. For a line or bus fault, the two circuit breakers on the sides of the affected bus section open to isolate the fault. The remaining circuits operate without interruption. For a breaker failure, the two breakers on the sides of the affected breaker open, along with a transfer trip to a remote breaker, to isolate the failed breaker and remove two bus sections from service.

The ring bus arrangement provides for circuit breaker maintenance since any breaker can normally be removed from service without interruption of service to any circuits. As a result, separate circuit breaker bypass facilities are not required.

A number of equipment arrangements may be used to provide a ring bus configuration, depending on anticipated substation expansion and possible system modifications. Figure 13 illustrates a typical ring bus configuration. The arrangement shows four circuit positions, which is a practical maximum for a ring bus configuration. Rather than expanding the ring bus to accommodate additional circuits, other more flexible and reliable configurations, such as the breaker-and-a-half scheme, can be adopted. The ring bus arrangement shown in Figure 13 is readily adaptable in the future to a breaker-and-a-half configuration as shown in Figure 14. However, the relay and control panels have to be carefully planned to be modified later for breaker-and-a-half operation.



**Figure 13**

Bay centerline spacing should be carefully planned to permit equipment maintenance and removal.

**Advantages:**

- Flexible operation
- High reliability
- Isolation of bus sections and circuit breakers for maintenance without disrupting circuit operation
- Double feed to each circuit
- No main buses
- Expandable to breaker-and-a-half configuration
- Economic design

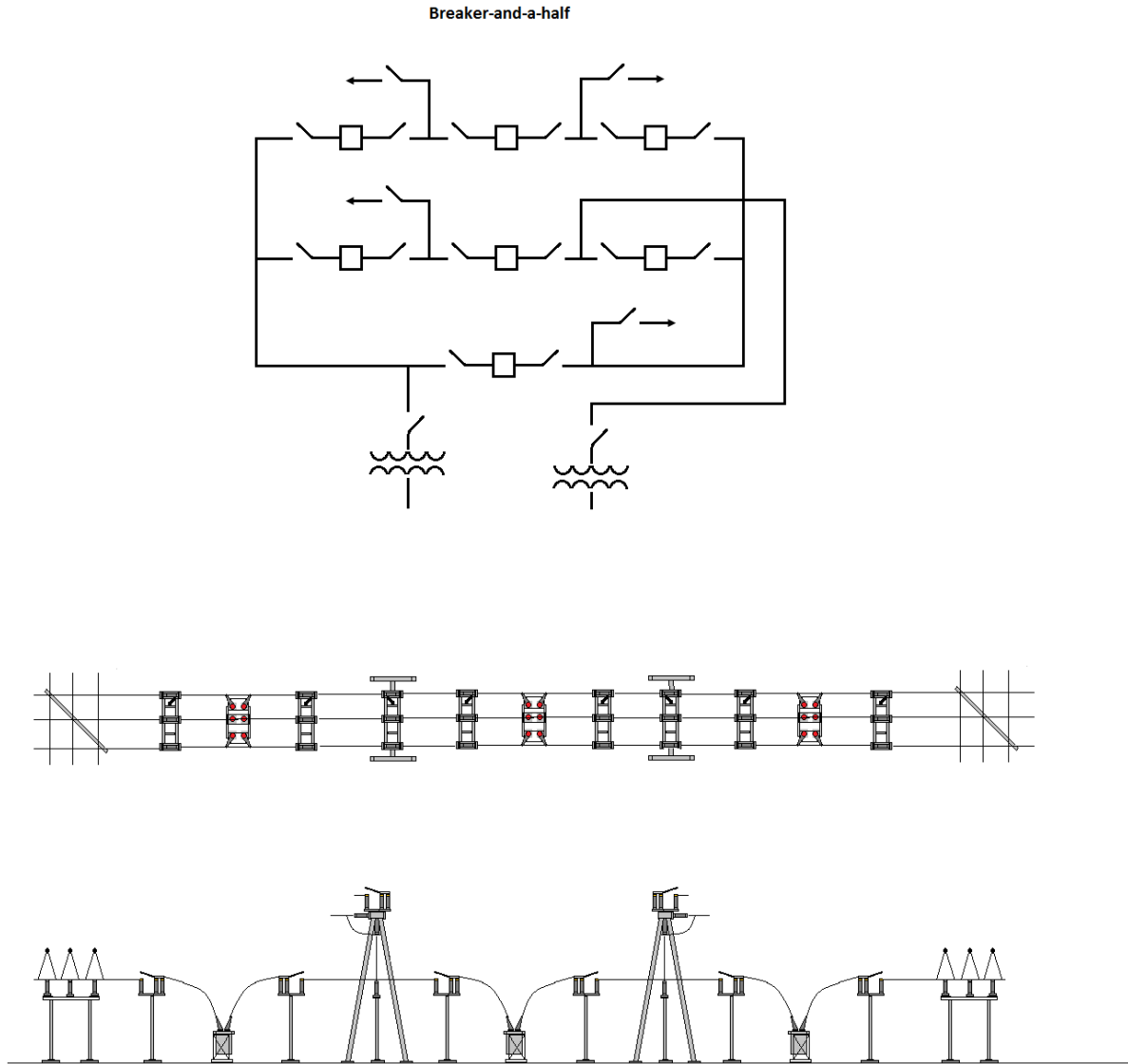
**Disadvantages:**

- Ring may be split by faults on two circuits or a fault during breaker maintenance to leave possibly undesirable circuit combinations (supply/load) on the remaining bus sections. Some consider this, however, to be a second contingency factor.
- Each circuit has to have its own potential source for relaying.
- This configuration is usually limited to four circuit positions, although larger rings are in service, including 10-position ring buses. A 6-position ring bus is usually considered as a maximum limit for the number of terminals in a ring bus.
- This is a more involved relay scheme since each breaker has to respond to faults on two circuits.
- Automatic reclose schemes may be complex.

**Breaker-and-a-Half**

The *breaker-and-a-half configuration* consists of two main buses, each normally energized. Electrically connected between the buses are three circuit breakers and, between each two breakers, a circuit as diagrammed in Figure 14. In this arrangement, three circuit breakers are used for two independent circuits; hence, each circuit shares the common center circuit breaker, so there are one-and-a-half circuit breakers per circuit.

The breaker-and-a-half configuration provides for circuit breaker maintenance, since any breaker can be removed from service without interrupting any circuits. Additionally, faults on either of the main buses cause no circuit interruptions. Failure of a circuit breaker results in the loss of two circuits if a common breaker fails and only one circuit if an outside breaker fails. A typical bus configuration for a breaker-and-a-half arrangement is shown in Figure 14. This is the same basic equipment assemblage as described for the ring bus scheme.



**Figure 14**

Frequently, substations are initially constructed with a ring bus arrangement and ultimately expanded into a breaker-and-a-half configuration to obtain the additional flexibility and reliability required with the additional circuits.

Bay centerline spacing should be carefully planned to permit equipment maintenance and removal.

Advantages:

- Flexible operation

- High reliability
- Can isolate either main bus for maintenance without disrupting service
- Can isolate any circuit breaker for maintenance without disrupting service
- Double feed to each circuit
- Bus fault does not interrupt service to any circuits
- All switching done with circuit breakers

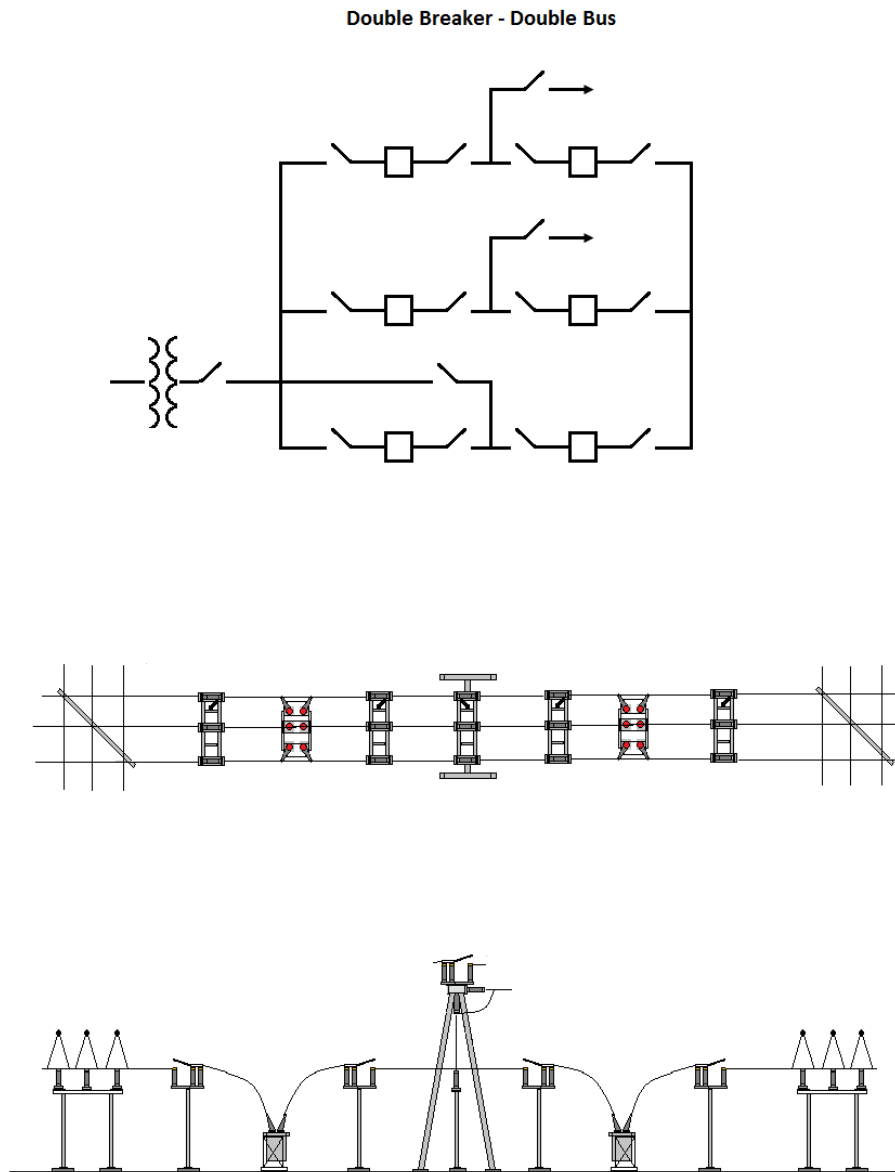
Disadvantages:

- One-and-a-half breakers are required per circuit.
- Relaying is involved, since the center breaker has to respond to faults of either of its associated circuits.
- Each circuit should have its own potential source for relaying.

### **Double Breaker–Double Bus**

The *double breaker–double bus configuration* consists of two main buses, each normally energized. Electrically connected between the buses are two circuit breakers and, between the breakers, one circuit, as diagrammed in Figure 15. Two circuit breakers are required for each circuit.

In the double breaker–double bus configuration, any circuit breaker can be removed from service without interruption of any circuits. Faults on either of the main buses cause no circuit interruptions. Circuit breaker failure results in the loss of only one circuit. A typical bus configuration for a double breaker–double bus arrangement is shown in Figure 15.



**Figure 15**

Use of the double breaker–double bus configuration is usually limited to large generating stations because of the high cost. The additional reliability afforded by this arrangement over the breaker-and-a-half scheme usually cannot be justified for conventional transmission or distribution substations.

Occasionally, at a generating station, one bay of a breaker-and-a-half arrangement is used as a double breaker–double bus arrangement for a generator terminal to provide equal access to either main bus.

Advantages:

- Flexible operation
- Very high reliability
- Isolation of either main bus for maintenance without disrupting service
- Isolation of any circuit breaker for maintenance without disrupting service
- Double feed to each circuit
- No interruption of service to any circuits from bus fault
- Loss of only one circuit for breaker failure
- All switching with circuit breakers

Disadvantages:

- This configuration carries a high cost.
- Two circuit breakers are required for each circuit.

**Relative Switching Scheme Costs**

The selection of a station switching scheme is the result of the evaluation of many factors, including such intangibles as personal preference and judgment. Whatever arrangement is finally selected should meet all known or anticipated requirements, such as operating and maintenance criteria, future expansion, and reliability. To assist in the evaluation, Table 1 provides a reasonable measure for the basis of economic comparison.

Switching Scheme	Relative Cost Comparison
Single Bus	100%
Sectionalized Bus	122%
Main & Transfer Bus	143%
Ring Bus	114%
Breaker-and-a-Half	158%
Double Breaker-Double Bus	214%

The comparison is based on four-circuit low-profile arrangements with power circuit breakers in all circuits. Power transformer costs are not included. In schemes utilizing other protective

devices or different circuit quantities, the relative costs may vary from those listed. Prepare detailed construction estimates for all schemes under consideration.



## Chapter 3

### Insulation Protection

Substation electrical equipment is subject to abnormal conditions as a result of direct lightning strokes, lightning surges, switching surges, and faults on the system. These abnormal conditions can cause overvoltages that may result in equipment flashover or insulation failure. To prevent equipment damage and/or system shutdown from overvoltages, protective devices are used to limit the overvoltages to reasonable levels. Application of these devices is usually a compromise between the costs of the devices and the degree of protection desired.

The protection provided for substations and substation equipment can be broken into two main parts:

1. Surge protection, employed to protect the equipment from damaging overvoltages caused by lightning surges, switching surges, and system faults
2. Direct stroke protection, employed to protect the equipment from direct lightning strokes

#### Surge Protection

*Surge arresters* are used to protect equipment against overvoltages caused by incoming surges. The arresters function by discharging surge current to the ground system and then interrupt the current to prevent flow of normal power frequency follow current to ground.

Since the effects of a direct lightning stroke to an unshielded substation can be devastating, it is recommended that some form of direct stroke protection be provided. Direct stroke protection normally consists of shielding the substation equipment by using lightning masts, overhead shield wires, or a combination of these devices. The types and arrangements of protective schemes used are based on the size and configuration of the substation equipment.

Overhead shield wires are often used to provide direct stroke protection. The shield wires can be supported by the circuit pull-off structures, if conveniently located, to extend over the substation. Since these shield wires are located above substation buses and equipment, breakage could result in outage of and/or damage to equipment. To minimize possible breakage, the overhead shield wire systems are constructed from high-quality, high-strength materials. Shield wires should be limited to a maximum design tension of 2,000 pounds per conductor under the appropriate loading conditions as defined in the National Electrical Safety Code. This tension is based only on wire strength and has to be coordinated with support structure design. Lower tensions may be required for certain applications, depending on the capabilities of the support structures. Sag has to be considered to ensure adequate clearance from energized equipment.

A complete overhead shield wire system should include protection for overhead circuits entering or leaving the substation. In areas not employing transmission line shielding, substation shield wire systems should be extended at least one-half mile away from the substation to limit the exposure of the phase conductors to direct strokes near the substation. Strokes occurring on the circuits beyond the shielding will usually be attenuated enough by the time they reach the substation to be discharged successfully by the surge arresters without causing equipment damage. For adequate protection, the circuit wire systems should be directly connected to the substation shield wire system.

Shielding masts can be used for nearly all types of substations to provide protection against direct lightning strokes. They are particularly useful in large substations and those of low-profile design. Shielding masts can be guyed or self-supporting steel poles or lattice-type towers and are usually made of steel. Other materials, such as precast concrete or aluminum, can also be used. In some instances, shielding masts can also be used to provide support for substation lighting equipment.

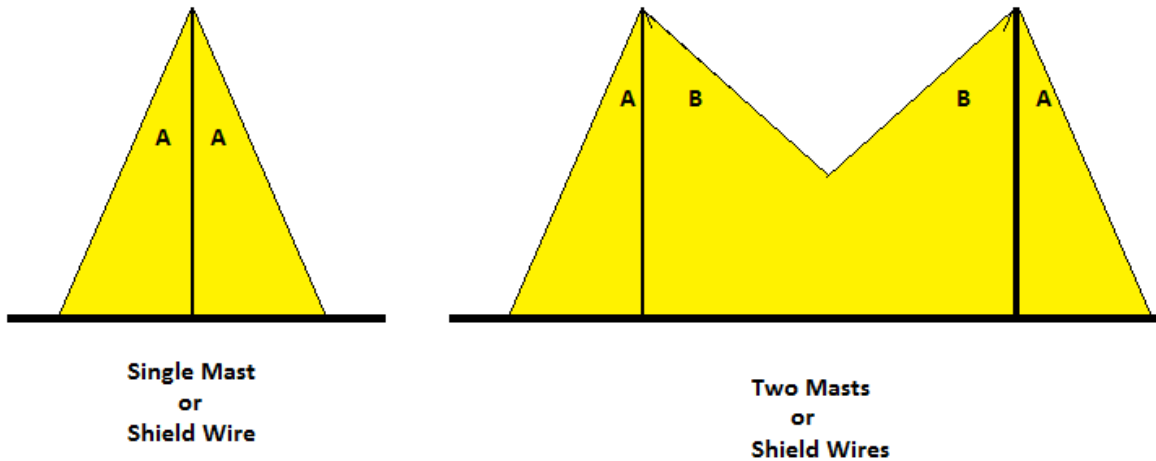
There are two widely used methods for designing substation lightning protection:

1. Fixed angle
2. Rolling sphere

The zone of protection of a shielding system is the volume of space inside which equipment is considered adequately protected by the system. A shielding system allowing no more than 0.1 percent of the total predicted number of lightning strokes to terminate on the protected equipment is considered adequate for most situations.

The *fixed angle design* method uses vertical angles to determine the number, position, and height of shielding masts and wires. The shaded areas in Figure 16 illustrate the zones of protection afforded by single- and double-mast or shield wire systems. For a single mast, the zone of protection consists of a cone. For a single shield wire, the zone of protection is a wedge. When two or more masts or shield wires are used, the zones of protection of each overlap to provide complete coverage. Figure 16 also lists the ranges of angles that have been used for various shielding systems.

### Mast Shielding



Angle	Range	Recommended
A	20 - 40 Degrees	30 Degrees
B	40 - 60 Degrees	45 Degrees

Figure 16

The *rolling sphere method* involves rolling an imaginary sphere of a prescribed radius over the substation. The sphere rolls up and over lightning masts, shield wires, and other grounded metal objects intended for lightning shielding. A piece of equipment is protected from a direct stroke if it remains below the curved surface of the sphere by virtue of the sphere's being elevated by shield wires or other devices. Equipment that touches the sphere or penetrates its surface is not protected. The basic concept is shown in Figure 17.

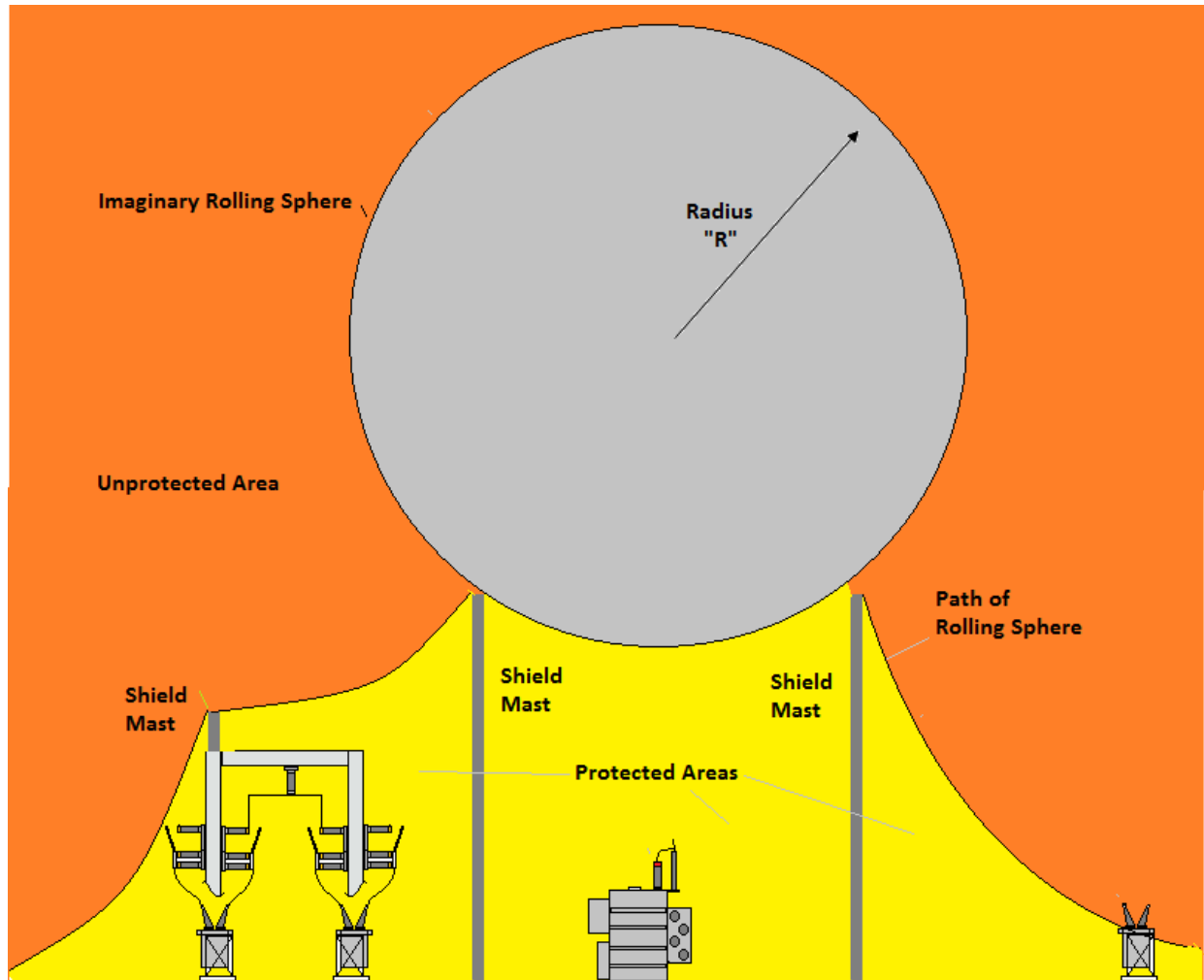


Figure 17

The radius of the sphere is determined by calculating the strike distance. The strike distance is the length of the final jump of the stepped leader as its potential exceeds the breakdown resistance of the last gap of air to ground. A stepped leader is the static discharge that propagates from a cloud into the air.

The allowable stroke current that may be received by a substation bus without exceeding the withstand value, or BIL, of the substation is defined by,

$$I_s = \frac{2.2 * BIL}{Z_s}$$

Where:

$I_s$  = Allowable stroke current in kiloamperes

BIL = Basic lightning impulse level in kilovolts

Zs = Surge impedance of the conductor through which the surge is passing in ohms

The striking distance, indicated in Figure 17 by “R,” may be calculated using,

$$R_f = 26.25 * K * I_s^{0.65}$$

Where:

Rf = Strike distance in feet

Is = Return strike in kiloamperes

K = A coefficient to account for different striking distances to a mast, shield wire, or the ground plane. K = 1 for strokes to wires or the ground plane, and K = 1.2 for strokes to a lightning mast.

These equations provide a very basic evaluation of the lightning protection provided by the rolling sphere method.

The engineer designing the shielding system needs to also take into account the isokeraunic level of the area where the substation will be built. The isokeraunic level is the average annual number of thunderstorm days for a given locality. The U.S. Weather Bureau publishes a chart that shows the isokeraunic levels across the United States. See Figure 18 on the following page.

### ISOKERAUNIC LEVELS FOR THE UNITED STATES

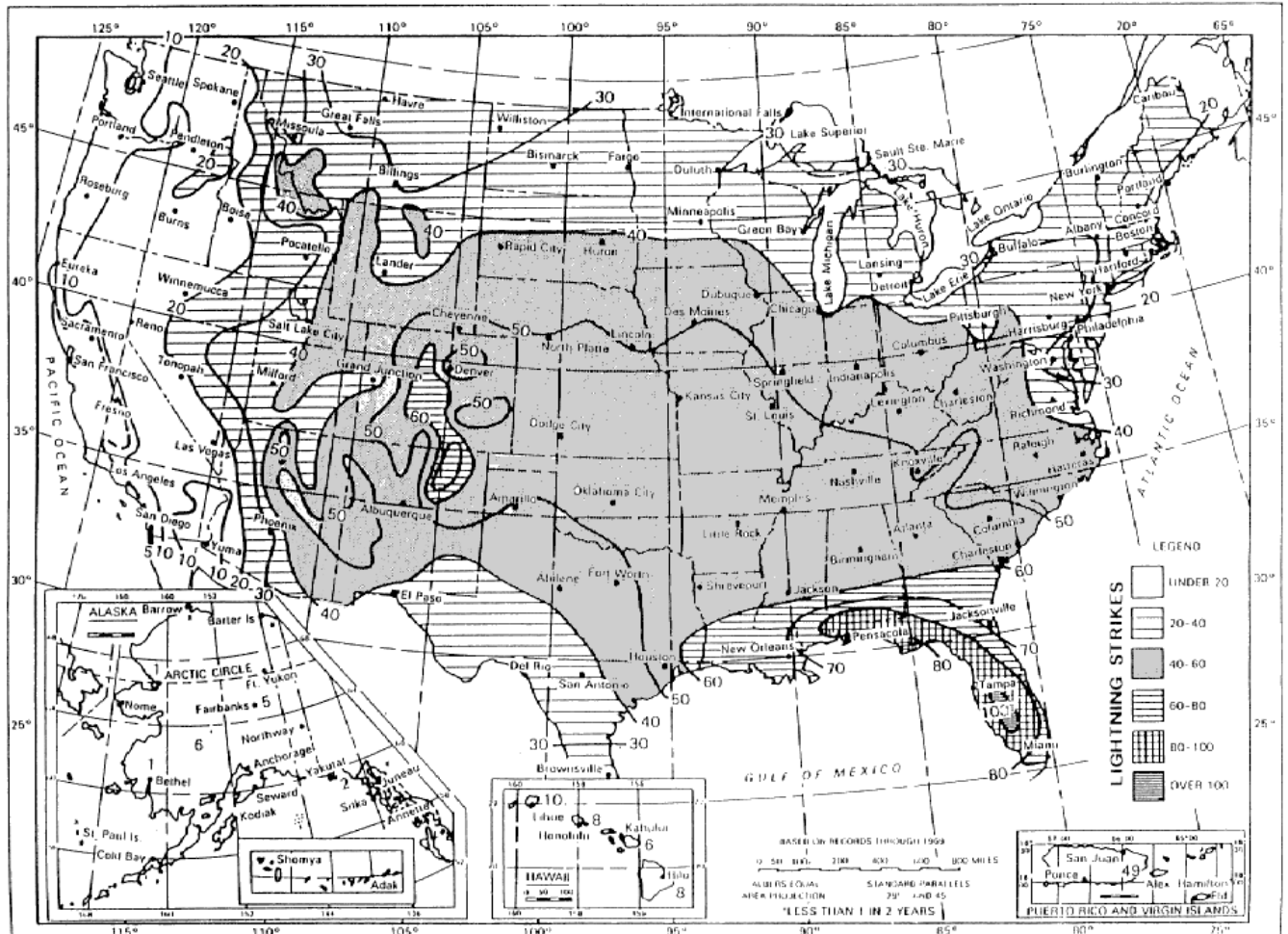


Figure 18

A shielding system cannot effectively protect substation equipment unless adequately grounded. Multiple low impedance connections from the shielding system to the substation ground grid are essential. It is beneficial to use at least two separate connections to ensure continuity and reliability. Whenever non-conducting masts or supports are used, install separate ground cables to establish a direct connection from the shield system to the substation ground system.

## Chapter 4 Substation Insulators

This chapter covers both outdoor apparatus insulators (e.g., pin and post type insulators) and suspension insulators.

### Outdoor Apparatus Insulators

*Outdoor apparatus insulators* are used primarily to support rigid buswork and other electrical equipment operated above ground potential. Apparatus insulators are normally manufactured from electrical-grade wet-process porcelain and are available in two major types: cap and pin-type and post-type. Other types are also available from some insulator manufacturers.



For apparatus insulators, impulse withstand voltages are commonly referred to as BILs. Apparatus insulators are available with BIL ratings as shown in Table 2. Use of the BILs for the nominal system voltages listed will normally ensure adequate coordination with protective devices and insulation systems of other equipment for most operating conditions. In areas of extremely high contamination, it may be desirable to increase the insulator BIL to levels higher than listed.

Table 2 BIL Ratings for Equipment	
Nominal Voltage	BIL
14.4	110
23	150
34.5	200
46	250
69	350
115	550

230	1050
-----	------

Equipment that depends on air for its insulating medium will have a lower dielectric strength when operated at higher altitudes than when operating at lower altitudes. For altitudes above 3300 feet, the correction factors shown in Table 3 should be applied to reduce the insulator BILs.

*Cap and pin-type* apparatus insulators are the original insulator type used in substation construction. While cap and pin insulators are still in use, post-type insulators are more commonly used today in substation design and are recommended for any new construction or rebuilding of existing facilities.

*Post-type apparatus insulators* are the type most often used today for new substation construction. The uniform profile and smaller diameter enhance insulator appearance. Post insulator types in general use are made of porcelain and polymer. The polymer type is less rigid than porcelain or composite and is not recommended for switch supports.

<b>Table 3 BIL Altitude Correction Factors</b>	
<b>Altitude (Feet)</b>	<b>Correction Factor</b>
3,300	1.00
4,000	0.98
5,000	0.95
6,000	0.92
7,000	0.89
8,000	0.86
9,000	0.83
10,000	0.80
12,000	0.75
14,000	0.70
16,000	0.65
18,000	0.61
20,000	0.56



Porcelain insulators are generally manufactured from one piece of electrical-grade wet-process porcelain formed with a number of vertical skirts to achieve the required electrical characteristics. End caps for mounting the insulators are cemented to the porcelain. The insulators are manufactured with a minimum number of joints, which inherently reduces deflections.

The short skirts of post insulators make them less susceptible to damage from flashovers. Even if some of the skirts are damaged, insulation integrity is usually maintained since the dry arcing distances are not greatly affected.



Post-type insulators are available in two types: *stacking* and *non-stacking*. Single non-stacking insulators are normally used through nominal voltages of 69 kV (350 kV BIL). At nominal voltages of 115 kV (550 kV BIL) and above, stacking insulators are used.

Post-type apparatus insulators are manufactured and tested in accordance with the following standards:

- ANSI C29.1 “Test Methods for Electrical Power Insulators”
- ANSI C29.9 “American National Standard for Wet-Process Porcelain Insulators (Apparatus, Post Type)”

Post-type apparatus insulators depend on the insulating material contours to achieve the required leakage distances. Skirt breakage on a post type usually will not cause insulator flashover since a much smaller percentage of the total leakage distance is destroyed compared to the cap and pin type. Post-type apparatus insulators generally have longer leakage distances than their counterparts, particularly at the lower BILs. In areas of high contamination it is usually desirable to utilize insulators with either longer than standard leakage distances or higher BILs to prevent electrical breakdown from surface contamination.

Application of insulators in unusual situations such as high contamination can sometimes best be accomplished by referring the problem to the insulator manufacturers for recommendations.

Most apparatus insulators are available in several mechanical strength ratings, based primarily on the cantilever strength of the insulators. The various ratings available can be found in ANSI and NEMA standards and in manufacturers' literature.

For most applications, cantilever strength is the most important mechanical characteristic. However, depending on the actual insulator application, some of the other characteristics can become important and should be considered. These insulator characteristics include tensile strength, compressive strength, and torsional strength. The design and manufacture of post-type apparatus insulators allow equal cantilever strength ratings in both upright and under-hung mounting positions.

Typical characteristics of cap and pin-type and post-type apparatus insulators can be found in Tables 4 and 5, respectively. Post insulators are recommended.

<b>Table 4 Cap &amp; Pin Insulator Characteristics</b>						
<b>BIL (kV)</b>	<b>Tech Ref</b>	<b>Cantilever Strength</b>		<b>Bolt Circle (in)</b>	<b>Height (in)</b>	<b>Leakage Distance (in)</b>
		<b>Upright (lbs)</b>	<b>Underhung (lbs)</b>			
95	TR-1	2,000	1,000	3	7.5	7.5
110	TR-4	2,000	1,000	3	10	12
150	TR-7	2,000	1,000	3	12	20
200	TR-10	2,000	1,000	3	15	28
250	TR-13	2,000	1,000	3	18	36
350	TR-16	1,500	1,000	3	29	52
550	TR-19	1,700	1,470	5	43.5	99
1050	TR-128	750	700	5	87	198

**Table 5  
Post-Type Insulator Characteristics**

BIL (kV)	Tech Ref	Cantilever Strength		Bolt Circle (in)		Height (in)	Leakage Distance (in)
		Upright (lbs)	Underhung (lbs)	Top	Bottom		
95	TR-202	2,000	2,000	3	3	7.5	10.5
110	TR-205	2,000	2,000	3	3	10	15.5
150	TR-208	2,000	2,000	3	3	14	24
200	TR-210	2,000	2,000	3	3	18	37
250	TR-214	2,000	2,000	3	3	22	43
350	TR-216	1,500	1,500	3	3	30	72
550	TR-286	1,700	1,700	5	5	45	99
1050	TR-312	800	800	5	5	92	198

Most apparatus insulators are furnished with end caps with four mounting holes arranged in either 3-inch, 5-inch, or 7-inch bolt circles, or 12-inch or 14-inch bolt circles, depending on the insulator strength and voltage rating. The mounting holes are usually tapped for bolts of 1/2" with 13 threads per inch, 5/8" with 11 threads per inch, or 3/4" with 10 threads per inch, respectively. Adapters are available to go from one bolt circle size to another.

Upright or under-hung mounting usually does not present major problems, provided the insulators are utilized within their mechanical and electrical capabilities. When the insulators are installed horizontally, the weight of the insulators, fittings, buses, and any other supported equipment has to be considered to determine the permissible loads. Some manufacturers recommend reducing the allowable loads from the tabulated values for horizontally mounted insulators. Unusual applications can be referred to the manufacturers for recommendations.

**Suspension Insulators**

*Suspension insulators* are used as insulation and support for strain buses in substations. Suspension insulators are available in several forms to suit individual requirements.



Distribution deadend-type suspension insulators can be used at distribution voltages for substation strain buses. Distribution deadend suspension insulators normally have clevis-type connections. Conventional suspension insulators are normally used for strain bus insulation at higher voltages and can be furnished with either clevis or ball and socket connections. The conventional suspension insulators most commonly used are 10 inches in diameter and 5  $\frac{3}{4}$  inches in length. Suspension insulators are manufactured out of porcelain, polymer, and glass.

To achieve the necessary electrical characteristics, a number of suspension insulators are strung together in series. It is important to coordinate the insulation characteristics of suspension insulator strings with the insulation systems of other substation equipment and the characteristics of various insulation protective devices. The quantity of suspension insulators chosen for a particular application should be large enough to prevent unnecessary flashovers. Over-insulation, however, can result in flashovers occurring from phase to phase rather than from phase to ground. Consequently, the quantity of insulators should be small enough that all flashovers occur to ground.

Table 6 lists the recommended minimum quantities of standard 5  $\frac{3}{4}$  x 10 in. suspension insulators for particular nominal system voltages and BILs.

<b>Table 6</b>		
<b>Minimum Quantity of Suspension Insulators</b>		
<b>Nominal Voltage (Phase-to-Phase)</b>	<b>BIL (kV)</b>	<b>Qty</b>
7.5	95	1
14.4	110	2
23	150	2
34.5	200	3
46	250	4
69	350	5
115	550	8
230	1050	12

Additional insulators should be considered under the following conditions:

1. Above 3,300 feet, the correction factors listed in Table 3 should be applied to the BILs and the insulator quantities correspondingly increased.
2. In areas of high contamination, it may be necessary to increase the insulator quantities or consider the use of specially designed equipment.
3. When dead-ending on steel structures, an additional insulator is typically added.
4. When installed at an angle other than vertical, one or two insulators should be added when the angle from vertical approaches 45 degrees and 90 degrees, respectively.

These strength ratings are not the actual loads the insulators are designed to operate under, but represent ultimate strengths. The insulators also have proof test ratings specified in ANSI Std. C29.2 as one half the mechanical–electrical ratings. These ratings are the actual loads that the insulators have withstood during testing. The maximum suspension insulator loading should not exceed 40 percent of the mechanical– electrical strength ratings.

## Chapter 5

### Electrical Clearances

This chapter covers some of the electric clearances associated with electric substations. Table 7 lists the electrical clearances for outdoor substation construction. The values identified as minimums should be maintained or exceeded at all times. Phase-to-ground and phase-to-phase clearances should be coordinated to ensure that possible flashovers occur from phase to ground rather than from phase to phase.

**Table 7**  
**Substation Clearances**

Nominal Voltage (Phase-to-Phase)	Max Voltage P-P (kV)	BIL (kV)	Rigid Conductors (in)	Phase Spacing Rigid Bus P-P (in)	Rigid Conductors to Ground (in)	Overhead conductors to Ground (personnel safety) (feet)	Overhead Conductors to Roadway inside fence (feet)
7.5	8.3	95	7	18	6	8	20
14.4	15.5	110	15	24	7	9	21
23	25.8	150	15	30	10	10	22
34.5	38	200	18	36	13	10	22
46	48.3	250	21	48	17	10	22
69	72.5	350	31	60	25	11	23
115	121	550	53	84	42	12	25
230	242	1050	89	132	71	15	27

Table 8 lists the phase spacing of various types of outdoor air switches. The minimum metal-to-metal clearances should be maintained at all times with the switches in the open position, closed position, or anywhere between the open and closed positions.

<b>Table 8</b> <b>Outdoor Air Switch</b> <b>Phase Spacing</b>						
Nominal Voltage (Phase-to-Phase)	Max Voltage P-P (kV)	BIL (kV)	Metal-to-Metal Minimum Separation (inches)	Centerline-to-Centerline Phase Spacing		
				Vertical Break	Side Break	All Horn Gap
7.5	8.3	95	7	18	30	36
14.4	15.5	110	12	24	30	36
23	25.8	150	15	30	36	48
34.5	38	200	18	36	48	60
46	48.3	250	21	48	60	72
69	72.5	350	31	60	72	84
115	121	550	53	84	108	120
138	145	650	63	96	132	144
161	169	750	72	108	156	168
230	242	900	89	132	192	192
230	242	1050	105	156	216	216
345	362	1050	105	156	216	216
345	362	1300	119	174	-	-

When non-rigid conductors are used for outdoor overhead substation buses, the movement of the conductors caused by temperature changes and wind and ice loads has to be considered. The usual practice is to increase the centerline-to-centerline bus spacing and the phase-to-ground clearances to compensate for these conditions. Increase the minimum metal-to-metal, bus centerline-to-centerline, and minimum ground clearances listed in Table 7 by at least 50 percent for non-rigid conductors. Check to ensure that the minimum metal-to-metal clearances listed in Tables 7 and 8 are maintained or exceeded at all times for all expected temperature and loading conditions. The movement of non-rigid conductors can also be calculated using the NESC conductor movement envelopes for line conductors.

In some locations, contamination from airborne particles necessitates increasing the minimum electrical clearances. Satisfactory operation can usually be obtained by using clearances one step

above those normally used. In extremely contaminated locations, additional clearance may be required.

Since the dielectric strength of air-insulated equipment decreases with increasing altitude, the clearances listed in Table 7 have to be modified for use at altitudes above 3,300 feet. To determine appropriate clearances for use above 3,300 feet, first de-rate the standard BILs by applying the factors listed in Table 3. Then choose the clearances from Table 7 corresponding to the de-rated BILs selected. For example, at an altitude of 8,000 feet, a maximum voltage of 121 kV is to be used. From Table 3, the standard BIL of 550 kV has to be de-rated by applying a multiplying factor of 0.86. Table 9 shows the effects of de-rating for 8,000 feet:

<b>Standard BIL's (kV)</b>	<b>Derated BIL's (kV)</b>
550	473
650	559
750	645

A 650 kV BIL should be selected for use at 8000 feet to provide a BIL equivalent to 550 kV at altitudes of 3,300 feet and below. The clearances to be used are those associated with the 650 kV standard BIL, as listed in Tables 7 and Table 8.

As an option to the above equipment selection, the engineer may evaluate the de-rated BIL in terms of the capability of surge arresters applied to the equipment to provide protection to the equipment. With applicable protective margins, surge arresters available today may be able to protect voltage-de-rated equipment without increasing the equipment BIL for compensation.

In addition to the electrical clearances previously described, it is necessary to provide adequate space for equipment maintenance. In arrangements where equipment such as power circuit breakers, reclosers, disconnect switches, power transformers, or other equipment has to be maintained while portions of adjacent equipment remain energized, provide sufficient space around the equipment to prevent accidental contact by maintenance personnel.

In arrangements with buses or equipment crossing over other buses and equipment, maintain adequate clearance between the adjacent buses and equipment for all operational conditions. Power transformers and power circuit breakers should be positioned to permit removal of any



bushing. Locate switches and other equipment with externally moving parts to prevent infringement on the minimum clearances listed in Tables 7 and 8 during operation or when in any position. Also consider conductor, equipment, or support structure movement during heavily loaded or deformed conditions.

The clearances listed in Tables 7 and 8 are adequate for most situations and exceed the requirements of the National Electrical Safety Code. The clearances listed in the NESC have to be maintained or exceeded at all times.

Another clearance requirement is the location of the substation perimeter fence with respect to live parts within the substation. A safety clearance zone is required to keep someone outside the substation from sticking an object through the fence and coming in contact with live parts or getting close enough to cause a flashover to occur. Use Figure 19 and Table 10 to locate exposed live parts outside the safety clearance zone.

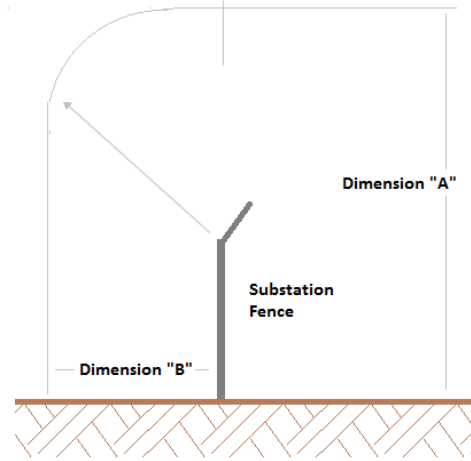


Figure 19

Table 10 Dimensions for Fence Safety Clearance		
Nominal Voltage (Phase-to-Phase)	Dimension A (Feet)	Dimension B (Feet)
<46,000	15.0	10.0
46,000 – 69,000	16.0	12.0
115,000	16.7	13.0
138,000	17.1	14.0
161,000	17.6	14.0
230,000	19.0	16.0
345,000	21.3	18.0
500,000	24.9	21.0
765,000	29.7	23.0
Notes: Assumes sea level atmospheric conditions. Increase values 3% for each 1,000 ft above 3,300 ft.		

## Summary

This course has looked at general information concerning the design of the substation physical arrangement including the various types of substations and typical layouts. In addition, bus configurations, insulation protection methods, insulator types, and electrical clearances were discussed.

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