PDHonline Course E468 (2 PDH)

Substations – Volume I – Design Parameters

Instructor: Lee Layton, PE

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
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Substation Design
Volume I
Design Parameters

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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, arrestor, 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.

Introduction

This is volume I of a multi-volume set of courses on the design of rural electric substations. The "rural" distinction implies that only open-air substation designs are covered though many of the concepts and ideas presented herein are applicable to urban substations. It covers rural transmission and distribution with air-insulated, outdoor substations up to 345 kV.

This volume is a broad overview of the design factors and data needed to design a substation. Subsequent volumes will explore equipment, foundations, structures, grounding, relaying and other items necessary to design an electrical substation.

Substations should be designed, constructed, and operated to meet customers' needs at the lowest possible cost commensurate with the quality of service desired. The typical system may include substations for voltage transformation, sectionalizing, distribution, and metering a number of times between generation and utilization.

Reliability Concerns

An example of an outage consideration for a substation would include a transmission switching station that operates with a simple main bus. An outage of the bus results in a complete interruption of power through the substation. The engineer will need to consider other equipment in the substation, such as a transfer bus or different multi-bus arrangement. The engineer should also evaluate the adjacent system to determine if the load can be diverted around the substation for outages to minimize the equipment that is installed in a substation.

Possible design responsibilities of the engineer are covered in this course, including preparation of construction drawings, material, equipment and labor specifications, and any other engineering design services that may be required.

A substation is part of a system and not an entity to itself. Normally, a power system is designed so that the effects of an outage (caused by the failure of a single component such as a transformer, transmission line, or distribution line) will result in minimal interruption of service and affect the fewest customers possible. Failure of one component in a system often forces a greater than normal load to be carried by other components of the system. Such contingencies are normally planned for and incorporated into design criteria.

When evaluating the switching arrangement for a substation, an engineer needs to be aware of the system configuration of which the substation will be a part. System contingency arrangements need to permit the outage of components in a substation for maintenance and unscheduled outages.

Most substations are designed to operate unattended. Remote indication, control, metering, and methods of communication are often provided so that systems and portions of systems can be monitored from a central point.

Substation planning considers the location, size, voltage, sources, loads, and ultimate function of a substation. If adequate planning is not followed, a substation may require unnecessary and costly modification.

Adequate engineering design provides direction for construction, procurement of material and equipment, and future maintenance requirements while taking into account environmental, safety, and reliability considerations.

Types of Substations

Substations may be categorized as distribution substations, transmission substations, switching substations, or any combination thereof.

One design tendency is to reduce costs by reducing the number of substations and taking advantage of economies of scale. Conversely, practical system design and reliability considerations tend to include many substations. One function of system studies is to balance these two viewpoints.

Distribution Substations

A distribution substation is a combination of switching, controlling, and voltage step-down equipment arranged to reduce sub-transmission voltage to primary distribution voltage for residential, commercial, and industrial loads.

Rural distribution substation capacities vary from maybe 1.5 MVA up to perhaps 35 MVA. These substations may be supplied radially, tapped from a sub-transmission line, or may have two sources of supply.

A special class of distribution substation would include a dedicated customer substation. This substation would be similar to a distribution substation except that all of its capacity would be reserved for the service of one customer. The secondary voltages of a dedicated substation would also be modified to match special requirements of the customer. Coordination with the customer is of primary importance in determining the technical requirements. Confirmation of the technical terms being used is likely to be required since electrical engineers in differing industries may use the same terms to describe similar, yet technically different, criteria.

Transmission Substations

A transmission substation is a combination of switching, controlling, and voltage step-down equipment arranged to reduce transmission voltage to sub-transmission voltage for distribution of electrical energy to distribution substations. Transmission substations frequently have two or more large transformers.

Transmission substations function as bulk power distribution centers, and their importance in the system often justifies bus and switching arrangements that are much more elaborate than distribution substations.

Switching Substations

A switching substation is a combination of switching and controlling equipment arranged to provide circuit protection and system switching flexibility. Flexible switching arrangements in a transmission network can aid in maintaining reliable service under certain abnormal or maintenance conditions.

Next we will look at the general design considerations for an electrical substation.

Chapter 1
General Design Considerations

Utilities should consider both short- and long-range plans in the development of their systems. Timely development of plans is not only essential for the physical and financial integrity of electrical systems, it is also essential in supplying customers with adequate service.

The long-range plan identifies the requirements of a substation not only for its initial use but also for some years in the future. Consider ultimate requirements during the initial design. Make economic comparisons to discover provisions are necessary for ease of addition.

> **Future Planning**
>
> Significant considerations for future construction are the outage requirements when equipment is added. These requirements should be considered with the utility's ability to serve the load during any outage.

Remember that development plans embrace philosophies of equipment and system operation and protection before construction is started. Changes in the utility's standard design philosophies should be reviewed by the personnel who design, operate, and maintain the proposed equipment. Departures from standard designs could jeopardize the operation of the system.

Site Considerations

Two of the most critical factors in the design of a substation are its location and siting. Failure to carefully consider these factors can result in excessive investment in the number of substations and associated transmission and distribution facilities.

It is becoming increasingly important to perform initial site investigations prior to the procurement of property. Previous uses of a property might render it very costly to use as a substation site. Such previous uses might include its use as a dumping ground where buried materials or toxic waste has to be removed prior to any grading or installation of foundations.

The following factors should be evaluated when selecting a substation site:

- Location of present and future load center
- Location of existing and future sources of power
- Availability of suitable right-of-way and access to site by overhead or underground transmission and distribution circuits
- Alternative land use considerations
- Location of existing distribution lines

- Nearness to all-weather highway and railroad siding, accessibility to heavy equipment under all weather conditions, and access roads into the site
- Possible objections regarding appearance, noise, or electrical effects
- Site maintenance requirements including equipment repair, watering, mowing, landscaping, storage, and painting
- Possible objections regarding the impact on other private or public facilities
- Soil resistivity
- Drainage and soil conditions
- Cost of earth removal, earth addition, and earthmoving
- Atmospheric conditions: salt and industrial contamination
- Cost of cleanup for contaminated soils or buried materials
- Space for future as well as present use
- Land title limitations, zoning, and ordinance restrictions
- General topographical features of site and immediately contiguous area; avoidance of earthquake fault lines, floodplains, wetlands, and prime or unique farmlands where possible
- Public safety
- Public concern; avoidance of schools, daycare centers, and playgrounds
- Security from theft, vandalism, damage, sabotage, and vagaries of weather
- Total cost including transmission and distribution lines with due consideration of environmental factors
- Threatened and endangered species and their critical habitat
- Cultural resources
- Possible adverse effects on neighboring communications facilities

A substation location should be chosen that precludes placing any communications facilities within the substation 300 V peak ground potential rise (GPR) zone of influence. See ANSI/IEEE Std. 367-1987, "Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault."

Environmental Considerations

Appearance is becoming increasingly important to the public. The general trend is to locate substations in a way that they are not strikingly visible to the public. A substation set back from a heavily traveled road may require little or no architectural treatment to be acceptable. Coordinate engineering of transmission, distribution, and substation facilities to develop the least overall objectionable layout. Consider underground distribution circuit exits for special applications.

The silhouette of a substation may be reduced in several ways, including the use of solid-shape structural sections. Lowering of the substation profile may also be accomplished by means other than underground circuits although this approach may necessitate a larger surface area, resulting in larger site requirements. Lower profile designs for substation high-voltage equipment may be cost-effective in design and in reducing the profile that the substation projects.

Landscaping or architectural screening may offer effective means to blend a substation into the surrounding environment. Landscaping has typically included the use of trees, bushes, and the like to screen the substation. In some cases, masonry walls or enclosures have been necessary to meet permitting requirements in special use areas. Some sites may provide a natural screening with either vegetation or natural barriers.

Generally, it is better to use complementary rather than contrasting colors. Sometimes, coloring can be used to blend substation equipment into the background.

Outdoor lighting of the substation site may have an effect on the acceptance of the substation in a community. Lighting is typically a means to deter vandalism. It also provides safety for line crews who may be performing maintenance at night. A means of switching off a portion of the lights at night to provide reduced lighting may make the site more acceptable to the community.

Substations should be safe for people who may have occasion to be near them. The primary means of ensuring public safety at substations is by the erection of a suitable barrier such as a metal fence. Unless local restrictions are more conservative, the fence needs to meet the minimum requirements specified in the National Electrical Safety Code and IEEE Std. 1119, “IEEE Guide for Fence Safety Clearances.”

Additional means of protecting the public are provided through adequate design of all facilities inside the fence and the addition of a peripheral ground outside the fence. Appropriate warning signs should be posted on the substation’s peripheral barrier fence. The engineer should specify their location and design. Substations, no matter how small, should have one sign per side, as a minimum. For each substation site, assess whether standard signs are sufficient. Special bilingual signs may be advisable for some areas. Additional signs, such as “No Trespassing,” may be advisable in some areas. See ANSI Std. Z535.2, “Environmental and Facility Safety Signs,” for further information.

Noise

Sources of audible noise within a substation include transformers, voltage regulators, circuit breakers, and other intermittent noise generators. Among the sources, transformers have the greatest potential for producing objectionable noise. The design engineer should consider audible noise reference documents and regulations.

Corona, which is localized incomplete dielectric failure, causes a hissing sound. Corona noise occurring at voltages of 230 kV and below is seldom serious. Corona noise is usually kept to a tolerable level if guidelines for minimizing electrical effects are followed. Design for 345 kV systems will normally require extra-high-voltage (EHV) connectors and fittings or corona shields to reduce the amount of noise from corona to tolerable levels. Table 1 lists guidelines for considering noise in land-use planning and control. The reaction to noise can be subjective, so each substation situation should be analyzed separately.

Table 1

Noise Zone Classification (dB)

Noise Zone	Exposure Class	Day-Night Average Sound Level (DNL)	Equivalent Sound Level (Leq)	Noise Exposure Forecast (NEF)	HUD Standards
A	Minimal	<55	<55	<20	Acceptable
B	Moderate	55>DNL<65	$55>L_{eq}<65$	25>NEF<30	
C-1	Significant	65>DNL<70	$65>L_{eq}<70$	30>NEF<35	Normally Unacceptable
C-2		70>DNL<75	$70>L_{eq}<75$	35>NEF<40	
D-1	Severe	75>DNL<80	$75>L_{eq}<80$	<45	
D-2		80>DNL<85	$80>L_{eq}<85$	45>NEF<50	Unacceptable
D-3		>85	>85	>50	

If the substation has to be located in or near a residential area, select a site with the greatest distance from nearby residences, and, if possible, avoid a direct line of sight with them. A site with natural barriers such as earth mounds or shrubbery is desirable since such barriers can help reduce the psychological impact of a new installation.

Good practice for noise control is to locate transformers the maximum possible distance from the substation fence. Once a transformer is located, its noise level at any distance can be estimated by using standard formulas. See IEEE Std. 1127, "IEEE Guide for the Design, Construction, and Operation of Electric Power Substations for Community Acceptance and Environmental Compatibility," for formulas that may be used. If noise is anticipated to be a problem, reduced sound levels are available from the transformer manufacturer or the equipment layout should be arranged to permit the installation of a sound barrier. Anticipated future requirements should also be considered since additional transformers will increase the noise level.

As a general rule, substation noise will not be a problem if, when combined with ambient noise, it is less than 5 dBA above the ambient noise level. It may be desirable to measure the ambient noise levels at locations of concern. Measurements should be taken during the quietest periods, approximately midnight to 4 a.m. Calculation of the resultant sound level will then indicate whether further study is required.

Consideration should be given to preventing radio and television interference that could result from visible corona. Significant corona could be caused by energized parts having small radii or from small-diameter conductors, particularly when conductive climatic conditions prevail. Experience has shown, though, that conductor fittings and energized parts other than conductors do not produce serious corona at phase-to-phase voltages of 230 kV and below. At 345 kV, electrical voltage gradients are such that corona shields and connectors designed to mitigate corona should be used. It is necessary, however, to consider the size of conductors. Connections to equipment such as voltage transformers and coupling capacitors should not be sized from a current-carrying standpoint only. From a corona standpoint, conductors should not be smaller than 3/0 at 230 kV or 1/0 at 161 kV and 138 kV. At 345 kV, equipment jumpers should consist of bundled conductors.

Water Pollution

Potential water pollution is another concern. Federal regulations in 40CFR110 and 112 provide guidance to prevent the pollution of navigable waterways. The essence of these regulations is that, upon the failure of a container filled with a pollutant, such as oil in a transformer or oil circuit breaker, no harmful quantity of such pollutant may be allowed to enter a navigable waterway. Absolute prevention and containment of oil spills is not required by the regulations; however, the discharge of harmful quantities of pollutants into navigable waterways is prohibited. The regulations and interpretations thereof are dynamic. It is necessary to have a Spill Prevention Control and Countermeasures (SPCC) plan of action for disposing of effluent, should spills or leaks occur. If more than 5.0 acres of land will be disturbed during construction, a stormwater discharge permit has to be obtained from the appropriate state agency prior to the start of construction. See the above-mentioned CFR regulations and IEEE Std. 980, "IEEE Guide for Containment and Control of Oil Spills in Substations," for assistance in determining the appropriateness of in-place structures and items to be included in an SPCC plan.

Weather

As dependence on the use of electricity grows, it is increasingly important that substations operate more reliably in extremes of weather than in the past. It is necessary to design a substation for the extreme temperatures expected. Extreme temperatures could affect circuit breakers, relay protection, or the bus. As a minimum, substations should be resistant to the expected wind velocities. Figure 1 shows the expected wind velocities in the United States.

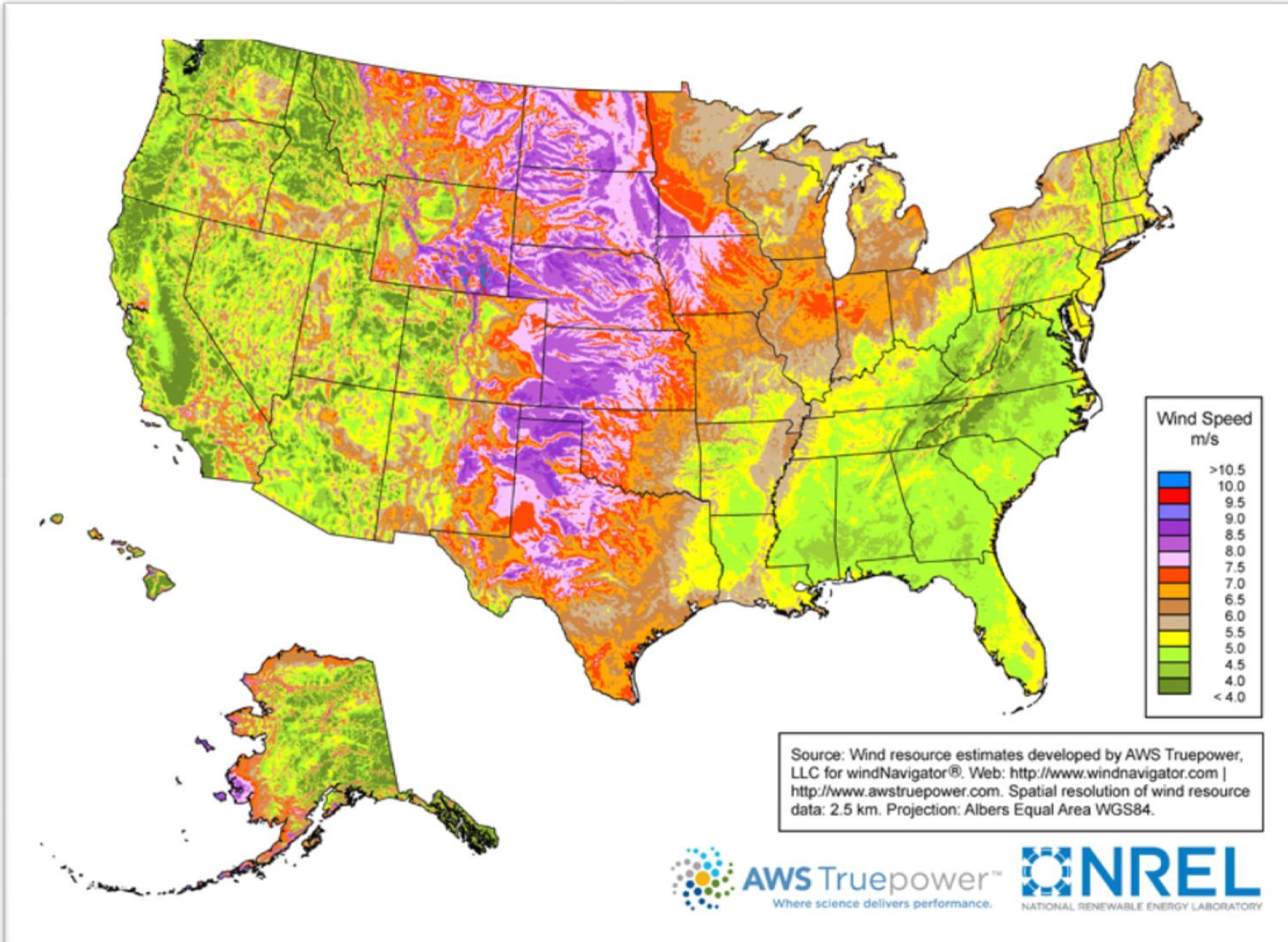


Figure 1

A substation should continue to operate despite ice accumulation. Generally, consensus equipment standards specify ice loadings for both electrical and mechanical withstands. The complete substation assembly should also be undamaged by ice accumulation. From the ice accumulation history for a given substation's location, the engineer can judge whether more severe loadings than consensus equipment standards are necessary.

A substation should be designed to be operable under predictable conditions of rainfall. Additionally, it is desirable that substation drainage be sufficient enough to exhibit little standing water within a few hours after a heavy rainfall.

Snow introduces an extremely variable hazard to substations because of uncertainties in drifting and accumulation. The substation has to be impervious to snow damage, and consideration needs to be given to snow accumulation and the maintenance of clearances. The engineer should seek local data on this weather variable.

The two measures normally employed for substation lightning protection are surge arresters and shielding. Surge arresters provide little protection against direct strokes. Shielding is provided by overhead wires, masts that are extensions of structures, or independent masts. A combination of surge arresters and shielding will reduce the probability of damage from lightning.

Consideration should be given to installation of differential thermostat-controlled heating in outdoor cabinets such as circuit breaker control cabinets where condensation could be a problem. In areas where fog occurs often, and particularly where airborne contamination exists, frequent insulator flashovers may occur. Methods of reducing flashovers include the application of special insulation and insulator cleaning.

Altitude

Equipment that depends on air for its insulating and cooling medium will have a higher temperature rise and a lower dielectric strength when operated at higher altitudes; see ANSI Std. C37.30, "Standard Definitions and Requirements for High-Voltage Air Switches, Insulators, and Bus Supports."

Surge arresters are designed for satisfactory operation at elevations up to a limit specified by the manufacturer. Applications above this limit are considered special, and the manufacturer should be consulted for a recommendation.

Dielectric strength of air, current ratings of conductors operated in air, and ambient temperatures should be corrected for altitude variation and be multiplied by the factors shown in Columns "A" and "B" of Table 2.

Table 2 Altitude Correction Factors			
Altitude (Feet)	Correction Factor		
	A	B	C
	Dielectric Strength	Current Rating	Ambient Temperatures
3,300	1.00	1.00	1.00
4,000	0.98	0.995	0.992
5,000	0.95	0.99	0.980
6,000	0.92	0.985	0.968
7,000	0.89	0.98	0.956
8,000	0.86	0.97	0.944
9,000	0.83	0.965	0.932
10,000	0.80	0.96	0.920
12,000	0.75	0.95	0.896
14,000	0.70	0.935	0.872

Earthquakes

Substations subjected to intense earthquakes will most likely be damaged; however, seismic design practices can minimize the damage. Although some substation equipment is inherently shock resistant, the foundations, structures, equipment anchors, insulation, and conductors may not be. Designs that minimize damage should be utilized in high seismic areas. Consideration should be given not only to replacement costs but also to lead times for delivery of replacement equipment.

IEEE Std. C57.114, "IEEE Seismic Guide for Power Transformers and Reactors," provides recommendations as to design considerations for the installation of transformers and reactors when seismic activity is likely.

Seismic loads are governed by the region of the country in which they occur. Figure 2 identifies the susceptibility of different areas of the country, with the higher numbered areas being more susceptible.

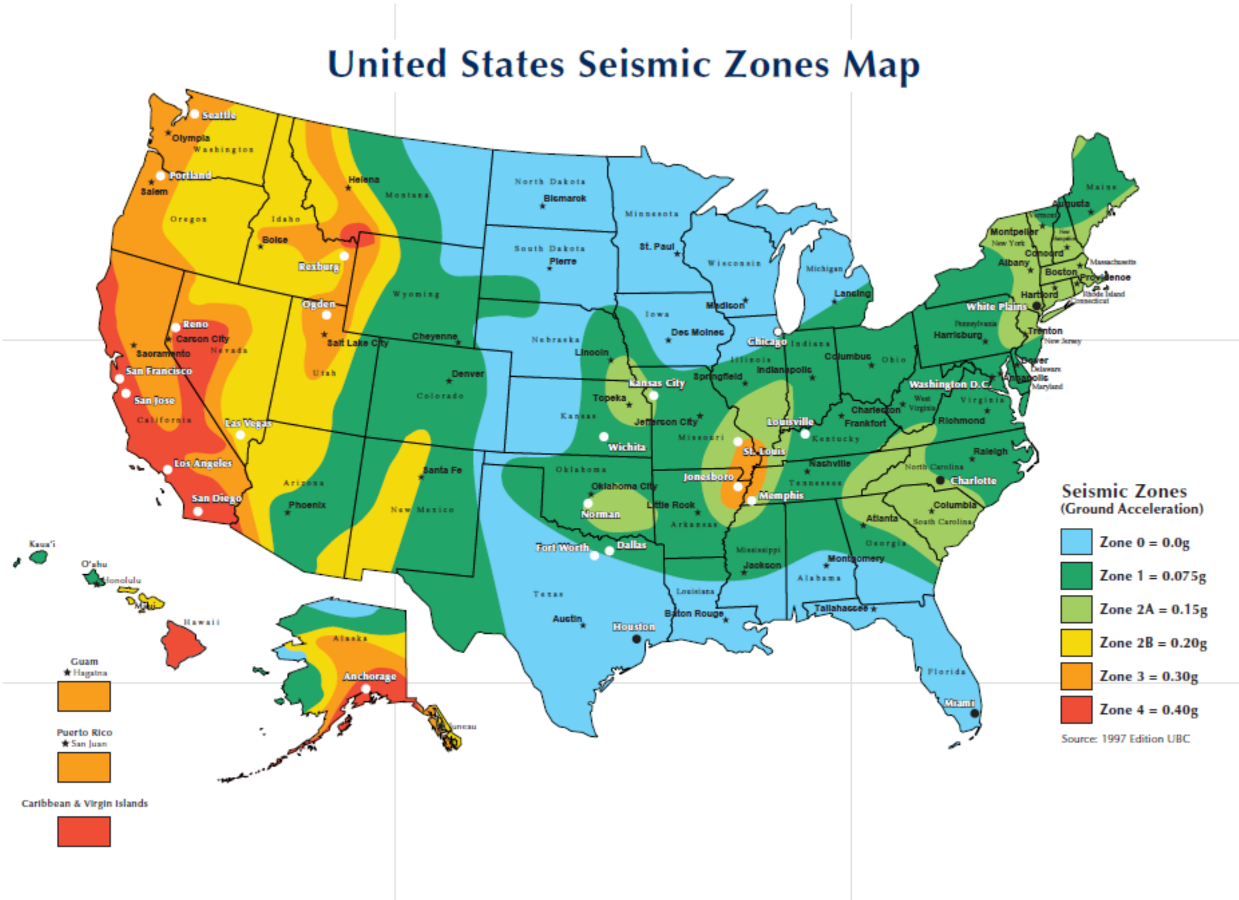


Figure 2

Other Considerations

A substation should be protected from wildlife and livestock. The primary means of protection is the perimeter barrier. This is generally a chain link fence that keeps out larger animals. It may also be necessary to have rodent and/or reptile barriers. It is recommended that all substation materials be non-nutrients, since impregnable barriers would be too difficult to attain. Insect screening should be applied where local experience indicates it is beneficial. Avoiding attractive nesting and perching sites usually minimizes bird damage. Adequate clearances should be provided to prevent electrocution of local bird species.

Airborne seeds, leaves, debris, dust, and salts that are local phenomena could be a problem. Buildup could occur that would compromise electrical insulation or interfere with cooling. Appropriate prevention measures should be included in the design of a substation expected to be exposed to such contamination.

Substations interface with roadways, area drainage, communications systems, and electric power lines. Sufficient lead time has to be allowed to coordinate activities with public agencies for roadway access and with communications agencies for communications facilities.

When locating a new substation, coordinate the location, design, and construction with other utilities operating in the area. Other utility concerns include but are not limited to:

- Telecommunications
- Cable television
- Water and sewer
- Gas
- Radio and television stations

There should be little difficulty ensuring proper substation interfacing with distribution, sub-transmission, and transmission lines. Timely plans should be made so there is mutual agreement between the substation engineer and the various line engineers on the following:

- Connecting hardware procurement responsibility
- Mating of hardware to line support structure
- Line identifications and electrical connections
- Substation orientation and line approach
- Phase conductor and shield wire identification
- Pull-off elevations, spacings, tensions, and angles

Confusion sometimes occurs in the matter of specifying line tensions in substations. In some cases, line tensions on the line side of a line approach or deadend structure will be much greater than on the line support structure in the substation. The substation engineer should specify the tension that will result in the maximum load on the substation line support structure with the wire under the most severe combination of temperature, wind, and ice loading. The condition at which maximum tension occurs has to be known in order to select appropriate overload factors.

As a general rule, takeoff tensions should not exceed 2,000 pounds per conductor for small distribution substations. However, the incoming transmission line alignment, wire size, and elevation differences can increase the required tensions.

Reliability Considerations

A prime objective in the operation of an electric power system is to provide reliable service within acceptable voltage limits. Information on reliability may be found in ANSI Std. C84.1-1995, "Electric Power Systems and Equipment-Voltage Rating (60 Hz)." Utilities that design substations to operate within the voltage levels specified in this ANSI Standard should have reasonably reliable substations.

Operating Considerations

For simplicity and ease of maintenance, substation equipment arrangements, electrical connections, signs, and nameplates should be as clear and concise as possible. Information on safety signs can be found in ANSI Std. Z535.2, “Environmental and Facility Safety Signs.”

A substation may occasionally experience emergency operating conditions requiring equipment to perform under abnormal situations. Depending on the length of time, the provision of unusual current-carrying capacity of some equipment or connections should always be considered and appropriately accounted for in the design.

Safety Considerations

It is paramount that substations be safe for the general public and for operating and maintenance personnel. Practical approaches include the employment and training of qualified personnel, appropriate working rules and procedures, proper design, and correct construction. The safeguarding of equipment also needs to be considered in substation design.

Personnel working standards are prescribed by regulations issued by the Occupational Safety and Health Administration (OSHA). These regulations are included in 29 CFR 1910 for general industry and 29 CFR 1926 for construction. In addition, various states may have standards the same as or stricter than those of OSHA. The engineer is expected to follow the regulations appropriate to the jurisdiction in which a substation is built.

It should be recognized that this material presents substation design guidance information only and not detailed regulatory provisions, especially related to safety. The engineer is responsible for researching and ensuring substations are designed in compliance with the applicable requirements of the National Electrical Safety Code, National Electrical Code, OSHA, and local regulations. The engineer is also responsible for analyzing expected local conditions, and, where warranted, including provisions in substation designs beyond the minimum provisions for safety established in the various regulatory codes.

Maintenance Considerations

Substation design needs to allow maintenance to be accomplished with a minimum impact on a substation’s operation. Allocation of adequate working space is necessary.

In selecting equipment, consider the service intervals recommended by the manufacturers and past experience in using a particular manufacturer's equipment.

Chapter 2
Documents and Drawings

Listed below are some of the documents or studies that may be required for the construction of a new substation. The timing and chronological order of the documents may vary, depending on the particular substation's requirements.

1. Site Comparison and Suitability Evaluation
2. Environmental Assessment
3. Substation Design Summary Form
4. Functional One-Line Diagram
5. Application for Zoning Variance
6. Specifications for Equipment
7. Request for Proposals to Furnish Equipment
8. Evaluation of Proposals to Furnish Equipment
9. Construction Plan Drawings
10. Backup Sketches and Calculations for Construction Plans
11. Substation Drawings (Detailed One-Line, Elementary, and Schematic Diagrams)
12. Requisitions for Material and Equipment
13. Application for Building Permit
14. Application for Permits for Roadway and Drainage Interface
15. Application for FCC License
16. Construction Specifications
17. Inquiry for Proposals to Furnish Construction
18. Evaluation of Contractor's Proposals
19. Comment Letters on Equipment Vendors' Submittals
20. Calculations for Selection of Protective Relaying and Devices
21. Economic Comparisons

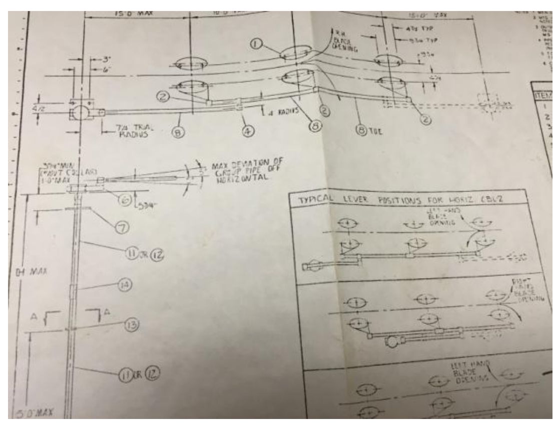
Documentation forms the basis for the expression and evaluation of engineering concepts. In its final form, a document fulfills its primary role of establishing design and functional requirements. A document also serves as a record of what was built, specified, or evaluated. The importance of good records in substation design deserves emphasis. Successful designs and accurate records are convenient references for designs and for standardized approaches for new substations. Records can also be very useful in diagnosing and correcting problems.

The chronology of a substation design generally follows the order shown in Table 3.

Table 3 **Substation Design Chronology**	
Sequence	**Item**
1	Identity need
2	Procure Real Estate
3	Select Major Equipment
4	Prepare Plans and Specifications
5	Selection of Construction Contractor
6	Construction
7	Inspection
8	Testing
9	Energization

Drawings

For a basic distribution substation, a "One-Line Diagram" and "Plot Plan" may be the only drawings that need to be custom made by the engineer. For example, if a substation is small, it may be possible to show foundation details on the "Plot Plan." Similarly, the grounding layout and details might also be shown on a "Plot Plan." Larger substations will, of necessity, require more extensive documentation. Substation drawings of any kind should conform to industry accepted quality requirements.



It is recommended that drafting practices be in accordance with American Drafting Standards Manual, ANSI Std. Y14. Prints of the drawings will be used in construction, not always under the most convenient environmental conditions. Experience indicates a preference for equipment outlines with detailed pictorial representations. Pertinent component interfaces and connections should be illustrated in adequate detail for construction and record purposes. The dimensions of pertinent distances need to be shown. Drawings, though made to scale, should not have to be scaled for construction purposes. Thought should be given to choosing scales and lettering sizes appropriate for the type of drawing. It is desirable to use bar-type graphic scales on all drawings since many of them may be reproduced in different sizes. Plans, elevations, and sections should be organized for maximum clarity. Tolerances should be noted on drawings, such as those that specify foundation anchor bolt locations and equipment mounting holes on control panels. Simplicity and clarity of drawings are essential.

Virtually all modern substations are designed on CADD systems. Parameters need to be established before the creation of any drawings with CADD. These parameters are basic to CADD and permit CADD to make use of its strength and flexibility to produce quality products. These parameters will ultimately lead to the increased productivity that users expect from CADD:

1. Establish or revise key drawing criteria. The engineer needs to know what is to be shown on each drawing.
2. Establish legends for the symbols that will be used.
3. Standardize the line weights and text sizes.
4. Establish standard layer or level schemes.
5. Provide for the ability to isolate layers and reference other files.
6. Provide for the ability to make changes on one file and have the changes reflected on related drawings, eliminating having to change the other drawings.
7. Establish a cell library or blocks, in a location for standard files, of items that will be continually reused in the utility's drawings.
8. Create seed files or prototype files that may be used as the base for drawing preparation.

A definitive legend should be included on the first sheet of each type of drawing. This legend should not only include the standard symbols, but all special symbols or designations. A set of notes is often found to be a desirable supplement on a drawing. Use judgment to avoid overdoing notation. It may be better to consider additional details on the drawings rather than a long list of notes. Electrical symbols should be in accordance with IEEE Std. 315, "Graphic Symbols for Electrical and Electronics Diagrams." Give proper care to the listing of reference drawings to ensure a coherent, concise pattern. Make drawing titles concise, accurate, and specific. They should not be so general that the drawing itself has to be viewed to see what it covers. Ensure that every drawing or revision to a drawing indicates the proper approvals and dates.

Types of Drawings

Following are the types of substation construction and reference drawings often required.

- One-Line Diagram - Switching
- One-Line Diagram - Functional Relaying
- Three-Line Diagram
- Electrical Plot Plan
- Site Preparation
- Fence Layout

- Electrical Layouts
- Structure Erection Diagrams
- Foundation Layouts
- Grounding Layout
- Conduit Layout
- Control House - Architectural, Equipment, Layout, Lighting, Etc.
- Station Service Diagrams AC and DC
- Cable Lists and Conduit Lists
- Bills of Material
- Drawing List
- Control Panels
- Schematic and Detailed Wiring Diagrams

One-line diagrams serve as the major substation reference drawings and require special emphasis. These references should be the first drawings prepared. The switching and functional relaying information may appear on the same one-line diagram if the presentation is not too complicated.

Acceptable symbols for some of the most common substation equipment are illustrated below and include the following figures,

Figure 3 - Power Transformer
Figure 4 - Three Phase Transformer with Tertiary
Figure 5 – Three-Phase Auto-Transformer
Figure 6 – Voltage Regulator
Figure 7 – Hook Stick Operated Disconnect Switch
Figure 8 – Three-Phase Gang-Operated Disconnect Switch
Figure 9 – Three-Phase Double Side-Break Disconnecting Switch with Motor Operator.
Figure 10 – Fused Disconnect
Figure 11 – Oil Circuit Recloser
Figure 12 – Circuit Breaker
Figure 13 – Surge Arrester
Figure 14 – Voltage Transformer
Figure 15 – Current Transformer
Figure 16 – Coupling Capacitor
Figure 17 – Coupling Capacitor with Wave Trap
Figure 18 – Disconnecting Clamp\
Figure 19 – Shunt Capacitor

Generally, these symbols are based on IEEE Std. 315. Drafting templates are commercially available to assist in developing one-line diagrams. Each symbol should be accompanied by the pertinent equipment information indicated.

Listed below are a few of the typical drawing symbols for an electrical substation.

Power Transformer

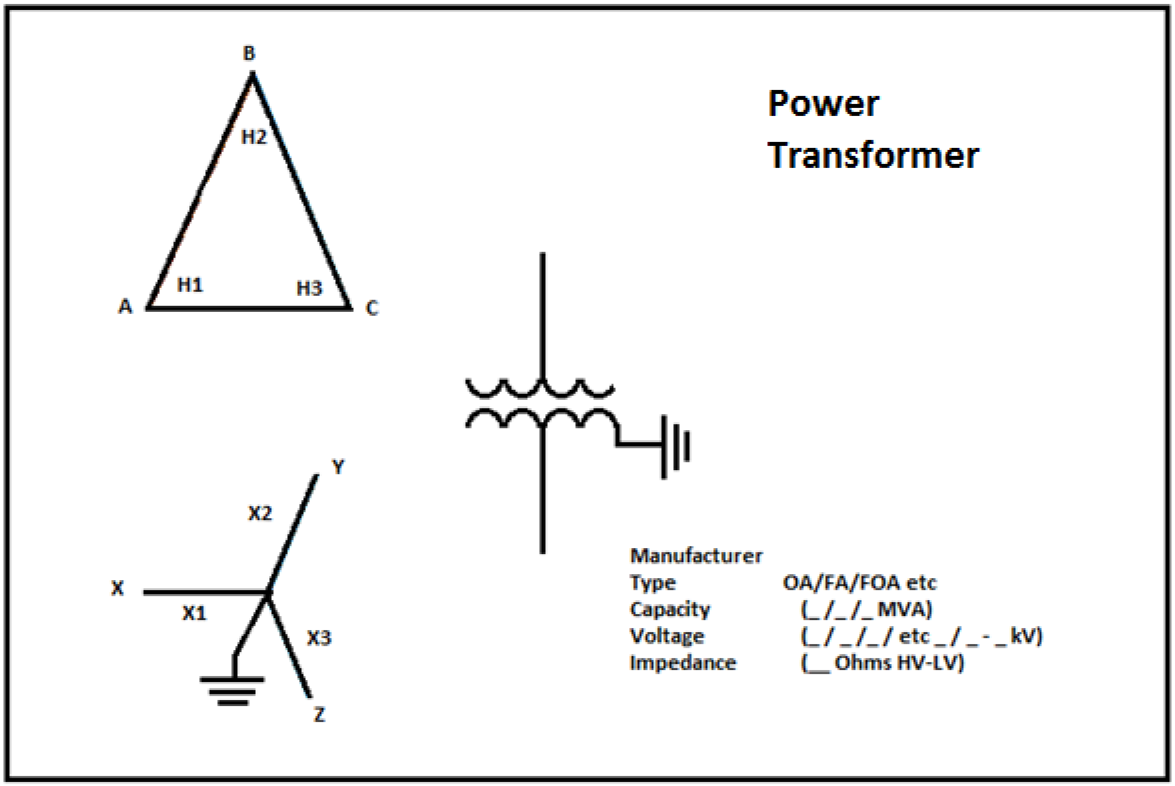


Figure 3

Three-Phase Transformer with Tertiary

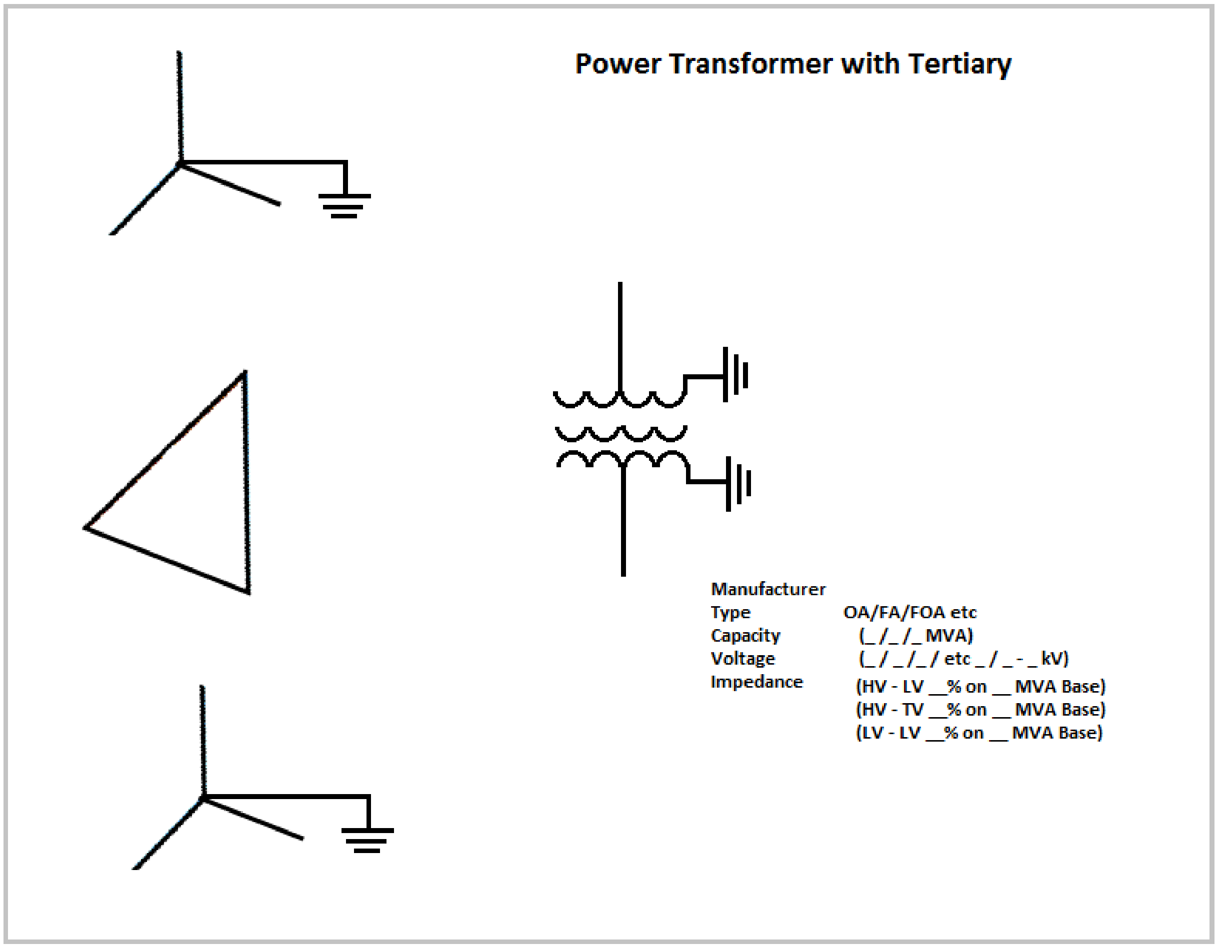


Figure 4

Three-Phase Auto-Transformer

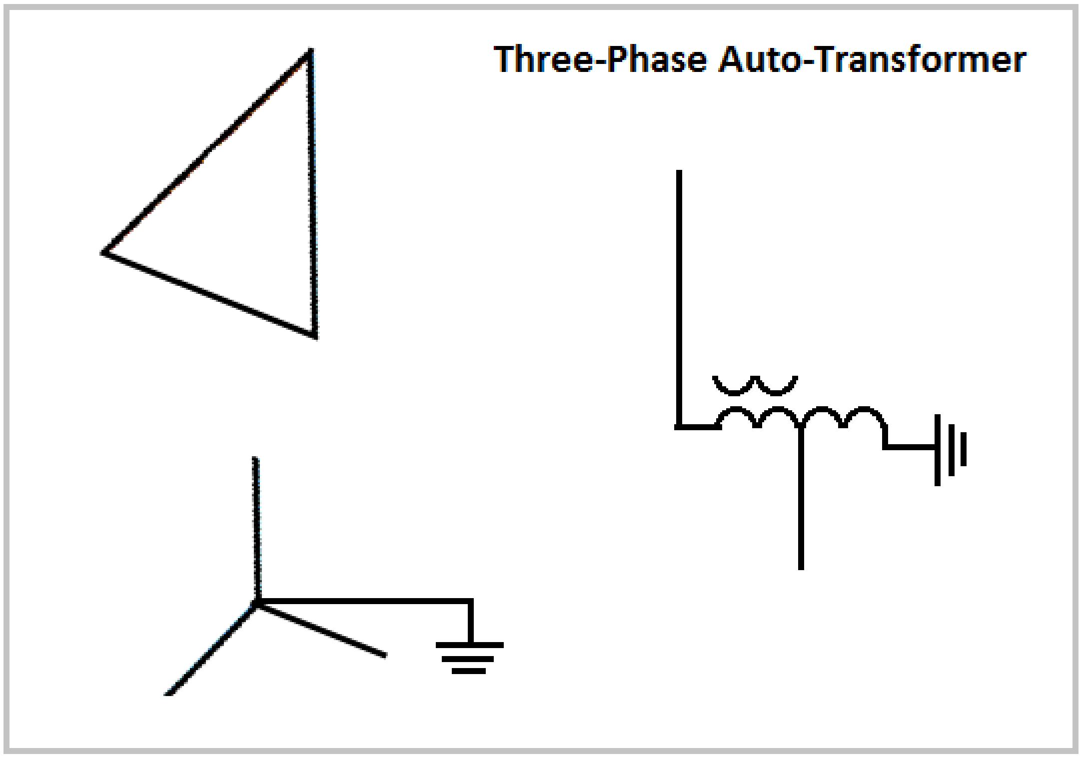


Figure 5

Step Voltage Regulator with Bypass Switch

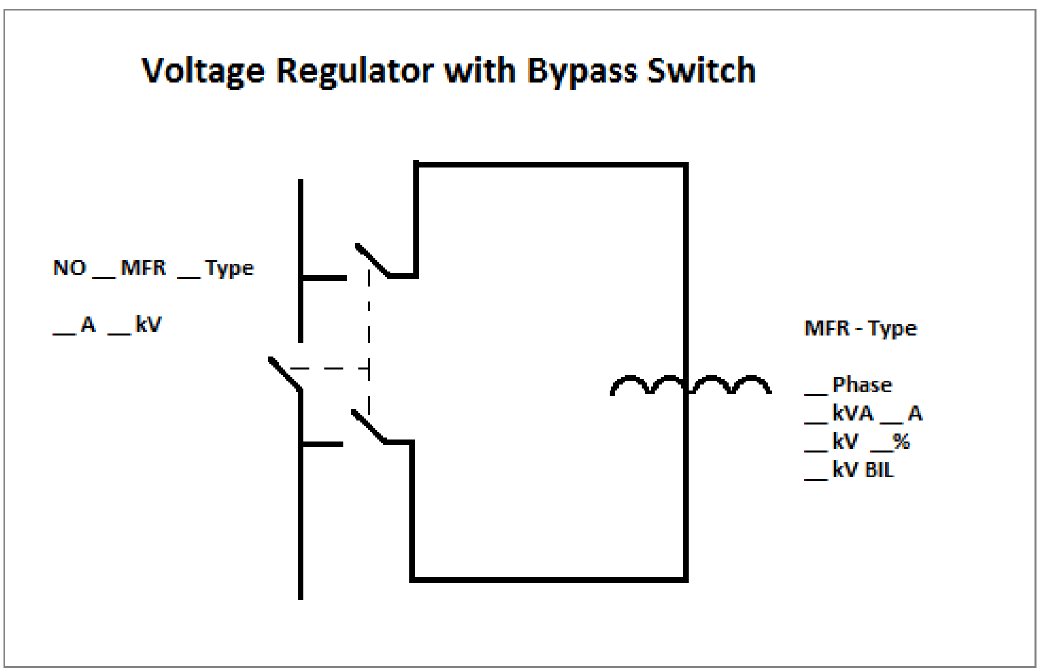


Figure 6

Hook Stick-Operated Disconnecting Switch

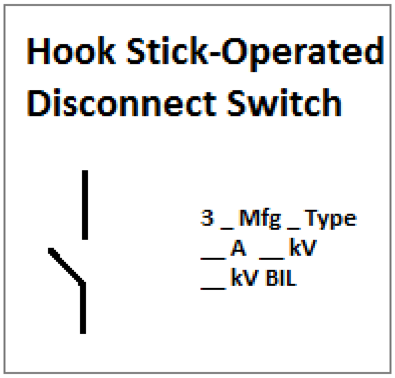


Figure 7

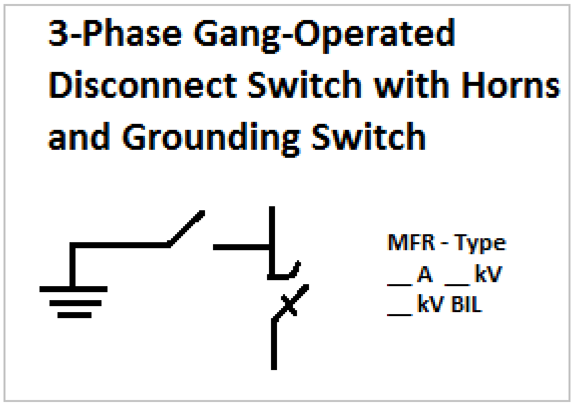


Figure 8

Three-Phase Gang-Operated Disconnecting Switch with Horn Gaps and Grounding Switch.

Three-Phase Double Side-Break Disconnecting Switch with Motor Operator

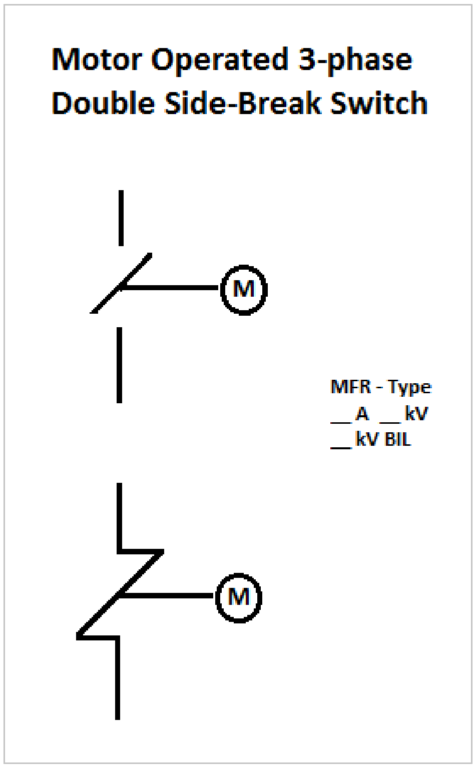


Figure 9

Fused Disconnect

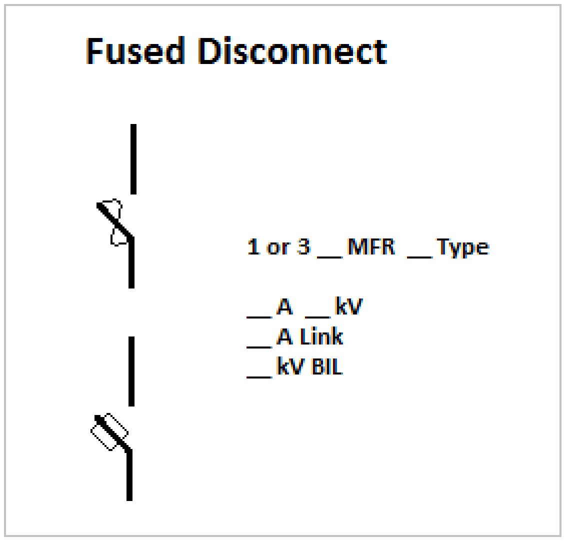


Figure 10

Oil Circuit Recloser

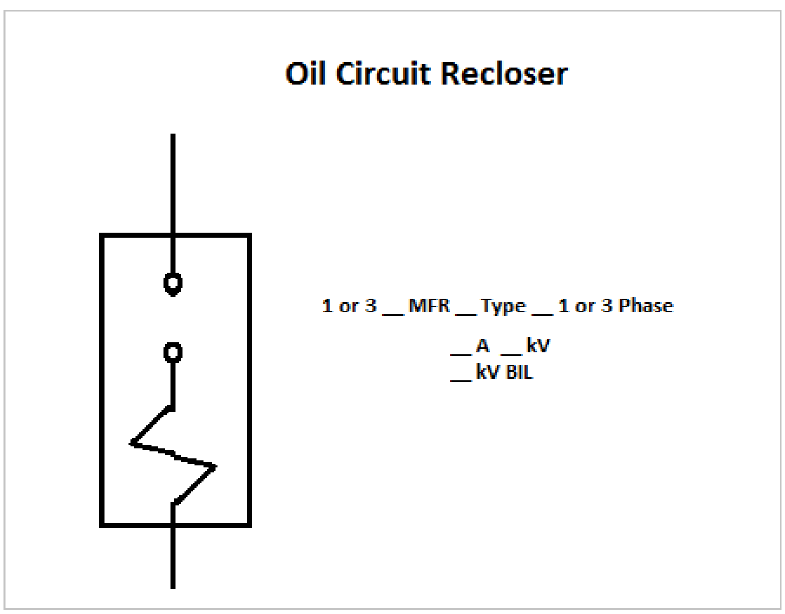


Figure 11

Circuit Breaker (Shown with Bushing-Type CTs and Reclosing Relay)

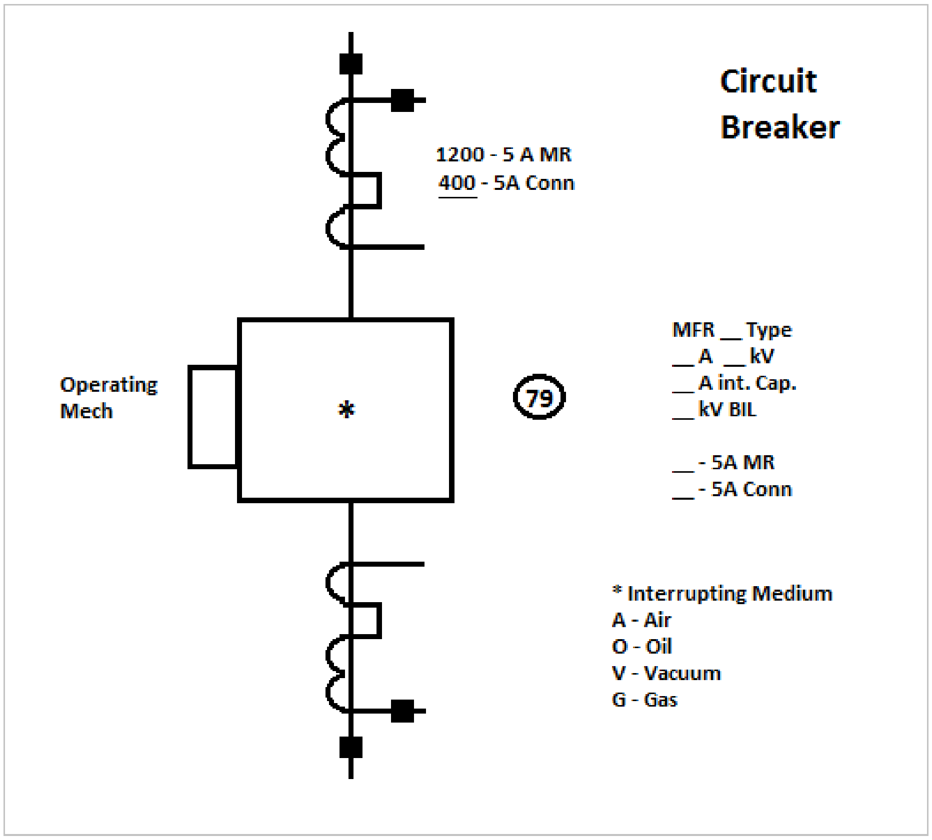


Figure 12

Surge Arrester

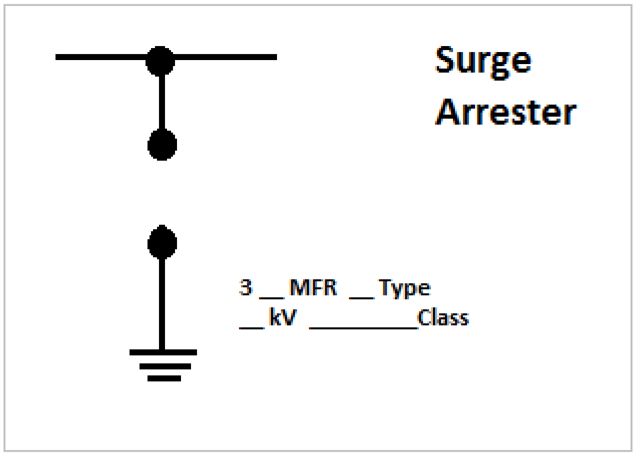


Figure 13

Voltage Transformer

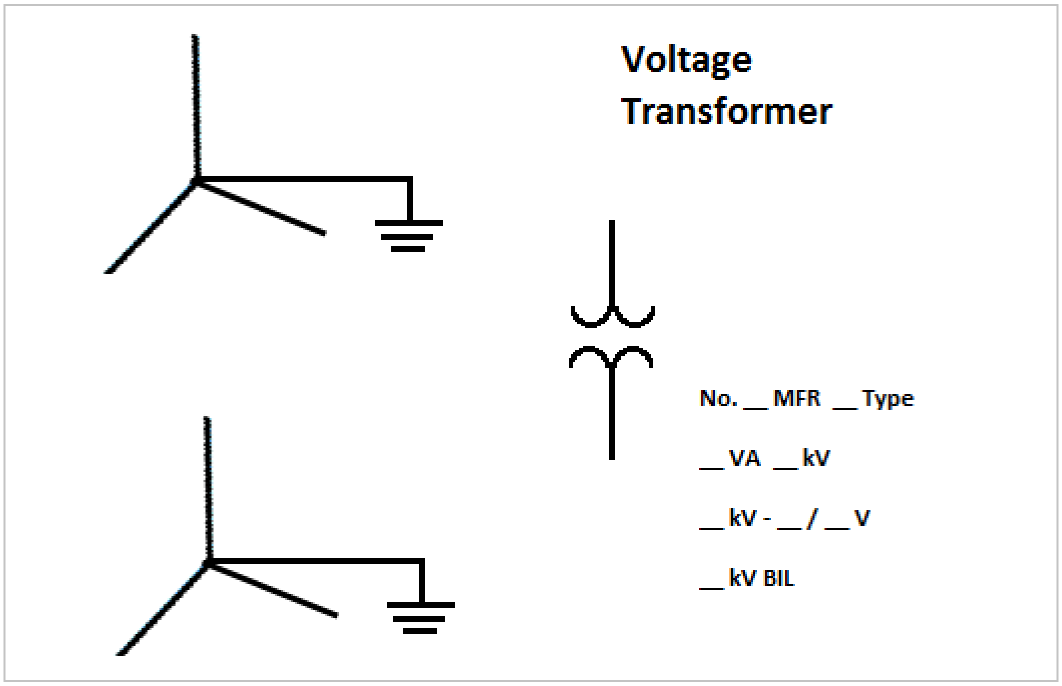


Figure 14

Current Transformer

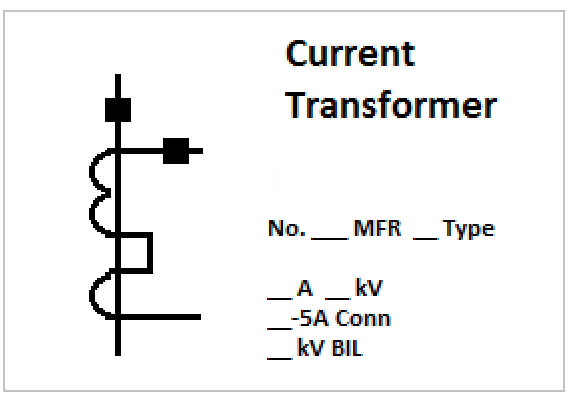


Figure 15

Coupling Capacitor with Voltage Transformer

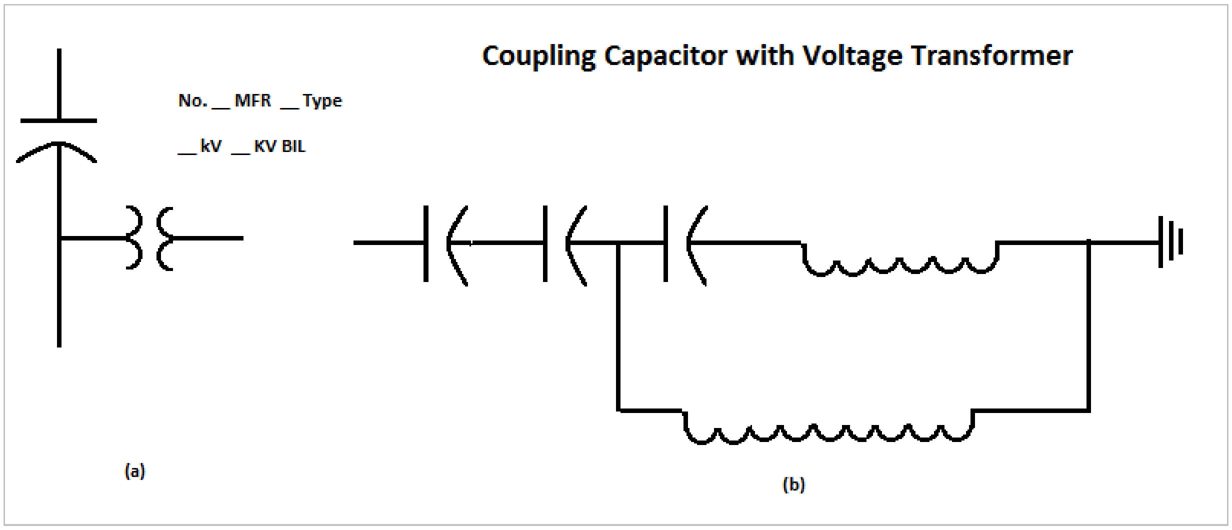


Figure 16

Coupling Capacitor, Wave Trap, Tuning Unit, and Power Line Carrier

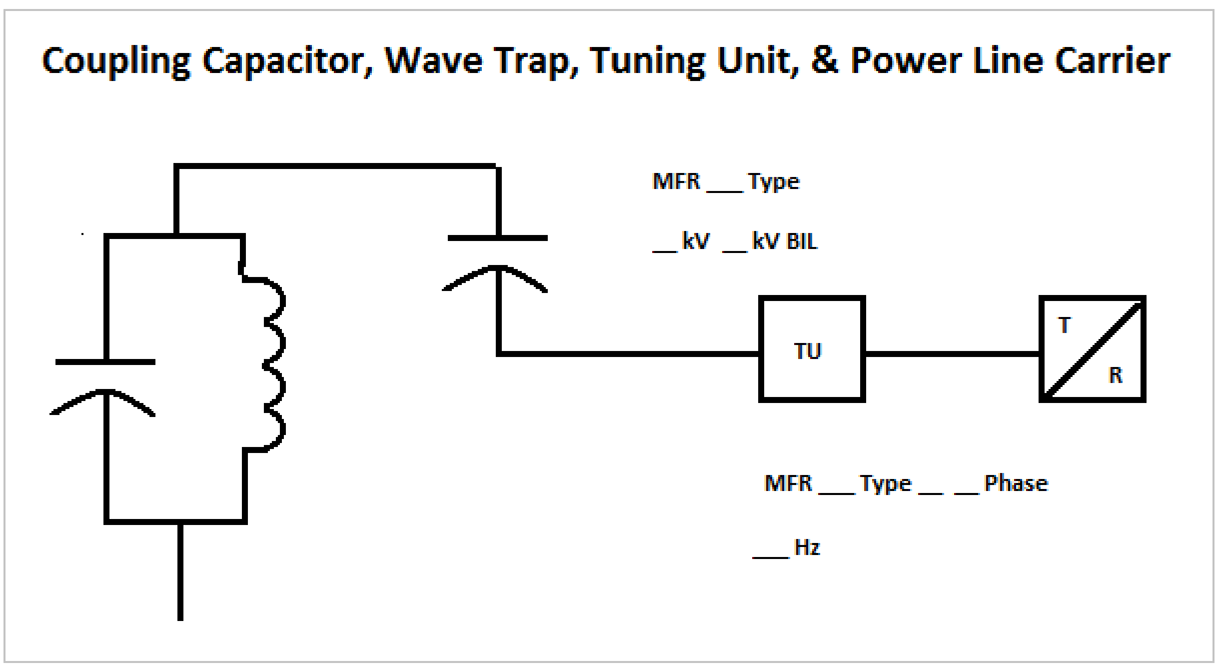


Figure 17

Disconnecting Clamp

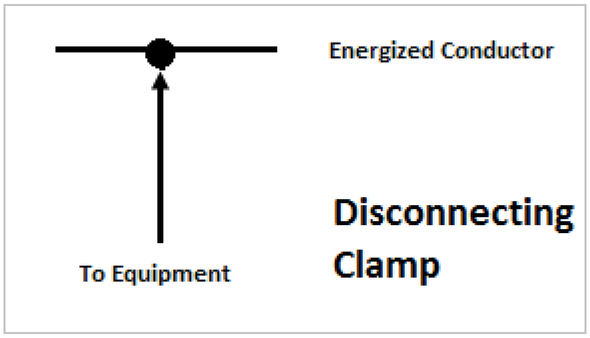


Figure 18

Shunt Capacitor

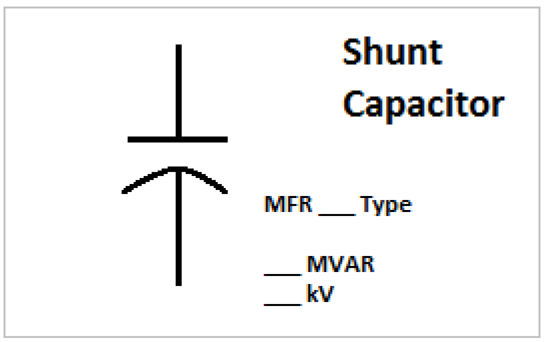


Figure 19

In addition, Figure 20 shows symbols commonly used in a one-line diagrams.

Basic One-Line Diagram Symbols

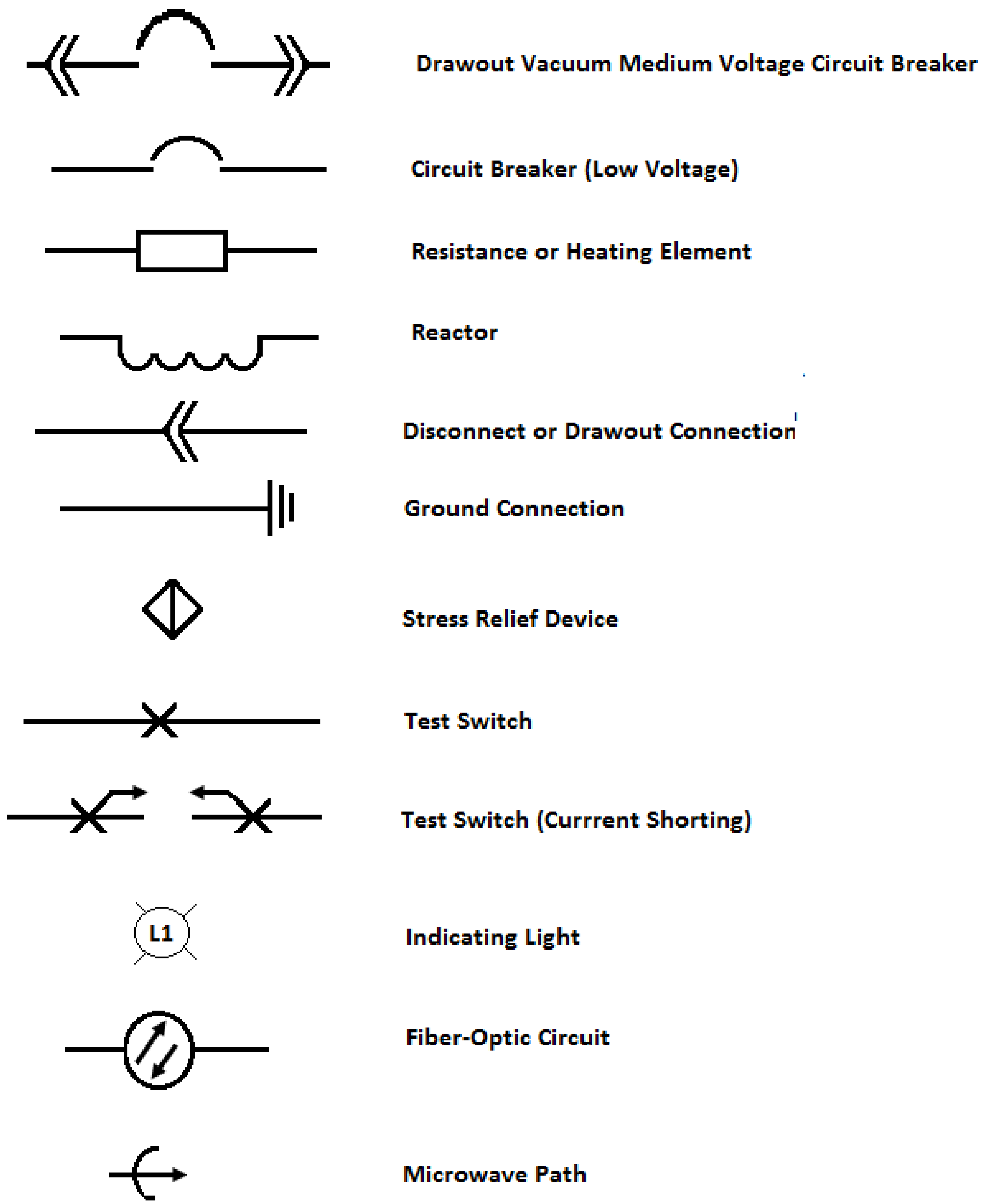


Figure 20

Figures 21, 22, and 23 provide elementary examples of symbols in combination. These include a typical relay drawing, a conceptual one-line diagram of a transmission substation, and a partial switching one-line diagram.

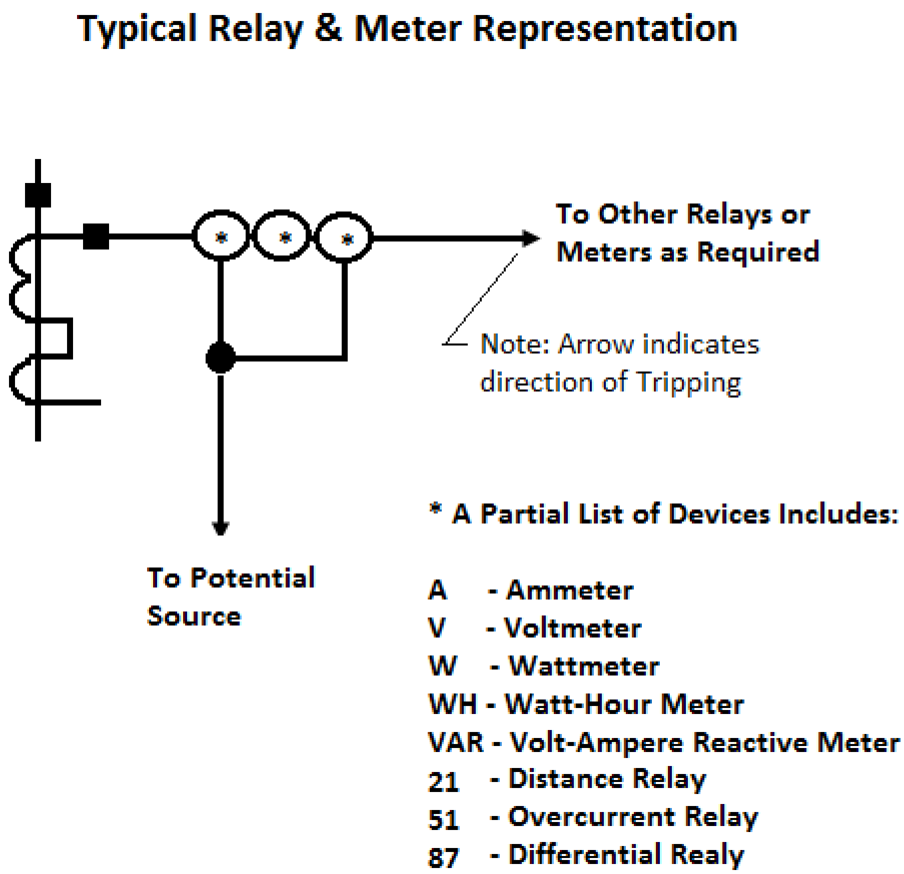


Figure 21

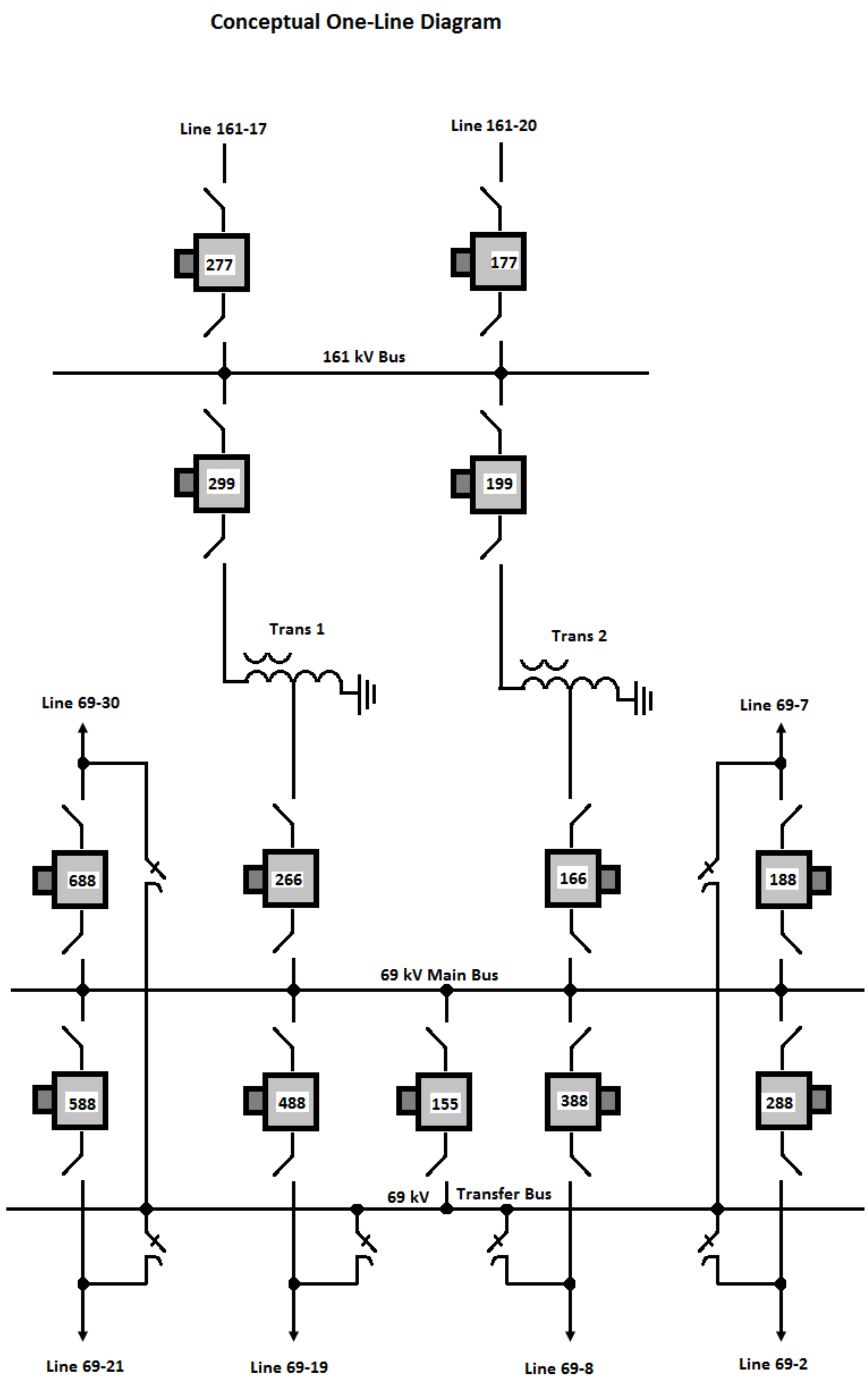

Conceptual One-Line Diagram
Line 161-17
Line 161-20
277
177
161 kV Bus
299
199
Trans 1
Trans 2
Line 69-30
Line 69-7
688
266
166
188
69 kV Main Bus
588
488
155
388
288
69 kV
Transfer Bus
Line 69-21
Line 69-19
Line 69-8
Line 69-2

Figure 22

Partial Switching One-Line Diagram

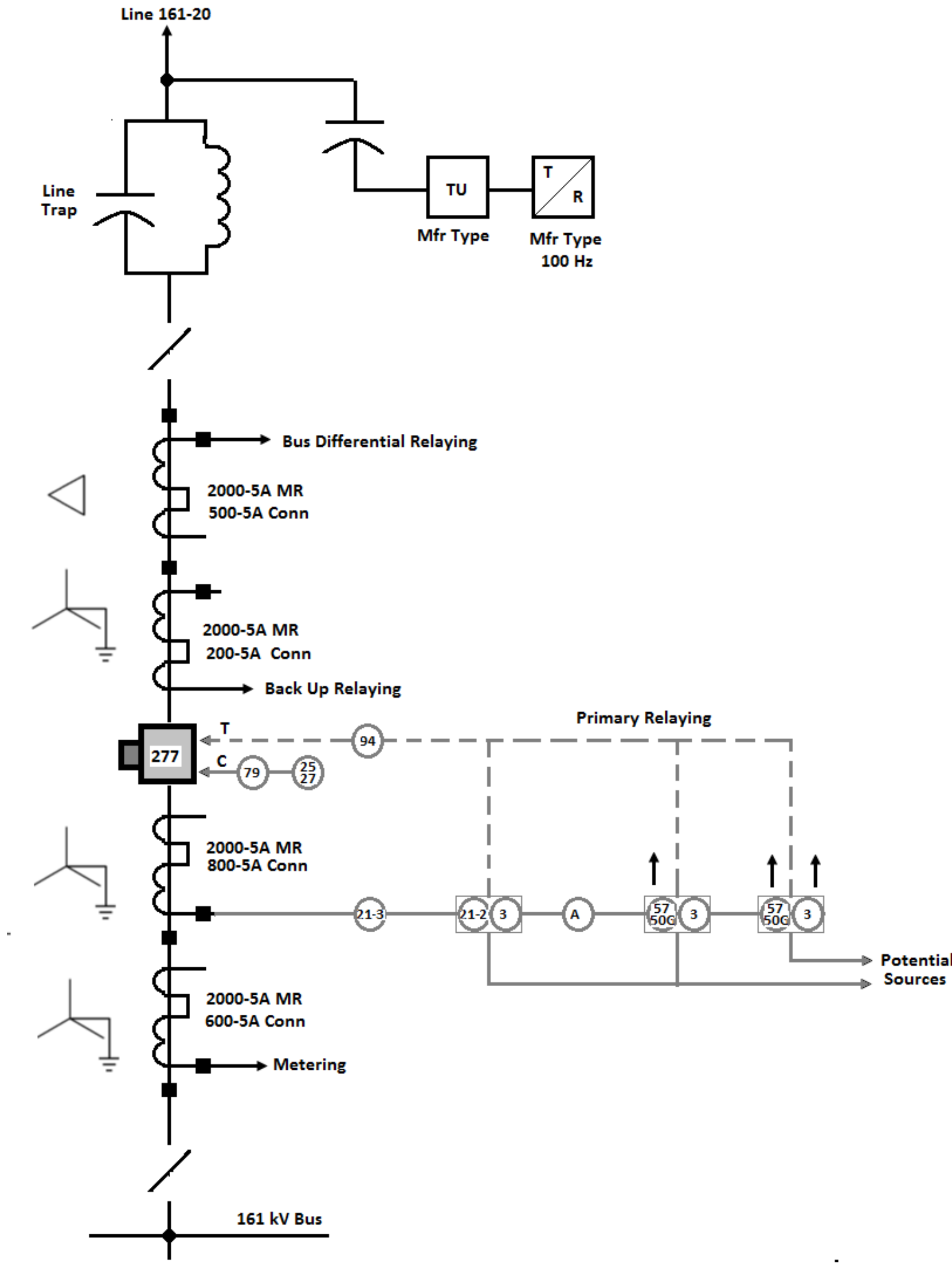


Figure 23

Summary

In this first volume of a multi-volume set of courses on the design of rural electric substations we have taken a very broad look at the design factors and data needed to design a substation. The next volume in this series discusses the physical layout and design configurations for substations. Subsequent volumes will explore equipment, foundations, structures, grounding, relaying and other items necessary to design an electrical substation.

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