CHAPTER 4

MAIN ELECTRIC SUPPLY STATIONS/SUBSTATIONS

4-1. Provisions.

At existing installations, new stations will be provided either when it is not possible or when it is impractical to modify an existing station to serve both the existing facilities and the new projects. The decision to modify an existing station or construct a new station will be made at the earliest practical stage of project planning.

a. Existing stations. Existing stations will be modified when the estimated life cycle cost of the required modification is less than the estimated life cycle cost of a new station. This decision will be subject to review and approval by the Using Agency in coordination with the utility company or other owners, operators, and users of the station. Factors to be considered in the decision to modify an existing station will include:

(1) Availability of surplus capacity in the existing station and lines.

(2) Space available for required station modifications.

(3) Age and condition of existing equipment.

(4) Location of the existing station with respect to the new load.

(5) Quantity, sizes, and rights-of-way for new transmission and distribution lines.

(6) Adequacy of transmission and distribution capacity.

(7) Need for voltage regulation or reclosing.

(8) Megavolt amperes (MVA) interrupting and withstand ratings of station and line equipment.

(9) Protective device coordination for both existing and new equipment.

(10) Serving utility rate schedule.

(11) Site-peculiar features that affect design, construction, operations, and maintenance costs.

(12) Capability of the modified station to meet the using agency's requirements for safe, reliable, available, and maintainable electrical service.

b. New stations. When a new station is contemplated at an existing installation served by a Main Electric Supply Station or Substation (a station is to be designated a "Main Electric Supply Station" when there is no power transformer and a "Main Electric Supply Substation" when power transformers constitute a station element), the total life cycle cost of station modifications with new distribution facilities will be compared against the cost of a new, dedicated station with less extensive distribution facilities, located in closer proximity to the new project than a modified existing station. Conjunctive billing is required if there is more than one point of service.

(1) *Locations near installation boundaries.* At an existing installation any new station should be located as near as practical to the installation boundary and be served by a single three-phase utility line from the existing station if the utility source is adequate to serve both the existing and new loads. New utility lines will be considered only when the existing source (or sources) is inadequate; when a new line is required to comply with the reliability, availability, or maintainability requirements of the Using Agency; when a new line is more cost effective than alternate methods; or when there are other justifications. Multiple power sources and two or more metering points generally should be avoided.

(2) *Locutions remote to installation boundaries.* Location of a new station remote to the installation's boundary or the need for more than one new main electric supply station/substation requires a waiver from the Host Command for Air Force projects. The request and justification for such a waiver will be furnished to that office by the field operating agency responsible for the design of new projects. Justifications will be based on cost effectiveness or other factors noted above and may include a discussion of the importance of new projects to national interests; probable consequences and expenses over the life of the project for lost production or lost manufacturing efforts associated with less reliable electrical services; or other reasonable causes that fully substantiate the more costly design addressed in the waiver request.

c. *Rates.* Based on the estimated demand and usage, all electrical service rate schedules applicable to the project will be evaluated to ensure an adequate supply of electrical power at the lowest available cost. Care will be taken to see that the chosen schedule compares favorably with that of any other utility serving the area, and that the rates are no higher than those paid by other customers for similar service. The possibility of recovering any connection charges, by deducting a certain percentage of each monthly bill by a fixed annual or monthly refund should be investigated. Utility rates, contract coordination, and negotiations will be coordinated with the U.S. Army

Center for Public Works, the Directorate of Army Power Procurement.

d. Rights-of-way. The Government grants all rights-of-way needed within their property limits and the utility procures all others. Utility-owned facilities will be located to avoid any interference with installation activities and planned functions.

e. Coordination. Selection of utility rate schedules and rights-of-way over Government property will be coordinated with, and approved by authorized personnel.

4-2. Ownership.

When electricity is supplied by a utility, equipment on the line side of the station transformers and the station transformers are normally provided by the utility. Government ownership of line equipment and power transformers should be considered when permitted by the utility and when Government ownership would be more economical based on an estimated life of 25 years for the transformers and line equipment. In making that determination, the cost of Government ownership must be compared against the corresponding cost for utility ownership, based on the same energy demands and usage and the different construction costs and applicable rate schedules.

4-3. Station Designation and Elements.

Station elements consist of apparatus associated with incoming and outgoing electrical power transmission and distribution circuits, and the equipment required for the instrumentation and control of the apparatus and circuits. The station elements may include power transformers with or without automatic load tap changing provisions. Separate voltage regulators may be provided to regulate station voltage when power transformers are not provided, or to regulate station voltage when nonautomatic load tap changing transformers are provided. Separate regulators may be preferred to prevent outage of power transformers because of outage of automatic load tap changing mechanisms, or to circumvent the problems associated with the parallel operation of transformers with dissimilar features or characteristics.

4-4. Main Electric Supply Station/Substation.

The main electric supply station/substation is the installation/utility interface point where further transmission, distribution and utilization of electrical power, the monitoring and control of such power or equipment and the protection of electrical equipment or systems becomes the sole responsibility of the Government. Electrical power will be supplied by the same utility over one or more incoming power lines that are metered by the use of items of equipment provided and maintained by the utility. The design of new stations, or modifications to existing stations, must be coordinated with the supplying utility and with any other suppliers or users of power supplied through the station. Such coordination should be accomplished by the responsible field operating agency, or a designer employed to accomplish the coordination and design of new electrical facilities. Complete coordination should be performed to ensure proper protection for electrical equipment and systems, to obtain the required degree of availability, reliability and maintainability, and to achieve the most cost effective billing, construction, operation and maintenance costs during a station life of 25 years or less.

a. Billing. Since electric utility rates and rate structures vary from state to state and with the user's energy and demand requirements, the serving utility will be contacted at an early point in the planning process to assist in determining probable electric rates and charges. In dealing with a large user, the serving utility often has flexibility to negotiate a special rate. Where the new installation will be large, this aspect of utility charges will be vigorously pursued. A typical facility monthly electric bill will contain the following types of charges:

(1) Energy charge based upon kilowatt-hours (kWH) used. The energy charge may be based on time-of-day usage (the "on-peak" rate often being higher during the 12 daytime hours of the normal five day work week than during the "off-peak" remaining time). Additionally, many utilities charge more for energy used during the "peak-season" summer months than for energy used during the "off-peak-season" fall, winter, and spring months.

(2) Demand charge based upon the maximum kilowatts (kW) used. This charge is based on the maximum rate at which energy is used (kW demand) for a period of 15, 30, or 60 consecutive minutes (depending on the utility) during "on-peak" hours. Alternately, demand charges may be based partially on "on-peak" demand and partially on "off-peak" demand.

(3) *Power factor charge.* This charge may be based upon the facility power factor recorded during the maximum demand period or upon total kWH and total kilovar-hours (kVARH). Often the power factor adjustment is a multiplication factor applied to the kWH and/or the kW demand. Some utilities will charge a penalty for low power factor (below the 0.85 to 0.90 range) and offer a credit for a high power factor.

(4) *Fuel adjustment charge.* This charge is a surcharge or a credit to the energy charge and is based upon the price paid by the utility for fuel for its generating stations.

(5) *Facility charge.* This is a fixed monthly charge which is based upon the sophistication of the utility's revenue metering equipment, ownership (utility or user) of the main supply station(s), and number of points metered.

b. Revenue metering. A utility provides a totalizing watthour meter equipped with a demand register that is supplied by highly accurate instrument transformers. A demand type of varhour meter will be provided by the utility when the rate schedule includes a power factor charge. Utility meters cannot be used for any other purpose without prior approval by the utility. Revenue metering equipment will be provided by the Government only when required by the utility, and will comply with the utility requirements.

c. Energy conservation requirements. Reduction in energy usage is a national goal. Several programs have been implemented to effect energy reduction, including utility monitoring and control systems (UMCS). Provide for future UMCS monitoring by installing the following equipment during substation construction: potential and current transformers, watt and VAR transducers, circuit breakers with auxiliary contacts, and watt-hour meters with pulse initiators for interface to UMCS equipment. See TM 5-815-2 for additional information.

d. Power factor correction. Provisions for future installation of shunt capacitor equipment will not be initially provided in the main electric supply station. Power factor correction capacitors should be provided at or near the terminals of inductive devices to minimize energy losses in the electrical supply systems.

e. Protection. The ratings and settings of overcurrent protective devices will be selected to afford optimum protection of the electrical equipment and systems. Utilities will have additional requirements when any electric power generating units on the site are to be paralleled with the utility. The utility may also have special requirements for protection and coordination of its system on a nonparalleled installation. Some utilities have carrier relaying schemes, and may require the Government to provide line relays, or companion type relays, power supplies and housing for carrier relaying equipment. Auxiliary equipment such as batteries and chargers, annunciator panels, and supervisory or telemetering equipment may need to be provided or housed or supplied. Written utility requirements and approval of the system proposed will be obtained in the criteria development or early design stages of a project.

f. Short-circuit capacity. The available short-circuit capacity of the electrical power sources influences the design of circuit-controlling and protective devices located in the station, and those provided in the distribution system. The serving utility's future planned short-circuit current should be considered in the design as well as the short-circuit current available at the time of design.

g. Coordination study. A short-circuit study and a protective devices coordination study will be performed for each new or modified station or substation. The studies will be performed at a date early enough to ensure that proper equipment can be specified and proper protection provided. Refer to IEEE Std 242 and TM 5-811-14 for guidance regarding coordinated power system protection. A short-circuit and protective devices coordination study will be prepared to be used as a basis for equipment ratings and protective devices settings, and, for large projects, will include settings for 20, 40, 60, 80, and 100 percent load using typical devices.

4-5. Environmental Aspects.

The main electric supply station/substation should be as environmentally pleasing as possible without a significant increase in costs. The environmental impact will be evaluated for compliance with current local and Federal regulations. Army regulations are listed in AR 200-2.

a. Noise mitigation. The impact of transformer noise will be considered, particularly in developed areas or areas of planned development where noise abatement will be mandatory. In warehouse and industrial areas, noise impact will also be evaluated. Transformers with 115 kV primaries, that comply with ANSI and NEMA standards for noise levels, will transmit only about 50 to 55 decibels to a point 100 feet from the transformer. The most economical way of obtaining acceptable noise levels is to locate the station at least 100 feet from the nearest facility.

b. Appearance. The following requirements not only assure that the physical appearance of the station will be acceptable, but should decrease maintenance problems.

(1) *Structure-mounted equipment.* The use of metal structures with tubular or H-beam supports is considered the most desirable design. The conventional lattice structure is unattractive in appearance and more difficult to maintain. Except for incoming line structures which require the

extra height, low-profile structures will be installed.

(2) *Transformers.* Unit substations require less land space, are less visually objectionable and, because of the integrated transformer and secondary connections, are more reliable than transformers located separate from the associated switchgear.

(3) *Connection to aerial distribution lines.* Underground connections from a new or modified station to feeders or incoming lines will be provided when phase-to-phase voltage is less than 35 kV. Underground installation of cabling enhances the appearance of the station installation.

4-6. Incoming line Switching Equipment.

Equipment required for the switching of incoming lines, and for the protection of primary station elements when required, may be provided by the supplying utility or by the Government to meet any requirements of the utility and the needs of the using agency. The following applies to the instances where such equipment is provided by the Government, with the concurrence of the utility. The exact type, ratings and the consequent cost will depend on the protective coordination required, the voltage rating of the incoming lines or feeders, the full-load current and the fault current availability at the station. Figure 4-1 includes an example of converting fault MVA to symmetrical fault current. Refer to IEEE Std 242 for calculation and application of asymmetrical fault currents.

a. Circuit breakers. Circuit breakers are more costly than other equipment, used singly or in combination, to accomplish line switching and to protect station elements. However, circuit breakers will be used for all switching stations and substations, when stations are served by more than one incoming line or contain transformers rated 10 MVA or above, when economically justified, when required to obtain the required degree of reliability, or when their use is required for coordinated circuit protection or switching to limit the duration and frequency of outages to the installation. Circuit breakers will be of the oil or sulfur hexafluoride (SF,) type when the incoming line voltage is greater than 35 kV, nominal. When air and vacuum circuit breakers have adequate continuous current and interrupting ratings, those oilless types will be considered for use as line circuit breakers for lines rated at or below 35 kV. SF, breakers may also be used at line voltages below 35 kV. Standard ratings are listed in IEEE Std C37.04 and IEEE Std C37.06. The design of the station will include provisions to isolate circuit breakers and to bypass them with power fuse disconnecting units when required to ensure continued protection of station buses and equipment when circuit breakers are out-of-service. The bypass feature is not required if other circuit equipment can protect station elements when circuit breakers are inoperative, or if the utility line breakers afford the required degree of protection. Where only one incoming line serves the entire base or installation, disconnect switches and a fused by-pass switch unit will be specified to allow

USING VALUES BELOW

MVA = Utility company short circuit contribution in MVA

kV = Utility company transmission voltage in kV

kA_s = Utility company short circuit contribution in symmetrical kiloamperes (rms)

IN FORMULA BELOW

$$kA_s = \frac{MVA}{kV \times \sqrt{3}} \quad \ldots\ldots \quad (1)$$

EXAMPLE FOR DEVICE SIZING

Utility company transmission voltage = 69 kV
Utility company short circuit contribution = 1,200 MVA

$$kA_s = \frac{1{,}200}{69 \times \sqrt{3}} = 10\ kA \quad \ldots\ldots\ldots \quad (1)$$

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Figure 4-1. Converting Utility Company Short-Circuit MVA to Current.

power to be supplied to the installation during periods of maintenance on the single incoming line circuit breaker. The possibility of high transient recovery voltages should be coordinated with the manufacturer and ANSI C37.011.

b. Power fuse disconnecting units. Power fuse disconnecting units may be used in conjunction with incoming line switches where circuits have a nominal voltage class of 46 kV through 169 kV and where required interrupting and continuous current ratings of fuses are not larger than those available. ANSI C37.46 lists maximum voltage and maximum interrupting ratings. Power fuses will be selected on the basis of maximum line-to-line voltage, regardless of whether the fuse will be applied to a grounded or ungrounded neutral system. Electrical clearances and spacings will comply with the clearances listed in ANSI C37.46. Selection and application of power fuse disconnecting units will be in accordance with IEEE Std C37.48.

c. Metal-enclosed interrupter switchgear. Metal-enclosed interrupter switchgear is more economical than circuit breakers in the initial cost, and may be used when more expensive switching and protective equipment cannot be justified. The use of such switchgear is to be limited to stations supplied by incoming lines rated 35 kV or below, and should be used primarily for unit substations and industrial or power plant applications. Metal-enclosed interrupter switchgear may be provided for primary protection of power transformers and for incoming line ties which are a part of a primary unit substation, when circuits have a nominal voltage class of 35 kV or lower and required interrupting and continuous current ratings of fuses are not larger than those available. Interrupter switchgear may also be used as a substitute for metal-clad switchgear equipped with power circuit breakers in certain instances. Since metal-enclosed interrupter switchgear is provided as a less expensive alternative, the increase in cost to provide motor operation or walk-in aisle space is rarely justified. Preferred ratings are given in IEEE Std C37.20.3 and ANSI C 37.32. Selection and application of metal-enclosed interrupter switchgear will be in accordance with IEEE Std C37.20.3 and IEEE Std C37.32.

d. Fault-interrupter switches. Fault-interrupter switches may be used for line switching and fault protection of station elements as a less costly substitute for circuit breakers. The interrupting ability of the switches is limited and their operation must be blocked if fault currents exceed the interrupting rating of the switches. This requires that a circuit breaker on the line side of the switch operate to clear the fault. Therefore, permission of the utility company must be obtained for the use of fault-interrupter switches when the circuit breaker or protective element ahead of the switches is under the exclusive control of the supplying utility, and the available fault current exceeds the interrupting rating of the fault-interrupter switches. These types of switches should not be used when the station is supplied by only one incoming line when the switches are to be used for the opening and closing of the line, as opposed to the protection of transformers and separate line switching equipment. The interrupting element of the switches is an SF, unit. Single SF, interrupter models are available at the following nominal voltage levels: 34.5, 46, 69, 115, 138, and 161 kV. Since there is considerable variation in interrupting ratings from manufacturer to manufacturer, fault-interrupter switches should be carefully specified only after the short circuit study has been completed.

e. Manual and motor-operated disconnect switches. Manual or motor-driven, group-operated disconnect switches may be used for line switching, as well as isolation of station elements, under no-load conditions. This requires the use of such switches in conjunction with other circuit protective and switching equipment. Disconnect switches must be interlocked with other equipment to ensure operation only under no-load conditions. For manual switches this may require key interlocking and for motor-driven switches this may require electrical interlocking, with the transformer's main secondary breaker. Serving utility practice and Using Agency operating requirements at each installation should be reviewed before specifying a manual or motor-driven disconnect switch. If there is an operating requirement for automatic opening of the disconnect switch, then the motor-driven variety should be specified. Where rapid and definite switch operation is required, for reasons of personnel or equipment safety (especially for larger switches at high-voltage levels), specify a motor-driven switch. Without a specific reason for a motor-driven disconnect switch, the less costly manual switch should be specified.

f. Sulphur hexafluoride (SF_6) equipment. Guidance for gas-insulated substation equipment is contained in IEEE C37.123. Each SF, interrupter, if located inside a structure, must be located in a room with direct outdoor ventilation and sensor unit which activates the room vent fan and a room entry alarm when the oxygen level in the room is above 19.5 percent. This requirement is to preclude jeopardizing personnel life or health. The entry alarm will be automatically silenced when the oxygen in the room is above 19.5 percent. Designs will require provision of an SF, gas sensor, controls, alarm, and calibration of the sensor system to indicate the unsafe level of SF, gas for personnel.

4-7. Substation Equipment.

a. Power transformers. Power transformers will be the outdoor, liquid-filled type. A more detailed discussion of transformers is presented in chapter 8.

(1) *Quantity of substation transformers.* The quantity of substation transformers to be installed in an existing substation will depend on the present configuration and features of the substation, and on any requirements of the utility and the Using Agency. The number of transformers to be installed in new substations should be two of like design, ratings, and characteristics when the maximum substation capacity is 40 MVA or less. A larger quantity may be required for substations with a greater capacity to comply with reliability, availability, or maintainability criteria of the Using Agency. The exact number of power transformers may be determined by the utility if transformers are to be supplied by the utility. Coordination with the utility and the Using Agency will be required when requirements imposed by the utility or the Using Agency dictate the design of new or modified substations. In any instance, a new substation should be constructed with not less than two transformers of ample capacity to prevent the outage of one transformer from causing a complete loss of power to an installation. This is not meant to always require 100 percent redundant transformer capacity. Unless 100 percent normal operation is required with one unit out of service by the Using Agency, each transformer should be sized from 50 to 75 percent of load for two transformers, or from 33 to 67 percent of load for three transformers.

(2) *Capacity of substation transformers.* The capacity of a new or modified substation transformers will be adequate to supply all installation or project demands determined during design. The capacity of substations will be sufficient to accommodate expected load growth in later years. Load growth should be based on increases of one to five percent of the estimated peak load per year, when more exact load growth information is not available. The base capacity or rating of new transformers will be the self-cooled rating for a 55 degrees C unit. Increased capacity of individual transformers will be obtained by specifying a dual thermal rating and forced-cooling provisions when available and necessary to accommodate load growth, and to allow for overloading of transformers without sacrificing transformer life.

(a) Dual thermal rating. Transformers with a dual thermal rating of 55/65 degrees C will permit operation of the transformers at 112 percent loading in a maximum daily average ambient temperature of 30 degrees C.

(b) Forced-air-cooling. Only single-stage fan cooling is available for the smaller sizes of power transformers. Single-stage air-cooling will provide an additional 15 percent capacity to units base rated 750 kVA to 2000 kVA and 25 percent for units base rated 2.5 to 10 MVA. Either single-or dual-stage forced-air-cooling can be obtained for units base rated 12 MVA and above, and will provide a 33.3 percent increase in the transformer capacity for each of the two stages of cooling. Single-stage cooling will be specified for all transformers when that option is available, and when the selection of that option is more cost effective than increasing the self-cooled rating of transformers to accommodate peak demands of limited duration. Provisions for future second-stage cooling will be specified for transformers when the option is available. Second-stage cooling may be specified to be provided initially when load demands are expected to increase substantially in early years following construction of the station, because of planned expansion of facilities at the installation.

(3) *Example of determining station capacity.* Figure 4-2 contains an example of determining the capacity of a new substation, based on the assumptions given. The example and the preceding assumes that power transformers will be installed in a daily average ambient temperature of 30 degrees C or less. The capacity and features of power transformers will be determined and selected in accordance with industry practices and standards when transformers are to be installed in a higher ambient temperature region, or when other assumptions made do not suit actual site conditions or standard transformer designs. Unusual service conditions will be determined and compensation will be made in specifying substation equipment.

(4) *Load-tap-changing (LTC) transformers.* Transformers may be equipped with manual tap changer mechanisms, operated under de-energized conditions, or automatic LTC mechanisms to compensate for voltage changes under varying load conditions. Automatic LTC transformers provide a convenient method of compensating for voltage changes in the primary or secondary voltage systems. However, failure of such automatic LTC provisions may cause the outage of the associated power transformer during the period required to

ASSUME LOADING

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Estimated peak load . . . . . . . . . . . . . 15 MVA
Estimated peak load duration. . . . . . . . . 8 hours
Estimated constant load . . . . . . . . . . . 7.5 MVA
Estimated constant load duration. . . . . . . 16 hours
Estimated load growth (not compounded). . . 3 percent per year
Estimated life of substation. . . . . . . . 25 years
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ASSUME INITIAL PROVISIONS OF

Two 7.5 MVA transformers (55/65 C temperature rise and 25 year life), which when provided with forced-air-cooling will raise capacity to 9.375 MVA at a 55 C temperature rise and to 10.5 WA at a 65 C temperature rise. Also assume space for future installation of a similar third unit.

AVAILABLE EXTRA CAPACITY AT 30° C AMBIENT

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1. Running transformers at 65 C (8.4 MVA) rather than
      55 C temperature rise . . . . . . . . . . . . . . . . . . . 12%
2. Using IEEE Std C57.92 peak load factors for normal
      life expectancy -
        Table 3(a) for self-cooled (OA) operation . . . . . . . 18%
        Table 3(e) for forced-air-cooled (FA) operation . . . . 13%
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CALCULATE TIME WHEN EACH CAPACITY INCREASE IS REQUIRED

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1. Length of time original capacity is acceptable:
      Total peak load capacity - 2 x 7.5 MVA x 1.12 x 1.18 - 19.8 MVA
      Peak load growth - 15 MVA + (15 MVA x 3% per year x 11 years) = 20.0 MVA
      Add forced-air cooling in eleventh year.
2. length of time fan cooling capacity is acceptable:
      Total peak load capacity - 2 x 10.5 MVA x 1.13 - 23.7 MVA
      Peak load growth - 15 MVA + (15 MVA x 3% per year x 20 years) = 24.0 MVA
      Add additional forced-air-cooled unit in twentieth year.
3. Ability of three units to handle capacity for 25-year life:
      Total peak load capacity - 3 x 10.5 MVA x 1.13 - 35.6 MVA
      Peak load growth - 15 MVA + (15 MVA x 3% per year x 25 years) - 26.3 MVA
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TO PROVIDE FOR ASSUMED LOADING

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1. Initial design . . . . . . . . . . . . . . . . . Install two 7.5 MVA units
2. Eleventh year. . . . . . . . . . . . . . . . . . Add forced-air-cooling
3. Twentieth year . . . . . . . . . . . . . . . . Add third 7.5 KVA unit
4. At end of 25-year life . . . . . . . . . . . . Units 74% loaded
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Figure 4-2. Example of Sizing Substation Transformer Capacity.

repair the automatic LTC mechanism. Separate voltage regulation equipment, therefore, is the preferred method of voltage regulation when a substation is equipped with only two transformers or a larger number of transformers that are incapable of supplying daily power demands during the outage of one automatic LTC transformer. Specification of automatic LTC transformers, or manual tap changer for de-energized operation (TCDO) features in conjunction with separate three-phase voltage regulators, should consider the effects of power factor correction capacitors when installed in the substation to improve the power factor. Capacitors do not regulate voltage unless they are automatically switched. However, they do increase the voltage level.

(5) *Transformer arrangement.* Transformers will be arranged for connections as shown in "arrangement one" in figure 4-3. Such an arrangement allows for the least expensive method of adding new transformers or switchgear in the future. Where the double-ended configuration shown in figure 4-3 is used, the substation will be configured to be served from two different transmission line sources. To increase the operational availability, consider bringing two different sources into the substation if the sources are available from the same commercial utility. Where service is available from a commercial loop or network system, the configuration will include provisions to serve the substation from either side of the loop or network source. Additional costs will be justified based on the facility mission, availability requirements, and/or an analysis of operation maintenance requirements which demonstrate significant increases in the availability factor (outage

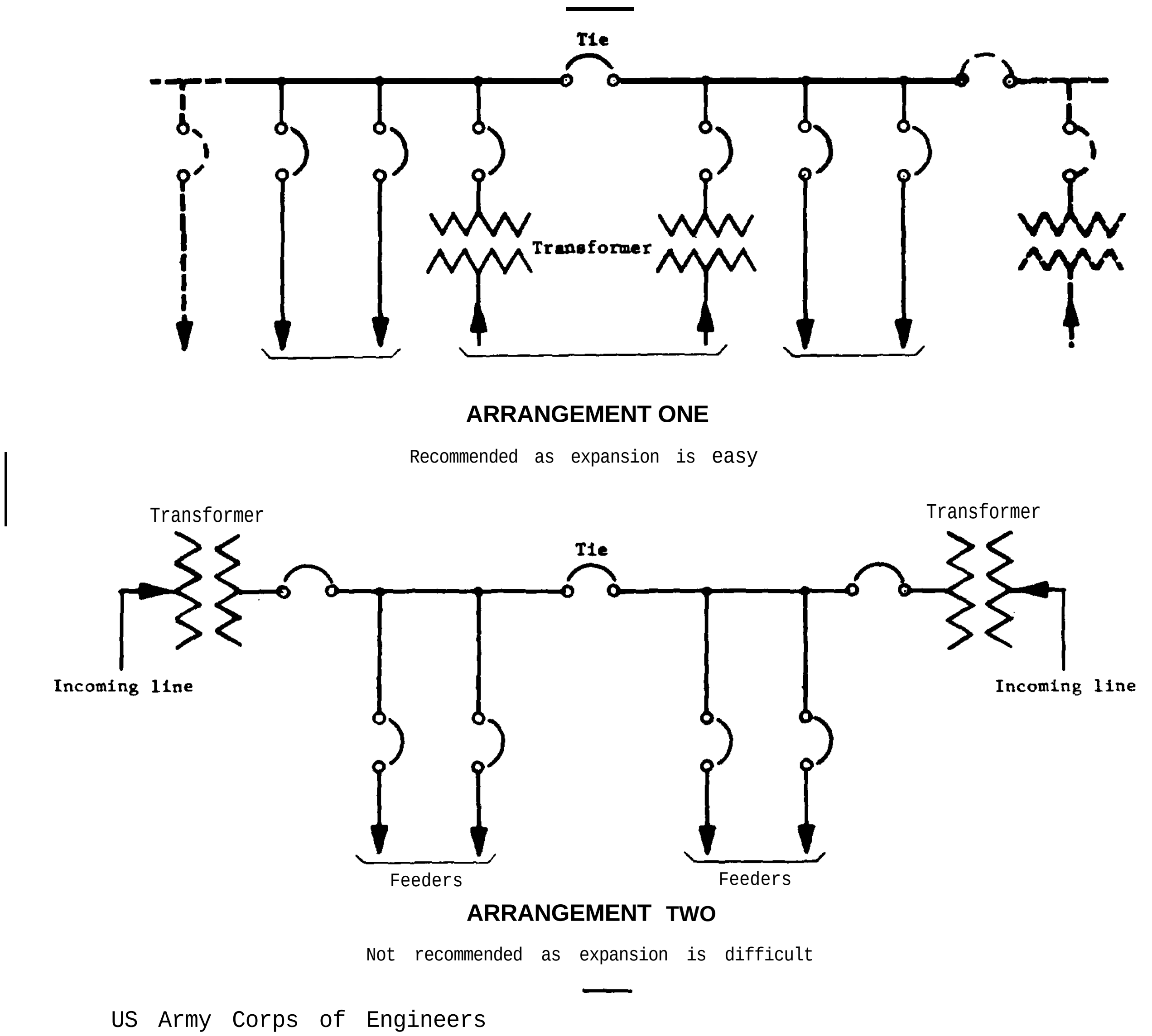

Figure 4-3. Single-Line of Primary Unit Substation with Two Transformers

time divided by the operating time during the analysis period).

(6) *Loss evaluation.* To ensure that a power transformer with specific losses is delivered by the manufacturer, a loss evaluation/economic evaluation will be performed in accordance with guidelines in IEEE C57.120. When the evaluation indicates a significant cost advantage over the life of the transformer, the designer will determine the cost of transformer losses, using the energy rates at the installation under design, and incorporate loss requirements in the project specification. The project specification may also include provision for rebates to the Government if loss requirements are not met, and additional payment to the Contractor if loss requirements are exceeded.

b. Voltage regulators. Voltage regulation will be provided when required to obtain acceptable voltage levels at either new or existing stations. Step-voltage regulators may be required for switching stations and in substations that are not equipped with circuit study for a medium-voltage bus, only medium-voltage motors should be considered. The short circuit current contribution from low-voltage motors dies out very rapidly and is further reduced by the impedance of the medium-to-low voltage transformer. Low-voltage motor feedback is considered only when calculating the short-circuit currents on the secondary system common to the motor and its source transformer(s).

c. Design of station. The initial design of new stations will include provisions to facilitate the addition of future lines, transformers, and associated equipment to minimize the expense for station expansion in later years. The area, fencing, grounding and station arrangement will be such

Transmission voltage - 69 kV

Distribution voltage - 13.8 kV

Assumed utility
short circuit capacity - Infinite

Assumed transformer rating - 25 MVA

69 kV corresponds to 350 kV BIL

Assumed transformer impedance - 8 percent

(25 MVA)/(0.08 percent) - 313 MVA

Use 500 MVA circuit breaker rating

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Figure 4-4. Circuit Breaker Interrupting Rating Approximation.

as to permit the installation of an additional incoming line and at least one additional power transformer and related equipment or materials in the future with a minimum of modifications. Station access roads, vehicle and personnel access gates and other station elements should be initially located to avoid relocation if the station is expanded in the future. Switching stations or conventional substations should be similarly designed to allow for future modifications at a minimum of cost. The design of modifications to existing stations should also allow for future expansion to the station with a minimum of expense whenever expansion is likely or possible.

4-8. Miscellaneous Station Design Criteria.

a. Metering and relaying. Meters and relays will be limited to the types and number required to comply with any requirements of the utility or the Using Agency, or to afford adequate protection of electrical power systems. Ranges selected will be based on the coordination study. Meters will be true RMS as required. Refer to TM 5-811-14 and IEEE Std 242 for guidance regarding coordinated power system protection.

(1) *Oil circuit breakers.* An ammeter and switch and phase over-current relays will be used when oil circuit breakers are specified. The meter and relays will be supplied by current transformers mounted in the bushing wells of the oil circuit breakers. IEEE Std 21 requires that potential taps be provided only on bushings having an insulation class of 115 kV or above. Therefore, separately mounted potential transformers will be specified when the incoming line voltage is less than 115 kV and when a potential source is required for instruments or relays. Otherwise, potential taps on bushings are to be specified.

(2) *Buses.* The metering of station buses is not required. Separate bus differential relaying provisions will be specified only when protection against bus faults is deemed to be sufficiently important to warrant the additional expense. Instead, consideration will be given to the relaying of buses in conjunction with any transformer differential relaying scheme. IEEE surveys indicate an extremely low failure rate on buses, with most failures attributed to the lack of adequate maintenance. This is opposed to the usual causes of electrical faults, such as birds, ice, lightning, wind, etc., or their effects.

(3) *Transformers.* The metering of transformer mains or conductors between the transformer secondary terminals and the switchgear is described below. The minimum relaying requirements are noted in table 4-1. Relays and meters or instruments will be located in the metal-clad switchgear.

(4) *Metal-clad switchgear.* Minimum metering requirements are indicated in table 4-2, and are in addition to any revenue metering or other types of metering required by the utility or the Using Agency. Minimum relaying requirements are similarly shown in table 4-3. Provisions will be made

Table 4-1. Minimum Relaying for Transformers

Relay function	*ANSI &vice number*	*Transformer minimum unit capacity or other requirement*	*Device actuation*
Winding or top oil temperature	49		Forced-air cooling and alarm reporting system
Fault (sudden) pressure	63	On all units where the primary breaker can be tripped	Tip and lock-out primary and secondary via 86T relay
Transformer differential	67	Only where a primary circuit breaker is provided and unit is 10 MVA or larger, except where justified for smaller units	Primary and secondary circuit breaker tripping and lockout via 86T relay

Table 4-2. Minimum Metering for Metal-Clad Switchgear

Type of meter	*ANSI abbreviation*	*Circuit metered*
Ammeter and 3-phase switch	AM	On all mains. On feeders only when transformer unit capacity exceeds 2.5 MVA
Voltmeter and 3-phase switch	VM	On all mains
Wattmeter	WM	On all mains. On feeders only when transformer unit capacity exceeds 10 MVA
Varmeter	VARM	On all mains
Watthour demand meter	WHDM	On all mains. (Demand period to correspond to the utility demand period)

Table 4-3. Minimum Relaying for Metal-Clad Switchgear

Relay function	*ANSI device number*	Circuit *breaker application*
Nondirectional overcurrent, phase and ground	51 and 51G or 51N	On all mains when short circuit current can flow in only one direction. The 51G relay should be used when a CT can be installed in the main transformer neutral-to-ground connection, otherwise the residually connect 51N should be used. "50" relays should not be used since coordination with downstream feeders is impossible.
Nondirectional overcurrent, phase and ground	50/51 or 51 and 50GS 50N, or 51N	On all feeders when short circuit current can flow in only one direction. The 50/51 relay should be used when there is no down-stream protective device. Use the 51 device when there is downstream protection. Where possible and where there is no downstream protection, use a zero-sequence ground-sensor, donut CT for sensitive 50GS protection. Where instantaneous protection is required but a ground-sensor cannot be used, specify the residually connected 50N device. Use the 51N where there is down-stream protection.
Directional overcurrent, phase and ground	67 and 67N	On all mains and tie lines when short circuit current can flow in both directions.
Automatic circuit reclosing	79	Feeders serving long overhead lines, except that the 79 relay may be installed on the main instead of the feeders when the transformer base rating is 2.5 MVA or lower.
Bus differential	87B	On all circuit breakers connected to the main supply station/substation bus.

for monitoring energy demand and consumption for the purpose of demand limiting or energy reduction required for separately specified energy monitoring and control system equipment. Such provisions will be limited to empty raceways extended from beneath switchgear units to a point two feet external to the switchgear foundation; to providing instrument transformers; and to furnishing transmitting devices.

(a) Automatic circuit reclosing relays. Automatic circuit reclosing relays should be specified for use in conjunction with aerial lines. Reclosing relays should be considered jointly with sectionalizing switches which should be installed to minimize the duration of outages of power to other facilities served by the same aerial line, as a result of sustained faults. The use of sectionalizing switches should be considered in relation to the line length and frequency of lightning storms at the installation as well as the nature of the loads. Studies indicate that between 75 and 90 percent of the faults on aerial lines are temporary and self-clearing, and are most commonly caused by lightning, "brushing" by tree limbs, "galloping" conductors, birds, and other external causes of a momentary nature. Such external causes are not common to underground cable systems. Therefore, the use of automatic circuit reclosing relays or other devices cannot be justified for underground feeders. For overhead feeders fed from metal-clad switchgear, a reclosing relay (device 79) may be added in accordance with table 4-3. In applying reclosers, consideration must be given to the continuous and short-circuit-interrupting ratings and to the selection of reclosing sequence. When two or more reclosing devices are connected in series, proper coordination is required between pick-up settings and reclosing sequences. Automatic reclosing should not be used on tie lines where there is a second source or on lines with an on-line genera-

tor. Additionally, lines serving large motors (above 50 hp) require special consideration before applying automatic reclosing. For these cases, improper application of automatic reclosing can result in an out-of-synchronism condition with catastrophic consequences. Refer to REA Bulletin 65-1 for additional guidance.

(b) Directional overcurrent or power relays. Relays will be specified when required to protect against the reverse flow of current or power when on site generation exists or is to be provided at the installation. Similar protection is to be afforded when electrical power is to be provided *over* separate incoming lines owned by different utilities and relaying is required to detect and correct abnormal conditions on the transmission or distribution lines that serve the installation.

(5) *Protective devices coordination.* A coordination study is necessary to determine settings of adjustable protective devices and ratings of associated power fuses. Coordination studies will be conducted in accordance with TM 5-811-14, IEEE Std 242, and chapter 1 of this manual.

b. Instrument transformers. Instrument transformers will be selected and applied in accordance with the references listed below. Accuracy classes are listed in IEEE Std C57.13. The designer will check the burdens connected to determine the actual accuracy class required.

(1) *Current transformers (CT) for power transformers.* For power transformer bushing type CTs, short-circuiting type terminal blocks will be located in the transformer terminal cabinet and in the switchgear or instrument and relay cabinet, as applicable. Where primary current sensing is necessary and neither oil circuit breakers nor primary switchgear are available, bushing-mounted CTs will be provided on power transformers. ANSI C57.12.10 permits a maximum of two CTs per bushing for power transformers. The number of CTs required is dependent upon whether differential relaying is required, whether the burden rating of a single transformer is adequate, or whether separate sets of current transformers are required for primary and backup relaying. Since instruments and meters are provided on the secondary side of power transformers, metering class accuracy is not necessary for most applications, unless devices specified in the project specifications are used for revenue metering. Only relaying class accuracy is available for multi-ratio units, so that when metering class accuracy is required, single-ratio units must be specified. The accuracy class ratings of CTs at standard burdens are given in IEEE Std C57.13. ANSI C57.12.10 requires a relay accuracy class of C200 minimum for CTs in power transformers. A "C" classification means the ratio error can be calculated, whereas a "T" classification is one which has to be derived by testing. IEEE Std C57.13 permits either classification.

(2) *CTs for circuit breakers.* Table 4-4 lists acceptable CT ratings for outdoor circuit breakers. For oil circuit breakers, short-circuiting type terminal blocks for CT leads will be located in the operating mechanism cabinet, and also in the metal-clad switchgear, if provided, or in the instrument and relay cabinet if metal-clad switchgear is not provided.

(3) *CTs for protective relays.* The following protective relays, where used, will have three-phase-sets of current transformers exclusively dedicated to their own use: bus differential relaying (87B), generator differential relaying (87G), line differential relaying (87L), motor differential relaying (87M), transformer differential relaying (87T). Ground sensor (zero-sequence) type CTs will be connected only to the ground fault relay since these CTs are unable to accurately serve any other relaying or metering.

(4) *CTs for metal-clad switchgear.* For metering CTs, the designer will specify the CT ratio and accuracy class based upon the present and future load current and the total connected burden. IEEE Std C37.20.2 lists accuracy class ratings for metal-clad switchgear. For protective relaying CTs, the designer will specify the CT ratio and the relaying accuracy class based upon the present and future full load current, the maximum short-circuit current available (including DC offset), interconnection with other CTs (if required), and the total connected burden. Separate three-phase-sets of CTs will be used for protective relaying and for metering on mains, ties, and feeders. For a feeder, if the only metering is an ammeter-and-switch, then both metering and relaying may be served by the same set of CTs.

(5) *Voltage transformers (VT).* VTs will be specified in sets of two (V-V connection) for 3-wire systems or three (Y-Y connection) for 4-wire systems. Single VTs may be specified for use with synchronizing/synchro-check relays (device 25) or under/over-voltage relays (devices 27, 59, or 27/59). Since VTs can be connected on either the source side or the bus side of the main circuit breaker, consideration will be given to metering and relaying needs before specifying the connection location. VTs will be connected to the source side of the main circuit breaker (and to the generator-side of generator breakers, if present); however, where there is a double-ended bus or a second source connected to the bus, an additional set of VTs (connected to the bus) may be needed. Where

Table 4-4. Current Transformer (CT) Accuracy Class Ratings for Outdoor Circuit Breakers

Nominal Voltage Class	*CT Ratio*	*"C" or "T"* *Accuracy* Class
	RELAYING SERVICE (MULTI-RATIO UNITS)	
115kV	1,200:5	800
	2,000:5	800
	3,000:5	800
	4,000:5	800
	5,000:5	800
69 kV	1,200:5	400
	2,000:5	800
	3,000:5	800
46 kV	600:5	100
	1,200:5	200
	2,000:5	400
	3,000:5	400
	4,000:5	800
	5,000:5	800
	METERING SERVICE (SINGLE-RATIO UNITS)	
115 kV to 46 kV	300:5	0.6B-0.5
	600:5	0.6B-0.5
	800:5	0.6B-0.5
	1,200:5	0.3B-0.5
	1,500:5	0.3B-0.5
	2,000:5	0.3B-0.5
	3,000:5	0.3B-0.5

metering VTs are provided, a 0.3 accuracy class will be specified, if available for the voltage rating and burden needed.

c. Control power. An ac power source will be provided to supply power to station equipment requiring an alternating-current source of power. An ac power source will also be provided when the utility or Using Agency requires a capacitor-tripping scheme for circuit breakers or other power switching apparatus to permit tripping following a power outage to the station. Otherwise, and because of greater reliability, a dc power source will be provided for the close and trip operations of circuit switching equipment, and for other equipment rated for direct-current applications. The dc power source will be a lead-calcium type of battery rated at 48 V, or at 125 V when the additional cost is warranted because of the ampere-hour capacity required to supply station loads. A battery-charger will be provided to ensure that the battery is fully-charged at all times. The battery charger will be equipped with separate alarm lights to indicate low ac source input voltage and low dc output voltage. In addition, alarm contacts will be provided for remote annunciation of low ac input and low dc output voltages. The battery and charger and a direct-current panelboard should be installed in the station switchgear assembly, to avoid the additional cost for a separate enclosure. The battery, charger and panelboard should be installed in a separate enclosure only when the capacity, voltage rating and consequent size of the battery warrants a separate housing, or when a separate control house is required to house the battery, charger, panelboard, annunciators, carrier current, supervisory, telemetering, relaying or other instrumentation or control equipment.

d. Control buses. When a tie circuit breaker is provided in a switchgear lineup, a control-power automatic-transfer-system will be provided to allow full control function even with the loss of either source. To accomplish this, the designer will specify that each bus be provided with a control power transformer (CPT) connected, via overcurrent protection, to the source side of the main circuit breaker or switch. Each CPT will be sized to easily handle the total control power requirements of both buses. The secondaries of the CPTs will be connected to the input terminals of a transfer relay, transfer contactor, or automatic transfer switch, depending upon the size of the load and the specific installation requirements. All the load for both buses will be connected to the output terminals of the transfer device. Upon loss of the "Normal" source, transfer to the "Backup" source should be instantaneous and retransfer back to the "Normal" source should be automatic. Features such as selectability of which source is

"Normal" and which is "Backup"; alarm in case of transfer; alarm in case of loss of a source; and time delay on retransfer will be specified depending upon the application.

e. Other equipment and personnel protection.

(1) *Surge protection and grounding.* Grounding, and surge protection against lightning and switching surges, are discussed in chapter 9.

(2) *Station enclosure.* A station fence, with three strands of barbed wire above a seven-foot high fence fabric, is the minimum requirement. Other station enclosure materials, or heights, may be required to provide equipment masking, sound attenuation, or protection against sabotage. A minimum lo-foot wide vehicle gate, a 3-foot wide personnel gate, and a sufficient access space for removal and replacement of station elements is required to permit maintenance or modifications to the station without interruption to the electrical service. Fencing will be grounded in accordance with IEEE Std 80 and the NESC.

f. Station protection and structures.

(1) *Station line structures. The* standard design of the manufacturers of aluminum or galvanized steel structures will be used to avoid the greater costs associated with specially designed structures. Structures will be designed to withstand all dynamic, static, or seismic forces that are likely to be imposed on structures during a 25-year life of the station, without damage or failure. A minimum of 1,000 pounds of tensile force will be assumed for stranded conductors to be terminated on station structures when conductors originate and terminate within the station, or when the station is supplied by incoming line conductors installed slack between the last pole or structure and the dead-end pole or structure within the station. Figure 4-5 is an example of a substation with incoming line structures for incoming lines rated 46 kV or above. Switching stations or substations with primary protective devices, and underground connections to the utility line, are all that is necessary for an incoming line voltage of 35kV or less. Figure 4-6 is an example of a switching station that is suitable when the incoming line voltage is 35 kV or less. Fenced outdoor switchgear will be less costly than indoor switchgear installed in a concrete-block structure without fencing. Aesthetic features and requirements may determine whether an indoor or outdoor installation is specified.

(2) *Protection.* The main electric supply stations will be protected against "lightning strikes" and the effects of lightning on incoming aerial lines. Protection of stations against lightning strikes to the station elements will be provided by static wires and aerial terminals installed above and on poles or structures to provide the necessary "cone of protection." Ground conductors will be grounded to the station ground grid and will be protected against physical damage and corrosion to terminations for ground conductors.

(3) *Foundations.* Foundations will be designed to support static, dynamic, and seismic loads of station elements. The designer will formulate foundations details based on the maximum loading on foundations by the equipment specified. A maximum soil bearing pressure of 4,000 pounds per square foot will be used as a basis of design. However, since sandy or soft clay soils can have soil bearing pressure of as low as 2,000 pounds per square foot, a knowledge of the actual site conditions may be necessary. When necessary to determine the actual soil type and bearing pressures, soil borings will be made and the resulting analysis will be used in the design. The guidelines contained in NEMA SG 6 will be used during designs, and will include a minimum safety factor of 1.5 for overturning loads.

(4) *Station and substation insulators.* Suspension insulators will be used to dead-end incoming line conductors, and apparatus post insulators will be used where conductors terminate on apparatus. Table 4-5 lists ratings of primary insulators by class. When specifying suspension insulators, select the appropriate ANSI Class dependent upon whether ball and socket (Class 52-3) or clevis eye (Class 52-4) suspension insulators are required or whether the choice can be a Contractor's option. The number of suspension insulators in tandem and the choice of the NEMA Technical Reference Number (TR) for apparatus post insulators are dependent upon the voltage level and the degree of atmospheric contamination. Lower ratings and fewer numbers of units than those shown in table 4-5 will not be used. Use the lower TR number in areas where the atmosphere is dry or where fog occurs only to a limited degree and there is no more than a moderate contamination from industrial type of activities. Use the higher TR number in areas where the atmosphere can be damp because medium to heavy fog is a common occurrence and there is a medium contamination.

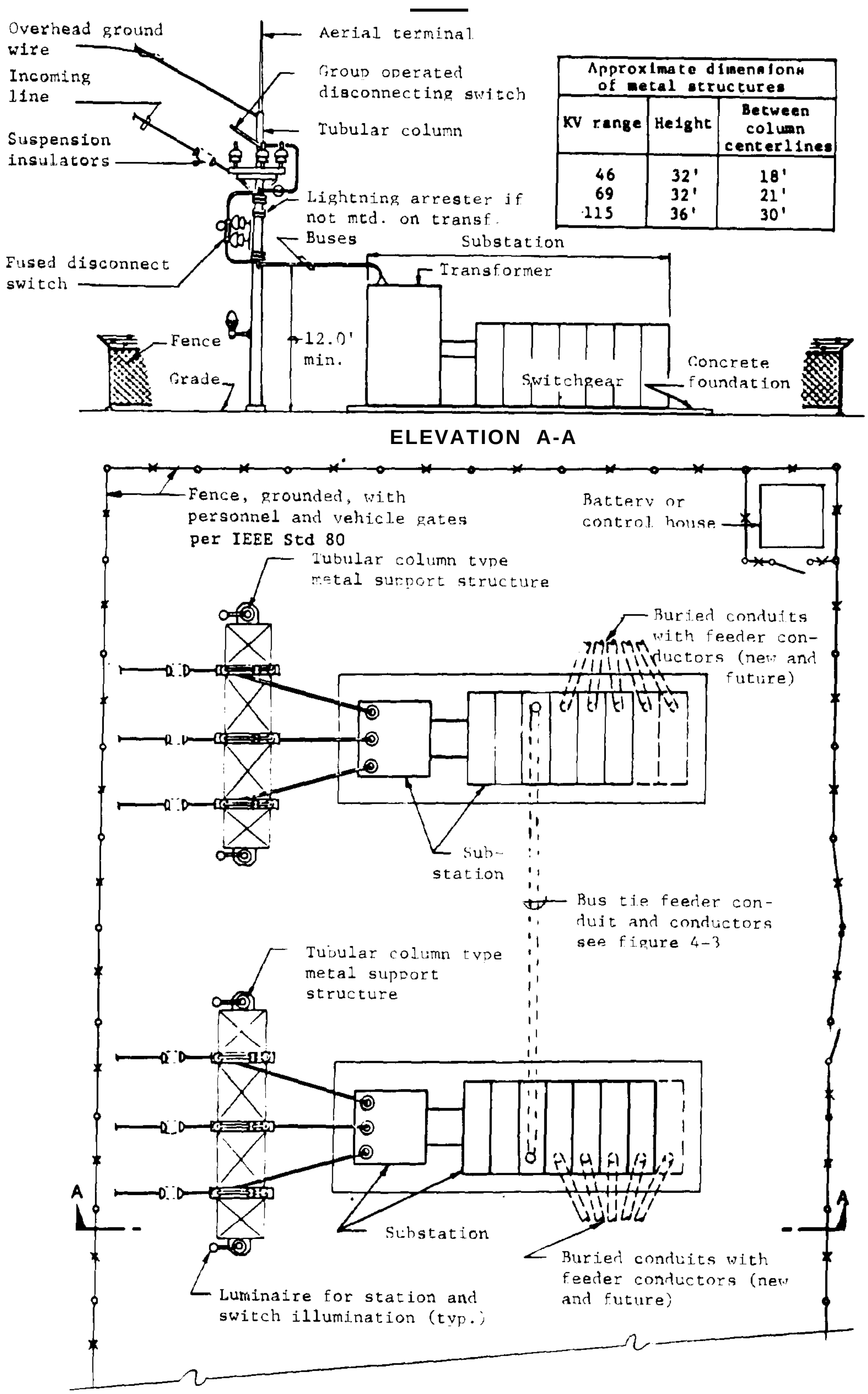
(5) *Station lighting.* Lighting levels will be in accordance with the levels listed in the NESC.

4-9. Substation Equipment at Air Force Installations.

a. Switchgear. Requirements are as follows:

(1) *Incoming supply section:*

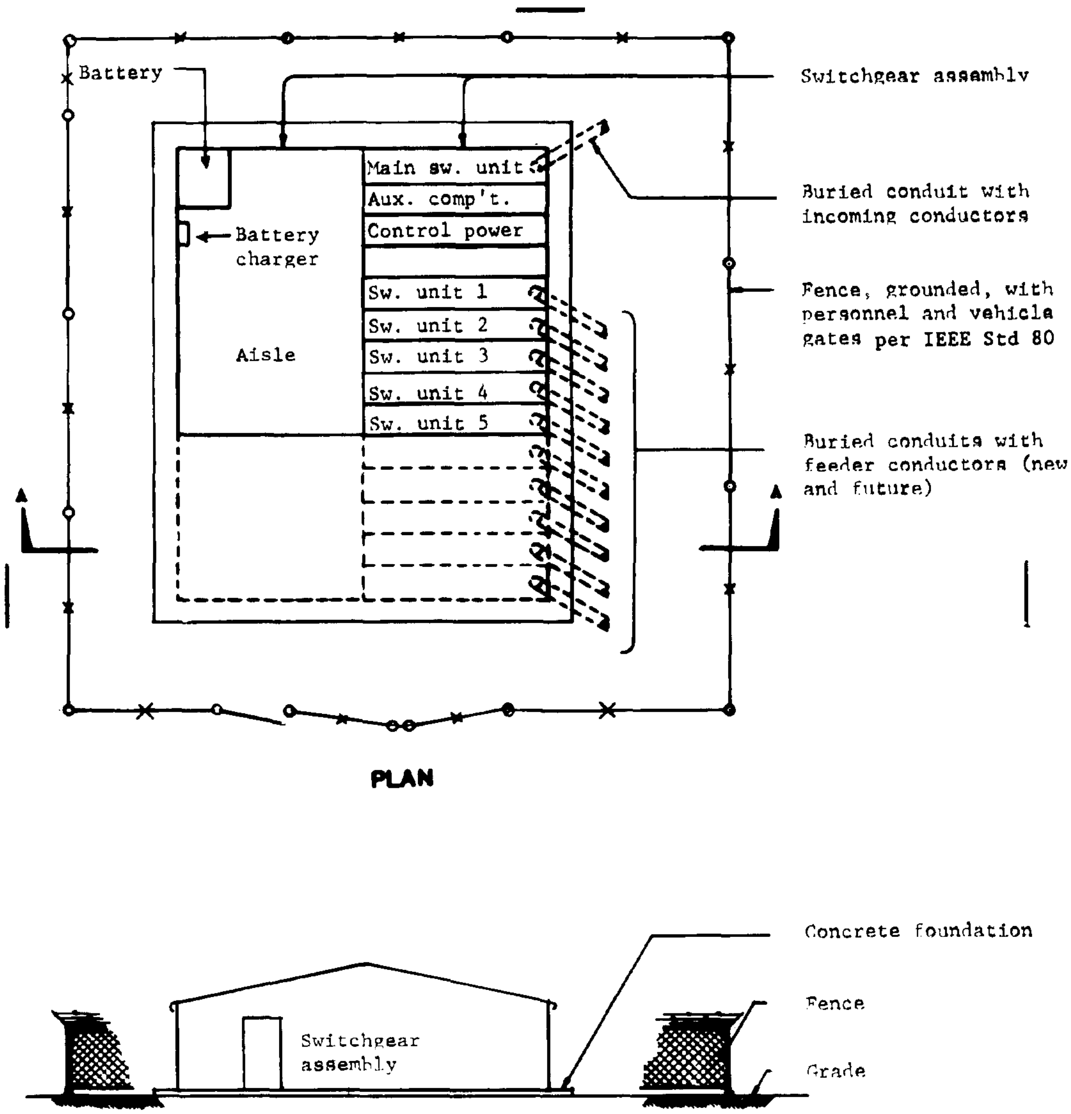
(a) Switches. Loadbreak/load interrupting, current limiting integrally or separately fused,



Approximate dimensions of metal structures		
KV range	Height	Between column centerlines
46	32'	18'
69	32'	21'
115	36'	30'

US Army Corps of Engineers

Figure 4-5. Primary Unit Substation, 46 kV Minimum.



US Army Corps of Engineers

Figure 4-6. Main Electric Supply Switching Station, 35 kV Maximum.

Table 4-5. Primary Insulator Ratings by Class.

Nominal Voltage	*NEMA* *TR*	*ANSI* *Class*	*Number*
115 kV	286; 288	52-3; 52-4	8; 9
69 kV	216; 286	52-3; 52-4	5; 6
46 kV	214; 216	52-3; 52-4	4; 5

group/gang operated, vacuum, sulfur hexafluoride (SF,), or other dielectric as approved by the Host Command coordinated with the Requiring Command (HOST/REQ CMD).

(b) Circuit breakers. Outdoor power type, metal-clad, sheltered aisle type, vacuum or air dielectric, group mounted, or individually mounted with vacuum, SF,, or other dielectric as approved by the HOST/REQ CMD.

(c) Metering. Ammeter, voltmeter, wattmeter, varmeter, and watthour demand meter. Provide strip-chart recorders if approved by the HOST/REQ CMD.

(d) Phase and ground undercurrent relays. A separate undercurrent relay shall be provided for each phase and for ground fault detection. Directional overcurrent relays shall be used to detect short-circuit current flowing in a particular direction. Directional power relays shall be used to detect power flow from Air Force generators into a commercial system. Other relays, such as transformer differentials, should also be installed as required by sound engineering practices.

(2) *Feeder sections.* Metal-clad sheltered aisle type, vacuum or air, dielectric, group mounting

circuit breakers are preferred. Metal enclosed circuit breakers or fused interrupting switches may be allowed depending upon the application and economics. Metering and relaying requirements are the same as (1) (c) and (d) above. Automatic reclosing relays shall be installed on each overhead feeder circuit. Automatic reclosers and sectionalizers shall be utilized on overhead circuits as called for in the coordination short-circuit study.

(3) *Operating equipment for breakers:*

(a) For substation capacity above 2,000 kVA, ac capacitor trip and ac solenoid close.

(b) For substation capacity above 2,000 kVA, ac capacitor trip and ac solenoid close, or battery trip and close.

b. Arresters. Station class is preferred, consideration should be given to gapless types such as zinc oxide, metal oxide varistor (MOV).

c. Voltage regulator. Step-feeder voltage regulator with by-pass gang operated switch on secondary bus only. At the supply point, a three-phase transformer with automatic load tap changers may be provided.

d. Transformers.

(1) Single-phase, self-cooled with provisions to increase capacity if externally cooled, delta wye if connected for three-phase service. Nonflammable liquid or epoxy insulation is preferred; however, high-fire-point liquid or oil insulation may be provided if it is approved by the HOST/REQ CMD.

(2) Three-phase transformers, delta wye connected, are preferred in lieu of single-phase transformers, size permitting, where the load can be served by a single three-phase transformer and where the transformer can be easily repaired or replaced upon failure of any winding and the load can be interrupted during such repair period.

(3) Four single-phase units may be provided where such spare capacity is required for 100 percent spare transformer capacity on site. Multiple installation of like substations for two or more blocks of load at the same general installation shall employ three-phase transformers in parallel or through secondary bus tie.

e. Foundations and fencings.

(1) Foundations and equipment pads. Concrete.

(2) Fencing. Chain link, eight feet in height topped with three strands of barbwire and complete with “High Voltage” signs.

(3) Fence gates for vehicles, minimum width, ten feet. Personnel gates, minimum width, three feet.

(4) Sufficient working space shall be provided so that transformers can be maintained and moved into and out of an area without disturbing adjacent transformers or any fixed equipment.

f. Polychlorinated Byphenyls. Polychlorinated byphenyls (PCB) contaminated transformers shall be disposed of in accordance with the requirements of the Environmental Protection Agency (EPA) as they are removed from service.