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Electrical Power Distribution Systems

3 PDH / 3 CE Hours

United Facilities Criteria
U. S. Department of Defense
UFC 3-550-03N

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Continuing Education for Architects and Engineers

Electrical Power Distribution Systems
Final Exam

1. With regards to *transformer losses*, in general, a heavily loaded transformer has lower losses, and therefore has __________, than when it is lightly loaded.
   a. lower life cycle cost
   b. longer life expectancy
   c. higher life cycle cost
   d. shorter life expectancy

2. Considering *line regulation*, the voltage drop for primary lines shall not exceed:
   a. 5 percent
   b. 3 percent
   c. 10 percent
   d. 2 percent

3. With respect to *cable types*, lead-sheathed cable is generally used for *submarine* (underwater) installations and is usually:
   a. carbon-composite
   b. clad in poly-vinyl chloride
   c. annealed-magnesium
   d. armored

4. In determining the *strength requirements* and the adequate physical and structural requirements for *overhead* system support *poles*, the designer should refer to ______________________________ and ANSI C2.
   a. ASTM-E2018
   b. Fink and Beaty, Standard Handbook for Electrical Engineers
   c. National Electrical Institute Wiring and Distribution Reference Volume 2
   d. United States Steel Structural Design Guide, 2005 Edition

5. Considering *hardware* for *overhead systems*, in locations sensitive to electromagnetic interference, primary lines should be installed:
   a. overhead
   b. in parallel
   c. underground
   d. inside lead pipes

6. *Capacitors* raise voltage levels by reducing the reactive line losses associated with _______________ between the capacitor installation and the power supply.
   a. resistance
   b. electro-magnetic interference
   c. reactive current flow
   d. current distortion

7. Where an *underwater* cable crossing is subjected to flow or tidal currents, ________ are usually required to prevent excessive drifting or shifting of the cable along the bottom.
   a. trenches
   b. conduits
   c. stand-offs
   d. anchors

8. Regarding *underground* cable insulation *advantages*, __________________ are thermosetting, solid dielectric compounds with excellent electrical insulation properties, good chemical resistance and physical strength characteristics, and both remain flexible at low temperatures.
   a. both XLP and EPR
   b. PVC and XLP
   c. both butyl rubber and EPR
   d. cambric and silicone-rubber

9. A ________________ *substation* is a unit substation in which the low-voltage section is above 1000 volts.
   a. load center secondary
   b. secondary unit rated
   c. articulated unit
   d. primary unit rated

10. With regards to *transformers*, primary unit *substations* require less land space, are visually less objectionable, and because of the integrated transformer to secondary connection, __________ than separate substation transformers and secondary protective devices.
    a. are less reliable.
    b. are more reliable
    c. are more complicated
    d. are more difficult to install

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APPENDIX A

MIL-HDBK 1004/2A
POWER DISTRIBUTION SYSTEMS

MIL-HDBK-1004/2A
15 JANUARY 1992
SUPERSEDING
MIL-HDBK-1004/2
31 MARCH 1988
INCLUDING NOTICE 1
15 FEBRUARY 1991

MILITARY HANDBOOK

POWER DISTRIBUTION SYSTEMS

AREA FACR

ABSTRACT

This handbook covers design criteria for electric power distribution systems including basic data, overhead and underground distribution systems, submarine cable systems, and substations. The basic design guidance has been developed from extensive reevaluation of facilities and is intended for use by experienced architects and engineers.

FOREWORD

This handbook has been developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. This handbook was prepared using, to the maximum extent feasible, national professional society, association, and institute standards. Deviations from this criteria, in the planning, engineering, design, and construction of Naval shore facilities, cannot be made without prior approval of NAVFACENGCOM HQ Code 04.

Design cannot remain static any more than can the functions it serves or the technologies it uses. Accordingly, recommendations for improvement are encouraged and should be furnished to Commander, Pacific Division, Naval Facilities Engineering Command, (Code 406), Pearl Harbor, HI 96860-7300; Telephone (808) 471-8436.

THIS HANDBOOK SHALL NOT BE USED AS A REFERENCE DOCUMENT FOR PROCUREMENT OF FACILITIES CONSTRUCTION. IT IS TO BE USED IN THE PURCHASE OF FACILITIES ENGINEERING STUDIES AND DESIGN (FINAL PLANS, SPECIFICATIONS, AND COST ESTIMATES). DO NOT REFERENCE IT IN MILITARY OR FEDERAL SPECIFICATIONS OR OTHER PROCUREMENT DOCUMENTS.

ELECTRICAL ENGINEERING CRITERIA MANUALS

Criteria Manual	Title	PA
MIL-HDBK-1004/1	Preliminary Design Considerations CHESDIV	
MIL-HDBK-1004/2	Power Distribution Systems	PACDIV
MIL-HDBK-1004/3	Switchgear and Relaying	CHESDIV
MIL-HDBK-1004/4	Electrical Utilization Systems	CHESDIV
DM-4.05	400-Hertz Medium-Voltage Conversion/ Distribution and Low-Voltage Utilization Systems	SOUTHDIV
MIL-HDBK-1004/6	Lightning Protection	CHESDIV
MIL-HDBK-1004/7	Wire Communication and Signal Systems	CHESDIV
DM-4.09	Energy Monitoring and Control Systems	ARMY
MIL-HDBK-1004/10	Cathodic Protection	NCEL

POWER DISTRIBUTION SYSTEMS

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SECTION 1: INTRODUCTION

1.1 Scope. This handbook presents data and considerations that are necessary for the proper design of overhead and underground distribution systems, submarine cable systems, and substations having medium-voltage (601 to 35,000 V) or low-voltage (up to 600 V) secondaries.

1.2 Cancellation. This handbook supersedes MIL-HDBK-1004/2, Power Distribution Systems, of 31 March 1988 and Notice 1 of 15 February 1991.

1.3 Technical Factors. Ensure that design does not violate these technical constraints.

1.3.1 Feeders. Do not exceed a 3 percent voltage drop for primary feeders; however, final sizing of feeders is based normally on their current-carrying capacities.

1.3.2 Current (Ampere) Levels and Interrupting Duties. Keep current levels and interrupting duties at reasonable values to avoid the use of heavy conductors and expensive switchgear.

1.3.3 Equipment Requirements. Equipment must, as a minimum, meet all requirements of the National Fire Protection Association (NFPA) 70, National Electrical Code (NEC).

1.3.4 Weather Extremes. Where severe extremes of weather occur such as heavy snow, high moisture, or fog, design should be modified to take such destructive elements into account. Design for tropical areas shall be in accordance with MIL-HDBK-1011/1, Tropical Engineering. Design for distribution in permafrost or frost-susceptible soils should be based on the guidance given in the U.S. Army Corp of Engineers, TM 5-852-5, Arctic and Subarctic Construction, Utilities. Locations where contamination by industry or salt air can occur may require over-insulation of electric lines. Local practice should usually be followed. The usual service conditions of many industry specifications are based on ambient temperatures not to exceed 40 degrees C (104 degrees F) and altitudes not to exceed 3,300 feet (1000 m). Specific industry standards referenced should be checked and unusual service conditions noted in the project specifications. Transformer ratings (overload capacity) may be extended or decreased dependent upon ambient temperatures as covered in Section 2.

1.3.5 Local Codes. Where state safety rules are predominantly accepted as a standard in that state, such rules may be used provided they are essentially as stringent as those of NFPA 70, the American National Standards Institute (ANSI) C2, National Electrical Safety Code (NESC), and approval of NAVFACENGCOM Headquarters is obtained. An example of such a code is the State of California Public Utilities Commission, General Order No. 95, Overhead Line Construction. This code is also of interest because it has more extensive coverage on armless construction than does ANSI C2, and it contains useful data on conductors, clearances, typical problems, and illustrative diagrams on various rules. The wind and ice loadings are different from those of ANSI C2, but the clearances illustrated are generally more stringent. Use of these illustrations will provide a safe and economic installation. The Institute of Electrical and Electronics Engineers (IEEE) also publishes Clapp, NESC Handbook which was developed to aid users in understanding and correctly applying this code.

1.4 Economic Factors. Base the number of circuits and voltage on economic considerations. Where necessary provide life cycle cost analyses in accordance with NAVFAC P-442, Economic Analysis Handbook.

1.4.1 Number of Circuits. Keep the number of circuits to a minimum without compromising reliability, continuity of service, or any of the technical factors stated previously and thus avoid excessive initial cost.

1.4.2 Voltage. Select a distribution voltage which most economically provides for the magnitude, voltage regulation, and length of feeders (refer to MIL-HDBK-1004/1, Preliminary Preliminary Design Considerations). Where groups of large motors are to be served by the distribution system, the most economical motor voltage is generally the most appropriate distribution voltage.

1.4.3 Transformer Losses. Most manufacturers offer a variety of designs where decreased loss design is offset by increased cost. Both no-load (core) and 100 percent load (coil) losses, plus transformer efficiencies at various levels are normally available from the manufacturer. In general, a heavily loaded transformer has lower losses, and therefore has lower life cycle cost, than when it is lightly loaded. Usually, transformers are manufactured with cores made of silicon-steel materials. More recently developed transformers, referred to as "the Amorphous Core Transformers," with cores made of amorphous metal, are also commecially available. In comparison with transformers with silicon steel cores the amorphous core transformers reduce core losses by approximately 70%. The initial cost of an amorphous core transformer is about twice that of a silicon steel core transformer, but the life cycle cost can be significantely lower as the initial cost decreases as the demand increases. A simplified approach to evaluating the cost of transformer losses is given in IEEE 141, Recommended Practice for Electric Power Distribution for Industrial Plants. A more detailed evaluation of distribution transformer losses is given in the Electrical Utility Engineering Reference Book, Distribution Systems. A method for specifying a transformer based upon minimum losses is provided in REA 65-2, Evaluation of Large Transformer Losses.

1.5 Special Construction. Refer to MIL-HDBK-1004/4, Electrical Utilization Systems, for criteria on the design of electrical work installed in earthquake areas. Refer to NAVFAC DM-4.05, 400-Hertz Medium-Voltage Conversion Distribution and Low-Voltage Utilization Systems, for criteria applying to 400-Hz, 4,160-V distribution systems. Refer to MIL-HDBK-1012/1, Electronic Facilities Engineering, for criteria on the design of electronic facilities. Incoming lines to electronic facilities shall be protected against lightning generated surges in accordance with MIL-HDBK-419, Grounding, Bonding, and Shielding for Electronics Equipments and Facilities.

1.6 Shore-To-Ship Distribution Systems. For each facility to be designed, contact the ultimate user and determine the normal and intermittent maximum power requirements anticipated; the quality limits for ship service requirements; and the safety regulations and cold iron needs for ungrounded power systems in accordance with MIL-HDBK-1025/2, Dockside Utilities for Ship Service.

1.7 Good Practice. For recognized good practice in electrical distribution design, refer to the following as appropriate to the requirement:

a) Beeman, Industrial Power Systems Handbook;

b) Fink and Beaty, Standard Handbook for Electrical Engineers, Reference Book;

c) Electrical Transmission and Distribution Reference Book;

d) Electrical Utility Engineering Reference Book, Distribution Systems; and

e) Underground Systems Reference Book.

SECTION 2: OVERHEAD DISTRIBUTION SYSTEMS

2.1 Circuit Design. Apply proper design criteria (refer to Table 1) to the specific project. Also refer to NFGS-16302, Overhead Electrical Work and NFGS-16335, Transformers, Substations and Switchgear, Exterior and MIL-HDBK-1190, Facility Planning and Design Guide.

Table 1
Information Required For Circuit Design

ITEM	SPECIFIC INFORMATION REQUIRED
Individual building demand loads	Determine proposed demand loads utilizing calculation methods similar to that used in Table 4 of MIL-HDBK-1004/1 or based on field measurements.
Coincident peak demand	Determine facility peak demand utilizing calculation methods similar to that use in Table 7 of MIL-HDBK-1004/1 or based on field measurements.
Number of circuits and voltage level	Select number of circuits and voltage level. Number of circuits will depend upon location and magnitude of individual loads. Voltage level or type of distribution should be in accordance with data in MIL-HDBK-1004/1. Provide sufficient future capacity (+ or - 25 percent).
Other considerations	Balance single phase loads on multi-phase circuits. Design large starting loads to have a minimal effect on demands.

2.1.1 Application. Use overhead distribution because it is generally less costly than underground. Where underground distribution is more cost effective, it should be used. When exceptions are considered, follow local requirements and practices. For example, in Adak, Alaska, distribution is placed underground in the unstable soil and manholes are placed above the surface to keep mud from seeping into them. Also, family housing areas and facilities in residential areas, such as Point Loma, California, require underground systems to be compatible with the neighborhood. Additional locations where overhead construction should be avoided are covered in MIL-HDBK-1004/1.

2.1.2 Capacity. Make provision for spare capacity in each portion of the circuit.

2.1.3 Wire Size. Select wire size in accordance with the current-carrying capacity required and, where applicable, the voltage-drop limitation.

2.1.4 Physical Features. Select physical design features in accordance with the type of circuit involved and the type of distribution; that is, primary or secondary. Select from the following types:

a) Open wire (bare or weatherproof) on insulators.

b) Aerial cable, self-supported or messenger-supported, consisting of insulated bundled single-conductor cable or multiple-conductor cable.

2.2 Line Materials. Design pole lines based on materials and construction methods specified in NFGS-16302.

2.2.1 Poles. Wood, concrete (reinforced with prestressing or pretensioning), or metal (steel or aluminum) may be used. Use concrete or metal poles only where they are more economical or special considerations warrant their use. Treat wood poles and crossarms as covered in NFGS-16302.

2.2.1.2 Heights and Classes. Limitations on pole heights and classes for wood poles are given in Table 2. Class normally used refers to primary poles spaced not more than 200 feet (61 m) apart, which serve industrial or housing areas and which are generally at least 40 feet (12 m) or more in height. See ANSI C2 for definition of classes. Refer to Table 3 for data on transformer poles. Refer to Fink and Beaty, Standard Handbook for Electrical Engineers to determine the limitations on minimum heights and classes for poles carrying other equipment.

2.2.1.3 Strength Requirements. Refer to Fink and Beaty, Standard Handbook for Electrical Engineers and ANSI C2 to determine the adequate physical and structural requirements.

2.2.1.4 Safety Factors. Refer to ANSI C2 for the minimum safety factors to be used.

2.2.1.5 Pole Installation. For pole depth, refer to the criteria in Fink and Beaty, Standard Handbook for Electrical Engineers and ANSI C2. Refer to Fink and Beaty, Standard Handbook for Electrical Engineers for pole placement with respect to anchors or braces. Footings or reinforcements of the pole butt-end shall be as required by foundation conditions.

2.2.1.6 Configuration. Use armless construction for aerial lines because it is less costly than crossarm construction and its use is aesthetically preferred. For the same reason, use neutral-supported, secondary cable over rack-supported individual conductors.

2.2.1.7 Crossarms. Use crossarms mainly for equipment support. Follow the criteria in Fink and Beaty, Standard Handbook for Electrical Engineers.

Table 2
Height and Class of Wood

POLE USE	MINIMUM HEIGHT FEET (METERS)(a)	MINIMUM CLASS PERMITTED	CLASS NORMALLY USED
Line pole	30 (9)	5	3 or 4
Corner pole (guyed)	30 (9)	5	3 or 4
Corner pole (unguyed)	30 (9)	2	--
Dead end pole (guyed)	30 (9)	5	3 or 4
Dead end pole (unguyed)	30 (9)	3	--
Transformer poles	35 (10.5)	See Table 3	2 or 3
Transformer platform using two poles:			
(1) Existing poles	--	5	--
(2) New poles	--	3	--
Underground cable riser poles 2.4 thru 35 kV	--	3	--
Pole--top switch	--	3	--

(a) Increase heights by not less than 5 feet (1.5 meters) if telephone or signal wires are caried or are likely to be installed.

2.2.2 Guys and Anchors. Provide guys and anchors to support poles or line towers against horizontal unbalanced loads caused by angles, corners, and dead ends of lines and where required because of extreme wind loadings. Refer to Fink and Beaty, Standard Handbook for Electrical Engineers for criteria.

2.2.2.1 Safety Requirements. Refer to ANSI C2 for minimum safety requirements.

2.2.2.2 Design of Earth Anchors. Consult the manufacturers' catalogs for types of earth anchors and design data. Select the equipment suitable for the particular soil conditions and the construction method to be used. Refer to NAVFAC DM-7.02, Foundations and Earth Structures for additional data on anchors.

Table 3
Wood Pole Sizes for Single Pole Transformer Installations

	MAXIMUM TRANSFORMER RATING (KVA)		
POLE MINIMUM CLASS	ONE SINGLE-PHASE	BANK OF THREE ONE SINGLE-PHASE (CLUSTER MOUNTED)	THREE-PHASE
5	5	--	--
4	15	--	--
4	25	--	--
3	37-1/2	--	15
3	--	3-15	30
2	50	3-25	45
2	75	3-37-1/2	75
1	100	3-50	112-1/2

2.2.3 <u>Conductors</u>. Refer to Fink and Beaty, <u>Standard Handbook for Electrical Engineers</u> for conductor characteristics.

2.2.3.1 <u>Size Limitations</u>. Normally limit the use of pole line conductors in accordance with Table 4, except for primary wires which usually should be not less than No. 6 AWG (13.3 square mm) copper or No. 2 AWG (33.6 square mm) aluminum. The range of conductors in Table 4 gives the most economical system from the installation, operational, and maintenance points of view. Special instances may require larger conductors. In all cases be sure that the type and size of conductors used has adequate strength for span lengths and loading conditions. Select conductor sizes to provide required minimum strengths in accordance with loading requirements of ANSI C2 for areas in the United States and in accordance with facility loading requirements for areas outside the United States.

2.2.3.2 <u>Normal Primary Lines</u>. Normally, specify bare conductors for primary lines stranded or solid construction as suitable to the size and composition as follows:

a) copper conductor, (Cu);
b) aluminum-alloy conductor, (AAC);
c) aluminum conductor, steel reinforced (ACSR); and
d) high-strength all-aluminum alloy conductor (AAAC).

2.2.3.3 <u>Tropical and Semitropical Locations</u>. For tropical and semitropical locations, use AAAC rather than ACSR because the steel strands of the ACSR are susceptible to corrosion.

Table 4
Conductor Sizes for Overhead Lines

CONDUCTOR TYPE	SIZE	
	Not larger than	Not smaller than
Copper	4/0 AWG (107 mm^2)	8 AWG (8.37 mm^2)
Aluminum	336.4 kcm (170 mm^2)	6 AWG (13.3mm^2)

2.2.3.4 Special Primary Line. In special instances, use of other conductors may be appropriate for primary conductors. Insulated conductor, copper or aluminum, preassembled nonmetallic sheathed or metallic sheathed, messenger-supported aerial cable is used where necessary to avoid exposure to open wire hazards; for example, high reliability service in heavy storm areas. Compound conductor materials such as copper-clad steel, aluminum-clad steel, galvanized steel, or bronze are used to provide high strength or corrosion resistance.

2.2.3.5 Utilization Lines. For secondary or service drop cable, use insulated multiplex type, either copper or aluminum.

2.2.3.6 Dissimilar Conductor Connections. Install appropriate connectors that are specifically designed for such use where necessary to connect aluminum conductors to copper conductors, in accordance with the instructions of the manufacturer. Contact with dissimilar conductor materials shall be minimized.

2.2.4 Insulators. To support bare or weatherproof conductors, select from the following types of insulator, as appropriate to the installation:

a) suspension type, single or multiple;
b) spool type;
c) line-post type;
d) strain type; and
e) pin type.

2.2.4.1 Insulator Combinations. Various types of insulators may be combined; for example, strain type for anchor poles or dead ends with either pin or line post for line insulation. Line-post types are considered to be both less expensive and superior to pin types.

2.2.4.2 Dimensions and Loads. For dimension of insulators and permissible loads, refer to the ANSI C29 standards as follows:

a) C29.1, Test Methods for Electrical Power Insulators;
b) C29.2, Insulators, Wet-Process Porcelain and Toughened Glass, Suspension Type;

c) C29.3, Wet-Process Porcelain Insulators, Spool Type;
d) C29.4, Wet-Process Porcelain Insulators, Strain Type;
e) C29.5, Wet-Process Porcelain Insulators, Low- and Medium-Voltage Types;
f) C29.6, Wet-Process Porcelain Insulators, High-Voltage Pin Type;
g) C29.7, Wet-Process Porcelain Insulators, High-Voltage Line-Post Type;
h) C29.8, Wet-Process Porcelain Insulators, Apparatus Cap and Pin Type; and
i) C29.9, Wet-Process Porcelain Insulators, Apparatus Post-Type.

In addition to the above, refer to the National Electrical Manufacturers Association NEMA HV-2, Application Guide for Ceramic Suspension Insulators. Also, refer to Fink and Beaty, Standard Handbook for Electrical Engineers.

2.2.4.3 Insulation Levels. The application of ANSI C2 requires higher insulation levels in locations where severe lightning, high atmospheric contamination, or other unfavorable conditions exist. This applies particularly to areas where saltspray contamination can cause increased operating stresses. Local practice in such areas should be checked in determining how much increased insulation is considered necessary for insulators and whether increased leakage distances for bushings and cable terminations is also desirable.

2.2.5 Hardware. In locations sensitive to electromagnetic interference, install lines underground. If aerial lines are provided, insulators must be of the radio-freed type. Provide hardware components with locknuts to avoid loose connections, which could cause static. Locknuts must be threaded, and of a type which will prevent loosening of the connection when wood members shrink.

2.3 Line Regulation. The voltage drop for primary lines shall not exceed 3 percent. Maintain the power factor of the line as close to unity as economically practical so as to minimize system losses. Regulation utilizing load-tap-changing transformers to correct line voltage variations resulting from changing loads or utility company sending-end voltage swings is covered in Section 5. Requirements for line equipment follow:

2.3.1 Step-Voltage Regulators. Step-voltage regulators can rarely be justified economically for new construction. They may be used on existing construction to meet voltage drop criteria when proven to be more cost effective than controlling the voltage drop by use of larger conductors, provision of additional lines, or by the installation of capacitors. Refer to Fink and Beaty, Standard Handbook for Electrical Engineers for methods of sizing feeder voltage regulators and for regulator safety and line drop compensation setting requirements. Single-phase regulators are preferable as being less costly but require more installation space.

2.3.2 Capacitors. Capacitors raise voltage levels by reducing the reactive line losses associated with reactive current flow between the capacitor installation and the power supply. It is rarely economical to apply them for voltage improvement only. Capacitors are justified when their cost over their service life is less than any utility company low-power-factor penalty cost. Take into account the cost of switching equipment to meet any functional or utility company prohibitions against a leading power factor. Base design on shunt power capacitors that conform to IEEE 18, Shunt Power Capacitors. Take into account the following considerations:

a) Fixed capacitance is the amount of capacitance that can be applied continuously without excessive voltage rise at reduced load.

b) Switched capacitance is an additional amount of capacitance that can be applied, if provision is made to switch off this additional amount when demand is reduced.

c) Select the type of capacitor switching that is best for the condition at hand. Possible choices include remote control of the capacitor switching device, time clock control, or power factor or voltage sensitive relay control.

d) Install capacitors in banks on poles, at-grade, or in a substation, as near as possible to the centroid of the area where correction is required.

2.4 Transformers. Transformers can be mounted on poles, at-grade, or indoors depending upon size and site requirements. Select a standardized three-phase transformer, except where the load is small enough to justify a single-phase transformer. Use oil-insulated transformers, except where site conditions or economic considerations make their use prohibitive. Consider loading, noise level, and transformer protection requirements. Do not use askarel-insulated and nonflammable, fluid-insulated transformers because of environmental concerns as to their insulation liquid. Use of other types of insulation must be economically or functionally justified. Less-flammable, liquid-insulated units may be necessary where oil-insulated transformers cannot meet fire-exposure requirements as listed in MIL-HDBK-1008, Fire Protection for Facilities Engineering, Design, and Construction. Epoxy-encased ventilated dry-type units may be appropriate in areas where liquid-insulation loss might result in water pollution.

2.4.1 Pole Mounting. For single-pole mounting, limit the size of single-phase or three-phase units in accordance with Table 3. Do not use pole-platform mounting (two-pole structures) except in instances where other methods are not satisfactory. It is recommended that maximum transformer size be limited to the sizes shown in Table 3. For installations of 225 to 500 kVA, pad-mounted, compartmental-type transformers are recommended.

2.4.2 At-Grade Mounting. For at-grade mounting on a concrete base, there is no kVA limit. Tamper-resistant transformers (classified as pad-mounted compartmental-type units) should generally not be specified in ratings of over 500 kVA, but in no case larger than 750 kVA. When sheet-metal enclosures are not tamper-resistant, provide ground-mounted units with a fenced enclosure or even a concrete or brick structure, where adverse weather conditions make such an installation advisable. For required clearances between buildings and insulated transformers, refer to MIL-HDBK-1008.

2.4.3 Indoor Installations. Indoor installations are covered in Section 5.

2.4.4 Overload Capacity. Consider the accelerated loss of equipment life if transformers are to be overloaded. Refer to ANSI C57.91 Guide for Loading Mineral-Oil-Overhead and Pad-Mounted Distribution Transformers Rated 500 kVA and Less with 65 Degrees C or 55 Degrees C Average Winding, C57.92 Guide for Loading Mineral-Oil-Immersed Power Transformers up to and Including 100 MVA with 55 Degree C or 65 Degree C Winding Rise, and C57.96 Guide for Loading Dry-Type Distribution and Power Transformers and Fink and Beaty, Standard Handbook for Electrical Engineers.

2.4.5 Transformer Noise Level. Refer to NEMA TR-1, Transformers, Regulators and Reactors for maximum permissible noise levels for transformers.

2.4.6 Overhead Distribution. Use the criteria in ANSI C57.12.20, Requirements for Overhead Type Distribution Transformers, 500 kVA and Smaller: High-Voltage 67,000 Volts and Below; Low-Voltage 15,000 Volts and Below. Do not use self-protected transformers having an internal secondary breaker, internal primary fusing, and integrally mounted surge arresters. These transformer accessories are provided for transformers generally described by industry as a pole-mounted type. The replacement of fuse links is considered to require specialized personnel not usually available at naval facilities.

2.5 Circuit Interrupting Devices. Select from fuses, circuit breakers, and automatic circuit reclosers for protective line considerations. Provide switches to localize defective portions of aerial and underground circuits and to accomplish dead-circuit work. Select from nonload-break or load-break type switches.

2.5.1 Fuses. After consideration of the necessary current-carrying capacities, interrupting duties, and time-current melting and clearing characteristics, select fuses from the following types:

a) open fusible link,
b) expulsion type,
c) boric-acid type, and
d) current-limiting type.

2.5.2 Current Limiting Protectors. These fusible type devices developed under an Electric Power Research Institute (EPRI) project, provide current limiting on up to 15.5-kV systems for up to 1,200 A continuous currents. Use them only where higher continuous ratings are required than are available from standard fused cutouts or power fuse disconnecting units.

2.5.3 Circuit Breakers. Use a circuit breaker rating adequate for the load interrupting duty and which provides selectivity with circuit breakers and fuses ahead of or after the circuit breaker.

2.5.4 Automatic Circuit Reclosers. Use the criteria in NEMA SG-13, Automatic Circuit Reclosers, Automatic Line Sectionalizers and Oil-Filled Capacitor Switches for Alternating Current Systems. Use of automatic reclosing for other than overhead lines serving residential or commercial loads may cause problems. In selecting the type of automatic circuit recloser, consider the reliability and continuity of service. Reclosers may consist of a circuit breaker or a multiple switching device. Reclosers operate so that a faulted circuit may be opened and then, either instantaneously or with deliberate time delay, reclosed. Up to three reclosures with varying time intervals may be used. Coordinate automatic circuit reclosers with fuses or circuit breakers on the same circuit.

2.5.5 Nonload-Break Switches. Use nonload-break switches only for the interruption of circuits that carry no appreciable load. Select the type applicable, depending on circuit importance, load, voltage, and fault circuit duty. The types available are porcelain disconnect fuse cutouts, plain or fused single-pole air disconnect switches, and disconnect fuse cutouts of various types. Refer to manufacturers' catalogs and NEMA SG-2, High-Voltage Fuses. Disconnecting and horn gap switches covered by ANSI C37.30, Definitions and Requirements for High-Voltage Air Switches, Insulators, and Bus Supports and ANSI C37.32, Schedules of Preferred Ratings, Manufacturing Specifications, and Application Guide for High-Voltage Air Switches, Bus Supports, and Switch Accessories are also nonload-break switches.

2.5.6 Load-Break Switches Load-break switches are provided with an interrupting device capable of disconnecting circuits under load. Fuse cutouts, (covered by NEMA SG-2) which are designed to be load-break are available, as are load interrupter switches which conform to ANSI C37.30 and C37.32. Vacuum switches provide load-break features. Vacuum switches can provide a wide variety of operators and should be considered as an economical method of providing automatic or remotely controlled switching.

2.6 Lightning Protection

2.6.1 Requirements. Lightning protection can be provided by installing surge (lightning) arresters, open or expulsion gaps, or overhead ground wires, or by all three methods combined. Also, consider the weather. For most distribution circuits, distribution surge arresters protecting transformers and aerial-to-underground transitions are adequate. Overhead ground wires are rarely considered to be an economical installation for distribution lines, but are often used for protection of transmission lines. In areas where annual lightning storms are few, no protection for lightning-induced surges may be necessary. Local naval facility or utility company practice should generally be followed (refer to MIL-HDBK-1004/6, Lightning Protection) for equipment protection, aerial-to-underground transition points, and other appropriate locations.

2.6.2 Application. Select the proper arrester in accordance with the Basic Impulse Insulation Level (BIL) that applies to the voltage level of the circuit. Follow the criteria in ANSI C62.1, Surge Arrestors for AC Power Circuits; ANSI C62.2, Guide for Application of Valve-Type Surge Arresters for Alternating Current Systems and ANSI C62.33, Varistor Surge-Protective Devices.

2.7 Clearances. Provide the necessary horizontal and vertical clearances from adjacent physical objects, such as buildings, structures, or other electric lines, as required by ANSI C2.

2.7.1 Contingency Interferences. Make provision to protect against contingency interferences, such as broken poles, broken crossarms, or broken circuit conductors.

2.7.2 Multipurpose Conditions. Provide for clearance conditions arising from multipurpose joint use of poles.

2.8 Grounding. For information on grounding of overhead distribution systems, refer to ANSI C2.

2.8.1 Safety. Provide grounding for all equipment and structures associated with electrical systems to prevent shock from static or dynamic voltages.

2.8.2 Ground Resistance Path. Provide a low impedance path at the source of fault currents, if a circuit contains a deliberate ground connection.

2.8.3 Maximum Ground Resistance. Do not exceed maximum ground resistance values specified in NFGS-16301, Underground Electrical Work and NFGS-16302, and ANSI C2. Consider the source of electric power, capacity, magnitude of fault current, and method of system grounding, as they affect this resistance.

2.8.4 Grounding Methods. Grounding provisions shall conform to NFPA 70. Grounding methods for transformers mounted at grade are covered in Section 5.

2.8.4.1 Ground Rods. Ground rods may be used either singly or in clusters. Drive the ground rods to ground water level for an effective and permanent installation. Provide for corrosion prevention by a proper choice of metals or by cathodic protection. Where ground water cannot be reached, chemicals such as magnesium sulphate ($MgSO_4$) or copper sulphate ($CuSO_4$) may be used to improve soil conductivity where necessary. Manufacturers of ground rods can provide data on such treatment. Provide for easy maintenance and periodic testing. Driving ground rods deeper using sectional rods may be more effective than using multiple rods. In many cases, soil variations and possible bedrock may make provision of additional rods less expensive.

2.8.4.2 Water Pipe Connections. Make no connection to any sprinkler piping in accordance with NFPA 24, Installation of Private Fire Service Mains and their Appurtenances. The electrical system may be grounded to a water supply system except where nonmetallic pipes, cathodically protected metallic pipes, or insulating couplings are incorporated in the water pipe system. Supplement the water pipe connection by other grounding electrodes where required by NFPA 70.

2.8.4.3 Combination of Grounding Methods. Where the ground resistance in an existing system is high, any of the aforementioned methods may be combined to effect improvement.

2.8.4.4 Ground Connections. Keep wires running from protective devices (for example, gaps, grading rings, expulsion or protection tubes, and surge arresters) to ground as straight and short as possible. Where bends are necessary, provide them of large radii to keep the surge impedance as low as possible.

2.8.5 Overhead Ground Wires. Where overhead ground wires are used for protection of electric lines, provide a ground connection from the overhead ground wire to a wire loop or a ground plate at the base of the pole or to a driven rod, depending on the existing soil conditions. Use of wire wraps or pole butt plates is allowed by ANSI C2 only in areas of very low soil resistivity. Ground the overhead ground wire at each pole.

2.8.6 Measurement of Ground Resistance. Measure ground resistance by using one of the following methods:

a) Three-Electrode Method. In the three-electrode method, two test electrodes shall be used to measure resistance of the third electrode, the ground point. A self-contained source of alternating current and a battery-operated vibrator source providing direct reading are commercially available.

b) Fall-of-Potential Method. The fall-of-potential method involves an ungrounded alternating current power source which circulates a measured current to ground. Voltage readings taken of the connection to auxiliary grounds allow use of Ohm's law to determine the ground resistance. Refer to Fink and Beaty, Standard Handbook for Electrical Engineers.

2.9 Service Drop to Buildings. Local considerations and current capacities dictate the type of service drop to buildings from overhead distribution systems. Provide either underground service into the building from a pole riser or self-supporting service cable strung from the pole to the building (refer to ANSI C2).

2.10 Right-of-Way. When not installed on government property, obtain a right-of-way for the electrical distribution or transmission system by outright purchase of the land or by limited or perpetual easement. In the case of easements, the right to perform maintenance on the line must be covered.

2.10.1 Widths. Where possible, the width of the right-of-way shall be sufficient to avoid all conflicts (refer to ANSI C2) between the line and other adjacent structures. This width includes all obstructions and underground utilities, except where necessary for the underground utilities to pass at right angles to the right-of-way. The requirements for minimum width on naval activities shall conform to the following right-of-way widths:

Line voltage (kV)	Recommended minimum right-of-way width across unimproved land in feet (meters)
Up to 7.5	40 (12)
7.5 to 20	60 (18)
20 to 35	80 (24)
35 to 68	80 (24)
68 to 92	80 (24)
92 to 120	100 (30)

2.10.2 Trees. Because trees adjacent to any overhead line pose a line clearance problem, ensure that growing trees do not result in any line outage or damage. Complete removal of all trees in the right-of-way is probably environmentally unacceptable. Remove tree species, which in conjunction with the weather and soil condition are liable to uprooting if their location poses a clear danger to the line. Otherwise trim trees to provide a hazard-free operation for at least 2 years. Competent persons shall do the trimming to avoid excessive tree damage and to assure that trees off the right-of-way are not trimmed by mistake. Obtain the landowner's permission for any trimming and conduct a though cleanup after trimming.

Section 3: UNDERGROUND DISTRIBUTION SYSTEMS

3.1 Circuit Design. Follow the circuit design procedure outlined in Section 2 of this handbook for overhead distribution systems. For additional criteria, refer to MIL-HDBK-1190.

3.2 Direct Burial. Install direct-burial cables only in areas that are rarely disturbed. After first considering economic, maintenance, and reliability effects, restrict direct burial to light loads, to roadway lighting systems, and to long untapped runs in low density areas. In some instances, a minimal amount of taps may be acceptable.

3.2.1 Protection. For protection against mechanical injury, medium-voltage direct-burial cables can be provided with a protective covering of metal armor. Consider the need for such protection, such as against dig-ins or because of possible termite or rodent attack, on a case-by-case basis. Possibly other protective means are more economical. Where corrosion considerations are of importance, provide armored cables with a plastic or synthetic rubber jacket. For cable specifications, refer to NFGS-16301. Provide a colored warning tape 6 inches (52.4 mm) above the direct-burial cable.

3.2.2 Installation

3.2.2.1 Trench Dimensions. Provide trenches in accordance with the requirements of NFGS-16301 and NFGS-02225 Excavation, Backfilling, and Compacting for Utilities.

3.2.2.2 Cable Protection. General installations shall be in accordance with requirements of NFGS-16301. Where additional protection of buried cable against dig-ins is necessary, provide a continuous 1-inch (25.4 mm) thick treated wood plank or a concrete slab, not less than 2 inches (50.8 mm) thick, located directly above a top layer of sand in lieu of or in addition to a protective covering. Accommodate protection against termites or rodents by using a chemical treatment. Obtain approval of the treatment by the facility prior to use.

3.3 Draw-In Systems. Draw-in systems consist of duct systems (which may include access points such as manholes and handholes) in which cable is drawn after the duct system has been installed. Provide a draw-in system where overhead distribution is not feasible (refer to MIL-HDBK-1004/1). Provide a draw-in system for distribution of large blocks of electric power, where many circuits follow the same route or are run under permanent hard pavements, or where service reliability is paramount.

3.3.1 Duct Lines

3.3.1.1 Routes. Select duct line routes to balance maximum flexibility with minimum cost and to avoid foundations for future buildings and other structures.

3.3.1.2 Multipurpose Conditions. Where it may be necessary to run communication lines along with electric power distribution lines, provide two isolated systems in separate manhole compartments. Where possible, run ducts in the same concrete envelope.

3.3.1.3 Clearance. Keep electric and communication ducts clear of all other underground utilities, especially high-temperature water or steam pipes.

3.3.1.4 Materials. Acceptable standard materials include the various types of plastic as specified in NFGS-16301. Rigid steel conduit may also be installed below grade and provided with field or factory applied coatings for corrosion protection where required.

3.3.1.5 Size of Ducts. Base the size of conduits in a duct bank shall be based on consideration of the following factors:

a) for general electric power distribution, do not use less than 5 inch (127 mm) ducts;

b) for communication duct banks, normally use 4 in. (101.6 mm) ducts although 3 inch (76.2 mm) ducts may be acceptable in some cases;

c) special cases may require use of larger sizes, but such sizes shall be functionally justified.

3.3.1.6 Arrangement of Duct Banks. For best heat dissipation, use an arrangement of two conduits wide or high. This may be impossible where a large number of ducts are involved. The vertical, two-conduit-wide arrangement enables the cables to be more easily racked on manhole walls but may not be as economical as the horizontal two-conduit-high arrangement. For dimensions and arrangement of duct banks see Figure 1. Encase conduits in concrete in accordance with NFGS-16301.

3.3.1.7 Drainage. Drain all ducts to manholes with a constant slope in accordance with NFGS-16301. Where two manholes are at different elevations, a single slope following the general slope of the terrain may be the most economical. Where grades are flat or crest between manholes, a single slope usually requires too much depth in one of the manholes. In this event, generally slope the duct from the crest area to both manholes, keeping a minimum earth coverage on the highest elevation.

3.3.1.8 Spare Capacity. Include ducts for planned future expansion, plus 25 percent additional spare ducts for unplanned expansion.

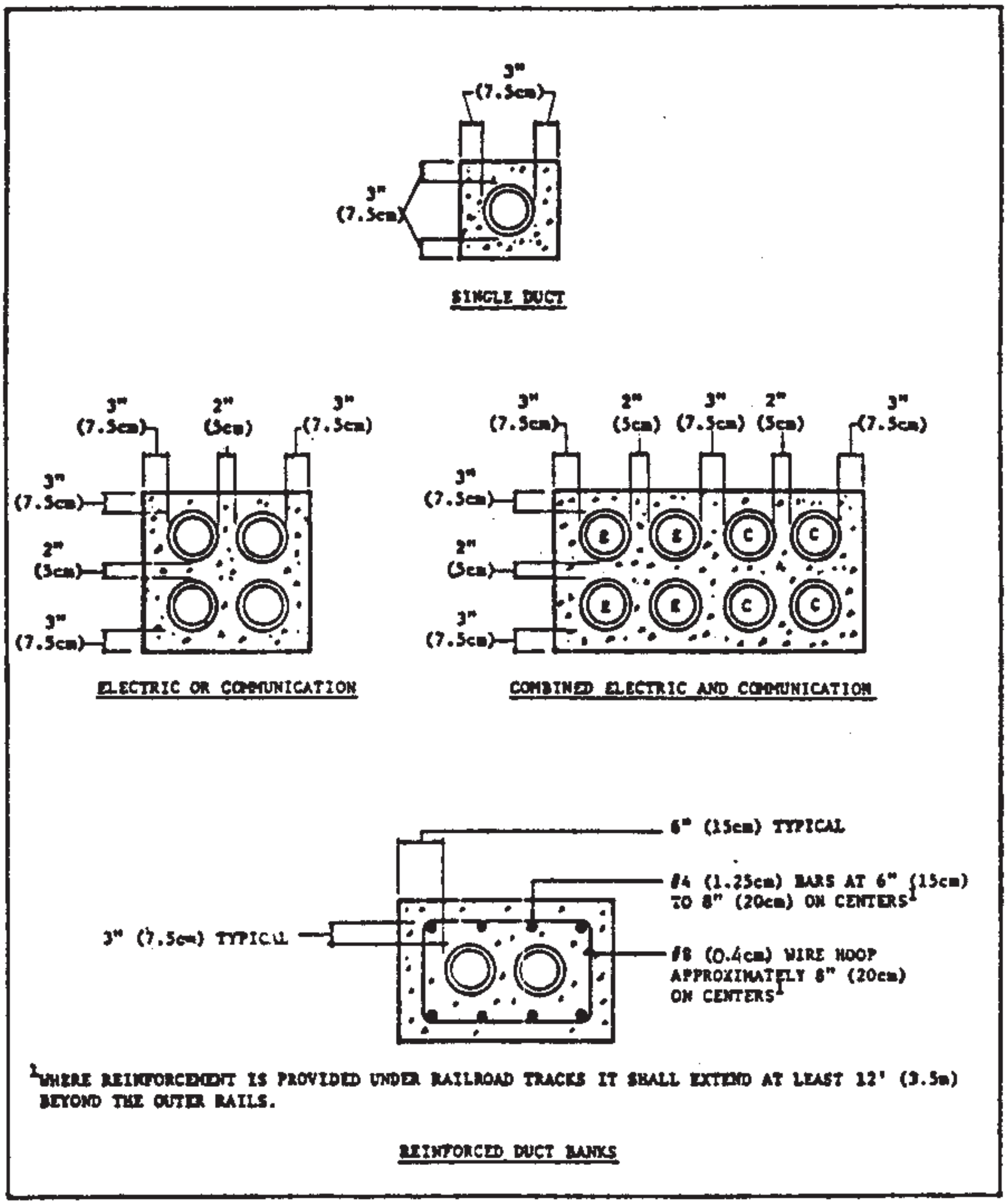


Figure 1
Duct Line Sections

3.3.2 Manholes and Handholes. Use double manholes where electric power and communication lines follow the same route. Select manholes and handholes of a suitable type from NFGS-16301.

3.3.2.1 Selection. Factors bearing on the choice of manholes and handholes are number, direction, and location of duct runs; cable racking arrangement; method of drainage; adequacy of work space (especially if equipment is to be installed in the manhole); and the size of the opening required to install and remove equipment.

3.3.2.2 Location. Place manholes or handholes at street intersections, where required for connection or splices, and where necessary to avoid conflict with other utilities. Manhole separation shall not exceed 600 feet (182.8 m) on straight pulls and 300 feet (91.2 m) on curved duct runs. Decrease spacing where necessary to prevent installation damage. Limit pull-in strain to a point that will not damage cable insulation or deform the cable. A description of maximum permissible pulling forces is given in the Underground Systems Reference Book.

3.3.2.3 Use. Use manholes for all main duct runs and wherever medium-voltage cable is installed. Handholes may be used on laterals from manhole and duct line systems for low-voltage power and communication lines for building services.

3.3.2.4 Construction of Manholes. Provde manholes not less than 6 feet (1.8 m) in depth, by 6 feet in length, by 4 feet in width with an access opening to the surface above (outer air) of not less than 30 inchrs (762 mm) in diameter. Provide manholes with a minimum wall space of 6 feet on all sides where splices are to be racked. Duct entrances into the manhole can be located near one end of long walls so that sharp bends of cables at the duct mouth are avoided, or else provide sufficient space for a reverse bend before the cable straightens out on the wall on which the cable is to be racked.

3.3.2.5 Construction of Handholes. Provide handholes not less than 4 feet (1.2 m) in depth, by 4 feet (1.2 m) in length, by 4 feet (1.2 m) in width with a standard manhole cover and sump of the same type provided for manholes. Generally at least four racks should be installed. Where more than two splices occur, a manhole may be more appropriate. Where splicing or pulling of low-voltage or communication cables requires an access point, but the volume provided by handhole is unnecessary, pullboxes may be more suitable for the installation.

3.3.2.6 Stubs. Provide a set of spare stubs so that the manhole wall will not need to be disturbed when a future extension is made.

3.3.2.7 Hardware. Select hardware applicable to each installation (refer to NFGS-16301). Where end-bells are provided, cable duct shields are necessary only for protection of metallic-sheathed cables.

3.4 Underground Cables. Cable installations make up a large portion of the initial distribution system investment, contribute to a lesser extent to the annual maintenance and operating costs, and affect system reliability. Therefore, underground cables and their accompanying protective and operating devices should be selected in accordance with criteria set forth in the following paragraphs. The joint specifications of the Insulated Cable Engineers Association-National Electrical Manufacturers Association (ICEA-NEMA) and the specifications of the Association of Edison Illuminating Companies (AEIC) should be used as covered by NFGS-16301. ICEA-NEMA specifications cover medium-voltage cables which are manufactured as stock items. Requiring medium-voltage cable to meet AEIC specifications should be limited to medium-voltage cables which are not stock items (35-kV rating) or where the footage installed is large enough for manufacturers to make a special run.

3.4.1 Single- or Multiple-Conductor Cables

3.4.1.1 Single-Conductor Cables. Single-conductor cables are usually used in distribution systems because the installed cost is less than that of multiple-conductor cables.

3.4.1.2 Multiple-Conductor Cables. Select multiple-conductor cables where justified by special considerations such as installation in cable trays, twisted to provide lower inductance for 400-Hz distribution systems, or for High-altitude Electromagnetic Pulse (HEMP) hardened systems.

3.4.2 Conductor Materials

3.4.2.1 Annealed Copper. Select annealed copper for high conductivity, flexibility, and ease of handling; it is used in all forms of insulated conductors.

3.4.2.2 Medium-Hard-Drawn Copper. Medium-hard-drawn copper has greater tensile strength than annealed copper but may not be available as a stock item. Its use in long pulls and unsupported vertical risers is acceptable; however, procurement difficulties make other designs more advisable.

3.4.2.3 Aluminum. Generally, aluminum conductors are permitted as a contractor's option to copper subject to the restrictions of NFGS-16301, except where corrosive conditions limit usage.

3.4.3 Preferred Cable Insulations. Insulation material to be used in a specific design depends on the system voltage and the thermal, mechanical, and chemical effects from the installation involved. Use crosslinked-Polyethylene (XLP) or ethylene-propylene rubber (EPR) whenever possible. These insulations provide the maximum rated conductor temperatures for operating, overload, and short-circuit conditions for cables rated up to a maximum of 35 kV.

3.4.3.1 Advantages. Both XLP and EPR are thermosetting, solid dielectric compounds with excellent electrical insulation properties, good chemical resistance and physical strength charateristics, and both remain flexible at low temperatures.

3.4.3.2 Disadvantages. Although EPR is more expensive than XLP and both have excellent moisture resistance, the degradation phenomenon called treeing appears to occur more frequently in XLP and is aggravated by the presence of water. EPR also is less susceptible to corona discharge activity than XLP, but in a properly designed and manufactured cable, damaging corona is not expected to be present at the usual operating voltages.

3.4.4 Other Insulations. Use other insulations only where special circumstances warrant their lower-rated conductor temperatures or their lower rated maximum voltage class. Use of such cables, especially those with metallic sheaths, must be functionally or economically justified.

3.4.4.1 Polyvinyl-Chloride. Select polyvinyl-chloride (PVC) mainly for power and control wiring for ratings of 2 kV or less. This thermoplastic is highly resistant to moisture, oils, chemicals, and abrasion, but has high dielectric losses.

3.4.4.2 Polyethylene. Select polyethylene mainly for roadway lighting, control, and communication cables. This thermoplastic has good moisture resistance and stable physical and electric characteristics under temperature variations. Polyethylene exhibits the same susceptibility to treeing and corona discharge as XLP.

3.4.4.3 Butyl-Rubber. This thermosetting insulation has high dielectric strength and is highly resistant to moisture, heat, and ozone. It can be used up to 35 kV, but has lower rated conductor temperatures than either XLP or EPR.

3.4.4.4 Silicone-Rubber. This thermosetting insulation is highly resistant to heat, ozone, and corona. It can be used in wet or dry locations, exposed, or in conduit. It has the highest rated conductor temperatures but can only be used for applications up to 5 kV.

3.4.4.5 Mineral-Insulated Cable. Mineral-insulated cable is completely sealed against the entrance of liquids and vapors along the cable run. It is rated at 600 maximum.

3.4.4.6 Rubber. Use rubber insulated conductors for ease of splicing, good moisture resistance, and low dielectric losses.

3.4.4.7 Varnished-Cambric. Use varnished cambric insulation for resistance to ozone and oil and for ease of splicing. Use varnished-cambric principally in conjunction with paper insulation where oil migration is a problem. Where installed in wet or highly humid locations or underground, provide varnished-cambric with a suitable sheath.

3.4.4.8 Paper-Insulation. Use paper-insulation for low ionization, long life, high dielectric strength, low dielectric losses, and good stable characteristics under temperature variations. As with varnished-cambric insulation, paper-insulation requires a suitable protective metallic-sheath. It may be specified as a contractor's option when existing cables are paper-insulated, or as a requirement when the extra cost is justified because neither XLP nor EPR provide the required qualities.

3.4.5 Cable Sheaths

3.4.5.1 Nonmetallic. Provide nonmetallic sheaths which are flexible, moisture repellent, and long-lasting.

3.4.5.2 Metallic. Cables exposed to mechanical damage or high internal pressure require a metallic sheath, such as lead, aluminum, or steel. Certain insulations require such protection in all cases, such as paper and varnished-cambric.

3.4.6 Cable Coverings. For corrosion protection of metallic sheaths, specify a suitable covering or jacket.

3.4.7 Shielded Cables. Provide shielding of a medium-voltage distribution cable to confine the electric field to the insulation itself, and to prevent leakage currents from reaching the outside surface of the cable. Insulation shielding is required on all nonmetallic-sheathed cable rated 2 kV and above and all metallic-sheathed cable rated 5 kV and above. Shields should be grounded to reduce the hazard of shock. Grounding is required at each splice and at each termination, otherwise dangerous induced shield voltages may occur.

3.4.8 Cable Splicing. Provide cable splices in accordance with NFGS-16301. Aluminum-to-copper and nonmetallic-jacketed to lead-covered cable connections are easily made when connectors and splicing materials are correctly utilized and installed so as to prevent any galvanic action or oil migration which might occur. Such transitions are not permitted when installing new lines; however, splices of this type may be necessary for connections between existing and new work.

3.4.9 Cable Fireproofing. Fireproof cables operating at 2,200 V or over, or exposed to the failure of other cables operating at these voltages, in manholes, handholes, and transformer vaults, as required by NFGS-16301. Exceptions may be made where physical separation, isolation by barriers, or other considerations permit, if approved by the local Naval Facilities Engineering Command (NAVFACENGCOM) having jurisdiction.

3.4.10 Cable Identification. Tag cables in all manholes to identify circuity, cable size, cable conductor and insulation type, voltage rating, manufacturer, and date installed. Cable identification provided on the insulation by the manufacturer need not be repeated unless covered up by fireproofing. In handholes and at other termination points only a circuit identification is required.

3.4.11 Gas Pressurized Cable. Sulfur hexaflouride gas pressurized cable or integrated gas spacer cable can be considered for use when used with either XLP or EPR insulations. The jackets of direct-burial cables or field-installed or factory-coilable conduits can be pressurized with this gas.

3.4.11.1 Sulfur hexaflouride Gas. This gas has five times the density of air and acts as an "invisible liquid" as it stays in place even when exposed to air. It is electro-negative with no oxygen or carbon; has a high arc resistance; will not support combustion; and is odorless, tasteless, and nontoxic. When used with XLP and EPR insulations, it prevents water vapor diffusion, water treeing, and gaseous ionization. It provides monitoring for indication of mechanical damage during shipment, installation, and during operation. Sulfur hexaflouride gas improves the lightning and impulse strength and can provide a rehealing of insulation after an electromagnetic pulse insulation failure. The gas pressure protects against internal corrosion of metal parts. The SF_6 gas provides extra electrical strength in splices and terminations.

3.4.11.2 Installation. Expand the requirements for integrated gas spacer cable of NFPA 70 to cover the XLP or EPR insulation requirement. Determine appropriate installation requirements for direct burial, in conduit, or as submarine cable from manufacturers. In cold climates, indicate temperature ranges, so a gaseous mixture which prevents liquification is achieved.

3.4.11.3 Optional Usage. Where adequate requirements are provided, gas pressurized cable may be used as an option to cables covered in NFGS-16301.

3.5 Underground Transformers. Use vaults to house transformers and associated equipment for underground distribution systems.

3.5.1 Equipment. Use subway (submersible) type equipment.

3.5.2 Vault Design. Design transformer vaults in accordance with MIL-HDBK-1008 and include the following provisions:

a) Provide adequate ventilation to prevent a transformer temperature in excess of the values prescribed in ANSI C57.12.00, General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers, and C57.12.01, General Requirements for Dry-Type Distribution and Power Transformers. This limitation requires that most of the electrical heat losses must be removed by ventilation; only a minor part can be dissipated by the vault walls. NFPA 70 recommends 3 inch (19 square cm) of clear grating area per kilovolt-ampere of transformer capacity. In localities with above average temperatures, such as tropical or subtropical areas, increase the grating area or supplement by forced ventilation, depending upon temperature extremes.

b) Provide adequate access for repairs, maintenance, and installation and removal of equipment. Refer to working space requirements covered in Section 5.

c) Provide isolation to prevent transmission of fires or explosions to adjacent vaults.

d) Provide all vaults with drainage. When normal drainage is not possible, provide a sump pit to permit the use of a portable pump.

3.6 Cable Ampacities. Design the current-carrying capacities for underground cables, either direct burial or in ducts, in accordance with NFPA 70 adjusted to fit the specific application. The NFPA 70 tables list individual ampacities for various sizes and number of conductors, with other assumed conditions, which may or may not apply to the design under consideration. Parameters given are as follows:

a) An ambient earth temperature of 68 degrees F (20 degrees C).

b) An arrangement with cables spaced either 7.5 inches (190.5 mm) or 24 inches (609.6 mm) center-to-center.

c) A 100 percent load factor.

d) A thermal resistance (RHO) of 90.

e) A conductor temperature of 194 degrees F (90 degrees C) or 167 degrees F (75 degrees C) dependent upon voltage.

Adjustment factors are given only for different ambient earth temperatures. No corrections are included for different load factors, thermal resistances, conductor spacings, or cable temperatures. A load factor of 50 percent and an RHO of 60 are not unusual which could increase the listed ampacity by as much as 15 to 50 percent. Detailed calculation methods along with ampacities for other conditions are contained in IEEE/ICEA P-46-426, Power Cable Ampacities.

3.7 Safety Considerations. Effectively ground all electrical equipment and hardware installed in vaults and manholes by the use of ground rods. Ground exterior shields of cables as covered previously. Ground metallic sheaths of cables at each splice and each termination. Bonding together of metallic sheaths in a manhole maintains the sheaths at a common potential near ground and reduces personnel danger and arcing when a cable fault occurs. Where it is the policy of the facility, a ground conductor may be required to be installed with each primary feeder and the ground conductor should be interconnected at manholes and vaults to their grounding systems.

Section 4: SUBMARINE CABLE SYSTEMS

4.1 Preliminary Considerations

4.1.1 Where Permitted. Use submarine cable only where local conditions rule out the use of any other system.

4.1.2 Installation Problems. Consider installation problems at the time of design. These problems (for example, practical length of cables, size of reels, and transportation to site) will vary for each particular installation.

4.2 Location Considerations. When considering locations, consider the soundings and the restrictions described in paras 4.2.1 through 4.2.4.

4.2.1 Soundings. Obtain soundings along several proposed crossings to obtain the most convenient profile. Within the United States, soundings can be obtained from the Department of the Army, Corps of Engineers. For locations outside the United States, consult local authorities.

4.2.2 Hydraulic Restrictions

4.2.2.1 Turbulences. Do not install submarine cables in waters where bottom turbulences may occur. Cables exposed to continuous vibration have short lives due to mechanical fatigue of metallic sheaths.

4.2.2.2 Currents. Provide cables installed across rivers with currents with a curved upstream concave alinement. Determination of the amount of curved alinement necessary depends upon the speed of the current.

4.2.2.3 Variable (Changing) Waters. Obtain approval for routes and minimum depths for crossings under variable waters from the Department of the Army, Corps of Engineers or by the corresponding authority.

4.2.3 Chemical Composition of Waters. Do not install submarine cable near sanitary sewers, chemical discharges, dumping areas, or wharves where waste material has accumulated. Make a provision based on a water analysis for any chemical reaction with the cable sheaths and coverings. Where feasible, consider the installation of cable integrally installed in a plastic conduit or provided with a protective corrosion-resistant jacket.

4.2.4 Marine Traffic. Bury any cables crossing through waters adjacent to marine traffic to a depth that eliminates any damage from dragging anchors. Large ships may drop anchors up to 15 feet (4.5 m) in depth on sand bottoms.

4.3 Installation. Install cables to lie on the bottom, with ample slack so that slight shifting will not place excessive strain on them. Because of the great weights involved when any considerable length of submarine cable is to be sunk across a waterway, use installation methods to keep tensile stresses at a minimum. The ideal lay of a submarine cable on a bottom is a series of horizontal S-curves. This pattern provides the slack necessary to prevent injurious straining of the cable. Where two parallel cables cross, provide a separation of 100 feet (30.5 m) to avoid fouling and to permit work space (refer to criteria in the Underground Systems Reference Book).

4.3.1 Burying Cable. In addition to laying cables on the bottom, consider burying them by the jetwater method. By this technique, the cable is installed simultaneously with the trenching operation. Several cables or cables integrally installed in plastic conduits can be installed at the same time. The installation of cable integrally installed in plastic conduit provides cable protection and facilitates future replacement.

4.3.2 Anchors. Where a cable crossing is subjected to flow or tidal currents, anchors are usually required to prevent excessive drifting or shifting of the cable along the bottom. These anchors can be made fast to the cable by a series of U-bolts that pass through a common base plate, thus affording a multiple grip. Either U-bolts, eyebolts, or other means may be provided for attachment of the anchor cable or chain. Ordinarily, anchors are masses of concrete large enough to resist current drag.

4.3.3 Warning Signs. Provide suitable warning signs to indicate the locations of the shore ends of a submarine cable. These signs should state that ship anchoring is prohibited in the immediate vicinity of the cable. Signs are required for every submarine cable crossing.

4.3.4 Pile Clusters. Frequently clusters of piles are driven on the upstream side of important cables where they enter and leave the water. These clusters supply visual aid in locating the points where the cable is anchored.

Clusters also provide a certain amount of mechanical protection for the cables, and furnish platforms on which to mount warning signs.

4.3.5 Maps. The development of accurate maps is one of the most important steps in an extension of a submarine cable installation. Maps indicate the exact location of the cable at various points along its length, as established by surveying instruments. To estimate cable movement or drifting on the bottom, the maps must also indicate the exact length of the cable installed between any two reference points.

4.4 Cable Types. Lead-sheathed cable is generally used for submarine installations and is usually armored. Insulations shall be Cross-linked Polyethylene (XLP) or Ethylene-Propylene-Rubber (EPR) except where the paper-insulated type is justified because it has qualities neither XLP nor EPR provide. Use multiple-conductor cable unless limited by physical factors.

4.4.1 Metallic-Sheathed Cable. Cables usually are sheathed with copper-bearing lead, but other alloys may be required where special conditions warrant nonstandard sheathing.

4.4.2 Armored Cable

4.4.2.1 Application. Use wire-armored cable where extreme tensile strength and high resistance to mechanical damage are required. In this type of cable, asphalt-impregnated-jute usually is applied directly over the lead sheath, and the wire-armor is applied over the jute to reduce mechanical damage and electrolytic corrosion. An additional covering of asphalt-impregnated-jute may be applied over the armor.

4.4.2.2 Wire-Armor. Wire-armor is usually made of galvanized steel wire. The galvanizing protects the armor from corrosion and reduces electrolytic corrosion of the lead sheath. This reduction, however, may be at the expense of the armor, because under certain conditions the zinc passes from the armor to the lead sheath.

4.4.3 Nonmetallic-Sheathed Cable. For submarine service, cables without a metallic sheath are satisfactory for certain applications. When cables without protective lead sheaths are used, they should be types manufactured specifically for submarine service. They may or may not require wire armor. Such cables are provided with insulation of extra thickness for all sizes and voltages.

4.4.4 Shielding. Nonmetallic-sheathed cables should be shielded throughout their lengths. Normally the voltage rating will already require shielding.

4.5 Electrical Connections. Cable termination, splicing, and bonding is as follows:

4.5.1 Terminations

4.5.1.1 Potheads. A lead-covered submarine cable is occasionally connected, at either or both ends, to an overhead line. Under such circumstances, use a pothead with an integral wiping sleeve as a convenient method of terminating the cable. This method eliminates the junction box on shore and associated labor costs of the extra cable splices. By bringing the submarine cable out of the ground in a suitable conduit sleeve, or other mechanical protective arrangement, the cable can be supported on a permanent steel or wooden structure. Cables in conduit strapped to the supporting structure, are then run directly into a pothead, which is mounted at the desired height on the same supporting structure.

4.5.1.2 Three-Conductor Potheads. Adverse atmospheric conditions can make it dangerous to use three-conductor potheads for such cable terminals. Under such conditions, the multiple-conductor cable may be spliced out with single-conductor cable and single-conductor potheads employed to permit increased clearances between pothead bushings.

4.5.2 Splices. Use maximum lengths of cables to reduce the number of splices. The types of splices shall be in accordance with NFGS-16301.

4.5.3 Bonding. Cable sheaths and armor shall be bonded together at every splice and at both shore ends.

SECTION 5: SUBSTATIONS

5.1 General Considerations. Substations are categorized in this handbook by type of system supplied and their physical location. Since there are many types, substation terminology and layouts are provided for guidance and to assist in understanding criteria applications.

Table 5
Substation Terminology

TERM	DEFINITION
Substation	An assemblage of equipment for purposes other than generation or utilization, through which electric energy in bulk is passed for the purpose of switching or modifying its characteristics.
Unit substation	A substation consisting primarily of one or more transformers which are mechanically and electrically connected to and coordinated in design with one or more switchgear or motor control assemblies, or combinations thereof.
Primary unit rated substation	A unit substation in which the low-voltage section is above 1000 volts. See NEMA 201, Primary Unit Substations.
Secondary unit rated substation	A unit substation in which the low-voltage section is 1000 volts and below. See NEMA 210, Secondary Unit Substations.
Articulated unit and substation (primary or secondary)	A unit substation in which the incoming, transforming outgoing sections are manufactured as one or more subassemblies intended for connection in the field.
Load center (a) secondary	A manufacturer's designation for an articulated unit substation with secondary switchgear (also known as a power center).
Integral transformer load center (a)	A load center with a secondary panelboard instead of secondary switchgear.
Pad-mounted compartmental-type transformer	A transformer utilized as part of an underground distribution system with enclosed compartment(s) for high- and low-voltage cables entering from below and mounted on a foundation pad.

(a) Terms not listed in IEEE Standard 100.

5.1.1.1 Type of System Supplied. Usually substations either supply secondary (utilization) voltages to buildings, or primary (distribution) voltages to large areas of a naval facility.

5.1.1.2 Location. Substations are located indoors or outdoors for utilization voltage service and outdoors normally for distribution voltage service.

5.1.2 Definitions. Definitions used by organizations which prepare standards on switchgear (ANSI, IEEE, NEMA) differ from those that manufacturers use. To provide a common basis for terms used in this handbook and in NFGS-16321, Interior Transformers, NFGS-16335, NFGS-16462, Pad-Mounted Transformers, and NFGS-16465, Interior Substations, the definitions of Table 5 are given. Except as noted, all usage in this manual and corresponding NFGS's agrees with the definitions of IEEE Standard 100, IEEE Standard Dictionary of Electrical and Electronic Terms.

5.1.3 Typical Substation Layouts. For typical substation layouts, see Figures 2, Compartmental-Type Transformer Installation, 3, Radial-Type Articulated Secondary Unit Substation Installation, 4, Secondary Unit Substation Grounding, and 5, Preferred Design for a Transmission to Distribution (Primary) Substation.

5.2 Indoor Unit Substations. Articulated unit substations with a primary voltage of 15 kV or less may be installed indoors. Substations are normally of the secondary unit type except where 2,400 V or 4,160 V secondary distribution is used to serve large motor loads. Pad-mounted compartmental-type units should generally be restricted to exterior locations.

5.2.1 Preliminary Considerations. Ensure material and equipment conforms to NFGS-16465 based on consideration of the following:

5.2.1.1 Location. Make a selection of the number of unit substations and their locations based on the most economical balance between the cost of a secondary distribution system and the cost of transformers, switchgear, and a primary distribution system. Install load centers where they are economical for small concentrated loads. Integral transformer load centers do not involve great installation expense. Dry types may be located in the same room with loads; they provide good voltage regulation and have minimum energy losses.

5.2.1.2 Capacity. Transformers larger than 500 kVA for 208Y/120 V building service are not permitted. Similarly, do not specify transformers in ratings of over 1,000 kVA or in exceptional cases larger than 1,500 kVA for 480Y/277 V building service and only where functionally required. The use of smaller transformers supplying larger loads adds flexibility and reliability to the system. Shore-to-ship service may require larger transformers. Transformers rated 1,500 kVA or larger should utilize secondary busway where a connection to a nonintegral secondary switchgear section is required unless such a connection is impracticable. Where larger transformer capacities are justified, provide current-limiting fuses in conjunction with primary or secondary protective devices or other methods of limiting the available fault current to an acceptable value.

5.2.1.3 Safety. All current-carrying parts of unit substations must be dead-front construction, usually in grounded metal enclosures. In some cases, nonmetallic enclosures, such as fiberglass may be functionally required. Provide interlocking to prevent accidental contact with live parts when working within the switchgear enclosure. For example, interlock access doors to primary fuse compartments so that access is possible only when the primary switch is open.

5.2.2 Design. A unit substation, by its definition, has coordinated sections; therefore, provisions for future addition are possible at minimum cost, if adequate space is provided.

5.2.2.1 Mounting. Provide a concrete base. Mount substations on channels or other supports which are flush with the top of the base.

5.2.2.2 Short-Circuit Duty. Coordinate circuit interrupting devices with each other. Each device shall be capable of clearing the maximum fault available. Bracing for bus bars and other current-carrying parts should be capable of withstanding the mechanical stresses produced by the maximum available short-circuit current.

5.2.2.3 Primary Protection. Use air-type load interrupter switches with current-limiting fuses, unless other protection such as circuit breakers or liquid-type switches are more appropriate. Use of circuit breakers may be required to provide sufficient interrupting duty, or because coordinated tripping is required. Circuit breakers are more reliable than switches, but their additional cost must be justified. Use of liquid-immersed switches is appropriate for certain installations, such as in underground vaults.

5.2.2.4 Lightning Protection. Coordinate lightning protection with other components of the distribution system that may be exposed to surge voltages. Provide arresters when necessary. When dry-type transformers with lower BIL???? ratings are used, extra protection may be required.

5.2.2.5 Secondary Protection. Use either metal-enclosed, low-voltage power or molded-case circuit breakers as protection. Normally for building services, molded-case units are used for less than 1,200 A and low-voltage power units are used for higher amperages. For shore-to-ship service, low voltage power units are required.

5.2.2.6 Instrumentation. Provide unit substations of more than 500 kVA with at least an ammeter and a secondary voltmeter. The use of wattmeters (recording or indicating) and voltmeters, for primary service metering, will depend on the individual installation. For provision of watthour demand meters with pulse initiators, see requirements for energy monitoring in this section.

5.2.3 Arrangements. Use standard arrangements where possible. Standard unit substations have the primary switch on the left, the transformer in the middle, the circuit breakers on the right, and space for future additions.

5.2.3.1 Reversed. Where conditions dictate otherwise, the reversed arrangement may be adopted.

5.2.3.2 Double-Ended. Use double-ended unit substations where two primary sources are required to provide reliability. See Figure 6 for a layout of a secondary-selective-type double-ended arrangement. Each transformer and its associated equipment shall be capable of carrying the essential loads of both sections. Refer to MIL-HDBK-1004/1 for additional policy on selection of electric power sources for standby service. In sizing the transformers, take into consideration allowable overloading. Refer to ANSI C57.91, C57.92, or C57.96, for overloading. Where the normal double-ended unit substation is used, provide for contemplated future expansion; this arrangement does not permit addition of unexpected future circuit breakers. For applications where future expansion may be greater than normal, or unpredictable, consider two other arrangements requiring more floor area and initial cost, but which permit easy addition of sections, or replacement of transformers with larger units. One arrangement has the primary, transforming, and secondary sections for each half in separate lineups, with a tie bus or conduit and wire connecting the two. The tie breaker may be in either lineup. The other arrangement has the primary and transforming sections, along with the secondary main breakers separate from the secondary lineup.

5.2.3.3 Secondary Spot-Network. Use secondary spot-network unit substations for loads requiring an unusually high service reliability where the increased cost can be justified. Figure 2 would represent a secondary spot-network substation with a two-transformer input to a multiple-feeder output, if the tie circuit breaker were eliminated and the secondary main circuit breakers were shown with network protectors. This system is the most reliable power supply for large loads, since any fault on the primary input to the secondary bus is automatically disconnected by the network protector operating at a speed which greatly minimizes voltage dips from faults or large transient loads. The extra cost of the additional transformers and network protectors plus possible increased secondary duty ratings from the increased short-circuit capacity of parallel transformers makes this a very expensive installation, especially when in the usual case, three or four transformers are paralled.

5.2.4 Transformer Insulations. Indoor unit substation transformers of the dry-type may be used and need not be installed in vaults. Less-flammable, liquid-insulated units may be installed without a vault where permitted by NFPA 70. Where vaults are required for less-flammable, liquid-insulated transformers in some cases and in all cases for oil-insulated transformers, their installation shall conform to NFPA 70. Provide an economic or functional justification for the type of unit provided. Select the insulation type on the basis of surrounding atmosphere and basic impulse insulation level required. Check loading characteristics from ANSI C57.91, C57.92, or C57.96 making sure that the lower impulse level standardly provided for dry-type units are adequately protected. Ensure equipment conforms to NFGS-16465.

5.2.4.1 Dry-Type Units. Conventional-ventilated, epoxy-encased-ventilated (cast resin), or gas-filled are all considered dry-type units. Normally the conventional-ventilated type, as the least costly, shall be installed. However, consider using the epoxy-encased type for units which serve in a stand-by status. Conventional units readily absorb moisture when not energized and need special handling when re-energized; epoxy-encased types do not. Epoxy-encased types can be considered to be better braced for short-circuit duty since the epoxy entirely supports the coils. Restrict gas-filled types to hazardous area locations, if such units cannot be located outside the dangerous area.

5.2.4.2 Nondry-Type Units. Install only less-flammable, liquid-insulated and oil-insulated units. Do not install askarel-insulated and nonflammable, fluid-insulated umits.

5.2.4.3 Insulation Comparisons. For a comparison of the various transformer insulations refer to Table 6. Cost comparison is based on the cost of oil filled outdoor type transformers. Cost percentages given first are for indoor locations. Second cost percentages given in parentheses are for outdoor locations. Costs are based upon transformers with cores made of silicon-steel materials. Amorphous Core Transformers, with cores made of amorphous metal, costs approximately twice the cost shown on Table 6. Cost of amorphous core transformers is based upon Year 1991 price. Refer to section paragraph 1.4.3 for more information on Amorphous Core Transformers.

5.2.5 Unit Substation Rooms. Ensure unit substation rooms do not contain any pipes, ducts, or other foreign systems, except those required for fire protection, ventilation, and drainage of the room; however, dry-type units may be installed without a separate room if piping is not run immediately over such units.

5.2.5.1 Drainage. Provide rooms containing liquid-insulated transformers with concrete curbs and an appropriate drainage system to prevent liquid from spreading to adjacent rooms. Use the criteria in NFPA 70 for unit substation rooms.

5.2.5.2 Access. Design equipment rooms where primary switching equipment, other than transformer switching, is installed with not less than two separate access doors for use by authorized personnel only.

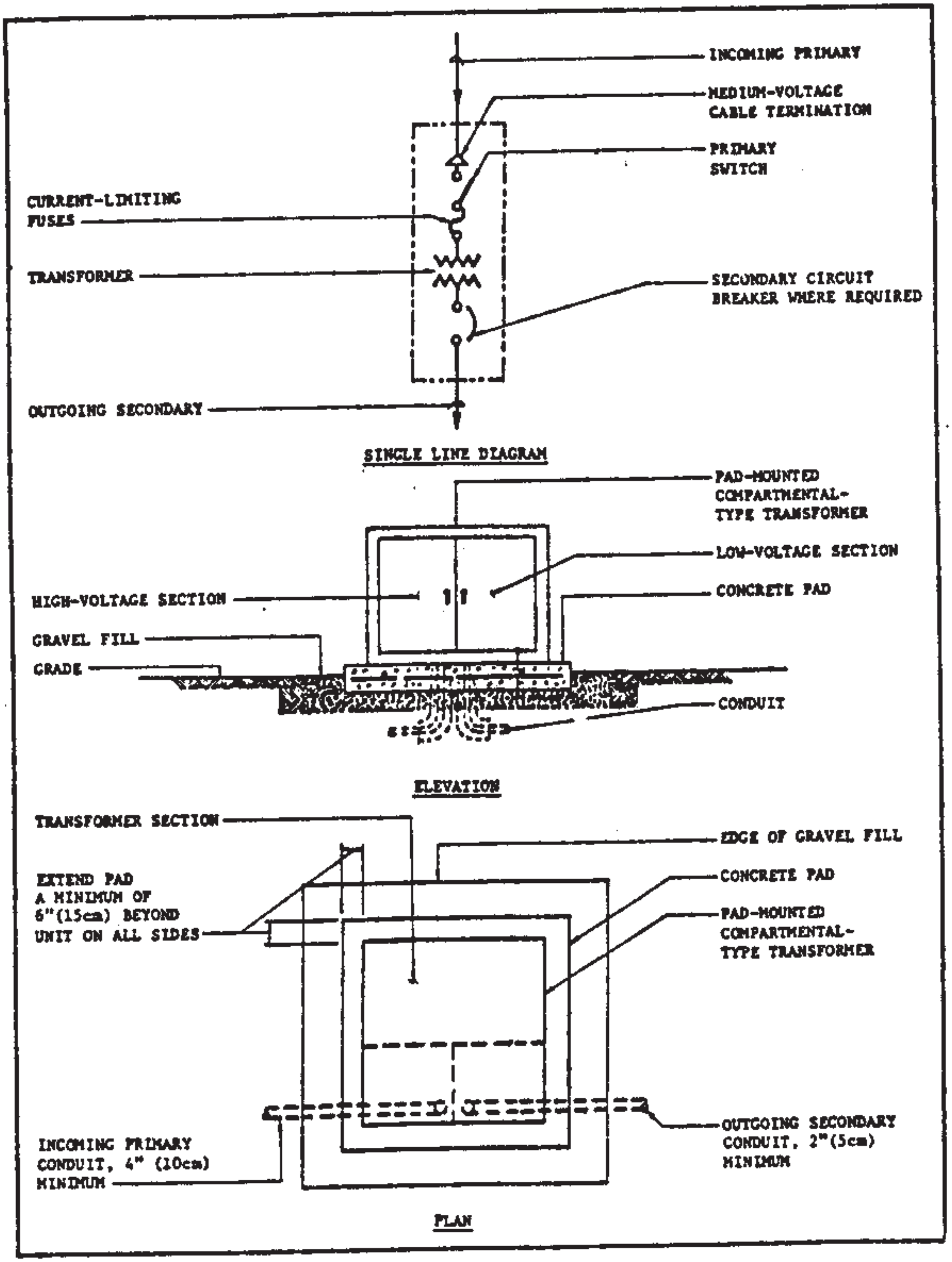


Figure 2
Pad-Mounted Compartmental-Type Transformer Installation

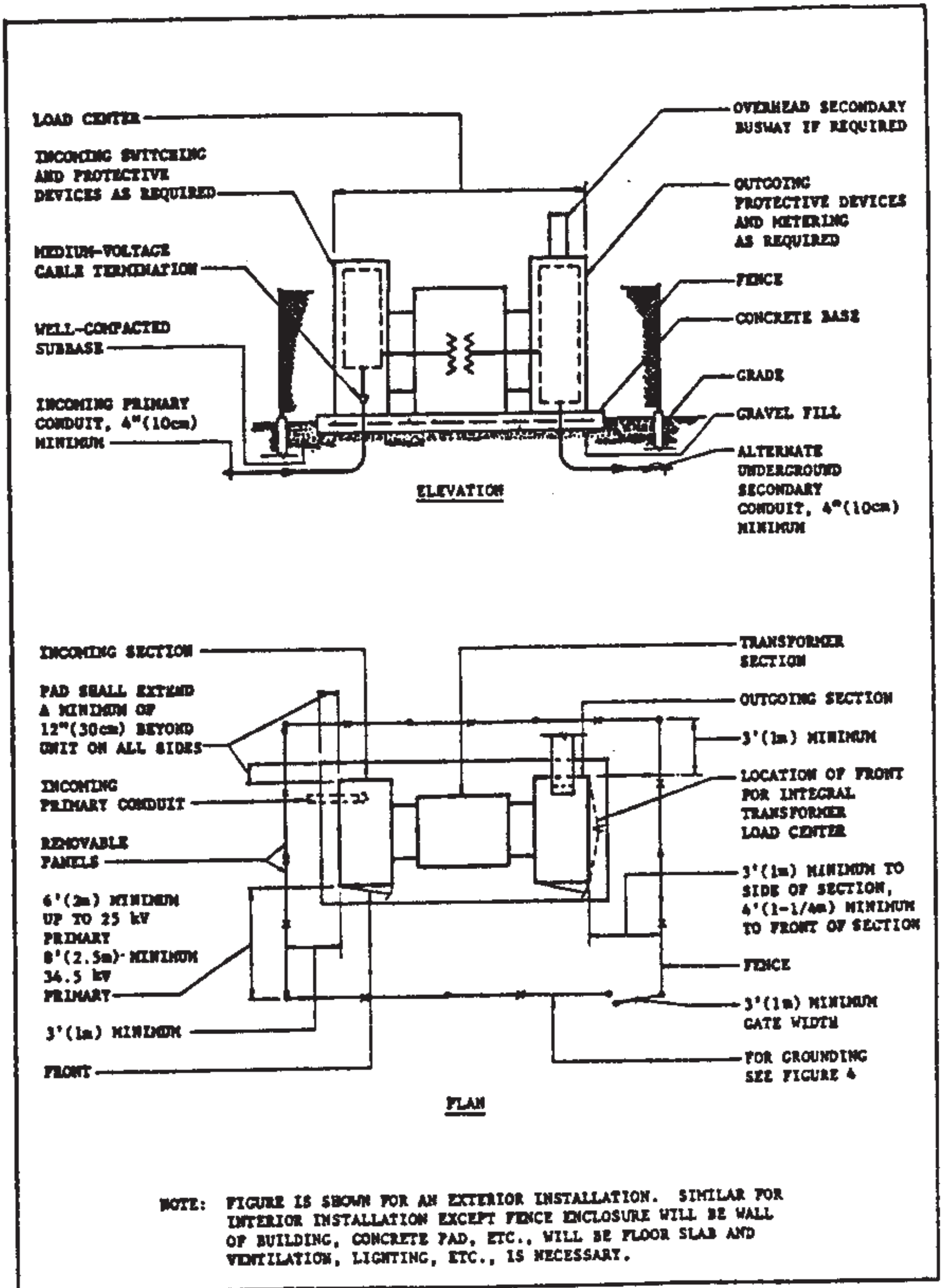


Figure 3
Radial-Type Articulated Secondary Unit Substation Installation

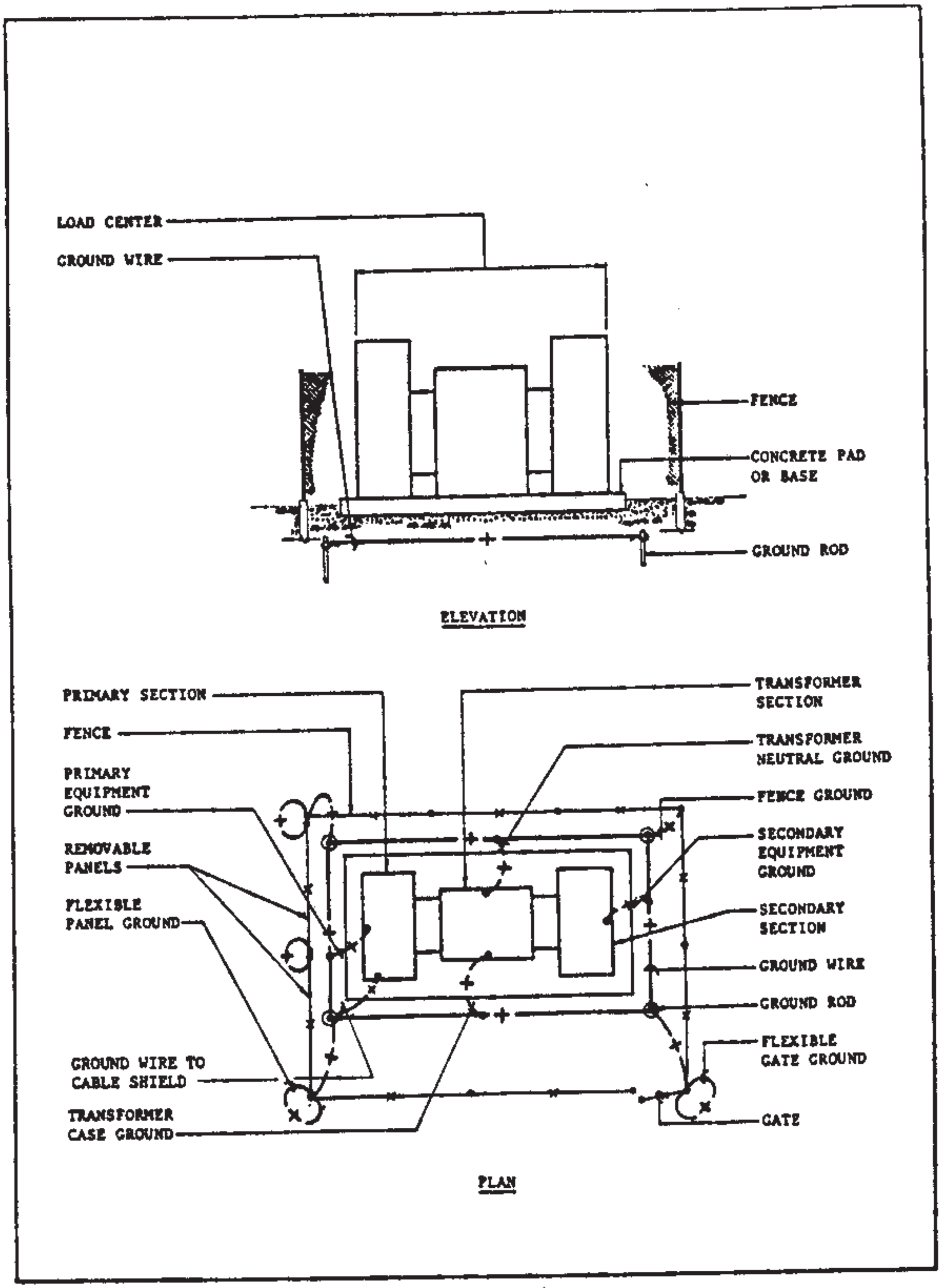


Figure 4
Secondary Unit Substation Grounding

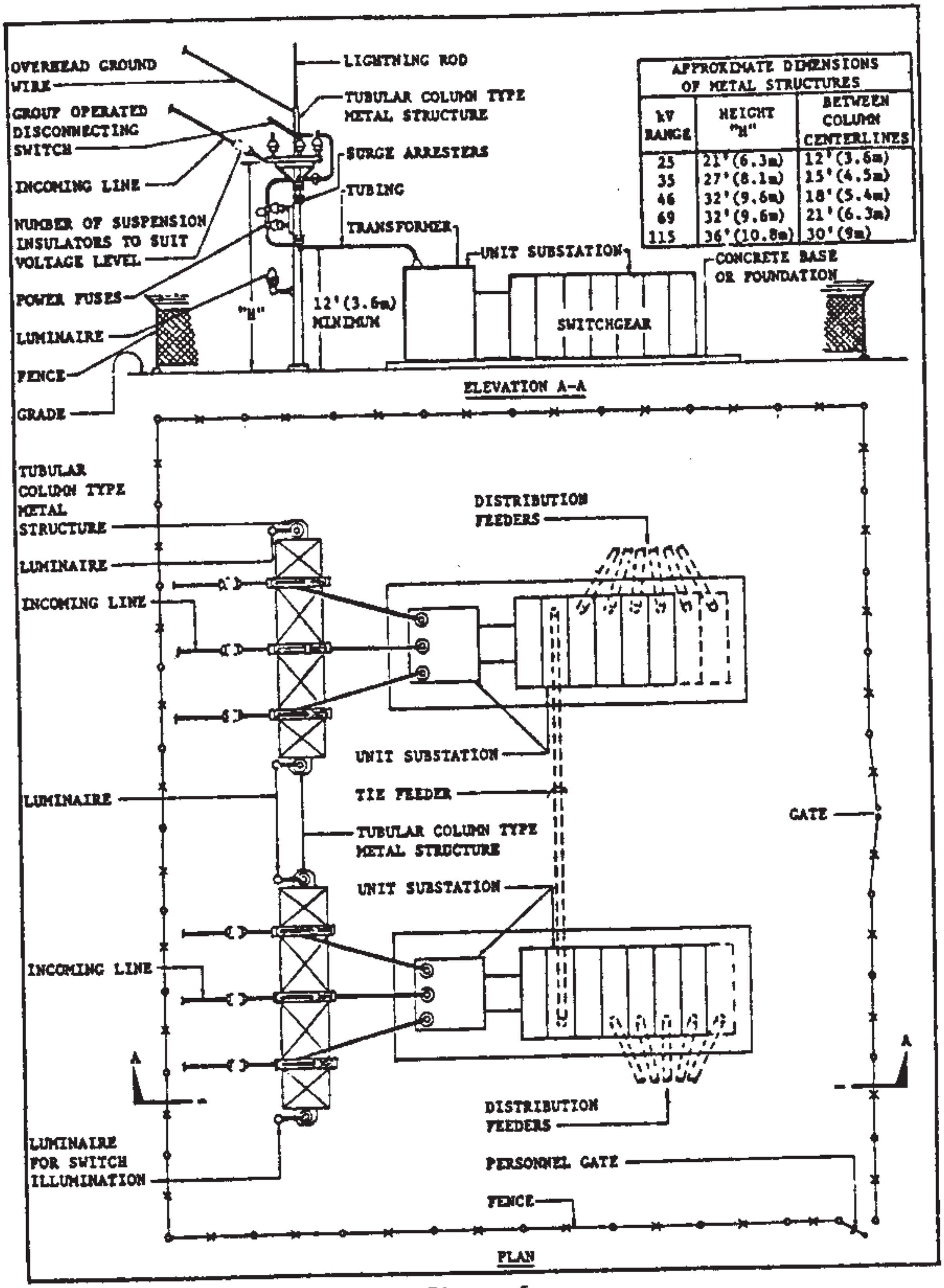
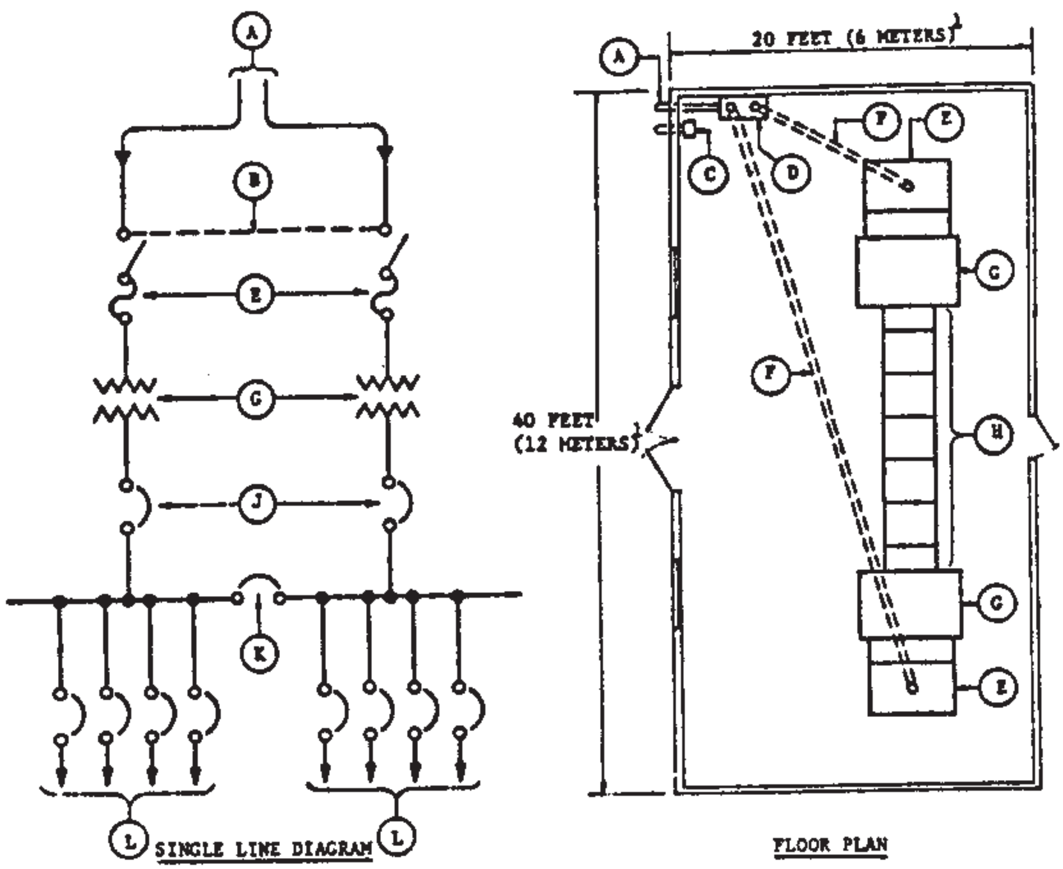


Figure 5
Preferred Design for a Transmission to Distribution (Primary) Substation



[1]± AS REQUIRED TO PROVIDE NEC WORKING SPACE

- (A) INCOMING MEDIUM-VOLTAGE SERVICE - TWO SERVICE REQUIRED
- (B) FEEDER TIE, PROVIDE WHEN ONE FEEDER WILL BE AVAILABLE ONLY AT A FUTURE DATE
- (C) SPARE DUCTS
- (D) PULLBOX (IF REQUIRED)
- (E) PRIMARY LOAD INTERRUPTER SWITCH AND CURRENT-LIMITING FUSES
- (F) MEDIUM-VOLTAGE CABLE IN DUCT
- (G) THREE-PHASE TRANSFORMER
- (H) LOW-VOLTAGE SWITCHGEAR SECTION
- (J) SECONDARY MAIN CIRCUIT BREAKERS WITH AUXILIARY ALARM CONTACTS
- (K) TIE CIRCUIT BREAKER INTERLOCKED WITH MAIN CIRCUIT BREAKERS
- (L) LOW-VOLTAGE FEEDERS

Figure 6
Secondary-Selective-Type Articulated Secondary Unit Substation Installation

5.2.5.3 Ventilation. Provide ventilation adequate to dissipate heat given off by transformers and associated equipment and to maintain safe operating temperatures. Gravity ventilation is usually not adequate for indoor substation rooms; in such cases, mechanical ventilation should be provided. In air-conditioned buildings, an economical and positive means of ventilating substation rooms is to exhaust tempered air from conditioned spaces through the substation room.

Table 6
Comparison of Types of Transformer Insulation

	LIQUID-INSULATEDDRY-TYPE				
TRANSFORMER QUALITIES	OIL	LESS-FLAMMABLE	CONVENTIONAL	EPOXY-ENCASED	GAS-FILLED
Relative Impulse strength (BIL)	100%	100%	Varies(1)	Varies(1)	Varies(1)
Temperature rating(degree C)	55 or 65	55 or 65	80 or 150	80 or 150	120
Relative audio sound level in dB (2)	X	X	X + 10 dB	X + 10 dB	X + 10 dB
Relative weight	125% :	100%	120%	80%	95%
Relative dimensions	100%	100%	100%	105%	120%
Application	outdoor(3)	all	indoor	all (4)	all
Maintenance	routine	routine	routine	routine	low
Relative Cost	237% (100%) 220% (220%)	200% (130%)		125% (127%)	200% (200%)

(1) Varies from 33 to 66% depending on voltage level. Higher BIL ratings for dry-type transformer are available, but an increased cost for conventional and gas-filled types.
(2) X indicates normal decibel level for liquid-immersed units.
(3) Indoor also in fire-resistant vaults when more economical than other types.
(4) Not recommended in extreme environment containing excessive dirt or dust or containing concentration of corrosive elements.

5.2.5.4 Noise. If local conditions require less than NEMA TR-1 recommended audio sound levels, make an economic comparison between the cost of transformers having lower than standard noise levels, and the cost of sound and vibration isolation of the transformer room. Avoid locating unit substation rooms near critical spaces requiring low noise levels, such as auditoriums, sick bays, or living quarters (refer to NAVFAC DM-1.03, Architectural Acoustics).

5.2.5.5 Emergency Lighting. Provide emergency lighting, of the battery-operated type, in unit substation rooms.

5.3 Outdoor Utilization Voltage Substations. Base material and equipment on NFGS-16335. Generally, transformers are be grade-mounted type subject to the limitation given in this section. Transformers may be pole-mounted type only when such transformers comply with the requirements given in Section 2.

5.3.1 Secondary Unit Substation Types. Secondary unit substations should generally follow the criteria given previously for indoor unit substations except that requirements for outdoor installations apply. Because these units are not tamperproof, protect substations from unauthorized access by chain link fencing of at least 7 feet (2.1 m) in height as a minimum requirement. Provide three strands of barbed wire above for additional protection only where such substations are in housing areas or otherwise exposed to military dependents or where required by the using agency. Other fence materials to provide equipment masking, sound absorption, or protection against sabotage may be necessary in some cases (see Figure 3).

5.3.2 Pad-Mounted Compartmental-Type Transformer Units. Provide units in accordance with the requirements of NFGS-16462. This specification limits the primary protective options to group-operated, load-break switches. Since such units are tamper resistant, they need not be fence-enclosed (see Figure 2).

5.3.2.1 Units 500 Kilovolt-Amperes and Smaller Units are not Provided with Either Taps or a Minimum Percent Impedance Unless Specified. To prevent excessive interrupting duty on secondary equipment it may be necessary to check manufacturers' ranges of available impedances, as there is no industry standard.

5.3.2.2 Units Larger than 500 kVA. Pad-mounted units in three-phase units larger than 500 kVA are available up to a capacity of 2,500 kVA. These units are less expensive than secondary substation units. However, because primary protective devices available for such larger sizes do not provide dead-front load-break features within the pad-mount construction, the use of units larger than 750 kVA is not recommended.

5.4 Outdoor Distribution Voltage Substations. Design these substations to meet the criteria for acceptable power sources in MIL-HDBK-1004/1 and the recommendations of the Base Exterior Architecture (BEA) plan.

5.4.1 Structure-Mounted Equipment. Structure-mounted equipment should be used for voltages above 35 kV. The use of modern low-profile metal structures with tubular type or H-beam supports is considered the most desirable design. The conventional lattice-type structure is unattractive in appearance, more difficult to maintain, and more vulnerable to the twisting forces from heavy winds (see Figure 5).

5.4.2 Transformers. Primary unit substations require less land space, are visually less objectionable, and because of the integrated transformer to secondary connection, are more reliable than separate substation transformers and secondary protective devices.

5.4.3 Connection to Primary Distribution Lines. An underground connection from the station to aerial lines should be provided when distribution voltage is 35 kV or less. An underground line not only provides aesthetic enhancement but reduces vulnerability to lightning or other weather or man-produced interruptions.

5.5 Substation Considerations. Consider the effects that the actual site electrical configuration, type of incoming and outgoing switching, need for supporting structures and surge protection, type of transformers, and control features have on a substation layout.

5.5.1 Site Effects. In the design of a substation, consider the following factors:

a) Architectural requirements; landscaping.

b) Exposure conditions; for example, at the seashore or in other corrosion-producing atmospheres.

c) Physical conditions such as snow or ice, sandstorms, altitude, and lack of rainfall.

d) Adjacent terrain and installations affect landscaping layout and noise treatment. Utilize the influence of the direction of prevailing winds on sound propagation to minimize noise exposure (refer to NAVFAC DM-1.03).

5.5.2 Electric Configuration. Determine the electrical configuration with the respect to provisions for adequate station capacity plus supply and feeder circuit conditions. Consider supply circuit requirements for the following conditions:

a) single or multiple supply,
b) supply circuit voltage and phases,
c) overhead or underground supply required, and
d) primary switching.

For feeder or load circuits, determine the following conditions:

a) number of circuits,
b) capacity of circuits,
c) voltage and phase, and
d) overhead or underground distribution required.

Finally, consider coordination of circuit protective devices between supply and feeder circuits.

5.5.3 Incoming-Line Switching. Design the substation with a minimum of incoming-line switching consistent with good maintenance and operation. For rating of equipment, refer to MIL-HDBK-1004/3, Switchgear and Relaying. Also, consider the methods described in paras 5.5.3.1 through 5.5.3.3.

5.5.3.1 Circuit Breakers. Use circuit breakers only when the circuit interrupting or relaying requirements do not allow the use of switches. Provide a disconnect and bypass switching features where drawout circuit breakers cannot be utilized.

5.5.3.2 Switches. Switches are covered in Section 2 of this handbook. For voltages of 15 kV or less, load interrupter or disconnect switches are available. Load interrupter switches disconnect circuits under fully loaded conditions and are therefore usually the most desirable choice. Use disconnect switches only to interrupt transformer exciting currents. The use of disconnect switches is not recommended, except for primary incoming lines where secondary circuit breakers can interrupt loads. Assure that operators do not open disconnect switches under load, either by interlocking with load switching equipment or by operating procedures.

5.5.3.3 Current Limiting Protectors. Current limiting protection devices are covered in Section 2. They are generally inappropriate for substation use where metal-enclosed or metal-clad switchgear for 15-kV applications provides a more desirable design.

5.5.4 Outgoing-Feeder Switchgear. For ratings and selection of equipment, refer to MIL-HDBK-1004/3.

5.5.4.1 600 V and Less. For load circuits below 600 V, select from one of the following:

a) metal-enclosed (low-voltage power) circuit breakers where reliability and the longer withstand rating period are desirable; or

b) molded-case circuit breakers. Molded-case circuit breakers must be further defined as to tripping and interrupting currents and whether fully-rated capability or other features are desirable. The use of the term "insulated case" conveys no minimum requirements in accordance with any recognized industry specification and should not be used.

5.5.4.2 Over 600 Volts. For load circuits over 600 V, use criteria in MIL-HDBK-1004/3 to select from the following:

a) either oilless, metal-clad, medium-voltage circuit breakers, preferably of the vacuum circuit breaker type; or
b) grounded, metal-tank type, frame-mounted circuit breakers, with open disconnecting switches. Circuit breakers may be oil, gas, vacuum, or compressed air type. Oil-insulated type shall be installed only in outdoor locations and only for voltages exceeding 35 kV.

5.5.5 Substation Structures. Depending on the chosen design, the substation structure may consist of the following:

a) flat concrete base without elevated structures, applicable for underground supply and load circuits served by metal-clad switchgear;

b) steel or aluminum superstructures mounted on concrete piers; or

c) a combination of either of the aforementioned systems.

5.5.6 Transformers

5.5.6.1 Selection. Consider the types of insulation that are suitable for the site and the system voltages (see Table 6). Select oil-insulated for outdoor applications, except where fire safety considerations require the use of less-flammable, liquid-insulated insulation which is not usually available for voltages above 34.5 kilovolts. For indoor installations, see the paragraph on transformer insulations of this section.

5.5.6.2 Cooling. Forced cooled ratings are only available on larger size transformers; check their availability before specifying. Dependent upon standard ratings and overload capacity calculations, specify the cooling method from one of the following:

a) self-cooled, type OA,
b) one-stage forced-cooled, type FA,
c) two-stage forced-cooled, type OA/FA,
d) one-stage double-forced-cooled; forced-oil, forced-air, type FOA, or
e) triple-rated, types OA/FA/FOA/ or OA/FA/FA.

5.5.6.3 Transformer Capacity. Choose the transformer rating by considering the maximum load to be carried for normal and contingency conditions and the possibility of accepting overloading with accelerated loss of system life. Transformers should be sized for 10 to 25 percent more than calculated loads to minimize future growth costs.

5.5.6.4 Fire Protection. For minimum safe distances of transformers to buildings and other fire protection criteria, refer to MIL-HDBK-1008. Also refer to IEEE 979, Guide for Substation Fire Protection.

5.5.6.5 Transformer Noise. Specify transformer noise levels as given in NEMA TR-1. When standard noise levels are found to be too high, estimate the cost effectiveness of sound minimizing methods such as:

a) specifying a transformer with a lower noise level,
b) utilizing sound barriers, or
c) designing a sound-absorbing enclosure.

5.5.7 Lightning Protection. Where supply or load circuits are overhead or when equipment is located on elevated structures, lightning protection is required in all areas, except those with few lightning storms annually. Data on the mean annual number of thunderstorm days in the continental United States is given in NFPA 78, Lightning Protection Code. Local practice for lightning protection should be followed. Install lightning rods on substation superstructures where required for lightning protection. Surge (lightning) arresters are required at all elevated structures for each circuit, for ground-mounted equipment served by overhead lines and not within the protective range of other arresters, and elsewhere where surges could damage equipment. Determine ratings of arresters according to the equipment to be protected, impulse insulation levels of equipment, and the expected discharge currents the arrester must withstand. Arresters are designed to discharge surges and are classed according to their protective level. They are constructed in various ways to provide nonlinear volt-time characteristics. The National Rural Electric Cooperative Association (NRECA) Research Project 82-5, Lightning Protection Manual for Rural Electric Systems provides a source of information concerning lightning protection for distribution systems.

5.5.7.1 Classes. Select class of arrester based on the following guidelines:

a) Use station-class surge arresters on substations with incoming and outgoing aerial circuits above 15 kV.

b) Use intermediate-class surge arresters on substations with incoming and outgoing aerial circuits above 600 V to 15 kV, except where station-class arresters are required on transformer terminals to provide adequate protection.

c) Use distribution-class arresters at substations where they provide adequate protection for switchgear and as backup protection for arresters located at the junction of overhead and underground incoming and outgoing lines.

5.5.7.2 Types. Arresters are designed so that at power frequencies current does not flow, but at a level of overvoltage which would damage system insulation, the arrester provides a low-impedance path to discharge lightning induced or other high frequency power surges.

The silicon-carbide valve arrester has an element with nonlinear volt-ampere characteristics which limits the follow current to a value that the series gap can interrupt. This type is being phased out by manufacturers.

The metal-oxide varistor type arrester provides the most modern solution to the problems resulting from surge voltages, since its gapless construction means there is no volt-time-gap sparkover characteristic to be considered.

5.5.7.3 Additional Requirements. Refer to MIL-HDBK-1004/6 for additional lightning protection criteria.

5.5.8 Control Features

5.5.8.1 Instrumentation. Instrumentation should be in accordance with metering and relaying requirements of MIL-HDBK-1004/3.

5.5.8.2 Energy Monitoring. Check local energy monitoring requirements to assist in energy conservation and appropriate load shedding. In general, instrument transformers belonging to a utility company cannot be used for monitoring. Watthour meters at distribution substations should be of the pulse initiator type. At utilization substations, it is suggested that watthour meters be provided with the pulse initiator feature, as the cost is not excessive. While the use of instantaneous and peak demand wattmeters for all transformers larger than 500 kVA is recommended, actual provisions should be those required by the activity. As a minimum, always provide at all new distribution substations, conduit installed to the location selected for a future monitoring panel from the following points:

a) energy sensing instrument transformers,
b) a 120 V power source, and
c) a communication line tie-in.

5.5.8.3 Control Cables. For control cables refer to IEEE No. 525, Guide for the Selection and Installation of Control and Low-Voltage Cable Systems in Substations.

5.6 Substation Working Space and Access Requirements. Design indoor and outdoor substation layouts to provide safe working space and access to meet the requirements of NFPA 70 keeping in mind any need for installing and removing equipment, vehicle access necessary for outdoor substations, and adequacy of floor or foundations to support equipment weights.

5.6.1 Design. Allocate adequate space early in the programming/planning stages. Future expansion space should be clearly delineated as should safety exit requirements. Interior space for substations is always at a premium, which can be further minimized by the intrusion of structural elements or installation of mechanical equipment. Electrical requirements are often underestimated.

5.6.2 Existing Construction. When electrical upgrading of existing construction is involved, take into account any extra space and costs required to meet current NFPA 70 code requirements. Working space and access requirements have become more stringent as successive codes are issued and many existing vaults or substation installations may not meet current criteria. If the design cannot meet current NFPA 70 requirements, then a waiver must be obtained from the proper authority.

5.7 Grounding. Provide a grounding electrode system for each substation and connect equipment and system grounds so as to provide personnel and equipment protection and grounding continuity.

5.7.1 Grounding Electrode Systems. Provide electrode systems made of either the girdle or grid type using horizontal conductors running between vertical ground rods.

5.7.1.1 Girdle Type. Use girdle type systems for pad-mounted com-partmental-type transformers and secondary unit substations (see Figure 4).

5.7.1.2 Grid Type. For the much larger voltage gradients at substations for utility-Navy interconnections use the grid-type, buried grounding network. Mesh spacings of 10 to 12 feet (3 to 3.5 m) are commonly used and normally such spacings can control surface voltage gradients even though the ground resistance may be relatively high.

5.7.1.3 Special Techniques. See recommendations of IEEE 80, Guide for Safety in Substation Grounding. Where the local utility or activity indicates the special grounding techniques are necessary because of poor soil conductivity, their recommendations should be followed. Refer to IEEE 142, Recommended Practice for Grounding of Industrial and Commercial Power Systems for a discussion of soil resistivity. Refer to NFGS-16302 for maximum allowable ground resistance values.

5.7.2 Equipment Grounding. Ground metallic enclosures, including cases of primary and secondary switchgear and transformers, to protect operating personnel.

5.7.3 System Grounding. Unless functional requirements prohibit grounding, provide all transformers with wye-connected neutral connections grounded independently at each voltage level, that is, at the transformer secondary.

5.7.3.1 Neutral Grounding. Normally, provide solid grounding, since this is the least expensive method of limiting transient overvoltages while obtaining sufficient ground fault current for selective tripping. Provide impedance grounding only when required to limit ground fault currents to acceptable values or where required by code, such as for portable substations or to match existing system design. Refer to MIL-HDBK-1004/1 for additional requirements.

5.7.3.2 Ground Fault Protection. Ground-fault protection for each system voltage level is independent of the protection at voltage levels for transformers connected delta-wye or delta-delta. A circuit breaker having ground fault protection can be set to operate for lower ground fault levels and provides fast operation since no downstream coordination is required. Fuses have fixed time-current characteristics. On secondary unit substations, low-voltage circuit breakers with ground fault tripping should be used on mains and on large or important feeder units as a minimum, if selectivity can be achieved. On distribution substations, the additional cost for circuit breakers must be justified on the basis that the improved selectivity is required for reliability. Refer to IEEE 242, Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, for ground fault protection application data.

5.7.4 Grounding Continuity. The most important consideration in grounding is assuring continuity of the grounding system. Provide special danger points such as metal-structure mounted switches and surge arresters of transmission to distribution substations (see Figure 5) with dual ground paths. Ground wires run with primary feeder cables may be required either because of existing station practice or for other reasons.

5.7.4.1 Fault Current. NFPA 70 requires a low impedance ground path for fault currents. Where reliable low impedance paths for utilization substations cannot be provided because of soil conditions, equipment locations, or other factors, install a ground wire with the primary feeder cable back to the distribution system substation.

5.7.4.2 Portable Substations. NFPA 70 requires that the exposed noncurrent-carrying metal parts of portable substations must be connected with an equipment grounding conductor run with the primary feeder back to the point where the system neutral impedance is grounded. The reason for such a requirement is that the mobility of the portable substation precludes a predesigned grounding electrode system.

5.8 Safety Considerations. Provide for public safety and for protection of operating personnel with respect to the factors described in paras. 5.8.1 through 5.8.5.

5.8.1 Fencing. Connect fencing, including gates, to substation grounding (refer to DM-5.12, Fencing, Gates, and Guard Towers). For aesthetic reasons, plastic-coated fabric may be used. Grounding this type of fabric requires removing the coating to get a good ground. A touch-up plastic should recoat any uncoated areas not covered by the ground connection. Application and material should be as recommended by the fence manufacturer.

5.8.2 Metal Enclosures. For personnel safety, use metal or fiberglass enclosures around all live parts.

5.8.3 Locking of Gates. Provide locks on gates. Interlock switchgear doors to prevent access to live parts.

5.8.4 Bonding of Gates. For grounding purposes, provide gates with bonding straps across hinges.

5.8.5 Legal Warning Signs. Legal warning signs are required on fences and electrical equipment enclosures which are unfenced. Guidance for warning signs in family housing and community center areas is given in NEMA 260, Safety Labels for Padmounted Switchgear and Transformers Sited in Public Areas.

REFERENCES

<u>ANSI Standards, American National Standards Institute</u> (ANSI), 1430 Broadway, New York, NY 10018.

ANSI C2-90	National Electrical Safety Code
ANSI C29.1-88	Test Methods for Electrical Power Insulators
ANSI C29.2-83	Insulators, Wet-Process Porcelain and Toughened Glass, Suspension Type
ANSI C29.3-86	Wet-Process Porcelain Insulators, Spool Type
ANSI C29.4-89	Wet-Process Porcelain Insulators, Strain Type
ANSI C29.5-84	Wet-Process Porcelain Insulators, Low- and Medium-Voltage Types
ANSI C29.6-84	Wet-Process Porcelain Insulators, High-Voltage Pin Type
ANSI C29.7-83	Wet-Process Porcelain Insulators, High -Voltage Line-Post Type
ANSI C29.8-85	Wet-Process Porcelain Insulators, Apparatus Cap and Pin Type
ANSI C29.9-83	Wet-Process Porcelain Insulators, Apparatus Post-Type
ANSI C37.30-71	Definitions and Requirements for High-Voltage Air Switches, Insulators, and Bus Supports
ANSI C37.32-90	Schedules of Preferred Ratings, Manufacturing Specifications, and Application Guide for High-Voltage Air Switches, Bus Supports, and Switch Accessories
ANSI C57.12.00-87	Standard Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformer
ANSI C57.12.01-79	General Requirements for Dry-Type Distribution and Power Transformers
ANSI C57.12.20-88	Requirements for Overhead Type Distribution Transformers, 500 kVA and Smaller: High-Voltage 67,000 Volts and Below; Low-Voltage 15,000 Volts and Below

ANSI C57.91-81	Guide for Loading Mineral-Oil-Overhead and Pad-Mounted Distribution Transformers Rated 500 kVA and Less with 65 Degrees C or 55 Degrees C Average Winding Rise
ANSI C57.92-81	Guide for Loading Mineral-Oil-Immersed Power Transformers up to and Including 100 MVA with 55 Degrees C or 65 Degrees C Winding Rise
ANSI C57.96-89	Guide for Loading Dry-Type Distribution and Power Transformers
ANSI C62.1-84	Surge Arresters for AC Power Circuits
ANSI C62.2-87	Guide for Application of Valve-Type Surge Arresters for Alternating Current Systems
ANSI C62.33-82	Varistor Surge Protective Devices

Electrical Transmission and Distribution Reference Book, Central Station Engineers, Westinghouse Electric Corporation, Pittsburgh, PA 15230, 1964

Electrical Utility Engineering Reference Book, Distribution Systems, Electrical Utility Engineers, Westinghouse Electric Corporation, East Pittsburgh, PA 15230, 1965.

Industrial Power Systems Handbook, Donald Beeman, Editor, McGraw Hill Book Company, New York, NY 10020, 1955.

Institute of Electrical and Electronic Engineers (IEEE), 345 East 47th Street, New York, NY 10017. The following publications are IEEE Standards.

IEEE 18-80	Shunt Power Capacitors
IEEE 80-86	Guide for Safety in Substation Grounding
IEEE 100-88	IEEE Standard Dictionary of Electrical and Electronics Terms
IEEE 141-86	Recommended Practice for Electric Power Distribution For Industrial Plants
IEEE 142-82	Recommended Practice for Grounding of Industrial and Commercial Power Systems
IEEE 242	Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

IEEE 525-87 Guide for the Selection and Installation of Control and Low-Voltage Cable Systems in Substations

IEEE 979-84 Guide for Substation Fire Protection

IEEE/ICEA P-46-426 Power Cable Ampacities, 1962

National Electric Safety Code (NESC) Handbook by Allen L. Clapp, 1984

NAVFAC Guide Specifications and Military Handbooks, available from Standardization Document Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

NFGS-02225	Excavation, Backfilling, and Compacting for Utilities
NFGS-16301	Underground Electrical Work
NFGS-16302	Overhead Electrical Work
NFGS-16321	Interior Transformers
NFGS-16335	Transformers, Substations and Switchgear, Exterior
NFGS-16462	Pad-Mounted Transformers
NFGS-16465	Interior Substations
MIL-HDBK-419	Grounding, Bonding, and Shielding for Electronics Equipment and Facilities in Two Volumes
MIL-HDBK-1004/1	Preliminary Design Considerations
MIL-HDBK-1004/3	Switchgear and Relaying
MIL-HDBK-1004/4	Electrical Utilization Systems
MIL-HDBK-1004/6	Lightning Protection
MIL-HDBK-1008	Fire Protection for Facilities Engineering, Design, and Construction
MIL-HDBK-1011/1	Tropical Engineering
MIL-HDBK-1012/1	Electronic Facilities Engineering
MIL-HDBK-1025/2	Dockside Utilities for Ship Service

MIL-HDBK-1190	Facility Planning and Design Guide,

National Electrical Manufacturers Association (NEMA), 2101 L Street, N.W., Washington, DC 20037.

NEMA 201	Primary Unit Substations
NEMA 210	Secondary Unit Substations
NEMA 260-82	Safety Labels for Padmounted Switchgear and Transformers Sited in Public Areas
NEMA HV-2-84	Application Guide for Ceramic Suspension Insulators
NEMA SG-2-86	High-Voltage Fuses
NEMA SG-13-83	Automatic Circuit Reclosers, Automatic Line Sectionalizers and Oil-Filled Capacitor Switches for Alternating Current Service
NEMA TR-1-80	Transformers, Regulators and Reactors

National Fire Protection Association (NFPA), Batterymarch Park, Quincy, MA 02269.

NFPA 24-87	Installation of Private Fire Service Mains and Their Appurtenances
NFPA 70-90	National Electrical Code
NFPA 78-89	Lightning Protection Code

Naval Facilities Engineering Command (NAVFAC) Design Manuals and P-Publications

DM-1.03	Architectural Acoustics
DM-4.05	400-Hertz Medium-Voltage Conversion/Distribution and Low-Voltage Utilization Systems
DM-4.09	Energy Monitoring and Control Systems
DM-7.02	Foundations and Earth Structures
DM-5.12	Fencing, Gates, and Guard Towers
P-442	Economic Analysis Handbook

Copies are available from the Commanding Officer, Naval Publications and Forms Center Directorate, ASO Code 10, 5801 Tabor Avenue, Philadelphia, PA 19120. Government activities must use the Military Standard Requisitioning and Issue Procedure (MILSTRIP), using the stock control number obtained from NAVSUP Publication 2002. Commercial organizations may obtain copies from the above address, Attention: Cash Sales, Code 1051.

NRECA Research Project, National Rural Electric Cooperative Association, 1800 Massachusetts Avenue NW, Washington, DC 20036.

NRECA 82-5-83	Lightning Protection Manual for Rural Electric Systems

Overhead Line Construction, General Order No. 95, State of California, Public Utilities Commission, Sacramento, CA 95820.

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