

UNIFIED FACILITIES CRITERIA (UFC)

ELECTRICAL POWER SUPPLY AND DISTRIBUTION



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UNIFIED FACILITIES CRITERIA (UFC)

ELECTRICAL POWER SUPPLY AND DISTRIBUTION

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U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by \1\ ... /1/)

Change No.	Date	Location

This UFC supersedes TM 5-811-1, dated February 1995. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is a document of a different number.

FOREWORD

\1\

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with [USD\(AT&L\) Memorandum](#) dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCEA) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: [Criteria Change Request \(CCR\)](#). The form is also accessible from the Internet sites listed below.

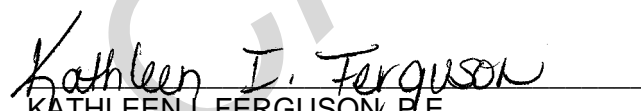
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- Whole Building Design Guide web site <http://dod.wbdg.org/>.

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 DEPARTMENTS OF THE ARMY
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ELECTRICAL POWER SUPPLY AND DISTRIBUTION

		Paragraph	Page
CHAPTER	1. GENERAL		
	Purpose	1-1	1-1
	Scope	1-2	1-1
	References	1-3	1-1
	Standards and Codes	1-4	1-1
	Power Supply Design Criteria	1-5	1-1
	Electrical Power Systems	1-6	1-1
	Design Procedures	1-7	1-2
	Evaluation and Selection of Energy Systems	1-8	1-2
	Design Analysis	1-9	1-4
	Service Conditions	1-10	1-5
	Explanation of Abbreviations and Terms	1-11	1-6
CHAPTER	2. ELECTRICAL POWER REQUIREMENTS		
	General	2-1	2-1
	Load Estimation	2-2	2-1
CHAPTER	3. VOLTAGE SELECTION		
	General	3-1	3-1
	System Voltage Classifications	3-2	3-1
	Selection of Primary Distribution Voltage for New Installations	3-3	3-1
	Selection of Primary Distribution Voltage for Existing Installations	3-4	3-2
	Commercial Power for Air Force Installations	3-5	3-3
	Selection of Primary Distribution Voltage for Air Force Installations	3-6	3-3
CHAPTER	4. MAIN ELECTRIC SUPPLY STATIONS/SUBSTATIONS		
	Provisions	4-1	4-1
	Ownership	4-2	4-2
	Station Designation and Elements	4-3	4-2
	Main Electric Supply Station/Substation	4-4	4-2
	Environmental Aspects	4-5	4-3
	Incoming Line Switching Equipment	4-6	4-4
	Substation Equipment	4-7	4-6
	Miscellaneous Station Design Criteria	4-8	4-9
	Substation Equipment at Air Force Installations	4-9	4-13
CHAPTER	5. ELECTRIC DISTRIBUTION LINES		
	Selection	5-1	5-1
	Types of Underground Lines	5-2	5-1
	Types of Aerial Lines	5-3	5-1
	Voltage Drop	5-4	5-2
	Power Factor Correction	5-5	5-2
	Medium-Voltage Circuits	5-6	5-3
	Pad-Mounted Line Sectionalizing Equipment	5-7	5-7
	Joint Electrical/Communication Lines for Air Force Installation	5-8	5-7
CHAPTER	6. AERIAL DISTRIBUTION LINES		
	General	6-1	6-1
	Installation Considerations	6-2	6-1
	Conductors	6-3	6-1
	Poles	6-4	6-6
	Circuit Configurations	6-5	6-7
	Insulators	6-6	6-7
	Guying	6-7	6-12
	Miscellaneous Items	6-8	6-16
	Air Force Installations	6-9	6-20
CHAPTER	7. UNDERGROUND DISTRIBUTION LINES		
	General	7-1	7-1
	Cable	7-2	7-1
	Duct Lines	7-3	7-6

*This manual supersedes TM 5-811-1/AFM 88-9, Chapter 1, dated 12 September 1984

		Paragraph	Page
	Manholes, Handholes, and Pullboxes	7-4	7-7
	Direct-Burial Cable Installations	7-5	7-10
CHAPTER	8. TRANSFORMER INSTALLATIONS		
	Definitions	8-1	8-1
	Installation of Distribution-to-Utilization Voltage Transformers	8-2	8-1
	Installation of Transmission-to-Distribution Voltage Transformers	8-3	8-4
	Transformer Dielectrics	8-4	8-7
	Transformer Characteristics	8-5	8-8
	Amorphous Metal-Core Transformers	8-6	8-12
	Transformers at Air Force Installations	8-7	8-12
CHAPTER	9. SURGE PROTECTION AND GROUNDING		
	Voltage Surges and Potential Gradients	9-1	9-1
	Methods of Controlling Voltage Surges and Potential Gradients	9-2	9-1
	Ground Electrodes	9-3	9-5
	Grounding Details and Requirements	9-4	9-6
CHAPTER	10. ROADWAY AND AREA LIGHTING		
	General	10-1	10-1
	Roadway Lighting Design	10-2	10-1
	Area Lighting Design	10-3	10-4
	Walkway and Bikeway Lighting Design	10-4	10-5
	Light Sources	10-5	10-5
	Lighting Control and Wiring System	10-6	10-6
CHAPTER	11. SECURITY LIGHTING		
	General	11-1	11-1
	Authorization	11-2	11-1
	Use of Security Lighting Systems	11-3	11-1
	Types of Areas to be Lighted	11-4	11-1
	Lighting Guidelines	11-5	11-2
	Light Sources	11-6	11-4
	Electrical Power Sources	11-7	11-4
	Luminaries	11-8	11-5
	Wiring and Control	11-9	11-5
	Field Measurement	11-10	11-6
APPENDIX	A. REFERENCES		A-1
	B. SIZING OF DISTRIBUTION TYPE TRANSFORMERS FOR FAMILY HOUSING UNITS		B-1
GLOSSARY			

List of Figures

Figure		Page
1-1.	Primary Distribution Arrangements Commonly Used.	1-3
2-1.	Illustration of Diversity Factor Application.	2-2
2-2.	Monthly Electric Cost Computation.	2-3
4-1.	Converting Utility Company Short-Circuit MVA to Current.	4-4
4-2.	Example of Sizing Substation Transformer Capacity.	4-7
4-3.	Single-Line of Primary Unit Substation with Two Transformers.	4-8
4-4.	Circuit Breaker Interrupting Rating Approximation.	4-9
4-5.	Primary Unit Substation, 46 kV Minimum.	4-14
4-6.	Main Electric Supply Switching Station, 35 kV Maximum.	4-15
5-1.	Normal Allocation of Voltage Drop.	5-3
5-2.	An Example of Voltage Drop Calculation.	5-4
5-3.	Average Energy Savings Example.	5-5
6-1.	An Example of an Aerial Conductor Strength Analysis.	6-5
6-2.	Tangent Construction Configurations.	6-8
6-3.	Armless Configurations.	6-9
6-4.	Crossarm Configurations.	6-10
6-5.	Neutral-Supported Secondary Cable Configurations.	6-11
6-6.	Ranges of Insulator Dimensions.	6-13
6-7.	Expanding Anchor Details.	6-15
6-8.	Types of Guy Installations.	6-16
6-9.	Guy Details.	6-17
6-10.	An Example of an In-Line Guy Strength Analysis.	6-18
6-11.	An Example of a Pole Strength Analysis.	6-19
7-1.	Fireproofing of Insulated Cables.	7-5
7-2.	Concrete Encased Duct Details.	7-8

	Page	
7-3.	Duct Line Drainage.	7-9
7-4.	Factors Influencing Manhole Design.	7-10
7-5.	A Scale Example of a Cable Installed in Manhole.	7-11
7-6.	Typical Double Manhole.	7-12
7-7.	Manhole Appurtenances.	7-13
7-8.	Electric or Communication Handhole.	7-14
7-9.	Pullbox Installation.	7-15
7-10.	Underground System Marker.	7-16
8-1.	Cluster-Mounted Transformer Bank Installation.	8-2
8-2.	Crossarm-Mounted Transformer Bank Installation.	8-3
8-3.	Pad-Mounted Compartmental Transformer Installation.	8-5
8-4.	Secondary Unit Substation Installation.	8-6
8-5.	Secondary Unit Substation Transformer Installation.	8-7
9-1.	Zones of Protection for Masts and Shield Wires.	9-4
9-2.	Grounding of a Main Electric Supply Substation.	9-7
9-3.	Grounding of Secondary Unit Substation Installation.	9-8
9-4.	Provision of Surge Arresters at a Medium-Voltage Riser Pole.	9-9
10-1.	Typical Roadway Lighting Installation.	10-2
10-2.	Lateral Lighting Distributions.	10-3
10-3.	Intersection Lighting Placement.	10-4
10-4.	Key to Standard HID Lamp Designations.	10-6
11-1.	Application of Required Lighting Intensities.	11-3

List of Tables

Table		Page
1-1.	Service Conditions.	1-6
2-1.	Typical Demands and Usages.	2-1
2-2.	Diversity Factors.	2-2
3-1.	System Use and Voltage Range Relationship to Equipment Rating.	3-1
3-2.	Nominal System Voltages.	3-2
4-1.	Minimum Relaying for Transformers.	4-9
4-2.	Minimum Metering for Metal-Clad Switchgear.	4-10
4-3.	Minimum Relaying for Metal-Clad Switchgear.	4-10
4-4.	Current Transformer (CT) Accuracy Class Ratings for Outdoor Circuit Breakers.	4-12
4-5.	Primary Insulator Ratings by Class.	4-15
5-1.	Three-Phase Medium-Voltage Circuit Loading Check Values.	5-6
6-1.	Conductors Materials-Physical Properties.	6-2
6-2.	Initial Stringing Sags for 200-Foot Spans.	6-3
6-3.	Final Loaded Tensions for 200-Foot Spans.	6-4
6-4.	Minimum Primary Wood Pole Lengths and Classes.	6-6
6-5.	Minimum Pole-Setting Depth.	6-6
6-6.	Relation of Crossarm Configuration to Conductor Size.	6-7
6-7.	Anchors Suitable for Various Soils.	6-14
7-1.	Rated Conductor Temperatures.	7-3
7-2.	Comparison of DC Test Voltages (kV).	7-6
8-1.	Transformer Standard Base kVA Ratings.	8-8
8-2.	Daily Allowable Peak Loads for Normal Life Expectancy.	8-9
8-3.	Loading on the Basis of Ambient Temperatures.	8-9
8-4.	Basic Impulse Insulation Levels.	8-10
8-5.	Standard Secondary Unit Substation Percent Impedances.	8-11
9-1.	Aerial-Mounted Liquid-Filled Transformer Surge Protective Margins.	9-2
9-2.	Resistance of One 5/8-Inch by 10-Foot Ground Rod in Various Soils.	9-6
10-1.	Illumination Versus Spacing.	10-1
10-2.	Sports Lighting.	10-4
10-3.	Characteristics of Light Sources.	10-5
11-1.	Security Lighting Requirements.	11-2
11-2.	Floodlight Beam Descriptions.	11-5
11-3.	Floodlight Class Descriptions.	11-?
B-1.	Demand Factors.	B-1

CHAPTER 1

GENERAL

1-1. Purpose.

This manual provides Department of the Army and Air Force policy and guidance for design criteria and standards for electrical power supply and distribution systems.

1-2. Scope.

The design criteria and standards contained within are the minimums acceptable for Department of the Army and Air Force installations for efficiency, economy, durability, maintainability, and reliability of electrical power supply and distribution systems. Where special conditions and problems are not covered in this manual, applicable industry standards will be followed. Modifications or additions to existing systems solely for the purpose of meeting criteria in this manual will not be authorized. The criteria and standards herein are not intended to be retroactively mandatory. The word "will" identifies guidance. The word "shall" identifies policy and is used when writing legal, contractual, requirements such as statements of work, specifications or any other documents that require compliance from the commercial/industrial sector. Clarifications of baseline design criteria, standards, policy, and guidance should be obtained through normal Army and Air Force channels, from HQU-SACE CEMP-ET, Washington, DC 20314-1000 or SQ AFCEA/ENE, 139 Barnes Drive, Suite 1, Tyndal AFB, FL 32403-5319.

1-3. References.

Appendix A contains a list of references used in this manual.

1-4. Standards and Codes.

Applicable electrical industry codes, standards, or publications referenced will apply to equipment, materials, and construction covered herein. The minimum requirements of the latest version of NFPA-70, the National Electrical Code (NEC), and ANSI C2, the National Electrical Safety Code (NESC), will be met and exceeded when more stringent requirements are specified and/or dictated.

1-5. Power Supply Design Criteria.

The designer will review the project requirements documents (Project Development Brochure, DD Form 1391 (FY, Military Construction Project Data), project requirements outline, source data,

functional flow diagrams, space requirements, security requirements, etc.) to determine the power supply configurations required to achieve the necessary degree of reliability, durability, maintainability, efficiency, and economy.

a. Reliability. System reliability describes and quantifies the ability of a system to consistently provide power to a facility. The designer will request using agency to provide the allowable frequency and duration of both forced and maintenance outages. The designer will evaluate the supply source reliability data (outage records) and determine the system configuration required to meet the required availability. For supply scenarios where the allowable outage frequency and duration requirements cannot be met with a single-source design, the designer will develop mathematical and supporting cost models for multiple-source or redundant-feed distribution systems to achieve the required availability, utilizing IEEE Std 493 methods. An alternative comparison assessment will be developed to evaluate the reliability choices utilizing IEEE Std 493 methods.

b. Durability. Electrical systems and electrical equipment will be designed for the design life of the facility: 25 years for permanent construction, 6 to 24 years for semi-permanent construction, and 5 years for temporary construction.

c. Maintainability. The design of electrical systems will incorporate features which provide access space for maintenance in accordance with the NEC and NESC, and means to replace equipment and field installed wiring without significant demolition and reconstruction of parts of the facility.

d. Economy. Agency criteria and AR 11-18 establish the economic consideration requirements which will be assessed for each facility. For Air Force, refer to AFR 173-15.

1-6. Electrical Power Systems.

Electrical power systems for Army and Air Force installations can be composed of subtransmission lines to main substations; distribution lines to distribution substations; utilization lines to distribution transformers; and generators to provide emergency, stand-by, and/or prime power for mission essential/critical loads. Generally, for Army base-wide distribution changeouts, the preferred CONUS voltage is 13.2 kV or 13.8 kV three-phase, three-wire, with delta primary and wye secondary transformer connections. When extending existing

distribution systems, the preferred distribution voltage is the same as the existing distribution voltage. Use of 15 kV nominal-class systems is preferable to 5 kV nominal-class systems unless system studies indicate a clear advantage over the 15 kV system. Use of solidly grounded, multiple-grounded systems is preferred over single-grounded or ungrounded systems. For Air Force, the preferred CONUS distribution is 12,470Y/7,200 volt, three-phase, with delta primary and wye secondary transformer connections. Voltages for facilities outside of the United States are specified in AFM 86-3.

1-7. Design Procedures.

Electrical power supply and distribution features will be planned/delineated concurrently with planning stages of new installations and/or new facilities on existing installations. The design process starts with the DD Form 1391, Military Construction Project Data. This form provides information necessary to categorize the power requirements of the project. Two vital pieces of information are contained in the form: the scope of the project which includes restoration, new facility, or new installation (these all require different approaches); and the mission classification which includes mission essential, or mission support. (Each is authorized a different degree of importance in the hierarchy of power supply configurations and equipment.) The next part of the design process involves estimating the power load requirements; defining the measures to be employed to meet the criticality requirements; and defining the project power source requirements. At this point a majority of the design bases can be formulated from the previous assessments and results, and final design features and configurations can be developed.

a. New installations. Electrical power supply and distribution systems for new installations will conform to prevailing utility company practices for that geographical area insofar as they do not conflict with criteria, standards, and policy contained within this manual.

b. Existing installations. Design for electrical power supply and distribution systems for new facilities on existing installations will be coordinated with the Facility Engineer or the Base Civil Engineer to assure compatibility with the electric utility master plan. Designs will be compatible with existing construction insofar as it does not conflict with criteria, standards, codes, and policy contained within this manual.

c. System configurations. Only radial, loop, or selective configurations as illustrated in figure 1-1

will be used. The configuration proposed will be commensurate with the degree of reliability required by the mission or use of the facility. The additional cost required to install loop or selective systems will be justified. Individual components such as loop or selective switches at transformers will be considered where the project will need increased reliability in the future. Special cases, involving large demands or high reliability requirements, may make the installation redundant sources of supply advisable. Hospital primary circuit arrangements will be in accordance with the requirements of MIL-HDBK 1191, Medical and Dental Treatment Facility Criteria, and other Medical Facilities Design office criteria.

d. Short-circuit and coordination studies. Short-circuit and protective devices coordination studies will be in accordance with IEEE Std 242 and TM 5-811-14. Both linear and nonlinear loading will be considered. Selection of protective devices and switchgear for a new electrical system will be based on a short-circuit protective device coordination analysis. For additions or modifications to an existing distribution system, the analysis will include all of the protective devices affected in the existing system. All protective devices will be properly coordinated to provide selective tripping.

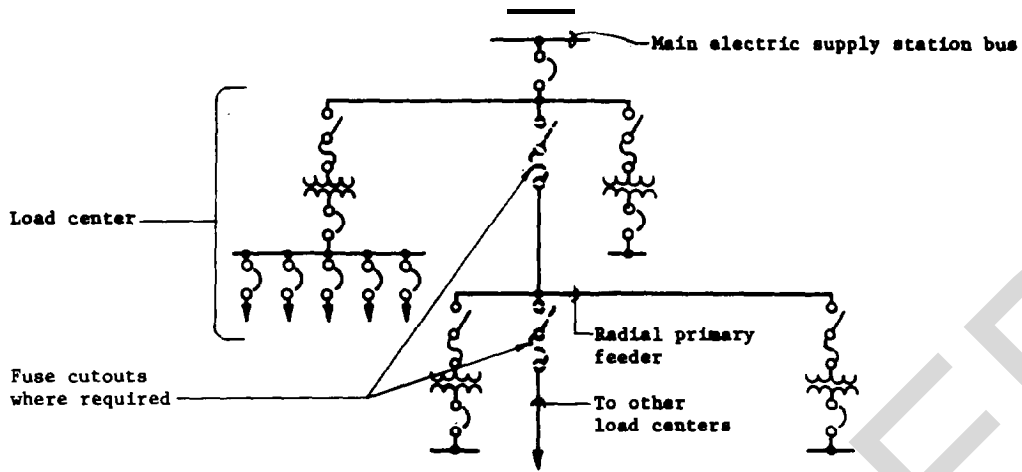
e. Expansion. Electrical power supply and distribution systems will be designed so that expansion will be possible. Refer to IEEE Std 141 for additional and more detailed information regarding the expansion of electrical systems.

1-8. Evaluation and Selection of Energy Systems.

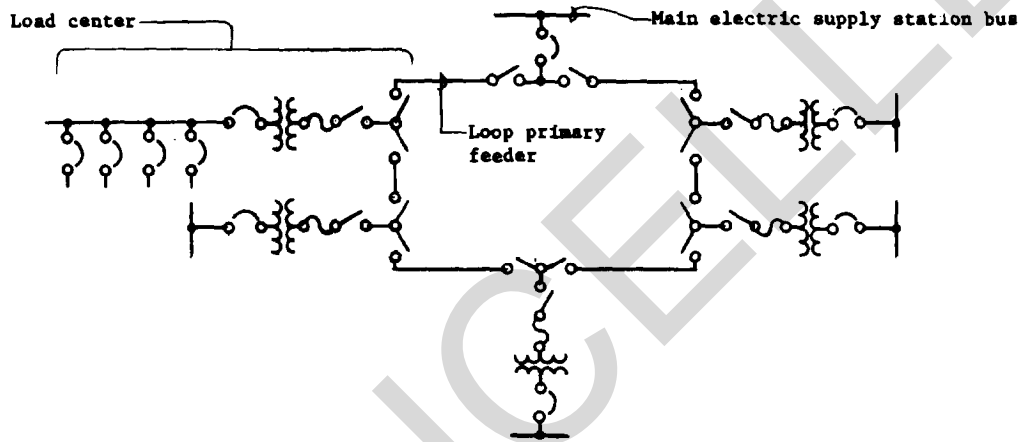
a. Selection of electrical energy sources for new installations. The most economical electrical energy source will be selected based on criteria and guidelines contained in agency criteria.

(1) *Feasibility study.* Where necessary to determine the most economical supply system, a life-cycle-cost analysis will be performed in accordance with methods discussed in 10 CFR 436, FEDERAL ENERGY MANAGEMENT AND PLANNING PROGRAMS. Choices include supply from a private, government owned generator plant, co-generation, solar energy, or combination of options.

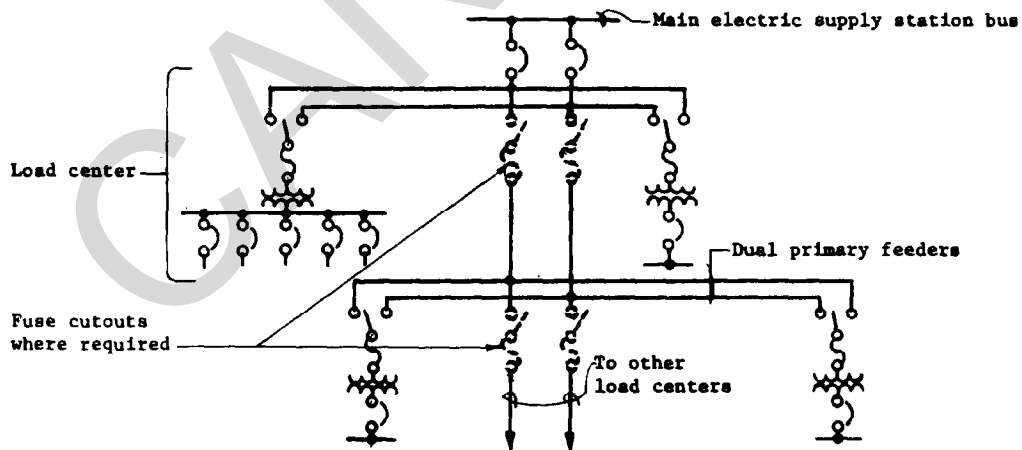
(2) *Potential energy sources.* In preparing feasibility studies, the potential energy sources compared will include coal, oil, and purchased electricity. Where applicable, refuse-derived, geothermal, or biomass-derived fuel will be considered. Factors affecting the choice of energy source will include availability, reliability, land right-of-way requirements, station or plant site needs, first costs for



POOREST AVAILABILITY - RADIAL SYSTEM



INTERMEDIATE AVAILABILITY - LOOP SYSTEM



GREATEST AVAILABILITY - SELECTIVE SYSTEM

US Army Corps of Engineers

Figure 1-1. Primary Distribution Arrangements Commonly Used.

the installation including any pollution abatement requirements, and annual costs for energy and operating personnel wages.

b. Selection of electrical energy sources for existing installations. Selection of an electrical energy source will be made when the existing source is inadequate to supply the requirements for the facility being added. If the facility is incorporated as a part of the overall installation master planning program, then the energy needs should have been forecast in the electrical systems master planning, and determination already made as to whether the existing electrical energy source should be expanded or whether some other alternative would be more economical. When the master plan does not provide the contemplated electrical requirements, an engineering study will be prepared.

(1) *Engineering studies.* Outside energy supplies will be evaluated based on the following:

(a) Reliability of the source.

(b) Cost of energy to the installation, based on projected demand and usage requirements.

(c) The suppliers ability to serve the present and the expected load for the next 5 years.

(d) System outages over the last five years, if available. Where outage information for at least one year is not available, or where it is meaningless because it applies to a system since changed, the system being considered will be evaluated on the basis of the utilities reliability projections.

(2) *Electrical master planning.* When an electrical master plan is not available, existing facilities will be evaluated by making a physical inspection of the existing facilities and accumulating the following data:

(a) Condition and characteristics of the existing off-site electrical energy sources including data previously listed.

(b) Number, condition, and characteristics of prime and auxiliary generating plants.

(c) Load information.

1-9. Design Analysis.

The designer preparing plans and specifications for work covered in this manual will also prepare an accompanying design analysis. The design analysis will completely cover the electrical design requirements for electrical systems necessary to the project. The design analysis will also be used to justify decisions recommended in concept or feasibility studies, although a separate section is not required if necessary material and computations are contained in a study, either in the body or in an appendix. The analysis will be submitted in two parts, a basis for design and design computations.

a. Basis for design. The basis for design will include a concise outline of functional features, including a description of existing systems and other considerations affecting the design. In addition, a full description of any special requirements and justification for any proposed departure from standard criteria are required.

(1) *Exterior electrical distribution systems.* The description of exterior electrical distribution systems will include statements on all features relevant to the specific project as follows:

(2) *Electrical power sources.* Electrical characteristics of the electrical power supply to an entire installation, or that portion of the installation involved, including circuit interrupting requirements and voltage regulation will be covered. A statement discussing the adequacy of the existing electrical power supply (including primary feeders) at the point of take-off will be given. If the electrical power source is inadequate, a statement of the measures proposed to correct the deficiency will be included. If a new electrical power source or local electrical generation is required, the various possibilities will be covered, except where the design directive has stipulated requirements. The advantages and disadvantages of various suitable methods will be analyzed and cost comparisons submitted. Where a design directive permits a choice among alternatives, the merits of each alternative will be examined. If the use of a certain system or equipment has been directed and the designer recommends another approach, the designer will indicate any deviation from the directed design and justify such deviations.

(3) *Loading.* An estimate of total connected loads, power factors, demand factors, diversity factors, load profiles where required, resulting demands, and sizes of proposed transformers to serve either the complete project or the various portions involved will be provided. Transformer peak loads and load cycling will be analyzed for transformers when appropriate. Designer will coordinate estimates with the using agency.

(4) *Electrical distribution systems.* The basis for selection of primary and secondary distribution voltages, and of overhead or underground construction will be provided. The proposed type of conductors such as copper or aluminum, bare or insulated, where each type is used, and any special basis for selection are required. Statements describing pertinent standards of design such as voltage drop, maximum primary circuit interrupting requirements, physical characteristics of overhead or underground circuits, switching, circuit protection, lightning protection, type of lighting units, and lighting intensities are required. Elec-

trical supply system sectionalizing for operation and maintenance will be defined, together with a description of switching and redundant circuits required to meet or optimize system availability. Any provisions for communication circuits to be installed by others, either aerially or underground, will be described.

(5) *Underground justification.* The basis for design will justify proposed underground construction by citing either criteria or authority for waiver of criteria.

(6) *Work performed by others.* If functional adequacy of the design is contingent on work to be performed by the Using Agency or the local utility, the basis for design will describe the limits of such work and the responsible agency.

b. Electrical generating plants. Wherever electric generating plants are required, pertinent data will be included in the basis for design.

(1) *Loading.* The estimated connected load, maximum demand, average demand, minimum demand, number of units proposed, their kW ratings, and reasons for the selection of these units will be indicated.

(2) *Prime mover specifications.* The class of plant, type of starting system, type and grade of fuel, and approximate storage capacity will be covered. The type of plant, whether completely manual, fully automatic, or semiautomatic, with reasons for the selection will be noted.

(3) *Voltage selection.* The selected voltage and reasons for the choice will be given. If commercial electrical power is not provided, the reasons why commercial power is not used will be stated. If operation in parallel with the serving utility is planned, a written utility company statement is necessary affirming agreement with this mode of operation.

(4) *Frequency and voltage regulation.* Frequency and voltage regulating requirements, including requirements for parallel operation, will be listed. A statement will be made that standard equipment is to be specified; where special equipment such as precise electrical power equipment is proposed, this special equipment will be fully justified. The additional cost of special equipment will be covered.

(5) *Cooling and heat recovery systems.* The type of cooling system and reason for selection is required, along with a description of the type of waste heat recovery, if any. An explanation is required to justify not utilizing waste heat.

c. Main electric supply stations. Where a main electric supply station is provided, the utility's system will be described including the utility's recommendations. Where pertinent, the utility's

systems will also be described relative to adequacy and dependability, along with other applicable data covered in the requirement for engineering studies.

d. Design computations. Computations will be provided to indicate that materials and systems are adequate, but not over-designed, and are correctly coordinated. Computations will be provided for (but not limited to) conductor sizing, cable pulling, strength requirements (structures, poles, concrete pads, supports, etc.), pole line span lengths, generator and transformer capacities, switch and switchgear ratings, and protective device selection. Load flow and voltage drop calculations will be provided for new distribution systems, feeders where large loads are being added, and for line extensions where loads are being placed on lines far from the substation or other source. Short-circuit and protective device calculations will be provided for new substations, distribution feeders from existing substations, and where new facilities requiring protective devices are to be installed. The calculations should provide adequate conductor and equipment short-circuit withstand-ampacity and demonstrate coordination under the upstream devices. Protective device calculations are mandatory when relay and circuit breaker trip settings must be determined. Situations where system coordination is not achievable will be noted. Short circuit and protective device calculations will be in accordance with TM 5-811-14 and IEEE STD 242. Grounding system calculations will be performed in accordance with IEEE Std 242 and Std 80.

1-10. Service Conditions.

Temperature, humidity, and other climatological factors as well as altitude will require special design techniques at some installations. Design techniques will comply with the standards listed in table 1-1.

a. Artic conditions. Basic engineering practices governing design and construction of electrical power systems in temperate areas will be applied to arctic and subarctic zones. Modifications, as necessary, in accordance with TM 5-349, TM 5-852-5, and AFM 88-19, will be made to combat snow and ice above ground and permafrost conditions in underlying subsoils. Methods used in temperate zones for installing electrical distribution poles are adequate in most cases; occasionally, special pole construction techniques, using cribs and tripods or blasting or drilling into the permafrost, will be required. Utilidors, which are usually rigid, insulated, and heated conduits with either crawl- or walk-through space for servicing and which are usually installed underground, may also be used.

Table 1-1. Service Conditions.

Item of Equipment	Standard
Batteries	IEEE 484
Seismic Design of Substations	IEEE 693
Battery Chargers	UL 1236
Instrument Transformers	IEEE C57.13
Switchgear	IEEE C37.20.1 IEEE C37.20.2 IEEE C37.20.3
Neutral Ground Resistors	IEEE 32
Power Circuit Breakers (Above 1000 Volts)	IEEE C37.04
Molded-Case Circuit Breakers	IEEE C37.13
Power Fuses	IEEE C37.40
Relays, Electrical Power Apparatus	IEEE C37.90
Step-Voltage Regulators	IEEE C57.15
Surge Arresters	IEEE C62.1
Switches	IEEE C37.30
Transformers	IEEE C57.12.00
Switchboards	NEMA PB 2

b. Tropic conditions. Basic engineering practices governing design and construction of electrical power systems in temperate areas will be applied to tropic zones. Potential problems which may result from corrosion and termite infestation, as well as the feasibility of using local materials, will be investigated in order to select the most suitable elements for the system. Outdoor switchgear will be enclosed and have space heaters with automatic controls. In typhoon areas, design will provide sufficient strength for the extreme wind loading conditions encountered. Where fungus control is required, the following paragraphs will be edited and included as a part of the project specifications as required:

(1) Contact surfaces of devices such as switches, fuses, and circuit breakers need not be treated. Other materials and components which are inherently fungus-resistant or are protected by hermetic sealing need not be treated.

(2) Circuit elements, not covered in above paragraph and which have a temperature rise of not more than 75 degrees F when operating at full load shall be treated in accordance with MIL-T-152. Circuit elements include, but are not limited to, cable, wire, terminals, switchgear, panelboards, capacitors, and coils.

(3) Circuit elements, such as motor coils, dry-type transformers, and similar electrical components, which have a temperature rise exceeding 75 degrees F when operating at full load shall not be coated with a fungitoxic compound. Instead, such components shall be given two coats of varnish and one sealer coat, both conforming to Type M, Class 130 of MIL-I-24092. Coats shall be applied by the vacuum-pressure, immersion, centrifugal, pulsating-pressure, or the built-in method so as to

fill interstices in the coils and preclude the entrapment of air or moisture. The sealer coat may also be applied by brushing or spraying.

c. Corrosive or contaminated atmospheres. Upgrading of equipment located in atmospheres where corrosion occurs (because of excessive humidity or from industry contamination which may be intensified by fog) will be provided only where local practice indicates the additional cost is justified.

(1) *Upgrading corrosion resistance.* Where a better than standard coating is required, a salt spray test will be specified for the finish. Length of the testing period will be in accordance with standard practice for the area.

(2) *Insulating devices.* Where over insulation in contaminated areas is required, bushings will be specified for the next higher basic impulse level (BIL) than required for that device insulation class.

d. Insect and rodent damage. The applications listed below will be investigated and implemented, as required, in areas where insect and rodent damage to underground cable installations is a problem. Proven local practice will also be followed.

(1) Use armored cable.

(2) Use cable with higher voltage rating.

(3) Use cable with full concentric neutral.

(4) Install animal guards around existing concrete pads and around pipe entrances on wood walls.

(5) On new installations, install buried fiberglass pads that animals cannot penetrate.

(6) Specify cable with rodent protection armor.

(7) Specify seals or cover all crevices greater than ¼-inch.

(8) Select foundation area plantings which do not compliment local area pest habitats.

(9) Do not use toxic chemical treatment of the soil.

e. Seismic design. The seismic design of electrical installations will comply with agency criteria; TM 5-809-10; and AFM 88-3, Chapter 13. The seismic design of electric substations will comply with IEEE 693.

f. Electromagnetic pulse (EMP) and high-altitude electromagnetic pulse (HEMP). EMP and HEMP requirements will be in accordance with MIL STD 188-125 and MIL HDBK 423.

g. Environmental compliance. The design will provide electrical systems which comply with Federal, state, and local environmental regulations. Transformer dielectric information in chapter 8 will be applied to all dielectric-filled equipment.

1-11. Explanation of Abbreviations and Terms. Abbreviations and terms used in this manual are explained in the glossary.

CHAPTER 2

ELECTRICAL POWER REQUIREMENTS

2-1. General.

The most feasible method of supplying and distributing electrical power will be determined by first quantifying the electrical power requirements (or maximum demand load) for the installation. In the early design stages, this demand should be based on area or population; in later design stages, summation of individual building connected loads modified by suitable demand and diversity factors will be used. For early stages, use of kW, kVA, and hp interchangeably on a one to one basis is sufficiently precise. During final design, hp will be converted to kVA; and kVA may be multiplied by the estimated power factor to obtain kW if required. The calculation of full load amperes will utilize kVA.

2-2. load Estimation.

Load estimation requires analysis of load characteristics and will take into account the demand factor relationship between connected loads and the actual demand imposed on the system.

a. *Preliminary loads.* The load data given in table 2-1 will be used to compute preliminary estimates of the expected maximum demands and electrical energy usage. These values allow computations to be made for either population or building area. Per capita loads are for an average daytime population.

b. *Demand factor.* Demand factors will be applied to connected loads when calculating the required ampacity of conductors, capacity of trans-

formers, and all equipment associated with distribution of electrical power to utilization equipment. Realistic demand factors will be calculated in early design stages to provide an economical, cost effective system while insuring that items of equipment and materials are adequate to serve existing, new, and future load demands. Demand factors utilized in later design stages will document and reflect the number, the type, the duty rating (continuous, intermittent, periodic, short time, and varying), and the wattage or voltampere rating of equipment supplied by a common source of power, and the diversity of operation of equipment served by the common source. No more than ten percent spare capacity will be considered during design unless spare capacity is authorized by follow-on projects approved for construction in later years. Demand factor is defined as the ratio of the maximum demand (largest demand during a specified time period) to the total connected load.

c. *Diversity factor.* Diversity factors will be applied to the demand loads when calculating the required ampacity of service and feeder conductors, distribution transformers, and all other distribution system equipment. Typical diversity factors are given in table 2-2 and an illustration of their use is shown in a demand flow relationship in figure 2-1. This illustration indicates the load at substation "X" would be 1/2.24 or 0.45 times the summation of the demands based on the given data. Since utilities calculate loads on a less conservative basis, diversity factors for main electrical supply stations on military installations will

Table 2-1. Typical Demands and Usages.

Service	Installation	Per capita		Per 1,000 square feet	
		Maximum demand kW	Usage per year kWh	Maximum demand kW	Usage per year kWh
Army Command	Development & Readiness Forces	1.0-3.0	7,500-25,000	0.5-2	5,000-20,000
	Training & Doctrine	0.5-1.2	3,000- 6,000	1-5	5,000-25,000
		0.6-1.2	2,500- 7,500	1-3	5,000-20,000
Air Force Base	Logistics Command	1.5-2.5	7,000-10,000	2-4	10,000-20,000
	Military Airlift Command	1.0-2.5	5,000-10,000	2-3	5,000-15,000
	Tactical Air Command	0.5-2.0	3,000- 6,000	2-5	10,000-20,000
	Training	1.0-1.5	4,000- 6,000	2-5	10,000-20,000

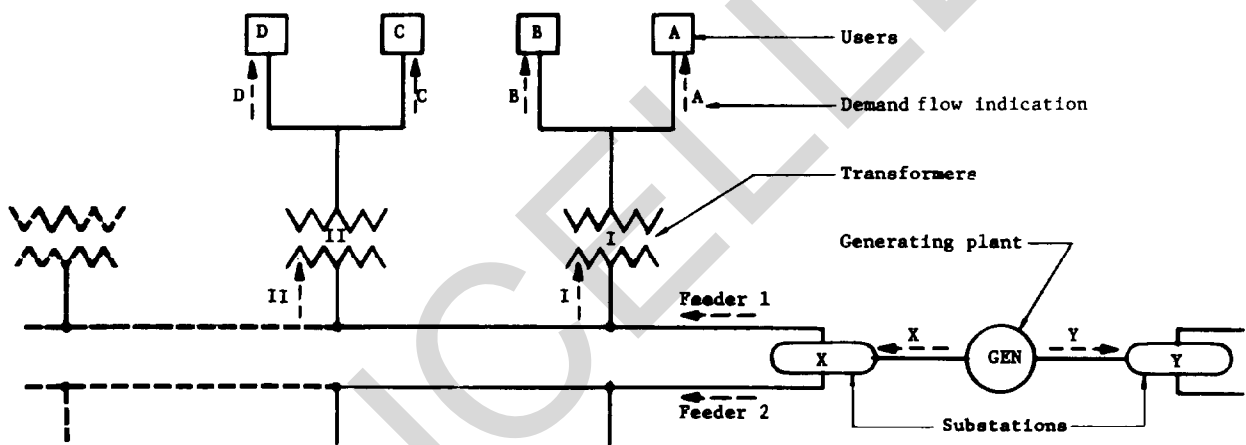
Table 2-2. Diversity Factors. *

Elements of system between which diversity factors are stated:	Diversity factors for			
	Residence lighting	Commercial lighting	General power	Large users
Between individual users.	2.0	1.46	1.45	-
Between transformers.	1.3	1.3	1.35	1.05
Between feeders	1.15	1.15	1.15	1.05
Between substations	1.1	1.10	1.1	1.1
From users to transformer.	2.0	1.46	1.45	-
From users to feeder	2.6	1.90	1.95	1.15
From users to substation.	3.0	2.18	2.24	1.32
From users to generating station	3.29	2.40	2.46	1.45

*From "Standard Handbook for Electrical Engineers" by Fink and Beaty, copyright 1987, by McGraw-Hill, Inc. Used with permission of McGraw-Hill Book Company.

be higher than the 2.24 shown in figure 2-1 (lower than 0.45 demand). Diversity factor is defined as the ratio of the sum of the individual maximum demands of various subsystems within a system to

the maximum demand of the system. The diversity of demands among transformers on a typical radial feeder makes the actual maximum load on the feeder less than the sum of the transformer loads.



ELECTRIC DEMAND FLOW DIAGRAM

ELECTRIC DEMAND FLOW RELATIONSHIPS^a

- Transformer I demand - (User(A + B)demands) / (User diversity factor)
- [(A + B) / 1.45] - User loads / (1.45)
- Feeder 1 demand - (Transformer I + II demands) / (Transformer diversity factor)
- [(A + B) / 1.45] + [(C + D) / 1.45] / 1.35 - User loads / (1.95)
- Substation X demand - (Feeder 1 + 2 demands) / (Feeder diversity factor)
- [(Veer loads) / 1.95] / 1.15 - User loads / (2.24)
- Generating plant demand - (Substation X + Y demands) / (Substation diversity factor)
- [(User loads) / (2.24) / 1.10] - User loads / (2.46)

^aFigures used are from general power column of table 2-2.

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Figure 2-1. Illustration of Diversity Factor Application.

d. *Energy costs.* An order of magnitude for energy costs will be computed as shown on figure 2-2 using population values from table 2-1. Cost comparisons have been simplified for clarity and do not include such items as fuel and power factor adjustment charges, “off-peak” or “on-peak” demands, or other billing practices used by utilities.

e. *Load factor.* Load factor is defined as the ratio of the average load over a designated period of time to the peak load occurring in that period. A low load factor indicates short-time demand peaks which can

result in heavy charges to the Using Agency. Where the load factor is determined to be less than 0.40, for loads which will affect the utility demand charges, an engineering and economic analysis will be performed to determine the optimum method for correcting the deficiency. Low load factor will be corrected by shedding loads or by peak-shaving generation during periods of peak demand.

f. *Family housing units.* Demand factors for transformers serving family housing areas will comply with the guidance in appendix B.

Air Force Training Base

Assume:

Population = 9,000

Demand charge = \$3.00 per kW of billing (maximum) demand

Energy charge = \$0.025 per kWh

1. Maximum demand per month =
 $9,000 \text{ people} \times 1.3 \text{ kW per capita} = 11,700 \text{ kW}$
2. Energy used per month =
 $(9,000 \text{ people} \times 4,000 \text{ kWh per year}) \div 12 \text{ months} = 3,000,000 \text{ kWh}$
3. Energy costs
 - a. Demand = $11,700 \text{ kW} \times \$3.00 \text{ per kW} = \$ 35,100.$
 - b. Energy = $3,000,000 \text{ kWh} \times \$0.025 \text{ per kWh} = \underline{\$ 75,000.}$

Total monthly energy cost = \$110,100.

US Army Corps of Engineers

Figure 2-2. Monthly Electric Cost Computation.

CHAPTER 3

VOLTAGE SELECTION

3-1. General.

The design of electric supply and distribution systems can proceed only after a distribution voltage level has been determined. The electrical impact of the installation or facility as well as its location will influence the selection. A new service may be necessary or extension of an existing service may be acceptable. Before discussing selection of the system voltage, system voltage terminology and preferred voltage ratings need to be defined. Refer to the glossary for definitions of standard voltage terms.

3-2. System Voltage Classifications.

Voltage systems are classified either by the system use or the voltage range. More specific methods include using the voltage rating of equipment, the nominal voltage class, or the nominal system voltage.

a. System use. The requirement for electric power transfer will cause certain voltage levels to be more economical than others. A transmission system transfers energy in bulk between the source of supply (the utility) and the center for local distribution (the main electric supply station). A primary distribution system delivers energy from a main electric supply station to utilization transformers. A secondary distribution system delivers energy from a utilization transformer to points of utilization.

b. Voltage ranges. Voltage ranges are classified as low-voltage (1 kV or less); medium-voltage (above 1 kV to 99.9 kV); and high-voltage (above 99.9 kV).

c. Voltage rating of equipment. Voltage rating of equipment is based on nominal voltage classes which, in conjunction with the maximum voltage rating for that class, provides a simple method for rating equipment. Table 3-1 indicates the nominal voltage class designation (also known as the insulation class) used in this manual, along with the maximum voltage rating that may be handled by the equipment, and the normal basic insulation level (BIL) applying, and relates these characteristics to system use and voltage range.

d. Nominal system voltage. The nominal system voltage is the nominal value assigned to designate a system of a given voltage class. Nominal system voltages are classified by IEEE Std 141 as standard and nonstandard voltages. Table 3-2 lists standard and nonstandard nominal system voltages.

3-3. Selection of Primary Distribution Voltage for New Installations.

A preferred nominal system voltage such as 12 kV, 12.5 kV, 13.2 kV or 13.8 kV, will be selected for the primary distribution system. On sizable installations where distances to loads are considerable or loads are large, the use of 34.5 kV or 24.9

Table 3-1. System Use and Voltage Range Relationship to Equipment Rating.

System use	Voltage range	Equipment rating		
		Nominal voltage class kV	Rated maximum voltage kV, rms	BIL kV
Transmission	High	230	242	900
		161	169	750
		138	145	650
		115	121	550
		69	72.5	350
		46	48.3	250
Primary distribution	Medium	35	38.0	200
		25	25.8	150
		15	15.5	110
		7.5	8.25	95
		5	5.08	95

<u>Standard Nominal System Voltages</u>	<u>Nonstandard Nominal System Voltages</u>
Low-Voltages:	
120	110, 115, 125
120/240	110/220, 115/230, 125/250
208Y/120	216Y/125
240/120	
240	230, 250
480Y/277	460Y/265
480	440
600	550, 575
Medium-Voltages:	
2400	2200, 2300
4160Y/2400	
4160	4000
4800	4600
6900	6600, 7200
8320Y/480	11 000, 11 500
12 000Y/6930	
12 460Y/7200	
13 200Y/7620	
13 200	
13 800Y/7970	14 400
13 800	
20 780Y/12 000	
22 860Y/13 200	
23 000	
24 940Y/14 400	
34 500Y/19 920	
34 500	33 000
46 000	44 000
69 000	66 000
High-Voltages:	
115 000	110 000, 120 000
138 000	132 000
161 000	154 000
230 000	220 000
Ultra-High Voltages:	
345 000	
500 000	
765 000	
1 100 000	

* Reprinted with permission from IEEE Std 141-1986, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants.

Table 3-2. Nominal System Voltages.

kV primary distribution systems may be more economical. Primary distribution voltages of the nominal 7.5 kV class and under will not be used, unless an off-site supply of a higher voltage is not available. Seldom is the lower voltage advantageous. For such cases, the size of the installation and the distances involved must make the use of voltages below 7.5 kV more economical in order to justify the selection.

3-4. Selection of Primary Distribution Voltage for Existing Installations.

When small facilities are added to an installation, the primary distribution system voltage within the addition will match the existing system. However, if the addition is substantial and large voltage drops or line losses can occur when existing voltages are retained, or if the main electric supply station is inadequate, then the economics of a higher voltage for the primary distribution system must be taken into account. The electrical master plan should have already provided for such deficiencies. When a master plan indicates a contem-

plated voltage increase, transformers for use in ongoing construction will be specified to have dual primary voltages, when economic and transformer delivery time considerations permit such a requirement. When a dual voltage, high-voltage transformer is specified, taps are not normally available for the lower voltage. For existing voltage drop problems, not having transformer taps available may create an untenable situation, requiring a facility boost transformer, or other means to serve the facility until the distribution system is upgraded. If the facility to be added is not included in the master plan, an engineering study will be necessary to determine the most feasible method of providing service. Acquisition or preparation of maps of transmission and distribution systems with distances between principle points and single line diagrams of the systems will be required. Then a determination of the extent to which the existing system voltage can satisfy installation requirements, or the economics of a higher voltage level and benefits of such a system will be evaluated.

3-5. Commercial Power for Air Force Installations.

Normally, the source of supply shall consist of a single tap into the nearest adequate utility company transmission line. Duplicate taps into the same source of generation or transmission shall be avoided. If duplicate taps are required for reliability, they shall have a single totalized metering point. Avoid multiple metering points for billing purposes. Metering of separate facilities or areas is encouraged for energy monitoring and control purposes. Engineering studies shall consider the entire cost of providing a reliable source of electric power. Arrange for the supply of commercial

power during design. Resolve rates, terms, and conditions of service before making a commitment for construction charges, or minimum billings. AFI 32-1061 requires correlated action.

3-6. Selection of Primary Distribution Voltage for Air Force Installations.

The preferred primary CONUS distribution voltage is that found in the general area. Major expansions to existing systems utilizing 2,400-2,400/4,160-, or 4,800 volt primaries shall generally be converted to 12,470/7,200 volt primary system.

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CHAPTER 4

MAIN ELECTRIC SUPPLY STATIONS/SUBSTATIONS

4-1. Provisions.

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

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

- (1) Availability of surplus capacity in the existing station and lines.
- (2) Space available for required station modifications.
- (3) Age and condition of existing equipment.
- (4) Location of the existing station with respect to the new load.
- (5) Quantity, sizes, and rights-of-way for new transmission and distribution lines.
- (6) Adequacy of transmission and distribution capacity.
- (7) Need for voltage regulation or reclosing.
- (8) Megavolt amperes (MVA) interrupting and withstand ratings of station and line equipment.
- (9) Protective device coordination for both existing and new equipment.
- (10) Serving utility rate schedule.
- (11) Site-peculiar features that affect design, construction, operations, and maintenance costs.
- (12) Capability of the modified station to meet the using agency's requirements for safe, reliable, available, and maintainable electrical service.

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

to the new project than a modified existing station. Conjunctive billing is required if there is more than one point of service.

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

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

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

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

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

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

4-2. Ownership.

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

4-3. Station Designation and Elements.

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

4-4. Main Electric Supply Station/Substation.

The main electric supply station/substation is the installation/utility interface point where further transmission, distribution and utilization of electrical power, the monitoring and control of such power or equipment and the protection of electrical equipment or systems becomes the sole responsibility of the Government. Electrical power will be supplied by the same utility over one or more

incoming power lines that are metered by the use of items of equipment provided and maintained by the utility. The design of new stations, or modifications to existing stations, must be coordinated with the supplying utility and with any other suppliers or users of power supplied through the station. Such coordination should be accomplished by the responsible field operating agency, or a designer employed to accomplish the coordination and design of new electrical facilities. Complete coordination should be performed to ensure proper protection for electrical equipment and systems, to obtain the required degree of availability, reliability and maintainability, and to achieve the most cost effective billing, construction, operation and maintenance costs during a station life of 25 years or less.

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

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

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

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

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

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

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

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

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

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

proposed will be obtained in the criteria development or early design stages of a project.

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

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

4-5. Environmental Aspects.

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

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

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

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

extra height, low-profile structures will be installed.

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

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

4-6. Incoming line Switching Equipment.

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

a. *Circuit breakers.* Circuit breakers are more costly than other equipment, used singly or in combination, to accomplish line switching and to protect station elements. However, circuit breakers will be used for all switching stations and substations, when stations are served by more than one incoming line or contain transformers rated 10 MVA or above, when economically justified, when required to obtain the required degree of reliability, or when their use is required for coordinated circuit protection or switching to limit the duration and frequency of outages to the installation. Circuit breakers will be of the oil or sulfur hexafluoride (SF₆) type when the incoming line voltage is greater than 35 kV, nominal. When air and vacuum circuit breakers have adequate continuous current and interrupting ratings, those oilless types will be considered for use as line circuit breakers for lines rated at or below 35 kV. SF₆ breakers may also be used at line voltages below 35 kV. Standard ratings are listed in IEEE Std C37.04 and IEEE Std C37.06. The design of the station will include provisions to isolate circuit breakers and to bypass them with power fuse disconnecting units when required to ensure continued protection of station buses and equipment when circuit breakers are out-of-service. The bypass feature is not required if other circuit equipment can protect station elements when circuit breakers are inoperative, or if the utility line breakers afford the required degree of protection. Where only one incoming line serves the entire base or installation, disconnect switches and a fused by-pass switch unit will be specified to allow

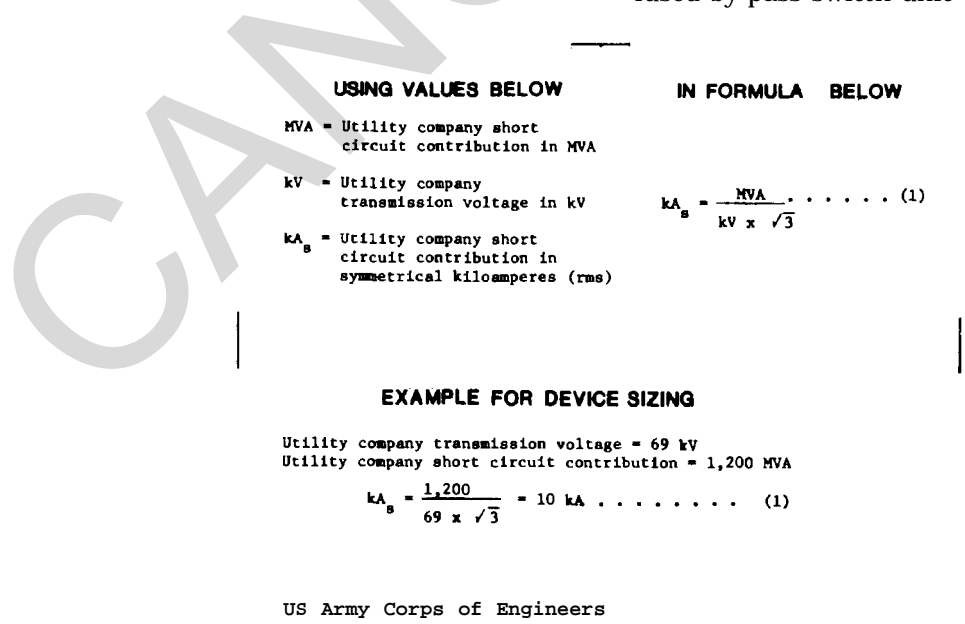


Figure 4-1. Converting Utility Company Short-Circuit MVA to Current.

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

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

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

d. Fault-interrupter switches. Fault-interrupter switches may be used for line switching and fault protection of station elements as a less costly substitute for circuit breakers. The interrupting ability of the switches is limited and their operation must be blocked if fault currents exceed the interrupting rating of the switches. This requires that a circuit breaker on the line side of the switch

operate to clear the fault. Therefore, permission of the utility company must be obtained for the use of fault-interrupter switches when the circuit breaker or protective element ahead of the switches is under the exclusive control of the supplying utility, and the available fault current exceeds the interrupting rating of the fault-interrupter switches. These types of switches should not be used when the station is supplied by only one incoming line when the switches are to be used for the opening and closing of the line, as opposed to the protection of transformers and separate line switching equipment. The interrupting element of the switches is an SF₆ unit. Single SF₆ interrupter models are available at the following nominal voltage levels: 34.5, 46, 69, 115, 138, and 161 kV. Since there is considerable variation in interrupting ratings from manufacturer to manufacturer, fault-interrupter switches should be carefully specified only after the short circuit study has been completed.

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

f. Sulphur hexafluoride (SF₆) equipment. Guidance for gas-insulated substation equipment is contained in IEEE C37.123. Each SF₆ interrupter, if located inside a structure, must be located in a room with direct outdoor ventilation and sensor unit which activates the room vent fan and a room entry alarm when the oxygen level in the room is above 19.5 percent. This requirement is to preclude jeopardizing personnel life or health. The entry alarm will be automatically silenced when

the oxygen in the room is above 19.5 percent. Designs will require provision of an SF₆ gas sensor, controls, alarm, and calibration of the sensor system to indicate the unsafe level of SF₆ gas for personnel.

4-7. Substation Equipment.

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

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

(2) *Capacity of substation transformers.* The capacity of a new or modified substation transformers will be adequate to supply all installation or project demands determined during design. The capacity of substations will be sufficient to accommodate expected load growth in later years. Load growth should be based on increases of one to five percent of the estimated peak load per year, when more exact load growth information is not available. The base capacity or rating of new transformers will be the self-cooled rating for a 55 degrees C unit. Increased capacity of individual transformers will be obtained by specifying a dual thermal rating and forced-cooling provisions when available and necessary to accommodate load growth,

and to allow for overloading of transformers without sacrificing transformer life.

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

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

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

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

ASSUME LOADING

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

ASSUME INITIAL PROVISIONS OF

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

AVAILABLE EXTRA CAPACITY AT 30° C AMBIENT

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

CALCULATE TIME WHEN EACH CAPACITY INCREASE IS REQUIRED

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

TO PROVIDE FOR ASSUMED LOADING

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

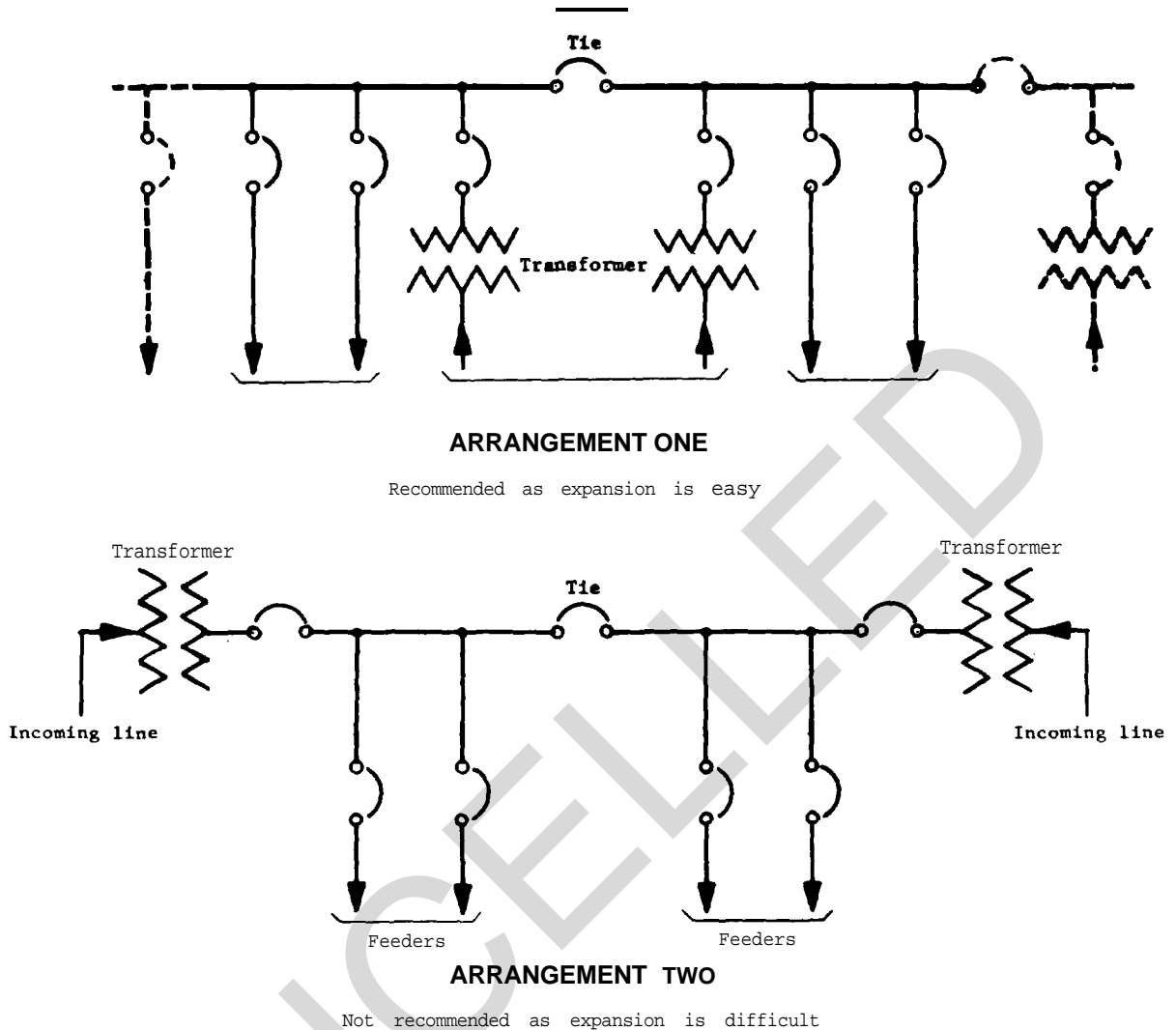
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Figure 4-2. Example of Sizing Substation Transformer Capacity.

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

(5) *Transformer arrangement.* Transformers will be arranged for connections as shown in

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



US Army Corps of Engineers

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

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

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

b. Voltage regulators. Voltage regulation will be provided when required to obtain acceptable volt-

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

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

- Transmission voltage - 69 kV
- Distribution voltage - 13.8 kV
- Assumed utility short circuit capacity - Infinite
- Assumed transformer rating - 25 MVA
- 69 kV corresponds to 350 kV BIL
- Assumed transformer impedance - 8 percent
- (25 MVA)/(0.08 percent) - 313 MVA
- Use 500 MVA circuit breaker rating

US Army Corps of Engineers

Figure 4-4. Circuit Breaker Interrupting Rating Approximation.

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

4-8. Miscellaneous Station Design Criteria.

a. *Metering and relaying.* Meters and relays will be limited to the types and number required to comply with any requirements of the utility or the Using Agency, or to afford adequate protection of electrical power systems. Ranges selected will be based on the coordination study. Meters will be

true RMS as required. Refer to TM 5-811-14 and IEEE Std 242 for guidance regarding coordinated power system protection.

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

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

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

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

Table 4-1. Minimum Relaying for Transformers

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

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

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

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

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

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

(a) *Automatic circuit reclosing relays.* Automatic circuit reclosing relays should be specified for use in conjunction with aerial lines. Reclosing relays should be considered jointly with sectionalizing switches which should be installed to minimize the duration of outages of power to other facilities served by the same aerial line, as a result of sustained faults. The use of sectionalizing switches should be considered in relation to the line length and frequency of lightning storms at the installation as well as the nature of the loads.

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

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

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

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

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

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

transformers. A "C" classification means the ratio error can be calculated, whereas a "T" classification is one which has to be derived by testing. IEEE Std C57.13 permits either classification.

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

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

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

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

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

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

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

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

The battery, charger and panelboard should be installed in a separate enclosure only when the capacity, voltage rating and consequent size of the battery warrants a separate housing, or when a separate control house is required to house the battery, charger, panelboard, annunciators, carrier current, supervisory, telemetering, relaying or other instrumentation or control equipment.

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

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

e. Other equipment and personnel protection.

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

(2) *Station enclosure.* A station fence, with three strands of barbed wire above a seven-foot high fence fabric, is the minimum requirement. Other station enclosure materials, or heights, may be required to provide equipment masking, sound attenuation, or protection against sabotage. A minimum 10-foot wide vehicle gate, a 3-foot wide personnel gate, and a sufficient access space for removal and replacement of station elements is required to permit maintenance or modifications to the station without interruption to the electrical service. Fencing will be grounded in accordance with IEEE Std 80 and the NESC.

f. Station protection and structures.

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

(2) *Protection.* The main electric supply stations will be protected against “lightning strikes” and the effects of lightning on incoming aerial lines. Protection of stations against lightning strikes to the station elements will be provided by

static wires and aerial terminals installed above and on poles or structures to provide the necessary “cone of protection.” Ground conductors will be grounded to the station ground grid and will be protected against physical damage and corrosion to terminations for ground conductors.

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

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

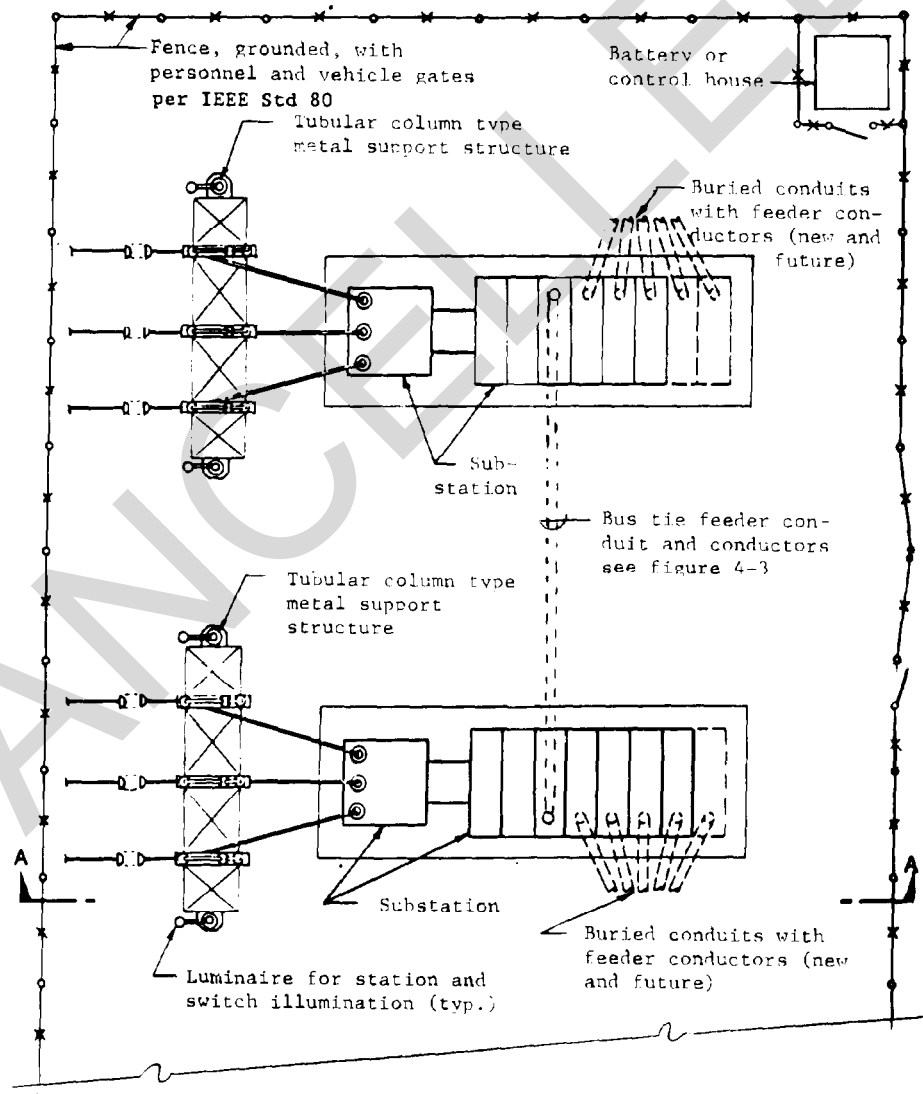
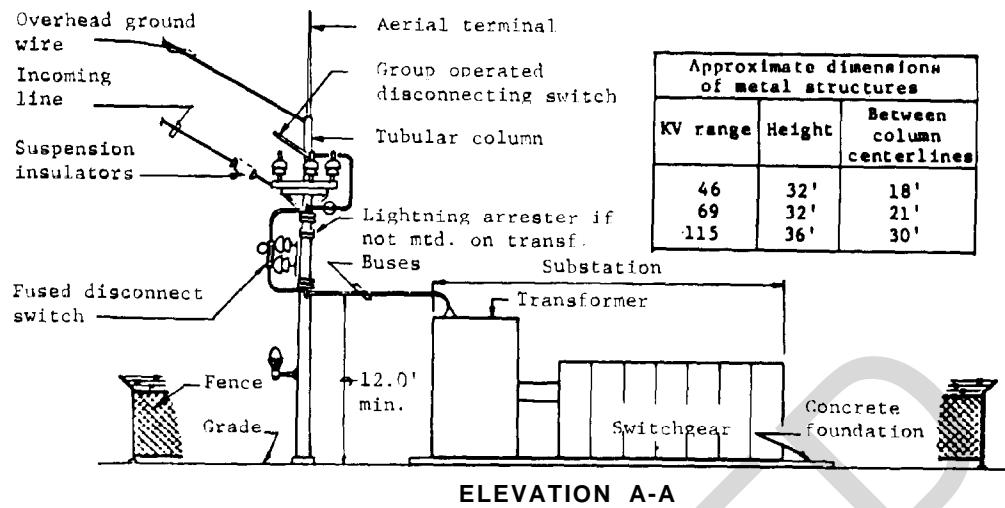
(5) *Station lighting.* Lighting levels will be in accordance with the levels listed in the NESC.

4-9. Substation Equipment at Air Force Installations.

a. Switchgear. Requirements are as follows:

(1) *Incoming supply section:*

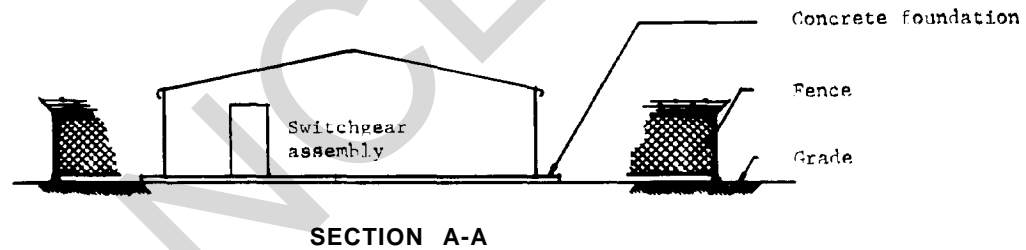
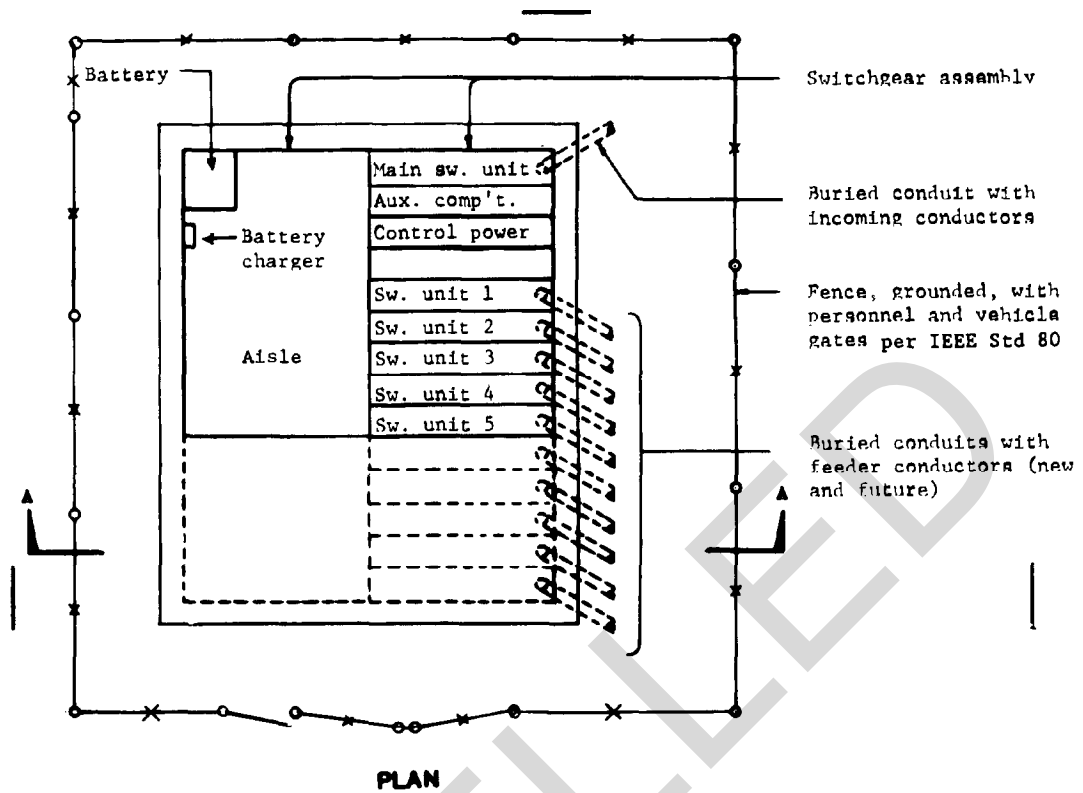
(a) *Switches.* Loadbreak/load interrupting, current limiting integrally or separately fused,



PLAN

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



US Army Corps of Engineers

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

Table 4-5. Primary Insulator Ratings by Class.

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

group/gang operated, vacuum, sulfur hexafluoride (SF₆), or other dielectric as approved by the Host Command coordinated with the Requiring Command (HOST/REQ CMD).

(b) *Circuit breakers.* Outdoor power type, metal-clad, sheltered aisle type, vacuum or air dielectric, group mounted, or individually mounted with vacuum, SF₆, or other dielectric as approved by the HOST/REQ CMD.

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

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

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

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

(3) *Operating equipment for breakers:*

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

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

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

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

d. *Transformers.*

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

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

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

e. *Foundations and fencings.*

(1) Foundations and equipment pads. Concrete.

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

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

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

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

CHAPTER 5

ELECTRIC DISTRIBUTION LINES

5-1. Selection.

Criteria for electric distribution lines will be based on the requirements of agency criteria. Distribution lines will be sized to meet current demand load, future loads, and line-loss factors.

a. Aerial line requirements. Aerial lines will be used in all areas, except in the following instances:

(1) Where aerial lines would constitute hazards such as near flight lines (where poles must be outside of the glide path) or near munitions buildings (where poles can be no closer than the length of the lines between the poles which support the lines unless effective means is provided to assure that energized lines cannot, on breaking, come in contact with the facility or its appurtenances).

(2) Where aerial lines would obstruct operations (e.g., interfere with crane-type, materials-handling equipment).

(3) Where aerial lines would interfere with high-frequency communication or electronic equipment. Aerial lines will not be within 250 feet of Communications-Electronic-Meteorological (CEM) Operation Buildings, not within 1,500 feet of receiving antennas, and not within 1,000 feet of other antennas.

(4) Where aerial installations would conflict with current policy for Family Housing Areas.

(5) Where areas have such high load densities that underground electric lines are economical. For Air Force projects, underground installation must be approved by the HOST COMMAND.

(6) Where aerial lines would be incompatible with the environment or architectural concept. For Air Force projects, underground installation must be approved by the HOST COMMAND.

b. Underground line requirements. Underground distribution lines will be provided for the exceptions listed above, for minor extensions to existing areas served by underground distribution lines, and for medium-voltage or large low-voltage electric services to buildings. When tying into an existing asbestos composite duct bank, proper environmental protocol will be followed.

5-2. Types of Underground lines.

There are two methods of installing underground lines. In the first method, underground raceway systems (ducts) are installed below grade and then cable is pulled through them. Ducts may or may not be provided with concrete encasement. The second method consists of underground cable sys-

tems installed directly in the ground. Cables may be the direct-burial type cable assemblies in coilable plastic duct, or cable assemblies in metallic armor (in direct-burial rated sheath). In this manual, the word duct will be used rather than conduit.

a. Requirements for medium-voltage lines. Where underground systems are provided, the following standards will be followed:

(1) In industrial and densely populated areas, cables will be installed in underground duct lines with manholes. Ducts will be concrete encased.

(2) In lightly populated areas, cable may be placed in non-concrete-encased duct or buried directly.

(3) The use of direct-burial cable will be limited to long untapped runs in lightly populated areas where the reliability requirements are low; or the facilities served by the cables have a short-term life; or for other reasons which would justify the use of the more economical direct-burial installations.

b. Secondary distribution lines and service conductors. Where underground systems are provided, the following guidelines will be observed:

(1) In industrial and densely populated areas, cables be installed in underground duct lines (with manholes, handholes, or pullboxes as applicable). Ducts will be concrete encased.

(2) In lightly populated areas, cable in non-concrete-encased duct or direct cable may be used.

(3) Low-voltage direct-burial cable will be restricted to applications where the load to be served is not anticipated to be increased; the underground cable can be replaced easily upon failure; and the cable system is not subject to disturbance or physical damage. The designer will coordinate burial requirements with the using or maintaining organization.

5-3. Types of Aerial lines.

Bare conductors will be used for medium-voltage circuits and insulated conductors will be used for low-voltage circuits.

a. Open wire medium-voltage construction. Bare wires will be installed on pole lines using either armless or crossarm construction. Since armless construction is more economical and presents a more pleasing appearance, it will be provided for new lines, except where prohibited by technical considerations, such as a line with many taps,

crossings, or overhead-to-underground transitions. Also, armless construction requires bucket trucks for maintenance due to loss of climbing space.

b. Insulated cable lines. Aerial insulated cables will be of the factory-assembled, messenger-supported type. The use of self-supported insulated cable or of messenger-supported insulated cable with insulated spacers will not be used.

(1) *Medium-voltage lines.* Such construction is advisable where it is necessary to avoid exposure to open wire hazards, for example, high reliability service in heavy storm areas. Cable will be of the factory-assembled, messenger-supported type.

(2) *Low-voltage lines.* Low-voltage lines will be of the neutral-supported secondary and service drop type which uses a bare messenger as a neutral conductor and as a support for insulated phase conductors. Weatherproof conductors (line wires), which are supported on secondary racks, are less attractive and more expensive to install than neutral-supported cable. Use of secondary-rack construction will be limited to minor extensions of existing systems.

5-4. Voltage Drop.

Voltage drop on the distribution system will comply with the minimum voltage requirements of ANSI C84.1. Voltage drop on the low-voltage distribution system will comply with the recommendations of the NEC. Figure 5-1 shows typical distribution of voltage drops through the supply system. Designers will consider all the system voltage drops in order to ensure that voltage levels are in accordance with ANSI C84.1 and the NEC.

a. Voltage drops. An example of an aerial line voltage drop calculation is given on figure 5-2. This example uses the approximate formula method which ignores angles and which is sufficiently accurate for all but abnormal conditions, such as where system power factors are extremely low. Proximity effects, sheath currents, and geometric construction may need to be taken into account in calculations of impedance for underground circuits. Various tables and voltage drop curves are available from manufacturers for underground circuits. For aerial circuits, impedance may be determined using values of resistance and reactance.

b. Resistance. For conductors of 500 kcmil and less at 60 Hz frequencies, the skin-effects of alternating current are negligible and direct-current resistance values can be used.

c. Reactance. Normal practice is to separate inductive reactance into two components. X_a is the reactance which results from flux within a radius of one foot of the conductor plus the internal

reactance of the conductor. X_d is the reactance which results from flux between the radius of one foot and the equivalent conductor spacing based on a mean distance (D). The two values of reactance can be found in conductor tables and added together for the total alternating-current reactance.

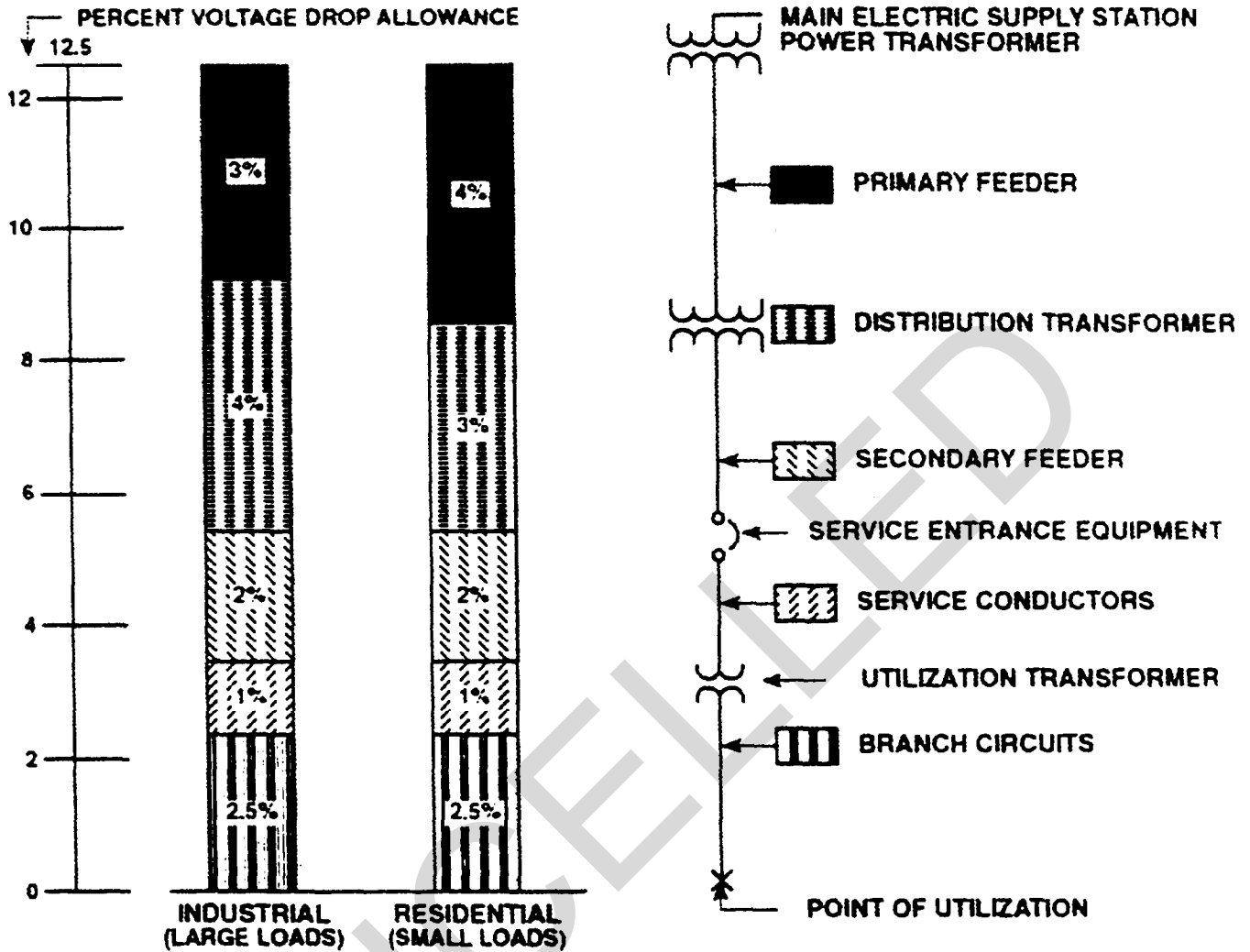
5-5. Power Factor Correction.

System power factor is influenced mainly by the characteristics and mechanical loads of the motors supplied. Such characteristics vary widely and therefore the kVAR capacity cannot be correctly estimated at the time of the distribution system design, but only after firm data is available. One year of operating history is needed before the amount of fixed and switched capacitance can be selected to best meet actual operating conditions. Large motors are often provided with integral capacitors.

a. Capacitor justification. Justification for application of line and station shunt capacitors requires a life-cycle cost analysis using the methodology in 10 CFR 436. Capacitors are justified when the savings to investment ratio of the installation is greater than one. An example of computing the average energy savings per year is shown on figure 5-3. Where a serving utility does not have a power factor clause, only line losses will apply.

b. Capacitor equipment. Capacitors for overhead distribution systems can be pole-mounted in banks of 300 to 1,800 kVAR for most medium-voltage systems up to 34.5 kV phase-to-phase. Pad-mounted capacitor equipment is available in the same range of sizes and voltage ratings for underground systems. Power capacitor equipment will have grounded wye connections so switch tanks and frames will be at ground potential for greater personnel safety. Grounded capacitors can bypass some line surges to ground, provide a low impedance path for harmonics, and group fusing need not be so precise. For maximum efficiencies, capacitor equipment will be located as close to the load controlled as is feasible. Surge arresters will be specified to limit the magnitude of voltage surges caused by capacitor switching. Applications of surge arresters will be in accordance with the IEEE C62 series of standards.

c. Capacitor control. Switched capacitors will be provided only when differences between full-load and light-load power factors warrant such control. The load and power factor profile of the system will determine the economics of switched control, and whether there is a necessity for more than one switching step. Time clock control is the least costly type of control, but can only be used where power factor and demand vary on a firm time



NORMAL ALLOCATION OF VOLTAGE DROP

Figure 5-1. Normal Allocation of Voltage Drop.

basis. Voltage control is used where objectionable voltage changes occur with varying voltages. Current control is used when loads change, but voltage is well regulated or load power factor remains substantially constant. Current control is effective also when power factor varies in a predictable manner with the load. Kilovar control is used when load voltage is regulated, but power factor varies in an unpredictable manner to corresponding load variations. More sophisticated current and voltage control than that covered by IEEE Std 18 can be provided, and manufacturers should be consulted for application and specification information.

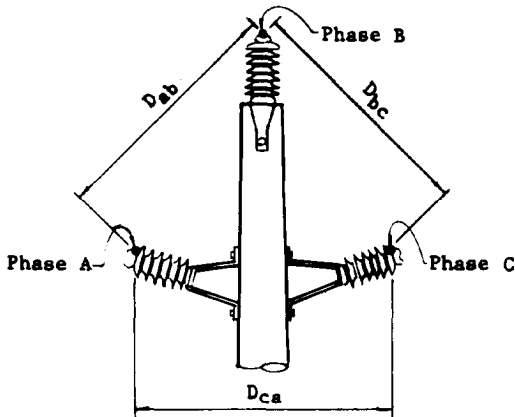
5-6. Medium-Voltage Circuits.

a. *Number.* The number of medium-voltage circuits will be determined on the basis that each

circuit must be capable of serving the load over the required distance without exceeding the allowable voltage drop. The number of circuits and conductor sizes will be determined by an economic evaluation of the possible configurations including construction requirements (span lengths, pole heights, pole classes) for conductor capacities at the primary distribution voltage and higher voltages.

(1) *Quick check values.* Table 5-1 has been prepared to allow a quick check of the capacities of three-phase medium-voltage circuits at 0.90 power factor by giving the approximate kilovolt-ampere-mile loading for a three percent voltage drop. For voltages not given, the use of a factor of the square of the ratio of the desired voltage divided by the known voltage times the megavolt-ampere-

IMPEDANCE FACTORS



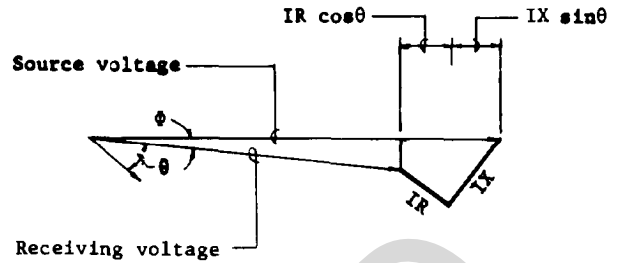
$$Z = R + j (X_a + X_d) \dots\dots\dots (1)$$

Where:

- R = 60 Hz resistance
- X_a = 60 Hz inductive reactance at 1-foot spacing
- X_d = 60 Hz inductive reactance for additional spacing D

$$D = [(D_{ab})(D_{bc})(D_{ca})]^{1/3} \dots\dots (2)$$

APPROXIMATE VOLTAGE DROP FORMULAS



Line-to-line voltage drop
 $= 1.732 I (R \cos \theta + X \sin \theta) \dots\dots\dots (3)$

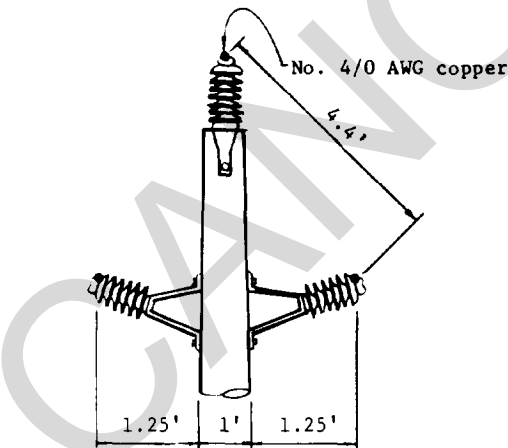
- Where: I = Line current in amperes
- θ = Phase angle between voltage and current or $\cos \theta$ = power factor
- R = Resistance of line in ohms, one conductor
- X = Reactance of line in ohms, one conductor

Formula (3) can be converted as follows to calculate percent voltage drop:

$$\% \text{ voltage drop} = \frac{\text{kVA} [R \cos \theta + (X_a + X_d) \sin \theta]}{10 (\text{kV})^2} \dots\dots (4)$$

Where: kVA is three-phase kVA and kV is line-to-line kilovolts. For single-phase circuits the percent drop is twice this value, and kVA is single-phase kVA.

EXAMPLE



- Given:
- $\cos \theta = 0.90$ $\sin \theta = 0.436$
- kVA = 15,000 kV = 13.8

Find voltage drop for one mile of line
 Percent voltage drop =

$$15,000 \left[\frac{(0.273)(0.9) + (0.674)(0.436)}{10(13.8)^2} \right] = 4.28\% \text{ voltage drop} \dots\dots\dots (4)$$

$$(3.5' \times 4.4' \times 4.4')^{1/3} = 4.08' \dots\dots (2)$$

$$0.278 \Omega/\text{mile (Table 4-29)}^a$$

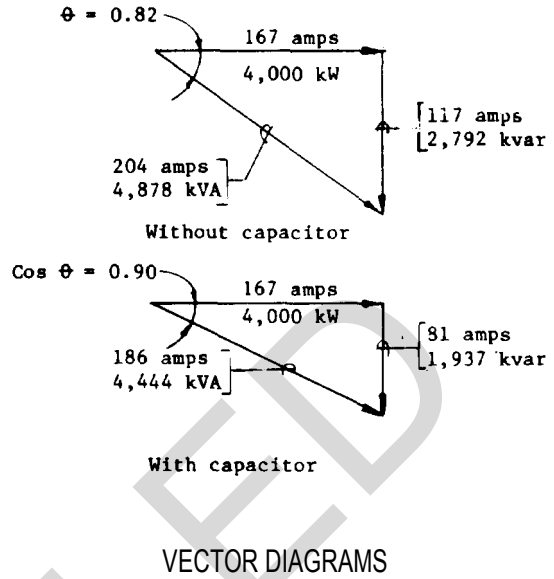
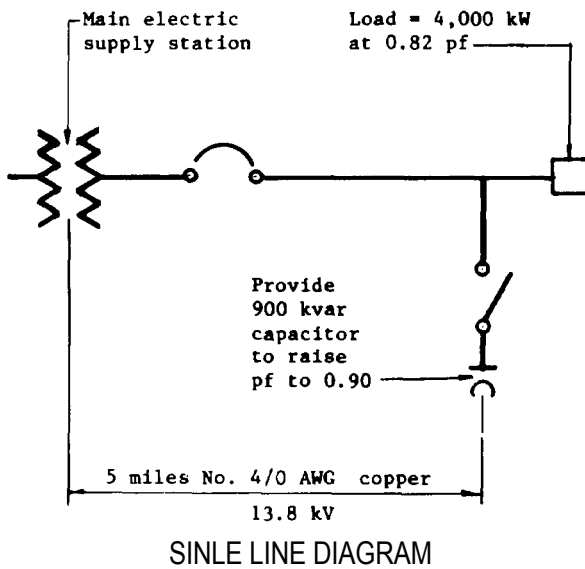
$$0.503 \Omega/\text{mile (Table 4-29)}^a$$

$$0.171 \Omega/\text{mile (Table 4-34)}^a$$

$$0.278 + j0.674 \Omega/\text{mile} \dots\dots\dots (1)$$

^aTables are from Standard Handbook for Electrical Engineers (Eleventh Edition).

Figure 5-2. An Example of Voltage Drop Calculation.



ASSUMED UTILITY RATES

Energy charge
- \$0.035 per kWh

Power factor
clause credit
= 0.001 times value
in percent that
power factor (pf)
is raised above a
stipulated amount.

Losses - I^2R
= $[(204^2 - 186^2) \text{ amperes}] \times 5 \text{ miles} \times 3 \text{ conductors} \times 0.278 \text{ ohms per mile}$
= 29.27 kw

Line loss savings = 29.27 kw x 0.6 load factor x 4,000 hours x \$0.035
= \$2459 a year

Power factor savings (increase 82 percent to 90 percent)
= 4,000 kw x 0.6 load factor x 4,000 hours x \$0.035 x [0.001 x 8]
= \$2,690 a year

Total Savings = \$2459 + \$2,690 = \$5149 a Year

CALCULATIONS

us Army Corps of Engineers

Figure 5-3. Average Energy Savings Example.

miles will provide a sufficiently accurate determination. For instance, taking the value for aerial No. 4/0 AWG copper at 25 kV or 29.2 megavolt-ampere-miles and multiplying by $(35/25)^2$ gives a value of 57.2 megavolt-ampere-miles which is almost the value given in table 5-1. For underground circuits, where proximity effects apply, a greater variation will be encountered, but estimated demand loads are probably within the same accuracy range.

(2) *New feeders.* For new installations, with estimated demands based on requirements covered in chapter 2 and estimated feeder lengths based on the site plan, a determination of circuit requirements can be made. Feeders will be large enough to allow a growth factor of 25 percent of the design maximum demand.

(3) *Existing feeders.* Circuit capability will be determined by measuring loads over a suitable period of time. Where such information is unavailable, knowledge of the station maximum demand and overall transformer capacity can permit determining an installation's demand factor on the basis of overall connected transformer capacity. Circuit capability can be roughly evaluated by totaling the transformers connected to the feeder and applying this factor; however, this method is too inaccurate as a basis for justifying new feeders or adding large loads.

b. *Automatic circuit reclosers.* Chapter 4 covers provision of reclosing relays on outgoing feeder circuit breakers at a main electric supply station. Where a reclosing relay on a station circuit breaker does not provide a protective zone which

Table 5-1. Three-Phase Medium-Voltage Circuit Loading Check Values.

Type of line	Material	Wire size AWC or kcmil	Maximum amperes	Voltage			
				4.16kV	13.8kV	25kV	35kV
				Megavolt-ampere-mile ^b (Maximum megawatt load)			
Aerial lines ^c	Copper	4/0	480	0.8(3.1)	8.8(10.3)	29.2(18.7)	57.3(26.2)
		2/0	360	0.6(2.3)	6.2(7.7)	22.4(14.0)	44.1(19.6)
		1/0	310	0.5(2.0)	5.9(6.7)	19.5(12.1)	38.1(16.9)
		1	270	0.5(1.7)	5.1(5.8)	16.5(10.5)	32.3(14.7)
		2	230	0.4(1.5)	4.3(4.9)	14.1(8.8)	27.6(12.5)
		4	180	0.3(1.2)	3.0(3.8)	9.8(7.0)	19.2(9.8)
		6	130	0.2(0.8)	2.0(2.8)	6.7(5.1)	13.1(7.1)
Aerial lines ^c	ACSR	336.4	530	0.8(3.4)	9.3(11.4)	30.4(20.7)	59.8(28.9)
		4/0	340	0.5(2.2)	5.9(7.3)	19.4(13.3)	38.0(18.5)
		3/0	300	0.5(1.9)	5.1(6.5)	16.7(11.7)	32.7(16.7)
		2/0	270	0.5(1.8)	4.4(5.8)	14.4(10.5)	28.3(14.7)
		1/0	230	0.3(1.5)	3.7(4.9)	12.2(9.0)	23.9(12.5)
		2	200	0.2(1.2)	2.7(3.9)	8.9(7.0)	17.5(9.8)
		Underground lines ^d	Copper	500	465		26.0(10.0)
2/0	230				9.9(4.9)	32.4(9.0)	
Underground lines ^d	Aluminum	350	305		14.5(6.6)	47.2(10.8)	
		4/0	230		9.8(4.9)	31.8(9.0)	
		1/0	155		5.4(3.3)	17.5(6.0)	

^a For balanced loads.
^b For loads having a 90 percent power factor this value represents a 3 percent voltage drop. The values given parenthesis represent the megawatt capacity of the wire and values were computed using the method shown on figure 5-1.
^c Based on values from Standard Handbook for Electrical Engineers (Eleventh Edition) for 60 Hz circuits approximately 75 percent loaded and operating at a temperature of 50° C and an equivalent spacing of 5 feet.
^d For conductors operating at 40° C.

covers an entire feeder because of circuit length and impedance, automatic circuit reclosers or reclosing circuit breakers may be necessary remote from the station. This application of automatic circuit reclosers will be provided only to protect the aerial portions of the feeder, and only when reclosing is also provided on that feeder at the main electric supply station.

c. *Connections to transformers.* Normal transformer circuit design will eliminate most circuit elements which produce the destructive voltages which can arise from ferroresonance.

(1) *Overvoltage.* Ferroresonant overvoltages occur when the ratio of the distributed line-to-ground capacitive reactance (Xc) in series with the transformer magnetizing (no-load) inductive reactance (Xm) is nearly equal and the effective resistance in the circuit is minimal (almost no load connected to the transformer). At such times the circuit may be near resonance resulting in a total circuit impedance close to zero. Under these conditions, a high current will flow and cause correspondingly high voltages.

(2) *Overvoltage prevention.* Destructive overvoltages do not occur when group-operated switching is provided. Pole-mounted transformers are switched so close to transformer terminals that there is not sufficient line capacitance for resonance. Clearing of one fuse in a line should not be a problem, because the transformer is loaded at that time. Very rarely are aerial lines long enough to provide enough capacitance to cause ferroresonance.

(3) *Occurrence.* Ferroresonance may occur on long underground circuits which are single-pole switched. Since the occurrence of ferroresonance cannot be reliably predicted, group-operated switches are required for, and should be integral to, ground-mounted transformers.

d. *Transition points.* Transition points between aerial and underground sections (riser poles) will be provided with primary fuse cutouts and surge arresters for protection of the underground cables and cable-supplied equipment. When the underground service supplies two or more transformers, some of which may be remotely located, fuse

cutouts will be of the loadbreak type. When the underground feeder supplies only one transformer installation in the immediate vicinity of the riser pole, nonloadbreak fused cutouts may be acceptable. Where the capacity of the line is more than the maximum ampere rating of fuse cutouts, power fuse units will be installed. Installation of lines having an ampere rating above that of power fuses will be avoided, since more expensive protection devices such as those covered in chapter 4, will be necessary. Group-operated loadbreak switches used for sectionalizing aerial-to-underground connections can be either integrally fused or nonfused devices. Overcurrent protection is necessary to protect underground systems. Group-operated loadbreak switches at transition poles are not justifiable solely on the basis of preventing possible ferroresonance, since such switches at ground-mounted transformers will eliminate most causes of transform ferroresonance.

5-7. Pad Mounted Sectionalizing Equipment.

a. *Pad-mounted, metal-enclosed switchgear.* Pad-mounted, metal-enclosed switchgear (air-, oil-, gas-, or vacuum-insulated) may be utilized to provide group-operated, load-break switch operation, sectionalizing points for large underground distribution systems, and over-current protection (fuses) for lateral feeders from a main feeder. Additionally, they may be employed to provide group-operated, load-break switch operation for large three-phase loads requiring interruption of all phases simultaneously. Switchgear is also available to provide manual switching between alternate primary sources. Application of switchgear will be based on operational needs, protective devices coordination requirements, size of the primary system and loads, and cost comparisons among alternatives.

b. *Pad-mounted sectionalizing terminals.* These devices are dead-front, cable-terminating enclosures which employ separable, load-break connectors and load-break, feed-through bushings. They do not provide over-current protection. They provide a means to splice cables above ground and provide lateral feeder taps from a main feeder, while maintaining the ability to sectionalize the underground cables at that point for operation and maintenance. These devices will not be substituted for pad-mounted, metal-enclosed switchgear and should be used only where isolation of lateral feeds

is necessary for operation or maintenance and the application does not require a switchgear. They can be used for opening a de-energized circuit during maintenance for fault isolation at a much lower cost than a fused or non-fused disconnect switch. They can also be used to open a de-energized radial feeder for maintenance, again at less cost than a disconnect switch. If provided in a project design, the contract specifications shall include provision of standoff bushings for phase isolation (“parking”) of each conductor, and instruction signs on the enclosure which state that the connectors are not to be disconnected/connected while energized.

5-8. Joint Electrical/Communication lines for Air Force Installations.

a. *Electrical.* Where overhead construction is required, electrical distribution shall be located along street or roads to avoid the use of separate poles for street lights.

b. *Poles, duckbanks, and manholes:*

(1) For economy, telephone lines and television cables shall be carried on the same poles or in the same ductbank as electrical power lines.

(2) Joint use of manholes is permitted if the power cables and communications cables are separated from each other by a masonry wall and a separate manhole cover is installed in each section.

c. *Additional factors.* Underground construction for either electrical distribution or communications systems shall meet the provisions of this manual and technical requirements such as airfield clearance, proximity to radio and radar installations, and security control of closed circuits, unless specifically authorized by a waiver of these criteria.

d. *Overhead cable limits.* No more than two telephone cables shall normally be installed per pole. Quantity of twisted pairs and conductor sizes (AWG) for cables exceeding diameter and weight limitations begin with:

5 lb/ft Quantity-AWG	2-inch diameter Quantity-AWG
303-19	303-19
606-22	508-22
909-24	909-24

e. *Routing of telephone cable.* Telephone cables shall not be installed on poles until arrangements have been made for adequate guying.

CHAPTER 6

AERIAL DISTRIBUTION LINES

6-1 General.

Aerial lines will be provided in all areas as established in chapter 5. In order to use the same poles for both aerial distribution and roadway lighting and to avoid interference with possible future projects, consideration will be given to installing pole lines adjacent to roadways.

a. Symbols and codes. For uniformity, symbols will comply with ANSI Y32.9. Installation will comply with the requirements of the NESC for Grade B construction and the NEC as required. The loading district will be that applying to the location of the installation as required by the NESC. Where state safety rules are predominantly accepted, such rules may be used provided they are at least as stringent as those of the NESC.

b. Circuit configurations. Typical circuit configurations and details are provided later in this chapter as a general guide in the design. In addition, publications of the Rural Electrification Administration (REA) will be helpful.

c. Other conditions. Service conditions are covered in chapter 1. Special items such as overhead grounding conductors, grounding, and surge protection are covered in chapter 9. Other conditions will follow the guidelines established by the NESC, the REA, or the local utility as applicable.

6-2. Installation Considerations.

Design of span lengths for aerial lines will be based on such factors as conductor sizes, conductor loadings (conductor weight, wind loading, and ice loading), and load density. Rural area design will be predicated on the most economical span length for the terrain, NESC loading area, conductor size and strength, functional use, and the requirements of joint-use communication lines. Designs for areas such as military base housing, administration, maintenance, and support areas will consider area functional use, span length for the terrain, NESC loading area, conductor size and strength, and the requirements of joint-use communication lines, street and area lighting. Distribution criteria for ammunition plant or process facilities will be based on all of the above and include the requirements of AMCR-385-100. No more than two medium-voltage circuits will be installed on one pole. Switches to facilitate the transfer of load will be provided where circuitry makes this provision economically justifiable. Pole line configuration

will include provisions for raptor protection in accordance with Federal and state laws. Consult REA Bulletin 61-10, "Protection of Bald and Golden Eagles from Powerlines." The requirement for wooden cross-arm braces should be verified for each state and land area in accordance with the Bald Eagle Protection Act of 1940 (16 U.S.C. 688 et seq.) as amended; the Endangered Species Act of 1973 (87 Stat. 1064); and Migratory Bird Treaty of 1918 (16 U.S.C. 703 et seq.) as amended. Sources include the Bureau of Land Management, U.S. Department of the Interior and Federal, state and local land management or wildlife conservation agencies.

6-3. Conductors.

a. Sizes. Where possible, conductor sizes will be limited to a maximum of No. 4/0 AWG copper or equivalent aluminum. Conductor sizes above No. 4/0 AWG copper or equivalent aluminum will be justified by an economic analysis of the alternatives (such as additional circuits or a higher distribution or sub-transmission voltage). The economical minimum conductor size for circuits serving administrative, support and housing areas is No. 2 AWG hard down copper or equivalent aluminum. For small, isolated loads a minimum size of No. 6 AWG copper or equivalent aluminum will be used.

b. Material. Aluminum conductor steel reinforced (ACSR), aluminum alloys, or hard-drawn copper (CU) may be used for medium-voltage lines. Low-voltage conductors may be of aluminum alloys with ACSR messengers or of copper. However, the selection of copper or aluminum will be justified based upon an analysis using life, environmental, and cost factors.

(1) *Type of aluminum alloys.* In their standards and data publications, the Aluminum Association recognizes three alloys of aluminum as suitable for electric conductors. All-aluminum-conductors, formerly known as hard-drawn aluminum or EC grade are now designated as alloy 1350-H19 and the acronym to be used will be AAC. This alloy with a 61 percent copper conductivity is not a preferred type because of the alloy's low inherent tensile strength. The intermediate strength (5005-H19), alloy will not be used since the conductivity is only one percent greater than the high-strength alloy. The high-strength

6201-T81 (acronym AAAC) alloy with a 52.5 percent copper conductivity is often used as a substitute for ACSR where problems of corrosion have resulted because of the combination of both aluminum and steel in ACSR conductors.

(2) *Use of other conductors.* Special conductors such as copper-clad steel may be used where the application warrants. Conductor selection, where corrosive or salt-laden atmospheres are encountered, may require investigation. The determination of acceptable conductors for special atmospheres will be based on evaluations which will consider local utility practices. Table 6-1 indicates

physical properties of conductors for commonly used materials.

c. *Conductor insulation.* Most medium-voltage conductor installations use bare conductors. Where the use of insulated cable has been justified for medium-voltage lines, the insulation will conform to the requirements applying to underground conductors covered in chapter 7. Messenger wire composition and weatherproof covering, for low-voltage lines will be in accordance with applicable ICEA/NEMA requirements.

d. *Sags and tensions.* The maximum tension in a span is limited by the strength of the wire and

Conductor material ^a	ASTM standard number	Size		Number of strands	Diameter inches D _c	Weight lb/ft W _c	Area in ² A _c	Breaking strength lb	Ampacity ^{d&e} amperes A
		AWG	kcmil						
CU (copper, hard-drawn) E = 17 x 10 ⁶ X = 9.4 x 10 ⁶	B1 or B8	6	26.2	Solid	0.162	0.079	0.021	1,280	91
		4	41.7	7	0.232	0.129	0.033	1,940	141
		2	66.4	7	0.292	0.205	0.052	3,042	186
		1	83.7	7	0.328	0.258	0.066	3,804	220
		1/0	105.6	7	0.368	0.326	0.083	4,752	245
		2/0	133.1	7	0.414	0.411	0.105	5,926	283
		4/0	211.6	7	0.527	0.653	0.166	9,154	385
AAC (all-aluminum-conductor, 1350-H19) E = 10 x 10 ⁶ X = 12.8 x 10 ⁶	B231	4	41.7	7	0.232	0.039	0.033	881	100
		2	66.4	7	0.292	0.062	0.052	1,350	137
		1/0	105.6	7	0.368	0.099	0.083	1,990	180
		2/0	133.1	7	0.414	0.125	0.105	2,510	220
		3/0	167.8	7	0.464	0.158	0.132	3,040	260
		4/0	211.6	7	0.522	0.199	0.160	3,830	280
		--	336.4	19	0.666	0.316	0.264	6,150	400
AAAC (all-aluminum-alloy-conductor, 6201-T81) E = 10 x 10 ⁶ X = 12.8 x 10 ⁶	B399	4	48.7	7	0.250	0.046	0.038	1,760	150
		2	77.4 ^b	7	0.316	0.073	0.061	2,800	200
		1/0	123.3	7	0.398	0.116	0.097	4,460	270
		2/0	155.4	7	0.477	0.146	0.122	5,390	315
		3/0	195.7	7	0.502	0.184	0.154	6,790	365
		4/0	246.9	7	0.563	0.232	0.194	8,560	420
		--	394.5	19	0.720	0.370	0.310	13,300	570
ACSR ^c (aluminum-conductor-steel-reinforced) E = 11.5 x 10 ⁶ X = 10.5 x 10 ⁶	B232	4	41.7	6/1	0.257	0.067	0.041	2,290	112
		2	66.4	6/1	0.316	0.091	0.061	2,850	147
		1/0	105.6	6/1	0.398	0.145	0.097	4,380	194
		2/0	133.1	6/1	0.447	0.183	0.122	5,300	220
		3/0	167.8	6/1	0.502	0.231	0.154	6,620	252
		4/0	211.6	6/1	0.563	0.291	0.194	8,350	282
		--	336.4	26/7	0.720	0.463	0.307	14,100	360

^a E = final modulus of elasticity in lb/in², X = final coefficient thermal expansion per degrees F.

^b Size of AAAC is approximately 15 percent larger than AAC to give equivalent current-carrying capacity.

^c Strength given for ACSR/GA. First number denotes number of aluminum strands, second number denotes number of steel strands.

^d Current ratings for CU, AAC, & ACSR based on: Copper conductivity 98.0% IACS; aluminum conductivity 61.0% IACS; average temperature rise 30° C above ambient temperature 40° C; frequency 60 Hz.; horizontal position; outdoors; wind velocity 2 feet per second, crosswise; 18 inch minimum line spacing.

^e Current ratings for AAAC based on: ASTM minimum conductivity 52.5% IACS; average temperature rise 50° C above ambient temperature 25° C; frequency 60 Hz.; horizontal position; outdoors; wind velocity 2 feet per second, crosswise; 18 inch minimum line spacing.

Table 6-1. Conductors Materials-Physical Properties.

its supporting elements. The NESC permits conductor sags, such that for ice and wind loadings applying, the tension of the conductor must not exceed 60 percent of the conductor's rated breaking strength. Also, the tension at 60 degrees F (15 degrees C), without external load, will not exceed 35 percent of the initial unloaded tension and 25 percent of the final unloaded tension. In the case of conductors having a triangular cross section, such as cables composed of three wires, the final unloaded tension at 60 degrees F (15 degrees C) will not exceed 30 percent of the rated breaking strength of the conductor. Refer to the NESC for specific and detailed requirements regarding the application of aerial distribution lines. Both under normal and maximum ice and wind conditions, any conductor will not be loaded beyond limits of safety. In some areas, it may be common practice to reduce the maximum loaded tension to 40 percent or less.

(1) *Initial sags.* Typical initial stringing sags are given in table 6-2 for various conductor materials, sizes, and loading districts for a

200-foot span, since this is a commonly used ruling span. For other ruling spans, manufacturers will be consulted. A ruling span is an assumed "design span" that assures average tension throughout a line of nonuniform span lengths between deadends and can be calculated exactly by the following equation where S is distance between spans, from 1 span up to n spans. The large variations in temperatures, wind, and ice conditions encountered at various military installations makes it extremely important that conductors be properly sagged. The copper-equivalent sizes, given in table 6-2, are based generally on assuming that aluminum conductors two sizes larger than copper are equivalent in ampacity. To sag conductors properly, the conductor manufacturer's published data must be used.

$$\text{Ruling span} = \frac{(S_1^3 + S_2^3 + S_3^3 + \dots + S_n^3)^{1/2}}{(S_1 + S_2 + S_3 + \dots + S_n)^{1/2}} \quad (\text{eq 6-1})$$

(2) *Final sags and tensions.* The final loaded tension data shown in table 6-3 indicates final

Conductors	AWG copper (aluminum)	Stringing temperature 30°F			Stringing temperature 60°F			Stringing temperature 90°F		
		Loading districts			Loading districts			Loading districts		
		Light	Medium	Heavy	Light	Medium	Heavy	Light	Medium	Heavy
Material		Stringing sag feet								
CU		1.2	1.3	1.5	1.6	1.8	2.0	2.0	2.3	2.6
AAC		0.8	0.9	1.1	1.1	1.3	1.7	1.6	2.0	2.5
AAAC	4/0(336.4)	0.4	0.5	0.7	0.5	0.7	0.9	0.7	1.0	1.3
ACSR		0.5	0.6	0.8	0.6	0.7	1.0	0.7	1.0	1.4
CU		1.2	1.4	1.5	1.5	1.8	2.0	2.0	2.3	2.6
AAC		0.8	0.9	1.2	1.1	1.4	1.8	1.8	2.2	2.7
AAAC	2/0(4/0)	0.4	0.5	0.6	0.5	0.7	0.9	0.7	0.9	1.3
ACSR		0.6	0.7	0.8	0.7	0.9	1.0	0.9	1.2	1.4
CU		1.2	1.5	1.5	1.5	1.9	2.0	2.0	2.5	2.6
AAC		0.9	0.9	1.7	1.5	1.4	2.5	2.1	2.2	3.3
AAAC	1/0(3/0)	0.4	0.5	0.6	0.5	0.7	0.9	0.7	0.9	1.3
ACSR		0.6	0.7	0.7	0.7	0.9	1.0	0.9	1.2	1.4
CU		1.2	1.5	1.5	1.5	2.0	2.0	2.0	2.6	2.6
AAC		0.8	0.9	2.2	1.0	1.3	3.0	1.7	2.1	3.8
AAAC	1(2/0)	0.4	0.5	0.6	0.5	0.7	0.9	0.7	0.9	1.3
ACSR		0.6	0.7	0.7	0.7	0.8	0.9	0.9	1.2	1.3
CU		1.2	1.7	1.5	1.5	2.2	2.0	2.0	2.8	2.6
AAAC		0.7	0.9	3.5	1.1	1.3	4.2	1.7	2.1	4.8
AAAC	2/(1/0)	0.4	0.5	0.6	0.5	0.6	0.8	0.6	0.8	1.1
ACSR		0.5	0.6	0.6	0.7	0.8	0.8	0.8	1.1	1.1
CU		1.7	2.1	2.7	1.8	2.7	3.2	2.3	3.3	3.8
AAAC		0.7	1.0	5.8	0.9	1.6	6.3	1.5	2.4	6.7
AAAC	4(2)	0.4	0.5	0.6	0.5	0.6	0.7	0.6	0.8	1.1
ACSR		0.5	0.6	0.6	0.6	0.7	0.7	0.7	1.0	1.0
CU		1.5	--	--	2.0	--	--	2.5	--	--
AAC		0.7	3.0	9.7	0.9	3.7	10.0	1.4	5.0	10.2
AAAC	6(4)	0.4	0.5	0.9	0.5	0.6	1.4	0.6	0.8	2.1
ACSR		0.5	0.5	0.9	0.6	0.7	1.4	0.7	0.9	2.0

Table 6-2. Initial Stringing Sags for 200-Foot Spans.

loaded tensions and sags for conductors which were initially strung to the sags of table 6-2. Sags are a maximum at the indicated loading conditions. Tensions will be less at higher temperatures when wind and ice loads do not apply (final unloaded conditions).

(3) *Unusual loading conditions.* The NESC stipulates loading and installation requirements for normal conditions, as shown in table 6-3; however, many areas will be subjected to climatic conditions much more severe than those listed, in respect to both wind and ice loads. In these instances, a complete analysis will be required to determine acceptable sagging versus strength. An example of an aerial conductor strength analysis is given in figure 6-1. Pole line analyses will be provided and will show calculations for pole strengths, guying, span length, and sags. This type of calculation requires making an assumption (in this case that conductor sag equal 2.06 feet) and then checking the validity of the assumption,

which can be tedious and time-consuming. Conductor manufacturers have computer programs which have been developed to perform these calculations. The assumed value of 2.06 feet of sag and 3,350 pounds tension are different from the values given in table 6-3 where the values listed are 2.4 feet of sag and 2,870 pounds tension. The variation results because of elastic creep; however, the variation in values of about 15 percent, in this case, provides a more conservative design or an additional safety factor.

e. Conductors for Air Force installations.

(1) Minor extensions to systems using copper conductors shall be made with copper.

(2) Major extensions to existing systems and new systems shall be of bare hard drawn copper, aluminum, or steel reinforced aluminum.

(3) Self-supporting aerial cable with insulated cable lashed to the neutral messenger or individual insulated cables supported from the messenger with insulated spacers may be utilized if approved

Conductors		Loading districts					
		Light		Medium		Heavy	
		9 lb/ft ² horizontal wind no ice 30°F		4 lb/ft ² horizontal wind 1/4-inch radial ice 15°F		4 lb/ft ² horizontal wind 1/2-inch radial ice 0°F	
Material	AWG copper (aluminum)	Tension lb	Sag ft	Tension lb	Sag ft	Tension lb	Sag ft
CU	4/0(336.4)	2,900	a	3,000	a	3,350	a
AAC		1,675	1.9	2,060	2.2	2,620	2.8
AAAC		3,460	1.0	3,610	1.4	3,970	2.0
ACSR		3,670	1.0	3,850	1.4	4,260	1.9
CU	2/0(4.0)	1,800	a	1,950	a	2,350	a
AAC		1,180	2.1	1,490	2.5	1,920	3.3
AAAC		2,270	1.2	2,430	1.6	2,780	2.4
ACSR		2,250	1.2	2,460	1.7	2,870	2.4
CU	1/0(3/0)	1,450	a	1,550	a	2,000	a
AAC		1,130	1.9	1,270	2.7	1,520	4.0
AAAC		1,820	1.3	1,990	1.8	2,340	2.7
ACSR		1,810	1.4	2,020	1.9	2,430	2.7
CU	1(2/0)	1,200	a	1,300	a	1,700	a
AAC		840	2.3	1,110	2.9	1,260	4.5
AAAC		1,475	1.4	1,650	2.1	1,980	3.0
ACSR		1,480	1.5	1,690	2.1	2,078	2.9
CU	2(1/0)	940	a	1,050	a	1,450	a
AAC		700	2.4	960	3.2	1,000	5.5
AAAC		1,230	1.5	1,400	2.3	1,720	3.2
ACSR		1,240	1.5	1,440	2.3	1,800	3.2
CU	4(2)	540	a	720	a	1,000	a
AAC		520	2.7	675	4.1	680	7.5
AAAC		810	1.8	990	2.9	1,280	4.0
ACSR		850	1.8	1,050	2.8	1,370	3.8
CU	6(4)	350	a	a	a	a	a
AAC		380	3.0	440	5.8	440	10.9
AAAC		550	2.0	730	3.6	880	5.5
ACSR		580	2.1	790	3.4	930	5.2

Table 6-3. Final Loaded Tensions for 200-Foot Spans.

USING VALUES BELOW

- w_c = Conductor weight, unloaded (lb/ft)
- L = Length of pole spacing (ft)
- d = Conductor sag (ft)
- T = Tension (lb)
- ΔL = Length conductor is greater than pole spacing based on parabolic formula (in)
- D_c = Conductor diameter (in)
- D_n = Conductor plus NESC additional ice thickness requirement (in)
- W = NESC wind force requirement (lb/ft²)
- w_h = Horizontal loading (lb/ft)
- I_w = Ice weight factor of 0.396 lb/ft per in² based on NESC weight of ice (57 lb/ft³)
- w_i = Weight of ice (lb)
- w_v = Vertical loading (lb/ft)
- k = Constant to be added to resultant from NESC table 251-1
- w_{c1} = Conductor weight, loaded (lb/ft)
- T_s = Stringing tension (lb)
- T_1 = Tension under NESC loading conditions (lb)
- ΔT = Increase in loaded tension over stringing tension (lb)
- A_c = Conductor cross-section (in²)
- ΔS = Increase in stress (lb/in²)
- E = Modulus of elasticity of conductor
- ΔL_s = Increase in length from stress increase (in)
- X = Thermal expansion coefficient per (° F)
- Δt = Change in temperature between stringing temperature and loaded temperature (° F)
- ΔL_t = Decrease in length from temperature decrease (in)

IN FORMULAS BELOW

$$T = \frac{w_c L^2}{8d} \dots \dots \dots (1)$$

$$\Delta L = \frac{8d^2}{3L} \times 12 = \frac{32d^2}{L} \dots \dots \dots (2)$$

$$D_n = D_c + (2 \times \text{ice thickness}^a) \dots \dots (3)$$

^aIce thickness from NESC table 250-1

$$w_h = \frac{WD_n}{12} \dots \dots \dots (4)$$

$$w_i = \frac{\pi}{4}(D_n^2 - D_c^2)I_w \dots \dots \dots (5)$$

$$w_v = w_c + w_i \dots \dots \dots (6)$$

$$w_{c1} = (w_v^2 + w_h^2)^{1/2} + k \dots \dots \dots (7)$$

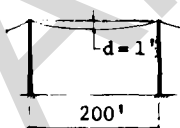
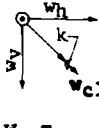
$$\Delta T = T_1 - T_s \dots \dots \dots (8)$$

$$\Delta S = \frac{\Delta T}{A_c} \dots \dots \dots (9)$$

$$\Delta L_s = \frac{\Delta S(12L)}{E} \dots \dots \dots (10)$$

$$\Delta L_t = X(\Delta t)(12L) \dots \dots \dots (11)$$

EXAMPLE FOR HEAVY LOADING DISTRICT

INITIAL CONDITIONS	FINAL LOADED WEIGHT	FINAL LOADED CONDITIONS
Primary #4/0 AWG ACSR $D_c = 0.563$ in $A_c = 0.194$ in ² $w_c = 0.291$ lb/ft $E = 11.5 \times 10^6$ $X = 10.5 \times 10^{-6}$ 60° F stringing temperature 	 $w_h = \frac{4[0.563 + (2 \times 0.5)]}{12}$ $w_{c1} = 0.521$ lb/ft..(3),(4) $w_v = 0.291 + \frac{\pi}{4}(1.56^2 - 0.563^2)(0.396) = 0.952$ lb/ft(5),(6) $w_{c1} = (0.952^2 + 0.521^2)^{1/2} + 0.30 = 1.38$ lb/ft (7)	$T_1^a = \frac{(1.38)(200)^2}{8(2.06)} = 3,350$ lb...(1) $\Delta T = 3,350 - 1,455 = 1,895$ lb..(8) $\Delta S = \frac{1,895}{0.194} = 9,773$ lb/in ²(9) $\Delta L_s = \frac{9,773(12 \times 200)}{11.5 \times 10^6} = 2.04$ "..(10) $\Delta L_t = 10.5 \times 10^{-6}(60 - 0)(12 \times 200) = 1.51$ "(11) Loaded $\Delta L = 2.04 - 1.51 + 0.16 = 0.69$ " Check: $\Delta L = \frac{32(2.06)^2}{200} = 0.68$ "...(2) ^a The value 2.06 in the formula was assumed
Rated breaking strength of conductor = 8,350 lb NESC requirement for maximum load = 8,350 x 60% = 5,190 lb 3,350 lb (1) < 5,190 lb		

^{to} Courtesy of **Keller & Gannon**

Figure 6-1. An Example of an Aerial Conductor Strength Analysis.

by the Host Command coordinated with the Requiring Command (HOST/REQ CMD).

(4) Aluminum conductors shall be terminated in compression type lugs or connectors filled with a high temperature oxide inhibitor compound.

6-4. Poles.

a. *Types.* Solid wood poles will be used for electric distribution lines, while concrete and steel poles will be used for roadway or area lighting circuits carried underground or separately from distribution lines. Concrete or steel poles may be justified for medium-voltage distribution circuits where wood poles do not provide adequate strength, or where climatic conditions cause wood poles to deteriorate rapidly. Laminated wood poles will not be used for electric distribution lines. However, in some instances the surrounding environment may make their installation appropriate for roadway and area lighting applications.

(1) *Wood poles.* Solid wood poles are covered by ANSI 05.1. Pole strengths are designated by classes 1 through 10 for normal strengths and H1 through H6 for higher strengths. These classes establish pole circumference limitations for each class and species of wood.

(2) *Concrete poles.* Normal reinforced concrete poles are not strong enough for the wind and ice loads which prevail in some areas. Either centrifugally spun or cast, prestressed concrete poles are acceptable, but special pole design, based on calculations of pole loads, will be necessary to assure adequate strength. Where strength requirements dictate excessive concrete pole diameters, steel poles will be used.

(3) *Tapered tubular metal poles.* Galvanized steel poles are covered by AASHTO LTS-2, but no classes are given. Aluminum poles are not acceptable, since corrosion may be a problem and aluminum poles do not provide adequate strength.

b. *Lengths and strengths.* Pole lengths will be selected conservatively, making allowance for the installation of communication lines and the required pole setting depth. Communication space will include allowance for telephone lines, and may include allowance for fire alarm, television, or other signal circuits as required. If at the time of design, exact requirements cannot be determined, a 2-foot space allocation is ample and will be provided on all poles even though present plans do not include telephone lines. Longer poles will be provided in areas where the future installation of additional electric circuits and equipment can be reasonably expected. Pole strengths will meet the NESC requirements for grade "B" construction for the applicable loading district. Since the normal maintenance activity does not have the financial or personnel capabilities of a utility, it may be necessary to use pole strengths greater than code minimums. Table 6-4 indicates pole lengths and classes (strengths) which are considered the minimum for normal use. Poles less than 40 feet in length, or classes 6 through 10, will not be installed for medium-voltage lines. The required pole embedment is dependent upon the loading district and upon soil conditions. A pole length and strength calculation is shown on figure 6-2.

c. *Pole-setting depths.* In normal firm ground, minimum pole-setting depths will be as shown in table 6-5. In rocky or swampy soil, pole-setting depths will be decreased or increased accordingly.

Table 6-4. Minimum Primary Wood Pole Lengths and Classes

Length feet	Class
40	4 or 5
45	3 or 4
50	2 or 3

Table 6-5. Minimum Pole-Setting Depth.
(Feet and Inches)

Pole Length (Feet)	Straight Pole Lines	Curves, Corners, and Points of Extra Strain	Pole Length (feet)	Straight Pole Lines	Curves, Corners, and Points of Extra Strain
20	5-0	5-0	65	8-6	9-0
25	5-6	5-6	70	9-0	9-6
30	5-6	5-6	75	9-6	10-0
35	6-0	6-0	80	10-0	10-6
40	6-0	6-6	85	10-6	11-0
45	6-6	7-0	90	11-0	11-6
50	7-0	7-6	95	11-6	12-0
55	7-6	8-0	100	12-0	12-6
60	8-0	8-6			

6-5. Circuit Configurations.

Preferred and alternate configurations for tangent construction are shown on figure 6-2. Also shown on this figure are methods of mounting overhead ground wires and locations for primary neutrals when required. Insulation shown on the figures in this chapter is for a nominal 15 kV class.

a. *Medium-voltage circuit configurations.* Armless and crossarm mounting, shown in figures 6-3 and 6-4 respectively, are both used for open conductors. REA Bulletin 61-12 provides additional details on armless construction. Triangular tangent construction requires the least pole space and is the most economical. Where such a configuration is not suitable, because of special requirements such as the need for an overhead ground wire, vertical tangent construction will be provided. Requirements for overhead ground wires are covered in chapter 9. Crossarm construction as shown on figure 6-4 will be limited to equipment installations, or where use of armless construction would result in excessive pole heights. However, other technical considerations, such as a line with many taps, crossings, or overhead-to-underground transitions, may impact the decision. Also, armless construction requires bucket trucks for maintenance due to loss of climbing space.

(1) *Angles at which guying is required.* Guying requirements for other than in-line circuits are dependent upon the angle of deviation, the size of the conductor, and the loading district. REA pole details show guys for angles of deviation greater than two degrees on armless construction configurations, regardless of conductor size or loading. Local practice may permit larger angles for smaller conductors or vertical construction, but any pole where the angle of deviation of the line exceeds five degrees will be guyed. This requirement applies both to armless and crossarm construction.

(2) *Angles at which changes in configurations apply.* The degree to which the more rigid line-post or pin type insulator support can be used will also vary dependent upon the angle of deviation and the size of the conductor. Suspension insulators

can be used for any angle, but are a more expensive installation; therefore, their use will be required only when the line-post or pin type is unsuitable. Normal angles for armless configurations are shown on figure 6-3 and are in agreement with REA pole detail drawings. Table 6-6 indicates normal angles for crossarm configurations related to conductor size.

b. *Low-voltage circuit configurations.* Low-voltage circuits will be supported by clamping the bare neutral conductor of a neutral-supported secondary aerial cable to a spool/clevis insulator assembly as shown on figure 6-5 or by use of spool insulators on secondary racks supporting insulated phase and neutral conductors. Because of both the space requirements and the unattractive appearance, phase conductors supported on secondary racks will be limited to special circumstances.

6-6. Insulators.

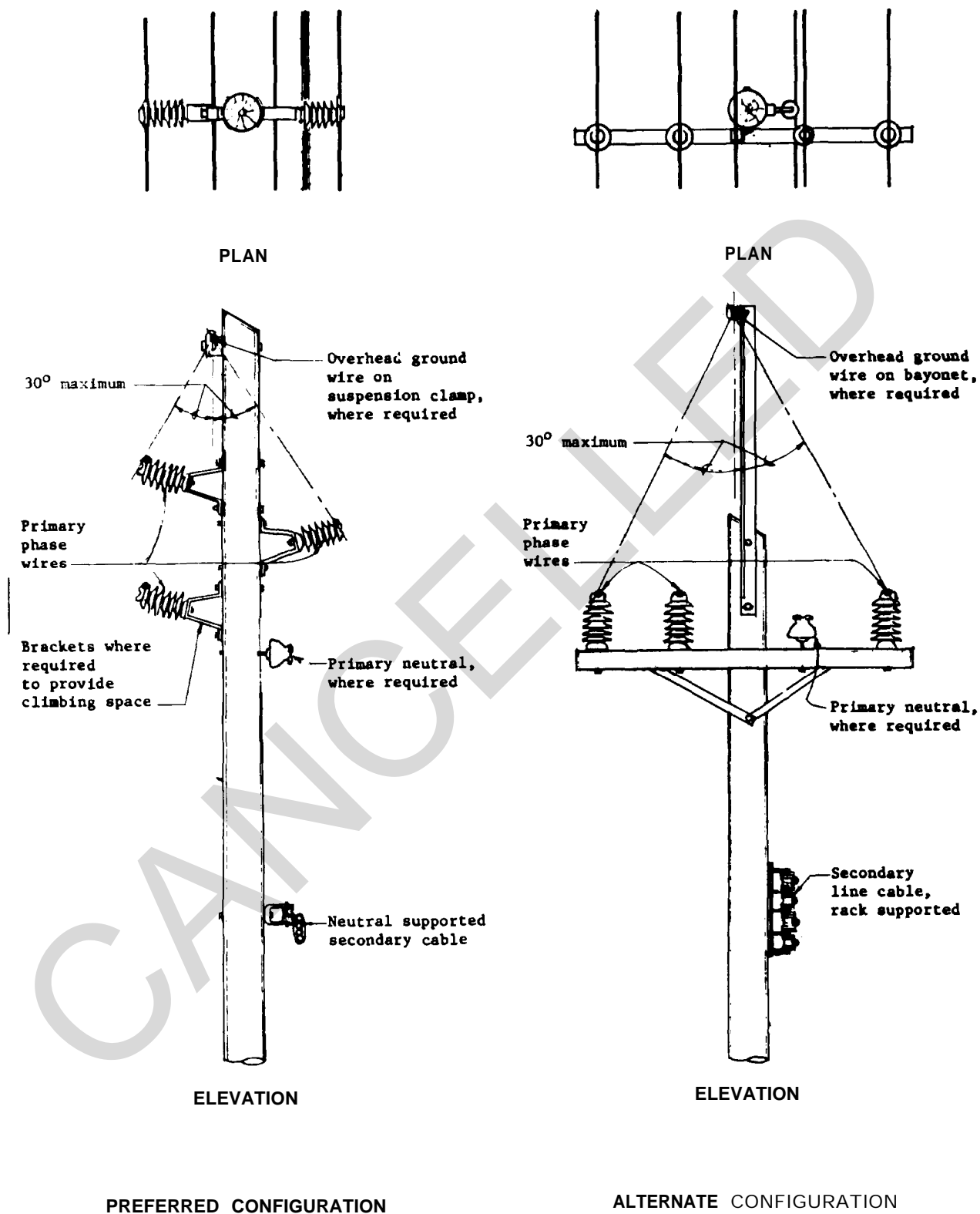
The operating performance of aerial lines is dependent upon the quality of the line insulators. Insulators will be of the wet process porcelain type; the only presently acceptable alternative in an appropriate situation is toughened glass, which is an industry standard only for suspension insulators. Glass is much more susceptible to shattering than porcelain; so where vandalism is a problem, glass will not be permitted. Polymer insulators have some advantages such as light weight and resistance to vandalism; once industry standards are issued, use of polymer units may be considered. Insulators need to provide ample mechanical strength for the expected ice and wind loads and must be capable of withstanding the stresses of lightning and switching surges without damage to the insulators. Operating stresses are increased under atmospheric conditions which causes pollutants to build up on the insulator surface. Various types of insulators are manufactured to meet requirements imposed by different applications. Each type is industry rated by ANSI in classes which establish dimensions and minimum electrical and mechanical performance values.

a. *Types.* Pin-type, line-post, or suspension insulators will be used for medium-voltage circuits;

Table 6-6. Relation of Crossarm Configuration to Conductor Size.^a

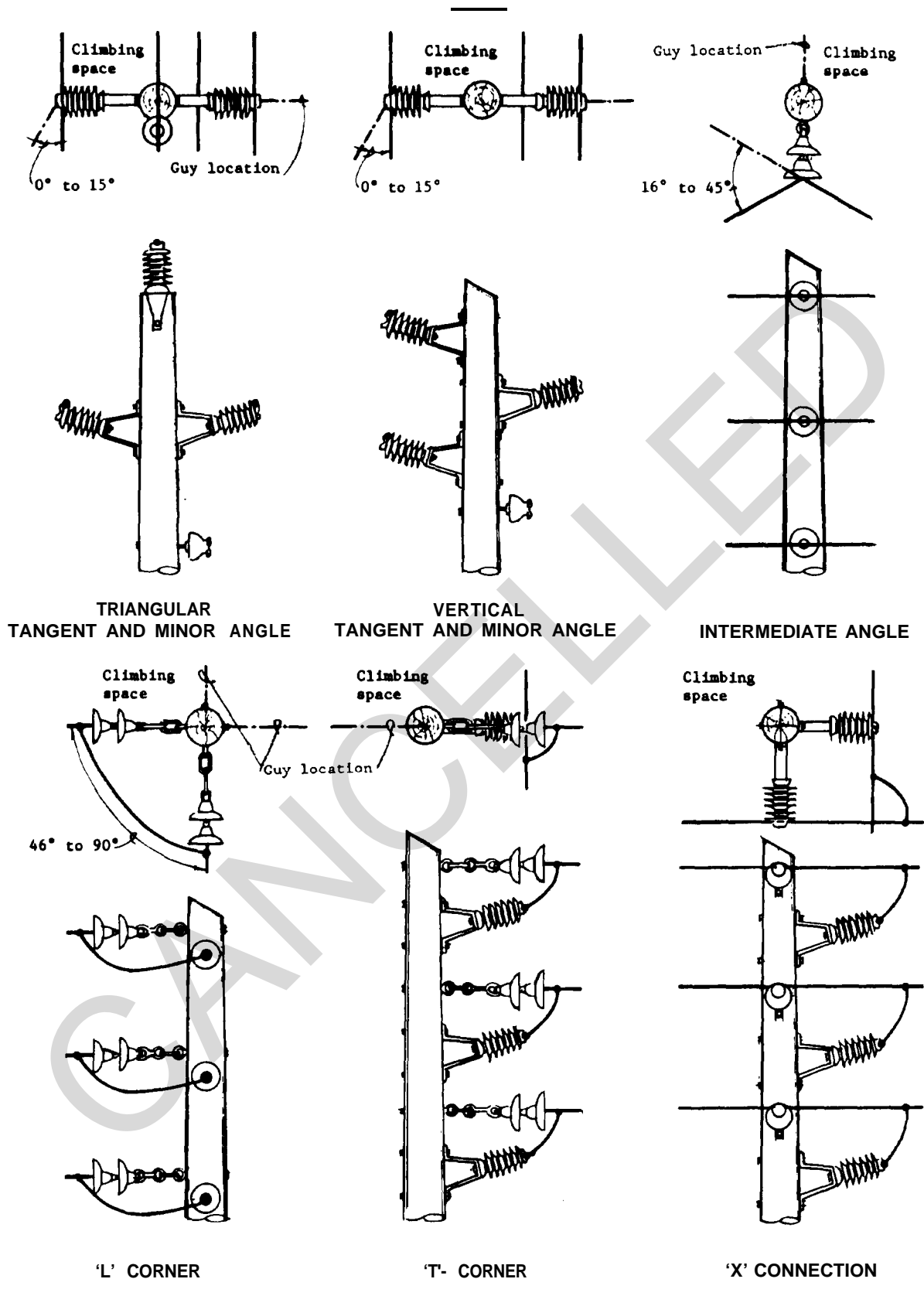
Maximum conductor size AWG	Tangent angle "A" degree	Minor angle "B" degree	Intermediate angle "C" degrees
4/0.....	0-1.....	2-4.....	5-45
1/0.....	0-3.....	4-8.....	9-45
2.....	0-5.....	6-12.....	13-45
6.....	0-11.....	12-24.....	25-45

^aCredit: US Corps of Engineers. Angles "A", "B", and "C" are shown on figure 6-3.



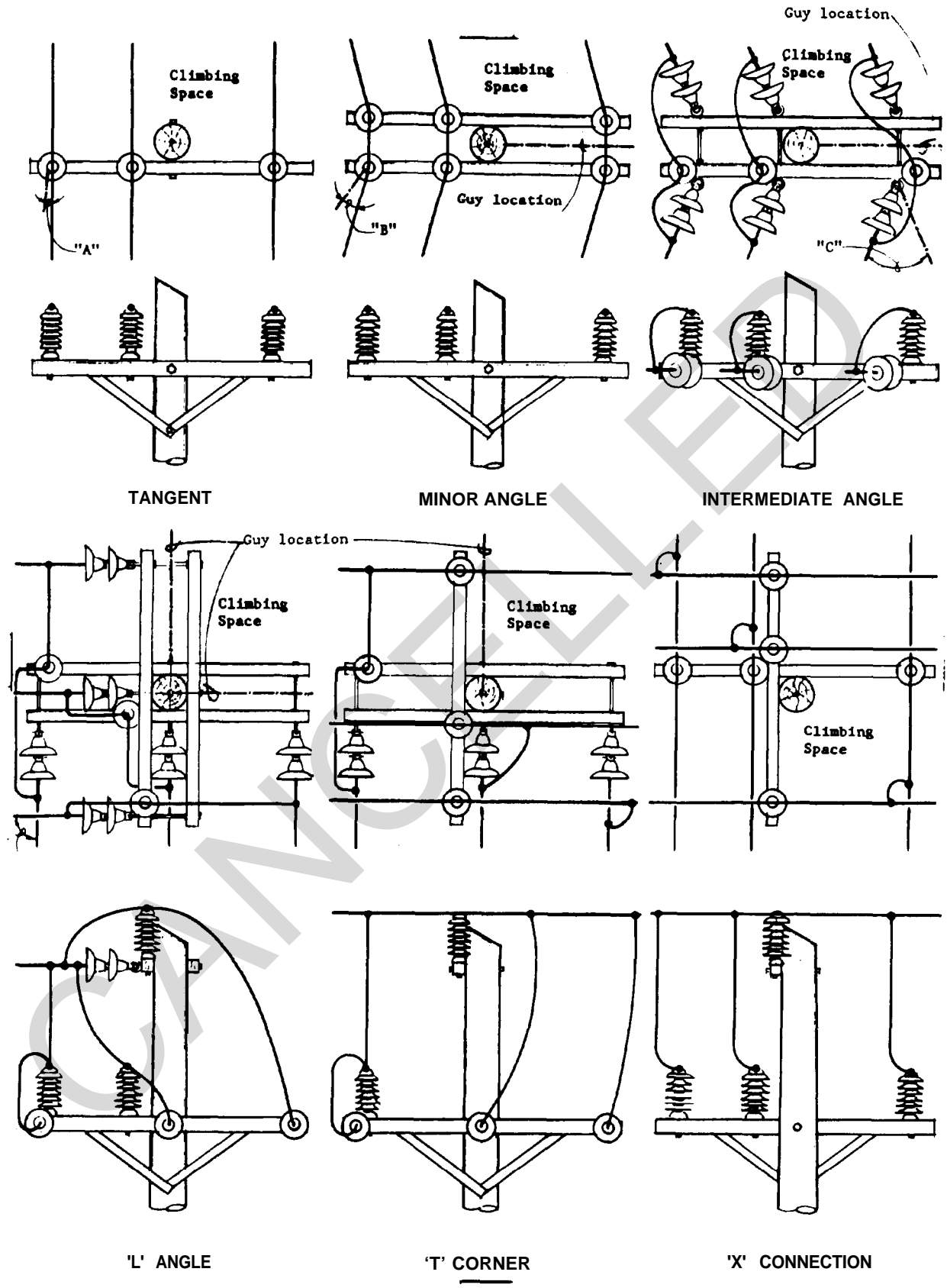
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Figure 6-2. Tangent Construction Configurations.



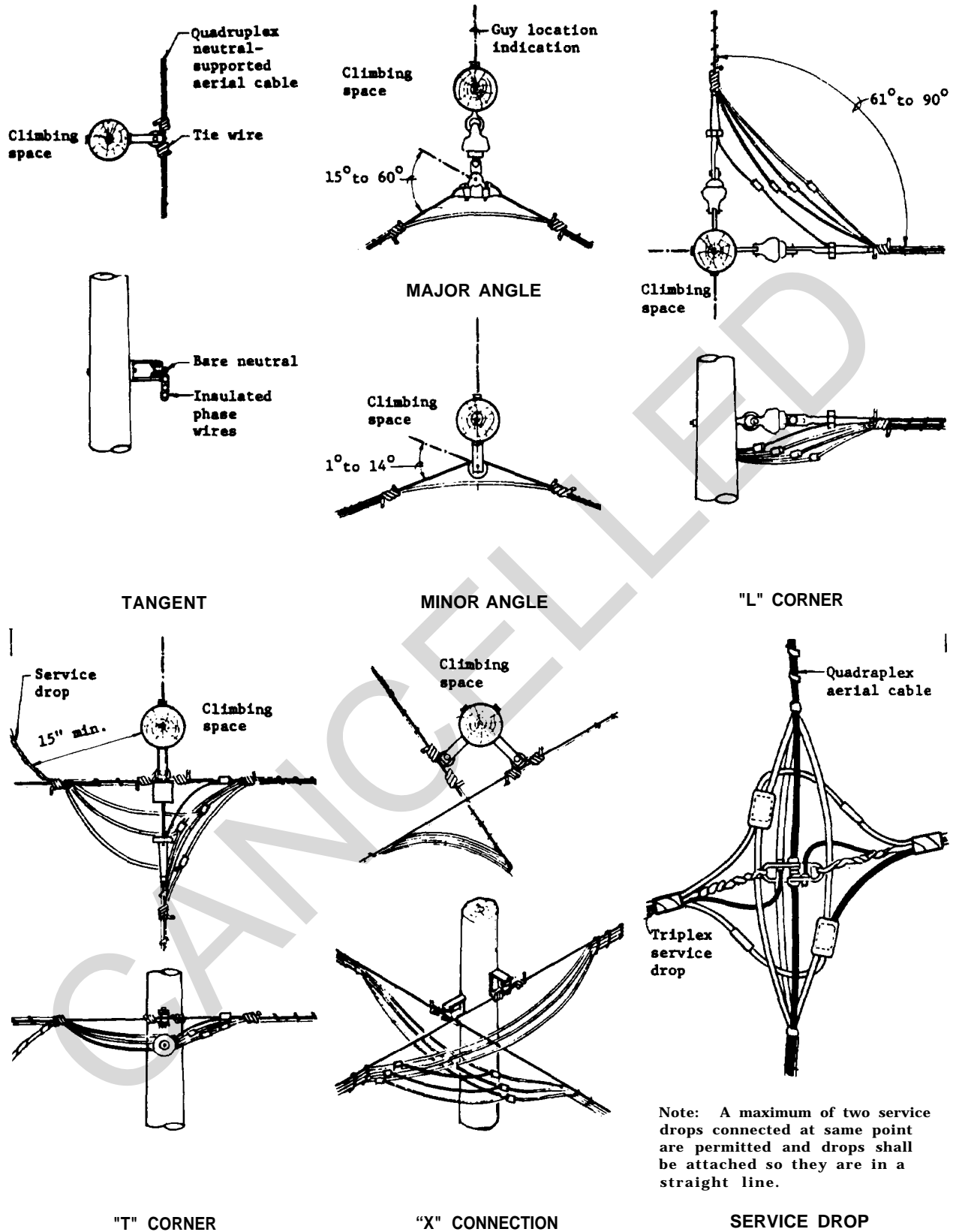
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Figure 6-3. Armless Configurations.



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Figure 6-4. Crossarm Configurations.



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Figure 6-5. Neutral-Supported Secondary Cable Configurations.

spool insulators for low-voltage circuits; and strain insulators for insulating guy wires. In crossarm construction, pin insulators may be used as a designer's option, but line-post insulators are superior in operation to corresponding pin types since line-post units are stronger, more resistant to vandalism, and inherently more radio-interference-free.

b. Classes. Selection of the class used is dependent upon operating voltage, strength requirements, and the degree of atmospheric pollution. Long periods without rain to wash off insulator contamination tend to aggravate the pollutant buildup problem. Selection of suitable insulator ratings will be based on local practice. Where lines are to be constructed on existing Government installations, that installation's experience or that of the serving utility will determine the insulation level used.

c. Dimensions. Figure 6-6 indicates dimensional ranges of insulators used. ANSI suspension Classes 52-3 and 52-4 have the same electrical, mechanical, and overall dimensions; but Class 52-3 has a ball-and-socket connection and Class 52-4 has a clevis eye connection. Selection of the type of connection provided is a matter of designer preference. Line-post insulators shown are either tie-top or clamp-top. The only difference between Class 57-1 and Class 57-11 is that Class 57-1 denotes a tie-top and Class 57-11 denotes a clamp-top. Tie-tops can be used for angles up to two degrees and clamp-tops are necessary for angles greater than fifteen degrees. For angles of three degrees to fifteen degrees, choice will be dependent upon mounting and loading requirements. Tie-top units are less expensive in cost, but a clamp-top eliminates both material and labor costs for the tie wire thus providing ease of installation. Where horizontal mounting is required there is, at present, no ANSI class; specifications therefore will indicate electrical, mechanical, and overall dimensions are the same as for the appropriate 57 subclass. Insulators with short studs (S) are used on armless configurations; those with long studs (L) are used on wood crossarm configurations.

d. Colors. Insulator colors available are brown and light gray. Light gray insulators will be used; however, in wooded areas or where lines are seen principally against hillside or tree-covered backgrounds, the brown glaze may provide a more acceptable appearance.

6-7. Guying.

Particular care will be taken to ensure that all points of strain in the pole lines are adequately guyed. Improperly or inadequately guyed lines

soon begin to sag, degrading the reliability of the line as well as creating an unsightly installation and increased maintenance.

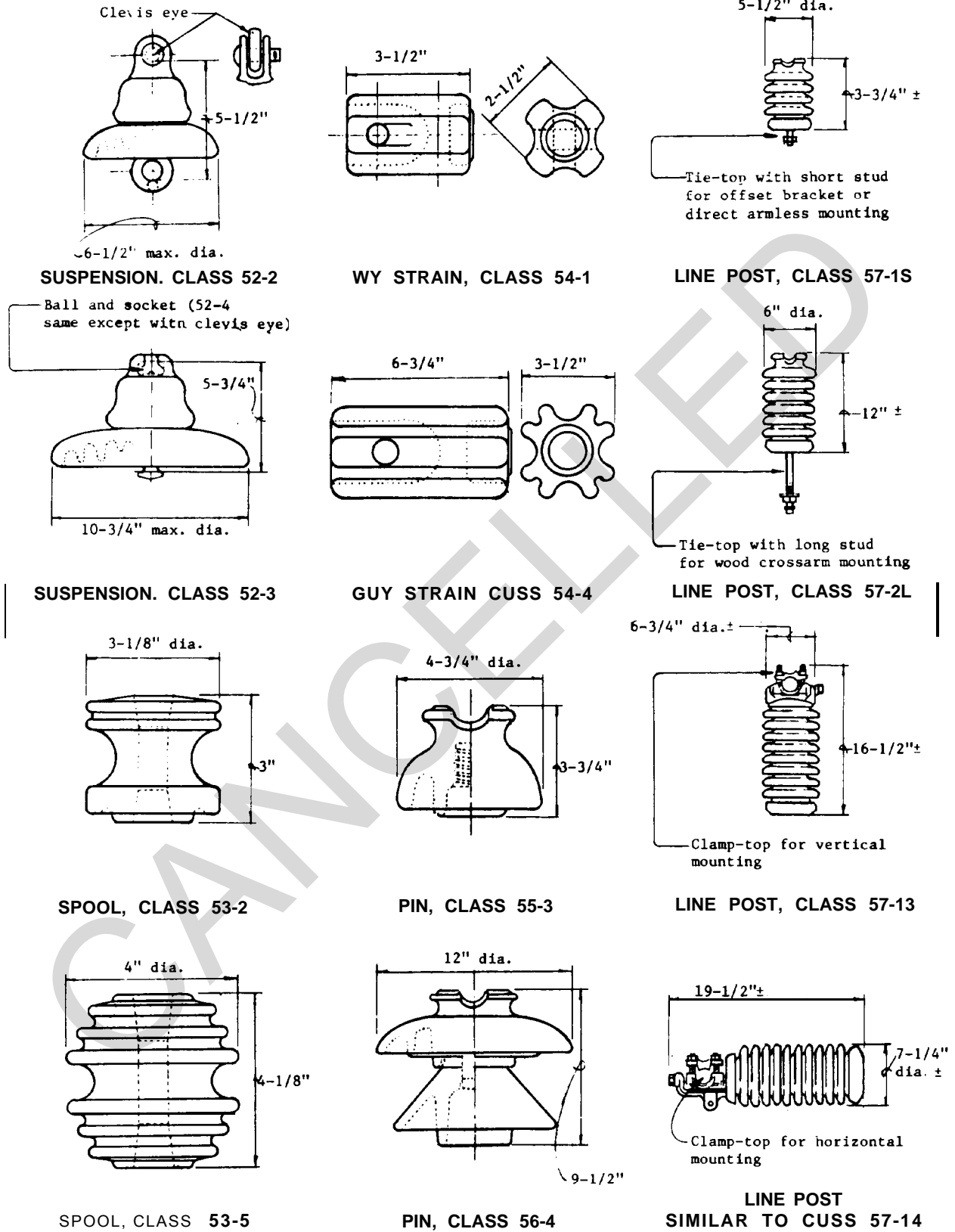
a. Components. A guy installation consists of various components as follows:

(1) *Guy wire (strand).* The strength of a guy installation is a function of the guy wire, the anchor, and the soil type. The rated breaking strength of the guy wire determines the requirements for all other components. Wire of either three or seven strands will be used. Each strand consists of a steel core having a protective coating of zinc, copper, or aluminum. Zinc coatings are available in standard ASTM coating weights. A Class A coating weight is half of a Class B coating weight and a third of a Class C coating weight. The coating weight used is dependent upon atmospheric corrosion with Class A used in dry or desert areas with little industrial contamination, Class C used in salt-laden or foggy areas or heavily contaminated locations, and Class B used elsewhere. Rated breaking strength used will be not less than 6,000 (6M) pounds. No more than two strengths of guys should be used for any one project. All guys will be sized for the maximum loading tension of the line.

(2) *Grounded guys.* Conductive poles such as steel or concrete, poles with overhead grounding conductors, and poles with guys connected to primary neutrals are considered grounded, since insertion of guy strain insulators does not isolate any portion of the pole from the ground.

(a) Connection to primary neutrals. For some installations, connection of primary neutrals to guys can improve secondary equipment protection. A detailed discussion of why this improvement is effected is given in REA Bulletin 83-1 which also covers the influence of such grounding on anchor rod corrosion. For other installations, such a connection may not meet local code requirements or will not be possible when the installation does not have a primary neutral system.

(b) Anchor corrosion. Corrosion can be a problem in systems that have primary neutrals interconnected with grounded guys when such systems are installed in areas having a low soil resistivity and a low ratio of buried steel to buried copper. In such cases, anchor rods and grounding electrodes will be of the same composition, either both of galvanized steel or both of copper-clad steel. The first installation is less expensive, but also provides more resistance. Choice of the anchor composition will be based on soil composition, resistivity, and corrosion properties. In highly corrosive soil conditions, anchor life has been extended by installing guy strain insulators in the



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Figure 6-6. Ranges of Insulator Dimensions.

guy wires. This isolates the anchor from the copper grounding systems installed at the poles. Furthermore, sacrificial magnesium anodes attached to the anchors may be cost effective.

(c) *Grounding conductors and guy wires.* Grounding conductors will always be copper regardless of the type of electrodes used. Guy wires will be of the same composition as electrodes and will be bonded to the hardware grounding conductor with approved clamps.

(3) *Nongrounded guys.* Where guy strain insulators are installed in a guy, to provide sectionalizing of grounded portions from nongrounded portions, that guy is considered ungrounded. Strain insulators will be provided in all guys on woodpoles, except where grounded guys are required or where local code requires sectionalizing in higher voltage lines.

(a) *Strain insulator location.* Insulators will be located in accordance with the NESC and so that in the event a guy wire is broken, the uninsulated upper portion of the guy wire cannot swing to any point less than eight feet above the ground. Insulators will be located at least six feet horizontally from the pole, which will provide separation between a lineman and the grounded guy wire segment. Where guy wires pass through line conductors or can fall on line conductors,

additional insulators may be required.

(b) *Strain insulator ratings.* Ratings and strengths of insulators will be suitable for the circuit insulated. Since the maximum available ANSI guy strain insulator strength is 20,000 (20M) pounds this requirement could limit nongrounded guy strengths to 20M and may require two or more downguys if more than a 20,000 pound pull is necessary. Stronger insulators, which are not ANSI listed, may be used also.

(4) *Anchors.* The type of anchor used must provide suitable resistance to uplift and therefore is dependent upon soil conditions. Table 6-7 indicates suitable anchor types based on a range of soils from hard to soft. While the soil descriptions are not an industry standard, manufacturers are familiar with this or similar classifications. For the majority of cases, the most suitable anchor is an expanding type as shown on figure 6-7, because most lines are installed in ordinary soils. Strengths for available sizes of expanding anchors are also shown on figure 6-7. Rock or swamp anchors are described in manufacturer's catalogs. In the past, log anchors consisting of 8-inch to 12-inch diameter by 4-foot to 5-foot long creosoted logs, have been used in marshy soil. Since log anchors tend to rot, no matter how well creosoted or otherwise treated, their use is prohibited. Ex-

Type of anchor	General type	No.	Classification description
Rock	Hard	1	Solid bedrock
		2	Dense clay; compact gravel; dense fine sand; laminated rock; slate; schist; sandstone
		3	Shale; broken bedrock; hardpan; compact clay-gravel mixtures
Expanding	Ordinary	4	Gravel; compact gravel and sand; claypan
		5	Medium-firm clay; loose sand and gravel; compact coarse sand
		6	Soft-plastic clay; loose coarse sand; clay silt; compact fine sand
Swamp or as suitable	Soft	7	Fill; loose fine sand; wet clays; silt
		8	Swamp; marsh; saturated silt; humus

* Based on copyrighted data, courtesy of A. B. Chance Company, Centralia, Missouri and reprinted with its express written permission.

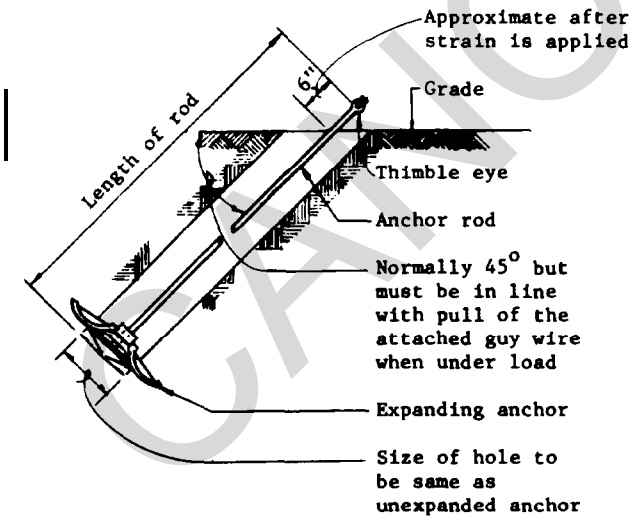
Table 6-7. Anchors Suitable for Various Soils.

panding anchors, with extra long anchor rods reaching firm underlying soil, may be acceptable in some cases. Multihelix screw anchors can also be installed in swampy soils when this type of anchor can provide the required holding power. Three-eye thimbles will be provided on all anchor rods. This permits use of individual down guys for primary, secondary, and communication circuits and anchors must provide adequate strength to support all of these loads.

(5) *Rod assemblies.* Rod assemblies must meet ANSI C135.2 tensile loading tests. A 5/8-inch diameter rod is rated at about 16,000 pounds breaking strength, a 3/4-inch diameter rod is rated at about 23,000 pounds, and a 1-inch diameter rod is rated at about 36,000 pounds, but some manufacturers offer a 3/4-inch diameter rod rated

Ratings ^a			
Holding power in ordinary soil pounds	Minimum anchor area square inches	Minimum rod diameter inches	Minimum rod length feet
6,000	90	5/8	7
8,000	100	5/8	7
10,000	120	3/4	8
12,000	135	3/4	8

^aFrom REA Bulletin 43-5.



Note: Projection of anchor rods above grade may be increased to a maximum of 12 inches in planting beds or other locations where necessary to prevent burying the eye.

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Figure 6-7. Expanding Anchor Details.

at 25,000 pounds and a 1-inch diameter rod rated at 40,000 pounds.

(6) *Guy markers.* The purpose of guy markers is to provide a substantial and conspicuous indication to pedestrians that an impediment to passage exists. Markers should be yellow to provide the greatest visibility, unless gray or other finishes are approved for the installation.

b. *Installation.* Guys are installed to balance line tensions and are therefore appropriate where lines begin, end, or where lines change direction.

(1) *Types.* Most installations utilize down guys, wherein the guy wire is led away from the pole at a 45 degree angle down to an anchor. Since this configuration can interfere with traffic, span or sidewalk guys may be necessary to shorten guy leads. Head guys will be provided at heavily loaded corners to reduce tension in a corner span and strain on the corner pole. Dead-end guys will be provided in long straight lines at not less than every 2,500 feet to limit the effects from line breaks. Storm guys will be provided in long straight lines at not less than every 5,000 feet to reinforce lines against storm effects. Various types of guys are shown schematically on figure 6-8. Figure 6-9 shows down and span guy requirements in more detail. Although several guys are shown on the down guy detail, a single guy is permissible when adequate holding strength is provided.

(2) *Guy lead angle and strength requirements.* A lead angle (lead) is the angle that a guy wire makes with the center line of the pole. As can be seen on figure 6-10, the greater the lead angle the larger the horizontal component and thus the lower the minimum breaking strength needed to provide the necessary holding capacity to balance conductor tension. However, for down guys, the greater the lead angle the more the guy interferes with other use of the space. Lead angles from 45 degrees (optimum) to 15 degrees (minimum) will be used to balance conductor tensions of 70 to 25 percent of the guy wire minimum rated breaking strength. Where clearances over pedestrian areas require sidewalk guys, the holding capacity will be greatly decreased because there is a bending moment on the pole at strut height; therefore, sidewalk guys will be installed only when no other method is feasible or the conductor tension is minimal. A computation for in-line guy strength requirements is shown on figure 6-10. Figure 6-11 gives an example of a pole strength analysis.

(3) *Bisect angle guys versus in-line guys.* The maximum permitted angle of line deviation for a single angle guy installation (one guy installed on the bisect of line angle) is 45 degrees. For greater

angles, a down guy installation in line with each direction of pull is required.

6-8. Miscellaneous Items.

a. *Pole line hardware.* Hardware will be of a type specifically developed for pole line installation in accordance with industry standards. All steel or wrought iron hardware will be hot-dip galvanized as specified in ANSI C135.1.

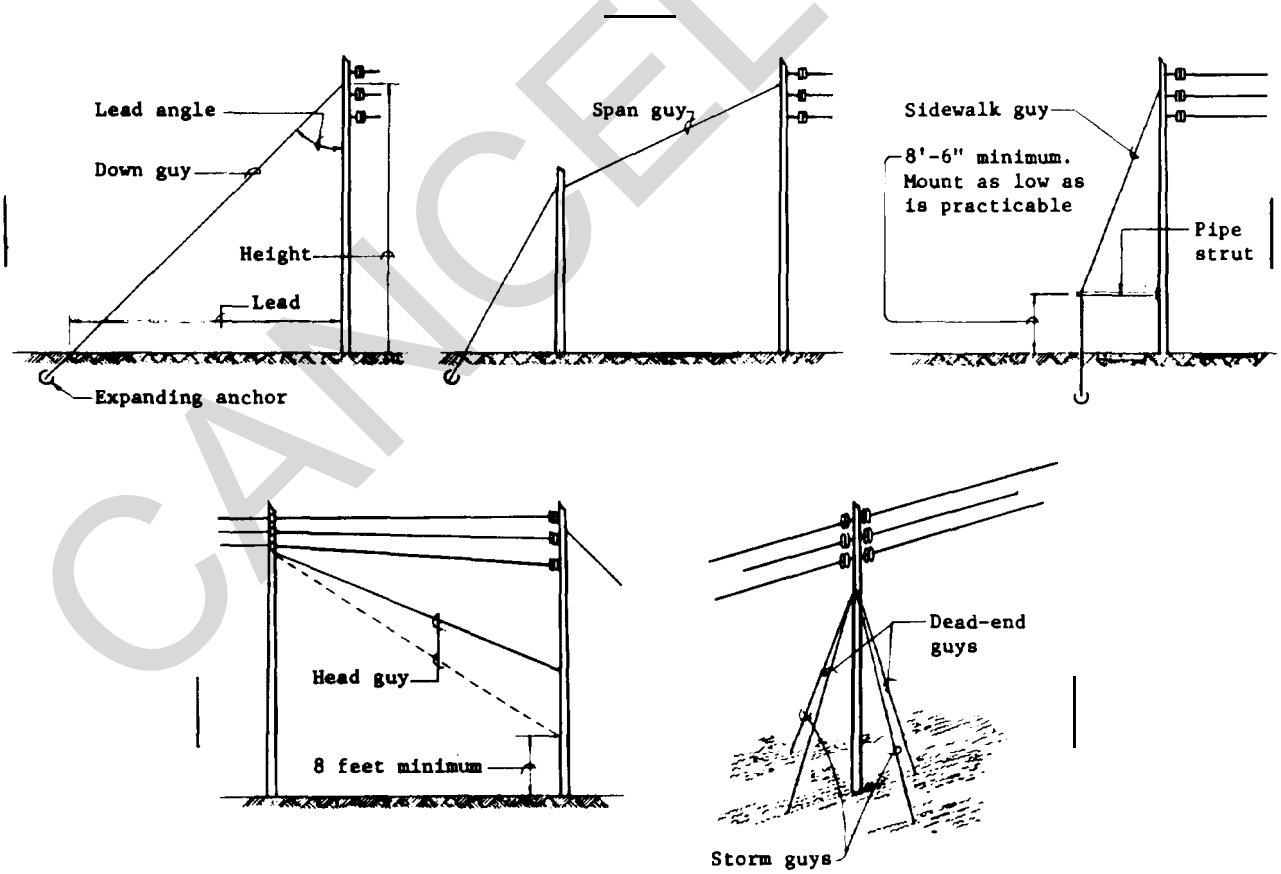
b. *Aerial line connector hardware.* Copper line connector hardware will be of copper alloys and aluminum line connector hardware will be of aluminum or aluminum-lined alloys. Since bolted line connectors aggravates the cold-flow tendencies of aluminum conductors and cause maintenance problems, other types of connections such as compression type will be used.

c. *Crossarms.* Laminated wood, synthetic materials, and channel iron brackets are occasionally used for equipment crossarm type supports; however, it is only for unusual installations that the use of anything other than solid wood crossarms can be justified. Flat braces will be specified for

8-foot crossarms and angle braces for 10-foot crossarms to agree with REA construction. An angle brace is also required on 8-foot arms where conductors having a breaking strength of more than 4500 pounds. Extreme loading conditions may also warrant the extra cost of the stronger angle brace under other circumstances. Metal cross-arm braces will reduce the effective BIL rating of the pole. In high lightning areas specify fiberglass braces.

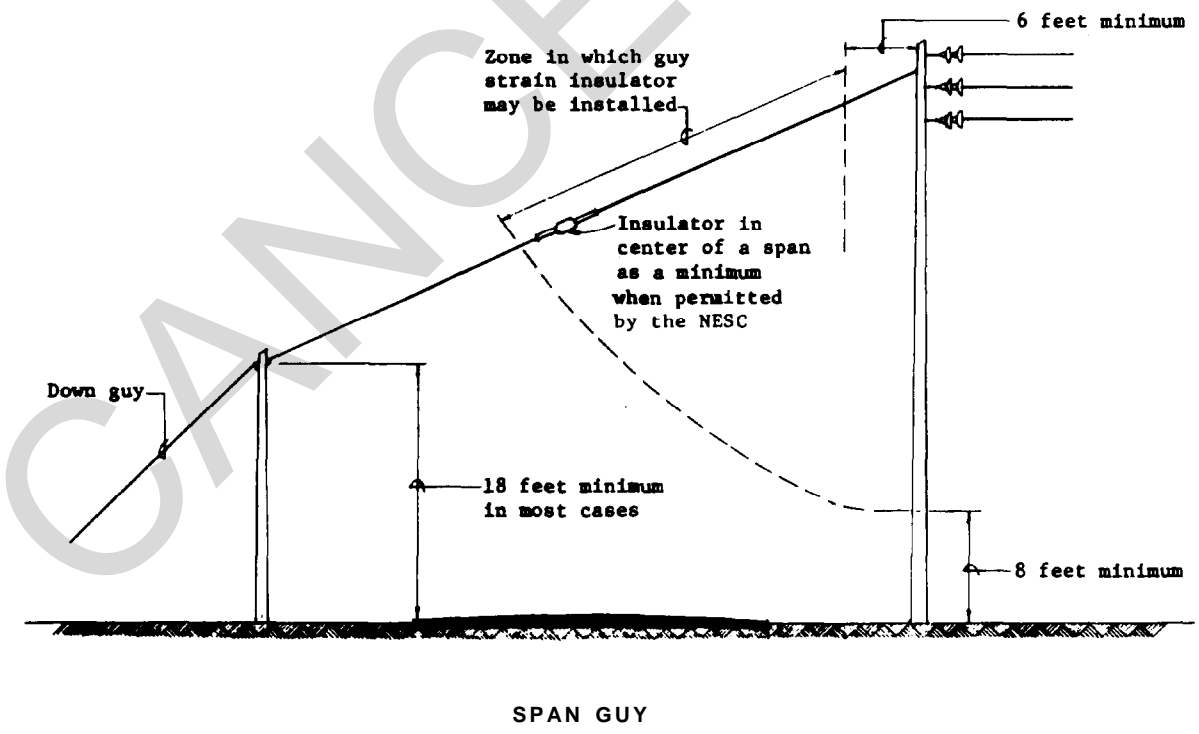
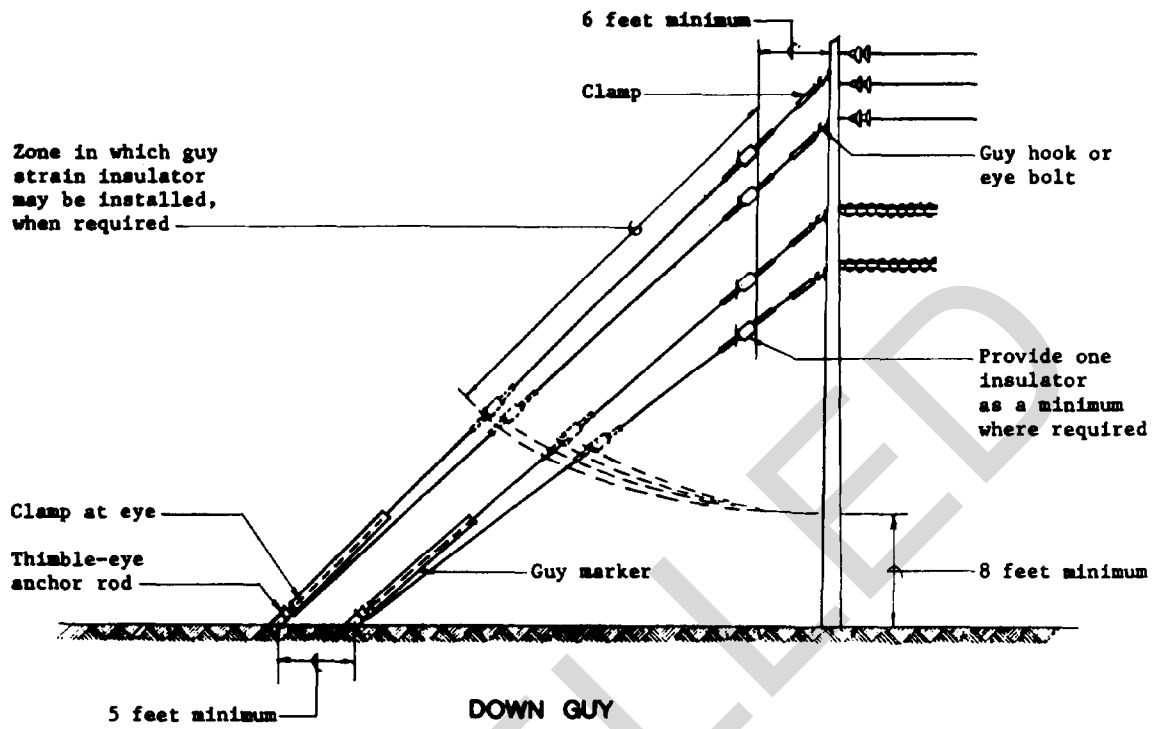
d. *Riser poles.* Conduits on riser poles should be equipped with bushings to protect cables where they exit the conduit and to minimize water entry.

e. *Fuse cutouts.* Selection of fuse cutout duty will be based on the voltage of the circuit and the continuous and interrupting current ratings necessary for equipment or feeder protection. Ratings for fuses, fuse cutouts, and fuse links will comply with IEEE Stds C37.42, C37.46, and C37.47. Enclosed fuse cutouts are available only for 5.2 kV and 7.8 kV ratings, but not for ultra heavy duty applications. Open fuse cutouts are available for ratings of 7.8 kV and higher.



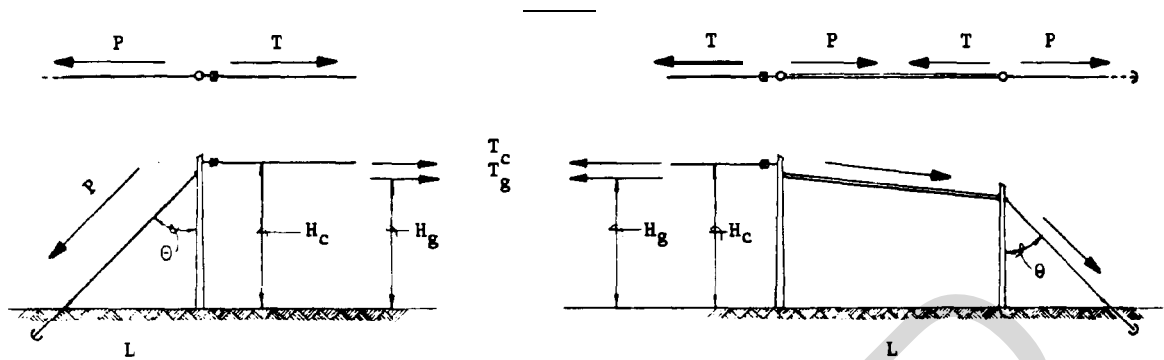
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Figure 6-8. Types of Guy Installations



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Figure 6-9. Guy Details.



USING VALUES BELOW

- L = Guy lead H_g = Guy attachment height H_c = Conductor attachment height
- θ = Lead angle, T_c = Individual conductor tension at point of pole connection
- T_g = Individual conductor tension at point of guy attachment
- T = Total of all conductor tensions at point of guy attachment
- P = Total pull on guy from all conductor tensions

IN FORMULAS BELOW

$$T_g = (T_c) \times (H_c/H_g) \tag{10-1}$$

$$T = T_{g1} + T_{g2} + T_{g3} + \dots \tag{10-2}$$

$$\theta = \text{Arc tangent } L/H_g \tag{10-3}$$

$$P = T/\sin \theta \tag{10-4}$$

APPLY NESC FACTORS

$$\text{Required guy strength} = (P) \times (\text{Overload}) \div (\text{Safety}) \tag{10-5}$$

EXAMPLE

Given: Three No. 1 AWG copper-equivalent ACSR conductors installed in a light loading district in a vertical configuration with the guy connected at a lead angle of 45° and at the same height as the center conductor.

Then: $T_c = 1,480$ pounds as given in table 6-3 (10-1)

$$T = 3 \times 1,480 \text{ pounds} = 4,440 \text{ pounds} \tag{10-2}$$

$$P = 4,440 \text{ pounds} \div 0.707 = 6,280 \text{ pounds} \tag{10-4}$$

$$\text{Required guy strength} = (6,280 \times 1.5) \div 0.9 = 10,466 \text{ pounds} \tag{10-5}$$

Use: 3/8 inch, 7 strand, utilities grade, zinc-coated, steel strand with a minimum breaking strength of 11,500 pounds (ASTM A 475)

^aCourtesy of Keller & Gannon

Figure 6-10. An Example of an In-Line Guy Strength Analysis.

USING VALUES BELOW

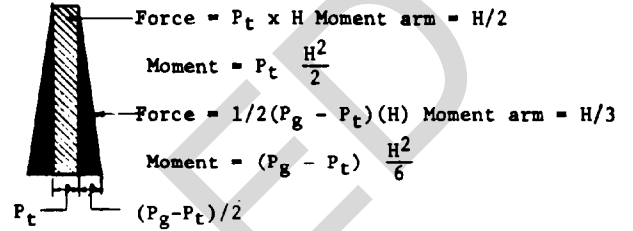
- D_c = Conductor diameter (in)
- D_n = Conductor plus NESC additional ice thickness requirement (in)
- W = NESC wind pressure requirement (lb/ft²)
- L = Length of pole spacing (ft)
- N = Number of conductors at same height above grade
- H_c = Height of conductor above grade (ft)
- M_c = Bending moment at base of pole from conductor (ft-lb)
- P_t = Wind pressure on pole at the top^a
- P_g = Wind pressure on pole at the ground^a
- C_t = Circumference of pole at top (in)
- C_g = Circumference of pole at grade (in)
- H_t = Height of top of pole above grade (ft)
- M_p = Bending moment at base of pole from wind on pole (ft-lb)
- S_m = Section modulus at base of pole (in³)
- O_f = Overload factor from NESC table 261-3
- F_s = Fiber stress in pole (lb/in²)

IN FORMULAS BELOW

$$D_n = D_c + (2 \times \text{ice thickness}^a) \dots (1)$$

^aIce thickness from NESC table 250-1

$$M_c = \frac{D_n W L N H_c}{12} \dots (2)$$



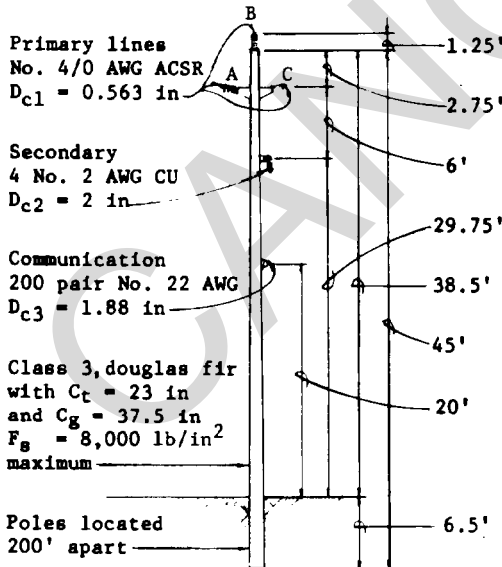
$$M_p = P_t \left(\frac{H^2}{2} \right) + (P_g - P_t) \left(\frac{H^2}{6} \right)$$

$$M_p = \frac{H^2 W}{72\pi} (2C_t + C_g) \dots (3)$$

$$S_m = \frac{\pi}{4} \left(\frac{C_g}{2\pi} \right)^3 = \frac{C_g^3}{32\pi^2} \dots (4)$$

$$F_s = \frac{12 (M_c + M_p) O_f}{S_m} \dots (5)$$

EXAMPLE FOR HEAVY LOADING DISTRICT



Check whether pole will carry load:

$$D_n = D_c + 2(0.5) \quad D_{n1} = 1.563'' \quad D_{n2} = 3'' \quad D_{n3} = 2.88'' \quad (1)$$

$$M_c = \frac{D_n^4 L N H_c}{12} = \frac{D_n L N H_c}{3} = \frac{(1.563)(200)(1)(39.75)}{3} + \frac{(1.563)(200)(2)(35.75)}{3} + \frac{(3)(200)(1)(29.75)}{3} + \frac{(2.88)(200)(1)(20)}{3} = 21,380 \text{ ft-lb} \dots (2)$$

$$M_p = \frac{H_t^2 (4)}{72\pi} (2C_t + C_g) = \frac{H_t^2}{18\pi} (46 + 37.5) = 2,190 \text{ ft-lb} \dots (3)$$

$$S_m = \frac{(37.5)^3}{32\pi^2} = 167 \text{ in}^3 \dots (4)$$

$$F_s = \frac{12 (21,380 + 2,190) \times 4}{167} = 6,775 \text{ lb/in}^2 \dots (5)$$

6,775 lb/in² < 8,000 lb/in²: pole will carry load

^a Lb per foot of circumferences

^b Courtesy of Keller & Gannon

Figure 6-11. An Example of a Pole Strength Analysis.

6-9. Air Force Installations.

a. Reclosers and sectionalizers. Reclosers and sectionalizers shall be fully rated and coordinated. Electronically controlled reclosers are preferred over hydraulically controlled ones. Reclosers may utilize vacuum or oil as the interrupting medium. Sectionalizers shall be automatic loadbreak, manual recock, and installed only as an integral part of the system protection scheme. They should not be installed for switching purposes only. Stirrups should be installed as appropriate to prevent damage to main conductors at junction poles.

b. Radio interference. Where suppression of radio interference is critical, special considerations shall be given to contacts between current carry-

ing conductors of dissimilar metals. The need for an interference-free environment may also necessitate the use of insulators coated or treated for radio noise suppression. Valve-type lightning arrester often cause radio interference and their use should be avoided. If required to suppress radio interference, utilize underground construction with transformers and equipment installed in grounded metal enclosures. High intensity discharge (HIS) lamps are also sources of high radio interference while filament lamps and low pressure sodium lamps are basically free of radio noise.

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

CHAPTER 7

UNDERGROUND DISTRIBUTION LINES

7-1. General.

Underground lines will be provided only in those areas as established in chapter 5. Underground line installation will be coordinated with the installation master plan to avoid conflict with construction of future facilities. Lines will normally be installed adjacent to roadways in urban, housing, or industrial plant areas, but may be routed as required to meet the project objectives. A careful study will be made of all underground utilities in order to ensure a minimum of interference between electrical lines and other underground utilities, whether existing, being constructed, or proposed as a definite future construction project. Electrical lines will be at least six feet from any steam or hot water lines, except at crossings where a one-foot separation from such lines is adequate.

a. Symbols and codes. For uniformity, symbols will comply with ANSI Y32.9. Installation will comply with the requirements of the NESC and the NEC as required. Where state safety rules are predominantly accepted, such rules may be used provided they are as stringent as those of the NESC.

b. Construction and other conditions. Typical underground construction details are shown later in this chapter. Service conditions are covered in chapter 1. Grounding and surge protection are covered in chapter 9. Other conditions will follow the guidelines established by the NESC, the Rural Electrification Authority (REA), or the local utility as applicable. Underground cable systems may employ manholes or above-ground sectionalizing and pulling cabinets depending on local geological conditions, potential for damage from vehicles and the required design life of the facility.

c. Air Force underground installations.

(1) *Secondary distribution.* All secondary underground cables may be installed in either concrete encased ducts or direct burial type ducts or conduit, or they may be direct burial type cables. Direct burial plastic conduit may be utilized when cable temperature conditions are within the conduit rating and where the conduit is not under large paved areas or building structures. Conductors shall be copper, although aluminum may be used in lieu of copper conductors No. 4 AWG and larger.

(2) *Primary distribution.*

(a) 5,000 volts or less-copper, single or

multiple conductor, metallic or non-metallic sheathed. Nonmetallic sheathed cable 2,000 volt to 5,000 volt rating shall be shielded.

(b) Above 5,000 volts-copper, metallic, or non-metallic sheathed, single or multiple conductor, shielded cable.

(c) Aluminum conductors of equivalent ampacities may be used in lieu of No. 4 AWG copper and larger copper conductors.

(d) Aluminum conductors shall be terminated in compression type lugs or connectors tilled with high temperature, oxide inhibitor compound.

(3) *Cable installation.* All primary underground cables shall be installed in concrete encased non-metallic ducts or concrete encased galvanized rigid steel conduits except as follows. Steel conduit, which is not concrete encased, shall be corrosion proof-coated (PVC, etc.) and shall be employed only for short runs between buildings or under paved areas. Direct buried ducts or direct buried cables may be employed for primary distribution (above 600 V) feeders located in areas which are remote to normal pedestrian and vehicle traffic. Consider using a direct buried, flexible polyethylene cable, duct type conduit with self contained cable to allow easier replacement. Concrete markers shall be provided at approximately 200 foot intervals and at each change in direction to indicate the location of underground cable route. Direct buried cable or cable duct, which is not concrete and metallic conduit encased, should be marked with a metallic/magnetic warning tape buried six to twelve inches below the surface and above the cable or duct. Cable warning tape shall be red or orange in color.

7-2. Cable.

Conductor material and insulation type will be specified. Restricting extensions of existing systems to a specific conductor material and insulation type in order to match an existing cable type is permitted only when a need has been established. Neutral cables, where required, will be installed with 600 V insulation unless concentric neutral cable is used. In duct lines, neutrals will be installed in the same conduit with associated phase cables.

a. Conductor material. Since underground conductors are continuously supported, soft-drawn copper or aluminum alloy 5005 provides adequate strength. However, the selection of copper or alu-

minimum will be justified based upon an analysis using life, environmental, and cost factors. The need for mechanical flexibility requires that conductors be stranded, and the NEC makes this mandatory for cables larger than No. 8 AWG installed in raceways. The installation of conductors larger than 500 kcmil is not economical, and such large cables should be used only under exceptional circumstances. Large ampacities can be served by parallel or multiple circuits. Three 15 kV, single-conductor, nonmetallic-jacketed cables larger than No. 4/0 AWG will require use of ducts larger than the standard four-inch size (i.e. three single-conductor cables making up a three-phase circuit and each having individual overall diameters greater than 1.25 inches will need to be installed in a duct larger than four inches). One three-conductor cable is more costly than three single-conductor cables, and use of multiple-conductor cable will be restricted to special conditions. Metallic-armored cable is such a special condition.

b. Insulation and jacket material. The type of insulation used will be dependent upon the voltage level and type of service required. Factors affecting selection will be the effects of the surrounding environment, the importance of the load in regard to operation of the installation, and whether peak loading is continuous or intermittent.

(1) *Medium-voltage cable.* Cable will be specified as 133 percent insulation level (ungrounded) which allows greater margin for voltage surges, insulation deterioration, and fault clearing time than does the use of the 100 percent insulation level (grounded). When marking guide specifications, refer to NFPA 70, which currently limits the minimum size to No. 1 AWG at 133 percent insulation for 15 kV to 28 kV systems and No. 2 AWG at 133 percent insulation for 8 kV to 15 kV systems. Medium-voltage cable above 3 kV will be shielded.

(a) Nonmetallic-jacketed cable. Nonmetallic-jacketed cable will be used, except where circumstances warrant other coverings. Insulation will be either crosslinked-polyethylene (XLP) for short life requirements, or ethylene-propylene-rubber (EPR) for long life requirements, in accordance with NEMA WC-7 and WC-8. Comparisons of various cable insulations, as shown in table 7-1, indicate the advantages of these two insulations over other types. Coverings (jackets) will be any of the rubber or plastic options covered by NEMA specifications. This option allows the use of cables which are available as stock items in small quantities. In some environments, however, selection of other jacket materials may be necessary because properties of some jacket materials may not provide

adequate cable protection. Special shielding or coverings will not be specified, unless the designer has checked that the footage installed for each different cable diameter is large enough for manufacturers to make the special runs required.

(b) Metallic-armored cable. Armored cable is justified only when cable is installed under water (submarine cables) and sometimes when installed in cable trays or trenches. Armored cable will have XLP or EPR insulation covered with a thermoplastic core covering and then provided with an interlocked-metal tape armor. A nonmetallic jacket is required for underground installations, where corrosion and moisture protection is required, for installations in outdoor cable trays, or for submarine cables. Submarine cable may also require a lead covering. Cable having a steel armor will be three-conductor type to avoid the high hysteresis and eddy current losses which can result when single-conductor cable is used.

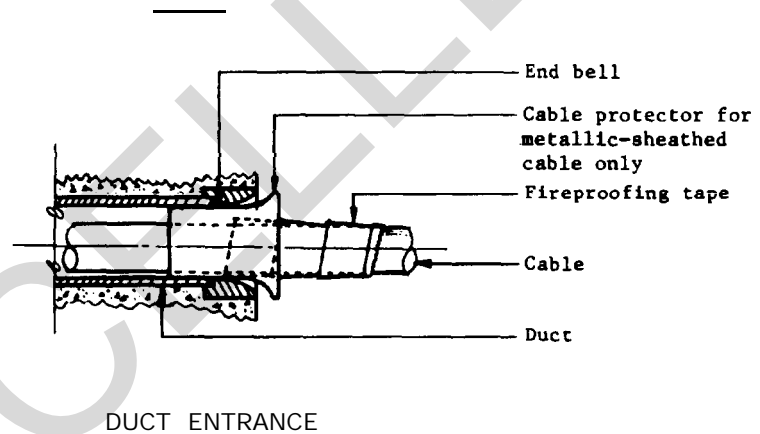
(c) Lead-covered cable. Lead-covered cables will not be used, unless extenuating circumstances prevail such as for submarine cable. The lead covering is both more costly and more difficult to handle. The use of laminated insulation such as for paper-insulated-lead-covered (PILC) or for varnished-cambric-lead-covered (VCLC) instead of the solid or extruded dielectrics such as crosslinked-polyethylene (XLP) or ethylenepropylene-rubber (EPR) is not approved. In addition, these cables have lower temperature ratings.

(2) *Low-voltage cables.* Cables suitable for below grade installations are listed in the NEC. Insulation will be either XLP (NEMA WC 7) or EPR (NEMA WC 8) and jackets or other protection will be in accordance with the applicable Underwriter's Laboratories (UL) specification covering that NEC type. Use of metal-clad (MC) cable will be limited as previously discussed for metallic-armored cable. The use of the less expensive Moisture-and-Heat-Resistant Thermoplastic (THWN) or Moisture-and-Heat-Resistant Cross-Linked Synthetic Polymer (XHHW) is not recommended for underground work as their thinner insulation has been designed for interior usage. Moisture-and-Heat Resistant Thermoplastic (THW) wiring does have the same thickness of insulation as Heat-Resistant Rubber (RHH)/Moisture-and-Heat Resistant Rubber (RHW)/Underground Service-Entrance (USE) wire, but polyvinylchloride insulation is considered to have only fair electrical and mechanical insulation properties as compared to the excellent properties exhibited by XLP and EPR insulation. UF cable may have a greater insulation thickness, but some sizes have a lower ampacity rating than does USE cable.

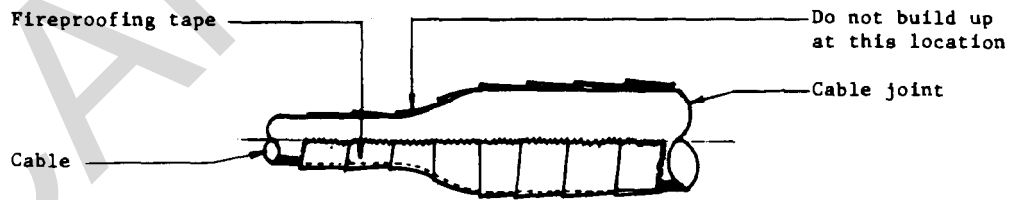
c. *Cable ampacity.* The current carrying capacities of cable will be in accordance with ampacities given in the NEC and IEEE/ICEA publications. There are many factors taken into account in determining these allowable ampacities such as operating temperatures, soil effects, shielding losses, and conductor configurations, but the variables which cause the most concern are circuit loading and location in a duct bank. Because of load diversity, peak demands for cables in a duct bank will not occur concurrently in most cases. This diversity factor will be taken into account when computing expected heat build-up in a duct bank. Heat dissipation from a cable is also influenced by the position occupied by the cable in a duct bank. Cables in duct bank corners dissipate heat more effectively than cables in interior ducts, because of the greater soil dissipating area and the smaller heat contribution from neighbor-

ing cables. Calculations of the position effect indicate that, to equalize operating temperatures, full-load ratings of cables appropriate for isolated (one-way) ducts should be decreased for multiple duct banks. For example, in an eight-way-duct bank the recommended full-load percentage decrease for each corner duct is 95 percent and for each interior duct is 83 percent giving an average load percentage decrease of 89 percent. This derating still allows provision for loads in excess of the normal feeder capacity usually found on military installations, as the summation of feeder capacities is generally from three to eight times the overall capacity of a main electric supply station.

d. *Power cable joints.* A splice which connects cables rated 2.5 kV and above is known as a power cable joint. Cable joints are composed of connectors to join two or more cables for the purpose of providing a continuous electric path plus necessary



DUCT ENTRANCE



CABLE JOINT

REQUIREMENTS

Fireproof only medium-voltage circuits (over 600-volts). Fireproof cables their entire length within the manhole and into the duct entrance as indicated.

US Army Corps of Engineers

Table 7-1. Rated Conductor Temperatures.

components for maintaining symmetrical stress distribution, minimizing voltage gradients, and maximizing environmental protection.

(1) *Connectors.* Connectors will be of the compression type or the plug-in type. Mechanical connectors of the bolted or screw type or thermal connectors of the soldered, brazed, or welded type will be used only in special cases where the application so warrants. Compression connectors above 5 kV need to be of the tapered-end type, or have semiconducting (semicon) tape or molded construction to give the same effect and thus limit stresses.

(2) *Other necessary joint components.* The other necessary components are contained with the connectors in kits to provide joints which range from the fully field-assembled type (taped) to those kits with mostly factory-formed parts (preformed) which require less installation labor. Factory preformed kits are preferred. The field-assembled kits will not be used unless the Contractor cannot locate the preformed kits, and the Contractor employs a cable splicer approved by the Contracting Officer.

(a) *Conventional taped or resin system splice kits.* These kits cost the least for materials and are used to make up a significant number of cable joints, but this type requires the most labor to install. Joints are longer and bulkier than other types. Quality is dependent upon the splicer's skill level, so joint workmanship can vary widely. Any kit selected must have splice tapes suitable for the cable insulation. Refer to IEEE Std 141 for details and specifications of cable joints.

(b) *Heat-shrinkable splice kits.* These kits include factory preformed splices which are heat-treated in the field to fit the conductor. This type is simpler to install than the conventional taped or resin type, and provides a less bulky splice than any of the other types. A kit will fit a range of cable sizes, but kits may not be available for other than solid dielectric single-conductor cables.

(c) *Separable insulated connectors.* Such connectors are fully factory preformed into the minimum of parts necessary to adapt either the receptacle and plug or the connector and splice body to the cable insulation, shielding, and jacket. Such joints cannot be used for laminated insulations, but provide a waterproof and totally submersible joint for solid or extruded dielectric insulations. These joints are the quickest to install, but the labor savings may be outweighed by the highest initial cost. Greater reliability has been reported by utility and industry records for these joints. Connections do provide disconnectability for future taps or for cable sectionalizing during fault test-

ing. Whenever separable insulated connectors are used for this application, they should be of the loadbreak type. The preformed kit must be suitable for the cable insulation and correctly sized for the cable diameter. Separable insulated connectors will not be used in manholes, except where necessary for reasons of clearance at airfields. Separable insulated connectors will not be used in direct burial applications.

(3) *Choice.* Any of the cable joints discussed may be permitted as a Contractor's option, whose selection is made by balancing labor savings against material costs. Disconnectable loadbreak separable connectors, which are the most expensive type of cable joints, will be used only where the disconnect feature is necessary. Metallic-armored cable splices will be enclosed in compound-filled metal splice boxes. Splice and terminator kits will be selected as recommended by the cable manufacturer.

(4) *Dissimilar material.* Both aluminum-to-copper conductor and nonmetallic-jacketed to lead-covered cable connections are easily made when connectors and splicing materials are correctly utilized and installed. While transitions from one material to another will not be permitted when installing new lines, such transitions between existing and new work are acceptable for extensions and additions.

e. *High-voltage cable terminations.* A device used for terminating alternating-current power cables having extruded, solid, or laminated insulation which is rated 2.5 kV and above is known as a high-voltage cable termination.

(1) *Provisions.* Such terminations are covered by IEEE Std 48 which requires terminations to be able to provide one or more of the following:

(a) Electric stress control for the cable insulation shield terminus.

(b) Complete external leakage insulation between the cable conductors and ground.

(c) A seal at the end of the cable against the entrance of the external environment which also maintains the pressure, if any, of the cable system.

(2) *Types.* Termination types are defined by IEEE Std 48 as Class 1, which provides all of the above three conditions (and includes potheads, a term now rapidly becoming obsolete), Class 2 which provides the first two conditions, and Class 3 which provides only the first condition. The first two classes include both indoor and outdoor types, but Class 3 can only be used indoors. Protection from direct exposure to solar radiation or precipitation is required for outdoor types.

(3) *Requirements.* Class 2 terminations with their unsealed ends are subject to tracking when

exposed to humidity changes occurring inside outdoor equipment. Class 3 terminations, with their exposed length in addition to the exposed end, can be more difficult to maintain plus more dangerous to maintenance personnel. Since the use of the more expensive Class 1 type causes an almost unnoticeable overall cost increase in the provision of a medium-voltage cable installation, only Class 1 terminations will be used. Either taped or preformed Class 1 terminations are acceptable. Use of the next higher BIL rating in contaminated areas is not recommended, as it is preferable to have a cable failure at the termination rather than within the cable length.

f. Fireproofing. High current arcs can cause heat or even flames which can destroy cables adjacent to the arc. To limit damage, cables are often fireproofed in manholes and vaults. Fireproofing should be limited to cables rated above 600 V. Fireproofing methods include wrapping the

cable with a fireproofing tape, spraying the cable with a fireproofing coating, or installing fire stops in the manhole. Medium-voltage cables and conductors in manholes that are taped or coated with a fireproofing material will be taped or coated for their entire length on an individual cable basis. Figure 7-1 shows cable fireproofing details for a taped installation. Polymeric elastomer tapes will be used. Asbestos tapes are not permitted. Where cables have been lubricated to enhance pulling into ducts, the lubricant will be removed from cables exposed in the manhole before fireproofing.

g. Insulation tests. Cable testing will be specified to be performed and successfully completed for all medium-voltage cable installations. Cable testing will include the testing of the adequacy of all cable splices and terminations, as applicable. Cables will be disconnected from equipment during the testing process. The first testing of new cables is performed by the cable manufacturer at the

Insulation Type	Max Voltage Temp. (kV)	Max Opr Temp. (°C)	Max OL ² Temp. (°C)	Max S/C ³ Temp. (°C)
Paper (solid-type) multiconductor and single conductor, shielded	9	95	115	200
	29	90	110	200
	49	80	100	200
	69	65	80	200
Varnished cambric	5	85	100	200
	15	77	85	200
	28	70	72	200
Polyethylene (natural) ⁴	5	75	95	150
	35	75	90	150
SBR rubber	2	75	95	200
Butyl rubber	5	90	105	20
	35	85	100	200
Oil-base rubber	35	70	85	200
Polyethylene (crosslinked) ⁴	35	90	130	250
EPR rubber ⁴	35	90	130	250
Chlorosulfonated polyethylene ⁴	2	90	130	250
Polyvinyl chloride	2	60	85	150
	2	75	95	150
	2	90	105	150
Silicone rubber	5	125	150	250
Ethylene tetrafluoroethylene ⁵	2	150	200	250

¹ Reprinted with permission from IEEE Std 141-1986.
² Operation at these overload (OL) temperatures shall not exceed 100 h/yr. Such 100 h overload periods shall not exceed five.
³ S/C = short-circuit
⁴ Cables are available in 69 kV and higher ratings.
⁵ For example, Tefzel.

Figure 7-1. Fireproofing of Insulated Cables.

factory, and is performed in accordance with industry standards. The designer will specify the field tests in accordance IEEE Std 400. Unless the cable accessory manufacturers indicate higher voltages are acceptable, test voltages will not exceed the recommendations of IEEE Std 404 for cable joints and IEEE Std 48 for cable terminations. Table 7-2 compares the recommendations of various standards regarding test voltages for insulation, terminations, and joints. Test voltages for 28 kV and 35 kV cable insulation should be in accordance with the AEIC standards since ICEA/NEMA standards do not cover 133 percent insulation for these two voltage classes. Tests for cables 600 volts and below will be specified in accordance with IEEE Std 422.

7-3. Duct lines.

Excluding Alaska and other permafrost locations, duct lines will be installed in accordance with the NESC regarding the frost line (i.e., below frost lines or restrained with backfill, concrete encasement, bracing, or other means to maintain its design position under stress of installation procedures, cable pulling operations, settling, or frost uplift). For permafrost locations, designs will incorporate duct line installation methods which are standard for the base, post, or local utility. In clay soil, not less than a three-inch layer of sand will cover the bottom of the duct trench before ducts are placed. Ducts will be covered with not less than a six-inch layer of sand after they are placed. Metallic conduit will not be used when concrete encasement is provided. When tying into an existing asbestos composite duct bank, proper environmental protocol will be followed. The designer will provide terrain profiles for all duct systems utilizing manholes. Systems utilizing above ground sectionalizing and pulling cabinets need profiles only in hilly or congested areas.

a. Construction.

(1) *Wall thickness.* Nonmetallic ducts are manufactured with thin-wall (type EB) and thick-wall (type DB) thicknesses. The thin-wall type is designed to be used with an added concrete encasement. The thick-wall type is used without encasement in concrete; this type of duct is installed with an earth fill separating the ducts in a bank, except that under areas used for vehicular traffic concrete encasement is necessary. Guidelines indicating where concrete encasement is necessary are provided in chapter 5.

(2) *Shape.* Most ducts have round exteriors with a round bore; however, octagonal and square exteriors are available, as are square bores. Square or octagonal exteriors may make stacking easier in some cases, but round bores are preferable for cable pulling.

(3) *Number.* Ducts are available in a single raceway configuration. Although some ducts are available in multiple duct units with from two to nine raceways in each length, this type will not be used for electric power cables.

b. *Systems.* For new projects, duct lines will be provided at the same time for both electric power and communication circuits. See TM 5-811-9 for communications systems requirements. Communication cables will be completely isolated from electric power cables in accordance with ANSI C2, by using separate conduits and access points, such as manholes. Separate electric and communication conduits may be installed in the same duct bank, however. For economy and space conservation, electric power and communication ducts may be installed in the same trench and manholes may be adjacent, when such arrangements suit the communication circuit requirements of the appropriate agency. Power and communication cable separation will be in accordance with ANSI C2. Fiber optic cable (and duct) spacing from power cable will be the same as for conventional cable and duct because of the continued use of hybrid systems, and to provide an increased margin of protection for the fiber optic cable.

c. *Sizes.* The nominal diameter of raceways for medium-voltage, communication, and other cables in ducts between manholes will be four inches, with larger ducts provided where 15 kV cables larger than No. 4/0 AWG are to be installed. The communication service duct to any building will not be less than three inches in diameter. Low-voltage power ducts supplying building services will be sized in accordance with the NEC. Exterior loads supplied from a building such as multiple lighting, control, or motor loads will be served with not less than 1-inch ducts. In general, sizes

Table 7-2. Comparison of DC Test Voltages (kV)

Cable Rated Voltage (kV)	133 Percent Insulation		Terminations	Joints on Extruded Dielectric Cable
	NEMA WC 7	AEIC CS5	IEEE No. 48	IEEE No. 404
Phase to Phase	WC 8	CS6		
2.5	25	-	40	-
5.0	25	-	50	25
8.7	35	-	65	35
15	65	-	75	55
25	100	-	105	75
28	-	125	115	85
34.5	-	155	140	100

of underground raceways installed should be the nominal 4-inch, 3-inch, 2-inch, or 1-inch size, except where large numbers of secondary ducts make this uneconomical, such as on tank farms.

d. Spare capacity. A sufficient number of spare ducts will be provided in duct systems between manholes to provide for at least a 25 percent increase in the number of cables. The number of spare ducts will be increased as required for future service to planned expansion. Such spare provisions do not apply to building service ducts, unless there is a definite planned expansion or a planned increase in reliability requires provision for duplicate feeders. Spare ducts should be plugged to prevent entry of debris and rodents.

e. Installation. Installation requirements for concrete-encased duct lines will meet requirements of ANSI C2. Figure 7-2 shows typical configurations, however, spacing and arrangement will be adapted to ensure adequate conductor ampacities in accordance with the NEC and IEEE/ICEA publications. Additional duct configurations are depicted in the NEC. Figure 7-3 indicates drainage requirements for underground ducts.

(1) *Maximum number of conduits in a duct run.* Electric power cables generate heat dependent upon the cable loading and resistance. Dissipation of this heat is no problem because of diversity of cable loading, as previously noted. More than eight ducts entering at any one point in a manhole provide a cable congestion which makes maintenance time-consuming and costly. Where the use of more than eight ducts in a single run is necessary, the minimum manhole size required, as noted later, will be increased. More than two duct entrances may require larger manhole sizes.

(2) *Configurations.* Arrangements for electric (E) and communication (C) ducts are given below:

4E or 4C	2 ducts wide by 2 deep
4E and 4C	4 ducts wide by 2 deep
6E or 6C	3 ducts wide by 2 deep
6E and 6C	6 ducts wide by 2 deep

(3) *Miscellaneous.*

(a) *Jacking.* Where ducts are jacked under existing pavement or used for exposed installations, rigid steel conduit will be installed because of its strength. To protect the corrosion-resistant conduit coating, predrilling or installing conduit inside a larger iron pipe sleeve (jack-and-sleeve) is required when conduits are jacked. For crossings of existing railroads and airfield pavements greater than 50 feet in length, the predrilling method or the jack-and-sleeve method will be used.

(b) *Duct line markers.* Duct line markers will be provided only for duct line stubouts or for other ducts whose locations are indeterminate because of duct curvature or terminations at com-

pletely below-grade structures. In addition to markers, 3-inch wide 5-mil brightly colored plastic tape placed approximately 12 inches below finished grade may be used.

7-4. Manholes, Handholes, and Pullboxes.

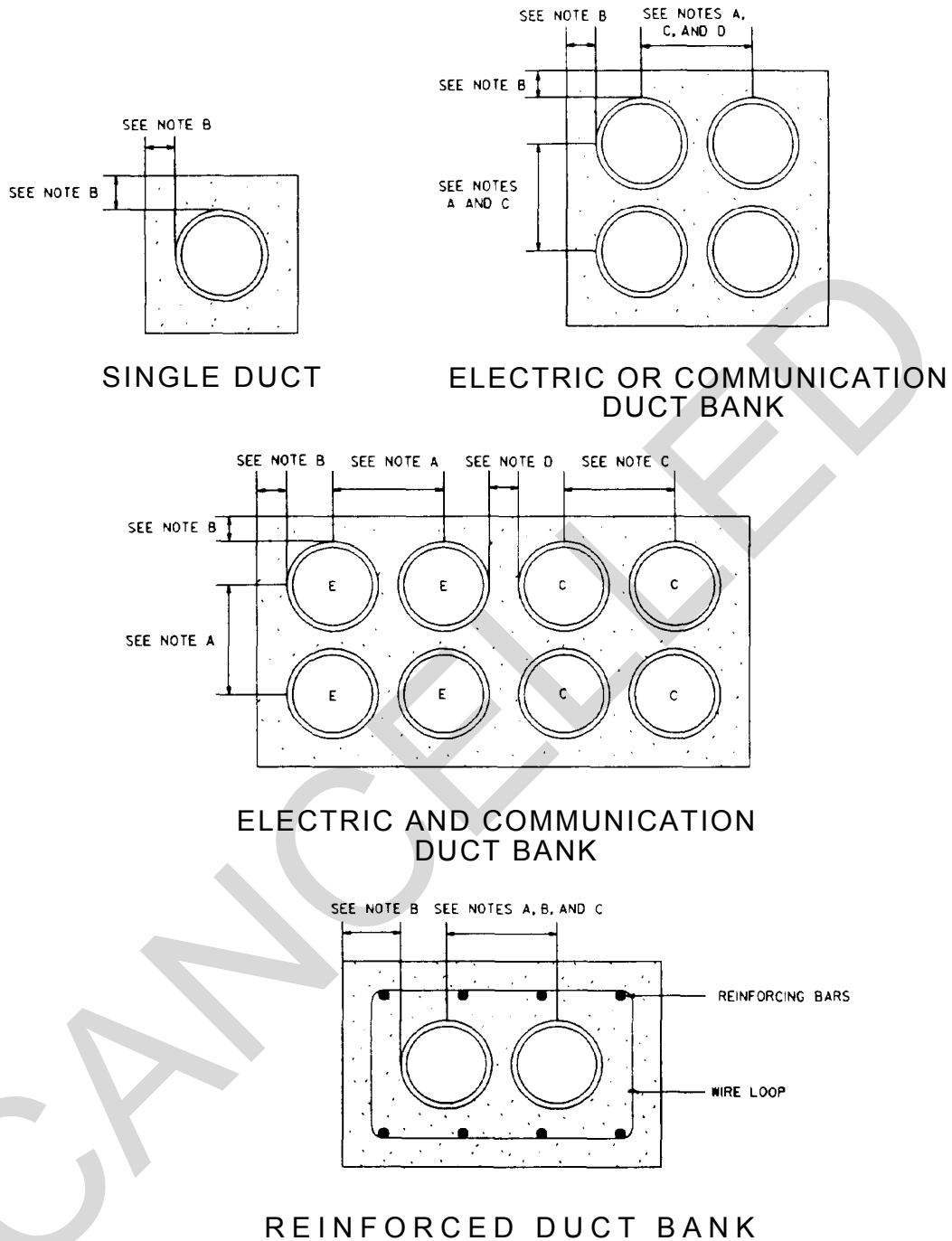
In traffic areas, design will be for a H20 wheel loading as defined by AASHTO HB-13.

a. Manholes. Manholes will normally be located at street intersections and will be spaced otherwise to meet facility needs; to conform to the facility master plan; or as required by the cable pulling calculations.

(1) *Criteria for construction.* Manholes will not be less than six feet in depth, by six feet in length, by four feet in width with an access opening to the surface above (outer air) of not less than 30 inches in diameter. Manholes will provide a minimum wall space of six feet on all sides where splices will 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 sufficient space will be provided for a reverse bend before the cable straightens out on the wall on which the cable is racked. Manhole elevations and elevations of duct lines entering manholes will be shown. For nonmetallic-jacketed cables, the minimum bending radius will be 12 times the overall cable diameter. Metallic-jacketed cable bends will be in accordance with ICEA/NEMA requirements or 12 times the overall cable diameter, whichever is greater. Figure 7-4 shows details of factors which affect lengths of manholes. A scale example of a specific cable size installed in a manhole is shown on figure 7-5.

(2) *Types of manholes.* A combination electric power and communications manhole suitable for use with most electric power and communication duct arrangements is shown on figure 7-6. Other arrangements are acceptable, but minimum inside dimensions and reinforcing will match requirements shown on figure 7-6. Generally, manhole drawings indicate the requirements for a cast-in-place concrete manhole. Precast manholes may be specified as a Contractor's option, when they provide the same inside dimensions, strength, and sealed joints comparable to the monolithic construction of case-in-place manholes. Prefabricated vaults of other than concrete construction will be restricted to direct-burial cable systems.

(3) *Prohibited devices.* Electrical equipment such as transformers or switches should not be installed in manholes or underground vaults, except in manholes adjacent to airfields where such installations may be necessary to meet airfield clearance requirements, or as specifically required



NOTES:

- A. ELECTRICAL SUPPLY DUCT:
ARRANGEMENTS, SIZES, AND DIMENSIONS SHOWN ABOVE WILL CONFORM TO THE REQUIREMENTS OF NFPA 70.
- B. ENCASEMENT DIMENSIONS ARE TO BE DETERMINED BASED ON LOCATION, BURIAL DEPTHS, AND STRENGTH REQUIREMENTS.
- C. COMMUNICATIONS SUPPLY DUCT:
SEPARATIONS ARE DEPENDENT ON COMMERCIALY AVAILABLE DUCT SPACERS FOR THE RESPECTIVE CONDUIT SIZE.
- D. ANSI C2 MINIMUM SEPARATION FOR SUPPLY-COMMUNICATION IS 3 INCHES CONCRETE.

Figure 7-2. Concrete Encased Duct Details

by the Using Agency, and then equipment will be of the type which can be submersed. Where the water table is high enough to flood manholes, water will be removed by portable pumps operated on a regular schedule. Permanently connected sump pumps will not be installed, except in special instances. Permanent ladders will not be installed; portable ladders will be used when required.

(4) *Manhole appurtenances.* Ground rods will be installed in one corner of each electric manhole for metallic shield or sheath grounding to reduce induced potential gradients. Dangerous gradients are not induced by communication circuits, so rods will not be installed in communication manholes. Other manhole appurtenances are shown on figure 7-7. Square covers will not be used because of the danger of the cover slipping through the opening. The traffic cover shown on figure 7-7 is suitable for AASHTO H20 wheel loadings. Pulling-in irons will be provided opposite each duct entrance or where there are provisions for future duct entrances. Sufficient cable racks will be installed to properly support cables on both sides of any cable splice and elsewhere as needed. Rack horizontal spacing will be 3 feet to 4-½ feet for electric power cables dependent upon the nature of the cable bends. At least two racks will be located on each wall, except, racks will not be more than 30 inches apart horizontally.

(5) Communication manholes are to be designed in accordance with Army Field Manual 11-486-5, Telecommunications Engineering Outside Plant Telephones, paragraphs 7-17 to 7-30.

b. Other Types of Cable Access Points. Where splicing or pulling of cables requires an access point, but the volume provided by a manhole is unnecessary, handholes or pullboxes will be provided as appropriate.

(1) *Handholes.* Handholes are used on laterals

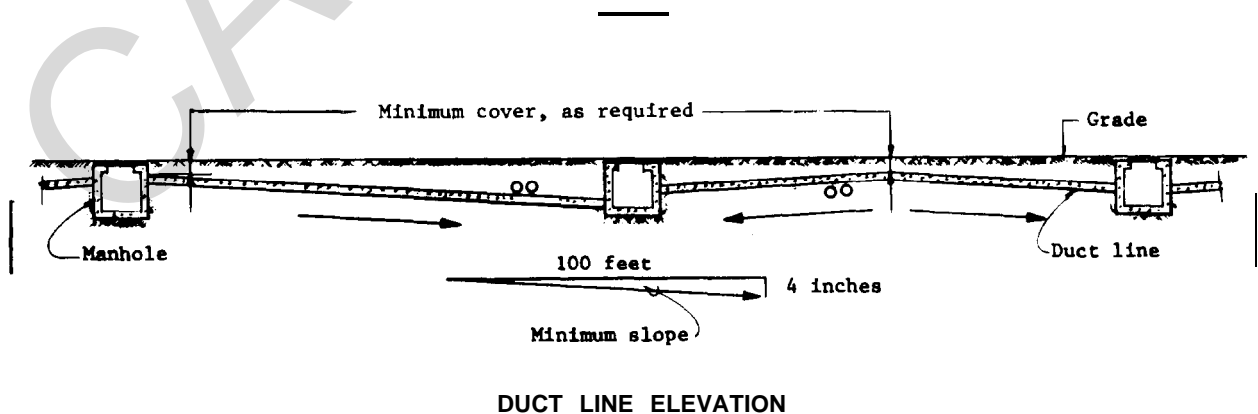
from manhole and ductline systems or other sources for low-voltage power and communication supply to building services. A handhole suitable for most electric power or communication usage is shown on figure 7-8. At least four racks will be installed. Where more than two splices occur, a manhole may be more appropriate.

(2) *Pullboxes.* Pullboxes are used for electric circuits supplying low-voltage electric loads which require conductors no larger than No. 1/0 AWG and no more than one 2-inch conduit entrance at each side. Where larger conduits are installed, handholes or manholes will be used. Because pullbox depths are less than two feet, conduits must always slope up into the pullbox. Pullboxes are also suitable for fire alarm, public address, and control circuits. Pullboxes will not be used for telephone circuits without the approval of the appropriate communication agency. Figure 7-9 shows standard sizes of pullboxes used for low-voltage installations. Pullboxes will not be used in areas subject to vehicular traffic. In such areas, handholes will be installed. The use of a pullbox at the base of a lighting pole is unnecessary in most cases.

c. Manholes at Air Force installations.

(1) *General requirements.* Manholes shall be adequately sized, shall comply with applicable requirements of OSHA, and AASHTO, and may be precast or cast-in-place. Openings should be round and not less than 32 inches in diameter.

(2) Manholes for aircraft operating and parking aprons. Electrical manholes in aprons shall be avoided. Cables shall be installed beyond the periphery of aprons. Electrical manholes shall maintain a distance of 50 feet from the edge of paving and 50 feet from any hydrant lateral control pit and 200 feet from a fueling point.



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Figure 7-3. Duct Line Drainage.

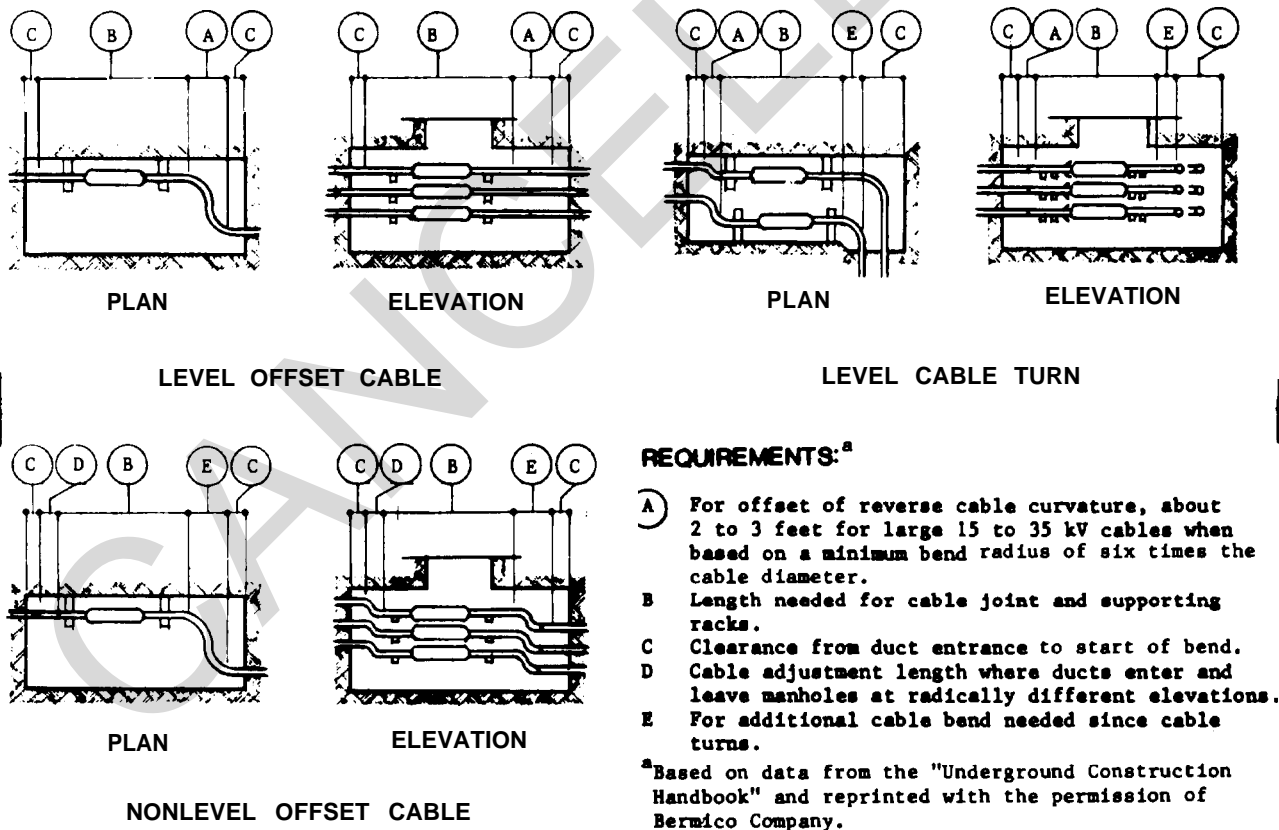
7-5. Direct-Burial Cable Installations.

Cables will be installed not less than the minimum depth required by the NEC or, excluding Alaska and other permafrost areas, as necessary to be below the frost line, whichever is greater.

a. *Protection.* In some locations, nonmetallic-jackets may not provide sufficient cable protection. Metal armor provides protection from rodents. Direct-burial cable with concentric neutral, installed in ducts, will incorporate the same overall jacket as that specified for direct burial. Where buried cable warning is required by the using agency, tape manufactured for this purpose will be provided. Where installed under traffic areas or

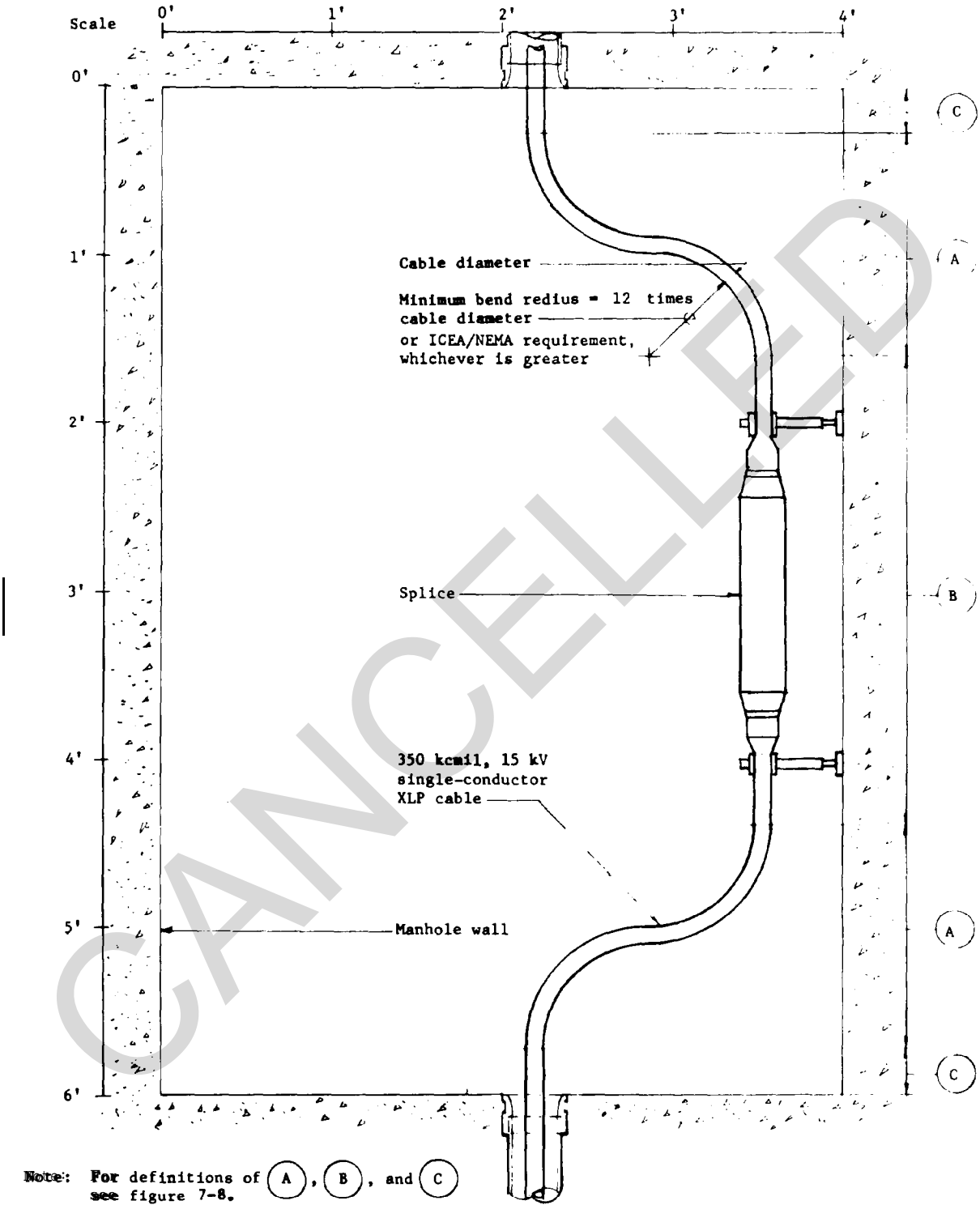
railroads, cables will be installed in concrete-encased ducts for protection. Under railroads and airfield crossings, concrete-encased ducts must be steel-reinforced.

b. *Markers.* Cable markers will be located near the ends of cable runs, at each cable joint or splice, at approximately every 500 feet along cable runs, and at changes in direction of cable runs. In addition to markers, a 3-inch wide 5-mil, brightly colored plastic tape placed approximately 12 inches below finished grade will be used. Where cable is used for lighting circuits and the lighting poles effectively provide indication of direction changes, markers are not required. Markers will be similar to the one shown on figure 7-10.



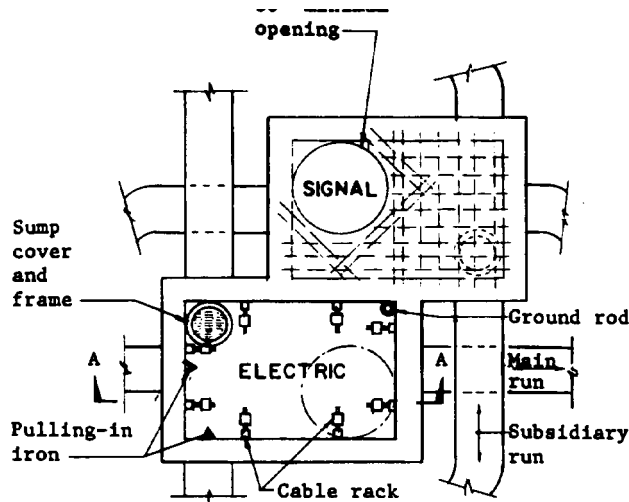
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Figure 7-4. Factors Influencing Manhole Design.

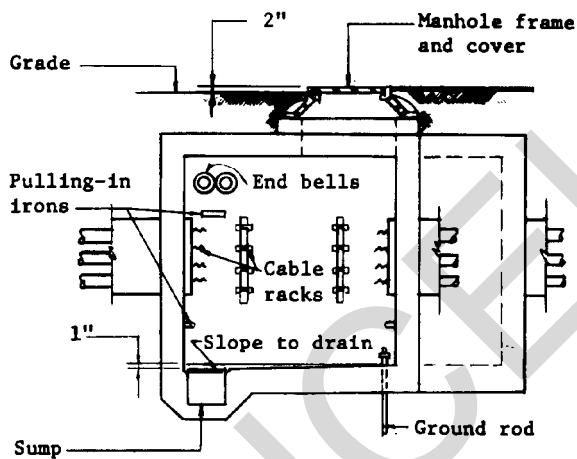


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Figure 7-5. A Scale Example of a Cable Installed in a Manhole



PLAN



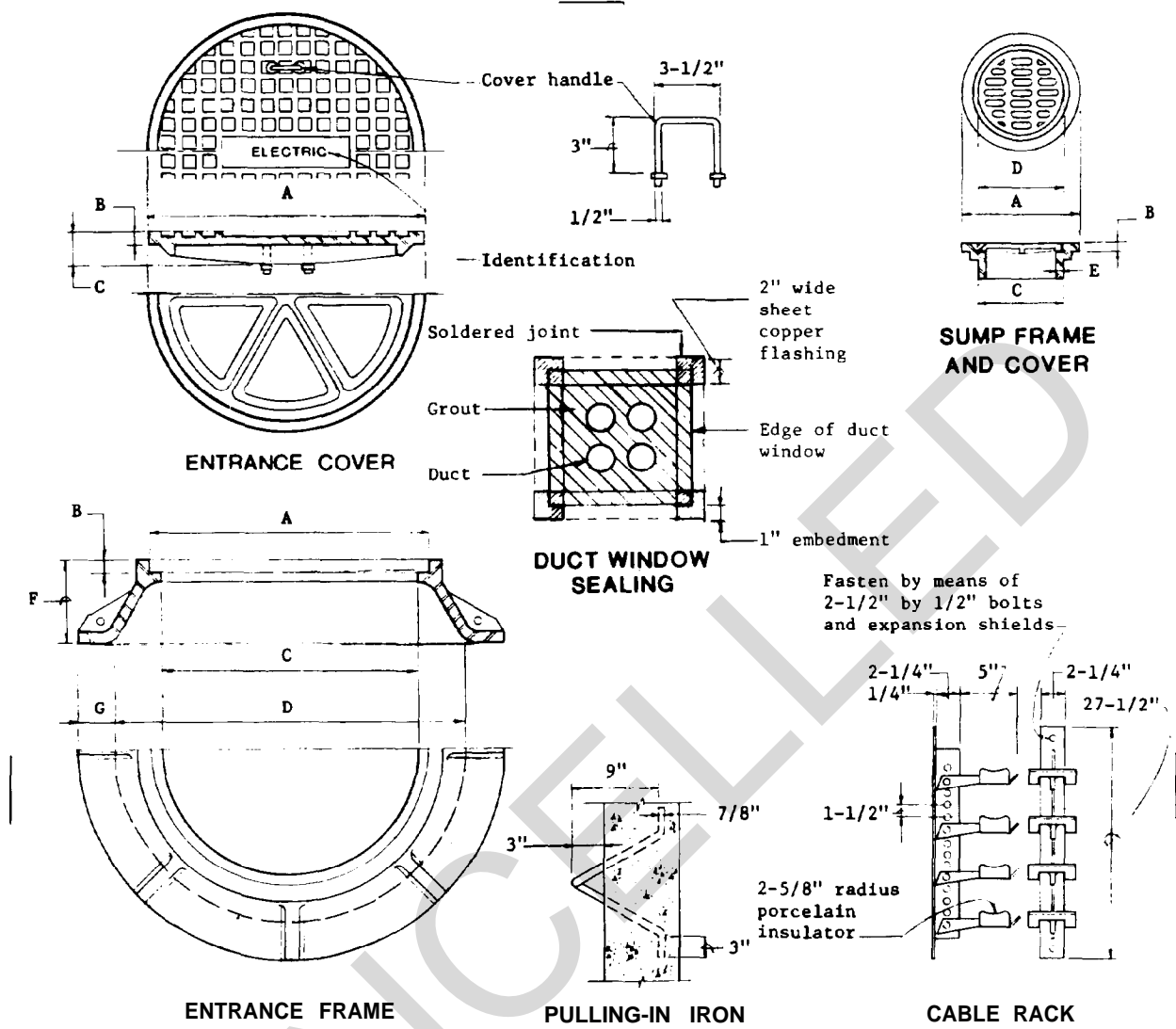
SECTION A - A

Construction requirements			
Clear minimum inside dimensions for installation and maintenance purposes			
Height	Length	Width	Sump depth
6 feet	6 feet	4 feet	1' foot
Minimum concrete thickness			
Manhole walls, top, and floor		Sump walls and floor	
8 inches		4 inches	
Minimum reinforcing ^a			
<ol style="list-style-type: none"> 1. Bars will be a minimum of No. 4 round deformed. 2. Walls and floor will have bars at 12 inches minimum on centers with a minimum 12 inch hook at corners and intersections. 3. The top will have bars installed as shown at 4 inches on center minimum laterally and longitudinally as appropriate, except that at openings also provide an additional bar at a two-inch spacing and two diagonal bars, each way at 45° to and located above lateral or longitudinal bars. 			

^aReinforcing will be increased where required to suit actual installation.

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Figure 7-6. Typical Double Manhole.



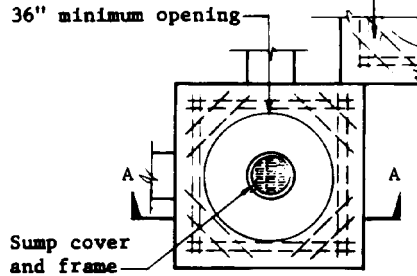
Appurtenance	Fed. Spec. RR-F-621 classification			Nominal	Dimensions inches						Remarks
	Type	Style	Size		A	B	C	D	E	F	
Manhole frame	III	A	30A 30C	30	32	1-3/8 2	30	41	4	10	Nontraffic Traffic
Manhole cover	D		30A 30B	30	31-7/8	1-3/8 2	2-5/8 3-1/4	-	-	-	Nontraffic Traffic
Handhole frame	III	A	36A 36C	36	38	1-3/8 2	36	47	4	10	Nontraffic Traffic
Handhole cover	D		a	36	37-7/8	1-3/8 2	2-5/8 3-1/4	-	-	-	Nontraffic Traffic
Sump frame	VII	-	-	12	15	1/2	12	13	3/8	-	b
Sump cover	I	-	-	12	-	1/2	-	13	-	-	b

^aModified to suit a 36-inch frame.
^bCircular instead of square shaped.

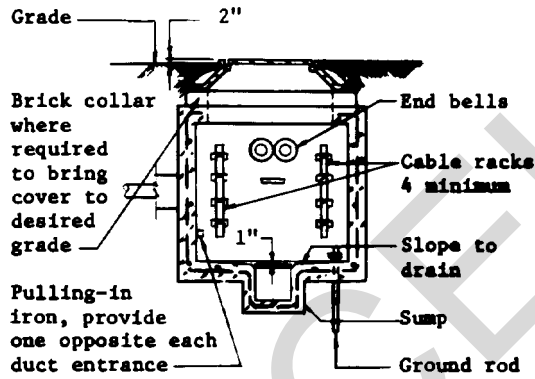
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Figure 7-7. Manhole Appurtenances.

Adjacent communication handhole, where applicable, shall be of the same construction as electric handhole, except without ground rod



PLAN



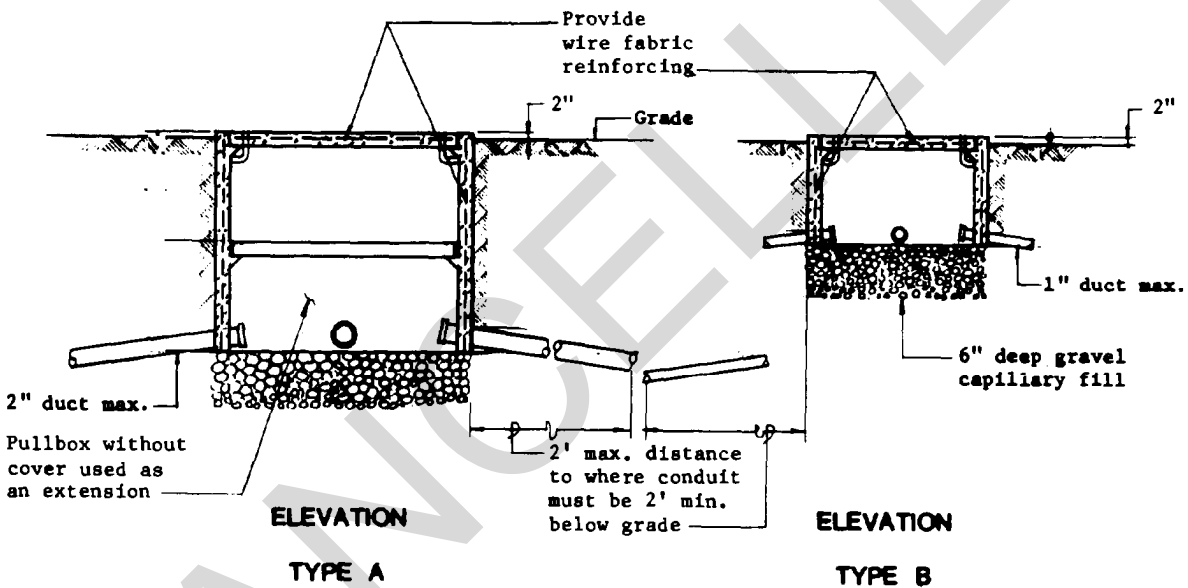
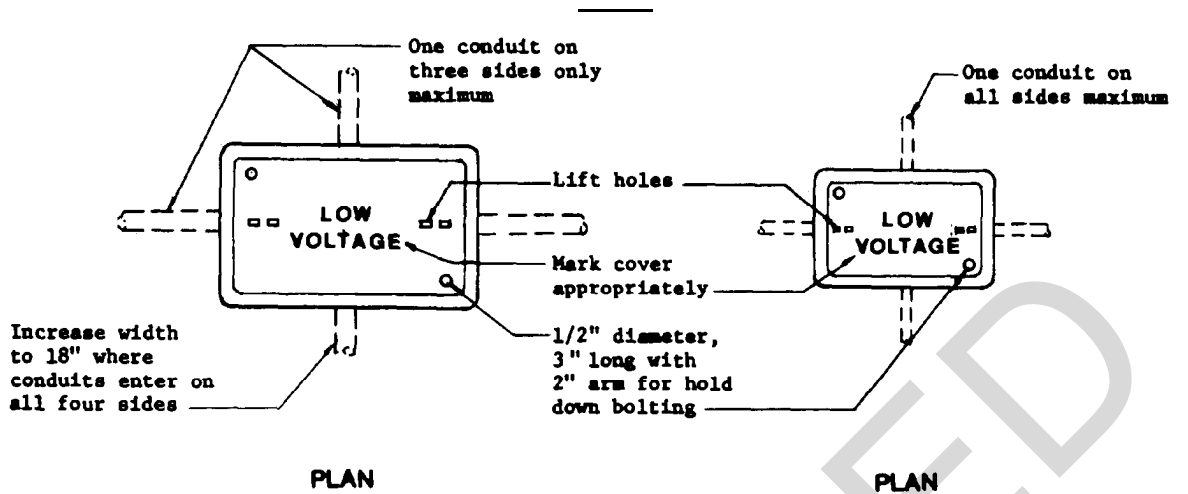
SECTION A-A

Construction requirements			
Clear minimum inside requirements for installation and maintenance purposes			
Height	Length	Width	Sump depth
4 feet	4 feet	4 feet	1 foot
Minimum concrete thickness			
Handhole walls, top, and floor		Sump walls and floor	
6 inches		4 inches	
Minimum reinforcing ^a			
<ol style="list-style-type: none"> 1. Bars will be a minimum of No. 4 round deformed. 2. Walls and floor will have bars at 8 inches maximum on centers with a minimum 12 inch hook at corners and intersections. 3. The top shall have bars installed as shown at a minimum of 2 inches from the opening and with a minimum 4 inches spacing between bars. 			

^aReinforcing shall be increased where required to suit actual installation. Minimum requirements are for a H20 wheel loading (AASHTO).

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Figure 7-8. Electric or Communication Handhole.



Minimum requirements: Box interior size, 22" long by 12" wide with 1-1/2" thick walls and 1-7/8" thick cover

Minimum requirements: Box interior size, 17" long by 10" wide with 1" thick walls and 1-5/8" thick cover

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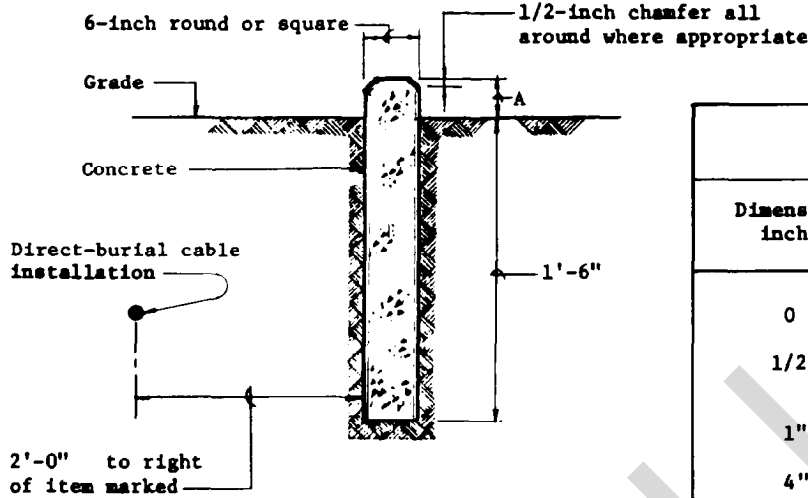
Figure 7-9. Pullbox Installation

Items impressed or cast in top will be V-shaped and have a minimum stroke of at least 1/4-inch wide by 1/4-inch deep

PLAN

3-inch letter "C" for direct-burial cable, "D" for duct line

3-inch arrow parallel to and 3-inch letter pointing to item marked for straight runs. Substitute an angular arrow pointing at item marked for runs changing direction with angle matching bend



ELEVATION

Suggested projections	
Dimension A inches	Location
0	Paved areas
1/2"	Grassed areas subject to mowing
1"	Graveled areas
4"	Uncultivated areas

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Figure 7-10. Underground System Marker.

CHAPTER 8

TRANSFORMER INSTALLATIONS

8-1. Definitions.

Transformers are classified in various ways according to their construction and application. In order to clarify usage in this manual, transformer terminology is defined in the glossary. Additional transformer definitions and terminology can be found in IEEE Std C57.12.80.

8-2. Installation of Distribution-to-Utilization Voltage Transformers.

a. Aerial mounting.

(1) Unit capacities, mountings, and types.

Aerial transformer installations may utilize a three-phase unit or banked single-phase units. Transformers, either singly or in banks, having an individual unit or combined capacity greater than 300 kVA will not be mounted on single wood poles. Special structural considerations will be given for single-pole installations greater than 100 kVA. Pole-platform mounting (two-pole structure) will not be used, except where other mounting methods are not satisfactory. Cluster mounting for transformer banks is preferred over crossarm mounting as less visually objectionable. Similarly, the cluster or three-phase bracket mountings will be permitted for mounting of surge arresters and cutouts if acceptable to the Using Agency responsible for the operation and maintenance of transformer installations. Figures 8-1 and 8-2 indicate transform bank installations. Self-protected transformers have internal primary fuses that must be replaced by experienced personnel. Therefore, self-protected transformers will not be specified.

(2) *Location.* Aerially mounted installations may supply several buildings. When that is the case, transformers will be installed at the pole location closest to the building with the greatest load. Secondary wiring should drop directly to the buildings served, if the span does not exceed 125 feet; otherwise, intermediate poles are required.

b. Ground level mounting.

(1) *Types and capacities.* Ground-level mounting may be either the pad-mounted compartmental type or the unit substation type. Figures 8-3 and 8-4 show a typical pad-mounted compartmental transformer installation. Figure 8-5 shows a typical secondary unit substation transformer installation. The use of conventional-type (pole-mounted) transformers, with connections to separate primary and secondary protective devices, is not permitted since this type of installation is more

dangerous, generally more difficult to maintain, requires more space, and there is rarely a significant cost saving since fencing is required. Pad-mounted compartmental transformers may only be used outdoors even when designed for both indoor and outdoor installation. Unit substation transformers may be used indoors or outdoors.

(2) *Pad-mounted compartmental liquid-insulated transformers.* Three-phase pad-mounted compartmental transformers may be applied in ANSI standard sizes through 2500 kVA, except that they will not be used where the primary voltage exceeds 15 kV or where fault currents are so large that standard equipment does not provide the required primary interrupting duty. The choice between pad-mounted, compartmental transformers and unit substations in conjunction with integral or non-integral load-center transformers will be based on: the application; potential for expansion; short circuit and protective device coordination; sound engineering judgment; accepted industry practice; and the operating, maintenance and reliability considerations listed below.

(a) If instruments and switches are routinely used by operators, choose unit substations and integral or non-integral load-center transformers. For pad-mounted compartmental transformers, instruments and operating devices are inside a locked compartment and are not readily accessible.

(b) Pad-mounted compartmental transformers require use of a switch stick for switch mechanism operation and cable-disconnection (due to the dead-front requirement). The typical high-voltage switch used with unit substations does not require use of a special tool and is therefore easier to operate.

(c) Fan cooling and 12 percent additional capacity for 55/65 degree C temperature rise is available for unit substations and integral load-center transformers, but is not available for pad-mounted compartmental transformers which are self-cooled; fans cannot be added to increase the cooling capacity.

(3) *Residential service.* Pad-mounted transformers will be routinely used in residential and light commercial service.

(4) *Industrial service.* Pad-mounted transformers may be used for industrial, commercial, or industrial application, provided that only one building is served; metering and secondary switch-gear can be located in the building; and short

SINGLE-GROUNDED OR
UNGROUNDED PRIMARY SYSTEM

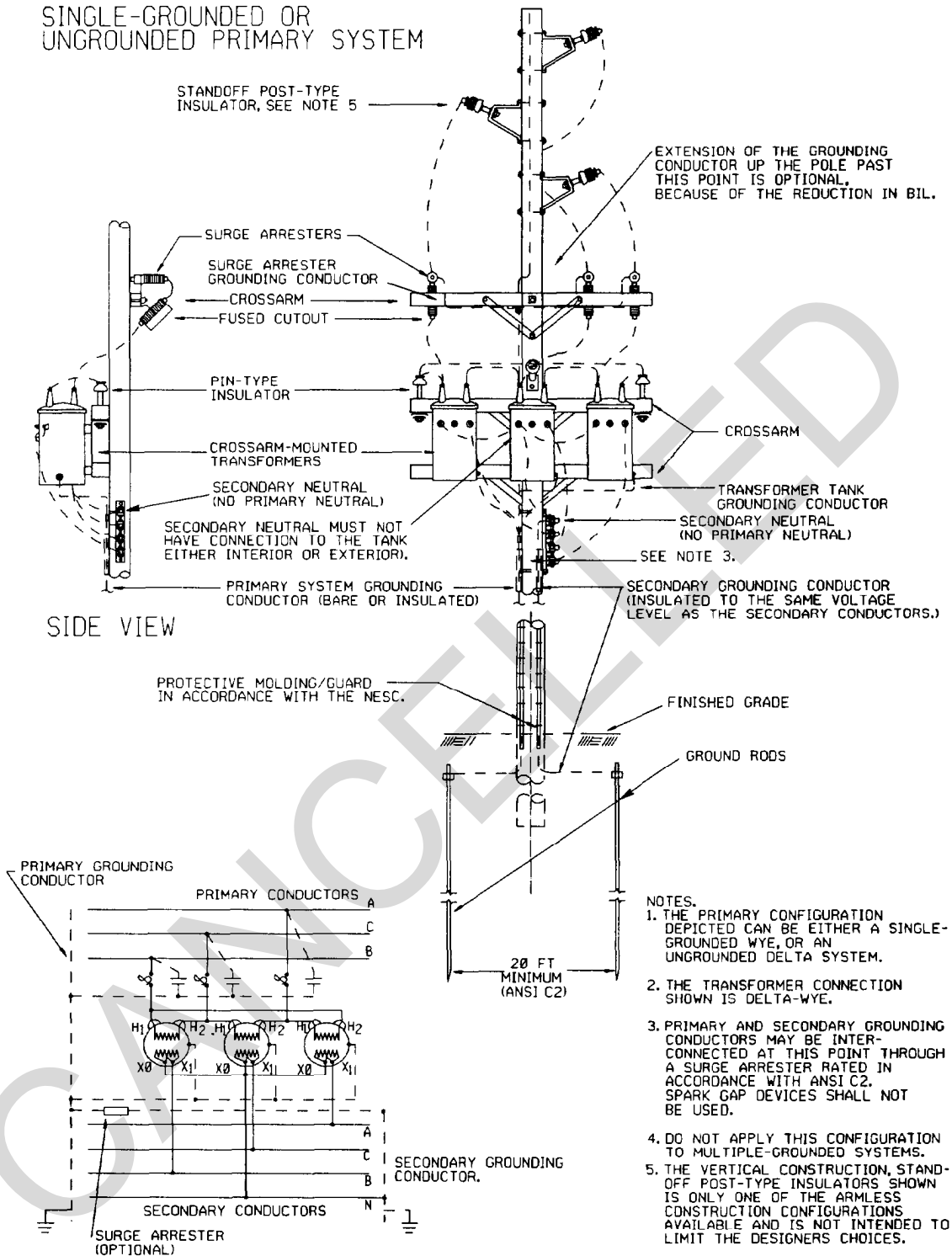
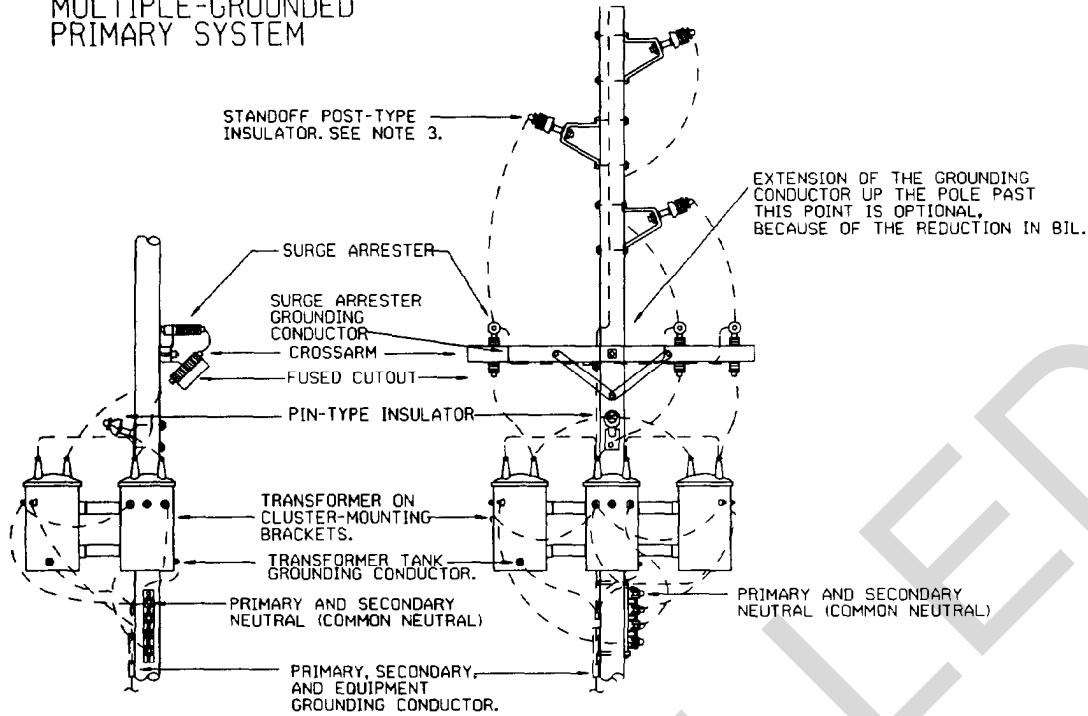


Figure 8-1. Cluster-Mounted Transformer Bank Installation.

MULTIPLE-GROUNDED
PRIMARY SYSTEM



SIDE VIEW

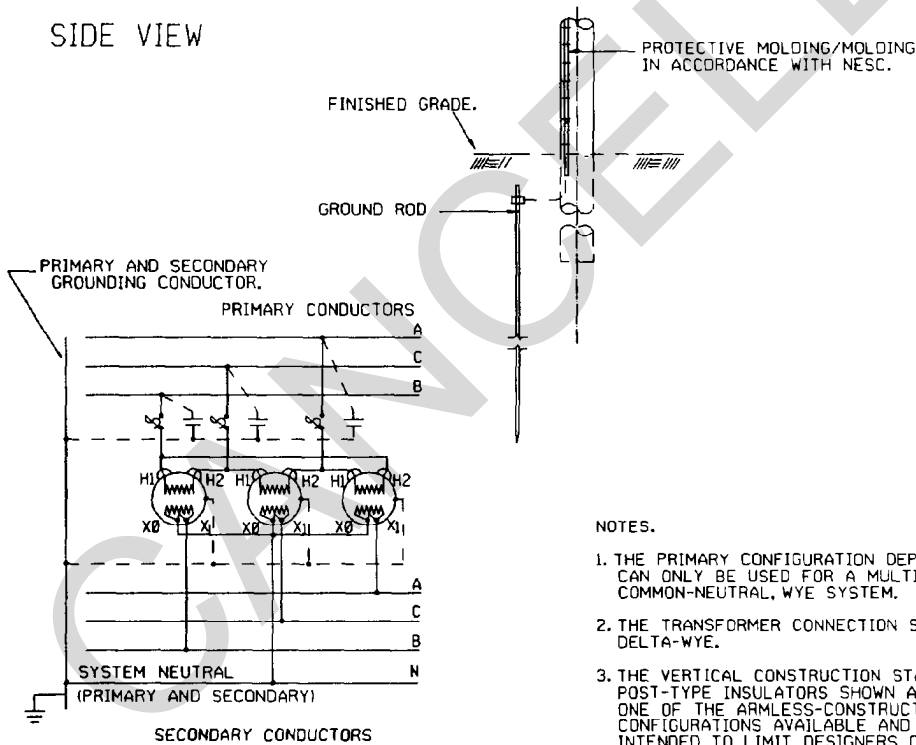


Figure 8-2. Crossarm-Mounted Transformer Bank Installation.

circuit and protective device coordination constraints are met.

(5) *Service for large loads.* Unit substations and integral and/or non-integral load-center transformers will be used for industrial, heavy commercial, and institutional applications involving large loads, multiple building serves, and the requirements for secondary bus protective devices.

(6) *Secondary unit substations.* Secondary unit substations with integral or nonintegral outgoing sections will be used. Since neither type is tamper-proof, fencing is required. Fence height will be in accordance with the NESC. Transformers larger than 1,500 kVA for 480Y/277 V service and 500 kVA for 280Y/120 V service should be avoided, because of the magnitude of their secondary fault currents. However, in some cases, it may be more feasible and cost effective to provide 2,000 kVA transformers for 480Y/277 V service and use current-limiting fuses in conjunction with circuit breakers to limit secondary fault currents. The using agency (for Air Force, the Host/REQ CMD) will stipulate demand meter requirements.

(7) *Location.* Exterior installations are preferred over interior installations because space costs are less; however, secondary feeder lengths may require an interior location or make interior installations economical in some cases.

(a) *Liquid-filled transformers installed outdoors.* Outdoor installations will comply with the NEC, MIL-HDBK-1008A, and the NESC. Transformers will be located to preclude any reasonable chance that products of combustion from a transformer fire will be drawn into the HVAC air intake of adjacent buildings. The location of pad-mounted transformers will be compatible with the architectural concept and protected from vehicular traffic. Architectural compatibility will be obtained by the proper location in relation to landscaping, the addition of shrubbery around the transformer, or the use of screened fence enclosures. The primary service will be underground from pad-mounted transformers. Secondary building connections will use underground cables or bus duct; however, the use of more than six underground cables per phase in parallel will not be permitted since complexity of connection can lead to maintenance and space problems.

(b) *Liquid-filled transformers installed indoors.* Indoor installations will comply with the NEC and MIL-HDBK-1008A. Transformer vaults will be located on the exterior wall of the building, vented to the outside and accessible only from outside the building under normal design conditions. Air intake fans and louvers of heating, ventilating, and air conditioning (HVAC) systems

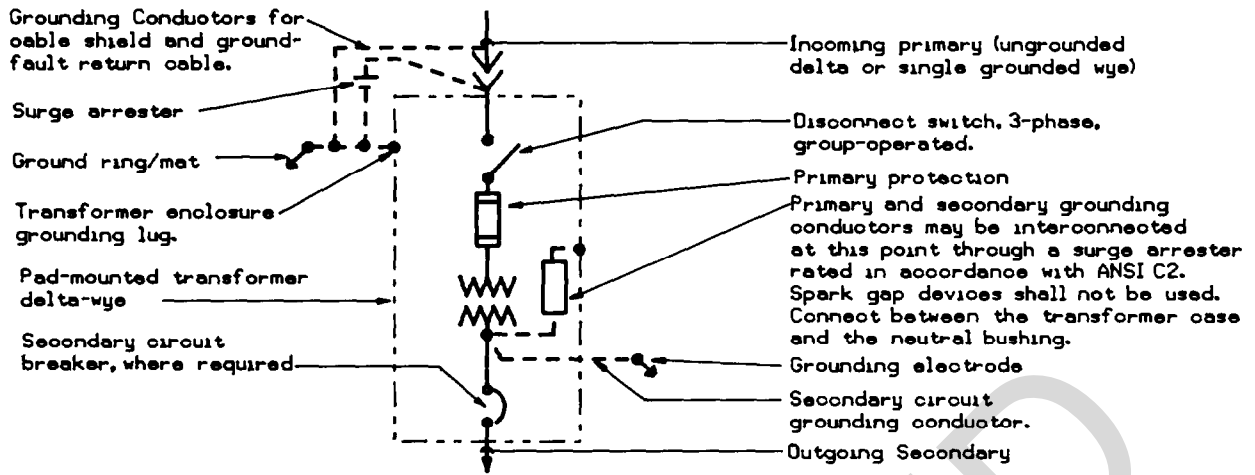
will be interlocked with the smoke and rate-of-rise detectors in the transformer vault and/or vault rooms. The smoke and rate-of-rise detectors will de-energize the HVAC air intake if a fire occurs in the transformer vault and/or vault rooms. This is not necessary if the HVAC intake is located on the roof or the opposite side of the building from the transformer vault. A sign will be posted on the access doors to a transformer vault which indicates the appropriate fire fighting equipment and procedures. Pipes and ducts will not be routed above indoor transformers.

(c) *Dry-type transformers.* Dry-type transformer applications will comply with the NEC and MIL-HDBK-1008A. Dry-type transformers will be located to preclude any reasonable chance that products of combustion from a transformer fire will be drawn into the building's HVAC system. Dry-type transformers in ventilated enclosures may be specified for indoor applications in clean, dry environments (not subject to blowing dust, excessive humidity, or corrosive atmosphere) and will be rated for the highest temperature of the location. Dry type transformers in non-ventilated enclosures may be used for indoor or outdoor applications, if the enclosure is rated for the environment. Hermetically-sealed dry transformers (filled with dry nitrogen) will not be specified due to their large size, the inability to add supplementary cooling, and problems associated with loss of gas. Transformers protected by cast- or impregnated-epoxy-resin may be used indoors and outdoors, where environmental conditions would shorten the life of a conventional dry transformer. Specifications will include epoxy encapsulation for the core and for both the high and low voltage windings. Each connection insulation must be compatible with the environment. The specification for medium-voltage primary transformers will require the basic insulation level to be the same as for liquid-filled transformers in the same voltage class, and will require the transformers to be tested in accordance with applicable ANSI tests for liquid-filled transformers.

c. *Underground Mounting.* Transformers in underground vaults are not permitted except where required to meet airfield clearances. Requirements are given in chapter 7 for equipment in underground vaults.

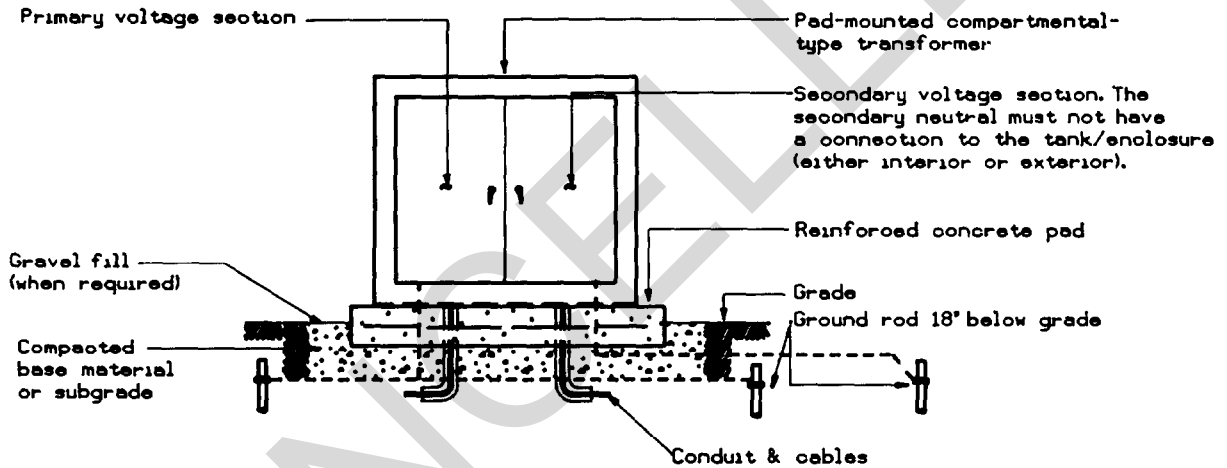
8-3. Installation of Transmission-to-Distribution Voltage Transformers.

These transformers are installed as part of the main electric supply station, since the secondary voltage will be of the 15 kV class or larger. Primary unit substation transformers will be used

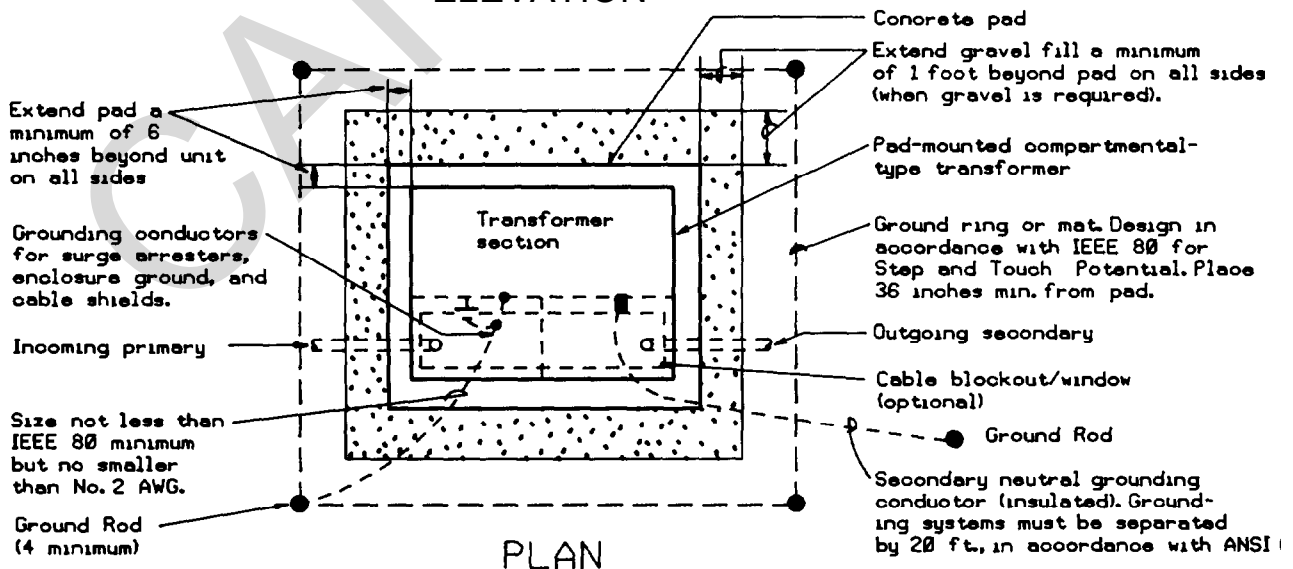


SINGLE LINE DIAGRAM

UNGROUND (DELTA) SYSTEM or SINGLE GROUNDED (WYE) SYSTEM

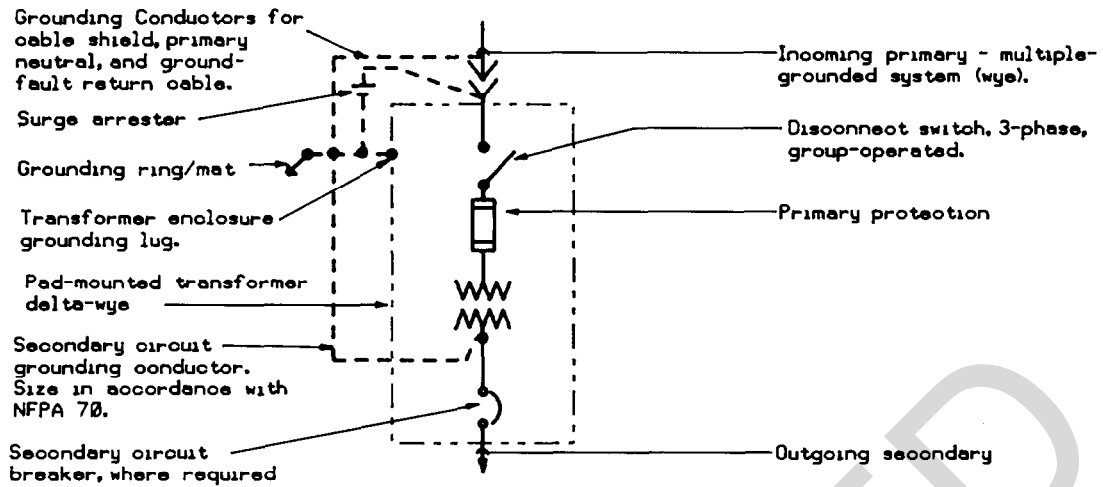


ELEVATION



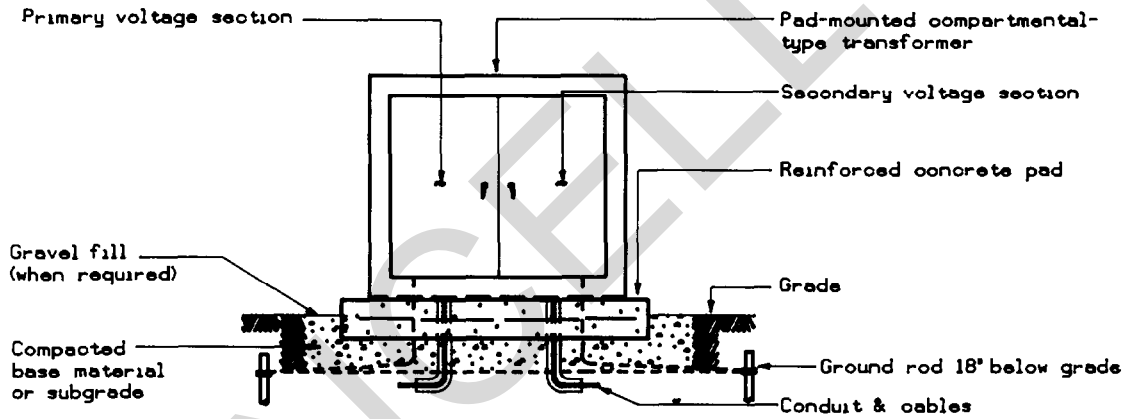
PLAN

Figure 8-3. Pad-Mounted Compartmental Transformer Installation.

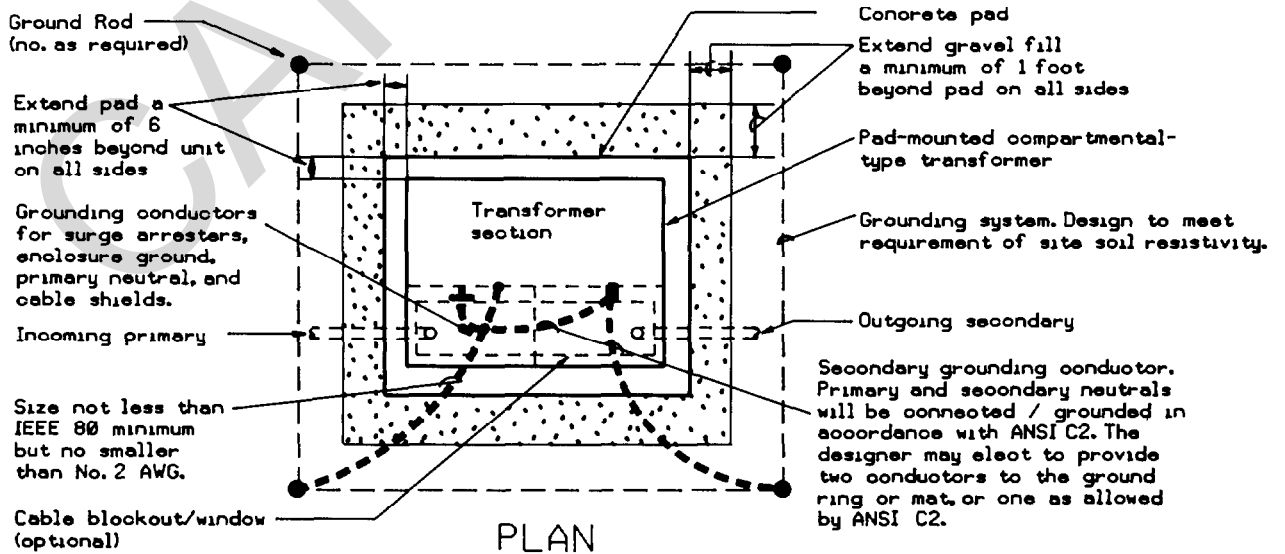


SINGLE LINE DIAGRAM

MULTIPLE-GROUNDED SYSTEM (WYE)

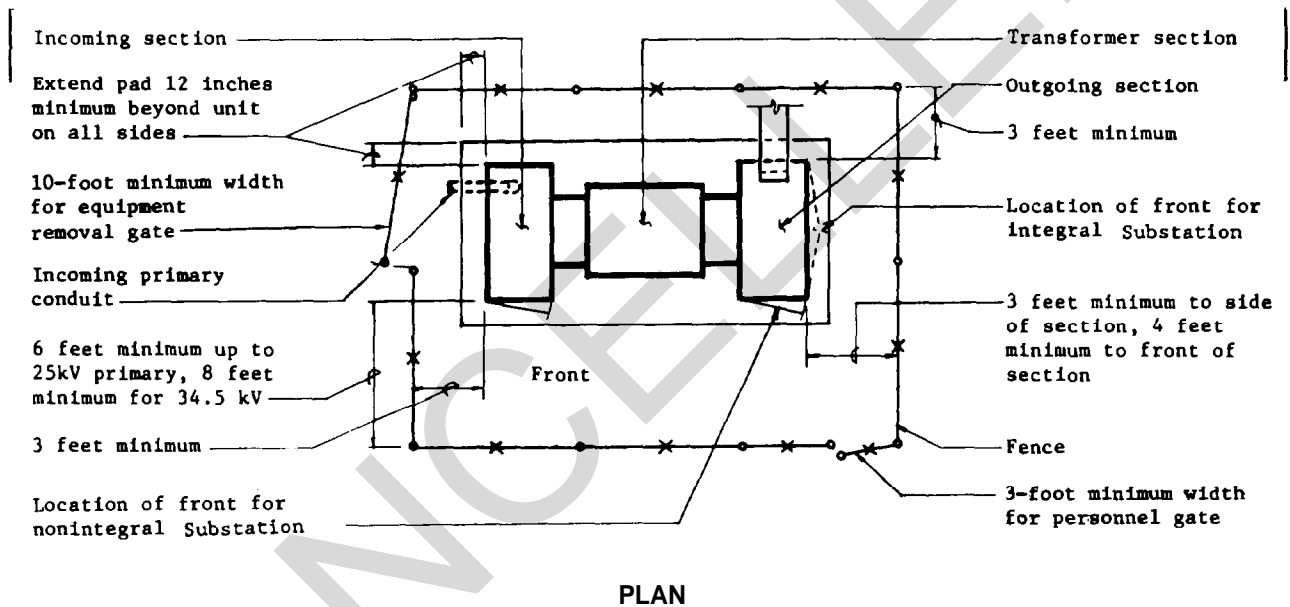
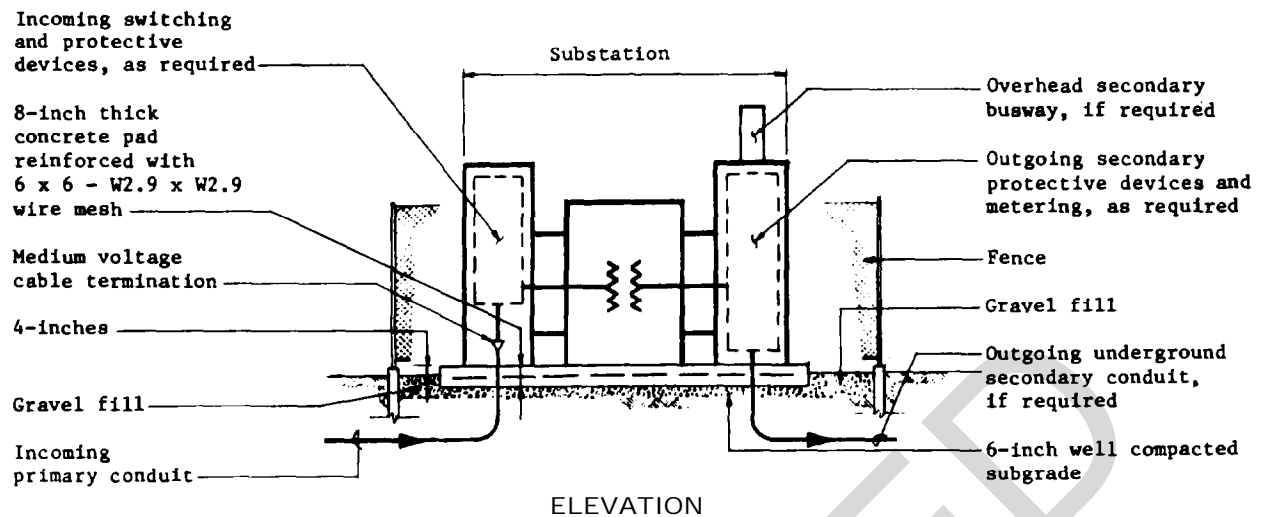


ELEVATION



PLAN

Figure 8-4. Secondary Unit Substation Transformer Installation.



Note: For grounding see figure 9-3.

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Figure 8-5. Secondary Unit Substation Transformer Installation.

to meet the criteria contained in chapter 4, as applicable.

8-4. Transformer Dielectrics.

In addition to the guidance listed below, the dielectric system will be selected based upon cost, the transformer's location within the building, the available space (liquid-filled units tend to have larger front-to-back dimensions, due to their radiators, than dry-type units), and the HVAC system in the room (dry type units tend to have higher losses than liquid-filled units). All dielectrics specified must meet the requirements of 40 CFR Part 761; "Polychlorinated Biphenyls (PCBs), Manufac-

turing, Processing, Distribution in Commerce, and Use Prohibitions."

a. *Mineral oil.* Mineral oil transformers will be used for outdoor installations only. Mineral oil is the preferred dielectric for outdoor installations.

b. *Less-flammable liquid.* Less-flammable liquid transformers may be used either outdoors or indoors, and will be installed in accordance with MIL-HDBK-1008A. Acceptable less-flammable liquids are limited to high-molecular-weight hydrocarbons and dimethyl silicone. Where less-flammable liquid transformers are proposed, a cost analysis will be provided which covers the acceptable alternatives and indicates that the most cost

effective transformer dielectric material has been selected. Costs will include all features necessary to provide a proper installation, including vaults, curbs, drains, exterior screening, interior floor space, and additional wiring as applicable.

c. Nonflammable fluid. Nonflammable fluids will not be used since there are no nonflammable fluid transformer dielectrics that are not toxic. Tetrachloroethylene (perchloroethylene) insulating fluid will not be used in any electrical equipment since the Environmental Protection Agency (EPA) has classified it as hazardous waste. However, tetrachloroethylene may be used as a cleaning agent during a refilling process provided the transformer is not located in an occupied space, has a low probability of overheating, and proper safety precautions are taken. Also, 1, 2, 4-trichlorobenzene (TCB) will not be used as an insulating fluid since it is a possible carcinogen. TCB may be used as a cleaning agent during the refilling process.

d. Existing dielectric hazards. The following will be performed when the dielectric composition of an existing transformer is not listed on the transformer nameplate or cannot be confirmed through procurement records:

(1) The dielectric will be verified either through the manufacturer's records or sample testing.

(2) If the dielectric is determined to be listed by EPA or NIOSH as a hazardous chemical (PCB, TCE/PCE, TCB, or Freon 113), a cost-risk analysis for each structure will be performed. The potential for catastrophic failure of the equipment will be determined for its design life using industry reliability data such as IEEE Std. 500. The consequences of failure will be analyzed and the costs to mitigate the consequences will be estimated. The cost of replacement or retrofit will be compared to the cost of mitigation. Costs to replace or retrofit will include costs for changing the type of dielectric, including relocation or physical isolation of the equipment.

(3) Where the cost-risk analysis requires elimination of the risk, replacement and refilling of

equipment will be evaluated to determine which is the most cost-effective.

(4) The hazardous chemical risk will be eliminated for those facilities which are mandatory for national security.

(5) The contract specifications will mandate that the contractor (or subcontractor) is or will be certified in the current EPA regulations for handling, storage, transportation, disposal, clean-up, safety and health hazards. The contract specifications will require that retrofitting of PCB contaminated equipment will result in a dielectric with less than 50 ppm PCB.

8-5. Transformer Characteristics.

a. Capacities. Capacities will be in accordance with the standard sizes listed in table 8-1. Pad-mounted compartmental units are not available for ratings of less than 25 kVA for single-phase units or 75 kVA for three-phase units. Transformer capacities selected will provide a rated capacity equivalent to not less than 90 percent of the load requirement calculated in accordance with guidelines covered in chapter 2, except that distribution transformers serving Family Housing Units will be sized in accordance with the demand factors given in Appendix A. ANSI loading factors may need to be taken into account.

b. Transformer life. Transformer life is dependent upon the thermal aging of the transformer. Normal life expectancy is based on operating transformers continuously at rated capacity to the limiting continuous duty temperature of the insulation. Thus the transformer operating temperature is the sum of the temperature rise (the increase in temperature of the transformer due to the load) and the ambient temperature (average temperature of the immediate air outside the transformer).

(1) *Load duration.* Aging of a transformer is a function of time and temperature. Transformers may be operated above rated load for short periods provided units are operated for much longer periods at loads below these limits, since thermal

Table 8-1. Transformer Standard Base kVA Ratings.⁸

Single-phase				Three-phase			
3	75	1250	10 000	15	300	3 750	25-000
5	100	1667	12 500	30	500	5 000	30 000
10	167	2500	16 667	45	750	7 500	37 500
15	250	3333	20 000	75	1000	10 000	50 000
25	333	5000	25 000	112-½	1500	12 000	60 000
37-½	500	6667	33 333	150	2000	15 000	75 000
50	833	8333		225	2500	20 000	100 000

⁸Reprinted with permission from ANSI/IEEE Standard 141-1986, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants, copyright 1986 by IEEE. (Table 68).

aging is a cumulative process and there is a time lag in insulation temperature rise. Table 8-2 indicates loads consistent for normal life expectancy at a 30 degrees C average ambient temperature. Table 8-3 may be used for approximating the loads permitted at other ambient temperatures, or the designer may use the tables in the applicable ANSI standards. Correction factors apply only from 0 degrees to 50 degrees C. Temperatures not in this range must be checked with the manufacturer. For further discussion on loading of transformers, see ANSI standards shown in table 8-3 plus IEEE Std C57.91 for 65 degrees C operation of overhead transformers.

(2) *Temperature ratings.* Transformers are rated for a hottest-spot temperature which will give normal life expectancy based on rated kVA loading.

(a) *Temperature rise.* The temperature rise specified will be 65 degrees C for liquid-filled transformers having a 120 degree C insulation and 150 degrees C for ventilated dry-type transformers having a 220 degree C insulation. If thermally upgraded insulation (greater winding temperature rise rating) is specified, then the transformer will have a longer life at rated capacity and will have more overload capacity. For example, liquid-filled transformers specified to have a 55 degrees C

temperature rise at rated kVA and to have an insulation upgraded to 65 degrees C (55 degrees/65 degrees rise) can carry continuously 122 percent of rated kVA. Likewise ventilated dry-type transformers with 220 degrees C insulation having 80 degrees C temperature rise can carry continuously 135 percent of rated kVA Thermal upgrading provides increased temperature rating or extended life at rated capacity. Thermal upgrading will not be specified for dry-type transformers and will be required for liquid-filled transformers only at main electric supply stations.

(b) *Ambient.* Since the temperature classification of the insulation system is a function of the ambient temperature, the ambient temperature very largely determines the load which can reasonably be carried by transformers in service. An average ambient temperature of 30 degrees C is used as the basis for nameplate ratings. Average ambient temperatures for the actual cooling air are then based on daily operation and the maximum ambient operating temperature in any 24-hour period can be no more than 10 degrees C above the average ambient temperature. The Using Agency will be contacted to determine the average ambient temperature if ANSI load factors are taken into account in transformer loadings. Most load estimates are sufficiently conservative

Table 8-2. Daily Allowable Peak Loads for Normal Life Expectancy.”

Peak load duration hours	Mineral-oil, self-cooled (65 C Rise)			Dry-type, self-cooled, (150 C Rise)		
	Allowable peak load in percent of rated capacity following and followed by the indicated percent constant load ^b					
	50%	70%	90%	50%	70%	90%
1/2	200.....	195.....	173	149.....	143.....	133
1	183.....	172.....	153	128.....	125.....	121
2	157.....	150.....	134	116.....	115.....	114
4	134.....	130.....	120	110.....	110.....	109
8	118.....	116.....	110	106.....	106.....	105

“This material is reproduced with the permission of the American National Standards Institute from the ANSI Standards entitled “Guide for Loading Mineral Oil-Immersed Power Transformers Up To and Including 100 MVA”, IEEE Std C57.92, copyright 1981 and “Guide for Loading Dry-Type Distribution and Power Transformers”, IEEE Std C57.96, copyright 1989.

^bAt 30°C ambient temperature.

Table 8-3. Loading on the Basis of Ambient Temperatures.^a

Transformer	For each degree C that the average ambient temperature is above or below 30° C the percent of rated kVA shall be	
	Increased for lower ambient	Decreased for higher ambient
Mineral-oil-immersed, self-cooled (65 C Rise)	1.5	1.0
Dry-type, self-cooled ventilated (150 C Rise)	0.35	0.35

^aThis material is reproduced with the permission of the American National Standards Institute from the ANSI Standards entitled “Guide for Loading Mineral-Oil-Immersed Power Transformers Up To and Including 100 MVA”, IEEE Std C57.92, copyright 1981 and “Guide for Loading Dry-Type Distribution and Power Transformers”, IEEE Std C57.96, copyright 1989.

to take into account any nameplate derating for units located in high ambient temperature areas. Low ambient temperature should not be a deciding factor in sizing of transformers, except where the installation has an average daily ambient of 20 degrees C or less.

(c) *Use of ANSI loading factors.* The influence of operating temperatures and load durations on transformer life may have to be taken into account in sizing transformers.

c. *Cooling provisions.* The rated capacities of 750 kVA and larger transformers can be increased by the addition of cooling fans, with the exception of pad-mounted compartmental units. ANSI C57.12.10 covers both the initial installation of cooling fans and the provisions which permit addition of future forced-air-cooling. Fan cooling can be controlled by either top-liquid temperature or winding temperature. The type of control will be left to the option of the manufacturer.

(1) *Main electric supply stations.* Forced-air-cooling will be provided in accordance with the criteria of chapter 4.

(2) *Secondary unit substation transformers.* Since secondary unit substation transformers supply electrical energy for direct utilization by motors, lights, and other devices, initial forced-air-cooling is not necessary in most cases. Provisions for addition of future forced-air-cooling will be provided only when such cooling equipment is a cost effective way to satisfy future load increases.

d. *Basic impulse levels.* Insulation characteristics for voltage surges of high magnitude but short duration, such as lightning or switching surges, are determined by impulse tests. The most common test is the application of either a 1.2 x 50

microsecond or a 1.5 x 40 microsecond full impulse voltage wave, dependent upon the industry specification. The crest value of the voltage wave is called the basic impulse insulation level (BILL) of the equipment involved. Standard basic impulse insulation levels have been established for each voltage reference class; however, equipment rated 15 kV and below is often built to a so-called "distribution-class" BIL rather than to the standard or "power-class" BIL. The distribution class BIL requirement is even lower for ventilated dry-type transformers than for liquid-filled transformers as shown in table 8-4, although BIL levels equivalent to those for distribution-class liquid-filled units can be obtained for some voltages at a relatively small cost increase. Ventilated dry-type transformers will always be provided with a BIL rating equivalent to liquid-filled units of the same rating. Use of external devices such as surge arresters to provide an adequate BIL protective level is not acceptable.

e. *Transformer connections.* The wye-wye connection of two-winding transformers requires that a fourth wire (neutral or ground) be installed throughout the length of distribution lines, and the solid grounding of the primary and secondary windings of transformers. Loss of either the primary or secondary ground and unbalanced loading can cause interference on communication circuits and result in excessive heating of the tanks of three-phase transformers. For those reasons, the wye-wye connection of two-winding transformers will be avoided whenever possible. A delta primary connection eliminates objectionable odd harmonic paths and a wye-secondary connection pro-

Table 8-4. Basic Impulse Insulation Levels

		Basic impulse level (BIL) kV			
		Liquid-immersed units		Ventilated dry-type units	
Insulation reference class kV	Normal duty for insulation reference class	C57.12.00 ^a	C57.12.00 ^a	C57.12.01 ^b	Available and mandatory
		requirement for power class	requirement for distribution class ^c	requirement	
5	60	75	60	30	60
15	110	110	95	60	110
25	150	150	150	110	150
35	200	200	200	150	200

^aReprinted with permission from IEEE Std C57.12.00-1987 "Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

^bReprinted with permission from IEEE Std C57.12.01-1969 "Standard General Requirements for Dry-Type Distribution, Power, and Regulating Transformers.

^cRating also applicable to primary and secondary units substations.

vides enhanced protection against low magnitude ground fault currents. Therefore, connections will be delta-wye, except where other connections are technically advantageous. When wye-wye connections cannot be avoided, a three-winding transformer will be specified. The tertiary winding will be specified to be delta connected to provide a path for the third harmonic currents. Elimination of ferroresonance is not an acceptable reason for providing a wye primary connection.

f. Impedance. Standard impedances will be used to the greatest extent possible for reasons of economy. However, industry standards do not specify the percent impedance for overhead transformers or for pad-mounted compartmental distribution transformers of 500 kVA and less. Manufacturers supply these units with such low impedances that normal interrupting duties for protective devices may be inadequate. For this reason, it may be necessary to specify minimum impedances for three-phase pad-mounted compartmental and overhead type transformers. These impedances will be no more than are required by industry standards for secondary unit substations of the same kVA rating as shown on table 8-5. Where the designer feels that circumstances warrant specifying a minimum impedance for overhead and single-phase pad-mounted compartmental units, the values of table 8-5 should be used. Values greater than 1.5 percent for transformers 75 kVA and smaller are not justified.

g. Voltage taps. Power transformers for use in transmission to distribution substation applications are normally provided with manual voltage taps at no additional cost. Since taps are not

always required by NEMA or ANSI standards for smaller distribution transformers, the specifications will require taps on transformers where they are available.

h. Factory tests.

(1) *Standard manufacturer's tests.* "Routine" factory tests, in accordance with IEEE Std C57.12.00, will be specified for all transformers. Optional "design" and "other" tests, in accordance with IEEE Std C57.12.00, will be specified for transformers supplying critical facilities. "Routine" tests are tests made for quality control by the manufacturer on every transformer, or representative samples, to verify during production that the transformer meets the design specifications. "Design" tests are those tests made to determine the adequacy of the design of a particular type, style, or model of transformer to meet its assigned ratings and to operate satisfactorily under normal service conditions or under special conditions if specified; and to demonstrate compliance with appropriate standards of the industry. Design tests are made only on representative samples. "Other" tests are tests so identified in individual product standards which may be specified by the purchaser in addition to routine tests.

(2) *ANSI impulse tests.* A reduced wave, chopped wave, and full wave impulse test, in accordance with IEEE Std C57.98 will be required on all transformers rated 200 kVA and above. Since such a test is mainly for quality control, tests must be run for each transformer. Prototype tests do not indicate quality control deficiencies.

(3) *Optional NEMA impulse tests.* These tests are expensive and will not be provided for distribu-

Transformer kVA	Percent impedance, when primary voltage is less than 15 kV ^a	Maximum three-phase short circuit amperes ^b			
		208Y/120 volts		480Y/277 volts	
		From transformer	100% motor contribution	From transformer	100% motor contribution
112.5	2.0	15,600	1,300	6,800	500
150	2.0	20,800	1,700	9,000	700
225	2.0	31,300	2,000	13,600	1,100
300	4.5	18,500	3,300	8,000	1,400
500	4.5	30,900	5,600	13,400	2,400
750	5.75	36,200	8,300	15,700	3,600
1,000	5.75	48,300	11,100	21,000	4,800
1,500	5.75	72,500	16,700	31,400	7,200
2,000	5.75	96,600	22,200	41,900	9,600

^a These impedance values are reproduced by permission from NEMA Standard Publication No. 210-1970(R 1976) entitled "Secondary Unit Substations."

^b Transformer short circuit current based on unlimited utility company contribution.

Table 8-5. Standard Secondary Unit Substation Percent Impedances.

tion transformers. These tests will be specified for large transformers only (50 MVA and larger) or where reduced insulation is provided on transformer windings rated 115 kV and above. Optional NEMA impulse tests include either a nominal test sequence consisting of a reduced full wave, two chopped waves, and one full wave or a combined test sequence which interposes two or more front-of-wave tests between the reduced full wave and the two chopped wave tests on the nominal test sequence.

8-6. Amorphous Metal-Core Transformers.

Amorphous metal-core transformers will be used only where it can be demonstrated that the life-cycle cost of the installation is less than or equal to standard transformers. It has been reported by some studies that amorphous metal-core transformers can save energy by reducing no-load losses by 60 to 70 percent. However, since the percent impedance is decreased, the short-circuit current will increase proportionally. Therefore, the electrical distribution equipment associated with amorphous metal-core transformers must be increased in size to withstand the increased short-circuit current. The resulting energy conservation may be offset by the increased withstand ratings.

8-7. Transformers at Air Force Installations.

a. Single phase, self-cooled, with provisions to increase capacity if externally cooled, delta-wye if

connected for three-phase service. Nonflammable liquid or epoxy insulation is preferred. However, high tire point liquid or oil insulation may be provided if they are approved by the HOST/REQ CMD.

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

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

d. If pole mounting is required, radial brackets or cluster mounting is preferred in lieu of cross-arm or platform mounting for sizes 3 to 75 kVA.

e. Avoid locating transformers adjacent to building front entrances in landscaped areas. Prefer pad-mounting at the rear or side area where feasible.

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

CHAPTER 9

SURGE PROTECTION AND GROUNDING

9-1. Voltage Surges and Potential Gradients.

Even the best designed electric system is subject to overvoltages resulting from physical conditions not subject to the owners control. Dangerous potential gradients can result also from improper design.

a. Causes. Lightning imposes voltage surges on aerial lines either by direct strokes or by induction. Such surges can be transmitted to underground lines. Opening and closing circuits in large generating plants or switching stations can raise voltages to two or three times normal for a brief period of time. In addition, excessive voltages and currents can result from short-circuit conditions when line-to-line or line-to-ground faults occur, because of inductive/capacitive characteristics of the line between the electric power source and the fault location. Transformer ferroresonance can create overvoltages also as discussed in chapter 5.

b. Elimination. Since voltage surges can result in personnel injuries from electrical shock, insulation damage to equipment, and possibly fire, surge arresters will be used to provide safe dissipation of these surges. Grounding systems will be designed to limit potential gradients to values established by IEEE Std 80. Proper relaying will ensure isolation and disconnection of faulty equipment and lines when a short-circuit occurs.

9-2. Methods of Controlling Voltage Surges and Potential Gradients.

a. Surge arresters. Surge arresters will be of the valve-type or the metal-oxide-varistor type. Gapless, metal-oxide arresters are preferred because of their better operating characteristics. Surge arresters are used to safeguard apparatus against hazards caused by abnormally high voltage surges. Such overvoltage can cause serious damage if arresters are not correctly coordinated with the insulation strength of the protected equipment, and are unable to discharge the energy properly. To function correctly, arrester protective levels must be lower than the insulation withstand strength of equipment to be protected. Surge arrester protective margins will comply with IEEE Std C62.1, IEEE Std C62.2, and IEEE Std C62.11.

b. Characteristics. Arrester characteristics will have protective margins coordinated with the appropriate equipment insulation characteristics in accordance with IEEE Std C62.2. Lead lengths must also be taken into account.

(1) *Impulse sparkover voltage.* Impulse sparkover voltage is the highest value of voltage attained by an impulse of a designated wave shape and polarity applied across the terminals of an arrester prior to the flow of discharge current. This voltage plus the lead length voltage contribution is the highest that can be impressed on protected equipment because, at this level, the arrester will sparkover and discharge the surge to ground. Arrester front-of-wave sparkover voltage will be compared to the insulation lightning impulse (chopped-wave) crest value that the protected equipment is required to withstand for purposes of determining the protective margin.

(2) *Discharge voltage.* Discharge voltage is the voltage that appears across the terminals of an arrester during passage of discharge current. Arrester maximum discharge voltage will be compared to the BIL value that the protected equipment is required to withstand for purposes of determining the protective margin.

(3) *Impulse protective level.* For a defined wave-shape, the impulse protective level is the higher of the maximum sparkover value or the corresponding discharge voltage value.

(4) *Maximum continuous operation voltage (MCOV).* the MCOV is the maximum designated root-mean-square (rms) value of power frequency voltage that may be applied continuously between the terminals of a gapless arrester.

(5) *Voltage rating.* The nameplate voltage rating of an arrester is the maximum permissible operating voltage at which the arrester can operate correctly.

(a) Operation. An arrester has a maximum voltage level above which the arrester cannot seal off the 60 Hz line (follow) current, after sparkover on surge voltage. If the correct nameplate rating is used, the arrester can interrupt 60 Hz line current even though there is a line-to-ground fault on another phase. If the 60 Hz follow current is not immediately extinguished, the arrester may fail.

(b) Sizing. On a modern overhead, grounded wye primary distribution system (effectively grounded system), the arrester is able to reseal at a voltage level that does not exceed 1.25 times the nominal line-to-ground voltage. For a main electric supply station with a 13,200Y/7,620 V secondary, the minimum arrester rating would be $1.25 \times 7.62 = 9.53$ kV. A 9-kV arrester might not reseal so a 10-kV arrester, which is the next higher standard

rating, must be provided. For ungrounded and high-resistance grounded systems, ratings must equal or exceed the phase-to-phase system voltage dependent upon the size of the maximum ground fault that could occur.

(6) *Lead length.* Lead length is the length of line connecting the line terminal of an arrester to the energized line (line lead) plus the length of the line (ground lead) connecting the ground terminal of an arrester to a common ground. On riser poles the common ground is the conducting shield or sheath of cable at the cable termination. Leads will be kept as short as practicable, since voltage drops of both leads must be added to the sparkover and discharge voltages of the arrester when figuring protective margins. A commonly used figure for lead voltage drop is 2 kV per foot of length.

c. Classification. Arrester classification is based on specified test requirements. Of the six classifications available, only the four arrester types which are designated as station, intermediate, distribution, and secondary have suitable operating characteristics. Table 9-1 indicates protective margins for liquid-filled transformers of various primary voltages. The discharge values are for a 10 kA impulse current crest, the current com-

monly used as a basis for insulation coordination on a medium-voltage distribution system.

(1) *Distribution class.* Distribution arresters, with the lowest protective margins for voltage systems above 1,000 V will be used as an economical way of providing lightning surge protection for distribution equipment. Aerial to underground risers require surge protection, as do transformers, capacitors, and regulators mounted on poles.

(2) *Station class.* Station arresters are capable of discharging the most surge energy and, therefore, will be used at main electric supply stations for protection of incoming aerial lines and where needed for protection of equipment not within the protective radius of an incoming line arrester such as transformers and regulators.

(3) *Intermediate class.* Intermediate class arresters have protective characteristics and costs somewhere between those of station class and distribution class types. Intermediate arresters will be used to protect pole-mounted transformers and aerial-to-underground risers at munitions areas. Elsewhere, when such units are proposed as a substitute for other classifications, their use will be justified, except where such use is the installation's normal policy.

Transformer insulation	Voltage level	Arrester		Protective ratio comparison ^a					
				Sparkover ^b			Discharge ^b		
		Classification	kV	Arrester kV	Trans. kV	Ratio	Arrester kV	Trans. BIL	Ratio
Liquid-filled	4,160	Distribution	6	32	69	2.2	24.5	60	2.5
		Intermediate	6	21	69	3.3	16	60	3.7
	12,000Y/6,930 or 12,470Y/7,200	Distribution	9	45	110	2.4	37	95	2.6
		Intermediate	9	33	110	3.3	28	95	3.4
		Station	9	31	110	3.5	21	95	4.5
	13,200Y/7,620 or 13,800	Distribution	10	41	110	2.5	41	95	2.3
		Intermediate	12	40	110	2.7	32	95	3.0
		Station	12	41	110	2.7	27	95	3.5
	24,940Y/14,400	Distribution	18	72	175	2.4	71	150	2.1
		Intermediate	21	70	175	2.5	56	150	2.7
		Station	21	68	175	2.6	48	150	3.1
	34,500Y/19,920	Distribution	27	91	230	2.5	98	200	2.0
		Intermediate	30	94	230	2.5	80	200	2.5
		Station	30	99	230	2.3	70	200	2.8

^a Lead length not included.

^b Characteristics are median of the range of maximums listed in IEEE Std C62.2 and are reproduced with the permission of the Institute of Electrical and Electronics Engineers, Inc., from the Standard entitled "Gapped Silicon-Carbide Surge Arresters for AC Systems," copyright 1987.

Table 9-1. Aerial-Mounted Liquid-Filled Transformer Surge Protective Margins

(4) *Secondary class.* Secondary arresters will be used only for low-voltage services at munitions areas and buildings which house computer and sensitive electronics equipment. Arresters will be located as close to the electrical service entrance as possible and a separate ground conductor from the secondary service entrance will be bonded to the building ground ring. Range of voltage ratings is 0.175 kV to 0.650 kV. Secondary class arresters are required on Air Force facilities.

d. Location. Arresters will be located as close to the equipment protected as is practicable, in accordance with IEEE Std C62.2. Arresters will be connected to line conductors ahead of any overcurrent protective devices to prevent the lightning discharge from passing through the device. For Air Force installations, additional arresters will also be installed at corner poles, deadends, on both sides of switches, riser poles, and on every tenth pole in long, straight distribution line runs.

(1) *Underground connections.* Procedures for estimating magnitudes of surge voltages at distances remote from the transition arrester location are very complex. IEEE Committee Report, Surge Protection of Cable-Connected Equipment on Higher-Voltage Distribution Systems, recommends doubling both the sparkover and the discharge plus lead voltage for the arrester and then requiring a 15 percent margin over the equipment insulation. This recommendation will be followed in areas with numerous lightning storms and may require intermediate arresters at transition poles, arresters at transformer stations, or both provisions for adequate protection.

(2) *Main electric supply station connections.* On main electric supply stations, the incoming aerial line switching devices and the transformer primary terminals are the main elements requiring surge protection.

(a) *Incoming lines.* Arresters will be located on the line side of any incoming line fuse to prevent the lightning discharge from passing through the fuse. Arresters need not be installed on the line side of group-operated disconnect switches. However, arresters will be connected close enough to protect the switch adequately when the switch is closed. Line entrance gaps may be used on the line side of any switch for protection when the switch is open. Where two-column structures are provided as in figure 4-6, arresters will be mounted on the load side as this structure configuration does not lend itself to line side connection. Other structures, such as a double square bay structure, have a configuration which makes location of the arrester on the line side of the switch the most practicable arrangement.

(b) *Transformers.* Arresters will be located and connected as close as practicable to the transformer to be protected, in accordance with IEEE Std C62.2. In regions of high lightning incidence, surge arresters will be mounted on each of the incoming aerial line structures and directly on each of the main supply transformers.

(c) *Generators.* In addition to surge arresters at transition points between aerial and underground lines, surge protection will be necessary within a generator plant. Surge arresters in parallel with surge protective capacitors will be installed either at the terminals of the generator switchgear bus for overall machinery protection or at the terminals of each generator, dependent upon the degree of protection required. Surge protective capacitors reduce steep wave fronts, which if imposed on rotating machinery could result in stresses exceeding a machine's insulation impulse strength.

e. Overhead ground (or shield) wires. Overhead ground wires are run parallel to and above electrical lines, in order to shield lines from a direct lightning stroke.

(1) *Transmission and distribution lines.* Overhead ground wires are used for protection of transmission lines, but rarely is such an installation economical for distribution lines. Overhead ground wires will not be installed to protect distribution lines, unless such an installation is necessary to be consistent with local usage.

(2) *Main electric supply stations.* Shielding will be provided because of the cost and importance of such stations. Transformer stations with incoming aerial lines above 15 kV will be shielded because of equipment cost. Such shielding reduces possible surge voltages. This shielding may take the form of lightning masts located on top of the station metal structure to provide the required cone of protection for apparatus and circuits within the station area. The incoming line will be shielded for at least 1/2 mile from the station to provide sufficient line impedance between the non-shielded line and the station, otherwise high discharge currents could occur resulting in excessive arrester discharge voltages. When the incoming lines belong to the serving utility and shielding cannot be provided, design calculations must assure adequate surge arrester protection or other methods of limiting magnitudes of traveling waves.

(a) *Zone of protection.* The zone of protection of a shielding system is the volume of space inside which equipment is considered to be shielded. The shaded areas on figure 9-1 illustrate the zones of protection for both single and double mast or wire

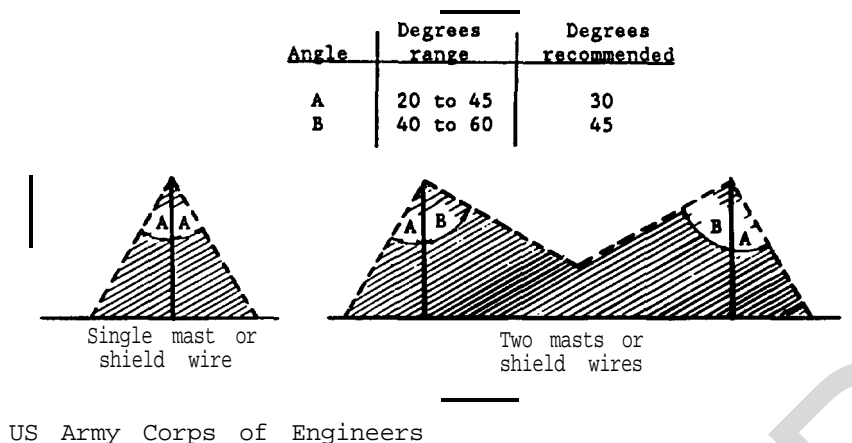


Figure 9-1. Zones of Protection for Masts and Shield Wires.

systems plus the range of angles often used and the maximum angles recommended.

(b) *Strength of wire.* Breakage of shield wires could result in outage and damage to equipment. To minimize possible damage, ground wires will be at least 7/16-inch, high-strength, zinc-coated steel (ASTM Std A 475) with a minimum breaking strength of 14,500 pound-force (lbf) and maximum design tension will be limited to 2,000 pounds per conductor.

f. *Grounding.* For safety reasons, electric power systems and equipment are intentionally grounded, so that insulation failure results in operation of protective devices to deenergize circuits, thus reducing risk to personnel. The word "grounding" is commonly used in electric power system work to cover both "system grounding" and "equipment grounding"; however, the distinction between system and equipment grounding must be recognized. A system ground is a connection to ground from one of the conductors of an electric circuit, normally the neutral conductor. An equipment ground is a connection to ground from non-current carrying metallic parts of the installation such as conduit and equipment cases of apparatus connected to an electric circuit. IEEE Std. 142 and ANSI C2 grounding practices will be used for all power generating and delivery systems.

(1) *System grounding.* System grounding discussed in IEEE Std. 142 includes ungrounded (3-wire); single-grounded (3-wire, source grounded); and multiple-grounded (4-wire) systems. The preferred system for new Army projects is the multiple-grounded four wire system. New Air Force projects will incorporate only multiple-grounded (4-wire) systems. See IEEE Std. 142 discussion of grounding and supply availability. Wye-connected electric distribution systems will be provided with a grounded neutral connection. Such intentional grounding minimizes the magnitude

and duration of over-voltages, thereby reducing the probability of insulation failure and equipment damage. Neutrals for each voltage level will be grounded independently at each electric power source; that is, at transformer secondaries and at generators.

(a) *Transformer neutral grounding.* Transformers which have wye-connected secondaries will be solidly grounded. Solid grounding is the least expensive method of limiting transient over-voltages while obtaining enough ground fault current for fast selective fault isolation. Other methods of grounding are resistance grounding and reactance grounding, but in most cases, reactance grounding of transformers provides no advantages over solid grounding. A disadvantage of systems grounded through resistors is that surge arrestors must be sized as if used on ungrounded systems, that is, with a voltage rating at least equal to the line-to-line voltage. Systems with voltage above 15 kV. will be solidly grounded because of the prohibitive cost of grounding equipment and the increased surge arrester cost. For voltages from 2.4 to 15 kV., solid grounding is preferable because distribution systems which supply transformers protected by primary fuses require enough fault current to melt primary fuses on a ground fault. However, in some cases, low-resistance grounding will be needed to limit ground fault currents to values less than withstand ratings of equipment when such equipment is designed for direct connection to voltages of the 2.4 to 15 kV level. Systems rated 600 V or less will be solidly-grounded except for applications such as continuous processes for industrial systems where shutdown would create a hazard, loss of materials, or equipment damage. For those applications, the designer will evaluate the use of a solidly-grounded wye-system with a back-up power supply, or a high-resistance-grounded wye-system. Use

of high-resistance grounded systems must be justified on the basis of a paramount necessity for service continuity.

(b) *Generator neutral grounding.* Generating units will be provided with reactor grounding only when solid grounding would cause ground fault current to exceed the short-circuit current for which the unit is braced and when harmonic current circulation needs to be minimized.

(2) *Equipment grounding.* Intentional equipment grounding maintains metallic surfaces at low potentials above ground, thereby decreasing possibility of electric shocks. System grounds and equipment grounds will be interconnected in accordance with ANSI C2 and the NEC. Some state safety orders do not permit grounding of enclosure cases supported on wood poles, when accidental contact with bare aerial lines might occur.

g. *Ground fault relaying.* Two types of ground fault relays are in general use. Ground overcurrent relays are used on medium- and high-voltage systems, and the less expensive ground fault protection device is used on low-voltage systems. Since no current or voltage is present in the ground conductor under normal system operation, ground relays can be made very sensitive. Ground relays can also be set to operate very quickly since coordination between voltage levels is not a constraint. Their use permits isolation of faulty equipment before short-circuits can cause damage.

(1) *Medium- and high-voltage systems.* The ground fault relay used will have the same time overcurrent characteristics as the overcurrent relays used for phase protection. The ground fault relay is interposed in the residual connection between the current transformers in each of the three phases and senses the fault current of a grounded wye connection. For further information on ground fault relaying see IEEE 141, IEEE 242 and TM 5-811-14.

(2) *Low-voltage systems.* Where low-voltage ground fault protection is required by the NEC, protection will be installed as a part of the switchboard, but some instances make installation advisable at the exterior transformer station. Although overcurrent relays can be used to meet the NEC requirements, the less expensive ground fault protection device is satisfactory.

(a) *Single electric source systems.* Ground fault protectors will utilize sensors of the vectorial summation type which either requires one sensor for each phase and the neutral (residual sensing) or one window type sensor around all three phases and the neutral (zero sequence sensing). Use of a single sensor on the main bonding jumper is not acceptable, because the additional grounding con-

nection at the transformer station provides a second path of fault current which is not sensed.

(b) *Multiple source electric systems.* Erroneous ground fault response can occur in multiple-source, three-phase, four-wire distribution systems. The common neutral conductors have multiple ground points providing alternate paths for fault currents, which if not properly monitored, can cause nuisance tripping or failure to trip. For such systems, a detailed analysis will be necessary to ensure ground fault protection that will trip appropriate circuit breakers dependent upon the fault location.

9-3. Ground Electrodes.

The most elaborate grounding system that can be designed may prove ineffective unless the connection of the system to earth is adequate and has a sufficiently low resistance. Since the desired resistance varies inversely with the fault current to ground, the larger the fault current the lower the resistance must be. For main electric supply stations and plants generating at medium voltages, the earth resistance will not exceed one ohm, and the ground grid will be designed in accordance with IEEE Std 80. For secondary unit substations and pad-mounted compartmental transformers larger than 500 kVA, earth resistance will not exceed five ohms, and the grounding system will be designed in accordance with IEEE Std 142 and IEEE Std 80. For electrical installations other than those listed above, the NEC requirement of 25 ohms maximum is acceptable.

a. *Resistivity of the soil.* The resistivity of the earth varies dependent upon its composition, as indicated in table 9-2. More moisture in the soil or a higher soil temperature decreases soil resistivity. The methods of providing earth connections given in this manual will be used to provide the required resistance to ground, except when the installation or the local utility indicates that special techniques are necessary. In that case, local practice will be followed.

b. *Elements of the system.* Ground cables will be copper. Other metals or metal combinations will be used only in those cases where the mechanical strength of copper is inadequate. Driven copper-clad steel ground rods will be specified as ground electrodes since such rods have a higher conductivity than most other types. Where low soil resistivities are encountered and galvanic corrosion may occur between adjacent ferrous metallic masses and the copper clad rods, consider the use of zinc coated steel or stainless steel rods. Stainless rods have a much longer life than zinc coated steel rods, especially in soils with high lime content, but

Table 9-2. Resistance of One 5/8-Inch by 10-Foot Ground Rod in Various Soils ^a.

Type of Soil	Resistance in ohms		
	Minimum	Average	Maximum
Ashes, cinders, brine waste	1.9	7.6	22
Clay, shale, gumbo, loam	1.1	13	53
Same, but with sand and gravel	3.3	50	433
Gravel, sand, stones, little clay or loam	19.2	300	1,460

^a Based on the resistivity of soils and formulas for calculation of resistance given in IEEE Std 142-1982. Use of a 3/4-inch diameter rod of the same length decreases resistance less than five percent.

stainless steel will corrode in certain soils and the higher cost of stainless steel must be justified. Stainless steel rods will not be used for Air Force installations. Use of pure copper rods must be justified because of the high cost and susceptibility of copper to damage during installation. The designer will coordinate and standardize grounding materials selection for each facility based on corrosive conditions, grounding materials requirements, cathodic protection, and lightning protection. Note that zinc coated rods do not conform to requirements of NFPA 78. While connection to an existing metallic water system provides low ground resistance, there is the possibility that water main maintenance or other work might result in accidental disconnection of grounds and create a hazardous condition. Therefore, such connections will only be provided as a secondary backup to made electrodes.

(1) *Additional electrodes.* Whenever the ground rod does not provide the required ground resistance, either longer or additional ground rods will be necessary. Since ground resistance decreases with an increase in ground rod depth, the use of longer ground rods is the most economical method. However, where rock is encountered, use of more rods, a ground mat, or a ground grid may be necessary. The space between rods will not be less than the length of a rod, and never less than six feet. The optimum spacing of ground rods is twice the length of the rod. Where the above methods do not result in the required resistance, electrolytic ground rods filled with nonhazardous metallic salts or bentonite slurry grounding wells may be used. Bentonite wells will be designed to meet criteria in IEEE 80.

(2) *Other made electrodes.* Butt grounds or ground plates may be provided on poles as an economical method of grounding the overhead ground wire, but their use is permitted only in areas where such an installation is local practice. These made electrodes will not be used as the sole grounding electrode for apparatus or neutral grounds, which require a ground rod installation as a minimum.

9-4. Grounding Details and Requirements.

Grounding will be provided in accordance with NESC, NEC, and IEEE Std 80.

a. *Main electric supply stations.* Because of the equipment layout within a station, steep voltage gradients might occur if each apparatus "island" were separately grounded.

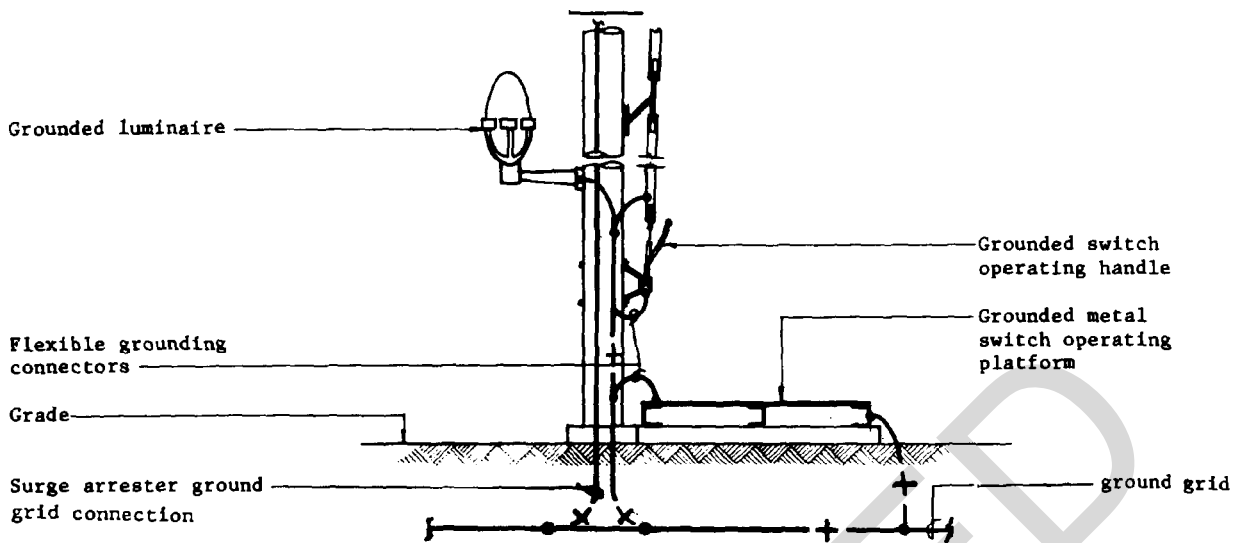
(1) *Ground grid.* In order to prevent steep-voltage gradients and also to design for maximum voltage excursions at the station, without the use of an excessive conductor size, a grid system designed in accordance with IEEE Std 80 will be installed below grade enveloping the fenced area. Figure 9-2 shows a typical substation grounding grid, Ground wire spacings of approximately 10 to 12 feet are commonly used. Exact spacing may be slightly more or less to suit station configurations. The perimeter ground wire will be installed not less than two feet outside the station fence to protect approaching personnel from step-and-touch potential exposure.

(2) *Special danger points.* Equipment operating handles are a special danger point because of the higher probability for coincidence of adverse factors, namely, the presence of a person contacting grounded equipment and performing an operation that can lead to electrical breakdown. If the grounding system is designed conservatively for safe mesh potentials, then the operator is not exposed to unsafe voltages. However, due to the uncertainty inherent in substation grounding design, a metal grounding platform, connected to the operating handle and to the grid in at least two places, will be placed so the operator must stand on the platform to operate the device (see fig. 9-2). This arrangement will be provided regardless of whether the operating handle is insulated.

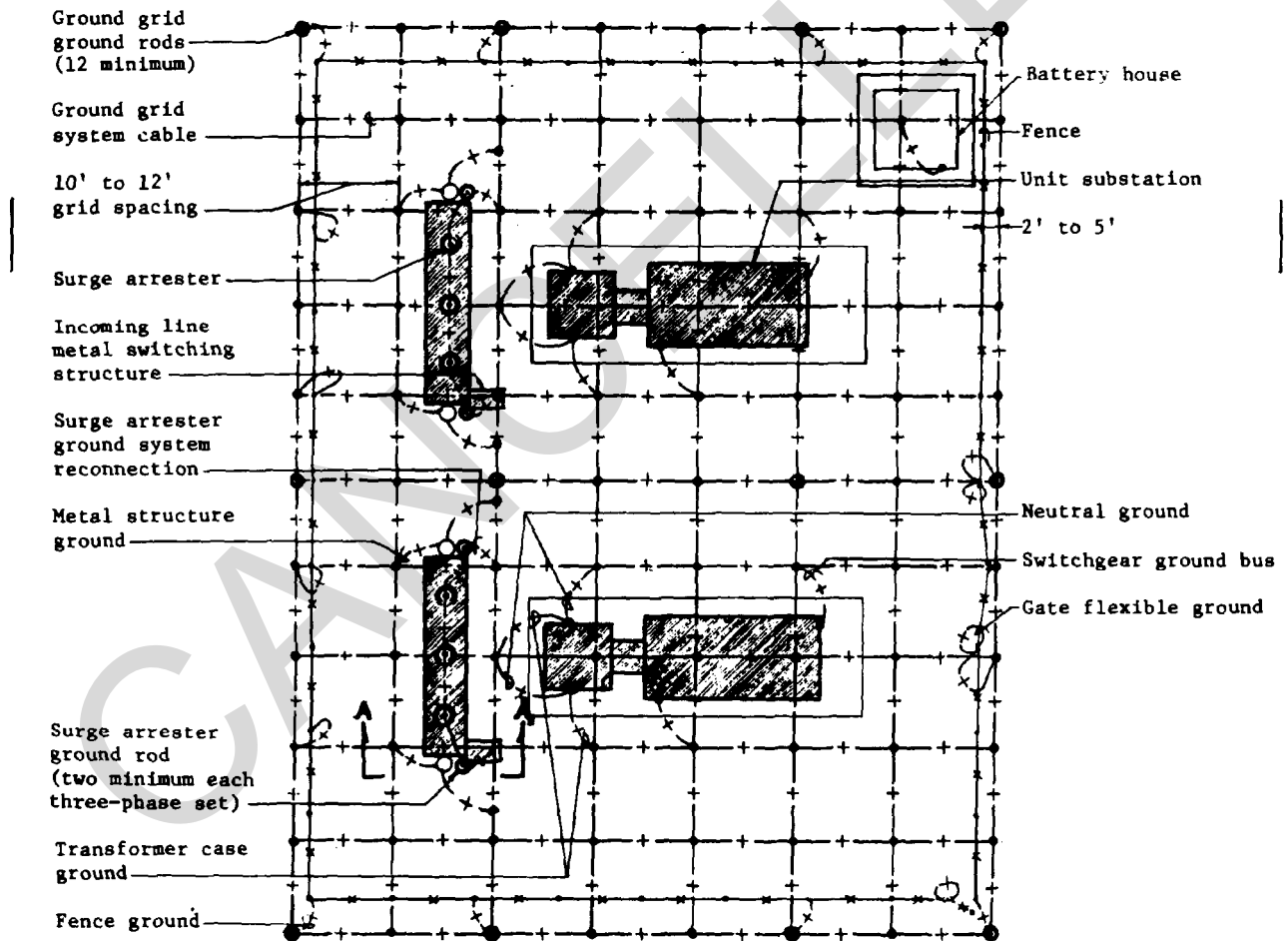
b. *Transformer installations.*

(1) *Multigrounded systems.* Primary and secondary grounding conductors will be interconnected as required by the NESC. Spark gaps will not be used. Grounding conductors will be sized in accordance with NEC and NESC standards.

(a) For aerial transformer installations (multi-grounded, common-neutral systems),



ELEVATION A - A



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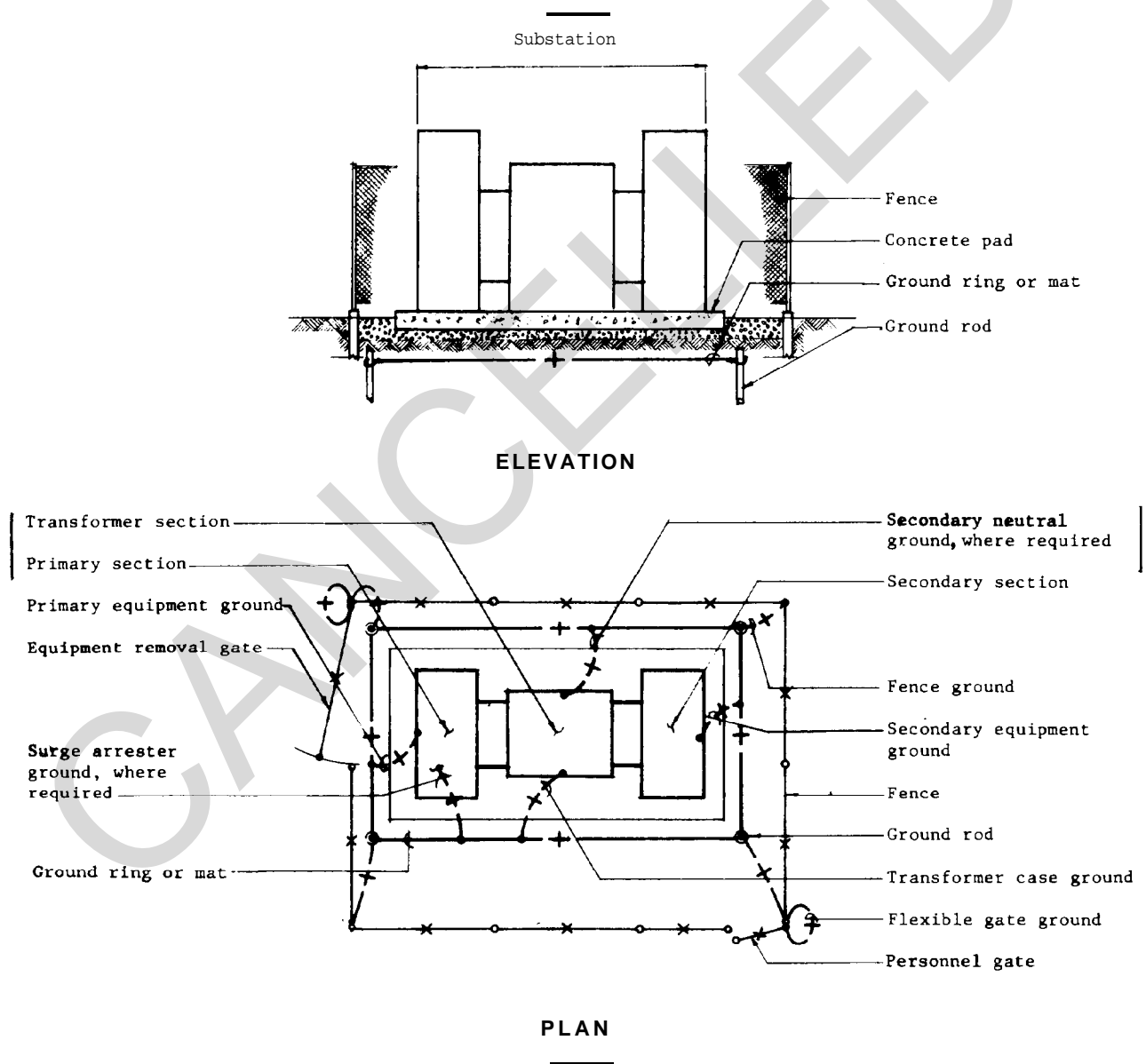
Figure 9-2. Grounding of a Main Electric Supply Substation.

grounding conductors will be directly interconnected at the transformer and then connected to a single, continuous, vertical grounding conductor run down the pole to a driven ground rod installation. Pole-butt grounds will not be used. Figures 8-1 and 8-2 illustrate aerial transformer grounding. All equipment, neutrals, surge arresters, and other items required to be grounded will be connected to this vertical grounding conductor.

(b) For pad-mounted transformer installations, grounding conductors will be connected directly to the transformer enclosure and then to the buried ground rods, mat, or ring. Figure 8-3, 8-4, 9-2, and 9-3 illustrate pad-mounted transformer grounding.

(2) *Ungrounded and single-grounded systems.* Primary and secondary grounding conductors of ungrounded or single-grounded systems will not be interconnected except through a secondary surge arrester as permitted by ANSI C2. Grounding conductors will be run separately to separate ground rods located not less than 20 feet apart as required by the NESC. The secondary grounding conductor will be insulated to the same level as the secondary connectors. Interconnection of grounding conductors below grade will not be permitted. Spark gaps will not be used.

c. *Medium-voltage riser poles.* Medium-voltage riser poles will be provided with surge arresters,



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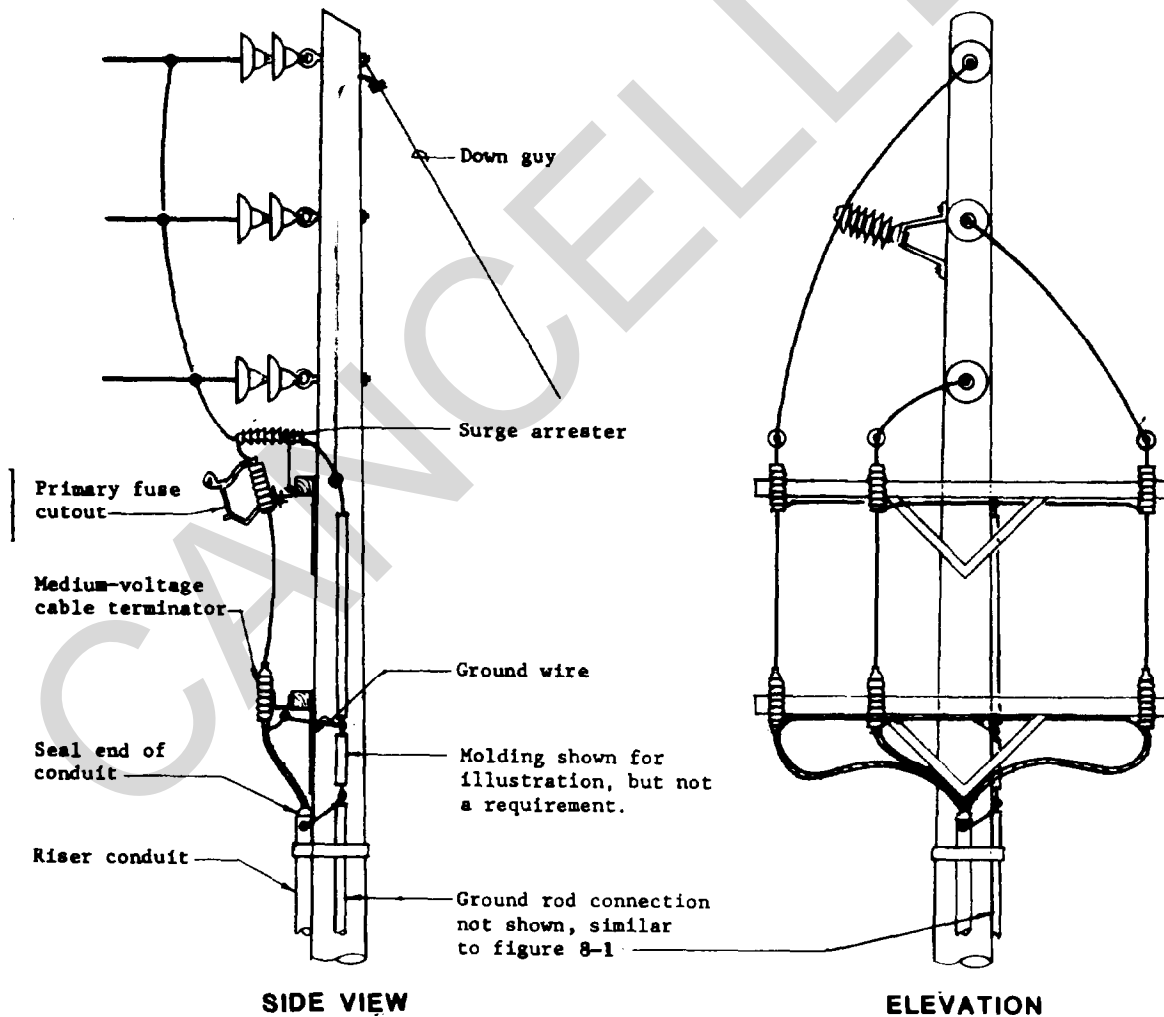
Figure 9-3. Grounding of Secondary Unit Substation Installation

even in areas having a low lightning incidence. Except for riser poles supplying critical facilities, the configuration for placement of surge arresters (i.e., at the cable termination or ahead of the fuse cutout) will follow local utility practice. For critical facilities, one set of arresters will be placed at the cable termination and another set ahead of the fuse cutout. Figure 9-4 illustrates a medium-voltage riser pole with arresters placed ahead of the fuse cutout to prevent lightning current from flowing through the fuse. Arresters are sometimes placed at the cable termination to reduce the length of the grounding conductor (and thus the voltage drop). However, this configuration allows the lightning current to flow through the fuse.

d. Miscellaneous. Conductive elements such as metal poles or reinforced concrete will be provided with an individual ground electrode connection in

addition to the required equipment grounding conductor. Possibility of mechanical damage, corrosion, and other conditions which can degrade the continuity of a grounding system make such multiple-grounding points necessary.

e. Instrumentation systems. Instrumentation systems will be grounded in accordance with NFPA 70. Because of the low-frequency nature of instrumentation systems, single-point grounding will be specified in accordance with MIL-HDBK-419A and FIPS Pub 94. For widely-separated installations, where it becomes impractical to implement single-point grounding, fiber-optic cable systems should be used for data transmission. Where fiber-optic cable is not practicable, follow grounding recommendations in MIL-HDBK-419A. Where transducers and associated devices are installed as an integral part of a facility, the instrumentation



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Figure 9-4. Provision of Surge Arresters at a Medium-Voltage Riser Pole.

grounding system will be coordinated with the single-point grounding system of other low-frequency networks. Inter-connection of such grounding systems will be made at a single point. Separate or isolated earth connections called "quiet grounds" (or any other such "name") will not be provided. Installations located less than 25 feet apart, with interfacing data cables, will have interconnected earth electrode systems. Installations located greater than 25 feet apart, with interfacing data cables, will be considered as stand alone installations, with individual earth electrode systems.

f. Ground fault return conductor. Medium voltage cable systems will incorporate a grounding conductor connected in parallel with the cable shields and bonded at each point where they are connected to ground. The conductor will be sized for the available system ground-fault, but will not be less than a # 2/0 AWG copper conductor. Metallic conduit is not an acceptable substitute for the conductor. The ground fault return conductor will not be required when concentric neutral cable is specified.

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CHAPTER 10

ROADWAY AND AREA LIGHTING

10-1. General.

Quantity and quality of illumination will conform to the latest issue of the Illumination Engineering Society's (IES) Lighting Handbook, except as modified in this chapter. Data contained in IES RP-8 provides a basic reference relating to the principles of standard roadway lighting practice. Unless otherwise indicated, illuminances are always on the horizontal plane at ground level. Where directed, illuminances will be modified to be in conformance with current energy conservation policies.

10-2. Roadway lighting Design.

a. *Illuminances.* The average maintained horizontal illumination recommended by IES is based on the type of traffic flow and the character of the surrounding area. On military installations, the values for road and area classification used will range from 4 lux (0.4 footcandles) to 13 lux (1.3 footcandles). Luminaires located along roadways and intersections at spacings ranging from 150 to 200 feet can provide illumination within this range as shown in table 10-1. The definitions of the IES classifications in table 10-1 can be found in the current IES Lighting Handbook. Spacings are approximate and may vary somewhat dependent upon the actual luminaire type, mounting height, roadway width, and other conditions applying. Lux and footcandles are related by an approximate 10-to-1 factor.

b. *Luminaires.* Luminaires of the enclosed type utilizing high-pressure sodium (HPS) lamps will be used. A discussion of the characteristics of various light sources is presented later in this chapter. Figure 10-1 indicates a typical roadway lighting installation. Bracket length is dependent upon the location of the luminaire and the roadway width,

but will not exceed 25 percent of the mounting height. Light distribution characteristics of any luminaire will suit the mounting height, road geometry, and uniformity required. Vertical and lateral light distribution and control of these characteristics will be indicated for each luminaire.

(1) *Vertical.* Vertical light distributions, based on spacing-to-mounting height ratios, are categorized as short, medium, and long distribution. Short distribution is suitable for pole spacings no greater than 4.5 times the mounting height; medium distribution is suitable for pole spacings from 4.5 to 7.5 times the mounting height; and long distribution is suitable for pole spacings from 7.5 to 12 times the mounting height. Medium distribution is the most appropriate choice for the mounting heights and spacings utilized on military installations.

(2) *Lateral.* Lateral (transverse) light distributions, based on the shape of the half candlepower isocandela trace which falls within the longitudinal distribution range, are classified as Types I through V. A general guide to their use, compiled from data in IES RP-8, is shown on figure 10-2. Selection is dependent upon whether the luminaire is situated at the side or at the center of the road, whether the luminaire is located between intersections or at an intersection, and the roadway width. Since most luminaires are mounted at the side of the road, Types II, III, or IV are used more often. Type II is used to light narrow roads, and types III and IV are used for lighting progressively wider roadways.

(3) *Control.* Control of the amount of light in the upper portion of the beam above maximum candlepower is classified as cutoff, semicutoff, or noncutoff. Semicutoff limits the lumen output above the nadir to 5 percent at 90 degrees horizon-

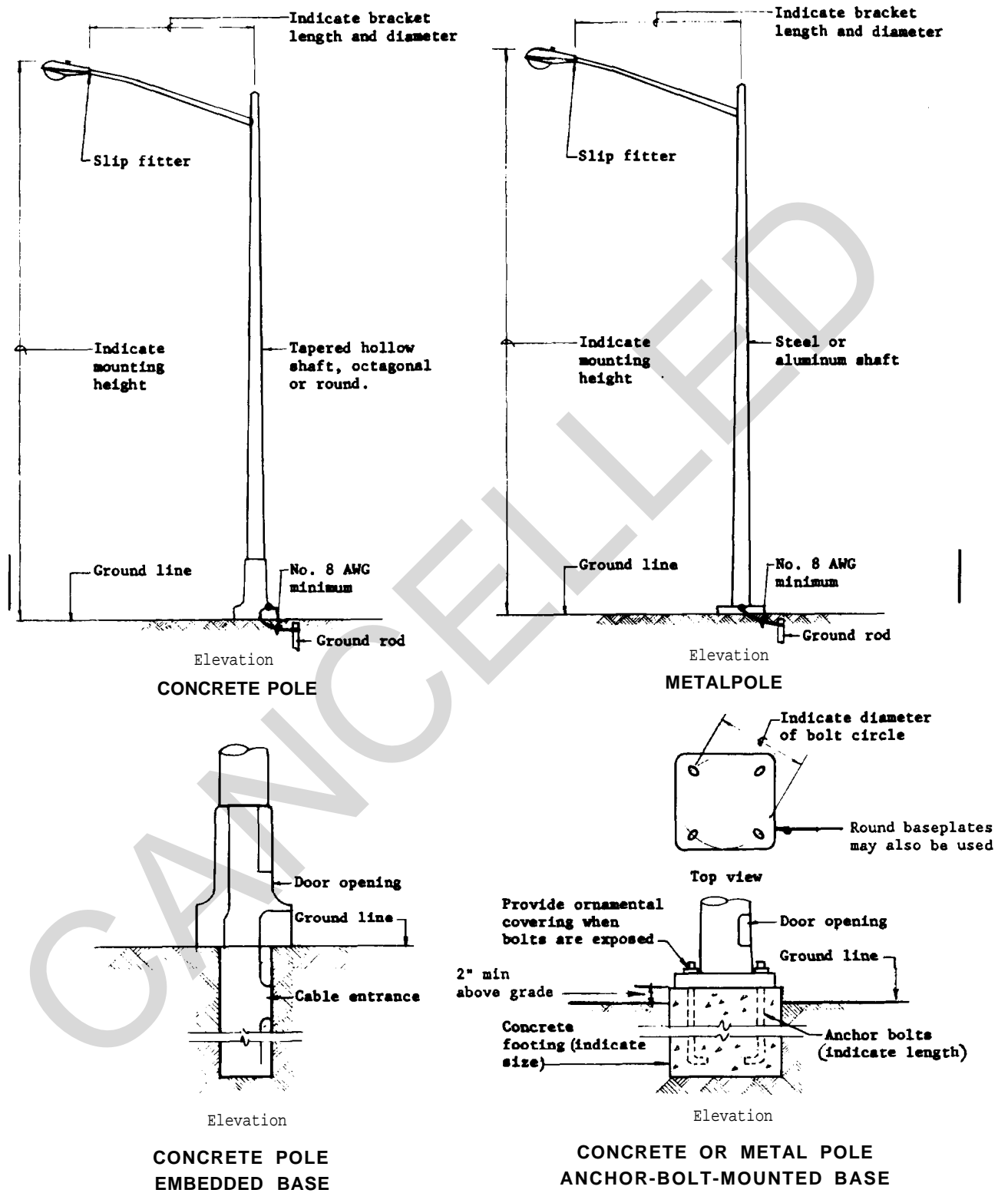
Table 10-1. Illumination Versus Spacing.

lux ^a (footcandles)	Spacing feet ^b	HPS lamp wattage	IES Classification	
			Road ^c	Area
4(0.4)	170	100	Local	Residential
9(0.9)	200	250	Collector	Intermediate
13(1.3)	150	250	Major	Intermediate

^a Required average maintained illuminance, with a uniformity ratio meeting IES requirements.

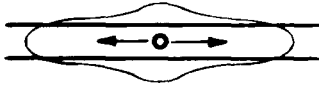
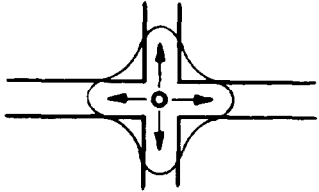
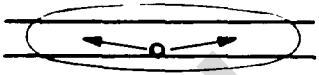
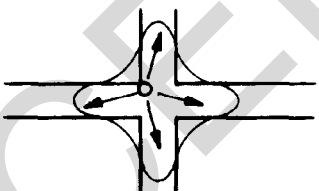
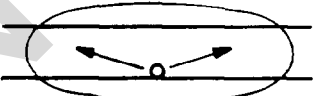
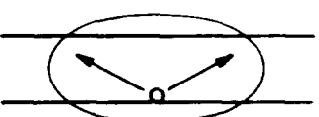
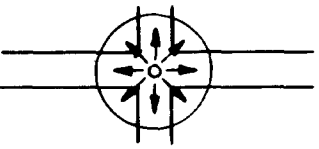
^b Based on units mounted 30 feet above the roadway on the same side. For intermediate areas, road width is assumed to be 40 feet and for residential areas to be 30 feet.

^c Based on R3 pavement classification.



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Figure 10-1. Typical Roadway Lighting Installation.

Distribution pattern number	Luminaire location with respect to roadway	Distribution pattern shape	Transverse roadway coverage (width) in multiples of mounting height (MH)	
			Transverse coverage	Placement
I	Center		Up to 2 x MH	Center suspension
I 4-way	Center		Up to 2 x MH	Local roadway intersections
II	Side		Up to 1.0 x MH	One side or staggered
II 4-way	Side		Up to 1.0 x MH	Local roadway intersections
III	Side		Up to 1.75 x MH	One side
			1.75 x MH and over	Staggered or opposite
IV	Side		Up to 2.75 x MH	One side
			2.75 x MH and over	Staggered or opposite
V	Center		Up to 2 x MH	Local roadway intersections

^a This material is reprinted by permission of the Illumination Engineering Society from IES RP-E-1983 entitled "Standard Practice for Roadway Lighting."

Figure 10-2. Lateral Lighting Distributions.

tally and to 20 percent at 80 degrees, whereas cutoff reduces these two percentages by one half, and noncutoff places no limitations. Semicutoff is selected as a compromise between noncutoff, where high brightness in the upper part of the beam produces both discomfort and disability glare, and cutoff, where lumen control necessitates closer spacings to satisfy uniformity requirements.

c. *Placement.* Luminaires will be located to provide uniformity of illumination with an average-to-minimum spacing ratio not to exceed three to one, except for local residential streets where the ratio may be as high as six to one; actual requirements will be checked against the IES Lighting Handbook guidelines. Luminaires for two and three lane roads will be placed on one side of the street for reasons of economy. Adequate coverage will be provided so that security is not degraded. For four lane roads, poles may have to be placed on both sides of the road for uniformity. The illumination at intersections will be at least twice that required on the intersecting roads. Figure 10-3 indicates that to meet this requirement, two luminaires are all that are necessary for two and three lane roads; but for intersections of four lanes or those with merging traffic, four luminaires are necessary.

10-3. Area lighting Design.

a. *Illuminances.* Illuminances will conform to the requirements contained in the IES Lighting Handbook for average maintained illumination, except as follows:

(1) Normal vehicle parking (including minor repair). Areas will have 5 lux (0.5 footcandles) average measured on 10-foot intervals, except where higher illuminances are approved. Often, roadway rather than floodlighting luminaires may be more suitable.

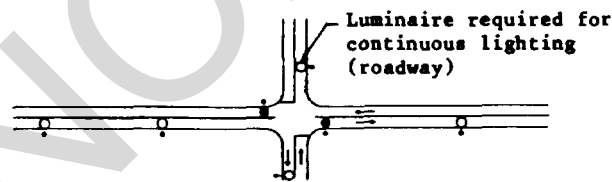
(2) *Sports lighting.* The classifications shown in table 10-2 will be used.

Table 10-2. Sports Lighting.

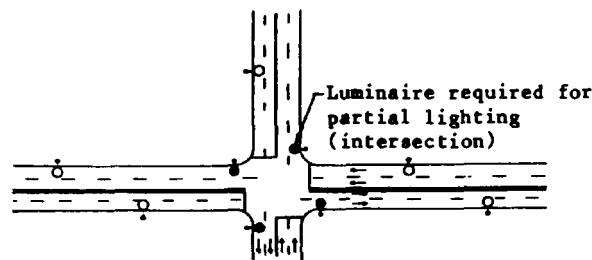
Baseball	Municipal and semi-professional
Softball	Industrial league
Football	Class III or IV
Other	Recreational

(3) *Storage areas.* Where lighting is required for nighttime use, a maximum of 20 lux (2 footcandles) will be provided, except where additional lighting has been justified or is required by the Using Agency.

(4) *Aircraft service areas.* Aircraft service areas will be illuminated in accordance with the criteria given in TM 5-811-5.



TWO LANE ROADS



FOUR LANE ROADS

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Figure 10-3. Intersection Lighting Placement.

b. Luminaires. Adjustable floodlights or roadway luminaires, with beam pattern selected for half over-lap, will be used as area lighting units. To provide economical coverage, a minimum of 60 percent of the beam lumens will fall within the area to be lighted. Floodlights will be enclosed type, either Heavy Duty (Class HD) or General Purpose (Class GP). A description of floodlight construction requirements is discussed in chapter 11. Use of Class 0 and Class 01 units, which are open types and accumulate more dirt, will be avoided.

c. Placement. Only areas with nighttime activities will be lighted. Floodlighting is not justified when used only for aesthetic purposes. Floodlights will be located on buildings, where practicable, or on poles or metal towers. Roadway luminaires adjacent to areas to be floodlighted may be utilized for both roadway and area lighting, where mounting height and spacing of units is appropriate for both types of illumination. Location of floodlights for apron and hardstands is covered in TM 5-811-5.

10-4. Walkway and Bikeway lighting Design.

Roadway lights and building exterior lights can serve also as walkway and bikeway lights. Maximum use will be made of multiple-purpose lighting systems.

a. Intensities. Values are dependent upon whether walkways and bikeways are adjacent to roadways or isolated from vehicular traffic.

(1) *Adjacent to roadways.* Walkways and bikeways will be illuminated to not less than one-half the maintained illumination required for adjacent roadways. Areas having changes in grade, such as

stairs and ramps, will require special treatment. Crosswalks in the middle of the block will be illuminated to 1.5 to 2 times the normal roadway lighting level.

(2) *Remote from roadways.* Walkways and bike ways remote from roadways will have a minimum of 5 lux (0.5 footcandle) average illumination measured on 10-foot intervals. Pedestrian tunnels will have 40 lux (4.0 footcandles), stairways will have 6 lux (0.6 footcandles), and overpasses will have 3 lux (0.3 footcandles) illumination.

b. Pole design. Where pole-mounted lights illuminate only walkways or bikeways, shorter poles are the most suitable, but luminaire height will not be less than 10 feet. Construction will be such as to minimize vandalism by use of break-resistant lenses, tamperproof screws, and sturdy poles.

10-5. Light Sources.

a. Selection. Selection of the light source will be made from high intensity discharge (HID) sources because of their luminous efficacy. The advantages and disadvantages of various lighting sources are listed in table 10-3.

b. Discussion.

(1) HPS lighting is the most energy efficient source which has an acceptable color rendition.

(2) Metal halide lamps have a good color rendition, but luminous efficacy, lumen maintenance (lumen output diminishes more rapidly throughout life), length of life, and restrike time make them a less than desirable source for many applications.

(3) *Unacceptable sources.* Fluorescent lighting has not been included in table 10-3 due to its relatively low luminous efficacy and the limited

Characteristics	Light sources			
	High-intensity discharge			Incandescent
	HPS	Metal halide	Mercury vapor	
Luminous efficacy (lumens/watt) ^b	45-135	70-110	20-60	15-25
Lumen maintenance	Good	very low	Poor	Good
Lamp life (kilohours)	10-24	5.5-20	12-24	1-3.5
lamp life (years) ^c	2.5-6	1.375-5	3-6	0.25-0.875
Startup time (minutes)	2-4	3-5	5-7	0
Restrike time (minutes)	1	10-15	3-6	0
Color rendition	Good	Good	Fair	Very Good
Neutral surface color effect	Yellow-pink	White	White	Yellow-white

^a Courtesy of Keller & Gannon (Rev. 1991, per IES data).

^b Ballast losses are included.

^c Computed based on 4,000 burning hours a year.

Table 10-3. Characteristics of Light Sources.

control possible with the tubular shape. Low-pressure sodium lighting is also not included, as the color is monochromatic and therefore is not considered suitable for general use. The amount of sodium in low-pressure sodium lamps requires special disposal methods if such lamps are not to pose a fire hazard. Incandescent lighting has not been included because of the extremely low luminous efficacy and short lamp life. Mercury vapor lighting is also not included because of lower luminous efficiencies, poor lumen maintenance, higher life cycle costs, and environmental considerations (mercury propagation and disposal).

c. Lamp designations. Lamps will be designated in accordance with the requirements of ANSI C78.380 in order to provide nationally applicable and convenient lamp identification symbols. These designations ensure interchangeability of lamps bearing the same symbol. Each lamp bearing an ANSI designation has been provided with that specific designation in accordance with the method shown on figure 10-4. Although technically low-pressure sodium lamps are not HID lamps, they are included under ANSI C78.380 as a convenience.

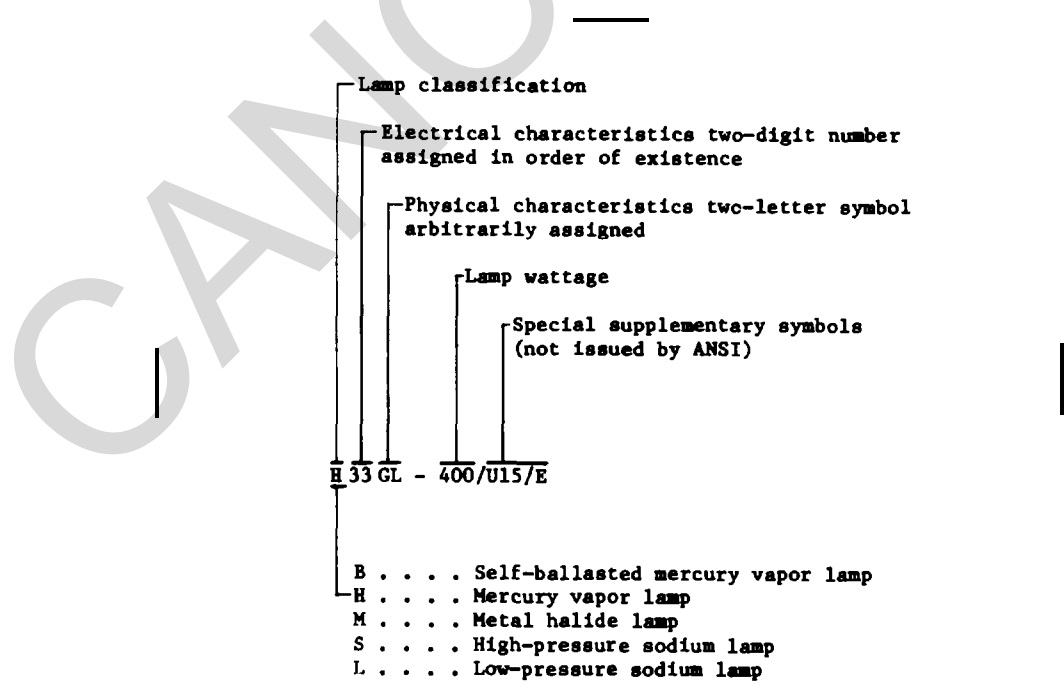
d. Ballast characteristics. Ballast circuits and operating characteristics vary dependent upon the type of ballast circuit provided. Both ANSI C82.4 and manufacturer's terminology for ballasts can be confusing and sometimes appear contradictory. For

that reason, HID ballasts will be specified by the operating characteristics desired. When ballast specifications cover indoor lamps the ANSI lamp ambient temperature range of 50 degrees F and above may be more appropriate than extending the range down to 5 degrees F, minus 22 degrees F, or minus 40 degrees F which are also available.

10-6. lighting Control and Wiring System.

a. On-off control. Luminaires for dusk to dawn operation will normally be controlled by a photoelectric cell installed on each luminaire; however, central control may be more economical for luminaires having fixed hours of operation. An automatic system using a time switch with an astronomical dial or a manual on-off control will be used for such cases.

b. Type of system. Multiple wiring systems will be installed, except for extensions to existing series systems or for long access roads where voltage drops exceeding that permitted for multiple lighting systems would occur. Circuits for multiple lighting will be designed to utilize the highest low-voltage level appropriate for the installation in order to keep wire sizes and voltage drops to a minimum. Lamps will be connected phase-to-neutral rather than phase-to-phase. Where practicable, units will be connected to transformers which serve other loads. Protection and disconnection of lighting circuits will be provided.



^aThis material is based on information provided in the ANSI Standard entitled "Method for the Designation of High-Intensity-Discharge Lamps" ANSI C78.380.

Figure 10-4. Key to Standard HID Lamp Designations.

c. Grounding. All lighting circuits will include an equipment grounding conductor. The equipment grounding conductor may be any conductor

approved by the NEC, and will be bonded to the noncurrent-carrying metal parts of each lighting standard and luminaire.

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CHAPTER 11

SECURITY LIGHTING

11-1. General.

Quantity and quality of illumination will conform to the latest edition of the Illuminating Engineering Society's (IES) Lighting Handbook, except as modified in this chapter. Specific requirements for Army security lighting are covered by AR 50-5-1 for nuclear weapons, AR 190-59 for chemical agents, AR 190-11 for arms, ammunition, and explosives, and AR 190-51 for Army property at unit and installation level. Other security lighting requirements pertaining to classified areas may be obtained from the Department of Defense. For Air Force security lighting requirements, AFI 31-301, Air Base Defense will be used. In all cases, project specific criteria will apply when such requirements are more rigorous than those provided in this manual.

11-2. Authorization.

The using agency determines when security lighting is necessary to illuminate boundaries and areas so that unauthorized entry is visible to those responsible for security. That determination should be based on what is being protected and the threat against which it is being protected. The using agency will also designate the maximum acceptable period for which loss of illumination can be tolerated so that acceptable backup sources can be provided. Without specific data, 2 minutes is considered the maximum outage period acceptable.

11-3. Use of Security Lighting Systems.

Lighting systems for security operations provide illumination for visual and closed-circuit television (CCTV) surveillance of boundaries, sensitive inner areas, and entry points. When CCTV is used as part of security operations, the lighting system will be coordinated with the CCTV system. The type of lighting system is determined by the installation environment and the intended use. Often two or more types of lighting systems are used within a single area.

a. Objective. The fundamental objective is that any system or combination of systems must always work to the maximum advantage of the security force and to the maximum disadvantage of the aggressor. The system will ensure a high probability of detection of unauthorized entry attempts and will thereby discourage aggressors. Lights will be spaced and located to minimize the impact of a

single lamp failure. Lighting system design will be reliable and easily maintainable.

b. Coordination. Where installed on airfields, security lighting must be coordinated with the flight safety officer so that aircraft takeoff, landing, and ground operations are not impaired. Airfield security lighting will be coordinated with airfield navigational lighting. Avoid glare lighting which interferes with the vision of occupants of adjacent areas and roadways. Where lighting near navigable waters is required, the U. S. Coast Guard will be contacted to determine if the system provided requires Coast Guard approval.

11-4. Types of Areas to be Lighted.

Three distinct types of areas are lighted. These areas are boundaries, sensitive inner areas, and entry points.

a. Boundaries. Illumination of a restricted area boundary includes exterior and interior clear zones adjacent to boundary barriers (fences) or, in some cases, the area between multiple barriers. The design will provide adequate light on the bordering area, glare light in the eyes of the aggressors, and minimum light on guard personnel. Glare which handicaps guards or authorized operations will be avoided. Poles will normally be placed inside the boundary fence and between the patrol road and boundary, but, the pole location must be coordinated with the user to ensure that the applicable egress requirements of the clear zone are not violated. The distance of poles from the fence will not be less than 5 feet, and this minimum distance will be used only where the patrol road is close to the fence. Either glare projection or controlled lighting will be provided. Glare projection lighting provides better protection and will be used to illuminate flat areas free of obstruction for at least 100 feet outside the fence. Illumination levels for controlled lighting will be adequate to detect a moving aggressor, either visually or by use of CCTV. Controlled lighting, which does not project masking glare, will be used when it is necessary to limit the width of the exterior lighted area, because glare would interfere with authorized activities or activities outside the installation. When designing for glare lighting, the designer will check for light pollution ordinances of local governing bodies.

b. Sensitive inner areas. The lighting for sensitive inner areas will be discussed with the appro-

Table 11-1. Security Lighting Requirements.

Type	Application		Illumination width feet		Minimum illumination	
	Lighting	Area	Inside	Outside	lux ^(a)	Location
Boundary	Glare	Isolated	25	100	2 (0.2) ^(b)	Outer lighted edge & 30 ft. out
			10	70	4 (0.4)	At fence
	Controlled	Semi-isolated	10	70	2 (0.2)	Outer lighted edge
					4 (0.4)	At fence
Sensitive inner area	Area	General	20-30	30-40	4 (0.4)	Outer lighted edge
					5 (0.5)	Within
		At structures	50	-	2-5	Entire area
					(0.2-0.5) ^(c)	
Entry point	Controlled	Pedestrian	25	25	20 (2)	Entry pavement and sidewalk
		Vehicular	50	50	10 (1)	

^a Horizontal plane at ground level (6 inches above grade) unless otherwise noted. Footcandles are shown in parentheses.

^b Vertical plane, 3 feet above grade.

^c Use the higher value for the more sensitive or confined areas.

^d Initial field measurements will be multiplied by light loss factors to determine the maintenance levels.

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appropriate security agency. Lighting installed and focused to illuminate the interior of a restricted area assists security forces in surveillance and may deter aggressors. The system will be designed so that detection of an aggressor within the restricted area is assured. Shadows, except those cast by aggressors, will be avoided. Sensitive areas or structures may include pier and dock areas, parking areas, vital buildings, storage areas, and vulnerable areas of the communication, power, and water distribution systems.

(1) *Luminaires.* Lighting units can range from ordinary floodlights to more elaborate pole-mounted fixtures capable of illuminating comparatively large sectors of adjacent terrain, such as those used for stadium lighting. Lighting units may also include pivotable, individual spotlights or searchlights. Where night operations which require work area lighting are conducted, the area lighting will be configured to facilitate the detection of unauthorized approach. Special purpose lighting may be necessary for some applications.

(2) *Towers.* Security towers, whether continuously or intermittently occupied, will be provided with a movable luminaire or searchlight which is controlled at the tower. High intensity illumination at long range is the essential characteristic of a movable lighting system.

c. Entry points. Lighting is installed at entry points through boundaries or into interior sensitive areas to facilitate accurate and rapid identification of personnel requiring entry into the area and complete inspection within and under vehicles. Entry point lighting will be installed in any restricted area for which entry controls are required during normal operations. Fixtures will be placed so that light sources are above and behind

the entry guard and facing persons or vehicles approaching the area. If the area is equipped with a boundary lighting system, the entry point light pattern will extend outward from the boundary or gate of the area. The entry (guardhouse) in such instances, will be inside the area in comparative darkness.

11-5. lighting Guidelines.

a. Area and boundary descriptions.

(1) The boundary is considered to be the perimeter fence. If there is no fence, the property line is the boundary.

(2) An isolated fenced boundary consists of fence lines around a large isolated facility where the area outside the fence is clear of obstructions for 100 feet or more, and the fence is at least 100 feet away from any inner buildings or operating areas.

(3) A semi-isolated fenced boundary consists of fence lines where the area outside the fence is clear for only 60 to 100 feet.

(4) A non-isolated fenced boundary consists of fence lines where the fence is adjacent to operating areas within the installation or to public thoroughfares or other installations outside the boundary. The width of the lighted area depends on the clear distances available.

(5) A sensitive inner area is a storage or open workspace inside a lighted boundary where additional security lighting is required, particularly for aisles, passageways, and vantage points of adjacent buildings.

(6) A sensitive inner structure is either within 20 feet of critical operations or houses critical operations (such as structures or buildings for power, heat, water, communications, explosive ma-

materials, critical materials, delicate machinery, classified material, and valuable finished products) where additional security lighting is required so that doorways, windows, and insets will not be in shadow.

(7) An entry point is where access to protected areas requires complete inspection of pedestrians, passenger cars, trucks, and freight cars entering or leaving.

(8) Because confined areas offer a place to hide, a shorter length of time is available to detect an aggressor. In these areas, illumination will be at higher levels and uniformly cover all surfaces requiring observation.

b. *CCTV lighting.* When CCTV is used as part of the exterior security system, coordinate the design of the lighting system with the CCTV to ensure proper operation of the CCTV system during hours of darkness.

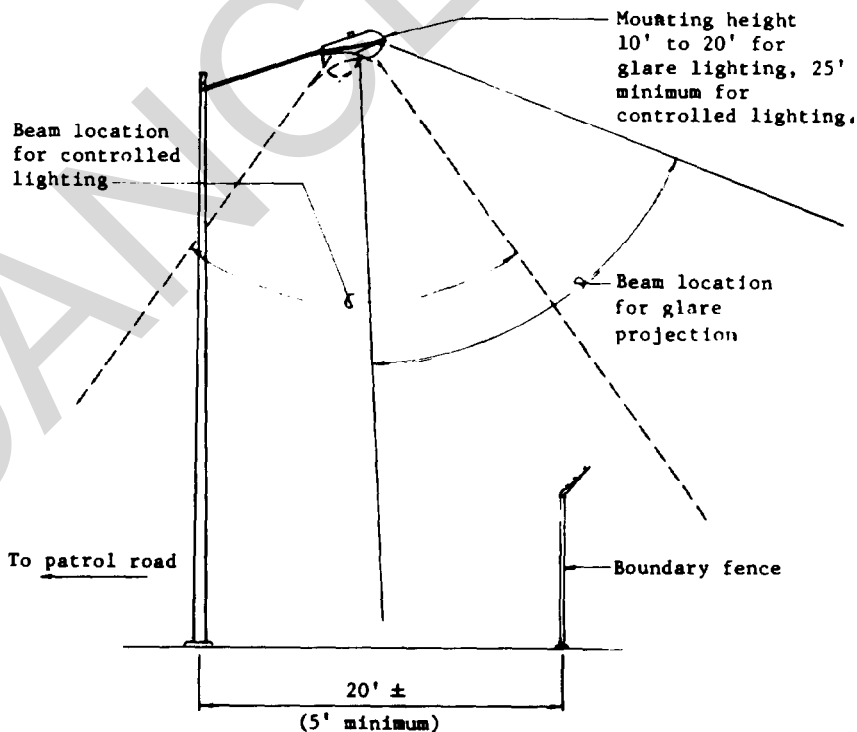
(1) *Balanced lighting.* The best image contrast is obtained by a scene that is uniformly illuminated. A CCTV outdoor lighting system must illuminate the entire surveillance area within a single camera's field of view so that the maximum light-to-dark ratio does not exceed 6 to 1, while providing the minimum faceplate illumination level required by the camera throughout the camera's field of view.

(2) *Camera and light source alignment.* The camera must be located below the plane of lighting fixtures used to illuminate the area. If side lighting is used, the camera should not look directly into the lighting plane. The lighting fixtures and camera should be aimed in the same direction.

(3) *Spectral compatibility.* There are many different types of CCTV cameras available for exterior use. Each type of camera has a specific spectral response. It is important that the spectral output of light sources used for exterior lighting in conjunction with CCTV systems is matched to the spectral response of the CCTV cameras.

c. *Intensities.* The type of lighting system, area to be covered, and minimum levels of illumination are shown in table 11-1, except where exceeded by other requirements and applicable criteria. Typical applications of security lighting systems are shown on figure 11-1. The illumination levels in table 11-1 are minimum maintained measured at any point at any time. These levels include the lamp lumen depreciation, fixture maintenance factors, and other applicable light loss factors.

d. *Quality of illumination.* The illumination uniformity ratio of the maximum to the minimum at any point to ensure adequate quality of lighting for visual assessment by security personnel will be



US Army Corps of Engineers

Figure 11-1. Application of Required Lighting Intensities

provided. The ratio in the entire clear zone outside the perimeter fence will not exceed 10 to 1 and within a 30-foot inner area will not exceed 6 to 1. Area lighting will not exceed a 6 to 1 ratio.

e. Design considerations. During design, consider field conditions that could affect or degrade performance. These conditions include extreme temperatures, dust, corrosion, uneven terrain, obstructions, and irregular line voltages. Design illumination level should be set above the criteria minimums and be increasingly conservative where one or more field conditions are uncontrolled.

11-6. Light Sources.

When designing system for CCTV, coordinate the restart capability with the user. In some cases security regulations require instant restart. High intensity discharge (HID) lamps are more energy-conserving than incandescent lamps, but they require several minutes to warm up and restart after a power interruption. The warmup time to reach 80 percent of normal output will require a few minutes or more. Restriking takes a minute for high-pressure sodium (HPS), but requires longer intervals for other HID sources. Specially designed lamps and auxiliary equipment are available where rapid start is required. Low-pressure sodium (LPS) lamps require 7 to 15 minutes to start, but most lamps will restrike immediately after a power interruption. Fluorescent and the higher wattage LPS lamps cannot be provided with the type of directional control needed for protective lighting systems, but may be used where such control is unnecessary, such as at guardhouses. Either HPS lamps or incandescent lamps are acceptable, but the energy savings that HPS lamps provide make their installation preferable. Incandescent lamps will be used only when a life cycle cost analysis indicates such a source is the most economical choice or when required by operational considerations. The instant-on characteristic of incandescent lighting is a major factor in favor of its use. When lighting remains "off" during normal nighttime conditions, but is turned "on" during alerts, such as in the use of searchlights, the 5- to 10-minute warmup time for HPS units cannot be tolerated, which results in incandescent lighting being the only practical alternative. Tungsten-halogen incandescent lamps, also known as quartz-iodine, with a longer lamp life than the conventional tungsten type, should be considered for incandescent lamp applications where appropriate. The LPS lamps may be considered if procurement and installation is in accordance with current Federal Acquisition Regulations (FAR). In addition, LPS lamps should be avoided

where accurate color rendition is required because they have a monochromatic spectrum. A one-third mix of another light source mixed with LPS may be used when color rendition is a factor. Very near infrared (VNIR) lighting used together with infrared sensitive CCTV cameras has been used to detect an aggressor without the aggressor's knowledge. VNIR is useful where visible light would be a problem (such as a flight line). VNIR will be applied only when directed by the using agency.

11-7. Electrical Power Sources.

a. Alternate electrical power requirement. In the event of an outage of normal electrical power, a reliable alternate electric power source is necessary to ensure continuous illumination. A standby generator will be used as the alternate source, except where the electric power requirements of the lighting system are small enough to make battery backup more economical. Either automatic or manual starting of the generator and load transfer will be provided depending on the permissible electric power outage duration. In some cases, portable generators or portable battery-operated lights are required in addition to stationary auxiliary electric power sources. Provision of portable units is not the designer's responsibility, beyond providing a connection point when directed by the using agency. The total design may require concrete pads adjacent to the connecting points for placement of the portable units.

b. Backup electrical power requirement.

(1) *Additional outage (restrike) time for HID lamps.* When HID lighting is used, the generator startup outage time is extended by the amount of time required to restrike the arc in an HID lamp plus the time required for the lamp to reach full lumen output. The shortest restrike time applies to HPS lamps and is less than 1 minute from a hot-lamp state. A lamp is considered to be hot for 3 minutes after loss of electric power. Cold-start time of 5 to 10 minutes for HPS lamps does not apply when auxiliary electric power is supplied. The total time lapse on loss of normal electric power to full HPS lamp lumen output including allowance for engine-generator startup is 4 to 5 minutes (10 to 17 seconds for generator startup plus 55 to 60 seconds to restrike and 3 to 4 minutes to full lamp lumen output).

(2) *Tolerable outage time.* Where the Using Agency has determined that the outage time or reduced lighting levels must be less than 4 to 5 minutes, lamps and auxiliary equipment with the desired output parameters for rapid startup and restrike will be specified. The lamp lumen output level at restrike of a hot restrike system is

inversely proportional to the time power is off. The lamp will restrike at approximately full lumen output only with a momentary power outage. Once the outage time reaches 30 seconds, the lumen output approaches zero at restrike and the time required until full lumen output is 3 to 5 minutes. The use of restrike systems should be carefully engineered to achieve the desired minimum illumination levels required.

(3) *Uninterruptible power supplies (UPS).* The UPS will not normally be used for security lighting systems. If the using agency or other criteria specifically requires the use of UPS, the contract documents must clearly identify the nonlinear nature and switching patterns of the load to be served. The UPS designed for computer loads will not perform satisfactorily for lighting applications.

11-8. Luminaires.

a. *Type.* Luminaires will be of the enclosed type with light distribution characteristics selected for the type of lighting system required. Characteristics of roadway type luminaires are discussed in chapter 10. Table 11-2 describes various beams and classes of floodlights which are appropriate for security lighting applications. Floodlighting luminaires will have a heavy-duty enclosed outer housing and a separate removable inner reflector.

b. *Specific usage requirements.*

(1) *Boundaries.* For boundary isolated area applications, glare projection luminaires may be used which have the rectangular distribution pattern that a floodlight with a wide horizontal distribution and a narrow vertical distribution (type 6 by 2) provides. For controlled lighting applications, use luminaires with wide lateral beam spread that roadway luminaires with IES type I through III distribution or floodlights with wide horizontal and medium to wide vertical distributions that types 6 by 3, 6 by 5, and 5 by 3 would provide.

(2) *Sensitive inner areas.* Inner area luminaires will have the circular symmetrical distribution that a roadway type V or floodlight 4 by 4 and 6 by 6 would provide. Where there is a general area lighting requirement for nighttime

activity, as defined in chapter 10, luminaires may provide both security lighting and area or roadway illumination.

(3) *Entry points.* Luminaires with symmetrical light distribution and a medium to wide spread beam are suitable for entry point lighting. Luminaires will be aimed at checkpoints from several directions to facilitate inspection.

(4) *Special purpose applications.* Special purpose applications may require use of spotlights, floodlights, or searchlights, depending upon the type of security required. Searchlights are appropriate where it is necessary to spot moving objects at great distances; the beam spread will be only about 6 degrees. Size and candle power of searchlights depends on the length of throw required, and the atmospheric conditions encountered. A 1,000,000 beam candle power searchlight (approximately 1,000 watts) has an effective range of approximately 1,000 feet. Where stationary lighting must be supplemented, truck-mounted units are available, but provision of such units is not the designer's responsibility.

11-9. Wiring and Control.

a. *Wiring systems.* Multiple systems will be installed, except where their use is clearly impracticable. The circuit protective devices, transformer, and wiring will be within the restricted area. Wiring will be located underground to minimize the possibility of sabotage or vandalism. Equipment and design will provide for simplicity and economy in system maintenance. To minimize security degradation during faults, feeders may be 3-phase, 4-wire with single pole overcurrent devices at the service equipment. Consecutive luminaires will be connected to alternate phases of 3-phase feeders. Supplemental in-line fuses will be placed at individual poles.

b. *On-off control.* On-off control will be automatic, manual, or manual/automatic as appropriate.

(1) *Automatic.* Boundary and area lighting on-off control will be automatic and will be activated during periods of darkness or at other times when visibility is reduced or by electronic security systems. In hostile environments, automatic on-off

Table 11-2. Floodlight Beam Descriptions.

<i>Floodlight type designation</i>	<i>Beam spread degrees</i>	<i>Beam description</i>
2	18 up to 29	Narrow
3	29 up to 46	Medium-narrow
4	46 up to 70	Medium
5	70 up to 100	Medium-wide
6	100 up to 130	Wide

control must be capable of being deactivated which may require either manual/automatic or manual on-off control depending upon the site.

(2) *Manual.* Wherever manual on-off control is appropriate, on-off controls will be accessible to and operable only by authorized personnel. Systems which are designed to remain "off" until needed will have "on-off" control at the surveillance location and will meet instant-on requirements.

c. *Grounding.* All lighting circuits will include an equipment grounding conductor. The equipment grounding conductor may be any conductor approved by the National Electrical Code, and will be bonded to the noncurrent-carrying metal parts of lighting standard and luminaires.

11-10. Field Measurements.

Whenever performance of the security lighting is to be measured after installation and compared to design criteria or predicted performance, design documents will need to identify test conditions, instrumentation, and expected, or acceptable, performance under specific conditions and at specific times. Illumination measurements should be performed after a 100-hour burn-in period. A set of baseline measurements to determine background illumination (contribution from moonlight, adjacent facilities, etc.) should be taken first and deducted to correct the field recordings. If design documents do not identify initial values, a multiplier (maintenance factor or light loss factor) should be stipulated to convert measured values to corresponding maintained illumination levels.

APPENDIX A

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APPENDIX B SIZING OF DISTRIBUTION TYPE TRANSFORMERS FOR FAMILY HOUSING UNITS

B-1. Application. Design factors apply only to aerial or pad-mounted compartmental distribution transformers supplying family housing units.

B-2. Distribution Transformers. Distribution transformers serving family housing areas will have the air conditioning or electric heating loads, whichever is larger, sized for 100 percent demand. The rest of the load will be sized in accordance with the demand factors of table B-1.

Table B-1. Demand Factors.

<i>Number of units</i>	<i>Demand factor percent</i>	<i>Number of units</i>	<i>Demand factor percent</i>	<i>Number of units</i>	<i>Demand factor percent</i>
1	80.0	19	18.0	37	13.2
2	60.0	20	17.5	38	13.0
3	50.0	21	17.1	39	12.8
4	45.0	22	16.6	40	12.6
5	40.0	23	16.1	41	12.4
6	35.0	24	15.8	42	12.2
7	32.0	25	15.6	43	12.0
8	29.0	26	15.4	44	11.8
9	27.0	27	15.2	45	11.6
10	25.0	28	15.0	46	11.4
11	24.0	29	14.8	47	11.2
12	23.0	30	14.6	48	11.0
13	22.0	31	14.4	49	10.8
14	21.0	32	14.2	50	10.6
15	20.0	33	14.0	51	10.4
16	19.4	34	13.8	52	10.2
17	18.7	35	13.6	53	10.1
18	18.3	36	13.4	54 ^a	10.0

^a Same demand factor applies to all quarters over 54.

GLOSSARY

Section I

Abbreviations

AEIC Association of Edison Illuminating Companies.	part of a municipality. The area contains land use which attracts a relatively heavy volume of night-time vehicular and/or pedestrian traffic on a frequent basis.
ANSI American National Standards Institute.	
ICEA Insulated Cable Engineers Association.	Conventional energy system A conventional energy system supplies electric energy which is not generated by the user and over which the user normally has only local control. Conventional energy systems are provided and supplied by a utility unless that electric source has been clearly demonstrated to be inadequate or unreliable, or another energy source has been proven to be more economical.
IEEE Institute of Electrical and Electronic Engineers.	
IES Illuminating Engineering Society.	
NEC National Electrical Code (NFPA-70).	Dead front (as applied to switches, circuit breakers, switchboards, and distribution panelboards) So designed, constructed, and installed that not current-carrying parts are normally exposed on the front.
NEMA National Electrical Manufacturers Association.	
NESC National Electrical Safety Code (ANSI C2).	Dead front (as applied to transformers) So constructed that there are not exposed live parts on the front of the assembly.
Section II Terms	
Angle of deviation (pole line) The angle by which a pole line deviates from a straight line.	
Basic impulse insulation level (BIL) A reference impulse insulation strength expressed in terms of the crest value of withstand voltage of a standard full impulse voltage wave.	Demand The electrical load at the receiving terminals averaged over a specified interval of time. Demand is expressed in kilowatts, kilovolt-amperes, amperes, or other suitable units. The interval of time is generally 15 minutes, 30 minutes, or one hour.
Coincident demand Any demand that occurs simultaneously with any other demand, also the sum of any set of coincident demands.	Demand factor The ratio of the maximum demand of a system to the total connected load of the system.
Collector The distributor and collector roadways servicing traffic between major and local roadways These are roadways used mainly for traffic movements within residential, commercial, and industrial areas.	Demand factor-(Max. demand)/(Total connected load) Discharge current The surge current that flows through an arrester when sparkover occurs.
Commercial A business area of a municipality where ordinarily there are many pedestrians during night hours. This definition applies to densely developed business areas outside, as well as within, the central	Discharge voltage The voltage that appears across the terminals of an arrester during passage of discharge current.
	Distribution transformer A transformer for transferring electrical energy from a primary distribution circuit to a secondary distribution circuit or consumer's service circuit. Distribution transformers are usually rated in the order of 5-500 kVA.

Distribution voltage

System voltage in the range of 5 kV to 34.5 kV. Distribution voltage (sometimes referred to as primary voltage) is normally transformed down to utilization voltage with distribution transformers.

Diversity factor

The ratio of the sum of the individual maximum demands of various subdivisions of the system to the maximum demand of the complete system. Diversity Factor-(Sum of Ind. Max. Demands)/(Max System Demand)

Equipment pole

A pole used to support equipment, such as transformers, in addition to supporting conductors.

Follow (power) current

The current from the connected power source that flows through an arrester during and following the passage of discharge current.

Guyed pole

Any pole strengthened with a guy wire.

High-fire-point liquid-insulated transformers

Same as less-flammable liquid-insulated transformers.

High-voltage

A class of nominal system voltages equal to or greater than 100,000 V.

Intermediate

Those areas of a municipality often characterized by moderately heavy nighttime pedestrian activity such as in blocks having libraries, community recreation centers, large apartment buildings, industrial buildings, or neighborhood retail stores.

Less-flammable liquid-insulated transformers

Fire point not less than 300 degrees C. Fire point is the lowest temperature at which a liquid will give off vapors sufficient for continuous combustion.

load factor

The ratio of the average load over a designated period of time to the peak load occurring in that period. Load factor is used by utilities to determine the excess capacity required to serve peak loads.

Loads factor-(Avg. Load)/(Peak Load)

Local

Roadways used primarily for direct access to residential, commercial, industrial, or other abutting property. They do not include roadways carrying through traffic. Long local roadways will generally

be divided into short sections by collector roadway systems.

Low-voltage

A class of nominal system voltage 1 kV or less.

Major

That part of the roadway system which serves as the principal network for through-traffic flow. The routes connect areas of principal traffic generation and important rural highways entering the city.

Maximum demand

The greatest of all demands that have occurred during a specified period of time.

Maximum system voltage

The highest root-mean-square phase-to-phase voltage that occurs on the system under normal operating conditions, and the highest root-mean-square phase-to-phase voltage for which equipment and other system components are designed for satisfactory continuous operation without derating of any kind. (When defining maximum system voltage, voltage transients and temporary over-voltages cause by abnormal system conditions, such as faults, load rejection, etc., are excluded. However, voltage transients and temporary over-voltages may affect equipment life and operating performance as well as conductor insulation and are considered in equipment application.)

Medium-voltage

A class of nominal system voltage above 1 kV to 99.9 kV.

Multi-grounded

A system grounding method where the neutral conductor is carried along with the phase conductors and grounded with at least four ground connections per mile. See the MESC.

NADIR

Lowest point.

Nominal system voltage

The root-mean-square phase-to-phase voltage by which the system is designated and to which certain operating characteristics of the system are related. (The nominal system voltage is near the voltage level at which the system normally operates. To allow for operating contingencies, systems generally operate at voltage levels about 5-10 percent below the maximum system voltage for which system components are designed.)

Nonflammable fluid-insulated transformers

No flash or fire point and not flammable in air. Flash point is the temperature at which a liquid

gives off sufficient vapor to form an ignitable mixture with the air.

Pad-mounted transformer

An outdoor transformer utilized as part of an underground distribution system, with enclosed compartment(s) for high voltage and low-voltage cables entering from below, and mounted on a foundation pad.

Pavement R1

Portland cement concrete road surface. Asphalt road surface with a minimum of 15 percent of the aggregates composed of artificial brightener. Mostly diffuse.

Pavement R2

Asphalt road surface with an aggregate composed of a minimum 60 percent gravel. Mixed (diffuse and specular).

Pavement R3

Asphalt road surface (regular and carpet seal) with dark aggregates (e.g., trap rock, blast furnace slag); rough texture after some months of use (typical highways). Slightly specular.

Pavement R4

Asphalt road surface with very smooth texture. Mostly specular.

Peak load

The maximum load consumed or produced by a unit or group of units in a stated period of time. It may be the maximum instantaneous load or the maximum average load over a designated period of time.

Power transformer

A transformer which transfers electrical energy in any part of the circuit between the generator and the distribution primary circuits.

Primary unit substation

A unit substation with secondary rated above 1000 V. For CEGS purposes, an articulated primary unit substation has both high voltage and low-voltage sections mechanically coupled to the transformer, while a standard primary unit substation has only the low-voltage section mechanically coupled to the transformer.

Primary voltage

Medium-voltage. Also, see distribution voltage.

Protective level

The maximum crest value of voltage that appears across an arrester's terminals under specified conditions of operation.

Reseal voltage

The voltage at which an arrester will stop conducting after discharge.

Residential

A residential development, or a mixture of residential and small commercial establishments, characterized by few pedestrians at night. This definition includes areas with single family homes, town houses, and/or small apartment buildings.

Secondary unit substation

A unit substation with secondary rated less than 1000V.

Secondary voltage

Low-voltage system. Also see utilization voltage.

Selective energy system

A selective energy system uses all the electric energy that the installation system can generate plus additional electric energy obtained from conventional sources. Selective energy systems may incorporate waste heat recovery systems.

Service voltage

The root-mean-square phase-to-phase or phase-to-neutral voltage at the point where the electrical system of the supplier and the user are connected.

Single-grounded

Ungrounded systems, which do not carry a neutral as such, and solidly grounded systems with neutrals that do not have at least four ground connections per mile are example of "single-grounded systems." See also ungrounded.

Station-type transformer

A transformer designed for installation in a station or substation.

Tangent pole

An in-line pole.

Total energy system

A total energy system supplies energy requirements for electricity, heating, air conditioning, and other uses from a single source making maximum use of available waste heat. Such a system is independent of other energy sources and is generated and controlled by the user.

Ungrounded

A common industry term for a wye-connected system with its common point connected to earth at the source through a high-independence, current-limiting connection. Ungrounded systems are one form of single-grounded systems.

Unit-substation transformer

A transformer which is mechanically and electrically connected to, and coordinated in design with, one or more switchgear or motor-control assemblies, or combinations thereof. See primary and secondary unit substations.

Utilization voltage

The root-mean square phase-to-phase or phase-to-

neutral voltage at the line terminals of utilization equipment. Utilization voltage is sometimes referred to as secondary voltage.

Voltage transformer (VT)

An instrument transformer which has its high voltage winding connected in parallel with the power source, which is to be measured. VT is a synonym for potential transformer (PT).

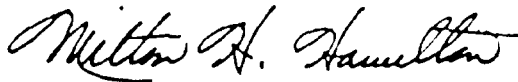
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