Electrical Installations in Petroleum Processing Plants

API RECOMMENDED PRACTICE 540
FOURTH EDITION, APRIL 1999

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- To participate with government and others in creating responsible laws, regulations and standards to safeguard the community, workplace and environment.
- To promote these principles and practices by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of similar raw materials, petroleum products and wastes.

Electrical Installations in Petroleum Processing Plants

Downstream Segment

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FOREWORD

This recommended practice provides information on electrical installations in petroleum facilities. It is intended for all individuals and organizations concerned with the safe design, installation, and operation of electrical systems in petroleum facilities.

This recommended practice has been developed by individuals with many years' experience in the petroleum industry. Although of interest to anyone seeking information on electrical systems in petroleum facilities, it is primarily intended to be used by individuals knowledgeable in engineering fundamentals who require specific guidance concerning currently accepted practices in the petroleum industry.

Suggested revisions are invited and should be submitted to the director of the Downstream Segment, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

IMPORTANT INFORMATION CONCERNING USE OF ASBESTOS OR ALTERNATIVE MATERIALS

Asbestos is specified or referenced for certain components of the equipment described in some API standards. It has been of extreme usefulness in minimizing fire hazards associated with petroleum processing. It has also been a universal sealing material, compatible with most refining fluid services.

Certain serious adverse health effects are associated with asbestos, among them the serious and often fatal diseases of lung cancer, asbestosis, and mesothelioma (a cancer of the chest and abdominal linings). The degree of exposure to asbestos varies with the product and the work practices involved.

Consult the most recent edition of the Occupational Safety and Health Administration (OSHA), U.S. Department of Labor, Occupational Safety and Health Standard for Asbestos, Tremolite, Anthophyllite, and Actinolite, 29 *Code of Federal Regulations* Section 1910.1001; the U.S. Environmental Protection Agency, National Emission Standard for Asbestos, 40 *Code of Federal Regulations* Sections 61.140 through 61.156; and the U.S. Environmental Protection Agency (EPA) rule on labeling requirements and phased banning of asbestos products (Sections 763.160-179).

There are currently in use and under development a number of substitute materials to replace asbestos in certain applications. Manufacturers and users are encouraged to develop and use effective substitute materials that can meet the specifications for, and operating requirements of, the equipment to which they would apply.

SAFETY AND HEALTH INFORMATION WITH RESPECT TO PARTICULAR PRODUCTS OR MATERIALS CAN BE OBTAINED FROM THE EMPLOYER, THE MANUFACTURER OR SUPPLIER OF THAT PRODUCT OR MATERIAL, OR THE MATERIAL SAFETY DATA SHEET.

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SECTION 1—INTRODUCTION

1.1 PURPOSE

This recommended practice provides information on electrical installations in petroleum facilities. Petroleum processing requires specialized equipment that continually processes, often at high rates and elevated temperatures and pressures, liquids, and gases that undergo both chemical and physical changes. Consequently, it is necessary that electrical installations and equipment in petroleum facilities be designed to prevent accidental ignition of flammable liquids and gases.

To maintain safety and operating continuity, requirements for the electrical systems in petroleum facilities are more stringent than those for most other manufacturing facilities. This recommended practice addresses specific requirements for those electrical systems.

1.2 SCOPE

This recommended practice is limited to electrical installations in petroleum facilities. It provides a basis for specifications included in engineering and construction contracts. Electrical equipment test standards are excluded from the scope of this recommended practice. Operation and maintenance are addressed only insofar as they affect electrical system design and electrical equipment selection. The subject of energy conservation is reviewed.

1.3 REFERENCES

1.3.1 The following standards, codes, and specifications are cited in this recommended practice:

API

RP 14F	*Design and Installation of Electrical Systems for Offshore Production Platforms*
RP 500	*Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2*
RP 505	*Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2*
Std 541	*Form-Wound Squirrel-Cage Induction Motors—250 Horsepower and Larger*
Std 546	*Brushless Synchronous Machines—500 kVA and Larger*
RP 552	*Recommended Practice for Transmission Systems*
Std 610	*Centrifugal Pumps for Petroleum, Heavy Duty Chemical and Gas Industry Service*
Std 614	*Lubrication, Shaft-Sealing, and Control-Oil Systems and Auxiliaries for Petroleum, Chemical and Gas Industry Service*
RP 651	*Cathodic Protection of Aboveground Storage Tanks*
RP 2001	*Fire Protection in Refineries*
RP 2003	*Protection Against Ignitions Arising out of Static, Lightning, and Stray Currents*

AEIC[1]

CS1	*Specification for Impregnated Paper-Insulated, Lead-Covered Cable, Solid Type*
CS5	*Specifications for Thermoplastic and Crosslinked Polyethylene Insulated Shielded Power Cables Rated 5 Through 46 kV*
CS6	*Specifications for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 Through 69 kV*

AGMA[2]

6019-E	*Gearmotors Using Spur, Helical, Herringbone, Straight Bevel, or Spiral Bevel Gears*

ANSI[3]

C80.1	*Specification for Rigid Steel Conduit, Zinc Coated*
C80.5	*Specification for Rigid Aluminum Conduit*
C84.1	*Electric Power Systems and Equipment Voltage Ratings (60 Hz)*

ASTM[4]

D877	*Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes*

CSA[5]

Canadian Electrical Code

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[1]Association of Edison Illuminating Companies, P.O. Box 2641, Birmingham, Alabama 35291.
[2]American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, Virginia 22314.
[3]American National Standards Institute, 1430 Broadway, New York, New York 10018.
[4]American Society of Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959.
[5]Canadian Standards Association, 178 Rexdale Boulevard, Rexdale, Ontario M9W 1R3, Canada.

EPA[6]

40 CFR Part 761	"Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions"

IEEE[7]

Std 32	*Standard Requirements, Terminology, and Test Procedures for Neutral Grounding Devices*
Std 80	*Guide for Safety in AC Substation Grounding*
Std 100	*Standard Dictionary of Electrical and Electronics Terms*
Std 141	*Recommended Practice for Electric Power Distribution for Industrial Plants* (Red Book)
Std 142	*Recommended Practice for Grounding of Industrial and Commercial Power Systems*
Std 242	*Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems* (Buff Book)
Std 399	*Recommended Practice for Industrial and Commercial Power Systems Analysis* (Brown Book)
Std 422	*Guide for the Design and Installation of Cable Systems in Power Generating Stations*
Std 446	*Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications*
Std 493	*Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems* (Gold Book)
Std 515	*Standard for the Testing, Design, Installation and Maintenance of Electrical Resistance Heat Tracing for Industrial Applications*
Std 518	*Guide for the Installation of Electrical Equipment to Minimize Noise Inputs to Controllers from External Sources*
Std 519	*Recommended Practice and Requirements for Harmonic Control in Electric Power Systems*
Std 576	*Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in the Petroleum and Chemical Industry*
Std 841	*Recommended Practice for Chemical Industry Severe Duty Squirrel-Cage Induction Motors 600 Volts and Below*
Std 844	*Recommended Practice for Electrical Impedance, Induction, and Skin Effect Heating of Pipelines and Vessels*
Std 1015	*Recommended Practice for Applying Low-Voltage Circuit Breakers Used in Industrial and Commercial Power Systems* (Blue Book)
Std 1100	*Recommended Practice for Powering and Grounding Sensitive Electronic Equipment*
C2	*National Electrical Safety Code*
C57.12.00	*General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers*
C57.12.01	*Standard General Requirements for Dry-type Distribution and Power Transformers Including those with Solid-cast and/or Resin-encapsulated Windings*
C57.92	*Guide for Loading Mineral-oil-immersed Power Transformers Up to and Including 100 MVA with 55°C or 65°C Average Winding Rise*
C57.96	*Guide for Loading Dry-Type Distribution and Power Transformers*
C57.106	*Guide for Acceptance and Maintenance of Insulating Oil in Equipment*
C57.111	*Guide for Acceptance of Silicone Insulating Fluid and Its Maintenance in Transformers*
C57.121	*Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers*

NACE[8]

RP 0169	*Control of External Corrosion on Underground or Submerged Metallic Piping Systems*
RP 0176	*Corrosion Control of Steel Fixed Offshore Platforms Associated with Petroleum Production*
RP 0675	*Control of External Corrosion on Offshore Steel Pipelines*

NEMA[9]

ICS 1	*General Standards for Industrial Control and Systems*
ICS 6	*Enclosures for Industrial Controls and Systems*
MG 1	*Motors and Generators*

[6]United States Environmental Protection Agency/National Center for Environmental Publications, P.O. Box 42419, Cincinnati, Ohio 45242-2419.

[7]Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08855-1331.

[8]NACE International, 1440 South Creek Drive, Houston, Texas 77084.

[9]National Electrical Manufacturers Association, 1300 North 17th Street, Suite 1847, Rosslyn, Virginia 22209.

MG 2	*Safety Standard for Construction and Guide for Selection, Installation and Use of Electric Motors and Generators*
WC 3	*Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy*
WC 5	*Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy*
WC 7	*Cross-Linked-Thermosetting-Polyethylene-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy*
WC 8	*Ethylene-Propylene-Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy*

NFPA[10]

	Fire Protection Handbook
30	*Flammable and Combustible Liquids Code*
37	*Standard for Stationary Combustion Engines and Gas Turbines*
54	*Fuel Gas Code*
69	*Explosion Prevention Systems*
70	*National Electrical Code*
70E	*Electrical Safety Requirements for Employee Workplaces*
77	*Recommended Practice on Static Electricity*
90A	*Standard for the Installation of Air Conditioning and Ventilating Systems*
91	*Standard for Exhaust Systems for Air Conveying of Materials*
110	*Emergency and Standby Power Systems*
325	*Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids*
496	*Standard for Purged and Pressurized Enclosures for Electrical Equipment*
497	*Classification of Flammable Liquids, Gases, or Vapors and of Hazardous Classified) Locations for Electrical Installations in Chemical Process Areas*
499	*Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*
780	*Lightning Protection Code*

[10]National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02269.

UL[11]

674	*Electric Motors and Generators for Use in Hazardous Locations, Class I, Groups C and D, Class II, Groups E, F, and G*
698	*Industrial Control Equipment for Use in Hazardous (Classified) Locations*
913	*Intrinsically Safe Apparatus and Associated Apparatus for Use in Hazardous (Classified) Locations*
1242	*Intermediate Metal Conduit*

1.3.2 The following publications are not specifically referenced in this recommended practice, but provide guidance in the design of electrical systems for petroleum facilities:

IEEE[7]

Std 493	*Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems*
Std 739	*Recommended Practice for Energy Conservation and Cost Effective Planning in Industrial Facilities*

IES[12]

RP 7	*Practice for Industrial Lighting Handbook*

ISA[13]

RP 12.1	*Definitions and Information Pertaining to Electrical Instruments in Hazardous Locations*
S12.4	*Instrument Purging for Reduction of Hazardous Area Classification*
RP 12.6	*Installation of Intrinsically Safe Systems for Hazardous (Classified) Locations*
S12.13,	Part I, *Performance Requirements, Combustible Gas Detectors*
RP 12.13,	Part II, *Installation Operation and Maintenance of Combustible Gas Detection Instruments*

Note: Includes former Bureau of Mines Bulletin 627, *Flammability Characteristics of Combustible Gases and Vapors* (no longer in print).

S12.16	*Electrical Apparatus for Use in Class I, Zone 1 Hazardous (Classified) Locations: Type of Protection—Increased Safety "e"*
S12.24.01	*Electrical Apparatus for Explosive Gas Atmospheres, Classifications of Hazardous (Classified) Locations*

[11]Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, Illinois 60062.

[12]Illuminating Engineering Society of North America, 120 Wall Street, Floor 17, New York, New York 10005-4001.

[13]International Society for Measurement and Control (ISA), P.O. Box 12277, Research Triangle Park, North Carolina 27709-2277.

S51.1 *Process Instrumentation Technology*

David N. Bishop, *Electrical Systems for Oil and Gas Production Facilities,*

P. J. Schram and M. W. Earley, *Electrical Installations in Hazardous Locations*

Ernest C. Magison, *Electrical Instruments in Hazardous Locations*

D. G. Fink and H. W. Beaty, *Standard Handbook for Electrical Engineers* (12th ed.), McGraw-Hill, New York, 1987

NACE[9]

RP 0176 *Corrosion Control of Steel Fixed Offshore Platforms Associated With Petroleum Production*

RP 0675 *Control of External Corrosion on Offshore Steel Pipelines*

NFPA[10]

499 *Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*

OSHA[14]

29 *CFR*

Part 1910 *Occupational Safety and Health Standards*

Part 1929.K *Electrical Standards for Construction*

[14]Occupational Safety and Health Administration, U.S. Department of Labor, 200 Constitution Avenue, N.W., Washington, D.C. 20210. The *Code of Federal Regulations* is available from the U.S. Government Printing Office, Washington, D.C. 20402-9325.

SECTION 2—CLASSIFIED LOCATIONS OR ELECTRICAL EQUIPMENT

2.1 PURPOSE

This section briefly reviews the classification of flammable liquids and gases, the classification of locations where fire or explosion hazards may exist due to flammable gases or vapors, or flammable liquids, and the application of electrical equipment in classified locations.

2.2 SCOPE

This section discusses only the general guidelines pertaining to the classification of locations. A more detailed discussion of the classification of locations can be found in API RP 500, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Division 1 and Division 2* and API RP 505, *Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I, Zone 0, Zone 1, and Zone 2.*

2.3 CLASSIFICATION OF FLAMMABLE AND COMBUSTIBLE LIQUIDS AND GASES

Note: Classifications used for defining liquids and gases should not be confused with the NFPA 70 classifications used for hazardous (classified) locations.

2.3.1 Definition of Flammable Liquids

As defined by NFPA 30, flammable liquids are liquids that have a flash point below 37.8°C (100°F) and a vapor pressure not exceeding 276 kilopascals absolute (40 pounds per square inch absolute) at 37.8°C (100°F). These liquids are divided into the following general classes:

a. Class IA includes the liquids that have flash points below 22.8°C (73°F) and boiling points below 37.8°C (100°F).
b. Class IB includes the liquids that have flash points below 22.8°C (73°F) and boiling points at or above 37.8°C (100°F).
c. Class IC includes the liquids that have flash points at or above 22.8°C (73°F) and boiling points below 37.8°C (100°F).

2.3.2 Definition of Combustible Liquids

As defined by NFPA 30, combustible liquids are liquids that have flash points at or above 37.8°C (100°F). These liquids are also divided into general classes:

a. Class II includes the liquids that have flash points at or above 37.8°C (100°F) and boiling points below 60°C (140°F).
b. Class III includes the liquids that have flash points above 60°C (140°F), and Class III liquids are subdivided as follows:

1. Class IIIA includes the liquids that have flash points at or above 60°C (140°F) and boiling points below 93.3°C (200°F).
2. Class IIIB includes the liquids that have flash points at or above 93.3°C (200°F).

2.3.3 Flammable Gases—Lighter-than-Air

Lighter-than-air gases that commonly are encountered include methane and a mixture of methane with small quantities of low-molecular-weight hydrocarbons, the mixtures generally being lighter-than-air. Hydrogen must be given a special mixture consideration because of its properties: a wide flammable (explosive)-mixture range, a high flame-propagation velocity, a low vapor density, a low minimum-ignition-energy level, and a relatively high ignition temperature [585°C (1085°F)].

2.3.4 Flammable Gases—Heavier-than-Air

Liquefied petroleum gases include propanes, butanes, and mixtures of the two having densities from 1.5 times to approximately 2.0 times that of air. Vapor pressures of these gases exceed 276 kilopascals absolute (40 pounds per square inch absolute) at 37.8°C (100°F).

2.4 CLASSIFICATION OF LOCATIONS

The National Electrical Code, NFPA 70, has established criteria for classifying locations that do or may contain flammable gases or vapors, flammable liquids, combustible dust, or ignitable fibers or flyings. Once a location has been classified, NFPA 70 specifies equipment requirements for each particular classification. The major effort involved in classifying a location is determining whether flammable gases are likely to exist in the location to be classified and, if they may exist, under what conditions and for how much of the time.

A Class I location is a location in which flammable gases or vapors are or may be present in the air in quantities sufficient to produce explosive or ignitable mixtures. NFPA 70 recognizes two systems for the classification of Class I locations, the Division system and the Zone system. In the Division system, Class I locations are subdivided into Division 1 and Division 2. Division 1 indicates that a flammable mixture may be present under normal operating conditions, and Division 2 indicates that a flammable mixture may be present only in the event of abnormal operating conditions or equipment malfunction. In the Zone system, Class I locations are subdivided into Zone 0, Zone 1, and Zone 2. In a similar manner to the Division system, NFPA 70 contains criteria for defining Zones based on the possibility of releases. In both systems, locations that are not classified as Division 1, Division 2, Zone 0, Zone 1, or Zone 2 are termed unclassified.

Once the existence and degree of ignitable substances in an area has been determined, the physical boundaries of the classified location must be determined. The most important factor to consider is that flammable gas or vapor alone will not produce an ignitable atmosphere; flammable gas or vapor must mix with a sufficient amount of air to become ignitable. Other factors to consider are the quantity and physical characteristics of whatever substance might be liberated and the natural tendency of gases or vapors to disperse in the atmosphere.

Once established, a location's classification and boundaries can be drawn on a plot plan of the process equipment for a given area. Such a drawing is a convenient reference source when selecting electrical equipment for and locating it in the classified area. The classification is incomplete until the dimensions around a source of liquid or gas are defined and documented. Typical height, width, and length dimensions are available in API RP 500 and 505 as well as NFPA 497.

API RP 500 and 505 are practical guides that specifically apply the NFPA 70 classification criteria to electrical installations in petroleum facilities. The recommended practices cover the factors that must be considered in area classification; they provide a questionnaire-type procedure for determining the proper classification of a location; and they illustrate methods for establishing the degree and extent of a location to be classified.

Sound judgment must accompany the use of the recommendations in API RP 500 and RP 505. When, in the opinion of a qualified person, particular conditions are better or worse than average, the pertinent recommendations should be modified accordingly.

2.5 ELECTRICAL EQUIPMENT FOR CLASSIFIED LOCATIONS

Each location in a petroleum facility that is classified must be carefully evaluated to ensure that proper electrical equipment is selected. Most classified atmospheres in petroleum facilities are Class I, Group D; however, certain areas may involve other classes and groups: in particular, Class I, Groups B and C and Class II, Group F. (See NFPA 70 and NFPA 499 for further discussion of Class II locations. See NFPA 70 and 497 for the correlation of material groupings for Division and Zones) To comply with NFPA 70, electrical equipment suitable for the specific area classification must be used.

One indication that electrical equipment installed in classified locations is suitable for the defined locations is that it is approved by a Nationally Recognized Testing Laboratory (NRTL). Certain electrical equipment, such as induction motors for installation in Division 2 and Zone 2 areas, are specifically permitted in NFPA 70 and do not require specific markings or NRTL approvals for use in classified areas.

2.6 ALTERNATIVE DESIGN IN CLASSIFIED LOCATIONS

For applications where it is necessary to install equipment that is not suitable or available for the classification, the following alternative designs may be utilized. These applications may be desirable because equipment is not suitably manufactured for a particular classification, it is more cost effective to secure the alternative equipment, or design preference prohibits such equipment.

2.6.1 Physical Isolation

Physical isolation is an effective, and perhaps the most commonly used, method for installing electrical equipment not otherwise suitable for classified locations. For example, where motors are located in a classified location, the motor starters and control equipment can be installed outside the classified location. This permits the use of less expensive equipment in locations that are more convenient for maintenance.

2.6.2 Pressurized Rooms and Enclosures

According to NFPA 70, classified locations may be reduced or eliminated by adequate positive-pressure ventilation. Authoritative information on design criteria is provided in NFPA 496. Positive-pressurization and purging are based on the principle that an enclosure or room located in a classified location can be purged with clean air or inert gas at sufficient, continuous flow and positive pressure to reduce the original concentration of flammable gas or vapor to a safe level and to maintain this level.

There are three types of purging, each having specific design requirements:

a. Type X purging reduces the classification within an enclosure from Division 1 to unclassified.

b. Type Y purging reduces the classification within an enclosure from Division 1 to Division 2.

c. Type Z purging reduces the classification within an enclosure from Division 2 to unclassified.

2.6.3 Intrinsically Safe Installations

One approach to the application of electrical equipment in classified locations is to use intrinsically safe devices and wiring methods. This method is used primarily for instrumentation and process control. Intrinsically safe equipment and wiring are incapable of releasing the electrical or thermal energy necessary, under normal or abnormal conditions, to ignite a specific hazardous atmospheric mixture in its most ignitable concentration. Information on the design and evaluation of intrinsically safe equipment and wiring to be used in classified locations is provided in UL 913. Intrinsically safe installations should comply with NFPA 70 Article 504.

2.6.4 Other Alternatives

2.6.4.1 NFPA 70 describes several other acceptable protection techniques for electrical equipment and installations in classified areas. These include: oil immersion, nonincendive, and hermetically sealed.

2.6.4.2 Adequate ventilation methods and the use of combustible gas detection, as defined in API RP 500 and RP 505, are techniques that may allow the reduction of the area classification.

SECTION 3—ELECTRICAL ENERGY EFFICIENCY

3.1 PURPOSE

This section reviews energy efficiency as it applies to the selection of electrical equipment for petroleum facilities and to the application of the equipment in those facilities.

3.2 SCOPE

Electrical efficiency is discussed as a part of the broader concept of energy conservation. The definition of efficiency is given, and design considerations are reviewed for specific types of equipment. Economic evaluation is addressed. Other efficiency related topics, such as power factor and demand control, are briefly discussed. Useful definitions and conversion factors are provided at the end of the section.

3.3 THE ROLE OF ELECTRICAL EFFICIENCY

a. Electrical systems provide an important opportunity for energy conservation. The electrical losses in the distribution and utilization equipment of a refinery power system can range as high as 20%. For a 60 megawatt (MW) facility operating 8,000 hours per year and paying $0.07 per kilowatt-hour (kWh), the cost of these losses would exceed $6.5 million per year. A similar plant using an energy efficient electrical design could have 15% fewer losses and save $1 million per year compared to the less efficient design.

In addition to the direct benefits of increased electrical efficiency, there are also some indirect benefits. Reduced losses in electrical equipment can result in lower operating temperatures and prolonged equipment life. For indoor applications, reduced losses also decrease the heat load on air conditioning equipment.

When considering electrical efficiency, it is also useful to recall that, due to losses in the generation, transmission, and distribution of electricity, a 1 kWh reduction in electrical usage saves the equivalent of 4 to 5 kWh of raw fuel.

3.4 DEFINITION OF EFFICIENCY

Efficiency is defined as the ratio of power output to power input or energy output to energy input:

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}} \text{ or } \frac{\text{Energy output}}{\text{Energy input}} \quad (1)$$

Power output can be related to power losses in equipment by the following:

$$\text{Power output} = \text{Power input} - \text{losses} \quad (2)$$

Therefore, efficiency can also be defined in terms of losses and power input

$$\text{Efficiency} = \frac{\text{Power input} - \text{losses}}{\text{Power input}} \text{ or } = 1 - \frac{\text{losses}}{\text{Power input}} \quad (3)$$

or in terms of losses and power output:

$$\text{Efficiency} = 1 - \frac{\text{losses}}{\text{Power output} + \text{losses}} \quad (4)$$

All the above formulae can be applied to energy by substituting kWh for power. In either case, higher efficiency is achieved by reducing operating losses.

3.5 SPECIFICATION CONSIDERATIONS

The specification of electrical equipment should include consideration for energy efficiency. The operating points for which efficiency data are desired should be specified. Usually ½, ¼, and full load data are requested. For large equipment, an efficiency curve should be requested. Guaranteed efficiency values, rather than nominal or average values, should be specified.

An economic evaluation factor (in dollars per kWh) should be included in the specification. See 3.6. Any economic penalty clauses should be clearly stated, and the operating point at which efficiency will be evaluated should be specified.

The testing method to be used for determining efficiency should be stated. Witnessed testing is recommended if economic penalty factors are involved. Payment terms that are to be contingent on receipt of the test results should be clearly stated.

3.6 ECONOMIC EVALUATION

3.6.1 Evaluation Factors

Competitive pressures to reduce the cost of processing have provided an incentive for adding capital investment that can cut the energy cost per barrel processed. The cost of adding new equipment, or replacing inefficient equipment must be offset by future energy cost savings. An economic evaluation is necessary to determine if the equipment costs will be offset by the future energy savings. Energy efficient electrical equipment normally demands a premium price. It is useful to develop a dollar-per-kilowatt factor to determine the value of saved energy for projects at a specific site. Several different methods for developing a $/kW factor are covered in the following sections.

3.6.2 Simple Payback

The least complex dollar-per-kilowatt factor is based on simple payback, which does not account for the depreciated value of future savings:

$$\$/\text{kW} = ChN\ (1 - T) \qquad (5)$$

where

$/ kW = profit to the user for reducing power usage by 1 kW,
C = cost of electricity, in dollars per kWh,
h = hours of operation per year,
N = number of years in evaluation period,
T = income tax rate paid by the user.

The use of the factor is demonstrated in the following example. Assume a piece of electrical equipment operates *continuously* at a location where the cost of electricity is $0.05/kWh, and the desired payback period is 5 years. Income is taxed at a 40% rate. The factor would be calculated as follows:

$$\$/\text{ kW} = \frac{\$0.05}{\text{kWh}} \times \frac{8760h}{\text{yr}} \times 5\text{yr} \times (1 - 0.40) = \$1{,}314 / \text{kW} \quad (6)$$

This factor is the expected cost for continuously operating a load of one kW for 5 years. This cost factor is then compared to the ratio of the price premium for high efficiency equipment divided by the loss reduction. If the ratio is less than $1,314, then it pays to spend the money for the high efficiency equipment. For example, if an energy efficient transformer costs $4,000 more than a standard transformer, and it reduces the losses by 5 kW, the incremental cost is ($4,000/5 kW) or $800/kW. The energy efficient unit should, therefore, be selected.

3.6.3 Time Value of Money

Equation 5 does not take into account the time value of money. Future savings should be adjusted for increases in power costs and the required cost of capital. The following equation provides a dollar-per-kilowatt factor that allows for power cost inflation and desired rate of return on investment.

$$\$/\text{ kW} = Ch\,(1 - T)\ \frac{1 + i^{N} - 1}{i(1+i)^{N}} \qquad (7)$$

where

$/ kW = profit to the user of reducing power usage by 1 kW,
C = cost of electricity, in dollars per kWh,
h = hours of operation per year,
N = number of years in evaluation period,
T = income tax rate paid by the user,
i = effective interest rate

$$= i = \frac{1 + R_2}{1 + R_1} - 1 \qquad (8),$$

R_1 = anticipated annual escalation rate for cost of electricity,
R_2 = desired annual rate of return on investment.

Using the example of equation 5 along with a 15% rate of return and an 8% power cost escalation rate, the dollar-per-kilowatt evaluation factor would be calculated as follows:

$$i = \frac{1 + 0.15}{1 + 0.08} - 1 = 0.0648 \qquad (9)$$

$$\$ / \text{kW} = (1 - 0.40) \times \frac{1 + 0.0648^{5} - 1}{0.0648\ (1 + 0.0648)^{5}} \qquad (10)$$

$$= \$1{,}093 / \text{kW}$$

This equation is a useful way to include the time value of money, and is suitable for most economic evaluations of energy efficiency improvements. For very large projects it may be desirable to use an evaluation method which further refines the preceding equations to allow for such factors as depreciation, tax investment credits, and variable escalation rates.

3.7 COGENERATION AND ENERGY RECOVERY

Power costs can be reduced by investing in-plant generation. The generation normally is added in the form of cogeneration. *Cogeneration* means using the waste heat from a power generating cycle for process heating; or conversely, using waste heat from a plant process to generate power. The generation cycle thermal efficiency thus can be increased from about 25% (typical industrial generating efficiency) to about 70% when waste heat is recovered. Power generated in the cogenerating mode is normally less expensive than purchased power and results in direct savings to the plant. Typical utility generating units operate at 35% efficiency, so the higher efficiency of cogenerating can make it an attractive option.

One of two power cycles are used for cogenerating, depending on the plant processes used to absorb the waste heat. The Brayton cycle includes a gas turbine to generate power, and a waste heat boiler to generate steam from the hot 500°C to 600°C (≈ 950°F to 1100°F) exhaust gases. In some

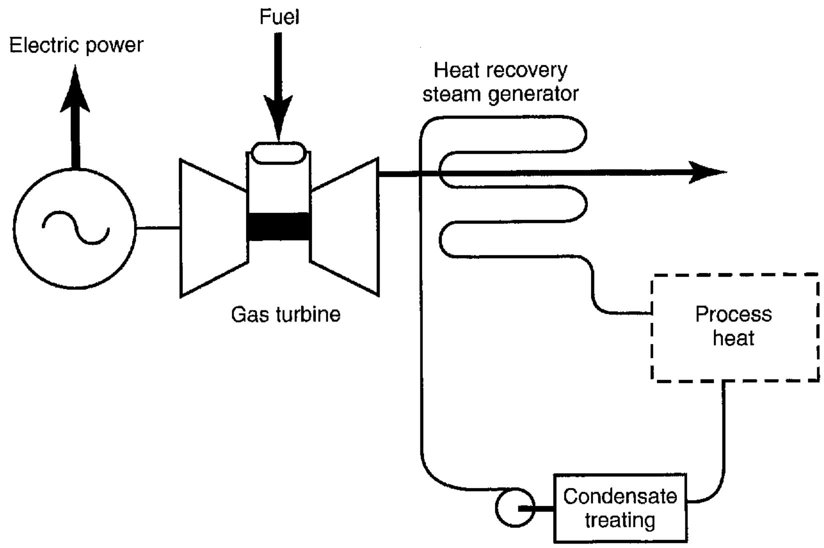


Figure 1—Brayton Cogeneration Cycle

instances, the exhaust flow can be sent into a process furnace to heat process feed. The recovery of the turbine exhaust heat reduces the amount of fuel normally required to provide an equal amount of thermal energy to the plant. The value of the saved fuel can be subtracted from the cost of the fuel to the gas turbine to arrive at the cost of power generated.

The Brayton (gas-turbine) cycle is considered a "topping" cycle because it consumes fuel and provides by-product heat to a consumer operating at a lower temperature. By contrast, a "bottoming" cycle consumes by-product heat from a higher temperature process and produces electric power.

The Carnot cycle uses a boiler and a steam turbine to recover thermal power, and can be configured as a topping cycle, or a bottoming cycle. When configured as topping cycle, the plant steam boilers generate steam at a higher pressure and temperature than is needed for heating plant processes. The steam turbine is used to extract from the steam while reducing the pressure and temperature from boiler steam conditions to process conditions. The extra fuel cost for raising the steam pressure and temperature above process conditions is the fuel cost for generating the power developed by the turbine.

A typical bottoming cycle uses a steam turbine to extract power from steam being generated from process waste heat, or steam being let down from one plant steam pressure level to a lower level, or being sent to a condenser on the way to a cooling tower. The bottoming cycle finds use in plants where large amounts of waste heat are available from the cooling of exothermic processes. This cycle generates electricity from some of the heat which would otherwise be sent into the atmosphere at the cooling tower.

Hot exhaust from gas turbine generators is sometimes used directly in a process without using a heat recovery steam gen-

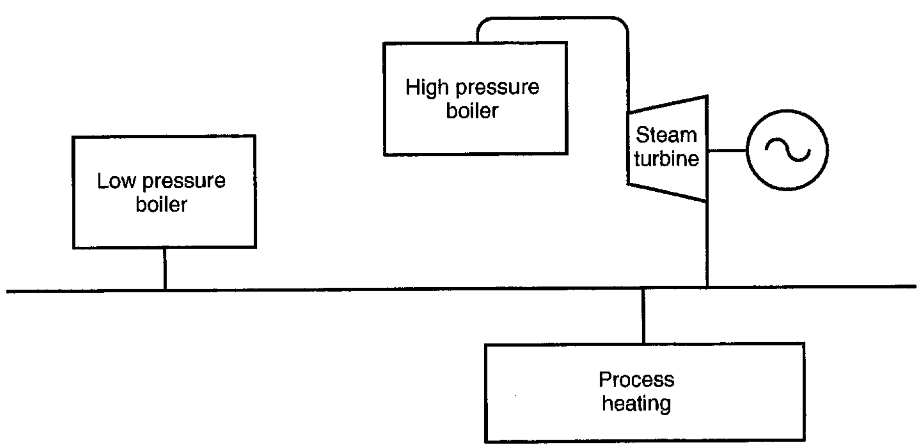


Figure 2—Carnot Topping Cycle

erator. Three examples of direct heating with turbine exhaust are: reducing the viscosity of products in transport pipelines; heating process feeds to process units; and supplying thermal energy for absorption refrigeration cycles.

Heating viscous products will lower viscosity and reduce the pumping energy required to transport the products through pipelines. Fired heaters are normally used for this. When gas turbines are sometimes used as generator drives to provide power for the transport pump motors, or are used to drive the pumps directly, the exhaust can be passed through an exchanger to heat the product, instead of using a fired heater. Using the waste heat from the gas turbine's exhaust will save the cost of the fuel used for a fired heater.

In process plants, gas turbine exhaust is used to heat feed stocks to processes, or to preheat combustion air for the process furnaces. This displaces much of the fuel that would otherwise be consumed.

The absorption refrigeration cycle uses a heat source to change the state of a refrigerant. The hot exhaust from a gas-turbine generator can be used with an absorption cycle to provide cooling. Absorption cycle equipment manufacturers can provide pre-engineered system elements to match the exhaust flow conditions of a number of gas turbines.

Sometimes there are opportunities to recover energy from process or utility streams. One method of energy recovery is the power recovery turbine, which is often used on catalytic cracking units to recover energy from the regenerator flue gases. The flue gases are directed through an expander which drives the unit's air blower, and an electric generator. The output of the generator is usually in the range of 5 megawatts to 10 megawatts (MW). Typically, an induction generator is used for this service.

A high-pressure fuel gas feed to a petroleum facility can also be used as a source of electric power by dropping the line pressure to plant utility pressure through an expander instead of a let-down valve. The expander is used to drive an induction generator adding power to the electric system. The majority of the gas flow goes through the expander, while a pressure control flow goes through a parallel control valve.

3.8 DESIGN CONSIDERATIONS

3.8.1 Transformers

Transformer efficiencies vary, depending on transformer characteristics. High-efficiency units can be purchased that provide efficiencies in excess of 99%. The importance of transformer efficiencies is that all power received from utilities (and much, if not all, received from in-plant generation) is transformed one or more times to reach utilization voltage levels; thus, the 1 or 2% losses occurring in transformers are applied to large blocks of power.

Transformer losses consist of no-load losses and load losses. No-load losses are losses resulting from energizing the primary winding at rated voltage with the secondary winding open-circuited. These losses include eddy current losses, hysteresis losses, dielectric losses, and losses due to the resistance of the primary winding to excitation current. The eddy current and hysteresis losses are the most significant component of no-load losses. Because these losses occur in the core of the transformer, no-load losses are sometimes referred to as core losses or iron losses. For a given voltage, no-load losses can be considered to be constant.

Load losses vary with the flow of load current and include I^2R losses, eddy current losses, and stray load losses. The I^2R losses are the most significant and are caused by the flow of load current in both primary and secondary windings. Higher efficiency transformers usually have copper windings to minimize I^2R losses. Where forced cooling is specified, additional energy is consumed by fans or oil circulating pumps.

While transformers should be sized on the basis of maximum load, they should be designed for maximum efficiency at normal operating load, and efficiency should be evaluated accordingly. When specifying transformers, the load at which efficiency will be evaluated should be given.

3.8.2 Motors and Generators

Motor loads are the major consumers of energy in process plants. Typically, they can account for 70% of the electrical energy consumption. Motor efficiencies vary from 65% for the smallest HP motors, to 98% for the largest motors. High efficiency designs are available for motors in the standard frame size range. In the United States, the 1992 Energy Policy Act requires energy efficient motors for most motor categories.

Motor losses consist of the following:

a. Stator I^2R loss.
b. Rotor I^2R loss.
c. Core loss (hysteresis and eddy current).
d. Friction and windage.
e. Stray-load loss.
f. Excitation equipment losses (for synchronous machines).

Manufacturing design parameters that affect motor losses include:

a. Quality and thickness of lamination steel.
b. Size of the air gap.
c. Stator and rotor resistances.
d. Slot configurations.
e. Number of poles (lower design speeds result in lower efficiencies).

Much effort is made to optimize these parameters because they also affect motor power factor, inrush current, and starting torque.

Operating conditions also affect motor efficiency. Typically, motor efficiency falls off rapidly as motor load is decreased below one-half of rated load. Operating a motor at less than rated voltage will cause a decrease in efficiency due to higher stator losses and rotor losses. Operating at overvoltage decreases efficiency because higher magnetizing current and saturation cause increased stator and core losses. Operating with unbalanced voltages will increase losses (due to negative sequence torque) and result in higher winding temperatures. Motors connected to variable speed drives experience higher losses because of the harmonic content of the supply voltage and the load current. This is due to higher than normal hysteresis and eddy currents induced in the stator and rotor steel by the harmonic currents.

3.8.3 Lighting Equipment

Although lighting does not represent a major percentage of the electrical energy consumption of a petroleum facility, it nonetheless provides another area where energy savings can be achieved. The following guidelines can result in an energy efficient lighting system:

a. Use the highest efficacy [lumens per watt (lm/W)] lamp that is capable of directing light to the task area involved.

b. Select efficient ballasts (e.g., electronic ballasts for fluorescent fixtures).

c. Maximize use of floodlights to illuminate general process areas.

d. Use photocell or time controls to turn off outdoor lighting during daylight hours.

e. Use manual controls for tower lighting with controls located at the tower base.

f. Monitor lighting levels and reduce them where appropriate. For building lighting, this produces additional energy savings because of the reduced load on air conditioning equipment.

g. Keep lamps and reflectors clean to obtain maximum light output.

3.8.4 Adjustable Speed Motor Control

Centrifugal pumps, fans, and compressors constitute a large percentage of the motor-driven loads in a petroleum facility. The torque requirements of these centrifugal loads vary as the square of the speed; thus, the brake horsepower required varies as the cube of the speed.

Traditionally, centrifugal loads have been designed to operate at constant speed with the process flow being controlled by some type of throttling means (pump control valves, fan dampers, or compressor inlet guide vanes). The energy losses from throttling can be substantial.

As an alternative to throttling, the speed of the centrifugal load can be controlled to obtain the desired flow rate without producing excessive pressure. Because the flow rate varies directly with speed while the horsepower requirement varies as the cube of the speed, using speed reduction to lower flow rates will result in a significant horsepower reduction. For example, reducing the flow to one-half its initial value by lowering the speed of the load will cause the brake horsepower of the load to be reduced to one-eighth of its initial value.

A typical pump head-flow curve is depicted in Figure 3 to further illustrate the attractiveness of using speed adjustment to control flow rate. The darker-shaded area to the lower left of each operating point indicates the power required for that operating point. The lighter-shaded area indicates the power savings that result from using speed reduction rather than throttling to control flow rate. In general, a steep system curve, or a steep pump curve, will accentuate the potential power savings. Also, the lower the static head involved, the greater the power savings will be as a percentage of overall power consumption.

The conventional methods for achieving speed adjustment include hydraulic couplings, adjustable sheave belt systems, eddy current clutches, and wound-rotor motors. These devices are relatively inefficient, however, and usually require frequent maintenance. DC motors allow speed adjustment with improved efficiency but are also prone to requiring frequent maintenance and are difficult to apply in classified areas. Electronic adjustable-frequency controllers also provide speed adjustment and have been improved over the last decade. They are now the method of choice when adjustable speed drives are needed. The maintenance level for these controllers is the lowest of the alternative methods, however, these drives create voltage and current harmonics which may require remedial modifications to the power system and drive motor. Adjustable-frequency controllers have relatively high efficiencies and can be used with induction motors which require low maintenance and are readily available for classified areas. (See also Section 2.)

The capital cost of adjustable-speed drive equipment is higher than for constant speed equipment, so an economic evaluation as outlined in 3.6 is required to determine if the potential energy savings offsets the increased cost. A major factor in such an evaluation will be the duty cycle of the equipment involved; i.e., the percentage of time that equipment will function at operating points requiring less horsepower than the design point. If the equipment is expected to operate at close to its design point for a high percentage of time, then using an adjustable-speed drive system is probably not warranted. It is also important to remember that the application of adjustable-speed drives requires the consideration of other design factors, such as avoiding the operation of equipment at critical speeds and evaluating the effects of system harmonics that may be generated by adjustable frequency drive equipment. (See also 6.10.4.)

3.8.5 Conductor Sizing

Power cables are another source of energy loss in an electrical system. The magnitude of the energy loss depends on the

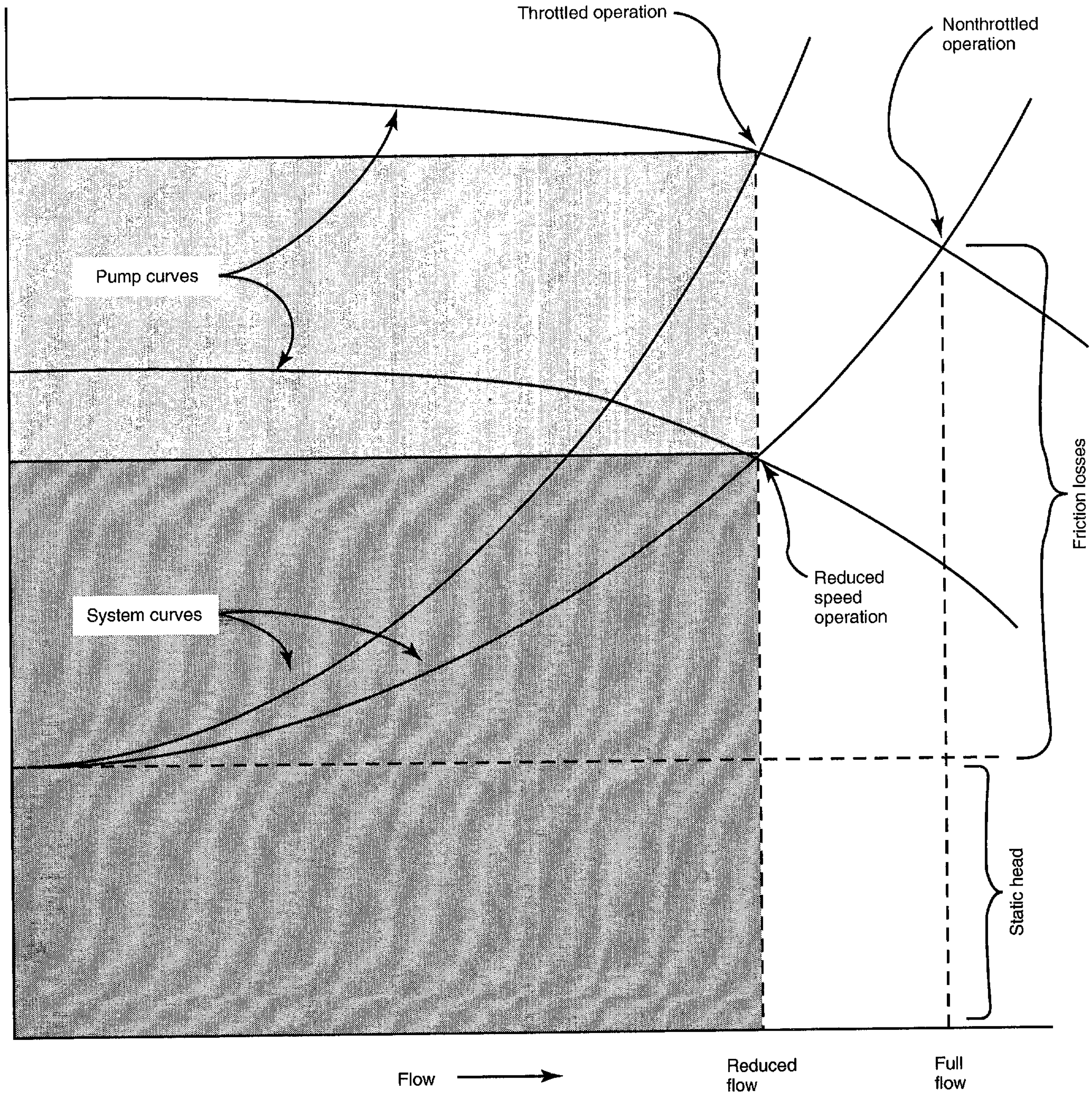


Figure 3—System Energy Losses: Adjustable Speed Versus Throttling

resistance of the cable as well as the amount of current expected to flow in the circuit. After power cables have been sized to meet the governing criteria (voltage drop, spare capacity, and the requirements of NFPA 70), a check should be made to determine if the anticipated energy loss in the cable would justify purchasing and installing the next larger size cable.

3.9 RELATIONSHIP TO POWER FACTOR

The apparent power consumed by an electrical system is expressed in kilovolt-amperes (kVA), and is composed of a kilowatt (kW) component and a kilovolt-ampere reactive (kvar) component. The kW component represents the real work extracted from the power system. The kvar component represents the magnetizing energy necessary for exciting electrical equipment such as motors and transformers, as well as the inductive and capacitive components of other devices on the system. Power factor is the ratio of kW to kVA and provides a measure of the percentage of kVA that is doing useful work.

The total current passing through the power system components (e.g., transformers, cables, transmission lines, switchgear) produces heating losses proportional to the square of the current (I^2R). The total current is proportional to the kVA, so by reducing kVA, losses can be reduced. To reduce kVA, it is only practical to cut exciting energy (kvar). In addition to wasting energy through transmission losses, excessive kvar loading uses up transformer, cable, and transmission line capacity, causing the supplying utility to overbuild their system. To control this, utilities pass on the excess cost through the use of power factor penalty clauses in power contracts. To avoid paying these penalties, power factor must be kept above a fixed value—normally between 0.90 and 0.94.

The large number of induction motors typical in a process plant can result in a low overall power factor on the system (0.85 power factor or less). Motors that are lightly loaded accentuate the problem because motor power factor decreases rapidly with decreasing load. The low power factor results in higher-than-necessary currents on the distribution system, resulting in higher losses. Improving the power factor will increase the overall efficiency of the power system. An improved power factor can also reduce or even eliminate power factor penalty charges if utility contracts contain such provisions.

The following actions can increase power factor, and reduce the associated losses:

a. Using high power factor rated equipment, such as high power factor lighting ballasts.

b. Using synchronous motors which can be operated at unity, or leading (capacitive) power factor.

c. Operating high efficiency induction motors at close to design horsepower.

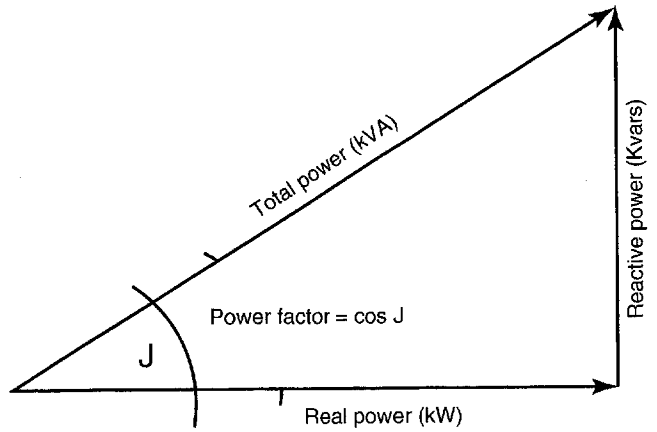


Figure 4—Power Relationship

d. Using power factor correction capacitors to supply the reactive requirements of inductive loads.

e. Increasing the excitation from in-plant generators.

f. Installing a static var compensator.

g. Controlling voltage so as to avoid overvoltage conditions.

When capacitors are applied to induction motors, the greatest benefit is obtained if the capacitors are installed at the motor terminals, and are switched on and off with the motor. Care must be taken in the application of power factor correction capacitors. Proper attention must be given to the effect that capacitors have on harmonic resonance, thermal overload sizing, circuit breaker switching capability, the lengthening of motor open-circuit time constants, and the possibility of motor self-excitation.

A synchronous condenser can also be used to improve power factor. This device is used mainly by utilities, however, and is not practical in most industrial plants.

3.10 DEFINITIONS AND CONVERSION FACTORS

The following is a list of definitions and conversion factors that are often useful in energy discussions:

a. 1 British thermal unit (Btu) equals the heat required to raise the temperature of 1 pound of water by 1°F.

b. 1 quad (quadrillion Btu) equals 1,015 Btu.

c. 1 therm equals 100,000 Btu.

d. 1 horsepower (Hp) equals 0.746 kW.

e. 1 kWh equals 3,413 Btu.

Note: Due to thermal losses, approximately 10,000 Btu of raw fuel are consumed to produce 1 kWh of electricity in a conventional utility generating station.

f. One 42-gallon barrel of fuel oil contains about 6 million Btu.

g. One cubic foot of natural gas contains about 1,000 Btu.

h. One ton of coal contains about 25 million Btu.

SECTION 4—FACILITY POWER SYSTEMS

4.1 PURPOSE

This section discusses the design considerations that must be evaluated for the development of a reliable and cost effective power system for continuously run petroleum facilities.

4.2 SCOPE

All aspects of facility power systems, from the point at which power is introduced into the facility to the points of utilization, are covered by this section. Topics include incoming lines for purchased power, in-plant generation, substations, transformers, switchgear, overhead distribution systems, voltage levels, system arrangements, protective relaying, fault currents, and system stability.

4.3 POWER SOURCES

4.3.1 Generated Power

Facility power stations not connected to public utility systems must be designed with redundancy to ensure a self-sufficiency for various operating contingencies. These power stations should have provisions for a cold (black) start and, as a minimum, should be designed to supply 100% of plant electrical loads after the loss of any single major component of the power generating system. Other contingencies, such as the capability of motor starting at reduced generation, should be considered.

4.3.1.1 Power Station Auxiliaries

Facility power stations that produce process steam and electricity must be provided with highly reliable station auxiliaries. The auxiliaries should be spared and supplied from a minimum of two independent sources devoted solely to providing auxiliaries. Critical auxiliaries for air, fuel, and water supplies should have steam-driven spares.

4.3.1.2 Power Station Bus Arrangements

The size and importance of the power station will determine the type of bus arrangement utilized for the main electrical connections. Small stations (less than 10 MW) frequently have only a single main bus as shown in Figure 5. Bus failures are not common, and fair reliability is obtained. It is necessary to shut down, however, when performing preventive maintenance to the main bus or when additions are made to the main bus. Circuit breakers must be taken out of service to be worked on, but this problem can be minimized by using drawout-type breakers. These disadvantages can result in disruption to essential station auxiliaries, such as draft fans, preheaters, boiler feed pumps, air compressors, and lighting.

Unit construction, illustrated in Figure 6, can be used in isolated power stations. With this construction, each generator has its own boiler or turbine, main bus, and boiler, or turbine auxiliary bus. Normally, the tie circuit breaker between the main buses is closed but will open in the event of a fault on either bus. In effect, the arrangement operates much the same as two independent power stations tied together. The main buses are tied together during normal operation, so each side must be rated for the total fault duty resulting from both generators.

A synchronizing bus scheme, shown in simplified form in Figure 7, is often used for a power station bus. This scheme offers a high degree of flexibility to add or remove generators and loads. The reactors serve to limit the amount of fault duty imposed on any one bus and to isolate voltage dips, to a degree, during faults. In this arrangement the loads on each bus are matched to the generating capacity on that bus to minimize the amount of load transfer through the synchronizing bus under normal operation.

The design of the power station bus arrangement should allow for future expansion, such as expanding a single or dual bus arrangement to a synchronizing bus arrangement. The design should also minimize the loss of generating capacity which would occur during a single fault or operating error.

4.3.1.3 Power Station Excitation Systems

The reliable generation of reactive power is a vital task performed by the generator field. The field is powered from an excitation system controlled by a voltage regulator system that maintains desired bus voltage conditions when operated in isolation. When operated in parallel with a utility, the voltage regulator system is biased to maintain a fixed reactive power or power factor. The two types of excitation systems in general use are brushless exciters, which are similar to those used on brushless synchronous motors; and static exciters, which feed power through slip rings to the generator field. With either system, means should be provided to ensure continued generator fault-current output for faults in close electrical proximity to the generator terminals, since these faults will severely depress the generator bus voltage. This will require the use of power current transformers for static excitation systems or a constant voltage source for the exciter field on a brushless system.

4.3.2 Purchased Power

When power is purchased from a utility, the following items, as a minimum, should be considered:

a. Source and number of feeders.
b. Reliability of utility system.
c. Capacity and voltage of circuits.
d. Power contracts and demand limitations.

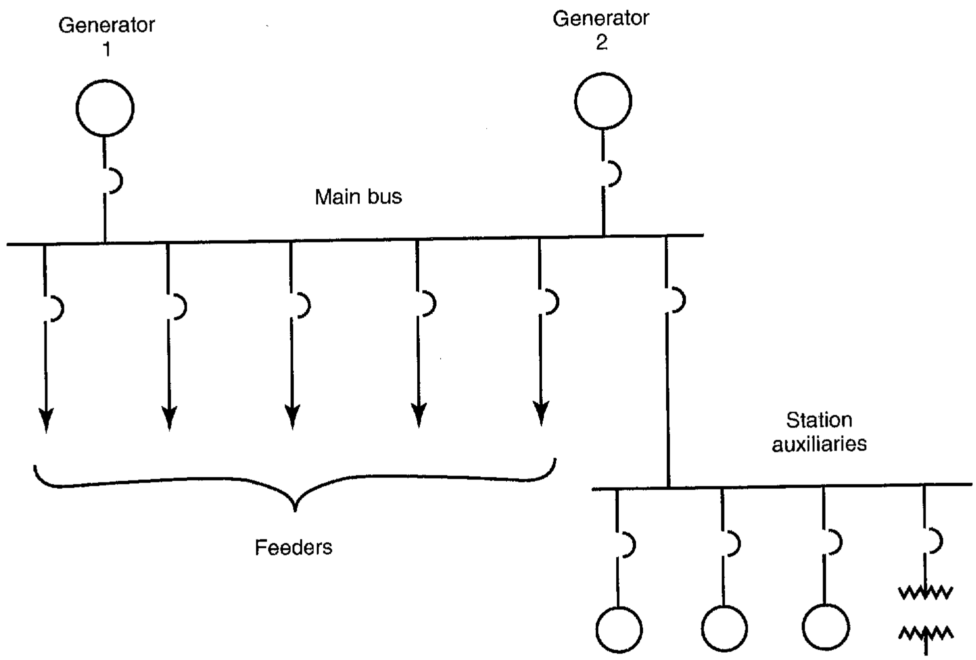


Figure 5—Single Main Bus Arrangement

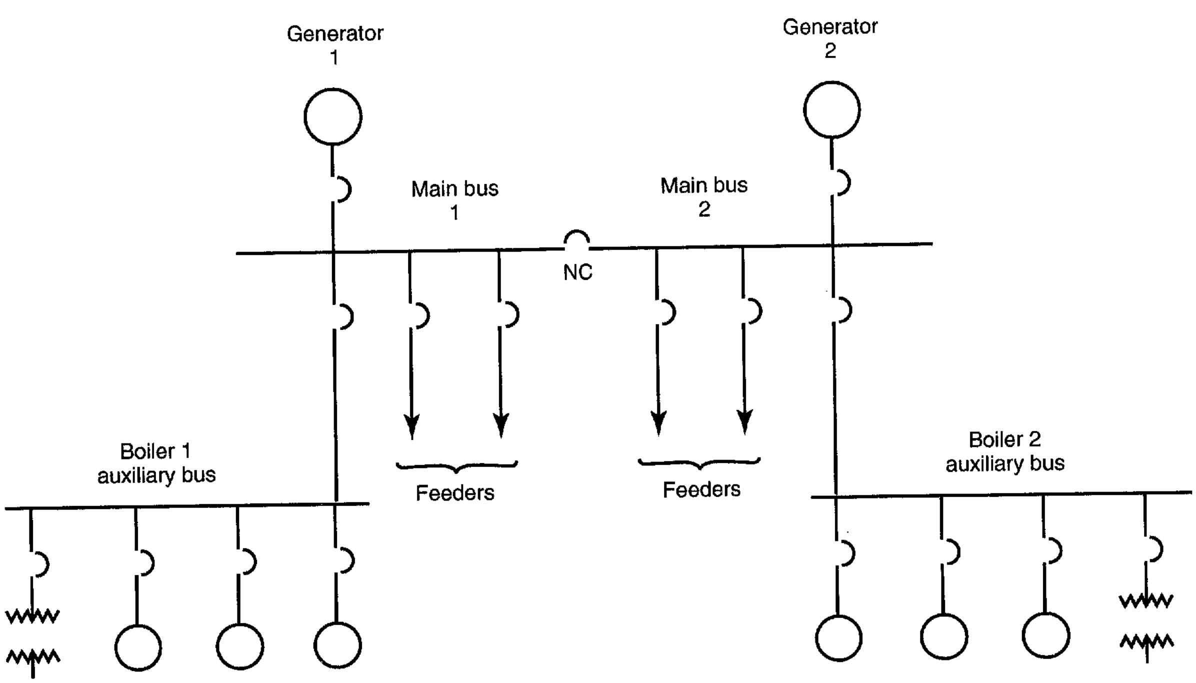


Figure 6—Unit Construction Bus Arrangement

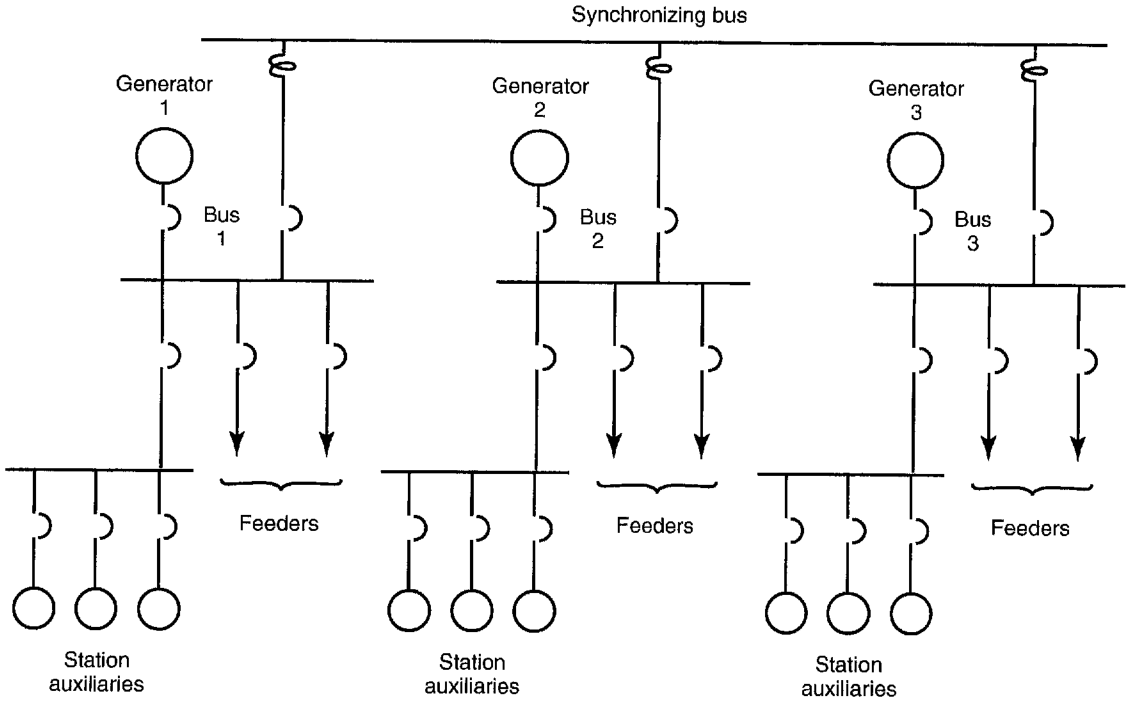


Figure 7—Synchronizing Bus Arrangement

e. Parallel operation of multiple incoming lines.
f. Automatic transfer scheme.
g. Voltage regulation.
h. Harmonic distortion, or harmonic current limitations.
i. Short-circuit current.
j. Coordination with utility relaying.
k. Motor starting requirements.
l. Reclosing procedures.
m. Substation and metering requirements.
n. System maintainability.
o. Future potential additions or modifications to the petroleum facility.

4.3.2.1 Source and Number of Feeders

When major portions of the plant load are supplied by purchased power, multiple feeders should be provided to increase service reliability. Circuits should have maximum electrical isolation or redundancy. Where possible, circuits should be separately routed to minimize the possibility of total outage resulting from exposure to fire or to mechanical damage.

4.3.2.2 Reliability of Utility System

Utilities should provide information concerning routing, the type of construction, and the extent to which their circuits are protected against outage. Performance records of pertinent utility feeders should be examined to determine the frequency and nature of service disturbances, the existence and speed of automatic reclosures, and the length of outages. Performance records should also be examined to determine if any actions have been taken to prevent recurrences of previous interruptions.

4.3.2.3 Capacity and Voltage of Circuits

Circuits should be sized so that if any one circuit is out of service, the remaining circuits have the capacity to carry the load continuously. Circuit voltage in most cases will depend on utility standards and the amount of purchased power required. When the voltage of incoming feeders is higher than the voltage selected for the facility, transformers of proper voltage rating will generally be included in each substation where utility feeders are terminated.

4.3.2.4 Power Contracts and Demand Limitations

The exact form of and terms set forth in power contracts will vary with the utility and region of the country. Energy charges include fuel adjustment costs as part of the contract. Demand charges are based both on kilowatts with power factor adjustments and on kilovolt-amperes. Power contracts may have maximum demand limitations or provisions under which demands beyond specified levels are supplied on an interruptible basis only. To determine the most favorable rate,

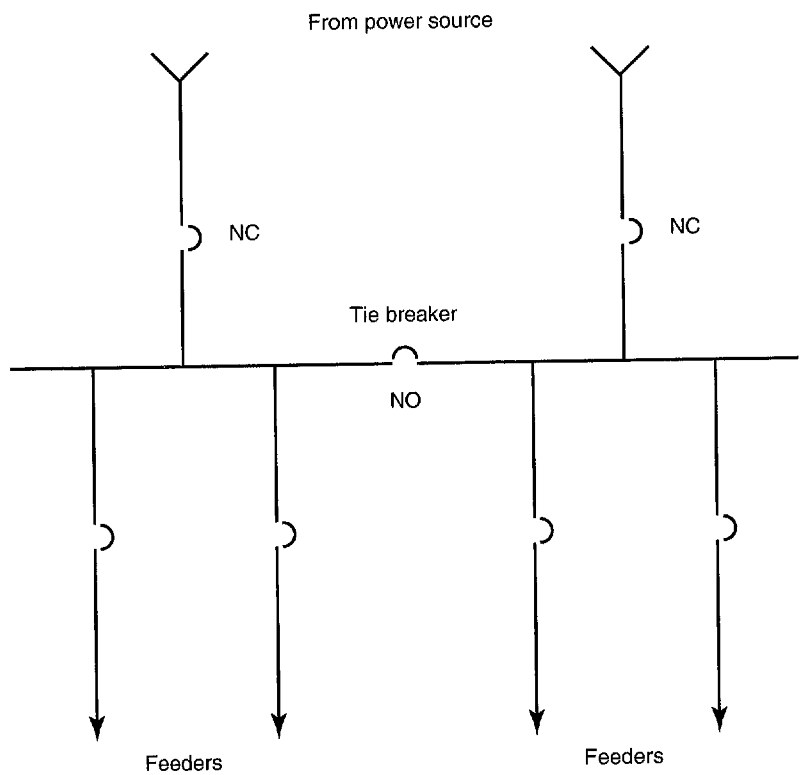


Figure 8—Purchased Power: Divided Feeder Operation

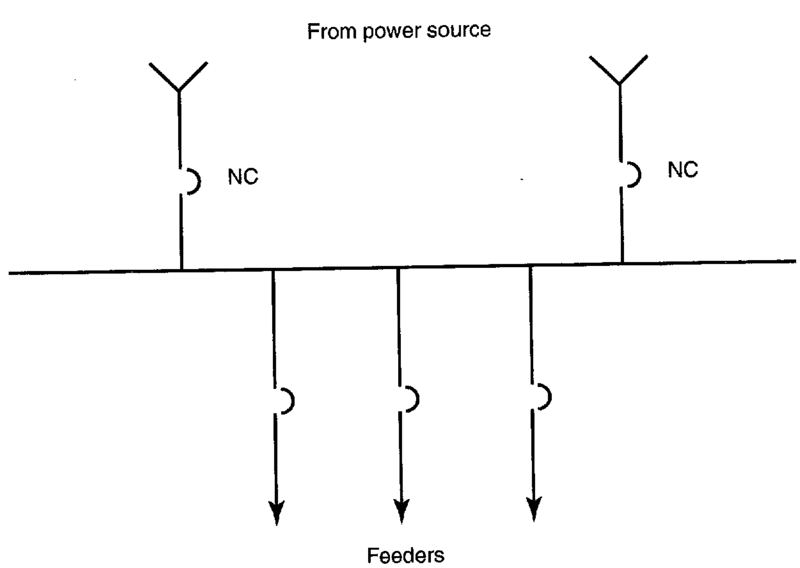


Figure 9—Purchased Power: Parallel Feeder Operation

it is essential to know firm demand and energy requirements as well as daily and seasonal load profiles.

4.3.2.5 Parallel Operation of Incoming Lines

The preferred operation of incoming utility lines is to parallel them on the substation bus. Typical arrangements are shown in Figures 8 and 9. Suitable relaying must be provided for proper system protection, and, before the feeders can be operated in parallel, protection must be provided (e.g., through the use of synchronization check relays) to verify that the voltages of the feeders are equal and synchronized.

4.3.2.6 Automatic Transfer Scheme

When incoming circuits cannot be paralleled, automatic transfer between the circuits should be considered. Load requirements should be checked carefully, and a regular testing method for the automatic transfer scheme should be included. Fast transfer schemes must consider the effects of residual voltage on motors and driven loads.

4.3.2.7 Voltage Regulation

Where utility or plant voltage varies (to unacceptable levels), automatic load-tap-changing transformers or other methods should be considered for maintaining close voltage regulation.

4.3.2.8 Harmonic Distortion, or Harmonic Current Limitations

Harmonic distortion, typically generated by nonsinusoidal waveforms originating from SCR rectifiers, adjustable speed drives, and similar electronic voltage and frequency controlled devices, can cause serious problems in electrical systems. Problems can include overloading and overheating of phase and neutral power systems; problems associated with high electrical noise on the system; inability of electronic hardware to synchronize; failure of frequency-sensitive circuits such as lighting ballasts; failure of adjustable speed drives and motor windings due to reflected waves; and many other abnormalities. IEEE Std 399 and Std 519 should be reviewed for systems with appreciable nonsinusoidal harmonics. Often, utilities will impose limitations on the maximum amount of harmonic current being generated by the customer into the utility supply.

4.3.2.9 Short-Circuit Current

The electrical system must be designed to accommodate the maximum short-circuit current that would result from the combined effect of both utility and in-plant sources. All system components, such as circuit breakers, transformers, and buses, must have ratings that can adequately withstand and interrupt the effects of the fault currents to which they are exposed. The minimum utility short-circuit level must also be known so that its effect on motor starting and protective relay settings can be determined.

4.3.2.10 Coordination with Utility Relaying

Proper coordination between substation and utility protective relaying is essential to minimize the number and duration of power outages. The proper relaying should be selected by the user in collaboration with the utility company.

4.3.2.11 Motor Starting Requirements

The voltage drop which occurs on the plant bus during motor starting should be calculated to ensure that plant and utility company limitations are met. The voltage-drop calculation should be based on the starting of the plant's largest motor with all other required plant loads in operation. Reduced-voltage starting or an auxiliary starting driver may be required when the utility system is not stiff enough to allow full-voltage starting.

4.3.2.12 Reclosing Procedures

Utilities may employ automatic reclosing schemes on overhead lines because the faults which occur on overhead lines are often transient in nature. The delay time and number of automatic reclosures are based on a review of such factors as the voltage level of the feeder and the feeding of the plant from either a radial distribution feeder or a tap on a transmission tie line. The delay time before and between automatic reclosures and the number of reclosures are required for the design of protective relaying and system control schemes.

4.3.2.13 Substation and Metering Requirements

Characteristics of a facility substation, should take into consideration:

a. Largest single load.
b. Total connected load.
c. Maximum allowable voltage drop.
d. Utility reliability.
e. Substation ownership (utility versus user).
f. Primary versus secondary metering.
g. Spare transformer capacity.
h. Future load growth and expansion requirements.
i. Grounding.
j. Isoceraunic (lightning frequency) level and protection schemes.
k. Facility life.
l. Maintainability as it would affect substation design.

4.3.2.14 System Maintainability

The electrical distribution and utilization system must be designed so that it can be inspected and maintained on a regular basis to assure reliable operation. Often, the maintenance of electrical facilities for a petroleum facility are maintained at the same maintenance intervals as other process equipment. The connection of unrelated process equipment should be avoided if it cannot be shutdown during the primary facility shutdown.

4.3.2.15 Facility Additions or Modifications

Design of electrical systems should take into consideration any potential additions or modifications of the facility. This is especially important when selecting equipment fault duty ratings and designing provisions for future expansion or additions.

4.3.3 Parallel Operation with Purchased and Generated Power

When a utility supplies a part of the facility power requirements and operates in parallel with plant generated power, the following must be considered:

a. Division and interchange of real and reactive power.
b. Protective relaying.
c. Service restoration procedures.

4.3.3.1 Division and Interchange of Real and Reactive Power

Power interchanges between utility and industrial systems can vary due to excess plant power generation, utility power restrictions, or load adjustments to maintain constant demand on the utility system. Contracts for the purchase of utility power should include the amount of kilowatts and kilovars and the division or interchange of them between the utility and the facility. If the utility line voltage is subject to wide variations, a method for controlling kilovar interchange as well as regulating voltage should be considered. Possible methods include automatic load-tap changers on transformers, power factor correction capacitors, and power factor control of the generator or synchronous motor excitation systems.

4.3.3.2 Protective Relaying

Protective relaying must be provided to protect the plant and its generation from faults or power loss in the utility system. The relaying must protect against adverse interactions between the systems and, if necessary for system stability, must act to isolate plant generation from the utility system. Impedance, reverse power, directional overcurrent, or underfrequency relays may be used to trip the incoming supply circuit breakers. If plant load exceeds generation, an automatic load-shedding system should be provided to relieve generation overloads after isolation and to maintain plant system stability.

4.3.3.3 Service Restoration Procedures

Various fault or switching conditions may cause facility and utility generating systems to separate. The usual sequence involves a fault transient disturbance affecting both systems until separation occurs, followed by recovery of the isolated systems. The fault transient may cause a voltage dip which will cause motors to drop off the line; however, if process conditions allow, important drives can have their control equipped to permit their restarting automatically when plant voltage recovers.

Operation of plant generation after separation may require automatically adjusting the load on plant generation to the load level that it can successfully restart automatically and supply continuously with acceptable voltage and frequency levels. If the plant has been receiving power from the public utility, voltage and frequency will fall unless load-shedding restores the proper balance or the plant turbine-generators can increase output to the proper level. If the plant had been sending power to the public utility before isolation, electrical output must be reduced. The effect of this reduction on plant steam system conditions must also be determined.

Paralleling of the plant generation and the utility system should be possible only at selected circuit breakers that are equipped with synchronizing switches connecting these breakers into the plant synchronizing system. Other circuit breakers where inadvertent paralleling is possible should be equipped with synchronizing-check relays that prevent closing unless voltage and frequency conditions at both terminals of the breakers are within prescribed limits. Relays which protect the system during fault conditions must be applied and set carefully to prevent separation from occurring during synchronizing swings.

A power system study is normally required to provide the proper protective relaying and settings as well as the generating system and load shedding system parameters necessary for system stability during the fault and recovery transients.

4.4 SYSTEM VOLTAGES

4.4.1 Selection

The selection of system voltages in a facility is based primarily on economics, with consideration given to the following factors:

a. Class of service available from the utility.
b. Total connected load.
c. Planning for future growth.
d. Plant standardization of equipment.
e. Density and distribution of the load.
f. Safety.
g. Interconnection to existing systems.
h. Equipment availability.
i. Practical conductor and equipment sizes.

4.4.2 Voltage Levels

The voltage levels in a facility can be divided as follows:

a. Less than or equal to 600 V (low).
b. From 601 V to 69,000 V (medium).
c. Greater than 69,000 V (high).

The low-voltage level is normally used to supply small motors, lighting, and controls. The medium-voltage level is normally used for larger motors and for distribution of small and medium blocks of power. Voltage levels of 34,500 V to 69,000 V may be used for large blocks of power. The high-voltage level is used for the transmission and distribution of bulk power.

4.5 POWER SYSTEM ARRANGEMENTS

Four basic types of power system arrangements are available: the radial, the primary-selective radial, the secondary-selective radial, and the secondary-selective parallel. The selection of a system arrangement is governed by factors such as service continuity, flexibility, regulation, efficiency, operating costs, investment costs, and reliability of the power source. Maintainability of equipment should be carefully considered because it affects all of these factors. Systems that utilize multiple supplies, loops, and ties can be quite complex. The number of relays, switches, and interlocks required by these systems necessitates careful engineering to avoid shutdowns resulting from equipment failures or improper operation.

4.5.1 Simple Radial System

The easiest system to understand, operate, and troubleshoot is the simple radial system shown in Figure 10. It is the least expensive system to install and is expandable. The disadvantage of the simple radial system is that it provides no alternate source of power. A failure in the primary breaker, cable, switch, or transformer can result in a process shutdown. Placing a single load group or process unit on a radial feeder will reduce the effects of a circuit failure on the overall facility.

4.5.2 Primary-Selective Radial System

The primary-selective radial system shown in Figure 11 provides better service continuity and more flexibility than the simple radial system because only half the transformers are on one feeder. Should a feeder fail, the affected loads can be switched to the other feeder. Voltage regulation in a primary-selective radial system is comparable to that of a simple radial system; however, the initial investment in a primary-selective radial system is higher.

4.5.3 Secondary-Selective Radial System

The secondary-selective radial system, shown in Figure 12, provides service continuity and voltage regulation. A feeder fault will cause half the load to be dropped, but service can be restored quickly through manual or automatic operation of the secondary tie breakers. Investment costs of this system are relatively high.

4.5.4 Secondary-Selective Parallel System

The secondary-selective parallel system, shown in Figure 13, provides uninterrupted service continuity and voltage regulation to all loads. The unit substation tie breaker is normally closed and an interruption of either of the source supplies will not interrupt any of the loads. This configuration is by far the most complex and costly, but may be justified based on consequences associated with process disruption. A consideration is that disturbances on one bus may affect loads connected to the other bus. Equipment fault ratings must be sized for the total fault duty from all sources.

4.6 POWER SYSTEM STUDIES

4.6.1 General

The planning, design and operation of a power system requires continual and comprehensive analyses to evaluate current system performance and to establish the effectiveness of alternative plans for system expansion.

4.6.2 System Studies

Studies that will assist in the evaluation of initial and future system performance, reliability, safety and ability to grow with production and/or operating changes are:

a. Load flow.
b. Cable ampacity.
c. Short-circuit.
d. Protective Device Coordination.
e. Stability.
f. Motor starting.
g. Insulation Coordination.
h. Reliability.
i. Grounding.
j. Harmonics.

The procedures for performing the above system studies are outlined in many publications devoted to the subject. Included among these are the following:

a. IEEE Std 80.
b. IEEE 141 (Red Book).
c. IEEE Std 242 (Buff Book).
d. IEEE Std 399 (Brown Book).
e. IEEE Std 493 (Gold Book).
f. IEEE Std 519.

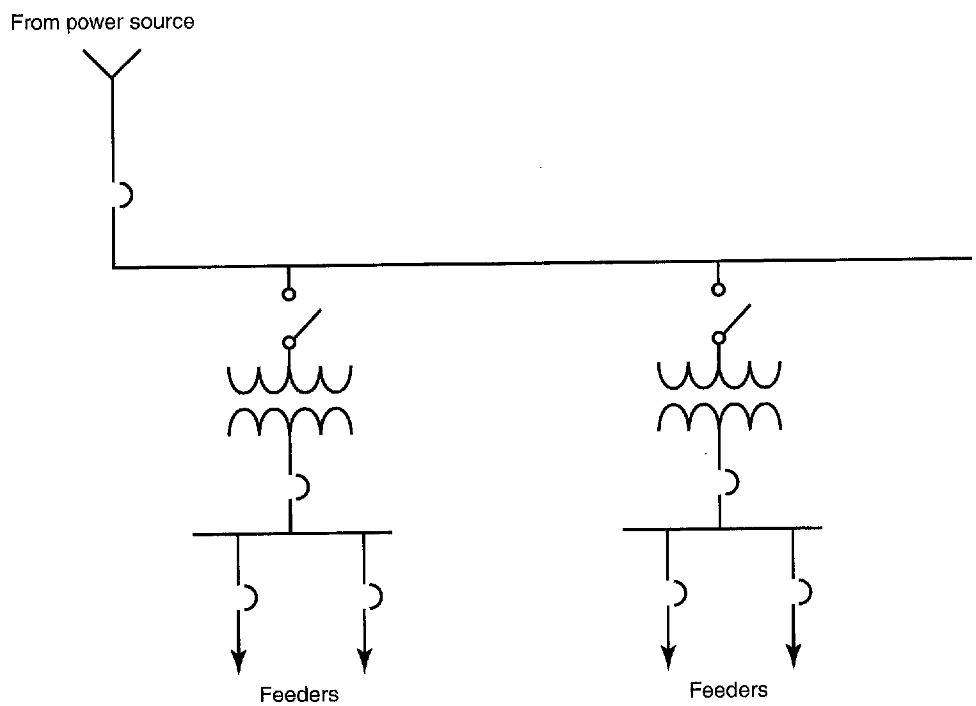


Figure 10—Simple Radial System

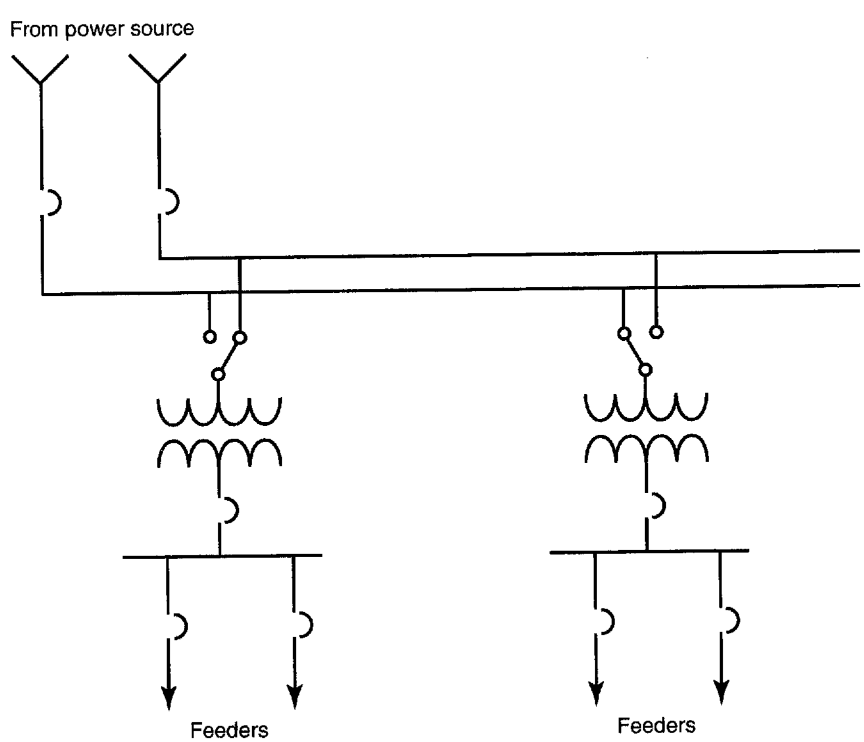
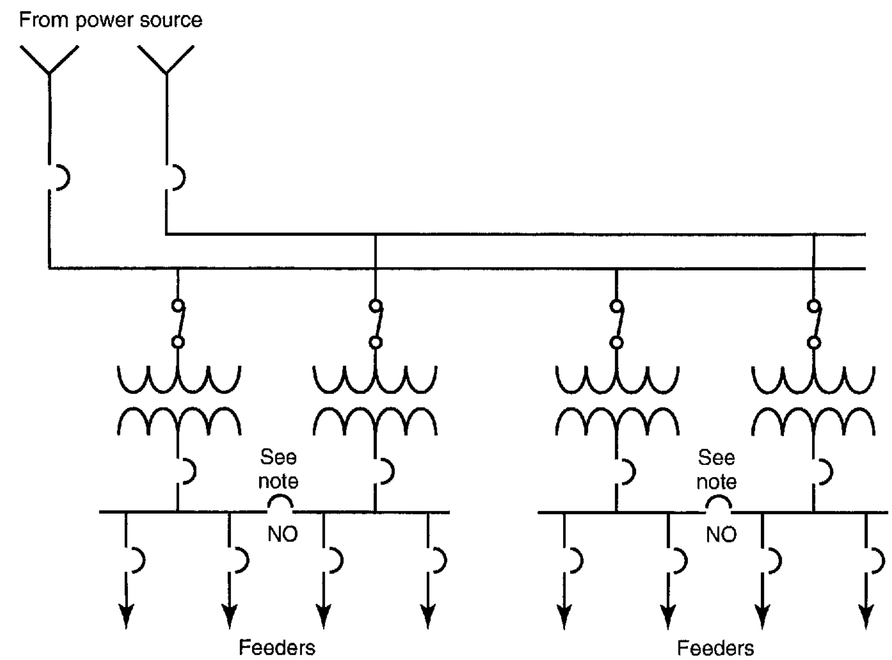


Figure 11—Primary-Selective Radial System



Note: For automatic mode of operation, tie breaker is interlocked to prevent closing unless one transformer breaker is open.

Figure 12—Secondary-Selective Radial System

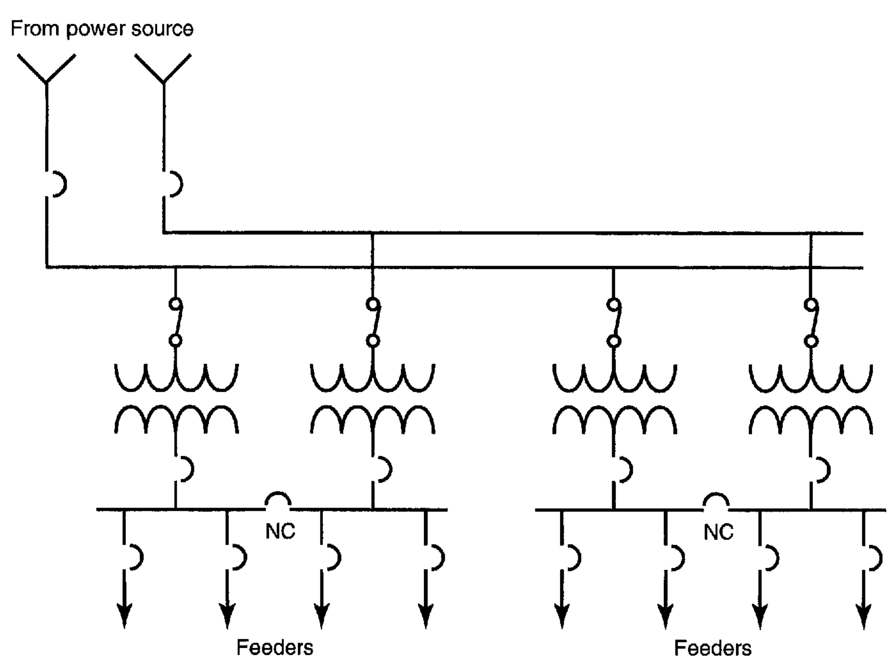


Figure 13—Secondary-Selective Parallel System

g. IEEE Std 1015 (Blue Book).

h. *Protective Relaying for Power Systems,* Volume I and Volume II, edited by Stanley H. Horowitz, American Electric Power Service Corporation.[15]

4.7 SYSTEM PROTECTION

4.7.1 Fault Considerations

When a facility's electric power system has to be designed and the appropriate equipment needs to be selected, the following fault considerations should be considered:

a. Possible or likely places where faults may occur.

b. Amount of fault current that the system can deliver.

c. Possible damage that may result from faults.

4.7.1.1 Location of Faults

Although faults can occur anyplace in an electrical system, the probability of occurrence varies at different locations. Switchgear, transformers, and buses have relatively few short circuits; and rotating machines, when maintained and protected against voltage surges, are not prone to failure. Bare overhead distribution systems, however, experience the highest incidence of faults.

4.7.1.2 Fault-Current Magnitudes

Devices used for fault-current interruption must have interrupting and momentary withstand ratings that can adequately handle the available fault currents. Inadequate ratings can result in failure of the equipment to perform its intended function. Such a failure can destroy the equipment and can result in potential danger to personnel and to other equipment.

Interrupting-device ratings should be based on the maximum fault current of the system at the point of application. The magnitude of fault current which the system can deliver depends on the sources of current and the impedance between the sources and the fault. The sources of current include in-plant generators and motors and connections to external power sources such as electric utilities. The fault-current capabilities of simple systems may be hand-calculated; those of more complex systems will require study using computer programs that are readily available. When selecting equipment, future expansion of the electrical system must be considered to ensure that ratings are adequate for the future current duty. Driving point voltage (voltage at the time of the fault) must be determined. It is not uncommon to see systems operating at 1.05 to 1.10 per unit voltage.

[15]Available from IEEE.

4.7.1.3 Damage From Faults

Faults which are not promptly isolated from the source of power can be very damaging: electrical and other apparatus can be damaged, fires can be started, and lives can be endangered. Lengthy production interruptions are a likely result of this kind of damage.

4.7.2 Fault Clearing Considerations

4.7.2.1 Procedure

To properly remove a fault from the electrical system, it must initially be detected by a fault sensing device. The fault sensing device then sends a signal to one or more fault clearing devices which will operate to isolate the faulted segment of the system. This process takes place automatically and quickly in order to minimize the damage caused by the fault. The fault clearing devices must have adequate interrupting and momentary withstand ratings as discussed in 4.7.1.2.

4.7.2.2 Dual-Purpose Devices

Some electrical devices provide both the sensing and the interrupting functions in the same enclosure without the interaction of peripheral devices. Examples of these devices are as follows:

a. Fuses of all voltage ratings.

b. Molded-case circuit breakers and insulated-case circuit breakers.

These devices have internal sensors (thermal, magnetic, or static) that detect the flow of fault currents and, through the direct molecular or mechanical action of these sensors, operate to clear the fault.

4.7.2.3 Single-Purpose Devices

Many electrical fault clearing devices receive an electrical signal to operate from a relay or set of relays. These devices take the relay signal, process that signal, and then operate a set of mechanical contacts to interrupt the flow of electric current running through them. Examples of these fault clearing devices are as follows:

a. Circuit breakers of all types other than the types discussed in 4.7.2.2. These include sulfur hexafluoride (SF_6), oil, air, and vacuum circuit breakers in a variety of configurations. Often, these circuit breakers are mounted in a lineup of switchgear, an arrangement discussed in 4.10.

b. Circuit switchers which are usually found on high-voltage circuits for transformer and feeder protection.

Since relays are a key element in the proper operation of these protective devices, some of the important considerations regarding relays are addressed in 4.7.3.

4.7.2.4 Coordination of Devices

Generally, a zone of protection is established around each system element, such as a bus, transmission line, generator, or transformer, and a fault in a zone should be cleared by the fault clearing devices around that particular zone. For the fault clearing devices to properly isolate a faulted section of a system, they must be properly coordinated. A coordinated device must protect the equipment in a zone and should be selective with upstream and downstream devices. This means that the protective device closest to a faulted section should open and interrupt the flow of fault current before other devices on the electrical system operate. This does not mean that other devices will not see the fault current flowing, but it means that they should not have had time to take any action toward opening to clear the fault. If a malfunction of the devices occurs around a particular zone, fault clearing devices in the next zone upstream should operate to clear a fault. Obviously, the upstream devices should delay long enough to give the primary clearing devices a chance to operate; however, the upstream fault clearing devices should not delay too long or the fault damage could be more extensive.

Selectivity between fault clearing devices in series should be maintained. The procedures for determining coordination margins (time interval between device curves) are outlined in many publications devoted to the subject. Included among these are the following:

a. IEEE Std 141.
b. IEEE Std 242.
c. IEEE Std 399.
d. *Applied Protective Relaying.*[15]

Fault clearing device coordination is vital to a facility power system. Particular attention must be paid to obtaining optimum settings and to recalculating and maintaining settings as system conditions change.

4.7.3 Relaying Considerations

4.7.3.1 Relay Dependability

A relay detects abnormal system conditions and often initiates breaker operation. Although a breaker may be properly selected and applied, it is useless if it fails to operate at the proper time and a nuisance if it operates when it should not because of improper setting or application of the relay.

4.7.3.2 Relay Selection

Electromechanical and static relays must be selected with care because types are available for almost every system requirement. The proper selection and application of relays is important to the electrical system and requires thorough study. Relays associated with facility power systems are used primarily for the protection of feeders, transformers, and rotating machines.

4.7.3.3 Relay Selectivity

Many relays have settings which allow their operating characteristics to be changed. Relays can be made, for example, to operate at different times when installed to look at the same set of abnormal system conditions. Used in conjunction with fault clearing devices, they can be used to establish the coordination of the fault clearing devices discussed in 4.7.2.4. Desired protection can only be ensured by choosing relays of the proper types and operation ranges and by determining the correct relay settings. Careful studies must be made of each switching configuration for various plant operating load conditions to arrive at the proper settings that will permit maximum load to be placed on line and carried while still protecting for minimum fault levels.

4.7.3.4 Relay Testing and Inspection

Testing and inspection of protective relays for proper settings and operation should be conducted when the relays are placed in service; testing and inspection should then be conducted at established intervals throughout the life of the relays. As much as possible, testing should be done by simulating appropriate current and voltages on the primaries or secondaries of the instrument transformers that serve the relays. Many static relays have self-test programs to alarm if the relay is malfunctioning.

4.8 FUSES

4.8.1 Uses

Fuses are used on facility power systems to protect equipment and cables from overload conditions and to interrupt fault currents when they occur. When applying fuses, single-phasing possibilities should be considered. Since fuses are single-phase devices, only one fuse may blow on a single-phase fault, leaving single-phase potential on a polyphase circuit. Also to be considered is that after repeated operation at a current near the fuse's melting point, the fuse may become damaged and operate quicker than desired.

4.8.2 Availability

Fuses may be obtained in every voltage level up to at least 138,000 V. There are varieties which are current limiting so that the energy allowed to flow during a fault condition is limited to a lower level than available on the supply side of the fuse, and there are many fuses designed for special applications such as for use in motor starter circuits.

4.8.3 Coordination Considerations

The variety of fuses available allows some flexibility in protective device coordination. Each fuse has a time-current characteristic envelope curve which is used to develop coordination plots for the power system. I^2t and let-through currents must be considered when coordinating fuses.

4.9 CIRCUIT BREAKERS

4.9.1 Uses

Circuit breakers, used on both AC and DC systems, are widely used in facility power systems. Found at almost every voltage level on the system, circuit breakers protect electrical system components from overloads and faults and isolate parts of the system when these conditions occur. Many circuit breaker applications involve switchgear, and switchgear applications are discussed in 4.10.

4.9.2 Types

Circuit breakers used on electrical systems with nominal system voltages less than or equal to 600 V come in a variety of styles. Some, like the molded-case circuit breakers, do not depend on external relays for sensing overloads and faults while others, like the air-break power circuit breakers, have external current sensors and static relay modules for sensing abnormal conditions. These devices are installed in a variety of equipment, such as panelboards, switchboards, and switchgear.

Circuit breakers used on systems with nominal system voltages of 600 V–15,000 V are generally installed in switchgear lineups. These breakers use relays for sensing fault conditions. The interrupting medium is generally air or vacuum in this voltage class.

Circuit breakers used on systems with nominal system voltages of 15,000 V–35,000 V may be installed in switchgear. Most breakers for higher voltage systems are individual free-standing outdoor types, and these higher voltage devices use oil or SF_6 as the interrupting medium. Relays are used for sensing fault conditions at all these installations.

4.9.3 Location

Circuit breakers are not listed by NRTL for direct use in classified locations. They are, therefore, installed in nonclassified locations, either indoors or outdoors, or when installed in a classified location, they must be installed in approved enclosures suitable for the location.

4.9.4 Inspection and Testing

Because many types of circuit breakers are available, it is not possible to discuss in this recommended practice inspection and testing procedures for all circuit breakers. A regular preventive maintenance program should be established. The manufacturer's installation and operating instruction books or a reliable electrical testing firm should be consulted to establish maintenance and testing requirements and intervals.

4.10 SWITCHGEAR

4.10.1 General

The term switchgear covers switching and interrupting devices and their combination with control, metering, protection, and regulating devices and also covers the assembly of these devices with associated interconnections, accessories, enclosures, and supporting structures. Switchgear is used primarily in connection with the generation, transmission, distribution, and conversion of electric power. Applications include controlling circuits serving generators, large motors, transformers, power circuit feeders, and other large electrical equipment.

4.10.2 Medium-Voltage Switchgear

In general, the 5-kV to 15-kV medium-voltage switchgear used in facilities is the metal-clad type with drawout circuit breakers and all pertinent auxiliaries contained within their own individual enclosures. Switchgear above the 15-kV class may be the metal-clad or stationary type. Other equipment installed in the switchgear is necessary buses, disconnecting devices, current and voltage transformers, control power transformers, interlocks, meters, relays, and control devices. The switchgear is generally in the 5-kV to 38-kV class with current ratings up to 3,000 amperes, and interrupting classifications ranging from 250 MVA to 1,500 MVA.

4.10.3 Low-Voltage Switchgear

Switchgear rated at 600 V is available for small loads that cannot be served economically at 5 kV and above. The preferred construction is metal-enclosed, using air-break or vacuum, drawout-type low-voltage power circuit breakers. Continuous current ratings are available to 6,000 amps, and interrupting current ratings range from 30,000 amps to 200,000 amps. Integral current limiting fuse devices are used to achieve higher interrupting duties.

4.10.4 Interrupting Medium

There are several options to consider when selecting the interrupting medium for medium-voltage switchgear. Air-break and oil-immersed circuit breakers are rapidly being phased out by vacuum and SF_6 circuit breakers. An assessment of the circuit breaker installed cost, operating characteristics, and maintenance requirements is required and must be evaluated to determine which type should be applied. Low-voltage switchgear is most commonly either air-break or vacuum-break.

Where an interrupting medium is considered for an application for the first time, interrupting characteristics should be reviewed at rated conditions. Maintenance procedure details should be fully understood prior to the selection.

4.10.5 Location

Manufacturers do not list switchgear as suitable for use in a classified location. In practice, switchgear that serves process units must be either located adjacent to the classified location or installed in a pressurized room.

Processing plant switchgear frequently takes the form of a unit substation, which consists of a transformer (single-ended) or transformers (double-ended) that supply utilization voltage to a group of feeder circuit breakers. Unit substations may be purchased as neat, compact units well adapted for either indoor or outdoor plant use. Transformers and switchgear may be purchased separately and installed indoors or outdoors as desired.

4.10.6 Installation Types

4.10.6.1 Indoor Switchgear

Indoor switchgear (NEMA 1 or NEMA 12 enclosure) is not as expensive as outdoor switchgear (NEMA 3R or 4X enclosure); however, the former requires indoor space which affects the overall cost. The cost of providing the indoor location may be offset by the reduced maintenance and equipment costs and by the increased reliability resulting from a more benign equipment environment. A common location is often used to house both switchgear and motor control equipment.

4.10.6.2 Outdoor Switchgear

Outdoor switchgear is basically indoor switchgear mounted in a weatherproof enclosure. The following types of enclosures are available:

a. Enclosure without an aisle.
b. Enclosure with an aisle in front of the switchgear.
c. Enclosure with a common aisle between two switchgear lineups.

An aisle facilitates the maintenance and operation of the switchgear.

4.10.6.3 Electrical Power Centers

The use of prefabricated electrical power centers is appropriate for some applications where work at the site is to be minimized. These prefabricated electrical power centers are modular structures equipped with lighting, heating, and ventilating equipment. Requiring only assembly and internal connections on site, they can be shipped as a unit or in modular sections with switchgear, motor control centers, and other equipment already installed.

4.10.7 Preventive Maintenance

Preventive maintenance, including inspection and testing of switchgear, should be carried out on a regular schedule, with the time interval between inspections varying with environment and service. The range of intervals is usually 1 to 5 years, with experience with the particular installations dictating any changes to the schedule. Preventive maintenance should include all tasks necessary to assure the reliable operation of the switchgear during the maintenance interval. This maintenance should include inspecting the overload unit settings and other breaker parts, such as contacts and arc chutes for air circuit breakers; or vacuum interrupter, vacuum integrity, and contact erosion indicators on vacuum circuit breakers. Maintenance also includes checking the trip devices by a test set available from the equipment manufacturer.

4.11 TRANSFORMERS

4.11.1 General

This information is confined primarily to distribution and power transformers. Other types of transformers which are applied within the petroleum industry are mentioned briefly, but these other types usually operate as part of an electrical equipment package.

4.11.2 Transformer Types

4.11.2.1 Distribution and Power Transformers

Distribution and power transformers are used to isolate different voltage systems from each other and to reduce or increase voltages to their optimum utilization levels. These transformers may be integral parts of unit substations and motor control centers, or they may be located at a remote site.

Unit substation transformers are mechanically and electrically connected to unit substation equipment or motor control centers. Aside from the physical size and certain features of construction, unit substation transformers are applied in the same manner and for the same purposes as distribution and power transformers.

Power transformers are frequently used to step-down plant distribution voltage to motor utilization levels (e.g., 13.8 kV to 4,160 V or 6,600 V). Often, a captive transformer is used to supply a single large motor, usually greater than or equal to 2,500 HP. The added impedance of the captive transformer in the motor supply circuit lowers voltage and starting in-rush current. The captive transformer should be designed for the required motor starting and operating duty. The captive transformer-motor combination may be selected over the direct-connected motor for reason of design, system stability, or motor economics.

Step-up power transformer or transformer/rectifier sets are often used for desalting and precipitation processes where the plant voltage must be increased to the level required at the desalter or precipitator electrodes.

4.11.2.2 Instrument Transformers

Instrument transformers are used for metering and relaying, have a high degree of accuracy, and have limited capacity. The accuracy of transformation depends on the application because metering and relaying require different accuracies. The degree of accuracy is also subject to the effects of load and fault current.

Voltage transformers are employed to step down primary voltage to a secondary voltage, normally 120 V, at the rated primary voltage. Current transformers are employed to transform primary current to a secondary current, normally 5 amps, at the rated primary current. For some applications, current transformers with multiratio primary taps are used.

4.11.2.3 Autotransformers

The autotransformer is a single-winding transformer in which the lower voltage is obtained by a tap position between the line terminals. Unlike a two-winding distribution or power transformer, a single-winding transformer does not isolate the high-voltage and low-voltage windings.

Autotransformers are frequently used to provide an economical tie between two systems of different voltage levels (e.g., a 4,160-V to a 2400-V system and a 138-kV to a 69-kV system). They are also used for motor control in some types of reduced voltage starter packages.

4.11.2.4 Other Transformers

Other specialty transformers are zigzag grounding, constant voltage, and low-noise isolation transformers. Zigzag grounding transformers are used to derive a neutral for system grounding purposes and can be used to provide a ground connection for delta-connected transformer secondaries. They permit ground-fault relaying and eliminate high transient voltages that can occur on ungrounded systems. Constant-voltage transformers provide a stable power supply for instrumentation and other loads requiring a constant voltage. Low-noise isolation transformers are used to supply power to digital-based systems, such as computers, that are highly susceptible to voltage transients. Transformers are frequently applied to provide isolation for the input to adjustable speed drives. A three-winding transformer (a single primary with a wye- and a delta-connected secondary) can be used to reduce power system harmonics through harmonic current cancellation.

4.11.3 Ratings

4.11.3.1 Voltage and Frequency

The voltage rating for transformers is determined primarily by the system voltage available and the utilization voltage required. For 60-Hz electric power systems, it is recommended that the voltage rating conform to one of the voltage ratings given in ANSI C84.1.

Consideration in the selection of these voltage ratings could result in procurement and maintenance economies due to the ability to parallel and interchange transformers. Attention to voltage tap ratings will permit added flexibility in matching transformers to system voltages.

Due to a worldwide lack of standardization of AC system frequency, the transformer frequency should always be specified.

4.11.3.2 Capacity and Duty

The recommended kilovolt-ampere (kVA) ratings of transformers are given in ANSI or NEMA standards. These ratings should be on a continuous basis without exceeding the temperature limitations for continuous-rated transformers. Captive transformer design should take into account the magnitude of starting current, the duration of motor acceleration, and the permissible starting frequency of the motor.

4.11.3.3 Temperature Rise

The rated kVA of a transformer is the load which can be carried continuously at rated voltage and frequency without exceeding the specified temperature rise. A transformer should have a normal life at its rated kVA if the specified temperature rise is not exceeded, the ambient temperature does not peak above 40°C (104°F), and the ambient temperature does not rise above 30°C (86°F) for a 24-hour average.

Oil-filled transformers are limited to a winding temperature rise, as measured by resistance, of 65°C (117°F) or 55°C/65°C (99°F/117°F) and a hottest-spot winding temperature rise of 80°C (144°F). Dry-type transformers are divided into the following temperature rise specifications:

a. Class 150 C has Class B winding insulation and is limited to an average rise of 80°C (144°F) with a hot spot of 110°C (198°F).
b. Class 185 C has Class F winding insulation and is limited to an average rise of 115°C (207°F) with a hot spot of 145°C (261°F).
c. Class 220 C has Class H winding insulation and is limited to an average rise of 150°C (270°F) with a hot spot of 180°C (324°F).

More detailed information on temperature rise specifications is contained in IEEE C57.91 and IEEE C57.96.

If operated outside of these temperature limitations, the transformer must be rerated on the basis of the actual load cycle and ambient temperature to attain its normal life expectancy. The transformer manufacturer should be consulted for these figures. As a rule of thumb, insulation life is cut in half for each 10°C rise in operating temperature.

When load is applied to a transformer, the heating and cooling curves vary exponentially. The time constant for the windings is 5 to 10 minutes and for the oil is 2 to 4 hours. A time equal to approximately five time constants is required for the items to reach their ultimate temperature. Short-time overloads of 1 hour or less are permissible, however, as long as the hottest spot copper temperature does not exceed 150°C (302°F) for an oil-filled transformer. Overloads of more than one-hour in duration should be avoided.

Transformers operated to altitudes greater than 1,000 m (3,300 ft) above sea level are subject to special rating correction factors which may be obtained from the manufacturer.

4.11.3.4 Insulation

The basic impulse level (BIL), which indicates a transformer's ability to withstand transient over-voltages, and the applicable manufacturer's test voltages are given in IEEE C57.12.00 for liquid-filled transformers, and IEEE C57.12.01 for dry-type transformers. The dielectric strength of transformers that depend on air for insulation decreases as altitude increases. Insulation-class correction factors for altitudes greater than 1,000 m (3,300 feet) are covered in IEEE C57.12.01.

4.11.3.5 Efficiency and Regulation

Efficiency and regulation are fixed by the manufacturer's design, although more efficient designs are available at higher cost, if the loss evaluation warrants them.

4.11.3.6 Impedance

The impedance is expressed as a percentage of the transformer base kilovolt-ampere rating and is determined by the internal characteristics of the transformer, which include its core design, resistance, and geometry of windings. The manufacturer's standard impedance, in accordance with ANSI standards, is normally acceptable to facilitate parallel operation and minimize cost. In some instances, it may be desirable to install a transformer with greater-than-standard impedance to limit the short-circuit duty on secondary switchgear. In other instances, a transformer with lower-than-standard impedance is used to facilitate motor starting by reducing the voltage drop.

4.11.4 Applications

4.11.4.1 Location

Transformers and associated secondary switchgear should be located as near to their load centers as practical while minimizing exposure to fire and mechanical damage. The location should preferably be unclassified. In cases where the transformer must be in a classified location, all auxiliary devices associated with the transformer must be suitable for the classification. For Class I, Division 2, or Zone 2 locations, it is sometimes practical to locate the transformer outside a pressurized switchgear room with a secondary throat connection for a busway supply through the wall of the room to the switchgear.

4.11.4.2 Grounding

Neutral grounding of transformer secondaries should be considered. The type of grounding chosen is based on factors such as voltage levels, ground-fault levels, and continuity of service. The neutral ground is obtained by bringing out the neutral connection on a wye-connected secondary or by using a zigzag transformer on a delta-connected secondary. The neutral is either solidly grounded or grounded through resistance or reactance.

4.11.4.3 Parallel Operation

Proper operation of parallel transformers requires that the transformers be connected properly and that their characteristics be within certain tolerances—refer to IEEE C57.12.00 and IEEE C57.12.01 for acceptable tolerances for parallel operation. To divide the connected load according to the rating of the parallel banks, the following must be the same: the internal impedance, the transformation ratio, and the phase relationship. It is not possible to parallel delta-wye or wye-delta banks with a delta-delta bank because of the 30° phase shift that is present in the secondary.

4.11.4.4 Testing and Maintenance

A systematic testing and maintenance program should be established for transformers. It should include the inspection and cleaning of bushings, the testing and gas analysis of transformer oil, and the vacuum cleaning of dry-type transformers. The manufacturer's test report for each transformer should be kept on record. This report contains results of dielectric tests and measurements of resistance, excitation current, impedance, ratio, temperature rise, polarity, and phase relation. The dielectric strength of new transformer oil should not be less than 30 kV when measured in accordance with ASTM D877. Refer to IEEE C57.106 for mineral oil testing, to IEEE C57.111 for silicone fluid testing, and to IEEE C57.121 for Less Flammable Hydrocarbon Fluid testing.

When dielectric testing of transformer windings is performed, the test parameter limitations set forth in the standards should not be exceeded (see 4.11.3.4).

Dielectric testing of bushings is also covered by standards. High-voltage DC test equipment is available to provide nondestructive and accurate testing of insulation. This method of testing is preferable to high-voltage AC test procedures. Power factor tests are also used to indicate the condition of transformer insulation. When a program of power factor testing is planned, the transformer factory testing should include a power factor test so that the results will be available for comparison with later field testing.

4.11.5 Construction and Accessories

4.11.5.1 Oil-Filled Transformers

Transformer oil is used to insulate and cool the windings and to protect the core and windings from corrosive and hazardous vapors. Transformer oil should include a suitable oxygen inhibitor to prevent deterioration of the dielectric. The sealed-tank system is standard for transformers rated 2,500 kVA, 200-kV basic impulse level and less, and is often used on larger sizes as well. Inert-gas-pressurized sealed tanks are sometimes provided on larger or critical-service transformers.

Standard accessories for oil-filled transformers include a no-load tap changer, a ground pad, a nameplate, a liquid-level gauge, an oil temperature indicator, a drain valve, a top filter valve, a pressure-vacuum gauge, and jack bosses. Optional features pertain to the type of bushings, fan controls, winding temperature indication, sudden pressure relay, terminal blocks, junction boxes, disconnect switches, and throat connections. Where applicable, terminal chambers must allow adequate space for stress-relief terminations on shielded cable. Current and voltage transformers, to serve metering and relaying, are often provided in special, separate termination chambers. Multi-ratio current transformers are often located within the transformer tank. Consideration should be given to a hottest-spot temperature detector where the system operation may subject the transformer to emergency loading conditions (e.g., where automatic bus transfer between two transformers is provided). Transformer gauges can be provided with alarm contacts to allow remote annunciation of transformer problems. All transformer accessories must be suitable for the area classification where the transformer is to be installed.

4.11.5.2 Transformer Fluid

4.11.5.2.1 Mineral Oil-Filled Transformers

Regulations require users of transformers containing polychlorinated biphenyls (PCBs) to maintain specific records, to comply with specified procedures in case of leakage and for disposal, and to fulfill other requirements. Users of PCB-filled or PCB-contaminated oil-filled transformers should consult applicable federal and state regulations. Transformers containing PCBs are no longer manufactured because of federal environmental and health regulations (see 40 *CFR* Part 761.).

4.11.5.2.2 Less-Flammable Hydrocarbon Fluid and Silicon Insulating Fluid-Filled Transformers

Transformers with less-flammable hydrocarbon fluid and silicon insulating fluid insulation media, are available for use where mineral oil-filled transformers would constitute a fire hazard, and are substitutes for the PCB-type transformers. The less-flammable, hydrocarbon type has several specific restrictions on indoor use; while the silicon insulating fluid-type may be used indoors with only the same vault requirement for ratings over 35 kV that applies for PCB-filled transformers (see NFPA 70). Silicon insulating fluid is generally not used above 35 kV.

4.11.5.3 Dry-Type Transformers

Ventilated dry-type transformers, as distinguished from sealed dry-type transformers, are used for indoor locations. Weatherproof units are available for outdoor use, primarily for lighting services where the primary voltage is usually 480 V. They are lightweight compared to oil-filled transformers, making them more economical to install. Only minimum maintenance, including a periodic cleaning of the windings, is required.

Ventilated dry-type transformers have several disadvantages, compared with liquid- or fluid-filled transformers:

a. They have a lower standard basic impulse level.
b. They lack an overload rating.
c. Their use may result in a higher noise level.
d. Their windings are more exposed to the environment.

Surge capacitors and arresters can be installed to compensate for the lower basic impulse level, and forced-air cooling equipment can be used to increase transformer capacity. Where the environment presents corrosive vapors, the transformers can be obtained as completely sealed, nitrogen-pressurized units.

4.11.5.4 Cast-Coil Transformers

Cast-coil transformers are fabricated with a solid dielectric completely encapsulating the primary and secondary coils, which are mounted in a suitable, ventilated enclosure. This results in a transformer that is contaminant and moisture resistant, has low maintenance, and has impulse ratings comparable to other dry-type transformers.

4.11.5.5 Transformer Taps

Transformers should be provided with fully rated kVA taps suitable for tap changing under no-load conditions. Tap changers are designed in uniform 2.5% or 5% steps above and below rated voltage. The number of taps above and below rated voltage and their magnitude will depend on individual requirements. Two 2.5% taps above and below rated voltage are often specified.

Large power transformers may be equipped with automatic, fully rated kilovolt-ampere taps suitable for adjusting voltage under full-load conditions.

4.11.5.6 Forced-Air Cooling

The kilovolt-ampere rating of the transformer is determined by the temperature rating of the winding insulation. One means of increasing transformer capacity is to keep the winding insulation within its rating by increasing the effective cooling of the transformer. This can be accomplished with forced-air cooling. Where load growth is anticipated, consideration should be given to providing fans for forced-air cooling; or to providing the brackets, temperature switch, and wiring necessary to accommodate the future addition of fans.

Forced-air cooling of a transformer also allows increased capacity while holding the impedance to a value that permits the use of secondary switching equipment of lesser interrupting capacity. Forced-air-cooled transformers should be considered when automatic bus transfer is provided between the secondaries of two transformers. With this arrangement, the transformer may be more economically loaded under normal operation. Forced-air cooling also permits carrying additional load (up to ⅓ on large transformers) without exceeding the specified temperature limits.

4.11.5.7 Forced-Oil Cooling

Forced-oil cooling is another method of increasing transformer capacity because it reduces oil temperature. The pumping and circulating of oil is common in the design of larger (above 8 MVA) power transformers.

4.11.6 Loading

A properly designed electrical system will seldom require the emergency loading of transformers. System growth may, however, make such loading necessary, in which case IEEE C57.91 should be consulted.

4.12 OVERHEAD ELECTRIC POWER DISTRIBUTION

4.12.1 General

The use of open conductors, pre-assembled or field-spun aerial cable, and spacer cable supported by poles or structures for distribution systems outside of process limits, utility areas, and operational areas should be subject to engineering approval. Overhead electrical distribution systems should be designed and installed in accordance with the requirements of NFPA 70, ANSI/IEEE C2, and applicable state and local codes.

4.12.2 Materials

Most pole-line materials conform to the standards and suggested specifications of the Edison Electric Institute (EEI)[16] or are similar in design, material, and workmanship. Special structures, such as A-Frame or H-Frame structures, may be required for the support of a line or a group of lines whose loading is in excess of that which can be safely or economically supported on single poles or other simple structures.

4.12.3 Aerial Cable

Aerial cable provides an alternative to open conductor distribution. Aerial cable is available in single- and three-conductor types, shielded or nonshielded; and aerial cable with a self-supporting synthetic jacket is preferred. Messengers of self-supporting cable should be grounded at frequent intervals. Surge arresters should be installed at terminal poles where aerial cable is connected to open conductors.

4.12.4 Metal-Clad Cable

Metal-clad (Type MC) cable supported by a messenger may be used as an alternative to aerial cable. Metal-clad cable consists of one or more conductors with necessary insulation, shielding, and fillers over which a suitable metallic sheath is applied. A jacket is normally supplied over the sheath. Generally, this sheath should not be relied on as a grounding conductor; a grounding conductor should be installed in the cable interstices during manufacture.

4.12.5 Accessibility

All parts of the overhead distribution system that must be examined or adjusted during normal operation should be readily accessible to authorized personnel. Provisions should be made to ensure adequate climbing spaces, working spaces, working facilities, and clearances between conductors. The electrical clearances must be established in accordance with ANSI/IEEE C2 and any applicable state and local codes.

4.12.6 Isolation and Guarding

To provide for the safety of employees not authorized to approach conductors and other current-carrying parts of electrical supply lines, the arrangement of live parts must ensure adequate clearance to ground, or guards should be installed to isolate these parts effectively from accidental contact.

4.12.7 Grounding of Circuits and Equipment

Grounding of circuits and equipment should conform to ANSI/IEEE C2 and any applicable state and local codes. Metallic sheaths, conduits, metal supports, fixtures, frames, cases, and other similar noncurrent carrying parts should be properly grounded. A temporary ground for maintenance purposes should consist of a secure mechanical connection to a buried metallic structure or driven ground rod. Resistance of such a ground should limit touch and step potentials to acceptable levels in accordance with IEEE 80.

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[16]Edison Electric Institute, 701 Pennsylvania Avenue, Washington, D.C. 20004.

4.12.8 Clearances

The clearances specified for conductors in ANSI/IEEE C2, Section 23, are a minimum recommendation. Any applicable local and state requirements must also be considered.

4.12.9 Location

4.12.9.1 Routing

The recommended routing for overhead lines is along facility roads or streets. When lines must be located in tank areas or other locations that are not reached by roadways, it is recommended that the lines be routed along earthen firewalls, the toe of dikes, or other logical routes. The location of overhead lines should comply with the requirements of applicable fire codes; and wherever possible, lines should be routed so as to minimize exposure to damage from fires originating in equipment or structures along their routes. Lines should not be run in areas where interference with crane booms and similar apparatus is likely during normal plant operation or routine maintenance.

4.12.9.2 Water Spray Exposure

Overhead lines should be located far enough from cooling towers, spray ponds, and other sources of water spray to avoid fouling their insulation and corroding their metal parts. When this is not practical, the lines should be designed and constructed to withstand the particular type of exposure to which they will be subjected. This may require overinsulation of the exposed sections of lines, the use of materials to withstand the corrosive effects of the spray, or other measures.

4.12.9.3 Petrochemical Exposure

When overhead lines are exposed to petrochemicals or other similar contaminants, the lines should be designed to withstand the effects of such contaminants. Specially approved silicon-type grease on the insulators, bushings, and similar items provides a strong deterrent to current leakage and insulator flashover. Silicon tends to absorb the foreign matter deposited on the dielectric material and continually provides a nonconducting, water-repellent exterior seal for the equipment.

4.12.9.4 Lines Adjacent to an NFPA 70 Defined Class I Location

When installed adjacent to or traversing Class I locations, overhead lines should be placed so that the current-carrying components will be outside the space that may contain flammable gases or vapors (see API RP 500). Conventional overhead-line construction normally meets this requirement because of the isolation naturally afforded by the horizontal distance from, or elevation above, the classified location.

SECTION 5—GROUNDING AND LIGHTNING PROTECTION

5.1 PURPOSE

This section provides a guide to the general principles of grounding and lightning protection as they apply to petroleum processing plants.

5.2 SCOPE

This section is limited to the consideration of grounding practices in the following categories:

a. System grounding: The protection of electrical equipment and the reliability of an electrical system.
b. Equipment grounding: The protection of personnel against electric shock.
c. Lightning protection against the hazards of fire and explosion, as well as damage to electrical equipment, caused by lightning.

5.3 STATIC ELECTRICITY AND STRAY CURRENTS

The application of bonding and grounding for protection against the effects of static electricity and stray currents (such as currents associated with cathodic protection) is not covered in this section. These important subjects are discussed in API RP 2003 and NFPA 77.

5.4 SYSTEM GROUNDING

5.4.1 General

Electric power distribution system grounding is concerned with the nature and location of an intentional conductive connection between the neutral (or derived neutral) of the system and the ground (earth). The common classifications of grounding methods used in industrial plant power distribution systems are as follows:

a. Ungrounded.
b. Low-resistance grounded.
c. High-resistance grounded.
d. Reactance grounded.
e. Solidly grounded.

The nature of system grounding significantly affects the magnitude of line-to-ground voltages under both steady-state and transient conditions. Without system grounding, severe overvoltages can occur; reducing insulation life and presenting a hazard to personnel. System grounding can control these overvoltages to acceptable levels. Further, NFPA 70 requires that certain systems be solidly grounded.

For these reasons, some type of system grounding is generally recommended.

The following grounding practice is recommended:

a. Systems rated at less than or equal to 480 V that supply phase-to-neutral loads must be solidly grounded. These include 120/240-V, single-phase, three-wire systems; 208Y/120-V, three-phase, four-wire systems; and 480Y/277-V, three-phase, four-wire systems.
b. Low-voltage (480-V and 600-V), three-wire systems should be either high-resistance grounded or solidly grounded.
c. All other plant distribution systems may be resistance grounded. These include 2,400 V through 34,500-V, three-phase, three-wire systems. (Open wire distribution may require solid grounding.)

A full discussion of the relative merits of the various systems is not within the scope of this section, but a brief summary of the principal features is included. A more extensive discussion of the subject can be found in IEEE Std 142.

5.4.2 Ungrounded System

In an ungrounded system, there is no intentional connection to ground, but the system is capacitively grounded because of the capacitance coupling to ground of every energized conductor. The operating advantage of this system is that a single line-to-ground fault will not result in a trip-out of the circuit because there is only a minor charging current flowing to ground. During such a fault, the other phases will be subject to line-to-ground voltages equal to the full line-to-line voltage; therefore, insulation for equipment used in such a system must be properly rated for this condition. Further, because of the capacitance coupling to ground, the ungrounded system is subject to overvoltages (five times normal or more) as a result of an intermittent-contact ground fault (arcing ground) or a high inductive-reactance connected from one phase to ground.

The advantage of the ungrounded system will be lost if the ground is allowed to persist until a second ground occurs. A second ground would cause an outage if it is on another phase. An adequate ground detection system, along with a program for removing grounds, is essential for satisfactory operation of an ungrounded system.

5.4.3 Grounded Systems

Resistance grounding employs a resistor connected between the system neutral and ground. This resistor is in parallel with the total system-to-ground capacitive reactance.

The high-resistance grounded system employs a resistance value equal to or slightly less than the total system-to-ground capacitive reactance. (The size of the resistor is normally expressed in amperes.) This will limit the ground-fault current to a few amperes and will eliminate the high transient overvoltages that can be created by an inductive reactance connected from one phase to ground or from an intermittent-contact ground fault. The high-resistance grounded system also provides a convenient means for detection of and alarm on a ground fault and facilitates the use of equipment which can determine the fault location without electrical system shutdown. In addition, this system is similar to the ungrounded system in that it can continue operation with a single line-to-ground fault if the maximum fault current (and total system-to-ground capacitive charging current) is limited to less than 10 amps (see IEEE 142 for additional information). The ground fault, once detected, should be cleared as soon as possible because the system is not designed to operate with the ground fault condition indefinitely.

The low-resistance grounded system uses a value of resistance that is sized to give a ground-fault current value suitable for relaying purposes (see IEEE 32 for resistor time rating). Typical current values will range from 200 amps on systems using sensitive window-type current transformer ground-sensor relaying to 2,000 amps on the larger systems using ground-responsive relays connected in current transformer residual circuits. This system provides a controlled value of ground-fault current and eliminates the overvoltage problems of the ungrounded system, but the action of a three phase circuit-switching device is required to clear a single line-to-ground fault.

Installation of resistance-grounded systems requires that equipment basic impulse levels as well as the application of surge arresters be reviewed carefully.

The solidly grounded system gives the greatest control of overvoltages but develops the highest ground-fault currents. These high currents may cause damage in equipment and may create other shock-hazard problems for personnel if equipment grounding is inadequate. However, the high magnitude ground current may be desirable to ensure effective operation of phase-overcurrent trips or interrupters.

Cable shields must be sized to carry the available ground-fault current for the duration of the fault without exceeding cable thermal limitations.

Reactance-grounded systems are not ordinarily employed in industrial power systems and will not be discussed here.

5.5 EQUIPMENT GROUNDING

5.5.1 Purpose

Equipment grounding accomplishes the following:

a. Ensures that all of the parts of a structure or an equipment enclosure are not at a voltage above ground that would be dangerous to personnel. Adequate ground connections and devices should to ensure that abnormal conditions, such as ground faults or lightning strokes, will not raise the potential of the structure or enclosure to a dangerous level.

b. Provides an effective path over which fault currents involving ground can flow without sparking or overheating to avoid ignition of combustible atmospheres or materials.

5.5.2 Grounded Equipment

The metal framework of all buildings and structures housing or supporting electrical equipment and all noncurrent-carrying metal parts of electrical equipment and devices should be grounded by connection to a grounding system. In general, equipment grounding conductors should be connected as directly as practicable to the electrical system ground. Routing the grounding conductors as close as practicable to supply conductors will minimize the voltage drop under fault conditions.

5.5.3 Equipment Grounding System

The principal requirement of an equipment grounding system is to maintain the resistance to earth of structures and equipment enclosures at the lowest practicable value. With an adequate system, the potential to ground during fault conditions will not be dangerous to personnel (because of equalizing of potentials) and equipment, and protective devices will operate properly.

Grounding-system connections may be made in various ways. The grounding system for a large or complex plant may involve an extensive network of equipment enclosures and structure ground grids interconnected by cables to provide an overall plant-grounding system. Specific requirements for grounding systems are given in NFPA 70, and detailed information is included in IEEE Std 142.

5.5.4 Specific Grounding Applications

5.5.4.1 Structures and Process Equipment

Steel building frameworks, switchgear structures, and similar installations should be grounded at several points (at least two per structure) with substantial connection to the grounding system grid. Tanks, vessels, stacks, exchangers, and similar equipment not directly supported by or bolted to a grounded supporting structure should be grounded using a minimum of two connections to the grounding system grid. Special attention should be paid to piping systems to assure the pipe is adequately grounded. Inadequate grounding could result in a difference of potential if for example the pipe was separated at a flange to replace a gasket. This could result in arcing, sparking, or a shocking an employee performing the work.

5.5.4.2 Motors and Generators

Motor and generator enclosures should be connected to the overall plant grounding system. This connection is accomplished with a mechanically and electrically continuous equipment-grounding conductor that is routed with the phase conductors of the machine. This may be a conductor run with phase conductors inside a conduit, a continuous-threaded rigid conduit system, a cable tray system, or another NFPA-70-approved method. In any case, the grounding connection must provide a low-impedance circuit from the machine enclosure back to the electrical system ground. Where conduit or trays are used, joints must be made up tightly, and bonding jumpers should be installed at expansion joints and similar locations. The bonding jumpers should be inspected periodically to insure a low impedance connection.

Supplemental grounding protection should be provided by connecting an additional grounding conductor from each machine to the local grounding system grid. The purpose of this connection is to equalize potentials in the immediate vicinity of each machine.

5.5.4.3 Metallic-Sheathed and Metallic-Shielded Cables

The metallic sheath and metallic shield (if applicable) of any power cable should be continuous over the entire run and should be grounded at each end. Grounding of the shield at both ends may require the cable to be derated due to circulating currents. Grounding at one end is permissible if a 25-V gradient is not exceeded (see IEEE Std 422 for method of estimating shield voltages). If any metallic-sheathed or metallic-shielded cables are spliced, care must be taken to obtain continuity as well as an effective physical connection with the metallic sheath or shield at the splice. Where metallic armor is used over metallic sheath, sheath and armor should be bonded together and connected to the ground system at each end of the cable and at any accessible splices. The metallic sheath on metal-clad cable may also be used as an equipment- grounding conductor if the sheath is a continuous corrugated tube. However, a separate grounding conductor installed in the cable interstices during manufacture is recommended. The distinctions between sheaths, armoring, and shields can be obscure. An overall welded metal covering is referred to as a sheath but it may act as an armor and a shield (see IEEE Std 100 for additional information). Adjustable speed drive applications may require that one end of the cable metallic shield remain ungrounded to prevent common mode voltages and circulating ground currents.

5.5.4.4 Conductor Enclosures

NFPA 70 requires that exposed metallic noncurrent-carrying enclosures of electrical devices be grounded. This includes conduit, wireways, and similar wiring materials. Where the continuity of the enclosure is assured by its construction, a grounding connection at its termination points will be adequate. If continuity is not assured by the construction, care must be taken to provide adequate connections of all sections to the grounding system grid.

5.5.4.5 Enclosures for Electrical Equipment

Switchgear, control centers, and similar electrical equipment should include a ground bus. Where the equipment consists of a lineup of two or more sections, two grounding connections to the grounding system grid, one on each end of the ground bus, are recommended.

5.5.4.6 Fences

Metal fences and gates enclosing electrical equipment or substations must be connected to the grounding system grid. A number of factors are involved here, including the resistance to ground of the substation grounding system, the distance of the fence from grounding electrodes, and voltage gradients in the soil. (For additional information, see IEEE Std 80 and Std 142.)

5.5.5 Portable Electrical Equipment

This paragraph is limited to consideration of portable electrical equipment operating at less than or equal to 600 volts; portable equipment operating at higher voltages is applied infrequently and requires special consideration. IEEE Std 142 provides information on portable electrical equipment operating at higher voltages.

Portable electrical equipment poses one of the greatest potential hazards to personnel, so it is mandatory that the enclosures of portable equipment of any type be maintained at ground potential or be protected by an approved system of double insulation.

Portable electrical equipment that is without double insulation and is operating above 50 V must be provided with a cord containing a separate grounding conductor which terminates in a grounding-type plug that is used with a matching receptacle. The grounding contact of the receptacle must be properly tied to a grounding system. NFPA 70 requires ground-fault circuit interrupters for all 125 V single-phase 15 amp and 20 amp receptacle outlets on temporary wiring used for maintenance or construction. An assured grounding program is an acceptable alternative to ground-fault circuit interrupters (for additional information see NFPA 70, 305–6). The ground-fault circuit interrupter is for personnel safety and is not to be confused with ground-fault protection of equipment requirements for items such as electrical resistance heating elements.

5.5.6 Instrument Grounding

Special considerations apply to instrument grounding. All grounding systems should be tied together in accordance with NFPA 70. In general, a power supply, equipment, and cable shields should be brought to a single point on the overall plant grounding system (procedures are necessary to allow for safe troubleshooting that may require a momentary separation of the tie to the overall plant grounding system). (See 9.8 and IEEE Stds 518 and 1100 for additional information.)

5.6 CONNECTIONS TO EARTH

5.6.1 Acceptable Ground Resistance

Ideally, a ground connection would have zero resistance, but this is impossible. The resistance of a ground connection is a function of soil resistivity and the geometry of the grounding system. In soils of high resistivity, extensive arrangements may be required to obtain an acceptable low-resistance ground.

The allowable resistance varies inversely with the fault current to ground: the larger the fault current, the lower the resistance. For large substations and generating stations, the resistance of the system grounding grid should not exceed 1 ohm. For smaller substations and for industrial plants, a resistance of less than 5 ohms should be obtained, if practicable. NFPA 70 approves the use of a single-made electrode if its resistance does not exceed 25 ohms.

5.6.2 Grounding Electrodes

Driven ground rods, $^5/_8$ to 1 in. in diameter, and 8 or 10 ft long, are the most common type of grounding electrodes; however, a single ground rod is not adequate when relatively low resistance is required. A single $^3/_4$-in. x 10-ft ground rod will have a resistance to ground of over 6 ohms, even in soil of low resistivity (2,000 ohm-cm). A number of rods connected by buried cable can be used to obtain lower resistance, and longer rods can be used where soil conditions permit; however, because of mutual effects, ground resistance does not decrease in direct proportion to the number or length of rods. Buried metallic piping or other existing underground metallic structures, including concrete-encased electrodes, for example, rebar in concrete foundations (see NFPA 70, Article 250), are also frequently used as grounding electrodes. Ground mats consisting of buried cables with or without ground rods at cable intersections commonly form a portion of the grounding electrode system used at substations. (See IEEE Std 142 for additional information.)

5.6.3 Step and Touch Potentials

Where current flows into the soil from a grounding electrode, potential gradients are created in the soil. The grounding configuration should ensure that the potential gradients will not create a hazard to personnel standing or walking on the ground in the vicinity of a grounding electrode, or touching a grounded structure carrying ground current. (See IEEE Std 80 for additional information.)

5.6.4 Ground Resistance Measurement

In many installations, it is necessary to measure the resistance to earth of the grounding system to determine if the actual value of this resistance is within design limits. Methods for measuring ground network resistance are discussed briefly in IEEE Std 142, and in more detail in the *Standard Handbook For Electrical Engineers*.[7]

5.6.5 Corrosion Problems

Copper is commonly used for grounding system grids because of its resistance to corrosion and high conductivity. Because of the galvanic couple between copper and steel, an extensive copper grounding system grid may accelerate corrosion of steel piping and other buried structures that are connected to the system. Under this condition, galvanized steel ground rods and insulated or coated copper conductors could be used, but care must be taken to ensure that the grounding electrodes do not corrode and reduce their effectiveness; and that the use of insulated or coated conductors does not prevent the overall grounding system from maintaining safe step and touch potentials. Cathodic protection of the buried steel subject to corrosion should be considered to alleviate this problem.

5.7 LIGHTNING PROTECTION

5.7.1 General

Lightning is a very large electrical discharge in the atmosphere between the earth and a charged cloud or between two oppositely charged clouds. The energy in a lightning stroke can readily ignite flammable vapors; and damage to equipment and structures can result from the flow of lightning discharge current through any resistance in its path. Lightning protection systems use air terminals (rods, masts, or overhead ground wires) to intercept lightning strokes and to divert the lightning current to ground through circuits of low electrical impedance.

5.7.2 Zone of Protection

The zone of protection of an air terminal is defined by a circular arc concave upward, passing through the tip of the air terminal and tangent to the ground plane. For complete protection, the radius of the arc must be less than the striking distance of the lightning stroke. In practice, it is conservative to use a radius of 30 m (100 ft). For air terminals less than 15 m (50 ft) above the ground, the zone of protection may be assumed to be a cone with its apex at the top of the air terminal and a base radius equal to the air terminal height. All structures completely within the zone of protection may be considered essentially immune from direct lightning strokes. (See NFPA 780 for additional information.)

5.7.3 Need for Protection

A number of factors should be taken into consideration when deciding whether or not lightning protection devices are required. The major factors to be considered are as follows:

a. The frequency and severity of thunderstorms.
b. Personnel hazards.

c. Inherent self-protection of equipment.
d. Value or nature of the structure or contents and of other structures that might be involved if lightning caused a fire or explosion.
e. Possible operating loss caused by plant shutdowns.

5.7.4 Protected Equipment

5.7.4.1 Steel Structures, Tanks, Vessels, and Stacks

Ordinary steel structures, process columns, vessels, steel storage tanks, and steel stacks of a petroleum processing plant or similar installation will not be appreciably damaged by direct lightning strokes. However, it is necessary to ground the taller structures adequately to prevent possible damage to their reinforced concrete foundations, and to provide a zone of protection for electrical apparatus and other equipment in the immediate area. (See API RP 2003 and NFPA 780 for additional information.)

5.7.4.2 Electric Power Distribution Systems

Electric power distribution systems should be protected against lightning strokes to avoid damage to equipment, a plant shutdown, and personnel shock hazards. Overhead lines can be shielded from lightning strokes by the installation of overhead ground (static shield) wires that provide a triangle of protection for the phase conductors. Similarly, substations and outdoor switching equipment can be shielded by lightning towers or overhead static shield wires, but these shielding devices must be connected to an adequate grounding system to be effective. Aerial cable normally will be protected by its messenger cable if the messenger is adequately grounded at intervals defined in ANSI/IEEE C2. If the cable has a metallic sheath or armor, the sheath or armor should be bonded to the messenger cable at each grounding point. Feeders consisting of cables in metallic conduit are essentially self-protecting; but conduits and metal sheaths should be properly grounded and bonded to the equipment at each end.

5.7.5 Surge Arresters

When electrical equipment is connected to an electric power distribution system that is exposed to direct lightning strokes, or to voltage surges caused by indirect lightning strokes, the electrical equipment should be protected by suitable surge arresters. Arresters have the ability not only to pass essentially no current at line voltages but also to pass very high current at surge voltages with little voltage drop. This protection through surge arresters would be in addition to the types of shielding outlined in 5.7.4.2. (See IEEE Stds 141 and 242 for additional information.)

Arresters should be installed as close as possible to the equipment to be protected. They are recommended as follows:

a. At both high- and low-voltage terminals of distribution, and power transformers with open bushings.
b. At the junction of a transformer feeder cable and open-wire line for completely enclosed transformers. Depending on the cable length and the arrester rating, surge arresters may be required at the transformer terminals as well.
c. On open-wire lines, at each point where a cable junction is made.
d. At the terminals of dry-type transformers when fed from an exposed line.
e. At the terminals of important motors fed from an exposed line or supplied by a transformer fed from an exposed line.
f. On the secondary side of a transformer fed from an exposed line, for the protection of a group of motors (usually combined with surge capacitors at the motor terminals).

Arresters installed on systems connected to utility power should be coordinated with the utility.

5.7.6 Instrument Lightning Protection

Process instrument and control systems, remote tank gauging systems, and other similar low-energy systems can be damaged by lightning-induced transients even though they are protected from direct lightning strokes. Protection against such transients can be provided by combinations of series resistors with Zener diodes, metal oxide varistors, or other devices to bypass voltage surges to ground. Most equipment suppliers can recommend methods of transient suppression to protect their equipment; these recommendations should be followed. To be effective, the protective devices must be connected to an adequate grounding system.

5.7.7 Surge Capacitors

Surge capacitors are used to reduce the rate-of-rise of voltage surges to protect AC rotating machines and other equipment having low electrical impulse or turn-to-turn insulation strength. They are usually applied in conjunction with surge arresters and connected line-to-ground. The capacitor voltage rating must match the system voltage and be designed for surge protection applications. The connection leads between the capacitor and each phase and between the capacitors and ground must be as short as possible.

SECTION 6—MOTORS AND CONTROLLERS

6.1 PURPOSE

This section serves as a guide for selecting and applying motors and controllers to meet the varied demands of the petroleum industry. It highlights considerations which must be addressed in accordance with API Stds 541, 546, and IEEE Std 841.

6.2 SCOPE

Because of its broad application, the material presented in this section will be general in nature and reflect current petroleum industry practice. Industrial motors and controllers are manufactured in accordance with applicable standards published by IEEE, NEMA, ANSI, and API. When more specific or detailed information is required, the equipment manufacturer should be consulted.

Most driven equipment is constant speed. Three-phase AC motors are well suited to these applications. DC motors are not common in petroleum facilities because additional requirements would be necessary for their installation in classified locations. The high equipment and maintenance costs of DC motors and controls compared with three-phase AC motors also make the DC equipment unattractive.

6.3 MOTOR RATING AND EFFICIENCY

Motors have been rerated at various times, usually resulting in smaller frame sizes for given horsepower ratings. The last rerate program resulted in the NEMA T-frame series (143T through 445T, approximately $^3/_4$ HP through 250 HP). These motors are rated 200 V, 230 V, 460 V, and 575 V. Class B insulation is the minimum insulation used, but Class F insulation is normally specified. Individual manufacturers should be consulted for frame and horsepower assignments.

Since standard-efficiency T-frame motors may operate at higher insulation and bearing temperatures, it is recommended that care be exercised in sizing their associated loads. They should also be operated as near to rated voltage and frequency as possible.

Most manufacturers now offer high- and premium-efficiency motors at an increase in price. Where motors run continuously or for long periods of time, the reduction in power cost will usually justify the extra cost of the high-efficiency motors. The justification is based on power cost and rate of return required for the additional investment. This will vary with different companies and types of projects. Section 3 provides assistance with economic evaluation. The U.S. Energy Policy Act of 1992 (implemented October 24, 1997) effectively removes standard-efficiency, horizontal-footed motors rated through 200 HP from the new motor market within the United States. Similar action has taken place in Canada.

Many manufacturers offer severe-duty type motors that perform well in petroleum facility atmospheres (see IEEE Std 841). This standard requires severe duty features, high efficiency and having Class F insulation with Class B rise. The motor would normally have a 1.15 service factor, and if operated at 1.0 service factor (full-load nameplate rating), it will experience extended insulation and bearing life because of a lower operating temperature.

6.4 RELATIVE LOCATIONS OF MOTORS AND CONTROLLERS

It is common practice to use magnetically operated controllers and to install them remotely from the motors. These remotely mounted controllers will be group-mounted in one or more assemblies, usually motor control centers or switch racks. It is generally not practical to locate the controllers adjacent to the motors in a typical facility.

6.5 FREQUENCIES

A frequency of 60 Hz is recognized as the preferred standard for all AC systems and equipment in North America. Standard motors are also available for operation at frequencies of 25 Hz and 50 Hz.

6.6 STANDARD VOLTAGE FOR MOTORS

Most of the motors used in the industry have voltage ratings as indicated in 6.7. In addition to the ratings listed, other standard ratings are available and are sometimes used. For information regarding standard motor ratings, the user should refer to catalogs and other data available from manufacturers. Additional information may be obtained from current ANSI and NEMA standards.

6.7 MOTOR VOLTAGE SELECTION

6.7.1 Single-Phase Motors

Single-phase motors driving fixed equipment usually are rated to operate at 115 V or 230 V. For portable motors, 115 V is generally preferred, except where there is reason to use equipment designed for some lower voltage, such as 32 V. Because single-phase units frequently employ potentially sparking mechanisms, care should be exercised in the application of this type of motor in classified areas.

6.7.2 Three-Phase Motors

Depending upon local power system utilization practice, either 460-V or 575-V ratings are preferred for 60 Hz low-voltage service (less than 600 V). Motors with a rating of 460 V or 575 V have a voltage tolerance of ±10% (per NEMA MG 1) and are generally supplied from a 480-V or

600-V power system, respectively. Motors with ratings of 200 V, 208 V, and 230 V are generally not used except in instances where power is readily and economically available at the related service voltages, and where 480-V or 600-V service would entail undue expense.

For service in excess of 600 V, the preferred rated voltages for induction motors are 2,300 V and 4,000 V for motors up to 5,000 HP. For larger motors, the preferred rated motor voltages are 4,000 V, 6,600 V, and 13,200 V; one of these voltages must be selected to suit each specific application. Synchronous motors usually have nameplate voltage ratings that are identical to the service voltage of the system to which they are connected.

6.7.3 Voltage Breakpoint

The economic breakpoint between the installation of the low-voltage motors (600 V class) and the medium-voltage motors (2,300 V and higher) is usually in the range of 250 HP–300 HP. Motors with ratings of 2,300 V and 4,000 V are used for sizes up to 5,000 HP. The choice between 2,300 V and 4,000 V will depend on the economics of the individual plant under consideration. For motors above 5,000 HP, the economic breakpoint may dictate the use of 4,000 V or 6,600 V, with or without captive transformers, or even 13,200 V.

The economic breakpoint will vary depending on the local conditions and the relative number of large and small motors to be served at the location under consideration. If an economic breakpoint has not already been established, it is recommended that an engineering analysis be made before an installation is begun. This analysis will determine the economic dividing line, taking into account the cost of necessary transformers, controllers, breakers, and all other applicable elements.

After the breakpoint has been established and has been used as a guide for making installations at a particular plant or location, it is recommended that the economics be restudied regularly to make certain the previously established dividing line still holds. Allowance should be made for the value of maintaining interchangeability between motors of the same ratings and types.

6.7.4 Supply Voltage

Supply voltage and frequency at the motor terminals should be maintained within the limits of NEMA MG 1.

6.8 TEMPERATURE AND ALTITUDE CONSIDERATIONS IN MOTOR APPLICATIONS

6.8.1 Normal Temperature Operation

Motors of standard design and construction are suitable for operation at their standard ratings, provided the ambient temperature does not exceed 40°C (104°F); however, for conditions where higher ambient temperatures prevail continuously or for extended periods, the continuous duty rating of the motors should be reduced by some amount based on the operating ambient temperature. Refer to NEMA MG 1 if the motor is to be specified at ambient air temperature exceeding 40°C (104°F).

6.8.2 High Temperature Operation

Motors that are to be installed where the ambient temperature will normally exceed 40°C (104°F) should be considered as special. They should be able to provide dependable service at the expected ambient temperature; this includes fulfilling the requirements for satisfactory lubrication at abnormally high temperatures. Motors are available with design ambient temperatures nameplated higher than 40°C (104°F), usually 45°C (113°F) and 50°C (122°F).

6.8.3 Low Temperature Operation

Where ambient temperatures of less than 10°C (50°F) will be encountered for extended periods, consideration should be given to requirements for lubrication at low temperatures. The motor manufacturer, and API Stds 541 and 546 should be consulted for other low-temperature considerations. In many instances, a low-temperature grease is suitable. For temperatures less than –20°C (–4°F), special material and machining may be required. Close coordination with the equipment manufacturer is suggested for "Arctic Duty" service.

6.8.4 Elevation

Motors of standard design are suitable for installation at elevations up to 1,000 meters (3,300 feet). Applications above this elevation will result in increased heating and will require derating of the standard motors, or special design and manufacturing. The operating elevation should be specified so that manufacturers can make the necessary allowances for applications above 1,000 meters (3,300 feet). When operated at elevations above 1,000 meters (3,300 feet), the specific rating and altitude should be stamped on the nameplate.

6.9 OTHER CONDITIONS AFFECTING DESIGN AND APPLICATION

When motors are subjected to unusual conditions and there is doubt about the specifications when ordering, the manufacturer should be advised of the unusual conditions to be met, especially when the motors are to be used under the conditions shown in Table 1.

6.10 TYPES OF MOTOR CONSTRUCTION

6.10.1 Usual Types

Most of the motors used in petroleum facilities are of the three-phase, squirrel-cage induction type. Other types of motors have special applications or economic advantages; their uses are described in the following paragraphs.

6.10.2 Fractional Horsepower Motors

It is a common and convenient practice to use single-phase motors for all ratings up to a fixed size, such as $^1/_2$ horsepower or 1 horsepower, and to use three-phase motors for higher horsepower ratings. When a three-phase, low-voltage supply is readily available, there may be an economical advantage to using small three-phase motors. Three-phase motors are advantageous from a maintenance and safety standpoint because they contain no contact-making device.

An engineering analysis to determine if small three-phase motors can be used should be made for each application when the answer is not obvious. The difference in the cost of supplying current to the motors of the two types, when considered with other cost factors, is often sufficient to determine which installation should be made.

6.10.3 Synchronous Motors

Generally, synchronous motors are considered for large-horsepower and slow-speed applications where power factor improvements are justified and where other characteristics suit the applications. Low-speed engine-type synchronous motors are well suited for use as drives for slow-speed equipment such as reciprocating compressors and pumps. Synchronous motors often are used instead of induction motors, particularly at speeds less than 514 rpm where it is practical to avoid the use of gears or other speed-reducing equipment. High-speed synchronous motors are well adapted for use as drives for large rotating equipment such as fans, blowers, and centrifugal pumps. When the resulting improvement in power factor or efficiency will yield a satisfactory rate of return on the additional investment required, synchronous motors are preferred over squirrel-cage induction motors.

A 1.0 power factor synchronous motor is usually the most efficient selection; however, it will have a lower pullout torque than a leading power factor synchronous motor. This may be a significant consideration if system voltage dips are expected during operation.

Brushless synchronous motors are now used extensively in petroleum facilities. For excitation, the brushless system uses an AC exciter with shaft-mounted diode rectification. The AC exciter, in turn, receives its excitation and control from a small rectifier assembly and rheostat fed from the

Table 1—Conditions Affecting Motor Design

Conditions	Generally Applied Types
Exposed to chemical fumes.	Should use a chemical-type motor.
Operated in damp places.	Should use additional impregnation or sealed insulation system and space heater within the motor enclosure and main terminal box.
Driven at speeds in excess of rated speed.	Consult manufacturer.
Exposed to steam.	Should be totally enclosed.
Operated in poorly ventilated spaces.	Oversize the motor. For large motors, consider TEPV or TEWAC enclosure.
Operated in Class I locations.	See 6.13.
Exposed to temperatures under 10°C (50°F) or over 40°C (104°F).	Consider special insulation, lubrication, and materials.
Exposed to oil vapor.	Consider totally enclosed motors.
Exposed to salt air.	Should use totally enclosed construction and severe-duty motors.
Exposed to the weather.	Consider totally enclosed or weather-protected Type II motors.
Exposed to abnormal shock or vibration from external sources.	Consult manufacturer.
Where departure from rated voltage exceeds the limits specified in NEMA MG 1.	Consult manufacturer.
Applications where parallel operation of motor-driven generator is required or similar applications where two or more motors need to be matched according to speed-torque characteristics.	Consult manufacturer.
Unbalanced supply voltage.	Consult manufacturer.
Operated at elevations greater than 1,000 m (3,300 ft) above sea level.	Should be derated (consult manufacturer).
Other unusual conditions, such as extended period of idleness, special torque requirements, or unusual operating duty.	Should be derated (consult manufacturer).
Adjustable speed applications.	Consult manufacturer.

same AC source as the motor, or from a shaft-driven permanent-magnet generator. There are no brushes, commutator, or collector rings; these have been the disadvantages of synchronous machines in the past. Since there are no arcing devices in the brushless motor, it can be used in Class I, Division 2, or Zone 2 locations.

When a synchronous motor installation is made, it is recommended that the motor's DC excitation be arranged so that it is not readily adjustable by untrained personnel, and it can be seen that the proper excitation is maintained. Otherwise, it may be found that excitation is not being maintained at a normal value; with the result that the anticipated amount of power factor improvement is not being realized in actual service. Also, the performance of the motor may be adversely affected.

Unless there is a clear economic justification for preferring a synchronous motor over an induction motor (under the preceding conditions), the squirrel-cage induction motor, generally, would be recommended because of its greater simplicity, reliability, and maintainability.

6.10.4 Adjustable Speed Drives

The use of an adjustable speed drive and motor instead of a constant speed motor to meet process service conditions or save energy is often desirable. Typically, an adjustable-speed motor drive is one of the following types: a DC drive and motor, an adjustable-frequency AC drive and motor, or a wound-rotor motor drive.

Although the applications of adjustable-speed drives are somewhat limited, their use in today's facilities is gaining popularity. Pump, compressor, and blower applications may allow changes in flow by speed control without utilizing control valves or dampers. Elimination of conventional control valves, dampers, and gearboxes may result in added energy and investment savings; and the use of adjustable-speed drives where load varies will allow for more efficient energy utilization because these drives can be very efficient, even at reduced speeds.

6.10.4.1 DC Motor Drives

The DC motor design, one of the initial arrangements of electromechanical conversion, has existed for many years. DC motors may be used over their entire speed range, from 0% to 100% of their rated speed. Some characteristics which make DC motors desirable, besides adjustable speed use, are: excellent starting torque characteristics; relatively high efficiency throughout the speed range; and reliability.

Most DC motors are powered from AC-to-DC rectifiers, and the rectifiers are typically installed in locations that have controlled environments. These drives are available in a wide range of sizes.

Some of the ways that DC motor drives are used in petroleum facilities are as follows:

a. Vessel agitators.
b. Conveyor systems.
c. Continuous mixers and extruders and pelletizers (mainly in the petrochemical industry).
d. Blenders.
e. Fans.
f. Production drilling top drive and draw works.
g. Production drilling mud pumps.

DC motor drives have some disadvantages: they require more maintenance compared to other motor types and, especially in larger horsepower sizes, they are more difficult to apply in a classified location. DC motor drives using AC-to-DC rectifiers also have relatively poor power factors at low speeds, which is typical of static converter drives.

6.10.4.2 Adjustable Frequency Drives

Adjustable-frequency drives are available in sizes ranging from fractional horsepower units to units over 60,000 HP, depending on the manufacturer. Both squirrel-cage induction and synchronous motors may be used with adjustable-frequency drives. The AC drives typically may operate within the range of 10% to 100% of their rated speed, with some units capable of operating in excess of their rated speed. Speeds in excess of 11,000 rpm at an output rating of 3,500 HP have been achieved. Use of the higher output rating or higher speed motors requires care in application, operation, and maintenance. Some characteristics which make adjustable-frequency AC drives desirable, besides their adjustable speed, are their good starting-torque characteristics; their capability to provide a soft start; their high efficiency; their reliability; their low maintenance needs; and their no-fault contribution.

Large adjustable-frequency drives generally use a AC-to-DC rectifier coupled through a smoothing reactor to a DC-to-AC inverter. The power module enclosure for large machines requires a controlled environment and adequate clearances for maintenance.

Among the uses of adjustable-frequency AC drives in the petroleum facilities are the following:

a. Continuous mixers, extruders, and pelletizers (mainly in the petrochemical industry).
b. Vessel agitators.
c. Conveyors.
d. Pumps.
e. Blowers.
f. Compressors.
g. Fans.

Some disadvantages of adjustable-frequency AC drives are their initial cost, which is higher than some other speed control systems, and their controls, which may require more space than most other drive systems. These drives also produce harmonics that, if not controlled, may cause distribution system problems, such as excessive distribution system voltage distortion and overheating of the driven motor. These characteristics vary by manufacturer and drive type and should be reviewed individually. Special considerations may include filtering of the drive's output to prevent overstress of the motor winding insulation from excessive *dv/dt*, or providing motor winding insulation capable of withstanding the additional voltage stress.

Operating duty requirements, such as efficiency, power factor, harmonics, speed range, and current in-rush, should be specified for all applications. Depending on the criticality of the application, a bypass arrangement, or a backup drive, or a drive control module should be considered.

6.10.4.3 Wound-Rotor Motor Drives

The wound-rotor motor is similar to the squirrel-cage induction motor except that the rotor cage winding is connected to a set of collector (or "slip") rings and carbon brushes. An external adjustable resistance is connected to the collector rings, which allows the motor speed to be varied. Incremental steps are obtained through an arrangement of contractors and heavy duty (cast iron or steel) resistors. Near infinite variability is achieved with a liquid rheostat system. The wound-rotor motor drive typically operates within the 25%–100% range of its base rated speed. As other adjustable-speed drive systems have improved, the use of wound-rotor motor drives has diminished.

Some characteristics which make the wound-rotor motor desirable are: high starting torque; reduced in-rush current; and suitability for high-inertia loads requiring closely controlled acceleration.

Except for the addition of the rotor circuit speed control, the starting method for the wound-rotor motor drive is similar to the starting method for the AC induction motor. The uses of the wound-rotor motor drive in petroleum facilities are rather limited, though. Some disadvantages of the wound-rotor motor drive are as follows:

a. The motor collector rings cause enclosure problems in classified areas. This motor is complicated to build because of the rotor.
b. The limited speed adjustment range is generally smaller than other systems.
c. The motors have lower efficiency at lower speeds due to heat dissipation of rotor current through external resistors. Slip recovery systems can be used to help improve efficiency.

6.11 INSTALLATION

6.11.1 General

Generally, electrical and mechanical equipment for petroleum facilities is installed outdoors without shelter from the weather. This applies particularly to pumps, drivers, and associated equipment which are well-suited for outdoor service. In most cases, using equipment well-suited for outdoor service saves substantial expenditures for buildings in which to house equipment. Since these buildings tend to confine and accumulate the volatile hydrocarbons released by the process equipment located within their walls and in their immediate area, outdoor installations may also simplify the problem of preventing the accumulation of such releases. Experience has shown that outdoor operation of electric motors is practical and economical with properly selected equipment.

6.11.2 Outdoor Service

The following types of totally enclosed motors for outdoor service are obtainable:

a. Nonexplosionproof.
b. Explosionproof.
c. Pipe-ventilated, either self-ventilated or forced-ventilated.
d. Water-air-cooled.
e. Air-to-air-cooled.

Open weather-protected motors of various designs (NEMA Type I or II) are available, with air filters as an optional accessory. In sizes above 250 HP, weather-protected Type II motors have gained wide acceptance. Dripproof types have been used in various applications but are not usually recommended for general outdoor use in processing plants. (NEMA MG 1, Part 1, provides a full description of enclosure types.)

6.11.3 Accessibility

All motors should be designed to permit ready removal of the rotor and the bearings and facilitate the flushing and relubrication of the bearings. To facilitate inspections, adjustments, and repairs, all enclosed brush-type synchronous, enclosed wound-rotor, and enclosed commutating motors should have removable covers to allow ready access to the brushes, slip rings, and commutator. Eyebolts, or the equivalent, should be provided for lifting motors or parts weighing more than 65 kg (150 lbs).

6.12 CONSTRUCTION OF TOTALLY ENCLOSED MOTORS

External housings should completely encase totally enclosed motors. Designs in which the stator laminations form a part of the enclosure, or in which the stator laminations are otherwise exposed to the external cooling air, are not recommended.

Motor frames and enclosures preferably should be of cast iron because motors of this construction are best suited for conditions where they are used outdoors or exposed to corrosive conditions. Cast iron is not always available for the very small or very large horsepower sizes. For these cases, steel of adequate thickness with a proper protective coating is acceptable.

The conduit or terminal box should be of cast construction and should have a hub threaded for rigid conduit. For larger horsepower sizes, only sheet steel boxes may be available (see IEEE Std 841), particularly where auxiliary devices such as surge capacitors, lightning arresters, or differential current transformers are used.

Vertical motors should have a drip shield over the fan.

6.13 MOTORS FOR CLASS I LOCATIONS

6.13.1 Division 1 or Zone 1

6.13.1.1 Suitable Types

Motors for use in Class I, Division 1, locations, as defined in NFPA 70, should be the explosionproof type and must be suitable for use under the specific conditions to be encountered in service. Depending on the specific conditions, a motor may have to be suitable for Class I, Groups A, B, C, or D. If a motor size is not available as explosionproof for Groups A and B, then totally enclosed pipe-ventilated motors, totally enclosed inert-gas-filled motors, or submersible-type motors must be used. For more complete details, NFPA 70 may be referenced.

An increased safety type "Ex e" motor is suitable for areas classified as Zone 1, but not for Division 1 areas. Motors are not recommended for installation in Zone 0 areas. This type of motor is designed to have excellent winding integrity; limits on internal and external temperatures during starting, operation, and stalled conditions; defined clearances between the rotating and stationary parts; and power terminals that have provisions against loosening. It is generally a TEFC motor, but can be of any totally enclosed type. An integral part of the increased safety type "Ex e" motor application is the use of a specific overload relay with the motor to limit temperatures during a stall or overload.

6.13.1.2 Nationally Recognized Testing Laboratory (NRTL) Approval

When available, motors should bear an NRTL label of approval for the gas or vapor involved. The label shall include temperature limits or other items as required by NFPA 70 for approved equipment.

Most laboratories cannot test larger motors, particularly those with voltage ratings exceeding 600 V. Where third-party approval is desired, the manufacturer can generally perform the tests required for conformance at the manufacturing site and submit the results to the third party for approval. Site approval may also be required and the user should work with the local "authority having jurisdiction" (see the NFPA 70) to determine the approval or labeling requirements.

6.13.1.3 Care in Inspection

The hazardous approval label becomes void when the motor enclosure is opened unless the work is performed by a repair facility which is duly authorized (generally by the original NRTL).

6.13.2 Division 2 or Zone 2

6.13.2.1 Motors Having Arc-Making Devices

Motors for use in Class I, Division 2, locations, or in Zone 2 locations, as defined in NFPA 70, shall be the totally enclosed, explosionproof-type approved for Class I, Division 1, locations when the following devices are used in the motors:

a. Sliding contacts.
b. Centrifugal or other types of switching mechanisms, including motor overcurrent devices.
c. Integral resistance devices, used while the motors are either starting or running.

If these devices, however, are provided with separate explosionproof enclosures approved for Class I locations, then motor enclosures complying with 6.13.2.2 may be utilized.

6.13.2.2 Motors Having No Arc-Making Devices

In Class I, Division 2, locations, or in Zone 2 locations, NFPA 70 permits the installation of squirrel-cage induction motors in enclosures other than explosionproof-type. This is permitted because it is not probable that a motor will fail electrically during those rare periods when gases or vapors are present in ignitable quantities.

A motor intended for use in Class I, Division 2 or Zone 2 service should be constructed so that induced currents will not produce arcing, nor produce surface temperatures capable of causing ignition of the flammable vapor.

6.13.3 General

6.13.3.1 Mechanical Requirements

Motors for use in a Class I area, either Division 1 or Division 2, should be nonsparking mechanically as well as electrically. For example, the fan or fans of a fan-cooled motor should be made of nonsparking material.

6.13.3.2 Other Factors

Even when other considerations may not dictate the use of totally enclosed motors, factors like dust, dirt, drifting snow, and corrosive fumes may influence the type of enclosure to be used.

6.13.4 Totally Enclosed Forced-Ventilated (TEFV) Motors (also known as Totally Enclosed Pipe Ventilated [TEPV])

If an application for a classified location requires a synchronous or wound-rotor induction motor, a motor with a Totally Enclosed Forced-Ventilated (or TEPV) enclosure may be used to meet the requirements of the classified location. In some cases, the design will permit a pressurized enclosure around the collector or slip rings only; an example of this type of motor is one built with a gasketed steel metal housing.

If a motor has brushes or slip rings, it is recommended that its enclosure be provided with pressure-tight windows which permit observation of the brush or slip-ring operation. A separate source of ventilating air is provided for this type of motor, usually by a separate motor-driven blower, and the ventilating air must be drawn from a unclassified location. The air passage should also have filters to minimize the airborne dust. A common arrangement is to interlock the blower with the main motor controller so that the blower must be started and must remain in operation for some fixed period to assure that at least ten air changes have occurred before the main motor can be started. If air ventilation is lost, interlocks are often provided to shut down the main motor.

Other interlocks are as follows:

a. An auxiliary contact to detect the opening of the ventilation motor controller.

b. An air flow switch installed in the duct near the main motor to detect actual flow. The switch enclosure shall be suitable for the location classification.

6.13.5 Totally Enclosed Inert Gas-Filled Pressurized (TEIGF) Motors

For applications requiring a large induction or synchronous motor in a Class I, Division 1 location, a totally enclosed motor, pressurized internally with inert gas and arranged for water cooling or surface-air cooling, may be used (see NEMA MG 1 and NFPA 496). TEIGF-type of motors are rare and not readily available. In this type of application, the motor housing must be specially designed to be airtight and to provide tight closure around the shaft to prevent excessive loss of the pressurizing medium. In the event of a pressure failure, it is required to disconnect the motor from its power source. An alarm should be provided to signal an alarm if there is any increase in temperature of the motor beyond design limits.

Nitrogen is the preferred pressurizing medium. When a motor uses nitrogen as its pressurizing medium, the oil seals should be of a type that will prevent oil from being drawn into the motor when the motor is shut down. Where a water-cooled motor is used in this application, the cooling water should continue to flow through the motor heat exchanger when the motor is shut down.

The following accessories should be considered:

a. Indicators to show whether cooling water is flowing in the proper amount.

b. Warning alarms or automatic shut-off devices to operate as desired in the event of loss of pressure inside the motor, loss of the cooling water supply, water leakage from the cooler, and overheating of the stator windings or bearings.

c. Other devices required to give the degree of protection warranted for the particular application.

6.13.6 Totally Enclosed Water-to-Air Cooled Motors

Totally Enclosed Water-to-Air Cooled motors use water-to-air heat exchangers. A source of cooling water or glycol-water mixture is piped to the motor heat exchanger, and the internal air is circulated over the exchanger tubes. This cooled air is then passed through the stator and rotor cores to cool the motor. The majority of the heat generated in the motor is taken up by the water supplied to it with a small portion being radiated from the frame.

Totally enclosed water-to-air-cooled motors have an advantage when medium- and large-size motors are required, and where there is an environment that is hostile to motor windings and that might otherwise require the use of NEMA Type I or Type II weather-protected motors. Totally enclosed water-to-air cooled motors, however, require protection from the possibilities of loss of cooling water or low flow. Embedded winding temperature detectors are usually used in this type of motor. In many cases, the motor enclosure may have a "make-up" air inlet to provide an air inlet for bearing seals. Even though the air flow rate is relatively small, this air inlet should be provided with adequate filtration.

6.14 MOTORS FOR CLASS II LOCATIONS

6.14.1 Suitable Types

Motors for use in Class II locations, as defined in NFPA 70, shall be suitable for use in locations that are hazardous because of the presence of combustible dust.

6.14.2 Division 1

Motors should bear a third-party label of approval for Class II, Division 1, locations or be totally enclosed pipe-ventilated, meeting the temperature limitations for the specific dust on them or in their vicinity. Some explosionproof motors approved for Class I, Division 1 locations are also dust ignitionproof and are approved for Class II, Division 1 locations.

6.14.3 Division 2

For Class II, Division 2 locations, motors should be totally enclosed nonventilated, totally enclosed pipe-ventilated, totally enclosed fan-cooled, or totally enclosed dust-ignitionproof. The maximum full-load external temperature for these motors shall not exceed 120°C (248°F) for operation in free air (not dust blanketed). Certain exceptions are permitted by NFPA 70.

6.15 MOTOR SERVICE FACTOR

To apply a motor properly and economically, its service factor must be taken into account. A standard, integral-horsepower NEMA-frame open motor; or a high-efficiency, totally enclosed fan-cooled motor will generally have a service factor of 1.15 and will carry its rated nameplate load continuously without exceeding its rated temperature rise. It will continuously carry 115% of its rated full load without attaining excessive temperature, although its insulation temperature limit will be approached, thus reducing winding insulation life. The bearings will also operate at a higher temperature, affecting bearing lubrication and bearing life. It is recommended that the service factor rating be reserved for contingency use. Consideration should also be given to the speed and torque characteristics of the motor, which are based on a 1.0 service factor.

For the above NEMA-frame and other non-NEMA-frame motors the service factor is generally 1.0 with no margin for exceeding the nameplate rating. It is not good practice to impose continuous loads in excess of the nameplate rating on such motors; therefore, it is advisable to determine definitive load requirements and to size motors conservatively.

As an example, a certified copy of the characteristic curve of a centrifugal pump should be examined over its entire range to determine the maximum load the curve can impose on its driver. Regardless of service, motors with a service factor of 1.0 should not be operated continuously nor for extended periods at loads exceeding the nameplate rating. When heavier loading is permitted, it should be done only with the understanding that the reliability and motor life expectancy will be reduced. Additionally, other specifications may effect motor sizing, such as API Std 610.

6.16 FREQUENCY OF STARTING

NEMA-frame motors are capable of multiple starts per hour. The number of which is defined by NEMA Std MG 1, paragraph 12.54.1, and NEMA Std MG-10 paragraph 2.8.1.

Medium voltage motors are limited in their starting capability, usually to two starts from cold (or ambient) condition and one start from hot (or running temperature) condition. This is on the basis of a) the load inertia is within NEMA limits, b) the load start curve is a "square-of-speed" type curve, and c) the voltage at the motor terminals is greater than 90% (see 6.20). In between starts (while the motor is at rest), these units must be cooled (generally by convection) to a lower stator and rotor temperature prior to another attempted start. Motors that comply with API Std 541 or Std 546 usually have greater starting capabilities. This time between starts must be coordinated with the manufacturer for automatic-restart or frequentstart duty conditions.

Note: Time between hot starts may exceed 1 hour. Motors driving high inertia loads, or operating under high power system voltage drops should receive special consideration.

6.17 TEMPERATURE, VIBRATION, AND CURRENT INDICATORS

Motors larger than 1,000 HP and special-purpose motors frequently require temperature, current, vibration, air flow, water flow, or differential pressure monitoring. (See API Std 541 and 546 for proper application.)

6.18 CONDUIT OR TERMINAL BOX

Attention should be given to the size and direction of conduit entrances to motor terminal boxes. Sizing requirements of the local electrical code should be observed. Medium and high voltage main terminal boxes may also require special construction if ANSI/NEMA Type II design, space for stress cone-type cable termination, or auxiliary protection devices are used.

6.19 SPACE HEATERS

6.19.1 Application

In locations where motor windings are likely to be subjected to accumulations of excessive moisture during extended periods of idleness, consideration should be given to the installation of space heaters or direct winding heating control modules (which apply low power directly to the stator winding) to maintain the winding above the dew point. This applies, especially, to motors operating at greater than or equal to 2,300 V. Space heaters are particularly applicable to large totally enclosed motors installed outdoors and operated intermittently, and to vertical weather-protected motors, such as those used for water well service. Space heaters are also used in many large motors located indoors, particularly those that operate intermittently. Some designs of totally enclosed fan-cooled motors are adaptable to space heater installations while others are not. Space heaters are also recommended for terminal boxes that enclose surge protection components or instrument transformers.

6.19.2 Installation Precautions

Space heaters should be selected and applied in a manner that prevents unsafe surface temperatures, and they should possess the correct heater rating and element temperature as well as materials that are necessary for obtaining satisfactory operation and long life. Generally, sheaths made of Monel or other normally corrosion-resistant materials should be used. The maximum sheath temperature of space heaters must be limited to 80% of the ignition temperature of the gases or vapors expected within the area unless there are special reasons for a lower limit. It is common practice to operate space heaters at half the rated voltage (or other reduced voltages), or to specify low-surface temperature [e.g., 200°C (392°F)] to prevent excessive temperatures and to increase heater life. Space heater leads are often wired out to a separate terminal box.

6.19.3 Ratings

Space heaters usually have an operating voltage rating of 115 V or 230 V, single phase. Heating capacity should be sized to maintain the winding temperature 5°C to 10°C (10°F to 20°F) above ambient temperature.

6.19.4 Operation

When auxiliary contacts are used in the motor starter, the supply circuit to the motor heater is normally arranged to be de-energized automatically when the motor is started, and energized when the motor is stopped. If used, terminal box heaters are normally continuously energized or controlled by differential temperature thermostats. A local nameplate at or near the space heater auxiliary terminal box or connection point should indicate when a separately derived power source is employed.

6.19.5 Low-Voltage Winding Heating

Low-voltage winding heating is a method for heating a motor winding while the motor is shut down. This heating is accomplished by applying low voltage directly to one phase of the motor winding. The amount of heating voltage necessary to circulate the proper current in the winding and keep the internal temperature 5°C to 10°C (10°F to 20°F) above ambient must be selected. Approximately 5% voltage is normally sufficient to maintain this temperature. A low-voltage contactor must be interlocked with the main contactor to keep the two sources of power electrically separated. Low-voltage winding heating is normally used for small motors because it is usually more economical to use space heaters for motors over 100 HP.

6.20 BEARINGS AND LUBRICATION

6.20.1 Horizontal Motors

Motors are available with either antifriction (ball or roller) or hydrodynamic radial (sleeve) bearings. The type of bearing lubrication, whether oil, oil mist, or grease, should be chosen when the bearings are selected. Most NEMA-frame and IEEE-841 motors will have grease-lubricated antifriction bearings. Motors above NEMA standard sizes should be designed according to API Stds 541 and 546.

Most sleeve bearings for horizontal motors are oil-lubricated using oil rings. Except where a forced-oil lubrication system is used, the bearings should be equipped with constant-visible-level automatic oilers. Wick or yarn oilers are not satisfactory except for the smallest fractional horsepower motor sizes.

An opening should be provided to permit observation of the oil rings if the motor is in operation. Suitable slingers, pressure equalizers, and vents are required to prevent loss of lubricant and to maintain the proper level.

For large (1,000 HP), sleeve-bearing motors, particularly those used to drive equipment that requires forced-oil lubrication, consideration should also be given to using forced-oil lubrication for the motors. API Std 614 covers lubrication systems for special drive trains.

Sleeve-bearing motors, usually in the larger sizes, require the use of limited-end-float couplings to keep the motor rotors centered. When the couplings are properly installed, the motors will operate at or near their magnetic center.

Ball bearings for horizontal motors are usually grease-lubricated, except in the larger sizes and in horizontal motors that operate at higher speeds. Horizontal motors operating at higher speeds often use oil-lubricated ball or roller bearings.

Some manufacturers provide grease-lubricated ball-bearing motors with sealed bearings that permit several years of operation without regreasing. At the end of these periods, the bearings are either repacked or replaced. Because many bearing failures are the result of too-frequent greasing, overgreasing, or mixing of incompatible greases, motors which permit long periods between regreasings are the most desirable, particularly in plants that lack suitable maintenance personnel and control over their regreasing programs.

When oil mist lubrication is used, internal and noncontacting external shaft seals should be used. The seal and main lead insulation material shall be compatible with the oil.

6.20.2 Vertical Motors

The thrust bearings in vertical motors include antifriction (ball or roller) and plate-type thrust bearings. When oil is used as the lubricant for either thrust or guide bearings, the oil reservoir should be deep enough to serve as a settling chamber for foreign matter; should be provided with drain plugs accessible from outside the motor housings; and, except where a forced-oil type of lubrication system is used, should be equipped with constant-visible-level automatic oilers. In vertical motors, it is generally preferred that all bearings use the same type of lubricant. The magnitude and direction of external thrust, operating speed, and required bearing life will determine the type of bearing used.

Where required, it is common practice to supply motors that are subject to high thrust, equipped with bearings that are capable of carrying thrusts from driven equipment. The motors on vertical pumps are examples of motors equipped with bearings capable of carrying the high thrusts from the pump. When high-thrust driven equipment is being used, it is essential to specify the maximum thrust loads in both directions. (For vertical motor bearing requirements, see API Std 610.)

6.21 TORQUE REQUIREMENTS

6.21.1 Torque Considerations

Most motors used in petroleum processing and associated operations drive centrifugal or rotary pumps, centrifugal blowers, centrifugal compressors, and other equipment that do not impose unusually difficult torque requirements. Normal-torque motors are well-adapted to such equipment and usually will have sufficient torque to meet the normal conditions of service, provided the supply voltages are satisfactory. The net torque delivered by the motors to the driven equipment is less than the rated torque of the motors when the voltages at the terminals of the motors are less than the rated voltages of the motors. Table 2 shows characteristic torque variations of large squirrel-cage induction motors and synchronous motors, with respect to applied voltage.

For example, a motor capable of exerting a locked-rotor (or starting) torque of 100% (with respect to full-load running torque) with its nameplate voltage at its terminals may be found to have only 90% of its nameplate voltage at its terminals at the instant it is started across the line, due to a 10% voltage drop during this period of high current in-rush. The output torque developed by the motor is proportional to the terminal voltage squared times the full voltage locked-rotor torque; or, under a 10% voltage-drop condition, this is calculated to be: 0.9 x 0.9 x 100, or 81%.

Similarly, the entire starting torque curve is reduced by the same value. From NEMA MG 1 paragraph 20.41, a medium voltage induction motor minimum torque curve is 60% locked rotor; 60% pull-up; and 175% breakdown torque (under full voltage condition). Under a 20% voltage drop, this curve then becomes 38% / 38% / 112%. (See Figure 14.) Additionally, any further reductions in voltage due to line loss or auto-transformers will be added to the system drop. This figure also includes the typical "square-of-speed" type curve for centrifugal loads. The top line is for open valve or damper- type starting, while the lower line is for throttled-type starting (this example is for a 50% closed valve/damper start). It can be seen from this example that the effect of reducing the voltage at the motor terminals may prevent start-up unless the load-starting curve can be reduced.

Table 2—Characteristic Torques

Squirrel-Cage Induction Motors		Synchronous Motors	
Locked-rotor torque[a]	60%	Locked-rotor torque[a]	40%
Pull-up torque[a]	60%	Pull-in torque[a]	30%
Breakdown torque[a]	175%	Pull-out torque[b,c]	150%

[a]The output torque varies approximately as the square of applied voltage.
[b]The output torque varies directly as the applied voltage.
[c]With excitation constant.

6.21.2 Torque Analysis

The maximum torque that can be developed by a motor is proportional to the square of the voltage, resulting in acceleration torque reduction for reduced-system voltage. Power system, motor, and load characteristics should be evaluated to assure adequate torque during starting and acceleration. It should also be evaluated during re-acceleration and re-synchronizing following voltage sags and disturbances.

However, if the inspection of the available data does not yield a clear result, it is recommended that a detailed engineering analysis be performed to resolve marginal cases and to avoid any delays or inconveniences that may be caused by the failure of motor-driven equipment to start satisfactorily.

If reduced-voltage reactor or resistor starting is used, a substantial amount of impedance is introduced into the supply circuit of the motor when the controller is in the starting position. This impedance as well as the other impedance between the motor and its supply source must be taken into account. All reduced-voltage starting applications should evaluate the starting torque available versus that required by the load (acceleration torque) to determine that adequate torque margin is available for starting the load.

A torsional analysis should be undertaken for high-speed synchronous motors to determine the effects of torsional pulsations during across-the-line start acceleration of the motor and driven equipment.

6.21.3 Low-Voltage Considerations

Voltage that is lower than normal may exist, particularly during starting, because of the system's design or characteristics. Some causes for this lower-than-normal voltage are as follows:

a. The motor being started is large in relation to the capacity of the electrical supply system.

b. The supply circuit's length and design cause an unduly high voltage drop between the power source and motor.

Where it is questionable whether the voltage received at the terminals of the motor will be satisfactory, the voltage at that point should be calculated under the most unfavorable conditions likely to exist in actual service. In most cases, this will be at the instant of starting, when the current inrush is several times the rated full-load current and the power factor is low, usually in the 0.2 to 0.4 range. If the circuit under consideration will be used to carry other loads, the effect of these other loads on voltage should be taken into account at the same time.

When a synchronous motor is to be used, voltage conditions at the instant of pull-in should be checked. It must be determined that correct torque will be developed at the pull-in point with net voltage available at the motor terminals.

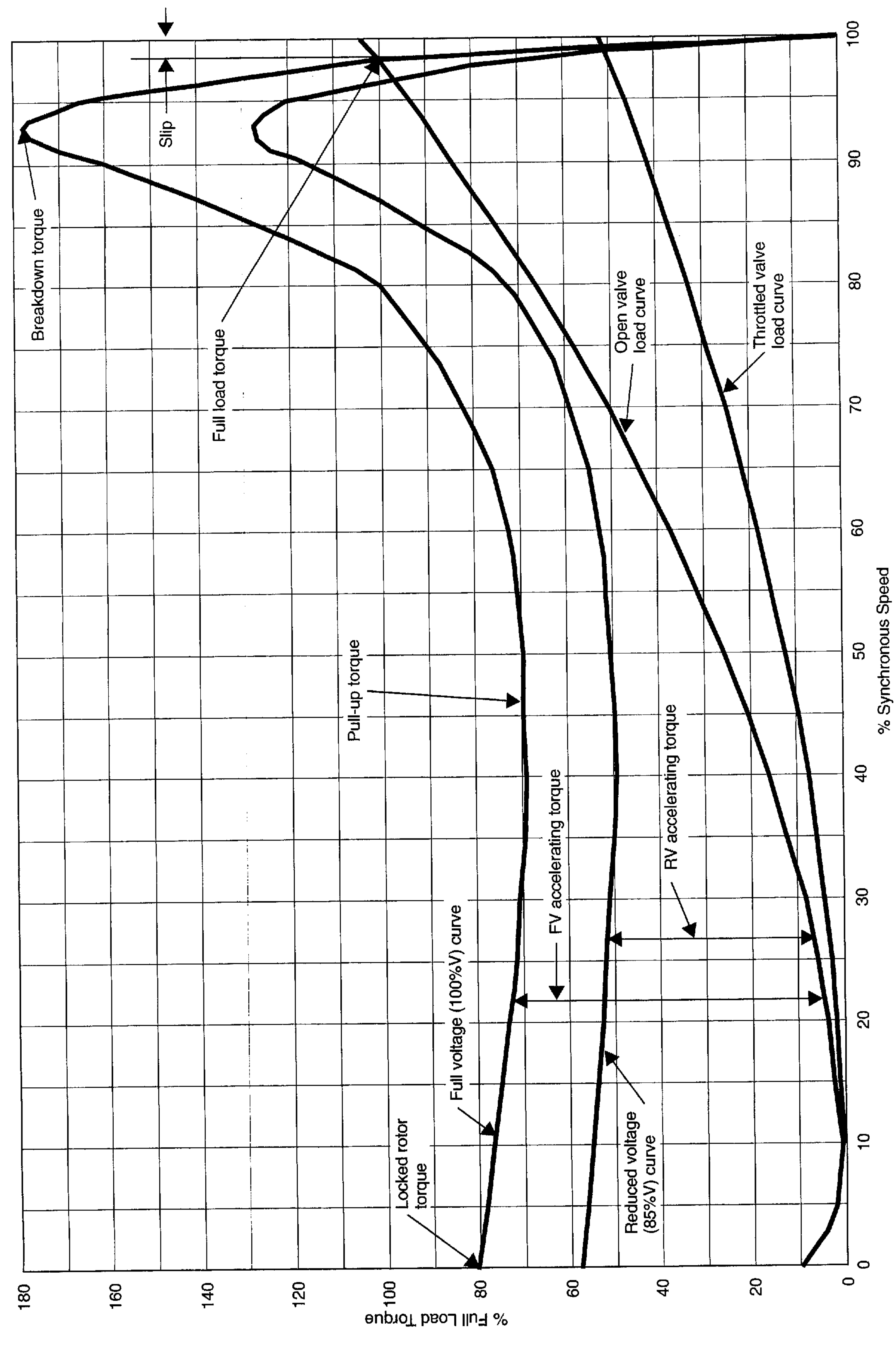


Figure 14—Combined Motor and Load Speed-Torque Curve

6.21.4 Minimum Torque Specifications

Occasionally, the normal starting torque characteristic of the motor will not be sufficient to accelerate the driven equipment. In these marginal cases, it is advisable to establish the minimum motor torque characteristic that is acceptable. For borderline cases, the motor torque characteristic (including any voltage drop considerations) should be specified to be 10% greater than the driven equipment starting-speed-torque curve throughout its entire range.

If the application requires more than normal torque, it will be appropriate to determine which will be more economical: to obtain a motor with higher than normal torque, within available limits, or to improve voltage at the point of utilization. In an extreme case, it may be correct to do both. In most instances, satisfactory results can be obtained most economically by determining torque requirements and specifying these requirements to suit the predetermined voltage conditions at the terminals of the motor.

In some cases, increased torque designs require higher in-rush current, increasing the voltage drop, which in turn, lowers the net output torque.

6.21.5 High Torque

For motors used to drive machines that require extra-high starting torque (e.g., most conventional pulverizers, shredders, crushers, and some air blowers or fans), it is advisable to predetermine the voltage conditions and to stipulate the torque requirements on the basis of anticipated voltage conditions, as net torque requirements may be high, even when the machine is started unloaded. High-torque motors are available for a variety of applications requiring higher-than-normal torque.

6.21.6 High-Inertia Loads

For high-inertia loads and other loads where the motor is subjected to heavy loading during acceleration (0% to 100% speed), calculations should be made to ensure it will have sufficient torque and thermal capacity to bring the driven equipment up to rated speed under actual operating conditions within the allowable length of time. A motor that drives equipment that may be subject to occasional sudden, heavy loads while running at rated speed should be checked to determine if it will have sufficient breakdown (induction motor) or pull-out (synchronous motor) torque under this condition to keep it from stalling or from abruptly losing speed. The use of high-slip motors, as well as the possible need for additional flywheel effect, should be considered for such conditions of service. This type of problem is not encountered often, but does call for detailed consideration of equipment and load characteristics.

Following a shutdown of a motor driving a high-inertia load, the restarting of the motor should be delayed sufficiently until the motor-generated voltage has decayed to a value of 25% or less of the rated voltage. Otherwise, high transient torques can be produced that exceed the mechanical limit of the motor shaft, coupling, or driven equipment.

6.21.7 Additional Torque Requirements.

Recognition should be given to the requirement for greater torque under certain conditions of operation. For example, in the case of a centrifugal blower or centrifugal pump, more torque is required to bring the machine up to rated speed with the discharge valve open than with it closed. If, for some reason, it is not practical to follow the customary practice of starting a centrifugal blower or pump with the discharge valve closed, sufficient torque should be made available to start it with the discharge valve open.

6.22 METHOD OF STARTING

6.22.1 Starting Control

Starting control for all motors is essentially the same. In the larger motor sizes, which represent a considerable investment of capital and upon which a higher degree of dependability is placed, the complexity of starting control increases. Larger motors can require power distribution systems with high system capacity to prevent undesirable voltage drops when the motors are started at full voltage under load. If these undesirable effects are produced, reduced-voltage starting should be considered. With reduced-voltage starting, the motor characteristics must be checked to ensure that there is sufficient torque to accelerate the load at the reduced voltage.

It is also important to consider the current in-rush to various motors following a voltage dip. The in-rush during reacceleration often will nearly equal the starting in-rush; so if motors are to operate satisfactorily through a voltage dip, the system must be stiff enough to handle the subsequent in-rush.

Control circuits which provide for the reacceleration of motors are complex and require additional considerations. Reduced-voltage controllers reduce the net torque exerted by the motors and, in some cases, may complicate the starting problem, especially for synchronous motors.

6.22.2 Full-Voltage Starting

In general, the full-voltage magnetic controllers supplied with air-break, vacuum-break, or oil-immersed contactors offer the simplest and most economical method for starting induction motors. See Figure 15 for an example of a simplified, full-voltage nonreversing starter using an air-break contactor. This method is based on acceptable motor-loading conditions and the ability of the power distribution system to function without undue voltage disturbance during motor start-up. Most motors, particularly the small and medium horsepower motors, are designed for full-voltage starting. Synchronous and large induction motors, usually at the higher voltages, require more control selectivity because their size may represent an exceptionally large portion of the available power system capacity. In this connection, circuit breakers operating at a normal breaker duty cycle may provide the dual service of controller and disconnecting means.

6.22.3 Reduced-Voltage Starting

The autotransformer, reactor, and resistor types of reduced-voltage controllers provide methods for decreasing the starting in-rush current of squirrel-cage and synchronous motors. See Figure 16 for an example of reduced-voltage starting using an autotransformer. Though more costly than the full-voltage controller method, these reduced-voltage controller methods may be required where specific high-inertia loads or system limitations are encountered

6.22.4 Wye-Delta Starting

A motor that normally has its windings connected in delta may be started by connecting its windings in wye. This reduces the current in-rush and starting torque to one-third of the full-voltage starting values. This method should only be used if moderate starting torque is satisfactory. This starting method usually requires an "open transition" where the motor is disconnected for a couple of seconds when changing from the wye to the delta configuration. When the motor is reconnected to the delta (run) configuration, the power system will be subjected to a severe current in-rush (approaching the full-voltage, locked rotor current) unless the transition time is made very short (less than 0.1 second). A short transition time is not recommended for most applications because of the risk of mechanical coupling or motor winding damage that could result from out-of-phase closure between the power system voltage and the residual motor voltage.

6.22.5 Solid-state Control

Soft-start controllers (reduced starting-current in-rush) using solid-state devices may also be used with or without a standard contactor to bypass the solid-state starter. Starting times for high inertia or high torque loads should be reviewed with the soft-start supplier.

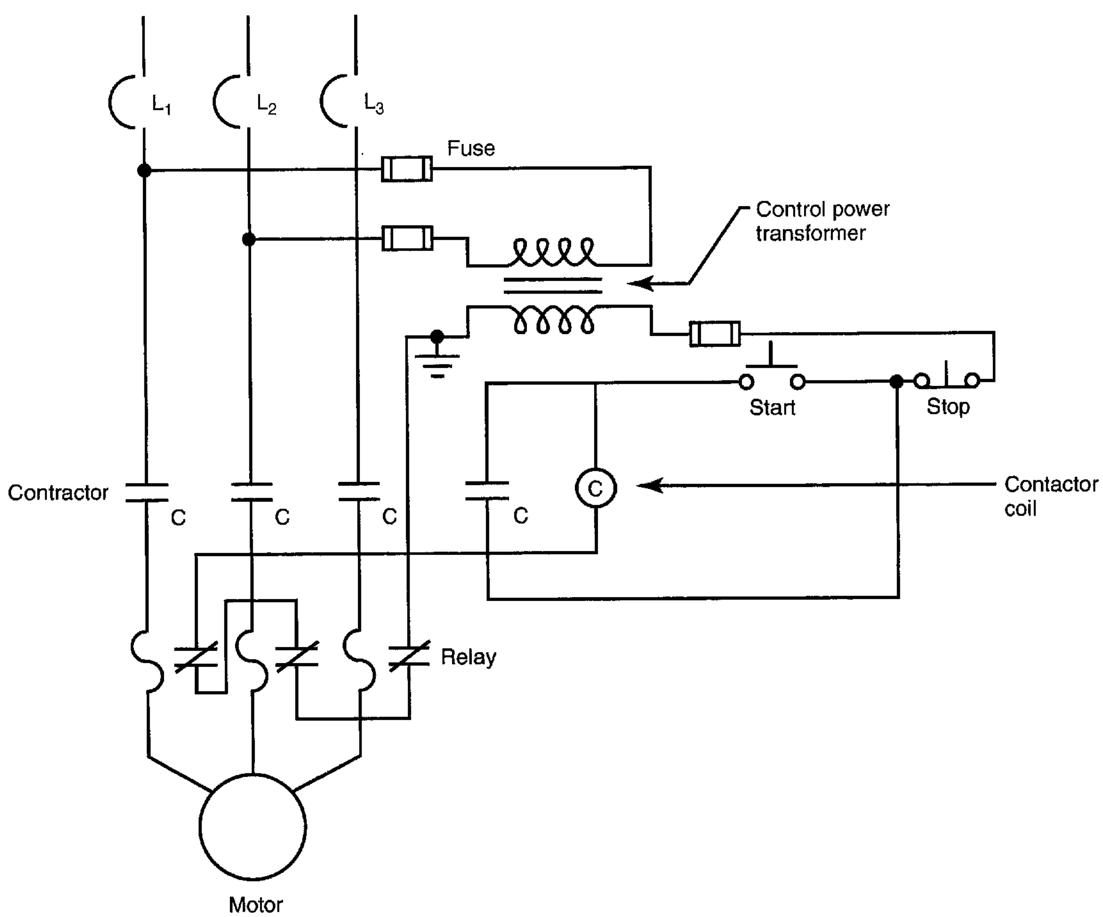


Figure 15—Typical Wiring Diagram for Full-Voltage Starting

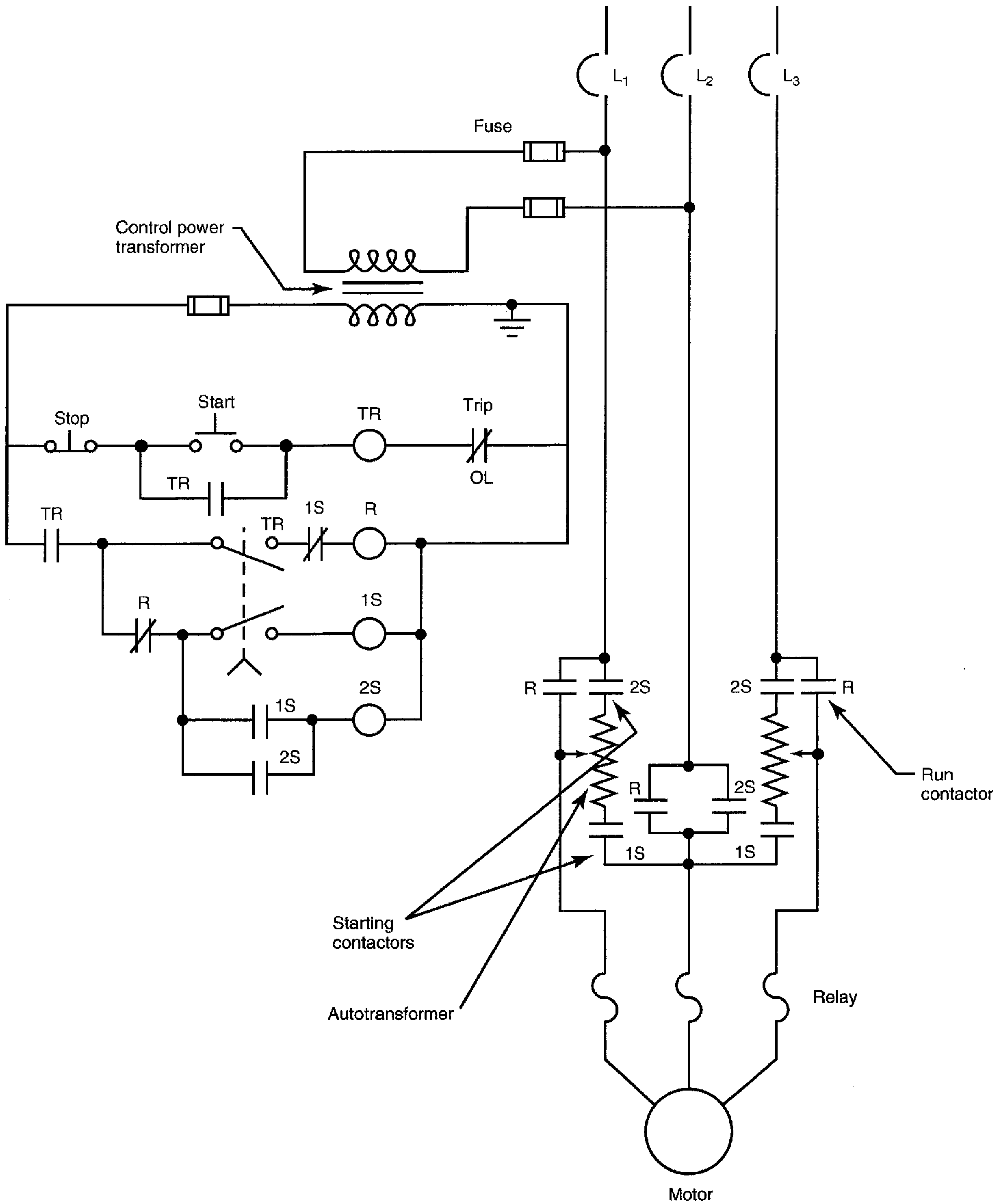


Figure 16—Typical Wiring Diagram for Autotransformer Method of Reduced-Voltage Starting

6.22.6 Capacitor Assisted Starting

Motors to be started on "weak" power systems can use a technique where a relatively large capacitor bank is switched onto the same bus as the motor an instant before the motor is connected. The capacitors provide most of the reactive requirements of the motor during the motor acceleration, minimizing the system voltage drop. As the motor accelerates to rated speed and the bus voltage recovers, the capacitor bank is disconnected. Surge arresters and surge capacitors, applied at the motor terminals, are recommended for this application to protect the motor from switching surges.

6.22.7 Wound Rotor Control

The typical wiring diagram for a wound rotor motor (Figure 17) begins with the basic control system for a full-voltage type motor (see Figure 15). Rpm adjustment is obtained through the addition of a speed control rheostat external to the motor enclosure, and near the motor control center, in a safe area. This variable resistance is typically implemented through sets of fixed contactors and resistors, or a stepless liquid rheostat. See 6.10.4.3 for concerns regarding the installation of wound rotor-type motors.

6.23 MOTOR CONTROLLERS

Motor controllers provide the means to start, regulate speed, and stop electric motors. In addition, controllers afford protection against abnormal operating conditions that may result in production losses, equipment damage, and exposure of personnel to unsafe conditions.

6.23.1 Selection of Control Equipment

When selecting control equipment, the power supply system, the type and size of the connected motor, and operational and service conditions should be taken into account. Affecting these conditions and requiring careful appraisal are the power supply, the controller size and rating, and the frequency of starting.

6.23.1.1 Power Supply

The ability of the power distribution system to satisfactorily handle motor starting loads is of major importance and in

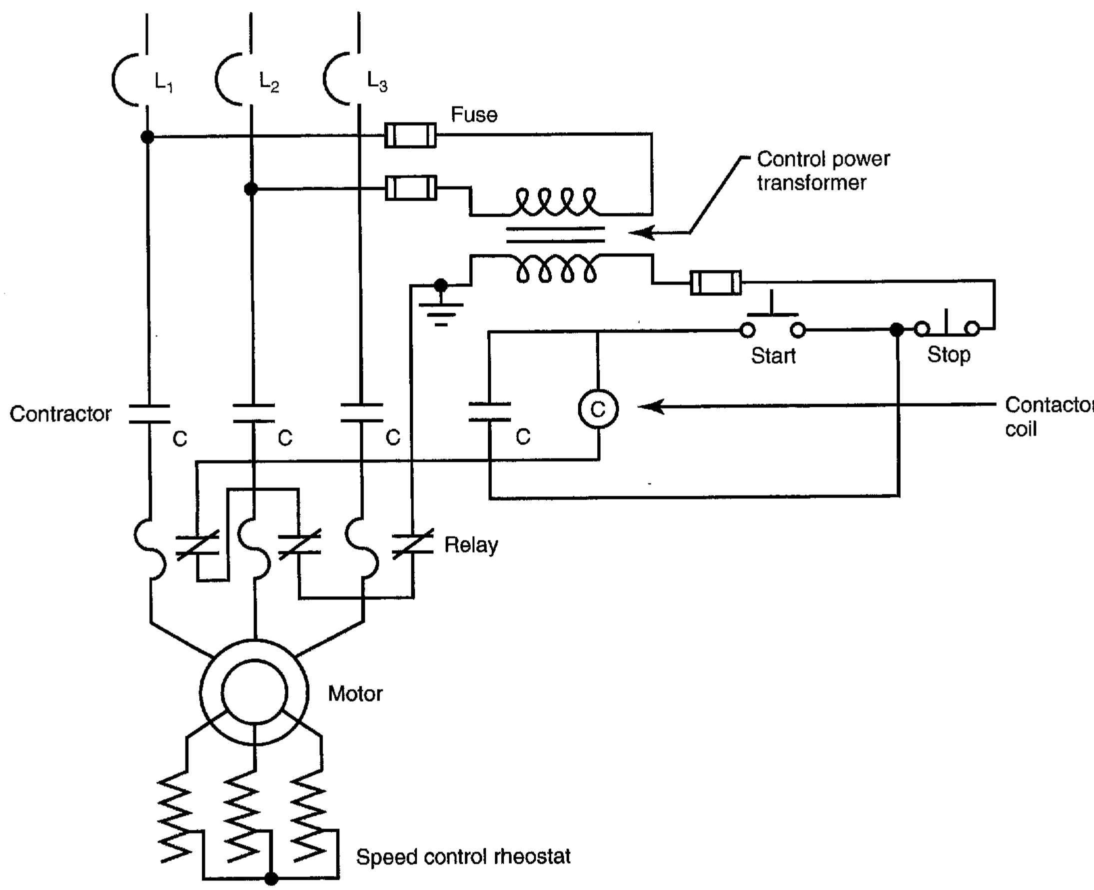


Figure 17—Typical Wiring Diagram for Wound-Rotor Motor Control

large measure determines the selection of control. This is true, particularly where objectionable voltage disturbances are produced by the starting of a few large motors representing the bulk of the system capacity. The full-voltage starting current of squirrel-cage induction motors and synchronous motors is several times full-load current (350% to 700%), so the system capacity must be able to supply the increased kilovolt-amperes without objectionable system disturbance. If this is not practical, an alternative starting method must be employed to confine the current in-rush and voltage drop to satisfactory levels.

6.23.1.2 Controller Size and Rating

Motor controllers are rated in horsepower or current-carrying capacity and must be capable of interrupting the motor locked-rotor current at the voltage specified. Industrial motor controllers bear the manufacturer's nameplate specifying their size, horsepower rating, and voltage. Controllers are supplied in several duty classifications and include the following types:

a. The continuous-duty type, which is capable of indefinitely carrying full-load motor current without exceeding a specified temperature rise of current-carrying parts.
b. The intermittent-duty type, which is used on cranes, machine tools, or other equipment requiring less sustained duty.

It is recommended that the user consult with the manufacturer to select adequate equipment for the operating conditions.

6.23.2 Manual Operation

Manual control has limited use, which is customarily for the starting of fractional horsepower, single-phase motors in the 120-V to 240-V range. Within the 240-V range, on-off control as well as motor overload protection is provided within the control enclosure. The overload protection is provided by trip-free thermal devices located in at least one side of single-phase units and in all three phases of three-phase units. Fused switches or circuit breakers providing a line-disconnect feature and short-circuit protection can be obtained in combination units (combined with the control in a common enclosure) or can be separately mounted. Low-voltage release may not be available; consequently, the control contacts remain closed during periods of power failure, thereby causing automatic restarts of the motor upon resumption of power. Manual control is not recommended for motors greater than 1 HP or for motors greater than 240 V because of increased risk to personnel.

6.23.3 Contactor Operation

The application of magnetic contactor control is the standard throughout the petroleum industry. Magnetic contactor control utilizes a magnetic contactor and a pushbutton, or automatic control device(s), to start and stop the motor. In general, the control voltage is at a level lower than the equipment utilization voltage.

The equipment is applied at standard voltage levels matching the motor requirements. Fuses, circuit breakers, or motor circuit protectors, separately or integrally mounted within the starter enclosure, provide the required disconnect and short-circuit protection. Thermal elements or current-sensitive devices, connected in all three phases of the control equipment, provide the overload protection. Three-wire control provides the undervoltage protection against automatic restart of motors after the restoration of failed voltage. Starters controlled by automatic devices are wired for undervoltage release (two-wire control permitting automatic restart after voltage restoration). The selection of the pushbutton or control location may be made to comply with desired operational requirements.

Where continuity of service or operating conditions demand, time-delay relaying is available to permit motors to ride through momentary voltage dips. The delay interval is critical because full voltage, particularly in the larger sizes, should not be applied to de-energized motors having residual voltages above 25% to 35% rated voltage, unless the motors have been designed for such applications.

The time-current characteristics of associated protective device and relaying equipment should be coordinated to ensure selective protection. Overload, locked-rotor, and short-circuit protection should be provided by the protection characteristics.

Medium-voltage circuit breakers, along with protective relays, are sometimes used with large motors to serve not only as controllers but also as the means for disconnection. These breakers will be electrically operated and can provide automatic control comparable to that of magnetically operated contactors; however, for frequent operation, magnetically operated contactors are more reliable because circuit breakers are not designed for such service.

6.23.4 Protective Relaying and Automatic Control

As a rule, the function of protective relaying is to disconnect the faulty equipment from the source of the electrical supply as quickly and with as little system disturbance as possible. In a comprehensive installation, each circuit or piece of equipment should operate independently under distress, and the protective relaying should be so selective that only the affected units are de-energized. In more detail, protective relaying must distinguish between abnormal equipment operation and system failures.

6.23.4.1 Overload Protection

Overload protection is applied to de-energize overloaded motors automatically before winding or conductor damage has been caused by excessive operating temperature. The motor controller thermal device, actuated by a self-contained heating element responsive to motor line current and selected for coordination with the type of motor enclosure, is frequently used and is available with either a manual or an automatic reset. Overload relays used on motors controlled by automatic devices must have manual reset.

Normally, the selection of a thermal device is based on a standard air ambient temperature reference of 40°C (104°F). For engine rooms, fire rooms, and similar elevated ambient locations, 50°C (122°F) may be chosen as the reference, but consideration must be given to the choice of thermal elements. This is of particular note where the ambient temperature at the motor is higher than that at the remotely located controller. Thermal elements, unless temperature compensated, are responsive to variations in ambient temperature. The necessity for oversized thermal elements can be prevented by carefully selecting control locations and by ample shielding against heat radiation. When controllers are located in areas subject to unusual ambient temperature variations or an ambient different from the motor, the temperature-compensated thermal relay is available. Large motors, greater than or equal to 250 HP, frequently use embedded detection-type thermal protection as the best indication of motor temperature.

Low-voltage motor controllers generally use one of the following devices:

a. The nonadjustable melting alloy.
b. The bimetallic strip.
c. Solid-state type.

The sizing or setting of these devices is based on the motor nameplate full-load current, the service factor, the ambient temperature of the motor and controller (specifically, whether the motor and controller are at the same or different ambient temperatures), and NFPA 70 requirements.

6.23.4.2 Additional Protection for Large Motors

Protective relays, electromechanical or solid state, are well adapted to provide all forms of protection. It is recommended that differential relay protection be provided for motors with ratings of 1,500 HP and over, and this requires that each phase of the wye connection in the motor winding be accessible. Differential relays are responsive to changes in the relationship between incoming and outgoing current. Undervoltage relays, responsive to voltage changes, are used to disconnect equipment from the line when the voltage fails or when dips below predetermined values are encountered. Phase-sequence voltage relays protect against reversed phase sequence; and negative-sequence voltage and current-balance relays provide protection against phase voltage unbalance and current unbalance, respectively. Induction disk overcurrent relays are frequently used with large motors for overload and fault protection. Motors operated on grounded systems greater than 600 V should be provided with ground-fault protection. Multifunction motor protection relays (solid-state type) are available that can provide some or all of the protection discussed in this section.

Overcurrent relays used for overload protection must be of the long-time-delay type to eliminate nuisance tripping on motor in-rush current. Protective relays with thermal detector inputs are also available. See IEEE Std 242, Chapter 9.

Partial and fully automatic control are used extensively in petroleum processing facilities. Because automatic control is closely related to protective relaying in its application, both should be considered when an overall selection is made.

Control power transformers are employed for magnetically operated controllers having motor voltages greater than or equal to 480 V; they are also employed where process instrumentation is involved. Control power transformers may be applied individually to specific equipment, or may serve a bus from which several controllers operate. Figures 15, 16, and 17 illustrate the use of an individual control power transformer in a motor controller. Both 120-V and most 240-V circuits derive control power directly from the source.

6.23.5 Types of Enclosures

Control enclosures are provided to protect personnel and to meet service and operating conditions. Several types are available, each designed to meet a particular application, such as being used in a corrosive, wet, dusty, or hazardous atmosphere, and in a general-purpose indoor location. The cost varies with the design, increasing with the severity and nature of the service conditions to be met (see Table 3).

6.23.6 Maintenance and Cost

The control equipment selected should satisfactorily handle the assigned duty. When borderline decisions regarding equipment size are to be made, excessive long-range maintenance or replacement may offset an apparent first-cost savings. In instances where explosionproof controllers are indicated for classified locations, a study of the comparative installed costs of remotely located general-purpose or weatherproof controllers may show substantial savings.

Special consideration should be given to severe service conditions, such as humidity and atmospheric or process corrosion, which may damage or render control elements ineffective. Availability of corrosion-resistant enclosure parts should be discussed with the equipment manufacturer. Also, the installation of control centers or grouping of control equipment should be considered for the possible savings and the convenience of maintenance.

Table 3—NEMA Enclosure Types for AC Motor Controllers

NEMA Type	Type of Enclosure	Characteristics	Where Used	Typical Application in Plants	Comparative Cost Combination Circuit Breaker Type Size 1	Comparative Cost Combination Circuit Breaker Type Size 4
1	General purpose—indoor	A Type 1 enclosure is designed to meet Underwriters Laboratories' most recent general specifications for enclosures. This enclosure is intended primarily to prevent accidental contact with the control apparatus.	Locations where enclosure prevents accidental contact with live parts, and indoor locations where normal atmospheric conditions prevail.	Office buildings, warehouses, change houses.	1.0	1.0
		When a nonventilated enclosure is specified for equipment consisting of devices that require ventilation (electronic devices and resistors), such devices may be mounted in ventilated portions of the enclosure, provided they are capable of operating satisfactorily and without hazard when so mounted.				
		A Type 1 enclosure is suitable for general-purpose applications indoors and under normal atmospheric conditions. It protects against dust, light, and indirect splashing but is not dusttight.				
		Flush-type enclosures (designed for mounting in a wall) have provisions for aligning with the flush plate and compensating for wall thickness.			1.1	
2	Dripproof—indoor	A Type 2 enclosure is similar to a Type 1 enclosure, but it also has drip shields or their equivalent.	Locations where condensation may be severe.	Refrigeration rooms and water pump-houses not classified and not corrosive.	1.1	1.1
		A Type 2 enclosure is suitable for applications where condensation may be severe, such as in cooling rooms and laundries. It provides protection against dust, falling liquids, and light splashing but is not dusttight.				
3	Dusttight, raintight, and sleet resistant—outdoor	A Type 3 enclosure is designed to provide protection against windblown dust and water. It is not sleet- or iceproof.	Locations subject to windblown dust and rain.	Outdoors on construction jobs and dusty locations.	1.2	1.2
		A Type 3 enclosure is suitable for use outdoors if ice is not a serious problem.				
3R	Rainproof, sleet resistant—outdoor	A Type 3R enclosure is designed to provide protection against rain. It is not dusttight or snow-, sleet-, or iceproof.	Locations subject to heavy rain.	Outdoors at commercial installations and on construction jobs.	1.2	1.2
		A Type 3R enclosure is suitable for use outdoors and will prevent the entrance of a rod of 0.125 inch diameter, except at drain holes.				
		Types 3 and 3R are usually combined in one enclosure type.				
3S	Dusttight, raintight, and sleet-proof—outdoor	A Type 3S enclosure is designed to provide protection against windblown dust and water and to provide for operation when covered with external ice or sleet. It may have auxiliary provisions for ice breaking.	Locations subject to heavy icing conditions.	Outdoors on ship decks or on construction site subject to heavy icing.	1.7	1.6

Table 3—NEMA Enclosure Types for AC Motor Controllers (Continued)

NEMA Type	Type of Enclosure	Characteristics	Where Used	Typical Application in Plants	Comparative Cost Combination Circuit Breaker Type Size 1	Comparative Cost Combination Circuit Breaker Type Size 4
		Type 4 enclosures are usually used for this service.				
4	Watertight and dusttight	A Type 4 enclosure, intended for use indoors or outdoors, protects the enclosed equipment against splashing water, seepage of water, falling or hose-directed water, and severe external condensation. A Type 4 enclosure is sleet-resistant but not sleetproof.	Outdoor locations or locations where the starter might be subjected to splashing or dripping water; not suitable for submersion in water.	Outdoors at pumps not in classified or corrosive locations.	1.7	1.6
4X	Watertight, dusttight, and corrosion-resistant	A Type 4X enclosure is the same as a Type 4 enclosure but is also corrosion-resistant.	Locations subject to splashing or dripping water where corrosion is also a problem.	Outdoor locations in chemical plants.	2.0	1.7
6	Submersible	A Type 6 enclosure is suitable for applications where the equipment may be subject to submersion in water, as in quarries, mines, and manholes. The design of the enclosure will depend on the specified conditions of pressure and time. It is also dusttight and sleet resistant.	Locations where the equipment is subject to submersion in water.	Normally not required.	4.0	4.0
7	Classified location; Class I—air break (see Note 2)	A Type 7 enclosure is designed to meet the application requirements for Class I locations as defined in Article 500 of NFPA 70 and is designed in accordance with the latest specifications of Underwriters Laboratories. A letter suffix in the type designation specifies the NFPA 70 group for which the enclosure is suitable.	Locations which are classified as Class I locations according to Article 500 of NFPA 70 due to the presence of flammable gases and vapors.	Class I, Division 1 and 2 areas, Groups A–D.	2.1	1.6
8	Classified location; Class I—oil immersed (see Note 2)	A Type 8 enclosure is designed to meet the application requirements for Class I locations as defined in Article 500 of NFPA 70 and is designed in accordance with the latest specifications of Underwriters Laboratories. The apparatus is immersed in oil. A letter suffix in the type designation specifies the NFPA 70 group for which the enclosure is suitable.	Locations which are classified as Class I locations according to Article 500 of NFPA 70 due to the presence of flammable gases and vapors.	Class I, Division 1 and 2 areas, Groups A–D.	2.5	1.8
9	Classified location; Class II—Groups E and G	A Type 9 enclosure is designed to meet the application requirements for Class II locations as defined in Article 500 of NFPA 70 and is designed in accordance with the latest specifications of Underwriters Laboratories. A letter suffix in the type designation specifies the NFPA 70 group for which the enclosure is suitable.	Locations which are classified as Class II locations according to Article 500 of NFPA 70 due to the presence of combustible dusts.	Class II areas, Groups E and G.	2.1	1.6
10	MSHA, U.S. Dept. of Labor	A Type 10 enclosure is designed to meet the latest requirements of MSHA.	Locations that must meet the latest requirements of MSHA.	Normally not required.		
11	Corrosion resistant and dripproof, oil immersed—indoor (see Notes 2 and 3)	A Type 11 enclosure is suitable for applications indoors where the equipment may be subject to corrosive acid or fumes, as in chemical plants, planting rooms, and sewage plants. The apparatus is immersed in oil.	Locations where acid or fumes are present.		2.2	1.7

Table 3—NEMA Enclosure Types for AC Motor Controllers (Continued)

NEMA Type	Type of Enclosure	Characteristics	Where Used	Typical Application in Plants	Comparative Cost Combination Circuit Breaker Type Size 1	Comparative Cost Combination Circuit Breaker Type Size 4
12	Industrial use—dusttight and driptight—indoor	A Type 12 enclosure is provided with an oil-resistant synthetic gasket between the case and the cover. The cover is hinged to swing horizontally and is held in place with captive closing hardware; a screwdriver or wrench must be used to release the cover from the hardware. There are no holes through the enclosure for mounting or for mounting controls within the enclosure and no conduit knockouts or conduit openings. Mounting feet or other suitable means for mounting are provided. When a Type 12 enclosure is specified for equipment consisting of devices which require ventilation (electronic devices and resistors), such devices may be mounted in a ventilated portion of the enclosure as long as they are capable of operating satisfactorily and without hazard when so mounted.	Locations where oil or coolant might enter the enclosure through mounting holes or unused conduit openings and where it is necessary to exclude dust, fibers, flyings, and lint.	Machine tool drive-in shops; chemical rooms in water treatment plants.	1.2	1.2
13	Oiltight and dusttight—indoor	A Type 13 enclosure, intended for use indoors, protects pilot devices, such as limit switches, foot switches, pushbuttons, selector switches, and pilot lights, against lint; dust; seepage; external condensation; and spraying water, oil, or coolant. A Type 13 enclosure has oil-resistant gaskets, external mounting means, no conduit knockouts or unsealed openings, and oiltight conduit entry.	Indoor locations subject to the contaminants listed.	Indoor dusty control areas or where subject to liquid spray.		

Notes:
1. MSHA = Mine Safety and Health Administration.
2. Any individual starter, circuit breaker, fuse, switch, fused disconnecting switch, or any combination of these items may be enclosed in any of the aforementioned enclosures. When NEMA Types 7, 8, and 11 enclosures are applied, a combination of enclosures may be required if the installation is outdoors or additional protection features other than the basic protection provided by the specific NEMA type are required. To standardize the practice in referring to equipment known as explosionproof (Types 7 and 8), apparatus designed for use in Class I, Group A–D locations, should be described in one of the following ways:
a. Control listed by a NRTL for use in Class I, Group (state specific group letter) locations.
b. Control designed to conform with the manufacturer's interpretation of the requirements of Underwriters Laboratories' standards or from its testing facilities.
c. Control of a size and nature for which there are no existing Underwriters Laboratories' standards or tests from a NRTL testing facility.
3. When an enclosure has to meet the requirements of NEMA Type 11, the design will depend on the conditions of exposure.
4. NEMA ICS 6 can provide more detailed information on enclosures and test requirements.

6.24 APPLICATION OF MOTOR CONTROL

6.24.1 Squirrel Cage Induction Motor

Because of its simplicity and adaptability to full-voltage starting, the squirrel-cage induction motor is widely used in constant-speed applications. Magnetic full-voltage starting with remote or automatic control is customarily applied for motor starting. (The wiring for this application is diagrammed in Figure 15.) Magnetic full-voltage starting is the most desirable and can prevent restart of motors after the return of failed voltage. There are cases, however, where automatic restarting is imperative because of critical process requirements. If automatic restarting is necessary, time-delay relaying can be provided, and if several motors are involved, the motors can be automatically restarted in sequence to prevent possible system disturbances.

Reduced-voltage starting, either manual or automatic, is employed to reduce the starting current on power systems of limited capacity if the reduced-starting torque is adequate for the connected equipment. Reduced-voltage starting also is employed when the driven load demands smooth starting. Several methods of applying reduced-voltage starting are available:

a. The autotransformer method offers variations in starting torque through selective starting taps. It provides maximum starting torque with minimum line current (see Figure 16).
b. The series resistor or reactor method offers simplicity of design and uses a more economical starter.
c. Wye-delta starting is also an economical method of reduced-voltage starting but produces a lower starting torque than the other methods.
d. The solid-state reduced-voltage starting method provides a smooth, stepless acceleration with current-limit control adjustable between the limits of approximately 150% and 425% of motor full-load current.

6.24.2 Synchronous Motor

The synchronous motor is applied principally in the large horsepower class, greater than or equal to 500 HP. Because of its limited starting characteristics, the synchronous motor is generally started under no-load conditions with DC field excitation automatically applied when the motor approaches synchronous speed. Variable field excitation may be used during normal operation to provide power factor correction and should be specified if required.

As is the case for squirrel-cage induction motors, full- and reduced-voltage controllers are available for starting; the selection depends on the local power source and operating conditions. There is a similarity in control except that the out-of-step protection automatically stops the motor when the motor drops out of synchronism.

A controller for a synchronous motor will generally include the following functions in addition to the functions of a controller for a squirrel-cage induction motor:

a. Protection of the field against overcurrents in normal or out-of-step operation.
b. Automatic field application that is responsive to the definite time, the relative frequency of the current in the field and stator, the power factor of the current to the stator winding, and other variables that may be used to obtain the desired result.

Both AC and DC meters should be provided.

6.24.3 Wound-Rotor Induction Motor

The wound-rotor induction motor meets the operating demands of controlled starting, in-rush current, and adjustable speeds with high starting torque. It is suitable for a high-inertia load where critical operations may require closely controlled acceleration. Starting facilities are similar to those of the squirrel-cage induction motor, except that the motor winding is brought out through slip rings and connected to a variable resistor or regenerative system. This arrangement provides selective speed control under varying conditions of load (see Figure 17).

The primary control device for starting a wound-rotor motor is usually the same as that used for a squirrel-cage induction motor. The secondary device for regulating the speed of a wound-rotor motor consists of an adjustable resistor or rheostat. It is general practice to interlock these primary and secondary control devices so that the motor cannot be started except when the resistor is set in minimum-speed position.

Application of wound rotor motors in petrochemical environments should be carefully reviewed because of the sparking nature of the brushes and slip rings.

6.25 MEANS OF DISCONNECTION

Means of disconnection are discussed in NFPA 70.

6.26 COORDINATION OF CONTROLLER APPLICATIONS WITH FUSES OR CIRCUIT BREAKERS ON LOW-VOLTAGE SYSTEMS

6.26.1 Normal Operation and Fault Conditions

A motor controller must be capable of starting and stopping its rated motor horsepower and interrupting motor locked-rotor current. Normally, the controller cannot interrupt fault currents resulting from short circuits and grounds so a circuit breaker, motor circuit protector, or a set of fuses is installed ahead of the controller. The protective devices must have sufficient capacity to interrupt the current safely and must be fast enough to clear the fault without damage to the contactor and overcurrent devices. They must also carry locked-rotor current long enough to allow the motor to accelerate to rated speed without opening the motor circuit and should preferably protect against excessive locked-rotor time. In addition, they should keep motor damage to a minimum in case of a fault within the motor.

The complete motor protection package normally consists of a disconnect device, fault-current protection, a contactor, time-lag overcurrent protection, and associated auxiliary devices. The disconnect and fault-current protection are often combined in a circuit breaker. Even though some components may be combined, all of these protective features must be included.

6.26.2 Fuse and Circuit Breaker Considerations

NFPA 70 provides general information on fuses and circuit breakers.

6.26.2.1 Fuses

Dual element (time-delay) fuses are better suited for motor branch-circuit protection than are fuses that open without delay; the time-delay feature avoids possible fuse opening during the period of high motor starting current. This allows the fuse to be sized more closely to the motor's rated full-load current.

Current-limiting fuses are also commonly used for this service because of the following:

a. For faults, they operate within $^1/_2$-cycle to reduce the damage caused by short-circuit current.

b. The magnitude of the short-circuit current is actually limited to less than the available short-circuit current, which may allow the use of smaller conductors in branch circuits. The fast operation of most fuses, however, makes it difficult and often impossible to coordinate them with other short-circuit protective devices.

c. Current-limiting fuses are not subject to aging; therefore, an ultimate false operation is avoided when these devices are used.

6.26.2.2 Circuit Breakers

It is essential to select a circuit breaker capable of closing into, carrying, and interrupting the highest fault current available at the point of installation.

6.27 OVERLOAD PROTECTION: SPECIAL APPLICATIONS

When a motor is to be used to drive a high-inertia load that requires a long time to accelerate to normal speed, a check should be made to determine if a special form of overload protection will be required. This will usually be the case if a standard protective device, set at the maximum current value affording proper protection for the motor, trips the motor off the line during the starting period.

To provide uninterrupted starting and at the same time provide the desired degree of protection against sustained high starting currents, it may be necessary, in some cases, to use a thermal device that is built into the motor stator winding. In other cases, it may be necessary to use long-time induction-disk or solid-state relays that are adjustable to suit the starting conditions, or to supply current to the overload protective device through a saturable core reactor or current transformer with characteristics suitable for limiting the current to the protective device during the starting period. If one of these forms of protection will not suffice, consideration should be given to other means of providing the desired degree of protection. If the ambient temperature varies, thermally compensated relays may be used.

A speed sensor or switch coupled to the motor shaft can also be integrated into the control system, particularly with the use of timing relay(s). Many of the multifunction protection relays (solid-state relays) available integrate this and other protective features.

6.28 VOLTAGE LIMITATIONS

In many cases, on a privately owned industrial supply system, it is practical to tolerate voltage fluctuations somewhat in excess of values that generally would be considered unacceptable on other systems. When a large motor is to be installed at a point where severe voltage dips will result, a check will determine whether the motor terminal voltage will be sufficient during the starting period to permit the motor to bring its load up to speed within a satisfactory time, and whether the resulting voltage disturbance will be acceptable, considering the requirements of other electrical equipment supplied by the system. Where the terminal voltage will be abnormally low, approaching the value at which the undervoltage device in a standard controller is designed to operate, it is recommended that the specification for the controller include the anticipated range of voltage from the minimum during starting to the maximum during normal operation.

6.29 APPLICATION OF OUTDOOR AND INDOOR TYPES

6.29.1 Outdoor -Type

It is common practice to install electric motors and driven equipment outdoors without protection from the weather, unless there is some good reason for providing a building or other form of shelter. Outdoor-type controllers may be used with these motors. The main consideration in this application is to avoid the use of buildings and other shelters as much as possible so that the possibility of an accumulation of flammable vapors or gases is reduced. Enclosures for controllers installed outdoors must meet all service requirements of the location.

6.29.2 Indoor -Type

Indoor-type controllers are sometimes used regardless of the location of the associated motors. It may be more economical to use indoor equipment in a building located in an unclassified area than to provide outdoor controllers that are suitable for all conditions of service.

6.30 PUSHBUTTON STATIONS

6.30.1 Location

If undervoltage protection is required, the pushbutton for operating the controller is generally of the momentary-contact, start-stop type and is installed in sight of and near the motor and its driven equipment and in a position that will facilitate ease and safety of operation. If a pushbutton is installed on or near a controller that is remote from the motor controlled, the pushbutton is generally of the stop-type installed only for the purpose of stopping the motor in an emergency.

6.30.2 Undervoltage Release

In installations where undervoltage release instead of undervoltage protection is to be provided, as in float-operated pumps, pressure-operated compressors, and other pilot-operated equipment, which function automatically on an on-off cycle, the pushbutton is generally of the maintained-contact type, wired in series with the pilot device.

6.31 ADDITIONAL REFERENCES

The following additional references are helpful in preparing definitive specifications and correctly applying motors and controllers:

a. AGMA 6019-E.
b. UL 674 and UL 698.
c. NEMA ICS 1 and NEMA MG 2.
d. API 541 data sheet guide.
e. API 546 data sheet guide.
f. IEEE Std 242.

SECTION 7—LIGHTING

7.1 PURPOSE

This section serves as a guide for the design of modern petroleum processing plant lighting facilities. It advocates the following principles:

a. Establishing recommended practices for processing plant lighting will ensure adequate and efficient lighting facilities that contribute to the safe and efficient operation and maintenance of the plant.
b. Processing plant lighting should not be considered just a necessary burden that only adds to the cost of production; rather, it should be considered an integral part of safe and efficient plant operation.
c. Lighting design practice should be kept up-to-date with new developments such as high intensity discharge (HID) lamps. Luminaires have been developed that make effective use of metallic additive and quartz light sources. High-pressure sodium luminaires are commonly used where high illuminances are required and where energy cost and reduced maintenance cost are important considerations. Applications of these new developments, where suitable, may offer the most efficient lighting installation.

7.2 SCOPE

The material in this section is intended to establish the following:

a. A general approach to the practice and principles of good lighting installation and maintenance.
b. Basic criteria for the design of new processing plant lighting.
c. Recommended illuminances for most processing plant areas.
d. A basis for estimating lighting power requirements in new processing plant design.

7.3 DEFINITION OF TERMS

7.3.1 brightness: The illuminance of a surface in any given direction.

7.3.2 brightness ratio: The ratio of brightness of surfaces.

7.3.3 diffusion: The breaking up of a beam of light and the spreading of its rays in many directions by a surface.

7.3.4 footcandle (ftc): A unit of illuminance.

7.3.5 glare: The condition in which brightness or the contrast of brightnesses interferes with vision.

7.3.6 illuminance: The density of luminous flux incident upon a surface.

7.3.7 illuminance level: A prescribed amount of illuminance:

a. *Initial* is the amount of illuminance obtained when the luminaires are new and clean and when the lamps are first energized.
b. *In service* or *maintained* is the average amount of illuminance over an extended period of time. This is lower than the initial illuminance for several reasons noted under light loss factor.

7.3.8 luminaire: A complete lighting unit including the lamp, globe, reflector, refractor, housing, and support that is integral with the housing.

7.3.9 light loss factor: A factor that represents the average-to-initial illuminance ratio of a lighting system. It represents the depreciation and deterioration of a lighting system caused by the following:

a. Loss of lamp lumens as a result of aging.
b. Decrease in lamp and luminaire output resulting from dust, dirt, insects, and chemical changes in the luminaire's reflecting surface.
c. Increased absorption of the light output of the luminaires by dust, dirt, and chemical changes in the room's reflecting surfaces.
d. Differences between actual and design lamp voltages.

7.3.10 lux: The SI unit of illuminance. One lux is one lumen per square meter.

7.3.11 mounting height: The distance from the bottom of the luminaire to the surface used as a reference.

7.3.12 reflection factor: The ratio of the light reflected by the body to the incident light.

7.3.13 seeing or visual task: The object being regarded and its background.

7.3.14 utilization: The total flux received by a surface divided by the total flux from the lamps illuminating it.

7.4 LIGHTING FACILITIES

7.4.1 Recommended Illumination

The data in Table 4 cover the minimum average maintained (in service), horizontal lighting illuminance requirements of most processing plant areas; however, it must be clearly understood that lighting installations should be designed to meet the conditions peculiar to the tasks of each area. For instance, Table 4 indicates a minimum illuminance of 5 (ftc) in service for operating platforms on general process units. Obviously, if there are instruments and control valves that must be operated constantly, the 5-ftc illuminance is insufficient. Supplemental lighting on the immediate control area or a general increase in the illuminance on that platform is necessary. In this sense, the data shown in Table 4 serve only as a guide to good lighting practice.

Note: These illuminances are not intended to be mandatory by enactment into law; they are a recommended practice to be considered in the design of new facilities.

a. Indicates vertical illuminance.

b. Refer to local Coast Guard, port authority, or governing body for required navigational lights.

c. The use of many areas in petroleum and chemical plants is often different from what the designation may infer. The areas are generally small, their occupancy is low (restricted to plant personnel) and infrequent, and they are only occupied by personnel trained to conduct themselves safely under unusual conditions. For these reasons, illuminances may be different from those recommended for other industries and for commercial, educational, or public areas.

d. Refer to local Federal Aviation Administration regulations for required navigational and obstruction lighting and marking.

e. Refer to Tables 7.2A and 7.2B in API RP 14F for recommended illumination levels for offshore production platforms.

7.4.2 Petroleum Processing Plant Areas

As shown in Table 4, the three basic areas to consider when planning lighting facilities are process areas, nonprocess areas, and buildings. Buildings peculiar to process and nonprocess areas have been included in Table 4.

The three basic areas are broken down into more specific areas or activities. Under process areas and the more specific areas of general process units, minimum lighting requirements are given for areas such as pump rows, heat exchangers, and operating platforms.

7.4.3 Lamp Types

The following types of lamps are commercially available and frequently used in refinery installations:

a. Incandescent, including tungsten and halogen.
b. Fluorescent.
c. Mercury vapor.
d. Metal halide.
e. High-pressure sodium.

Incandescent and fluorescent lamps, including halogen and tungsten, can be used in luminaires with direct, semidirect, and general-diffuse outputs, while high-intensity discharge lamps can be used in luminaires with direct and semidirect outputs. Efficacies for incandescent lamps range from 4 to 24 lumens per watt (lm/W) and for fluorescent lamps range from 75 to 80 (lm/W).

Compared with incandescent lamps, mercury vapor lamps offer the advantages of longer average life and higher lumen output; however, with the advent of metal halide and high-pressure sodium lamps, the mercury vapor lamp is considered by many to be obsolete, except in existing plants having similar lamps. The mercury vapor lamp is considered obsolete because of its rapid lumen depreciation and low lumens-per-watt (lm/W) characteristics. Also, the warm-up period and restrike may vary between 3 minutes and 7 minutes. As with other HID lamps, these ballasts have power factors in the 40% to 50% range unless corrected; capacitor correction results in power factors in the 90% range. Efficacies for mercury vapor lamps range from 38 to 63 lm/W, excluding ballast losses. Average lamp life is 24,000 hours, but it is recommended that lamps be replaced at 16,000 hours due to rapid lumen depreciation.

Metal halide lamps are similar in construction to mercury vapor lamps. The difference is that metal halides are added to the mercury and argon in the arc tube. The efficacies are improved to the range of 75 lm/W to 125 lm/W, excluding ballast loss. The color rendering is quite white and is usually superior to the phosphor-coated mercury vapor lamp. The warm-up time for metal halide lamps is 2 minutes to 4 minutes, and restrike time varies from 5 minutes to 15 minutes, depending on the type. Power factors in the 90% range can be obtained. Lamp life varies from 3,000 hours to 20,000 hours. Metal halide lamps have more rapid lumen depreciation than do mercury vapor lamps, and have high surface operating temperatures which must be considered before application in classified locations. The lamp life and lumen output are affected by burning position.

Currently, most engineering activities by lamp manufacturers are focused on improvements in the overall efficiencies and life of the metal halide lamps. A series of pulse start metal halide lamps have been developed with features of improved lamp life, lumen maintenance, and the use of more efficient ballast systems. These lamps have wattages ranging from 150 W to 400 W with efficacy 90 lm/W to 110 lm/W; lamp life of 15,000 to 30,000 hours; improved warm-up time of 2 minutes; and restrike time of 3 minutes to 4 minutes. A 33% improvement in lumen maintenance can be seen in these lamps.

High-pressure sodium lamps have efficacies that range from 77 lm/W to 140 lm/W, depending on size. The color rendition is a distinct orange. Warm-up time for high-pressure sodium lamps is from 3 minutes to 4 minutes. Restrike time is less than 1 minute, and instant restrike devices are offered for 50-W to 150-W high-pressure sodium lamps. Power factors range from 40% to 99% depending on the ballast type and the age of the lamp. Lamp life is 24,000 hours.

HID lighting may be supplemented by incandescent or fluorescent lighting which would provide illumination during the initial warm-up time and during the restrike time after an extinction caused by voltage dips in the 10% to 60% range, depending on ballast type. If required, a push-to-test switch can be installed with a fixture that uses the re-strike feature. This switch will allow the testing of the restrike dur-

Table 4—Illuminances Currently Recommended for Petroleum, Chemical, and Petrochemical Plants

Area or Activity	Maintained Horizontal Illuminance (unless noted) Lux	Footcandles	Elevation Location	Millimeters	Inches
	Process Areas				
General process units					
Pump rows, valves, manifolds	50	5	Ground		
Heat exchangers	30	3	Ground		
Maintenance platforms	10	1	Floor		
Operating platforms	50	5	Floor		
Cooling towers (equipment areas)	50	5	Ground		
Furnaces	30	3	Ground		
Ladders and stairs (inactive)	10	1	Floor		
Ladders and stairs (active)	50	5	Floor		
Gauge glasses	50[a]	5[a]	Eye level		
Instruments (on process units)	50[a]	5[a]	Eye level		
Compressor houses	200	20	Floor		
Separators	50	5	Top of bay		
General area	10	1	Ground		
Control rooms and houses					
Ordinary control house	300	30	Floor		
Instrument panel	300[a]	30[a]		1700	66
Console	300[a]	30[a]		760	30
Back of panel	100[a]	10[a]		760	30
Central control house	500	50	Floor		
Instrument panel	500[a]	50[a]		1700	66
Console	500[a]	50[a]		760	30
Back of panel	100[a]	10[a]		900	36
Specialty process units					
Electrolytic cell room	50	5	Floor		
Electric furnace	50	5	Floor		
Conveyors	20	2	Surface		
Conveyor transfer points	50	5	Surface		
Kilns (operating area)	50	5	Floor		
Extruders and mixers	200	20	Floor		
	Nonprocess Areas				
Loading, unloading, and cooling water, pumphouses					
Pump area	50	5	Ground		
General control area	150	15	Floor		
Control panel	200[a]	20[a]		1100	45
Boiler and air compressor plants					
Indoor equipment	200	20	Floor		
Outdoor equipment	50	5	Ground		

Table 4—Illuminances Currently Recommended for Petroleum, Chemical, and Petrochemical Plants (Continued)

	Maintained Horizontal Illuminance (unless noted)		Elevation		
Area or Activity	Lux	Footcandles	Location	Millimeters	Inches
Tank fields (where lighting is required)					
Ladders and stairs	5	0.5	Floor		
Gauging area	10	1	Ground		
Manifold area	5	0.5	Floor		
Loading racks					
General area	50	5	Ground		
Tank car	100	10	Point		
Tank trucks, loading point	100	10	Point		
Tanker dock facilities[b]					
Offshore production platforms[e]					
Electrical substations and switch yards[c]					
Outdoor switch yards	20	2	Ground		
General substation (outdoor)	20	2	Ground		
Substation operating aisles	150	15	Floor		
General substation (indoor)	50	5	Floor		
Switch racks	50[a]	5[a]		1200	48
Plant road lighting (where lighting is required)[c]					
Frequent use (trucking)	4	0.4	Ground		
Infrequent use	2	0.2	Ground		
Plant parking lots[c]	1	0.1	Ground		
Aircraft obstruction lighting[d]					
Buildings[c]					
Administration buildings and offices					
Prolonged difficult task (drafting, designing)	1000	100		760	30
Difficult task (accounting, business machines)	750	75		760	30
Normal office work (reading, files, mail room)	500	50		760	30
Reception areas, stairways, washrooms	200	20		760	30
Hallways	200	20	Floor		
Equipment and service rooms	150	15	Floor		
Laboratories					
Qualitative, quantitative, and physical test	500	50		900	36
Research, experimental	500	50		900	36
Pilot plant, process, and specialty	300	30	Floor		
ASTM equipment knock test	300	30	Floor		
Glassware, washrooms	300	30		900	36
Fume hoods	300	30		900	36
Stockrooms	150	15	Floor		

Table 4—Illuminances Currently Recommended for Petroleum, Chemical, and Petrochemical Plants (Continued)

Area or Activity	Maintained Horizontal Illuminance (unless noted)		Elevation		
	Lux	Footcandles	Location	Millimeters	Inches
Warehouses and stockrooms[c]					
Indoor bulk storage	50	5	Floor		
Outdoor bulk storage	5	0.5	Ground		
Large bin storage	50	5		760	30
Small bin storage	100[a]	10[a]		760	30
Small parts storage	200[a]	20[a]		760	30
Countertops	300	30		1200	48
Repair shop[c]					
Large fabrication	200	20	Floor		
Bench and machine work	500	50		760	30
Craneway, aisles	150	15	Floor		
Small machine	300	30		760	30
Sheet metal	200	20		760	30
Electrical	200	20		760	30
Instrument	300	30		760	30
Change house[c]					
Locker room, shower	100	10	Floor		
Lavatory	100	10	Floor		
Clock house and entrance gatehouse[c]					
Card rack and clock area	100	10	Floor		
Entrance gate, inspection	150	15	Floor		
General	50	5	Floor		
Cafeteria					
Eating	300	30		760	30
Serving area	300	30		900	36
Food preparation	300	30		900	36
General (halls)	100	10	Floor		
Garage and firehouse					
Storage and minor repairs	100	10	Floor		
First aid room[c]	700	70		760	30

Note: These illuminances are not intended to be mandatory by enactment into law; they are a recommended practice to be considered in the design of new facilities.
[a]Indicates vertical illuminance.
[b]Refer to local Coast Guard, port authority, or governing body for required navigational lights.
[c]The use of many areas in petroleum and chemical plants is often different from what the designation may infer. The areas are generally small, their occupancy is low (restricted to plant personnel) and infrequent, and they are only occupied by personnel trained to conduct themselves safely under unusual conditions. For these reasons, illuminances may be different from those recommended for other industries and for commercial, educational, or public areas.
[d]Refer to local Federal Aviation Administration regulations for required navigational and obstruction lighting and marking.
[e]Refer to Tables 7.2A and 7.2B in API RP 14F for recommended levels of illumination for offshore production platforms.

ing normal operation by interrupting power to the fixture. This testing method will ensure that the restrike will function as intended after a major voltage dip or power failure.

7.5 LUMINAIRES

7.5.1 Selection

In choosing a luminaire, a separate study should be made for each application. Some of the factors influencing the final selection are appearance, efficiency, glare, density of equipment, frequency of operation, maintenance, required color rendition, and area classification.

7.5.2 Floodlighting

Floodlights provide area lighting at an economical cost. They must be located at suitable mounting heights and with unobstructed beam paths. Mounting can be on pipeways, vessel platforms, rigging structures, and floodlight poles. Floodlights are available with most lamp types, and with beam spreads from 10° to 18° (NEMA 1) to greater than 130° (NEMA 7).

7.5.3 Codes and Standards

Local codes, national codes, federal standards, professional standards, and manufacturers' standards relate to specific requirements that must be met in the construction and installation of a luminaire. Some codes and standards deal with fire and safety (electrical, mechanical, and thermal); others relate to performance and construction (materials and finishes). Conformance to the appropriate set of specification is often determined by certified laboratory tests. Certification is often denoted by an identifying label. Local code enforcement authorities may or may not require certification by an approved laboratory.

7.5.3.1 National Codes

NFPA 70, the *Canadian Electrical Code* (CEC), and similar codes in most major countries state specific electrical requirements which must be met by all electrical equipment, including luminaires.

7.5.3.2 National and International Standards

For electrical products, UL, CSA, and other similar organizations publish minimum safety standards that are in conformance with electrical codes. Luminaires approved by these organizations will meet the standards that ensure that they are acceptable for installation and are able to provide satisfactory service.

7.5.3.3 Industry Standards

Industry standards are published by various organizations that generally utilize national technical committees comprised of representatives from industry, inspection and protection agencies, and manufacturers. Conformance to these standards is not necessarily required, but it does offer many advantages to the user when conformance is specified. Standards organizations include the American Society for Testing and Materials (ASTM), Certified Ballast Manufacturers (CBM)[17], IEEE, IES, NEMA, and ANSI.

7.5.3.4 Manufacturers' Standards

Since codes and standards deal primarily with safety and performance, the specifier should be aware of the quality standards used by the manufacturer.

7.5.4 Ballast Considerations

Lamp ballasts must be taken into consideration when specifying luminaires for purchase. For all lamp types requiring ballasts, there are a variety of ballasts available. The design engineer should consult with the luminaire and lamp representatives to get more details.

HID luminaires may be purchased with a variety of ballast types having a range of power factors and costs; but with the introduction of the high-pressure sodium lamp, a new ballast consideration has been introduced. Unlike other HID lamps, the high-pressure sodium lamp is one with dynamic characteristics over its life. By carefully specifying high-pressure sodium luminaire ballast-types, the design engineer can achieve a good power factor over the life of the lamp. The design engineer's considerations when selecting the type of ballast to be used are energy efficiency (losses), lamp life, lumen output, wiring and circuitry (number of fixtures per circuit), and dip tolerance (ability to sustain the arc during a voltage dip).

Remote mounted ballasts are available to use with mercury vapor, metal halide or high-pressure sodium lighting fixtures. The distance that the ballast can be mounted away from the lamp is based on the type of lamp, wattage, ballast-to-lamp wire size, and whether an ignitor is involved. In general, ballasts for mercury vapor and metal halide lamps do not require ignitor, but ballasts for high-pressure sodium and the newer, low-wattage metal halide lamps require an ignitor for starting. The design engineer should consult with the ballast and luminaire representatives to determine the proper ballast-to-lamp distance and the minimum wire size required.

7.5.5 Application in Classified Locations

Some locations may be exposed to the release of flammable gases, vapors, or dusts. NFPA 70 requires that these locations be classified and sets forth rules for luminaires that may be

[17]Certified Ballast Manufacturers, 355 Lexington Avenue, 17th Floor, New York, New York 10017-6603.

installed in these areas. These luminaires must be approved for the class, division zone, and group in which they are to be used.

Identification, as required by NFPA 70, is provided for each approved luminaire as applicable, showing its class, group, and operating temperature range (see Table 5). The temperature rating of a luminaire approved for a Class I, Division 1 location (explosionproof) is based on the hottest spot on the exterior surface of the luminaire, generally the globe. The temperature rating of a Class I, Division 2 luminaire (enclosed and gasketed) is based on the hottest spot on the interior of the luminaire, generally the lamp wall. The maximum allowable temperature of the luminaire must be below the ignition temperature of the group of gases in the classified area.

In zone applications, the luminaires must be rated and approved for the specific zone designation where they are installed.

7.6 LIGHT QUALITY

7.6.1 Design Considerations

Lighting of good quality is as important as a sufficient quantity of lighting. Glare, uniformity, brightness ratios, diffusion, reflection factor, color, and surrounding color are the major considerations when designing quality lighting. Another consideration is that lighting installations using HID fixtures should be designed to avoid stroboscopic effect

7.6.2 Glare

Glare can be controlled to some extent by careful manipulation of the following design factors: the brightness of the source, the position of the source, and the brightness ratio between the viewed objects and their surroundings. The brightness ratio between the visual task and its near surroundings should be no more than 3:1, and the brightness ratio between the visual task and its far surroundings should be limited to 10:1.

7.6.3 Reflection

In buildings where tasks that require lighting are critical or prolonged, special attention to the proper reflection factors must be paid to the colors of walls, the ceilings, the furniture, and the equipment. In process units, reflection is extremely important and will contribute significantly to the overall light level. The amount of reflective surface, such as aluminum insulation sheathing, should be considered in the light-level calculations.

7.6.4 Color Rendition

With the application of HID lighting, color shift becomes an important consideration. Color shift occurs when an object is viewed in natural light and then under a light source, such as high-pressure sodium lighting. High-pressure sodium lighting is an economical source because of its high efficacy, but it has the greatest problem with color shift; mercury vapor and metal halide lighting provide good color rendition.

Background colors are critical with high-pressure sodium lighting. Safety colors that identify a first aid station or fire protection equipment can become obscure under high-pressure sodium lighting. Special paints are available that minimize color distortion and should be considered for use in areas which require safety colors.

Table 5—Temperature Marking Identification Numbers

Maximum Temperature		
°C	°F	Identification Number
450	842	T1
300	572	T2
280	536	T2A
260	500	T2B
230	446	T2C
215	419	T2D
200	392	T3
180	356	T3A
165	329	T3B
160	320	T3C
135	275	T4
120	248	T4A
100	212	T5
85	185	T6

Note: The temperature marking specified in the table shall not exceed the ignition temperature of the specific gas or vapor to be encountered. For information regarding ignition temperatures of gases and vapors, see NFPA 325M.

7.7 ILLUMINANCE

Although the fundamental purpose of illumination is to provide enough light with which to see the task, particular attention must be given to the type of task requiring illumination. Prolonged, difficult tasks, such as drafting or accounting, require the highest illuminance. Some critical tasks requiring illumination need much higher levels than the minimum values shown in Table 4. In general, exceptionally high illuminance is needed only in relatively small areas, where supplementary lighting equipment should be used.

7.8 INSTALLATION INITIAL VALUES

7.8.1 Light Loss Factor

To provide a design basis for new lighting installations, initial values of illuminance have been included in Table 4. These values are higher than the in-service or maintained values by an amount equal to a representative total light loss factor.

7.8.2 Initial Allowances

In designing a lighting installation, the light loss factor must be taken into account. This factor allows for all conditions that decrease the output of a luminaire over a period of time. The two major conditions are lamp lumen depreciation (LLD) and luminaire dirt depreciation (LDD); LDD is light loss from the accumulation of dust, grease, and other foreign matter on the luminaire and reflecting surfaces.

A lighting design is based on the maintained illumination, which must take into account the decreased output of the lamp as it ages and the decreased output of the luminaire between cleanings. For this reason, the initial illuminance is considerably higher. This initial illuminance, rather than the maintained illuminance, is the figure to be used when checking new installations for correctness of light output design.

The LLD value is the value published by the lamp manufacturer. The LDD value is a function of the in-service conditions and the type of luminaire selected. Values for luminaire dirt depreciation typically range from 0.70 to 0.97.

7.9 LIGHTING SYSTEM POWER SUPPLY

The choice of a voltage and distribution system for a lighting installation depends on the area to be supplied and the desired lighting load. The supply considered most desirable will vary throughout a processing plant and will, to some extent, depend on the power distribution system and the voltage. Some points to be considered in the selection of a lighting system power supply are depicted in Figure 18.

The effect of voltage dips and flicker on a lighting system should be considered when choosing a power supply system for lighting. Certain types of utilization equipment, such as motors, have a high initial inrush current when turned on and impose a heavy load at a low power factor for a very short time. This sudden increase in the current flowing to the load causes a momentary increase in the voltage drop along the distribution system, and a corresponding reduction in the voltage at the utilization equipment. A small dip of $^1/_4\%$–$^1/_2\%$ will cause a noticeable reduction in the light output of an incandescent lamp and a less noticeable reduction in the light output of HID type lamps.

When loads are turned on and off rapidly as in the case of resistance welders, or fluctuate rapidly as in the case of arc furnaces, the rapid fluctuations in the light output is called flicker. The effect of flicker depends on lighting intensity and working conditions. Flicker is more of a problem with incandescent lighting than with fluorescent and HID type lamps. When flicker continues over an appreciable period, voltage variations as low as $^1/_2\%$ may be objectionable. When objectionable flicker occurs, either the load causing the flicker should be reduced or eliminated, or the capacity of the supply system should be increased to reduce the voltage drop caused by the fluctuating load. In large plants, flicker-producing equipment should be segregated on separate transformers and feeders so as not to disturb flicker-sensitive equipment.

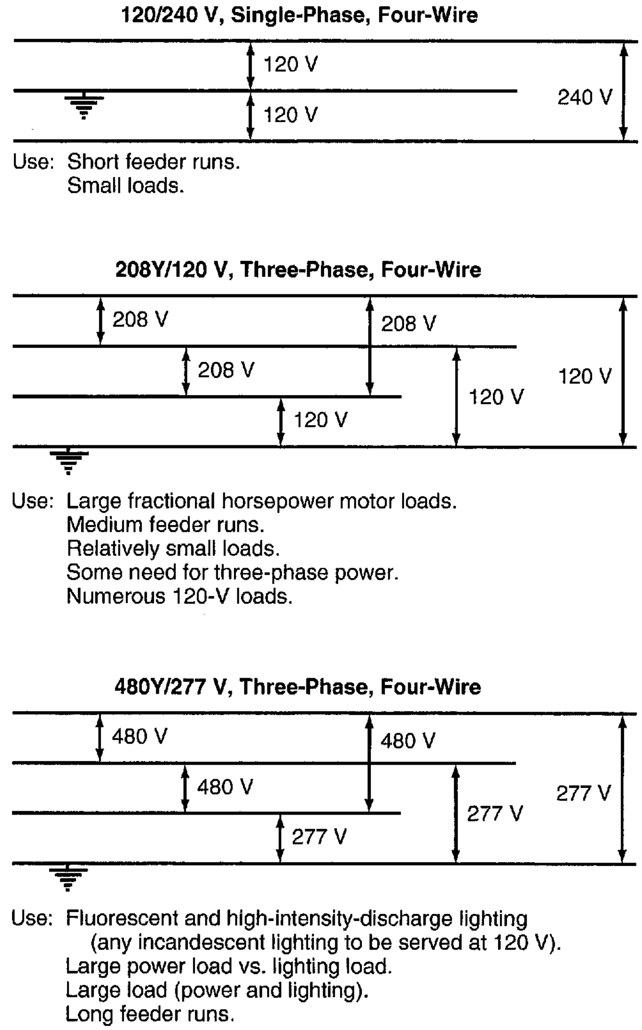


Figure 18—Lighting System Power Supply Considerations

7.10 EMERGENCY LIGHTING

7.10.1 Requirements

In the event of a power failure, operating personnel normally have planned operating or shut-down procedures that must be followed. Should power fail, an emergency lighting system must provide sufficient illumination to enable these procedures to be performed efficiently with a minimum of lost time.

7.10.2 Locations

Emergency lighting shall be provided in control houses of all types, at critical instruments, in large electrical substations, at safety showers and other safety equipment, and in laboratories. In general, emergency lighting should be provided in all locations where the ability to see during an emergency is necessary. Local, city, and state codes may require emergency lighting for special areas where personnel work; these codes should be checked.

7.10.3 Power Supplies

Emergency lighting power supplies may be as follows:

a. Engine-generator sets using either diesel or gas.

b. A turbine-generator using either steam or gas.

c. Station batteries, where available, providing 125 V direct current.

d. Battery-operated self-contained floodlights; the most economical for general lighting.

e. Battery-operated fluorescent fixtures.

In each case, if the primary power supply is lost, automatic operation either energizes the emergency lights or transfers the lighting load from the primary circuit to the emergency power supply.

In unattended areas such as substations, some lights may be put permanently on a DC source, such as the substation batteries, or on another source designed just for emergency use. These lights are controlled by a switch adjacent to the AC light switch. If there is a power failure, the DC lights may be switched on as required. This arrangement limits the drain on the battery to the periods when lighting is needed.

7.11 DESIGN CONSIDERATIONS

7.11.1 Efficiency

Escalation of energy costs requires the consideration of methods for reducing costs while not reducing the effectiveness of the lighting system. These methods can consist of the following:

a. Automatic light switching by photocell or clock-based timers.

b. Use of switches at towers and structures.

c. High-efficiency lamps and ballasts.

d. Optimum use of floodlights.

7.11.2 Maintenance

The effectiveness of a lighting installation is based on and proportional to the adequacy of its maintenance, so maintenance must be considered in the initial design of the processing plant lighting. Accessibility for lamp replacement and reflector cleaning should be considered when determining the location of a luminaire.

7.12 ESTIMATING ELECTRIC POWER REQUIREMENTS

For calculating the estimated watts load for lighting a particular processing plant area, Table 6 provides a W/ft^2/ftc constant for each different type of lamp and luminaire, indoor and outdoor. Using these constants, select the footcandle illuminance desired, multiply this level by the square footage of the area being considered, and then multiply by the constant. This will give the estimated lighting load for the area.

Table 6—Constants for Estimating Lighting Loads

Location	Service Area	Lamp Type	Type of Lighting	W/ft^2/ftc
Indoor	General, all types of areas	Incandescent	General diffuse	0.176
Indoor and outdoor	General, all types of areas	Incandescent	Direct or semidirect	0.143
Indoor	General, all types of areas	Fluorescent	General diffuse	0.077
Indoor	General, all types of areas	Fluorescent	Semidirect	0.067
Indoor and outdoor	General, all types of areas	Fluorescent or mercury	Direct	0.061
Outdoor	Process unit, small parking lot, protective lighting	High-pressure sodium	Direct floodlights	0.167
Outdoor	Loading docks, railroad yard lighting	High-pressure sodium	Direct floodlights	0.077
Outdoor	Large general area	High-pressure sodium	Direct floodlights	0.080

7.13 ILLUMINANCE METERS

Portable, light-sensitive-cell meters are simple and convenient to use, but they are not precision instruments. Under the most favorable conditions, measurements made in the field should not be expected to have an accuracy greater than 5%. All light-sensitive cells have certain inherent characteristics that should be recognized.

Meters without color correction can accurately read only the type of illumination for which they are calibrated (usually light from a filament lamp at a color temperature of 7,700 K). Most meters are made with a color-correcting filter that changes cell response to a reasonably close approximation of the standard eye response curve, which will be sufficiently accurate for ordinary purposes.

Meters are usually calibrated with light perpendicular to the cell surface; light from oblique angles or diffused light will give lower-than-true values unless correction procedures are used. This is the cosine effect or angle-of-incidence effect. The error may be as much as 25% when the light is from side windows only. Most present day meters have a diffusing cover plate or some other device to ensure that light from all directions is properly evaluated. A well-corrected cell has nearly a true cosine response at all angles of incidence. When using an uncorrected cell, direct light from a single source can be measured by holding the cell perpendicular to the light source and multiplying the reading by the cosine of the angle of incidence.

All light-sensitive cells are subject to fatigue. Meter indication drops slowly for several minutes until a constant value is reached. The effect is noticeable at high footcandle values. Prior to measurement, all recorded meters should be given as long an adaptation period as necessary before values are recorded.

SECTION 8—WIRING

8.1 PURPOSE

This section is intended as a guide for providing safe and reliable wiring systems for the petroleum processing industry.

8.2 SCOPE

This section covers the basic requirements for the design and installation of wiring systems using electrical raceways and cable trays. (For general guidelines concerning overhead distribution methods, see 4.11.) Because most electrical installations within a processing plant are in classified locations and are outdoors, this section pertains mainly to wiring practices for those locations.

8.3 GENERAL

8.3.1 All electrical installations should meet or exceed NFPA 70 requirements; ANSI/IEEE C2 requirements; and federal, state, and local requirements.

8.3.2 All raceways and cable trays should be selected and installed in accordance with the area classification as defined in API RP 500 or 505 and with the requirements of NFPA 70 for the area classification.

8.3.3 The wiring methods used in the operating, utility, and other similar areas of petroleum processing plants are:

a. Electrical conductors enclosed in conduit.

b. Cable—Type MC and Type TC as defined by NFPA 70.

8.3.4 Generally, the use of busways is limited to electrical rooms or buildings, substations, repair shops, and other similar locations.

8.3.5 The use of wireways should be restricted to short runs, where many electrical conductors may be collected. Electrical conductors may be collected on motor starter racks and at entrances to relay or control cabinets in electrical and instrument rooms.

8.3.6 The use of electrical metallic tubing and intermediate metal conduit should be restricted to indoor, dry, unclassified locations, such as offices and laboratories, where the installation would not be subject to mechanical damage.

8.3.7 The mechanical continuity of all raceways and the electrical continuity of metal raceways should be maintained throughout the electrical system. An additional grounding conductor installed with each power circuit should be considered.

8.3.8 Spacings between instrumentation circuits and power, lighting, and control circuits in raceways and cable trays should be maintained to prevent introduction of noise into the instrumentation circuits. Unless otherwise noted, spacing should be per API RP 552 or IEEE 518.

8.4 CONDUIT SYSTEMS

8.4.1 General

8.4.1.1 Conduit and associated fittings and boxes should be specifically manufactured for electrical installations.

8.4.1.2 The gasket material for conduit fittings and boxes should be neoprene or a plastic that is resistant to the process solids, liquids, and gases to which it may be exposed.

8.4.1.3 Conduits should be swabbed clean prior to the installation of wire and cable.

8.4.1.4 Commercial pulling compounds compatible with the jacket and insulation of the wire or cable being pulled should be used. Excess pulling compound should be removed before the conduit sealing compound is poured in the seal-fitting around the conductors.

8.4.1.5 Temporary openings in conduits should be plugged or capped to prevent moisture and foreign matter from entering during the construction phase of a job.

8.4.1.6 Conduit fittings and pull, splice, and junction boxes should be sized using dimensions and volume in accordance with NFPA 70.

8.4.2 Rigid Metal Conduit

8.4.2.1 The type of rigid metal conduit to be installed should be selected based on the type of exposure to which the conduit is to be subjected and, when applicable, on past plant experience.

8.4.2.2 The rigid metal conduit system selected should be composed of at least one of the following types:

a. Hot-dipped galvanized steel conduit, conduit elbows, and couplings used with ferrous fittings and enclosures having a protective coating of zinc and an outer finish. Where suitable for the environment, aluminum fittings and enclosures may be substituted for use with the steel conduit. Hot-dipped galvanized steel conduit should conform to ANSI C80.1.

b. Corrosion-resistant aluminum alloy conduit, conduit elbows, couplings, fittings, and enclosures containing not more than 0.4% copper. Aluminum conduit should conform to ANSI C80.5.

8.4.2.3 Rigid metal conduit should be cut square and reamed before threading.

8.4.2.4 A rigid metal conduit bend should be made with a radius of not less than the requirements found in NFPA 70.

The radius must be greater than the minimum bending radius of the cable. A field bend should be made with equipment specifically intended for the purpose and made so that the conduit is not injured and the internal diameter is not effectively reduced.

8.4.2.5 Threaded rigid metal conduit and fittings should be used for outdoor installations and are generally preferred for indoor installations.

8.4.2.6 Threaded conduit joints should be coated with an approved electrically conductive sealant and corrosion inhibitor that is not harmful to the conductor insulation. Aluminum conduit joints should be coated with anti-seizing compounds specifically made for use with aluminum. Threaded joints should be made with at least three fully engaged threads, or five fully engaged threads for explosionproof connections.

8.4.2.7 Running conduit threads are not acceptable. The threads shall have a taper of $^3/_4$-in./ft.

8.4.3 Intermediate Metal Conduit

8.4.3.1 The applicable requirements in 8.4.2 pertaining to rigid metal conduit also apply to intermediate metal conduit.

8.4.3.2 The intermediate metal conduit system should be composed of galvanized steel and should conform to UL 1242.

8.4.4 Rigid Nonmetallic Conduit

8.4.4.1 The type of rigid nonmetallic conduit to be installed should be selected based on cable-pulling resistance, construction techniques, and conduit exposure. Rigid nonmetallic conduit should not be used in Class I, aboveground installations.

8.4.4.2 The rigid nonmetallic conduit system selected should be composed of thermoplastic conduit (Schedule 40 or Schedule 80), conduit elbows, couplings, and similar fittings of polyvinyl chloride or high-density polyethylene. Lightwall plastic conduit should be installed only with a concrete encasement, and it should be used only when the insulation temperature limitation of the cable to be installed does not exceed the temperature limit for which the conduit is labeled. A field bend should be made with an approved bending means, preferably a heat box.

8.4.5 Liquidtight Flexible Metal Conduit

8.4.5.1 Liquidtight flexible metal conduit should have an integral grounding conductor, when available, and an outer liquidtight, nonmetallic, sunlight-resistant jacket. In some cases, an external bonding jumper may be required to meet NFPA 70 requirements.

8.4.5.2 Liquidtight flexible metal conduit should be installed with termination fittings approved for the purpose.

8.4.6 Abovegrade Installations

8.4.6.1 General

Rigid metal conduit, or cables in cable tray are considered the normal wiring methods for all outdoor above-grade installations and for all indoor installations subject to moisture, chemical fluids and solids, and mechanical damage.

In Class I, Division 2 locations and wet locations, conduit connections to equipment subject to vibration or movement should be made with approved liquidtight flexible metal conduit not exceeding 915 mm (36 in.) in length and with an equipment grounding conductor.

Conduit unions should be installed directly adjacent to equipment, such as motors and motor starters, subject to replacement or removal for repairs. This allows malfunctioning motors and motor starters to be removed without disturbing the conduit and supply conductors. Conduit unions provided at explosionproof enclosures should also be explosionproof and should be located between the conduit seal fittings and the enclosures.

Expansion joints should be provided in long conduit runs that are required to compensate for thermal expansion and contraction.

Conduit of $^1/_2$-in. size may be used for control panel, short-run instrumentation, and telephone wiring. Conduit of $^3/_4$-in. size should be the minimum used for lighting, power, and motor-control wiring.

8.4.6.2 Conduit Systems in Wet and Corrosive Areas

Precautions should be taken to prevent galvanic and atmospheric corrosion when metal conduit is installed in areas where continuous moisture may be present. In locations such as cooling towers, where excessive moisture is expected, corrosion-resistant conduit materials (aluminum and plastic-coated, rigid steel conduit) should be considered.

Plastic-coated rigid steel conduit systems should also be considered for use in areas where corrosive vapors or liquids may be prevalent. Galvanized conduit, couplings, and elbows with PVC coating bonded to the metal may be used for such systems. Careful attention should be given to the installation methods to maintain the integrity of the protective coating. Workers should use only roll-type benders and strap wrenches so that the plastic coating does not abrade or tear. All exposed conduit threads at the terminations should be thoroughly coated or covered with plastic sealant.

Epoxy-coated metal fittings and enclosures having cast metal covers, plastic-coated metal fittings, or suitable plastic enclosures should be considered where plastic-coated rigid steel or aluminum conduit systems are to be installed.

8.4.6.3 Conduit Drainage

Provisions for drainage should be installed in the vertical drops of long, outside, above-grade conduit runs at the points at which the conduits enter buildings, switchgear, control panels, lighting panelboards, and other similar enclosures. Long, outside, above-grade conduit runs that are extended below grade should be provided with drain fittings in the vertical drops directly above grade. In areas of high humidity and rapidly changing temperatures, drain requirements should be reviewed and enforced.

8.4.6.4 Conduit Routing

Exposed conduit should be installed parallel with or at right angles to walls, columns, and beams. Adequate clearances from high-temperature surfaces should be established for all conduit runs. Clearances of 152 mm (6 in.) from surfaces 45°C to 65°C (113°F to 149°F); and 305 mm (12 in.) from surfaces greater than 65°C (149°F) are recommended. Where it is necessary to route conduit close to high-temperature surfaces, a high-reflectance thermal barrier should be installed between the conduit and the surface.

Generally, conduits should be routed to allow pull boxes, junction boxes, and fittings to be accessed from platforms or structures without the use of scaffolding.

Wherever possible, conduit routing should be maintained at a specified minimum horizontal distance from high-fire-risk equipment. A distance of 7.6 m (25 ft) is often considered to be adequate. Conduits containing wiring that must be operable during a fire should be fireproofed when the conduits are installed closer than the specified minimum distance from high-fire-risk areas.

Conduits and fittings should be spaced away from continually moist surfaces.

Where portions of conduit runs are exposed to temperatures in excess of the design ambient temperature or where conduits have been fireproofed, additional derating of cable ampacity may be required.

8.4.6.5 Conduit Supports

All rigid metal conduit runs shall be properly fastened and supported at the intervals specified in NFPA 70. Standard conduit clamps and multiple conduit hangers are acceptable supports for most installations. One-hole malleable iron clamps, or other adequate methods, are recommended to support conduits installed on pipeways or structures subject to vibration or movement. Conduit supports should be fabricated from a material or should have a plating from a material that minimizes galvanic action.

Conduits for main feeders and long parallel runs of conduit for any service should not be directly supported from overhead piping. Conduits also should not be directly supported from insulated piping.

Conduit supports should be installed as close as practicable to vertical drops in horizontal conduit runs that support pendant-mounted lighting fixtures. Also, liquidtight flexible metal conduit should be supported only with devices that are used in standard trade practice and that are in strict accordance with the requirements of NFPA 70.

8.4.6.6 Conduit Terminations

Conduits that enter switchgear, motor control centers, and similar installations from below should project at least 25 mm (1 in.) above the finished floor or shall otherwise be terminated to provide for the addition of conduit fittings.

Spare conduits should be located nearest to the access openings to facilitate future cable installations. Spare conduits terminating within buildings and outside enclosures should have a coupling flush with the floor and plugged with a recessed square-head plug.

Spare low-voltage conduits that originate at buildings housing electrical facilities and that are routed underground to structures or columns for future extension overhead should be capped above grade. These conduits should be limited in number at a structure or column and should be spaced at the location to permit the future installation of staggered pulled boxes that only minimally project beyond the structure.

It is preferred that threaded conduit entrances be provided as integral parts of sheet metal enclosures if conduits are to be terminated at these enclosures (both for outdoor enclosures and, if the area is continually damp, indoor enclosures). If threaded entrances have not been provided, field-welded hubs or approved screwtight conduit hub fittings that are watertight and provide a positive ground are acceptable.

Generally, all conduits terminating or originating in Class I locations should be terminated in threaded conduit entrances. When this requirement may be impractical for Class I, Division 2 indoor installations, locknut-bushing and double-locknut terminations with bonding jumpers and proper fittings may be substituted. This means of bonding applies to all intervening raceways, fittings, boxes, and enclosures between the classified location and the point of grounding of the electrical service equipment.

Conduit bushings should be used where conduits at boxes or other enclosures are terminated unless the box or enclosure design provides an equivalent protection.

8.4.6.7 Conduit Seals

Explosionproof seal fittings located in compliance with NFPA 70 should be provided in conduit systems in classified locations to minimize the passage through the conduit of gases, vapors, and flames from one portion of the electrical installation to another.

Seal fittings shall be poured with a compound recommended by the fitting manufacturer. The sealing compound and fiber dam used in the fittings should not be affected by the surrounding atmospheres or liquids and should not have a melting point below 93°C (199°F). Combination explosion-proof drain-seal fittings may be used in classified locations where conduit drainage is required.

All conduits entering process control houses above grade at petroleum processing plants should be provided with explosionproof seal fittings outside the building walls. All conduits originating at manholes within petroleum processing plants should be provided with explosionproof seal fittings at the points of entry to buildings and electrical equipment enclosures.

Conduits that depend on single-seal diaphragms or tubes to prevent process liquids or gases from entering their electrical conduit systems should be provided with seal fittings for blocking passage of the fluids and with a means of venting the fluids to the atmosphere. This includes conduits routed to canned pumps and to devices used for flow, pressure, and analysis measurement.

Underground conduit runs that are completely within a non-classified location, and enter buildings below grade, should be sealed at their terminations with a mastic or expanded-foam compound. The compound should be impervious to liquids that may be in the ground. Ends of short conduit sleeves through building walls, used for the entrance of cables, should be sealed with mastic or expanded-foam compound.

8.4.7 Underground Installations

8.4.7.1 Wiring Methods

Generally, hot-dipped galvanized rigid steel conduit or rigid nonmetallic conduit that is encased in concrete (per NFPA 70, 501–4) should be used for underground conduit systems. Concrete-encased, rigid aluminum conduit should only be installed underground at those locations where prior performance has proven satisfactory and where it conforms with local codes and regulations. (Special requirements for the concrete envelope used with an aluminum conduit are found in 8.4.7.4.)

Rigid metal conduit should be used for underground installations whenever an extra-high-strength installation, such as in an equipment foundation, is required, and it is preferred for underground installations where only one or two relatively short runs of conduit are to be installed.

Subject to local practices and site conditions, the use of underground, galvanized rigid steel conduit without continuous concrete encasement may be considered for certain installations. Normally, the underground conduit should be provided with additional corrosion protection, such as a factory-applied plastic coating, a bitumastic coating, or a tape wrap. On low-investment installations where this protection may be omitted from underground conduit, additional protection should be provided at the grade line where the conduits emerge above grade.

In certain applications, specifically approved direct burial cable may be used.

8.4.7.2 Conduit Size

A minimum size for a conduit for installation underground should be established. A 1-in. minimum size for a conduit is recommended; however, a $^{3}/_{4}$-in. conduit installed underground to a single, isolated device, such as a motor control station or an instrument, is usually acceptable. A minimum size for an underground conduit for main distribution and for bulk cable routing between distribution centers should also be established.

The initial sizing of underground conduits for main distribution feeders should take into consideration the possible replacement of the conductors with a larger size to accommodate a future increase in load.

8.4.7.3 Conduit Bank Configurations

Conduit bank configurations should contain sufficient conduits for the present installation plus spare conduits for future use.

Consideration should be given to conduit bank configurations that will provide effective heat radiation when the duct banks contain power cables for mains and major feeders. The effect of certain duct bank configurations on cable ampacity is reflected in the ampacity tables of NFPA 70. Special calculations are required to determine the ampacity of cables installed in duct bank configurations that are not covered by NFPA 70. Consideration should also be given to conduit bank configurations and entry locations that provide the best racking conditions at manholes.

A specified minimum separation should be established between the outside surfaces of conduits in conduit banks.

8.4.7.4 Concrete Envelope

The concrete envelope surrounding the rigid conduits should have a specified thickness on the top, bottom, and sides. Where reinforced conduit bank sections are required, the thickness of the concrete envelope should be increased accordingly. Where conduits come to grade, the envelope should be extended at least 76 millimeters (3 inches) above grade and should be sloped for water runoff.

Red-pigmented concrete containing at least 5.9 kg/m^3 (10 lb/yd^3 yard) of red iron oxide should be used for the envelope. The concrete should be a 17.25-mPa (2,500-psi) mixture having a coarse aggregate not exceeding 19 mm ($^{3}/_{4}$-in.) in size. The concrete should have a low chloride content when aluminum conduit is encased.

8.4.7.5 Underground Conduit Bank Routing

The location of all underground conduit bank runs should be selected with consideration for future structural installations in the area. Generally, underground conduit runs for main feeders and all conduit bank runs should be routed parallel to plant coordinates and roadways and should not cross congested manufacturing or paved areas. Conduit banks should not be installed under foundations or in areas of excessive vibration.

Sections of steel conduit banks spanning under railroads and roadways, crossing disturbed soil, and crossing open trenches, such as for sewers and water mains, may require steel reinforcement for loading considerations. Where soil conditions are poor, anchors or footings may be required to support and hold a conduit bank run, especially on slopes.

Where possible, underground conduit bank runs should be routed in a straight line between terminations. Unavoidable bends should be made with a large radius and, wherever possible, should be located near a termination point.

The top of the concrete envelope should be located a specified minimum depth below grade, provided the bottom is below the frost line. This depth should be increased under roadways and further increased under the base of the rail at railroads. Underground conduit bank runs installed in systems using manholes should slope toward the manholes for drainage purposes.

To facilitate maintenance, an adequate horizontal and vertical separation should be provided between underground conduits or conduit banks and foreign structures, such as water mains, sewers, and gas lines. Where feasible, underground conduits and conduit banks should be routed above sewer lines and other piping that may contain hydrocarbons. A minimum separation between communication conduits and power conduits should also be established.

Care should be taken to avoid installing conduit and cable banks near or above hot process lines. When this can not be avoided, the heating effect of the source should be considered. This caution should also be considered for direct buried cables.

Rigid nonmetallic conduits should only be extended above grade as stub-ups within metal-enclosed switchgear or similar enclosures in nonclassified locations. Where above-grade extensions are to be rigid metal conduits, underground rigid nonmetallic conduits should be provided with adapters, enabling connection to the metal conduits. Adapters should be installed below grade within the concrete envelope. The adapters should not reduce the size of the conduits.

Note: For considerations on manhole and above-grade pull point locations, and installation practices associated with conduits and conduit bank systems, see 8.9.

8.5 ELECTRICAL METALLIC TUBING

The use of electrical metallic tubing (EMT) should be restricted in accordance with 8.3.6.

8.5.1 Applicable requirements of 8.4 pertaining to conduit systems also apply to electrical metallic tubing.

8.5.2 Compression-type fittings are recommended for use in electrical metallic tubing systems.

8.5.3 Electrical metallic tubing shall be securely supported at least every 3 m (10 ft) and within 920 mm (36 in.) of each outlet box, junction box, cabinet, and fitting.

8.6 BUSWAYS

8.6.1 Busways should not be used in the following locations:

a. In locations subject to physical damage, excessive vibration, or corrosive vapors.
b. In locations subject to dust, unless the busways are totally enclosed.
c. In Class I, Division 1 locations.
d. In Class I, Division 2 locations, unless the busways are enclosed and gasketed.
e. In nonclassified locations above classified locations, unless the busways are totally enclosed.
f. Above highly flammable materials or areas where personnel may congregate, unless the busways are totally enclosed.
g. In outdoor locations or in wet or damp locations, unless the busways are approved for the purpose.

8.6.2 To provide a low-resistance fault return path, busway enclosures should be securely fastened in place and bonded and grounded in conformance with NFPA 70.

8.6.3 Where high ground-fault currents may be available on large-capacity busways of solidly grounded electrical systems, consideration should be given to providing an internal grounding bus or, if it is not provided, to installing an externally mounted continuous grounding conductor bonded to each separate section of the busway enclosure and to ground.

8.6.4 All bolted busway joints should be made up and torqued in strict conformance with the manufacturer's instructions.

8.6.5 Sufficient clearance should be provided around busways to ensure efficient operation and adequate space for installing and maintaining the busway fittings and accessories.

8.6.6 Space heaters should be provided in outdoor busways.

8.7 WIREWAYS

8.7.1 Usage

8.7.1.1 Wireways should only be used where they are exposed and where they will not be subjected to physical damage or excessively corrosive conditions.

8.7.1.2 Industrial-quality wireways may be used in indoor and outdoor locations.

8.7.2 Construction

8.7.2.1 Minimum thickness of wireway covers and bodies should be established for installations in dry locations, in outdoor locations, and in locations where corrosive conditions may exist.

8.7.2.2 Generally, an enameled finish over a corrosion-resistant phosphated surface is acceptable for steel wireway construction. For extremely damp areas, aluminum construction or hot-dip galvanized steel construction with an enameled finish should be used.

8.7.2.3 Weatherproof wireways for outdoor or damp-area use should be provided with bolted covers and gaskets. Wireways for indoor, dry use may have hinged covers.

8.7.2.4 Wireways should not contain knockouts.

8.7.3 Installation

Sections of wireways should be joined together and supported in a manner that ensures continued rigidity and alignment without sacrificing ease of conductor installation or replacement.

8.8 CABLE TRAYS

8.8.1 Usage

8.8.1.1 Cable trays may be installed in accordance with NFPA 70 both indoors and outdoors in classified and unclassified locations. Additional information regarding cable tray applications and installation is available from the Cable Tray Institute.[18]

8.8.1.2 The type of cable to be installed in cable trays should be in conformance with applicable requirements of NFPA 70 and rated for cable tray use. Installations typically use multiconductor type ITC, TC, and MC cable.

8.8.2 Construction

8.8.2.1 Open-ladder or ventilated-trough trays should be used for cable tray systems.

8.8.2.2 Protective removable covers or enclosures should be considered on cable trays where the cables may be subject to damage from objects or liquids.

8.8.2.3 Cable trays, separators, fittings, and mounting hardware should be fabricated of hot-dip galvanized steel or corrosion-resistant alloy aluminum containing not more than 0.4% copper. Where severe corrosion conditions exist, cable tray systems fabricated of flame-retardant nonmetallic materials should be considered.

8.8.2.4 Nuts, bolts, and other small joining hardware for cable tray systems should be corrosion-resistant and should preferably be fabricated of stainless steel.

8.8.3 Routing

8.8.3.1 Cable trays should be supported at all turns and at spacing intervals recommended by the manufacturer.

8.8.3.2 Cable tray exposure and accessibility should be in accordance with NFPA 70.

8.8.4 Cable Arrangement

The arrangement and number of lighting, power, instrumentation and control cables to be installed in cable trays should be in strict accordance with NFPA 70.

8.8.5 Grounding

Cable trays should be bonded and effectively grounded in accordance with NFPA 70 to provide a continuous circuit for fault current. Materials for grounding should be compatible with those used for the tray fabrication.

8.9 MANHOLES AND ABOVE-GRADE PULL POINTS

8.9.1 General

8.9.1.1 Manholes should be installed only in major underground conduit banks where it is necessary to pull or splice cable. The preferred location for these manholes is in unclassified locations.

8.9.1.2 For underground conduits or conduit bank runs, above-grade pull points should be installed where it is necessary to pull or splice cables in any classified location. Above-grade pull points are preferred at locations within process or other operating areas, regardless of the area classification, where it is necessary to pull or splice conductors or cable in underground runs for control, lighting, and power circuits.

8.9.1.3 The location and spacing of manholes and above-grade pull points and the routing of interconnecting underground conduit banks or conduits require careful attention.

8.9.1.4 The basic criterion for achieving the maximum spacing of manholes or above-grade pull points is not to exceed the maximum cable- or wire-pulling tensions and sidewall pressures. These maximum tensions and pressures are contingent on the following:

a. Conductor material.
b. Size of the cable or wire.
c. Number of cables or wires installed in a single conduit.
d. Type of insulation, shielding, and sheath.
e. Size and type of conduit.
f. Number and radius of bends.

[18]Cable Tray Institute, 4101 Lake Boone Trail, Suite 201, Raleigh, North Carolina 27607.

g. Quality of the conduit and duct bank alignment.
h. Lubrication for pulling purposes.

8.9.1.5 Calculations substantiating the proposed underground design for large medium-voltage and high-voltage cable systems should be prepared. The calculations and installation should be in accordance with IEEE 576. The cable manufacturer's recommended cable pulling factors should be included with the calculations.

8.9.1.6 The underground system should not require specially designed equipment or generally unavailable sizes of accessory equipment for pulling or installing cables without damage.

8.9.1.7 For circuit identification, conductors should be permanently tagged at pull points housing multiple circuits.

8.9.2 Manholes

8.9.2.1 Manholes should be installed in or along roadways; installation of manholes in manufacturing areas and in areas having high water tables should be avoided; and manholes should not be installed in classified locations.

8.9.2.2 Manholes should have established minimum inside dimensions.

8.9.2.3 When sizing manholes, consideration should be given to the following factors:

a. Wall space required for making up splices.
b. Linear distance of straight sections for supporting splices and cables.
c. Space required for bending and training cables for offsets and differences in duct elevations, and changes in horizontal direction.
d. Vertical wall space required for racking cable and splices.
e. Working area required for cable pulling and splicing.
f. Number of ducts entering manholes and their elevation.

8.9.2.4 Manholes should have an established, minimum diameter top opening, and the covers and roof construction should be designed for the expected surface loading. Where feasible, the elevation of the top opening should be sufficient to minimize the entry of surface water.

8.9.2.5 Manholes should have provisions for the installation of anticipated future conduits.

8.9.2.6 To facilitate future cable installations, the initial cable routing in ducts and manholes should reflect the need for good access to spare and proposed ducts.

8.9.2.7 Using precast manholes may provide significant cost savings.

8.9.2.8 Manholes should be provided with sumps, preferably located in one corner of the manhole; and the manhole floor should be sloped toward the sump. Manholes should also be provided with pulling irons, cable racks, and ladders.

8.9.3 Above-Grade Pull Points

8.9.3.1 Where practicable, pull points for underground conduit runs should be grouped and installed in protected areas, such as along pipeway columns or similar structural supports. Where pull points are exposed to damage by mobile equipment, they should be protected by concrete-filled steel pipe stanchions set in concrete.

Wire and cable pull points should not be installed at locations used for access, maintenance, and other operations. Pull and junction boxes should be installed only at locations where they will be permanently accessible.

8.9.3.2 Generally, a separate pull box fitting should be provided for each motor supply circuit. Where applicable, the power and associated control leads of a low-voltage motor may use a common box or fitting.

8.9.3.3 Where separate pull boxes are not practicable, multi-purpose pull boxes may be used provided that they have the means for isolating conductors for different services.

8.9.3.4 Pull points should consist of approved sheet metal pull boxes or cast metal boxes and fittings. Nonmetallic boxes, where approved for the purpose, are an acceptable alternative in highly corrosive locations.

Minimum thickness of sheet metal pull boxes should be established. The minimum thickness will depend on whether the boxes are installed in dry locations, outdoor locations, or locations where corrosive conditions exist. The thickness will further depend on the material used for the fabrication (either aluminum or steel) and on the heavier sheet-metal requirement necessary for rigidity in large boxes.

Sheet steel boxes for outdoor locations and continuously damp indoor locations should have a hot-dip galvanized finish.

Gasketed cover joints should be provided; joints that are shielded from rain and water flowing directly across them are preferred.

8.9.3.5 Boxes and fittings used as pull points for underground conduit runs should be supported by steel members set in concrete.

8.10 WIRE AND CABLE

8.10.1 General

8.10.1.1 The selection of the wire and cable to be installed should be based on the following:

a. Conductor material.
b. Voltage level and grounding of the system in which the wire and cable will be applied.
c. Atmospheric conditions, ambient temperature, and type of physical exposure.

d. Availability of the wire and cable.
e. NFPA 70 National Electrical Code requirements.
f. Available types of cable terminators.
g. Method of installation.
h. Quality and degree of importance of service.
i. Classification of the area in which the wire and cable will be installed.
j. Type of wiring method to be used.
k. Possibility of exposure to chemicals that may be harmful to materials used in a particular cable construction.
l. Materials that may require special handling and disposal due to environmental regulations.

8.10.1.2 The construction and testing of rubber- and thermoplastic-insulated wire and cable should comply with NEMA WC 3 and WC 5, respectively.

8.10.1.3 The construction and testing of cross-linked polyethylene-insulated wire and cable should comply with NEMA WC 7 and AEIC CS5.

8.10.1.4 The construction and testing of ethylene-propylene-rubber-insulated wire and cable should comply with NEMA WC 8 and AEIC CS6.

8.10.1.5 The construction and testing of impregnated-paper-insulated, lead-covered cable, solid type, should be in accordance with AEIC CS1.

8.10.1.6 Generally, copper conductor should be used for all low-voltage wiring and is preferred for all medium- and high-voltage wiring. Aluminum conductors may be considered for medium- and high-voltage distribution feeders that are terminated with compression connectors and in enclosures specifically approved for the purpose.

8.10.2 Conductors

8.10.2.1 The minimum conductor size for 120-V, 120/208Y-V, and 120/240-V lighting and receptacle circuits should be 4-mm^2 [No. 12 American Wire Gauge (AWG)] copper.

Note: The metric wire sizes shown in these paragraphs are trade sizes and are not mathematical equivalents to the AWG sizes.

8.10.2.2 The minimum conductor size for single- or multiple-conductor general control wiring should be 2.5-mm^2 (No. 14 AWG) copper. The minimum conductor size in multiconductor cables for low-energy control wiring should be 1.5-mm^2 (No. 16 AWG) stranded copper. Voltage drop and pulling stresses should be considered when selecting the conductor size.

8.10.2.3 For supervisory control wiring, the conductor should be sized to meet the requirements of the connected equipment and in accordance with the manufacturer's recommendations.

8.10.2.4 The minimum conductor size for low-voltage power wiring should be 4-mm^2 (No. 12 AWG) copper.

8.10.2.5 For medium- and high-voltage cable, the minimum conductor size should be 16-mm^2 (No. 6 AWG) copper or 25-mm^2 (No. 4 AWG) aluminum.

8.10.2.6 Depending on the interrupting time of the circuit-protective devices, wire and cable should be capable of withstanding the system available short-circuit current without suffering damage.

8.10.2.7 Stranded conductors are generally used to facilitate installation and resist vibration damage. Solid conductors may be used for wiring items such as general-purpose receptacles and lighting circuits.

8.10.3 Insulation

8.10.3.1 The following types of insulation for low-voltage wire and cable are commonly used in petroleum facilities:

a. Thermoplastic (NFPA 70, Types THW, THWN, and THHN) at 75°C conductor temperature.

Note: Thermoplastic insulation is not recommended for use on DC circuits in wet locations. See NFPA 70, 310-13 for more information.

b. Ethylene-propylene-rubber (NFPA 70, RHW at 75°C conductor temperature and RHW-2 at 90°C conductor temperature).
c. Cross-linked polyethylene (NFPA 70, Type XHHW at 75°C conductor temperature and XHHW-2 at 90°C conductor temperature).

8.10.3.1.1 The commonly used insulation is the thermosetting type on larger conductors (16-mm^2 (No. 6 AWG) copper or 25-mm^2 (No. 4 AWG) aluminum) and above. Thermoplastic type insulation is more commonly used on smaller conductor sizes.

8.10.3.1.2 For single conductors installed in conduit additional insulation or jackets should be considered such as used on RHW and RHW-2.

8.10.3.2 The following types of insulation for medium-voltage wire and cable (5 kV, 15 kV, and 35 kV and 90°C and 105°C conductor temperature) are commonly used in petroleum processing plants:

a. Paper-insulated lead-covered.
b. Ethylene-propylene-rubber (NFPA 70, Type MV-90 or MV-105).
c. Cross-linked polyethylene (NFPA 70, Type MV-90).

Note: The effect of treeing on different types of insulations should be considered.

8.10.4 Shielding

8.10.4.1 Insulation shielding should be considered for all solid-dielectric insulated conductors to be operated above 2,000 V. Shielding should also be considered when in proximity to high-voltage installations.

8.10.4.2 Solid dielectric insulated cable to be operated above 2,000 V requires insulation shielding; however, by exception, nonshielded cable with a rating of 2,001 V–8,000 V may be applied, provided insulation and jacket requirements conform to NFPA 70.

8.10.4.3 There are several, recognized cable shielding methods available in standard cable construction. The available ground fault current and fault clearing time of the system in which cable is to be installed should be taken into consideration when selecting the insulation shielding.

8.10.5 Armor

8.10.5.1 Certain cable constructions employ armor jacketing above the insulation. When applied, several types of construction and materials are available.

8.10.5.2 Cable armor should normally be of a corrosion-resistant metal or hot-dipped galvanized steel.

8.10.6 Jacket

8.10.6.1 Armored cable that will be installed underground or in corrosive or outdoor locations should be provided with jacketing over the armor to protect the armor from damage and deterioration.

8.10.6.2 Armored cable with a rating of 600 V that is installed in wet locations should have an overall jacket under the armor, unless the armor is impervious to liquids.

8.10.6.3 Armored cable with a rating above 600 V should have an overall jacket under the armor, unless the armor is impervious to liquids.

8.10.6.4 Cables rated at 5,001 V–8,000 V that do not have insulation shielding, metallic sheaths, or armor should have single conductors with jackets resistant to ozone, electric discharge, and surface tracking and shall conform to NFPA 70. These jackets for multiconductor cables should be common coverings over the assembled single-conductor cables.

8.10.6.5 Outer jackets on cables that are exposed outdoors must be sunlight-resistant. The selection between a thermosetting jacket and a thermoplastic jacket should be based on the environment in which the cable will be installed.

8.10.7 Installation Requirements

8.10.7.1 General

8.10.7.1.1 All wire and cable installations shall be in accordance with the requirements of NFPA 70 and local codes and regulations. Details on proper installation, splicing, and testing are provided in IEEE 576.

8.10.7.1.2 The radii of cable bends should equal or exceed the minimum values specified by the manufacturer. For rubber, thermoplastic, cross-linked polyethylene, and ethylene-propylene-rubber insulated cable, the minimum bending radii specified in NEMA WC 3, WC 5, WC 7, and WC 8 and in NFPA 70 may be used when the manufacturer's data is not available.

8.10.7.1.3 Wire and cable pulling tensions and sidewall pressures should not exceed the maximum values specified by the manufacturer. The manufacturer's limitations on pulling cable at low ambient temperatures should also be enforced.

8.10.7.1.4 To obtain satisfactory medium- and high-voltage cable splices and terminations, the following prerequisites should be met:

a. All work should be done by qualified personnel.
b. Only the highest quality materials should be used.
c. The manufacturer's instructions should be followed.
d. Provisions should be taken to prevent the intrusion of moisture.
e. Cleanliness of tools, materials, work space, and splicer's clothing should be maintained.
f. Splices and terminations should be made only at ambient temperatures above the minimum temperature recommended by the manufacturer for handling the necessary materials.
g. All permanent splices and terminations should be made with compression connectors.

8.10.7.1.5 Taps and splices of low-voltage wire and cable should conform with the following specific requirements:

a. Wire connectors consisting of insulator caps and springs or set-screw inserts may be used only for taps and splices in lighting and convenience-receptacle branch-circuit wiring. These connectors should be taped to prevent the entry of moisture.
b. Pigtail-type taps and splices should be made only above grade in appropriate boxes or conduit fittings that are accessible.
c. Where practical, power conductors should be installed without splices between terminating points. Where splices are unavoidable, straight (in-line) splices using two-way compression connectors are preferred; however, where enclosure size limitations prohibit abovegrade straight splices, splices using bolted connectors are usually acceptable.

d. Splices of power conductors should be made only in an approved manner.

e. Where more than two control conductors are to be joined, the connection should normally be made only at terminal boards that are preferably located on equipment or panels. All connections should be accessible and should be identified so that individual conductors may be checked.

8.10.7.1.6 Where conductors for control wiring and instrumentation power supply wiring are to be connected to binding-screw terminal boards, the conductors should be provided with pressure terminals.

8.10.7.1.7 Circuit separation for different circuits and classes of service should conform with the following specific requirements:

a. Where single-conductor wiring is used for supply and control of a low-voltage motor, all conductors may be installed in the same conduit, provided the supply conductors are 25 mm^2 (No. 4 AWG) or smaller. Unless special multiple-conductor cable is used, separate conduits should be used for the supply and control conductors when the supply conductors are larger than 25 mm^2.

b. Single-conductor wiring for more than one motor should not be installed in a common raceway. Separate multiple-conductor cables for each motor may be installed in a common raceway, subject to engineering approval.

c. For each motor operating above 600 V, the motor supply and control conductors shall be installed in separate raceways.

d. Conductors for one or more lighting branch circuits may be run in common conduit or tubing.

e. Power system control, metering, instrument, alarm, and relaying circuits associated with a particular piece of electrical equipment, such as a transformer or motor, may be routed in a common raceway or cable, provided that all of the conductors have an insulation voltage rating equal to the highest system voltage level, and that noise interference between circuits will not be a problem.

f. Generally, substation control circuits associated with a single power source may be routed in a common raceway or cable. Station control circuits associated with primary-selective, secondary-selective, or spot-network substations that have alternate power sources should be separated according to their related power source. It is also preferable that differential relay circuits be kept separate from the other circuits.

g. Normally, telephone circuits should be routed in separate raceways. Subject to engineering approval, telephone and signal circuits operating below 65 V may be routed in the same raceway or cable support.

h. Special caution should be taken to ensure that the operating temperature of the cables, terminating devices, and terminations be consistent.

8.10.7.2 Wire and Cable in Raceway Systems

In raceway systems, the following requirements for wire and cable should be fulfilled:

a. The maximum allowable percentage that conduit and tubing may be filled by wire and cable shall be as specified in NFPA 70.

b. Medium- and high-voltage cables in manholes, cableways, pull boxes, trays, and splice boxes should be flameproofed if there is a possibility that a cable failure may damage other cables.

c. Cables and splices in manholes, pull boxes, and splice boxes should be arranged and supported to allow visual inspection, and to prevent excessive tension and pressure on the cable sheath and insulation.

d. The separation of phase conductors in individual ducts and conduits should be avoided.

e. Control cable in manholes should be flameproofed, and precautions should be taken to minimize inductive voltage effects.

8.10.7.3 Metal-Clad and Metal-Sheathed Cable Systems

Specific requirements for the installation of approved metal-clad and metal-sheathed cables above grade are as follows:

a. Metal-clad cables specifically approved as type HL may be installed in Class I, Division 1 as well as Division 2 locations and nonclassified areas. Cables must be terminated with fittings (terminations or glands) approved for the area classification.

b. Cables rated above 600 V should be installed in cable trays.

c. When planning cable routes, consideration should be given to the possibility of interference with piping and other equipment, and to the possibility of cable damage that may occur through normal facility operations such as traffic, maintenance, and release of corrosive materials.

d. Cables should be run between terminating points in one continuous length wherever practicable. Where splices cannot be avoided, they should be enclosed in accessible splice boxes or fittings.

e. A minimum separation between power cables and communication and instrumentation cables should be established and maintained for all cable runs (see 8.3.8).

f. A minimum spacing should be maintained between cables and high-temperature surfaces. Where necessary to route cables close to such surfaces, a high-reflectance thermal barrier should be installed between the cables and the surface.

g. Where practicable, cables should enter outdoor boxes and equipment enclosures from the bottom or the sides to prevent the entrance of water into the enclosures. Cables entering outdoor boxes or enclosures from the top should be provided with terminators specifically designed to prevent the entrance of water.

h. Subject to engineering approval, cables may be installed in Class I, Division 2 locations.

8.11 FIREPROOFING

8.11.1 General

8.11.1.1 When fireproofing of critical equipment, and associated wiring systems, is required (such as emergency block valves), special care should be taken in the selection of suitable materials for the application. In general, the installation should provide for the operation of critical equipment for 15 minutes exposed to a 1,100°C (2,000°F) fire.

8.11.1.2 For motor operators and junction boxes the following methods are commonly used:

a. Intumescent epoxy coating (preferred method).
b. Fireproofed boxes.
c. Fire blankets.

8.11.1.3 The following wiring methods are commonly used:

a. Fire-rated cable assemblies (preferred method).
b. Insulation over conduit systems.
c. Fire blankets over conduit systems.

SECTION 9—POWER SYSTEMS FOR INSTRUMENTATION AND PROCESS CONTROL

9.1 PURPOSE

This section reviews requirements for the continuous supply of electric power to a plant's instrumentation and process control systems. The requirements are essential for the safe operation of the facility and for the manufacture of ongrade products. Instrumentation is a rapidly evolving field, and the power system supporting the instrumentation must provide electric power of sufficient quantity, quality, and reliability to prevent situations which might lead to unsafe operating conditions, equipment failure, or the production of offgrade products. To properly design and select a satisfactory power system, it is essential to understand the importance of, the function of, and the relationship between all of the components which are part of the facility's control, shutdown, and monitoring systems.

9.2 SCOPE

This section covers the basic requirements for designing and selecting power systems for instrumentation and process control facilities. It is intended to establish the following:

a. Basic criteria necessary for designing and selecting a power system.
b. Recommended power systems for typical control systems.

9.3 BASIC DESIGN CRITERIA

To design and properly select a satisfactory power system, it will be necessary to define what criteria must be addressed in the selection and design of the power system. Typical criteria to be addressed are as follows:

a. Momentary interruptions in the supply to the plant electrical system.
b. Extended outages of the plant electrical system.
c. Transient conditions, such as harmonics, voltage regulation, and frequency stability, that are incompatible with the power quality requirements of the instrumentation and process control system.
d. Internal requirements of the instrumentation or process control systems.
e. The need for isolation or removal of major electrical components for maintenance without unacceptable load interruptions.
f. The loss of heating, ventilation, air conditioning, and pressurization.
g. Emergency lighting.
h. Interaction between the power system and the instrument air supply.
i. Methods of grounding and/or isolation of systems with separate remote (isolated) power supplies that will have interconnected signal wiring.

9.4 DESIGN CONSIDERATIONS

Each type of instrumentation and control system has basic requirements in terms of the following that must be considered when designing the overall power system.

9.4.1 Load Characteristics

9.4.1.1 General

The process control power system serves all of the control and measuring devices in addition to the interlock, alarm, and safety shutdown systems. These can be grouped into control and noncontrol circuits or loops. Typically, the control loops consist of the flow, pressure, temperature, and level controllers as well as the associated control valve, interlock, and safety shutdown systems. The noncontrol loops contain the indicating and recording instruments, annunciator and alarm panels, and gas stream analyzers. Careful consideration must be given to the type of control and measuring device, and the service of each control and measuring device, so that its power supply requirement is met. The typical load characteristics of the three types of control systems are described in 9.4.1.2 through 9.4.1.4.

9.4.1.2 Pneumatic Analog Control Systems

In a process plant that largely employs a pneumatic analog control system for process control, indicating, and recording instruments can usually be supplied from a relatively simple power supply and distribution system with a reliability level consistent with the required control functions. For the most part, instruments requiring the electric power supply will be limited to multipoint temperature indicators and recorders, solenoid valves, temperature and pressure alarm and trip circuits, and annunciator panels. Although a stabilized voltage source is required for some instruments, the power supply for the major part of the system will not require closely regulated voltage, frequency, and harmonic characteristics. Particular applications like flame detectors and fuel solenoids may require continuous electric (uninterruptible) power.

9.4.1.3 Electronic Analog Control Systems

A process plant employing an electronic analog control system will require a highly reliable power supply whose permissible voltage, frequency regulation, and, in some cases, harmonic content will be dictated by the particular instruments used. This supply capacity will be substantially larger than the supply for the pneumatic system.

Because control systems must be kept in operation during process plant emergencies, the power supply for the electronic analog control system will normally require some form of backup, such as standby generators or batteries with inverters (if AC powered), or batteries (if the systems require DC only). The backup maintains a power supply to critical instruments and control circuits during total power failures which affect the normal electric power supply.

9.4.1.4 Digital Systems

Digital process control computers and microprocessor-based instrumentation are now widely used in direct control, supervisory, and monitoring functions. These systems can require power supply capacities ranging from 10 kVA to as much as 300 kVA in large plants. The electric power supply usually must meet closely regulated voltage, frequency, and harmonics limits for the connected load, and the purchased utility or plant generation supply usually requires some conditioning to meet the requirements of the load.

Digital control system power supplies are frequently provided with two isolated, redundant, power input ports. The power supply sources should be separated as much as practical from the facility main power source(s) to obtain maximum reliability.

Uninterrupted power may be required to provide continuous control and monitoring during a power failure. The decision to install an Uninterruptible Power Supply (UPS) should be based on the effects to the facility resulting from a power failure. Each manufacturer of the control and monitoring systems will provide detailed power tolerances and requirements for this equipment. Careful consideration of these requirements is essential to providing a proper electric power supply and distribution system.

9.4.2 Reliability Grading

9.4.2.1 General

Reliability grading can be keyed to the ability to operate during power supply interruptions. Economic design requires that control loops be graded both with respect to reliability requirements under normal and emergency conditions and with respect to permissible voltage and frequency regulation and harmonic content limits.

Permissible interruption times are used to illustrate critical, semicritical, and noncritical loads, the three categories of loads requiring different degrees of power supply and distribution system reliability. Permissible interruption times, however, will vary according to control equipment characteristics. For instance, it is possible that use of a delayed dropout provision in a control loop may shift the control loop from a critical to a semicritical category. The three categories of loads are described in 9.4.2.2 through 9.4.2.4.

9.4.2.2 Critical

A critical load is any load which cannot be interrupted even momentarily or has a permissible interrupting time that may be limited to a value such as 4 milliseconds (ms). To maintain a critical load, a power supply independent of normal plant power supply interruptions is required. AC loads are supplied typically from a rectifier-battery-inverter (UPS) combination while DC loads are supplied from a battery-supplied bus. In some cases, rotary no-break generators are used.

Transfer from normal to standby supply will require solid-state switches which have essentially zero switching time. Typical examples are flame scanners in boiler safety systems; fuel system solenoid shutdown valves; and centrifugal compressor shutdown circuits, if they are designed to shut down when de-energized.

9.4.2.3 Semicritical

A semicritical load is any load that must operate during emergency conditions but can operate satisfactorily through short interruptions. For a semicritical load, an independent power supply available during power failures is required.

A semicritical load may be broken down into a load for which interruptions up to 0.2 sec are permitted and a load for which interruptions as long as 20 sec may be permitted. The typical control loop is in the 0.2-sec group; the noncontrol loop (temperature, indicator, and annunciator systems) is in the 20-sec group. Faster transfer from normal to standby supply, using electromechanical (contactor) switches with approximately a 100-ms switching time, is required for the 0.2-sec group; normal plant power supply delayed transfer until the start-up of the standby generators suffices for the 20-sec group.

9.4.2.4 Noncritical

A noncritical load is any load that may be dropped without affecting safe and orderly emergency operations. The power system during normal operating conditions must have a high degree of reliability. Tank gauging systems and quality analyzers are examples.

9.4.3 Quality Grading

Quality grading groups loads according to the stringency of the control devices' requirements, ensuring that realistic and not excessive limits are placed on power supply fluctuations. Exact limits on supply fluctuations must be coordinated with each equipment supplier. Typical high quality limits are as follows:

a. For AC loads:
   1. Voltage regulation: ± 2%.
   2. Frequency regulation: ± 1 Hz for 50/60 Hz systems.
   3. Total harmonic distortion: 3% maximum.

b. For DC loads:
   1. Voltage regulation: ± 1%.
   2. Voltage ripple: $^1/_2$% maximum.

9.5 ELECTRIC POWER SYSTEMS

9.5.1 General

The acceptability of the normal process plant power supply as the instrument supply will be determined by the reliability and quality requirements of the loads served. An independent power supply must be provided when the normal supply does not meet the load requirements. The length of time the particular load must function during abnormal or emergency electric power supply conditions must also be considered. Loads can be divided into categories that will determine the required capacity of the standby power supply. A $^1/_4$-hr supply period may be adequate for some loads; an 8-hr supply period may be adequate for others; and still others may require longer periods. Capacities for periods of 2 min to 3 hr are common for rectifier-battery-inverter (UPS) systems. When longer periods are required, or load requirements exceed 20 kVA, standby generators may be more economical.

9.5.2 Instrumentation and Control System Requirements

9.5.2.1 Pneumatic Analog Control Systems

Generally, the pneumatic analog control system can be satisfactorily supplied from the normal plant power system, assuming that this system has normal and alternate supplies that are reasonably independent of each other. This independence should be maintained in providing normal and alternate supplies to the main distribution bus of the process control power system. Where the plant has only a simple radial electrical distribution system, some provision for an alternate supply to the process control system main bus should be made.

In all cases, particular attention must be paid to the requirements of critical devices and circuits; examples of these critical devices and circuits are boiler plant control, safety devices, and associated circuits; compressor control and shutdown circuits; and critical motor-operated valves which must function after a total power failure. Special provisions, such as standby generator sets or rectifier-battery-inverter (UPS) combinations, may be required.

9.5.2.2 Electronic Analog and Digital Control Systems

The electronic analog control and digital computer monitoring and control systems impose more stringent demands on the power supply. Independent normal and alternate supplies to main AC and DC distribution buses are required. In most plants, it will be necessary to provide an independent generation supply either in the form of a generator or a rectifier-battery-inverter (UPS) combination. Where quality requirements are necessary, the independent generation supply serves as the normal supply. Particular attention must be paid to determining to what extent the supply from the plant power system can serve as the alternate source. By applying the reliability and quality grading characteristics, the capacity and degree of redundancy that must be provided in independent generation can be held to an economic minimum. Important factors in supply sizing are the amount of in-rush current expected and the supply in-rush response characteristic. The memory and data preservation requirements, self-protection features, and limits of process computers also have a major effect on power supply requirements.

9.5.3 Typical Power Supplies

Special equipment design and application problems are encountered where automatic transfer or parallel operation of power supplies is used. There are many combinations of rotating and static generation power supplies and plant power supplies that may be used. The operating conditions which must be met and the unique characteristics of the combination which is selected should be understood thoroughly before a final design is established.

Typical one-line diagrams of power supplies are illustrated in Figures 19, 20, and 21. Each facility will require a unique design; however, the concepts noted in the following sections can be applied to most supplies.

9.5.3.1 Rectifier-Battery-Inverter System [such as an Uninterruptible Power Supply (UPS)]

Many features are available with the rectifier-battery-inverter system. When specifying the system, the following features should be considered:

a. The type of battery system, considering the ability to maintain and test the condition of the batteries.
b. The ventilation of the batteries, if required.
c. The ampere-hour (A/hr) capacity of the battery bank.
d. The seismic requirements for the battery rack.
e. Rectifier input voltage, phase, and frequency.
f. The required inverter output voltage, phase, and frequency.
g. The inverter capacity, considering the largest load to be started, especially if it has high in-rush currents.
h. The ambient temperature and humidity range in which the system will operate. Will the loss of heating, ventilation, and air conditioning be detrimental to the system?
i. The space required to house the complete rectifier-battery-inverter system.

Some questions to consider when specifying the rectifier-battery-inverter system are as follows:

a. Where will the alternate supply originate? It should be a very reliable circuit(s) from the plant power system or another standby power supply.
b. Will the inverter automatically return to the primary source after power is restored?

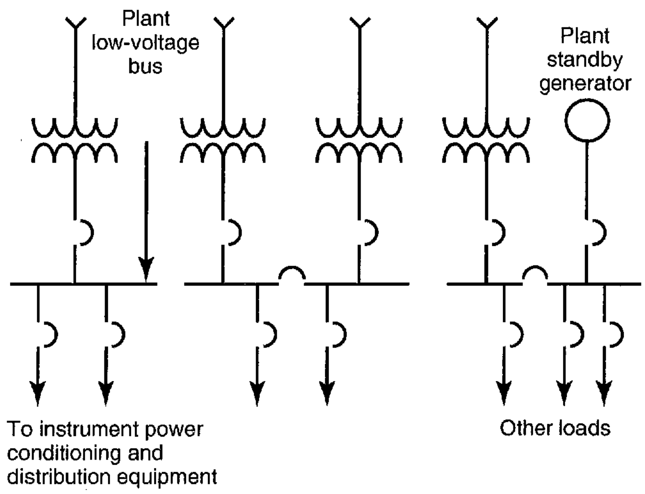


Figure 19—Typical Instrument Power Supplies: Standby Generator Not Required for Instrument Power

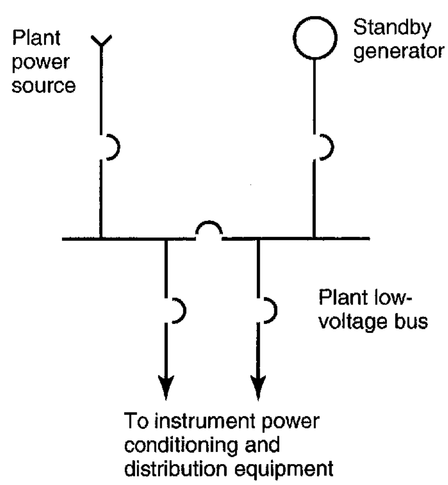


Figure 20—Typical Instrument Power Supply: Standby Generator Required for Instrument Power

c. Is a manual make-before-break output maintenance switch required?
d. Will some form of additional power conditioning, such as a low-noise transformer, be required? If it is required, the system vendor should be advised of the requirement.
e. What form of load overcurrent protection will be used? There must be coordination with the inverter output breaker or fuses.
f. Has the vendor been advised of the load supplied from the system? When selecting the system, the vendor must be advised of the exact type of load that would be supplied from the system.
g. Will maintenance bypass switches be required to facilitate maintenance and load testing of the rectifier, battery, inverter system?

9.5.3.2 Generators

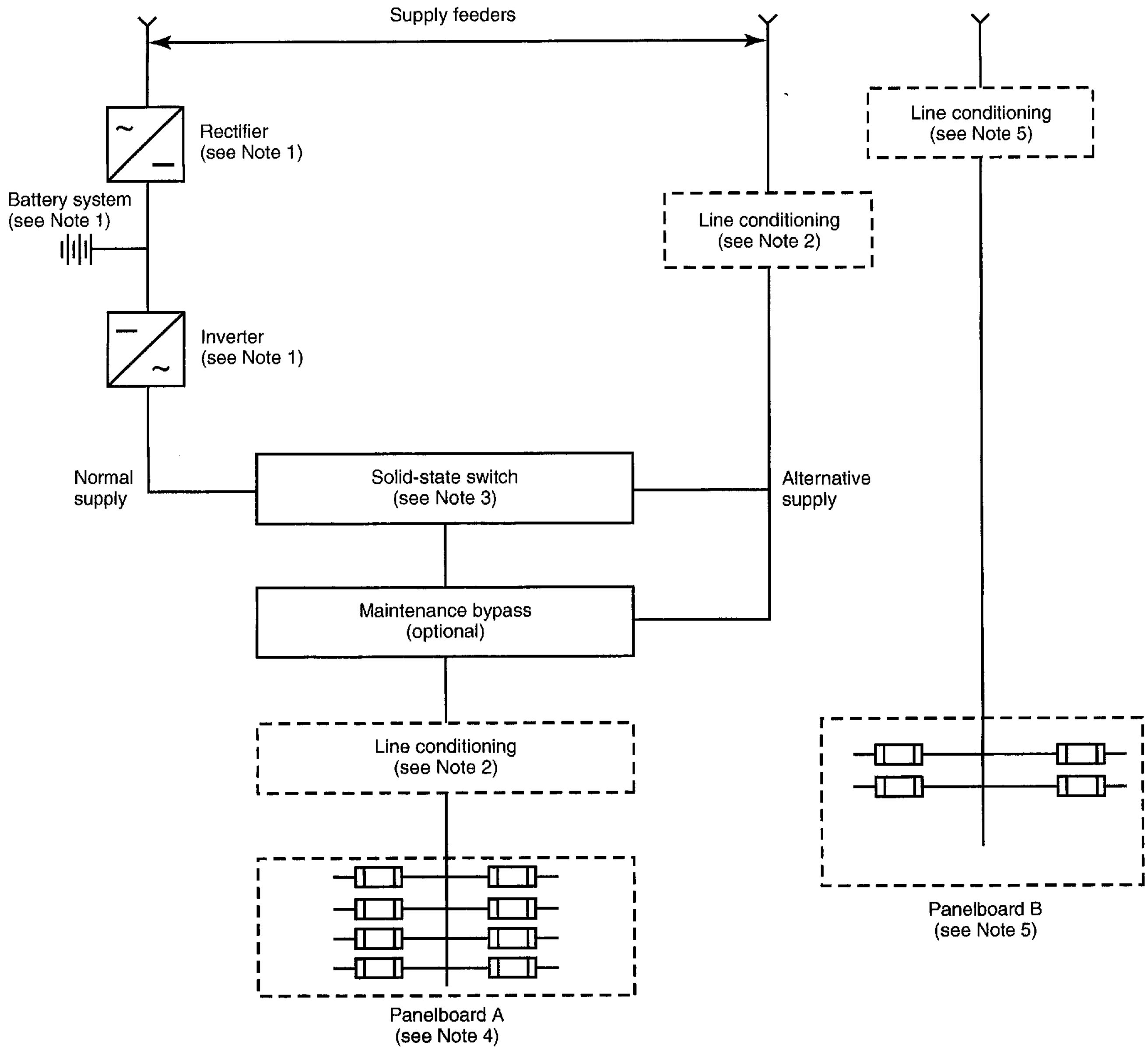
As with the features and questions to consider for the rectifier-battery-inverter system, there are many concepts to consider when designing a power system using in-plant generation. Some of the more prominent considerations are as follows:

a. Type of prime mover for the generator (gas turbine, steam turbine, electric motor; or gas or diesel engine).
b. Size of the generator, taking into account the largest load to be started especially if high inrush currents are involved.
c. Recommendations of IEEE Std 446 concerning emergency and standby power systems.
d. Recommendations of NFPA 110 concerning emergency and standby power systems.
e. Operation of the generator. Will the generator run continuously or will there be provisions for manual or automatic start? If the generator is to be operated in standby mode, then a regular testing program must be developed.
f. Paralleling of the equipment to operate in synchronism with another generator or with the normal plant power system.
g. Study of the governor characteristics for steam turbine prime movers.
h. Location of the generator, ensuring that safe operation can occur during hazardous conditions.
i. Need for either electronic or electromechanical switching to connect to the normal electrical supply. This is determined by the reliability grading.
j. Need for some form of load power conditioning.
k. Amount of flywheel effect required in a rotating set to maintain voltage and frequency during transfer.

9.6 DISTRIBUTION SYSTEM

9.6.1 General

The design of and investment in suitable power supply sources can be nullified by the failure to specify the details of the distribution system and its equipment. All equipment and circuits from the main distribution buses to the individual instrument's power supply circuit must be considered in the distribution system design and installation. The distribution system must be compatible with the reliability and quality requirements of the loads served and must maintain the levels that have been provided in the power supply. The basic system design should, by means of load division and circuit and equipment redundancy, ensure that any short circuit or overload trip affects an acceptable minimum number of instrument loads.



Notes:
1. A rotary-uninterruptible or normally operating generator(s) may be used in lieu of the rectifier-battery-inverter combination.
2. Some form of line conditioning, such as low-noise, isolation, or a constant-voltage transformer, may be required for some loads.
3. If loads can tolerate a momentary loss of supply, an electromechanical switch may be used for supply switching.
4. Fuses or circuit breakers should be selected to coordinate with upstream devices.
5. Panelboard "B" may be required to provide separate power inputs to DCS power supplies with separate input ports. The line conditioner may be replaced with a UPS/battery backup system if reliability requirements are justified.

Figure 21—Typical Instrument Power Supply with Supply Switching

9.6.2 Design Requirements

Requirements for the following components must be specified in the distribution system design:

a. Feeders from the supply sources to the main instrument power panelboard.
b. Feeders to main load panelboards, branch panelboards, and instrument and control panels.
c. Panelboards, including circuit breakers and fuses. The fuses may be required to coordinate with the upstream devices (see Figure 21). To avoid transfer-to-bypass and possible voltage depression during faults, Classes CC or J fuses, with as low an ampere rating as possible to serve the load, are recommended for the distribution panel branch circuit overcurrent protection.

Note: This will allow the UPS source to clear the fault rather than transferring to bypass to clear the fault.

d. Transfer switches.

9.6.3 Criteria for System Design

The following are some criteria for system design:

a. Normal and alternate feeders to distribution panelboards should be provided as required by reliability requirements.
b. Particular attention should be given to distribution panelboard load assignments. The loads on each process unit or major process section should be split so that a distribution bus failure cannot affect all of the control loops.
c. Main and important branch panelboards should have at least two separated or isolated bus sections, or separate panelboards should be used.
d. Circuit protection and disconnect means for each control loop supply should be provided.
e. All overcurrent and short-circuit protective devices should be coordinated so that the device closest to fault opens first.
f. The system should be able to transfer between sources without loss of supply.
g. Individual pieces of equipment should be redundant to lessen the probability of a total system failure.

9.7 WIRING METHODS

9.7.1 General

The actual circuit requirements for individual instruments will be determined by the type of instrument being served, and are a part of the instrument system design.

9.7.2 Power Wiring

Power supply and distribution system wiring for instrument and control system power shall comply with NFPA 70. Section 8 of this recommended practice should also be consulted for the various types of applicable power wiring used in petroleum processing plants.

9.7.3 Special Considerations

Wiring methods which are acceptable for power wiring may be used. Attention must be paid to special requirements which are a result of the circuit function. For instance, special attention should be paid to the routing of safety control and shutdown circuits. These circuits should be segregated from normal circuit routes to prevent a single accident from disabling both circuits. Fireproofing of exposed components of these circuits and use of wire insulation rated for high temperature may be necessary to preserve the circuit integrity for a specified time period during a fire. To facilitate the fast clearing of branch circuit faults by current-limiting fuses, the branch circuit wiring may need to be oversized to reduce the total circuit resistance (and subsequently increase the fault current available to make the fuses operate in their current-limiting region).

9.8 SYSTEM AND EQUIPMENT GROUNDING

Normal system and equipment grounding must be supplemented and modified by any special requirements imposed by the instrument and computer loads. Manufacturers of distributed control system computers and programmable controllers supply facilities' requirement manuals which may specify any special requirements for their equipment. Electrical safety is essential in the power system grounding design; therefore, the requirements of NFPA 70 for grounding must be satisfied. (Section 5 provides information on specific grounding practices in process plants.) The grounding of a power system for a distributed control system requires careful planning from the start of a project. A detailed grounding diagram should be developed for each project and reviewed with all of the equipment vendors.

9.9 CONSIDERATIONS FOR CLASSIFIED LOCATIONS

Equipment application and wiring methods for the power supply source and distribution system must comply with NFPA 70 requirements applicable to the particular classified location. Generally, this equipment and wiring will operate at energy levels which can cause ignition.

SECTION 10—SPECIAL EQUIPMENT

10.1 PURPOSE

This section covers special electrical equipment and installations encountered in a processing plant that are not covered in other sections of this publication.

10.2 SCOPE

This section is limited to a brief description of such installations. The need for or the extent of such installations is not defined in this section.

10.3 GENERAL

Many systems and pieces of equipment in a processing plant need electrical service that is somewhat different or has requirements other than those generally provided for by the usual power and lighting service. These include communication and signaling systems, Supervisory Control And Data Acquisition (SCADA) Systems, special lighting systems, and heat tracing. Consideration must be given to the special requirements of this equipment.

10.4 COMMUNICATION SYSTEMS

10.4.1 Radio Systems

Fixed radio equipment is used extensively in processing plants for communication between other fixed equipment, portable equipment, and mobile equipment. The fixed equipment is typically located in operation or maintenance centers and is used for dispatching, security, and process-unit communication.

Portable radio equipment is available in two forms, the hand-held, two-way communication device and the belt-mounted, call-pager system. The call-pager unit alerts its carrier, who, in turn, uses a telephone to communicate with the caller. Some call-pager units allow a more detailed messaging capability. Portable radio equipment that will be used in classified locations must be approved for use in such locations.

Mobile radio equipment is provided in vehicles used for deliveries, maintenance, security, and fire protection, and is also provided in vehicles used by facility management.

10.4.2 Telephone Systems

Most processing plants are served by the local telephone utility, which may furnish and install all wire, cable, terminal blocks, instruments, switchboards, batteries, battery chargers, and other miscellaneous equipment. It is the responsibility of the processing plant to furnish and install all conduit and junction boxes for the system. In recent years, many facilities have elected to furnish or lease their own instruments, switchboards, and connecting equipment.

Telephone instruments used in Division 1 locations must be of explosionproof construction. In Division 2 locations, standard telephones which have been tested and approved for Division 2 locations or telephones of explosionproof construction may be used. In nonclassified locations, instruments of standard construction may be used.

Telephone switching equipment is usually located in a telephone room in an office or other service building outside the process area. Distribution of telephone circuits within buildings is usually accomplished with multiconductor cables in conduit or underfloor ducts; or with plastic-sheathed cables in ceiling spaces and walls. Outdoors, the telephone distribution system may consist of multiconductor cable in conduit or underground ducts, direct burial cable, or aerial cable attached to poles carrying power and lighting feeders. Wiring methods must be suitable for the electrical area classification. Corrosion protection requirements, and reliability requirements should also be considered in selecting wiring methods.

Sound-powered telephones are used on operating units and in other classified areas. The instruments are voice-operated and require no electric power to operate. Associated with these sound-powered telephones is usually some type of signaling system which requires electric power. The voice and signaling system should not be installed in the same raceway unless the signaling circuit is intrinsically safe.

Bells, horns, howlers, and relays associated with communication equipment must be suitable for the electrical area classification in which they are installed.

10.4.3 Public Address Systems

Public address systems are commonly used for public address purposes as well as for paging plant personnel in process units. In some cases, they are used for addressing and paging entire plants. They are often used in conjunction with sirens or howlers to convey emergency warning information to plant personnel. Caution should be exercised in applying this type of equipment in classified areas (see NFPA 70).

10.5 SUPERVISORY CONTROL AND DATA ACQUISITION EQUIPMENT (SCADA)

Supervisory control and data acquisition (SCADA) equipment may be used for monitoring and controlling plant utility systems (e.g., electrical, cooling water, and steam systems). The user interface for this equipment is usually located in an operations control center. Through this equipment, circuit breaker positions (open or closed), pump status (running or not running), system parameters (e.g., flow, pressure, and load), and substation building pressurization systems can be monitored and controlled remotely.

10.6 CLOSED-CIRCUIT TELEVISION (CCTV)

Applications for closed-circuit television are numerous. Monitoring of process control boards and metering, as well as monitoring flare, boiler, and furnace flame patterns, is common. The largest application of television equipment in process facilities, however, is for security. In this application, it is used for monitoring operations at personnel, vehicle, and railroad gates, warehouses and storage areas. Video recording equipment is often used in conjunction with the CCTV system when historical records are required.

10.7 OBSTRUCTION AND WARNING LIGHTING

For tall structures and stacks, special obstruction or warning lights may be required by the Federal Aviation Administration or other authority having jurisdiction.

10.8 NAVIGATION LIGHTING

Piers and similar structures extending into navigable waters must be furnished with obstruction lighting as required by regulations of the U.S. Coast Guard or other authority having jurisdiction.

10.9 FIRE ALARM SYSTEMS

A fire alarm system is normally maintained within a processing plant. Some systems are elaborate while others are relatively simple. API RP 2001 discusses fire alarm requirements, and the NFPA *Fire Protection Handbook* discusses alarm facilities.

10.10 ELECTRIC HEAT TRACING

Electric-heat tracing systems are used for maintaining process piping or vessel temperatures and for freeze prevention. Electric heat tracing is used in lieu of steam-heat tracing where it is determined to be more economical or where precise temperature control is required.

Several types of electric heat tracing systems are available. These include electrical-resistance heat tracing as well as impedance, induction, and skin effect systems. Electrical-resistance heat tracing is typically used for applications on process units. Impedance, induction, or skin-effect electric heat tracing is typically applied on long pipelines to offsite locations or between facilities. IEEE Std 515 provides design guidance for electrical-resistance heat tracing systems. IEEE 844 provides similar guidance for impedance, induction, and skin effect systems.

Electric-heat tracing systems are typically powered from field distribution panelboards fed from dry-type transformers. Each panelboard circuit is used, within its capacity, to serve a continuous section of piping, associated valves and, if required, process instrumentation. Power circuit conductors must be suitable for the temperatures to which they will be exposed.

System disconnect and grounding arrangements should meet NEC Article 427 requirements. For electrical-resistance-type heat tracing systems, this includes a requirement that all heat-tracing circuits be provided with either ground fault protection or, for industrial establishments, an alarm indication of a ground fault.

All components of electric-heat tracing systems must be suitable for the area classification in which they will be installed.

10.11 CATHODIC PROTECTION SYSTEMS

Cathodic protection systems are used to provide corrosion protection for underground piping, tanks, or other metal structures that are in contact with the earth, and offshore facilities. Cathodic protection systems are either sacrificial anode or impressed current type. Cathodic protection surveys are typically performed to determine the type of system to be used.

Sacrificial anode systems do not require a power source. Impressed current systems require a DC power source that is supplied from a field transformer/rectifier assembly. Ammeters are often provided to allow monitoring of the current flow in impressed current circuits.

Design guidance for cathodic protection systems is provided by API RP 651 and NACE RP 0169. In the design of cathodic protection systems, consideration must be given to the adverse impact that such systems may have on any nearby electrical-grounding grid systems. For offshore installations, design guidance is given by NACE RP 0176 and NACE RP 0675.

Cathodic protection system components must be suitable for the area classification in which they are installed. Transformer/rectifier assemblies that are installed in classified locations are often designed to be oil-immersed.

10.12 DESALTERS AND PRECIPITATORS

10.12.1 Electrostatic desalters are used to reduce the salt and solids contents of crude oils. This reduces fouling and corrosion resulting from salt deposition on heat transfer surfaces, and acids formed by decomposition of the chloride salts. Typical solids which are removed from the crude oil include fine sand, clay and soil particles, iron oxide, and other contaminants which can be picked up during crude oil production and transportation. The desalting process can also improve catalyst life in downstream processes by partially rejecting certain metals that can cause catalyst deactivation.

Desalting is performed by mixing crude oil with water at temperatures from 90°C to 150°C. The salts are dissolved in the wash water and the oil and water phases are then separated in a settling vessel. A high-potential electrical field is applied across the settling vessel to facilitate the coalescing of the salt water droplets. Either AC or DC fields may be used, with potentials ranging from 16,000 V to 35,000 V. Energy consumption is typically 0.05 kWh to 0.15 kWh per barrel of feed.

In some cases, both AC and DC fields are used to provide high dewatering efficiency. The AC field is applied near the oil/water interface; and the DC field in the oil phase is applied above the interface. Efficiencies of up to 99% water removal in a single stage are claimed for the dual-field process. The dual-field electrostatic process provides efficient water separation at lower temperatures, resulting in a higher overall energy efficiency than for single field designs.

10.12.2 Electrostatic precipitators are used to remove solid particles from flue gas air streams an application of a DC field. Typically, precipitators are located in power plants, incinerators, and fluid catalytic cracking units.

10.13 PORTABLE EQUIPMENT

Much of the portable or mobile equipment used in processing plants requires electric power. Some examples of portable equipment requiring electric power are as follows:

a. Welding machines.
b. Motor-driven portable pumps.
c. Motor-driven portable compressors.
d. Power tools.
e. Extension and hand lamps.
f. Annealing machines.
g. Test instruments.
h. Tool trailers.
i. Storehouse trailers.
j. Office trailers.
k. Meter testing rigs.

This equipment operates at 600 V or less, single-phase or three-phase as required. Permanent receptacles are installed when periodic use of portable equipment justifies the installation. Otherwise, temporary wiring is used for supplying power. Particular attention should be given to grounding portable equipment for personnel protection. (Section 5 provides further discussion of this subject.)

SECTION 11—INHERENT ELECTRICAL SAFETY

11.1 GENERAL

11.1.1 The electrical engineer who intends to take advantage of incorporating electrical safety by design in his work needs first to obtain knowledge about the requirements for working safely in an atmosphere influenced by the presence of electricity.

11.1.2 The principal hazards of working around electrical equipment are electrical shock and electrical arc flash. While an electrical shock hazard involves contact, or approach so close that the intervening air gap breaks down and becomes conductive, the electrical arc flash hazard can extend a considerable distance from the exposed energized electrical conductor or circuit part.

11.1.3 The most effective protection against electrical hazards can be achieved by distance and/or by enclosure. Where exposed energized electrical conductors or circuit parts are present, the assigned employee must possess knowledge of, and must employ, electrical safe work practices.

11.2 REFERENCES

11.2.1 The principal sources of guidance for electrical safe work practices and safe electrical facilities are:

11.2.1.1 OSHA 29 *CFR* 1910

a. Subpart I—Personal Protective Equipment
   1910.137—Electrical protective equipment.
b. Subpart J—General Environmental Controls
   1910.145—Specifications for accident prevention signs and tags.
   1910.147—The control of hazardous energy (lockout tagout).
c. Subpart R—Special Industries
   1910.269—Electrical power generation, transmission and distribution.
d. Subpart S—Electrical
   1910.301—"Introduction"—This subpart addresses electrical safety requirements that are necessary for the practical safeguarding of employees in their workplaces.

Sections 1910.302 through 1910.399 contain five major divisions:

1910.302 through 1910.330—Contain design safety standards for electrical systems.
1910.302 through 1910.308—Contain design safety standards for electric utilization systems.
1910.309 through 1910.330—Reserved for possible future use for design safety standards for other electrical systems.
1910.331. through 1910.360—Contain safety-related work practices.
1910.361 through 1910.380—Reserved for future safety-related maintenance requirements.
1910.381 through 1910.398—Reserved for future safety requirements for special equipment.
1910.399—Definitions applicable to each division.

11.2.1.2 OSHA 29 *CFR* 1926

Subpart K—Electrical Standards for Construction

11.2.1.3 NFPA 70 *National Electrical Code*

The National Electrical Code deals primarily with the minimum design and installation requirements for electrical equipment. OSHA has determined that electrical facilities installed in accordance with the NEC are safe until the equipment is compromised by deterioration, or until an unsafe act or a combination of unsafe acts occur.

11.2.1.4 NFPA 70E *Electrical Safety Requirements for the Employee Workplace*

This document deals primarily with the minimum requirements for protecting employees working in and around electrical equipment. OSHA recognizes the benefits of a consensus standard for safe work practices in general industry and has encouraged the NFPA to pursue the full development of NFPA 70E. NFPA 70E attempts to develop specifics by which OSHA performance statements in Subpart S can be accomplished.

11.2.1.5 ANSI/IEEE C2 *National Electrical Safety Code*

The National Electrical Safety Code deals primarily with the minimum design, installation, and maintenance requirements related to overhead power lines, control and telecommunications installations. OSHA recognizes the benefits of a consensus standard for safe work practices in special industries and has encouraged the IEEE to pursue regular revisions of ANSI/IEEE C2. ANSI/IEEE C2 attempts to develop specifics by which OSHA performance statements in Subpart R can be measured.

11.3 SPECIFICS

11.3.1 Distance from potential sources of exposed energized electrical conductors and circuit parts can be achieved by various means. Qualified persons are permitted to approach much closer than are unqualified persons. Qualified persons by OSHA definition are "Ones familiar with the construction and operation of the electrical equipment and the electrical hazards involved with the work being performed."

11.3.1.1 Unqualified persons around voltages to ground of 50 kV or less must maintain a distance of 305 cm (10 ft). For voltages to ground over 50 kV, use 305 cm (10 ft) plus 10 cm (4 in.) for every kV over 50 kV.

11.3.1.2 Qualified persons must not approach closer than the distances shown in Subpart S, Table S-5.

11.3.1.3 Examples of distance are: the clear working space requirements of Subpart S, Table S-1; that to be achieved by use of control room breaker operation for remotely opening or closing switching devices; that achieved by use of mimic bus with control switches located remote from the front of metal enclosed or metal clad switchgear; or that to be achieved by use of umbilical cords having control switches for opening or closing the switching device on the far end.

11.3.2 Enclosures have varying degrees of integrity. The enclosures' principal functions are to protect the electrical conductors or circuit parts from the elements and from physical damage, as well as to isolate the electrical conductors and circuit parts from people. Deterioration of enclosures by corrosion, neglect, or mechanical damage can lead to exposure of electrical conductors or circuit parts.

11.3.2.1 Examples of enclosure—when properly applied and maintained can be counted on to contain the explosive force of an electrical arc or divert its effect in an innocuous direction—are: explosionproof enclosures that contain the explosive forces; or those of arc-resistant construction that direct the energy of the explosion through specially designed vents in the top or ends of the equipment to nonoccupied locations.

APPENDIX A—INFORMATIVE
INHERENT SAFETY CONSIDERATIONS

Appendix A is intended to provide additional items that may need to be addressed in the safe application of electrical equipment into petroleum processing facilities. A suggested approach is to use these items as discussion topics when defining the design scope with the project team. Communication between the user, Engineering & Construction Service (E&CS), and vendor is strongly urged to evaluate the desirability, capability and necessity of each item. It is recognized that no design could or would incorporate all of these items.

A.1 Switchgear and Motor Control Centers

Consider using the following features in the design:

a. Arc Resistant Switchgear for all metal-clad applications.

b. Use of current-limiting fuses for all 480 V and 600 V devices.

c. Equipment selection and sizing to minimize/reduce flash protection boundary.

d. Remote close/open of switchgear breakers.

e. Remote racking-in of switchgear breakers.

f. Secondary selective switchgear systems: Use of a second tie-breaker in series with the tie-breaker to ensure complete de-energization and isolation.

g. Secondary selective switchgear systems: Use of a second tie-breaker in parallel with the tie-breaker to facilitate on-line testing of the secondary selective system operation.

h. Local back-up trip provisions only of breakers normally closed/opened from a remote location.

i. CT shorting terminals to be located near relay wiring terminals for quick/easy access and shorting; and automatic shorting provisions whenever relays with current inputs are removed.

j. Use of insulated buses and bus ends in bus ducts, switchgear, motor control center, and switchracks.

k. Use of "finger safe" fuse-holders: the fuses are contained in a removable carrier with markable labels. *Finger safe* is defined as where live parts are inaccessible whether fuse is in, or out, or in-between.

l. Use of finger safe terminals in 120/208/240 V power panels, relay control panels, DCS/PLC control systems, metering and instrument panels, control room termination panels, etc.

m. Use of equipment with "built-in" transducers.

n. Use of "encapsulated" equipment.

o. Lockable, hinged-type rear doors at switchgear breakers.

p. Lockable front doors at switchgear breakers where it is unfeasible to place a lock on the switchgear breakers.

q. Provision to padlock all energy isolating devices, including fuse blocks in off-position.

r. Use of voltage-rated boots over switchgear bus joints in place of electrical taping to facilitate maintenance.

s. Use of "transparent inspection windows" in switchgear, switches, motor control centers, and transformers to allow inspection or monitoring of required components and functions.

t. Use of CT secondary, open-circuit protectors.

u. Segregation of electrical components with different voltages in common enclosures, cabinets, etc.

v. Moisture inhibitors in switchgear, instruments, junction boxes, enclosures, etc.

w. Interlocking of primary and secondary breakers of a power transformer to prevent back-feed through the transformer.

x. Provisions to manually trip breakers (on loss of trip power) without requiring the opening of the enclosure doors.

y. Interlocking to prevent any underrating because of system configuration, or out-of-synch closures at locations where synch check relays are not provided and an out-of-synch condition can occur.

z. Interlocking of all isolating switches (with no or inadequate interrupting rating) with interrupting devices suitable for fault interruption to ensure de-energized operation.

aa. Interlocking to prevent access to live parts.

bb. Interlocking to prevent closing of breakers or starters if trip power is not available.

cc. Indication of overload trips on all motor starters.

dd. Covers for all terminals containing potential sources 50 V and above.

ee. Utilization of single-phase relays to prevent failure of breaker tripping because of three-phase relay failure at the time of a fault.

ff. Utilization of lock-out relays to prevent closing of breakers/starters after a protective device operation.

gg. Utilization of single-phase relays vs three-phase relays to allow safe testing and calibration of relays while the equipment is energized.

hh. Utilization of independent current transformers and circuits/wiring for primary and back-up relaying.

ii. Installation of surface mounted flexitest switches on the switchgear to prevent relay trips during testing (blades of surface-mounted switches shall not be energized when open).

jj. Conveying all critical alarms to an attended location or control room.

A.2 Electrical System Grounding and Ground Fault Detection

Consider the following:

a. Existing 480 V and 600 V ungrounded wye systems: Install high-resistance grounding systems to enable quick alarm, detection, and isolation of ground faults in motor control centers and switchracks.
b. Existing 480 V and 600 V ungrounded delta systems: Install grounding transformers to create a system ground, and high-resistance grounding systems to enable quick alarm, detection, and isolation of ground faults in motor control centers and switchracks.
c. Ground-fault alarm and detection: Use zero sequence CTs in starters and breakers for quick alarm, detection, and isolation of ground faults in 480 V and 600 V motor control centers and switchracks with high-resistance grounding.
d. Auto/manual grounding of 1,000 V and above, feeders, capacitor banks, motors, etc., when switchgear breakers or motor starters are withdrawn. If grounding is provided, provide interlock with main switching device.

A.3 Substations

Consider the following:

a. Fire wall between power transformers.
b. Use of ground fault circuit interrupter (GFCI) receptacles.
c. Use of insulating mats in substations and motor control centers.
d. Use of concrete or metal post barriers around outdoor padmount transformers and other electrical equipment.
e. Use of toe-wall around battery bank to contain battery liquid in the event of battery leaks.
f. Use of plexiglass barrier at the battery bank to prevent unqualified persons from getting close to the exposed battery terminals.
g. Use of on-line monitoring of dissolved gas in transformer oil.

A.4 Labeling and Marking

Consider the following:

a. Mark flash protection boundary and personal protective equipment (PPE) requirements on each switchgear, switchrack, motor control center, etc. for energized work, work within flash protection boundary, etc.
b. Labeling/marking of instrument relays/meters, all should be labeled/marked both on front and rear of the switchgear doors to eliminate errors when troubleshooting.
c. Mimic one-line diagram on the front panel of uninterruptible power supply (UPS).
d. UPS shut-down, start-up, and manual-bypass procedures on the front panel of the UPS.
e. Procedures for manual restoration of and transfer of buses in secondary selective substations on the switchgear doors.
f. Caution for switchgear work: caution tags to be located near power transformers (PTs)/fuses/etc.

Examples:

1. Removing PT fuses will cause transfer of buses.
2. Removing PT will cause transfer of buses.
3. Removing PT fuses may shutdown large drivers.
4. Removing voltage relay may shutdown large driver.
5. Removing protection relay(s) may shutdown switchgear breaker(s).
6. Removing relay may shutdown switchgear bus, etc.

g. Caution for work on stored energy equipment: Caution tags to be located on electrical and mechanical stored energy equipment.

Examples:

1. Discharge capacitors prior to start of work on capacitors.
2. Discharge power cables prior to start of work on power cables.
3. Discharge motors prior to start of work on motors.
4. Discharge generators prior to start of work on generators.
5. Discharge springs prior to start of work on breakers.

h. All substation and outdoor equipment labeling to include the following:
1. Equipment number and name.
2. Source of incoming power supply.
3. Area/list of power users, etc.

i. Labeling for equipment with multiple incoming power sources to be as follows:
1. Equipment number and name.
2. Sources of incoming power supply.
3. Area/list of power users, etc.
4. Any special procedures required for the isolation of the multiple incoming power sources.

j. Caution for remote energization/start of equipment:
1. Label switchgear breakers, generators, motors, etc.; if these are designed for remote start or energization.
2. Use of audible signals at equipment prior to their energization/start.

A.5 Miscellaneous

Consider the following:

a. Fireproofing of cables/conduits in fire hazard area.
b. Fireproofing of motor-operated valves in fire hazard area.
c. Use of fluorescent yellow plastic covers on pole line guy wires to alert traffic in the area.
d. All incoming and alternate power source breakers for a UPS should be lockable type.

e. If UPS breakers and switches are located outside the inverter area, the UPS can be easily isolated and safely worked on.
f. Provide electric heat tracing control systems with capability to routinely monitor the integrity of the heaters and control system.
g. Use of pocket-size continuous-monitoring type gas detectors in place of "Hot Work Permit."

A.6 Documentation

Consider the following:

a. Single line diagrams.
b. Control schematics.
c. Protective device settings and equipment parameters.
d. Equipment operating maintenance, testing, and troubleshooting.
e. Procedures and applicable data.
f. Area classification drawings.

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