# Chapter 9 Electrical Design

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# Chapter 9 ELECTRICAL DESIGN

This chapter of the Design Standards and Guidelines (DSG) presents standards and guidelines for electrical design for Seattle Public Utilities (SPU) facilities. It includes master electrical specifications, standard drawings, and design calculations. The primary audience for this chapter is SPU electrical engineers and team members working on SPU infrastructure-related projects. DSG standards are shown as underlined text.

As SPU's first comprehensive electrical design document, this chapter is also intended to establish a historical baseline reference for typical electrical facilities and components. This information, used in conjunction with engineering judgment, appropriate codes, national standards, and other reference information, will ensure electrical systems that are safe and suited for the intended application. This DSG does not replace the judgment of an experienced, licensed Professional Engineer (PE). All electrical design for SPU infrastructure should be done under the supervision of an experienced, licensed PE.

## 9.1 KEY TERMS

Abbreviations and definitions given here follow either American usage or regulatory guidance.

### 9.1.1 Abbreviations

| Abbreviation | Term |
|---|---|
| A | amp |
| AC | alternating current |
| ADA | Americans with Disabilities Act |
| AHJ | Authority Having Jurisdiction |
| ANSI | American National Standards Institute |
| AWG | American wire gauge |
| BKR | breaker |
| CBD | cable block diagram |
| CCTV | closed-circuit television |
| CF | compact fluorescent |
| CKT | circuit |
| CRI | color rendition index or color rendering index |
| CSI | current source inverter |

| Abbreviation | Term |
|---|---|
| CSO | combined sewer overflow |
| CT | current transformer |
| DC | direct current |
| EMT | electrical metallic tubing |
| EPDM | ethylene propylene-diene monomer |
| EPR | ethylene-propylene rubber |
| FLA | full-load amps |
| FRP | fiber-reinforced plastic |
| ft | feet |
| G | grounding |
| HID | high-intensity discharge |
| hp | horsepower |
| HPS | high-pressure sodium |
| HVAC | heating, ventilation, and air conditioning |
| I&C | instrumentation and control |
| ICS | industrial control systems |
| IMC | intermediate metal conduit |
| kcmil | thousands of circular mils |
| kV | kilovolt |
| kVA | kilovolt ampere |
| LEL | Lower Explosive Limit |
| LOR | Local Off Remote |
| MCC | motor control center |
| MCP | motor circuit protectors |
| MH | metal halide |
| MOV | metal oxide varistor |
| NEC | National Electrical Code |
| NEMA | National Electrical Manufacturers Association |
| NRTL | Nationally Recognized Testing Laboratories |
| OSHA | Occupational Safety and Health Administration |
| PAC | programmable automation controller |
| PLC | programmable logic controller |
| PWM | pulse-width modulated |

| Abbreviation | Term |
|---|---|
| PVC | polyvinyl chloride |
| RCM | reliability centered maintenance |
| RGS | rigid galvanized steel |
| RMC | rigid metallic conduit |
| RMS | root mean square |
| RNC | rigid non-metallic conduit |
| RTD | resistance temperature devices |
| SAD | silicon avalanche diode |
| SCADA | supervisory control and data acquisition |
| SCL | Seattle City Light |
| SPD | surge protective device |
| SST | stainless steel |
| TSP | twisted shielded pair |
| TST | twisted shielded triad |
| UL | Underwriters Laboratory |
| UV | ultraviolet |
| V | volt |
| VA | volt ampere |
| VAR | volt ampere reactive |
| VFD | variable frequency drive |
| VVI | variable voltage inverter |
| XLPE | cross-linked polyethylene |

### 9.1.2 Definitions

| Term | Definition |
|---|---|
| codes | Refers to the legal documents whose use is determined by the jurisdictions governing a project or electrical manufacturing industry codes. Codes are typically geographically dependent. |
| guidelines | Advice for preparing an engineering design. Guidelines document suggested minimum requirements and analysis of design elements to produce a coordinated set of design drawings, specifications, or lifecycle cost estimates. Design guidelines answer *what*, *why*, *when* and *how* to apply design standards and the level of quality assurance required. See also *standard*s. |
| references | In this DSG chapter on Electrical Design, *references* are sources of content and include sufficient detail (e.g., document, section and table number, and/or title) that the user can easily refer to the source. The National Electrical Code (NEC) and National Electrical Manufacturers Association (NEMA) documents are frequent references in this chapter. |

| Term | Definition |
|---|---|
| regulations | Legal design standards that must be incorporated into the design. Examples include Occupational Safety and Health Administration (OSHA) requirements, the Americans with Disabilities Act (ADA), etc. |
| reliability centered maintenance (RCM) | A process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context. |
| standards | This DSG chapter on Electrical Design is an exception to the strict application of the word "standard." Because electrical design follows long-established industry standards, we have used the definition of standard in item #1 below.<br>1. Opinions and recommendations that form design guidelines that are not legal in nature but are considered a standard of practice. Standards are often published by industry associations but may also be established by SPU. See also *guidelines*.<br>2. For the DSG, the word *standard*, refers to the following: drawings, technical or material specifications, and minimum requirements needed to design a particular improvement. A design standard is adopted by the department and generally meets the functional and operational requirements at the lowest lifecycle cost. It serves as a reference for evaluating proposals from developers and contractors. For a standard, the word *must* refer to a mandatory requirement. The word *should* is used to denote a flexible requirement that is mandatory only under certain conditions. |

# 9.2 GENERAL INFORMATION

SPU electrical engineering design is project specific and applied to a variety of facility types. The role of the electrical design engineer varies accordingly. This section provides general background information on SPU facility types, electrical design elements, and design resources.

## 9.2.1 SPU Facility Types

SPU builds, operates, and maintains all water, wastewater, and solid waste facilities for the City of Seattle (the City). These include two large water treatment plants at the Tolt and Cedar watersheds, which private companies operate under long-term contracts. SPU's support facilities include offices, operations centers, maintenance facilities, and labs. For more information, see the relevant chapters in this DSG for each type of facility.

## 9.2.2 Electrical Design Considerations

This section describes basic electrical design considerations for SPU facilities.

### 9.2.2.1 Facility Related

### A. Type

The driving force behind every electrical design is the need to provide power for a particular purpose. For SPU, that purpose is determined by the type of facility. Factors that affect electrical design are a facility's purpose (e.g., whether it manages water or wastewater), age, upgrade history, capacity, and physical layout. For example, a water pump station will likely require large motor-driven pumps, while a flow monitoring vault will require minimal power.

## B. Loads

Facility loads (e.g., motors and lights) are users of electrical power and form the basis for calculating the size of an electrical system. Utility service and feeder sizes are based on National Electrical Code (NEC) and serving utility's requirements. The following items affect calculations:

- Size of the largest motor
- Heating, ventilation, and air conditioning (HVAC) and lighting loads
- Future expansion provisions
- Motor starting methods
- Unit process equipment

## C. Importance

A facility's *importance* is measured by the consequences of its failure to function. Loss of electrical power to SPU facilities could range from a minor consequence (e.g., loss of non-critical information) to a major consequence (e.g., threat to human life or property). Electrical design will often have to consider either on-site or portable backup power. At present, there are only two cost-effective choices for sources of backup power: engine-generators and batteries (uninterrupted power supply).

## D. Reliability

*Reliability* is a measure of the expected operational availability for an electrical system. The need for reliability is linked to a facility's importance and ease of maintenance. Although it is beneficial to have highly reliable systems at all times, it is costlier to design, build, and maintain such systems. The main way to increase reliability is to provide parallel or redundant components or systems so that a single failure will not disable the facility. For SPU reliability requirements, see DSG section 9.5.1.

## E. Environment

The type of SPU facility determines the environment in which electrical system components function. For example, wastewater pump stations have hazardous and corrosive conditions, while water pump stations have non-hazardous and dry conditions. Dry conditions, such as an electrical room or weatherproof enclosure, should be provided for most electrical gear. Some decisions affected by environmental conditions are enclosure National Electrical Manufacturers Association (NEMA) ratings, electrical materials selection, and installation methods.

## F. Construction

Construction design and methods influence electrical design in two ways:

1. Constraints and accommodations of the facility structure
2. Materials and installation choices available to the structure

Reduced material costs must be balanced against flexibility. Other factors to consider are available space and constructability. For example, a utility meter can often be installed in a switchboard lineup, but sometimes space is too tight and it is better to install a meter outside. As another example, a motor control center (MCC), though larger, is often a better fit for a tight space than individual controls.

#### G. Maintenance

SPU takes a reliability centered maintenance (RCM) approach to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context. This approach requires operation staff to define and describe their specific methodology related to the level of maintenance.

### 9.2.2.2 Safety

Safe electrical design is paramount. The electrical design engineer needs to be aware of the multiple sources and issues that affect project safety. Selecting listed and labeled equipment appropriate to function is only one consideration. Other safety considerations include where and how equipment is installed, as the environment determines how safely SPU Operations staff can interact with the equipment. Limiting access for unqualified persons protects the public, and selecting non-toxic materials is safer for the environment.

### 9.2.2.3 Location and Social Issues

Most SPU facilities are located in populated areas. In these areas, visual and other characteristics of the facility may negatively affect a neighborhood. Serious consideration should be given to reducing the visual footprint of the facility and its electrical service by placing them underground. Even underground, the generation of noise or odors cannot be ignored. When aboveground, equipment should be selected for quiet operation and generators should have a silencer and critical grade muffler. Any outside lights should be full cutoff and positioned to minimize spillover into the neighborhood.

### 9.2.2.4 Local Utilities

The electrical design engineer must inform local utilities of a project’s needs and incorporate the utilities’ requirements into electrical design, including power, communication, water, and sewer.

## 9.2.3 Electrical Design Elements

This section describes basic elements for electrical design of SPU facilities.

### 9.2.3.1 Power

Most SPU projects require one or more of the following power types:

- 240/120 volt (V) 1-phase
- 240/120V 3-phase open delta
- 208/120V 3-phase
- 480/277V, 3-phase
- 4,160/2,400V, 3-phase

From the local utility (usually Seattle City Light [SCL]), 480V services are 480/277V, 4-wire with a solidly grounded neutral wire at the main service breaker. Most 3-phase loads do not use a system neutral wire.

For most facilities with emergency power, the neutral is carried through to a transfer switch for connection to a generator neutral. A step-down transformer provides 120V power. Unless 240V power is required, a 208V/120V, 3-phase step-down transformer should be used.

Service size (ampacity) is usually 100 amps (A) for 1- phase and 200A or greater for 3-phase. Services above 225A should be configured with a current transformer (CT) enclosure and separate meter-base according to utility requirements. Large facilities with a switchgear lineup may include a service entrance and metering section.

The usual alternate power source for SPU facilities is a diesel-powered standby generator (genset). It may be permanently installed on-site at critical facilities or there may be provisions for connecting a portable genset. Critical SPU facilities often have both. Smaller facilities may use propane as the fuel source.

### 9.2.3.2 Codes

For a list of the codes that govern electrical design for SPU facilities, see DSG section 9.3.

### 9.2.3.3 Loads

The loads for a project are usually divided into two types:

- **Process** (loads fulfilling the purpose of the facility)
- **Facility** (loads necessary to keep the process loads functioning)

At SPU facilities, the main process loads are motors that drive pumps (see *DSG Chapter 11, Pump Stations* for typical pump requirements). Compressors, blowers, and fans compose the bulk of the other motor-driven loads. Unit process loads such as ultraviolet (UV) or ozone generation are also large users of electric power. Electrical heaters for air and water are the largest facility loads, with lights, receptacles, and special systems usually constituting less than 10% of the total load.

### 9.2.3.4 Lighting

Most SPU facilities require some combination of the following types of lights:

- **Light emitting diode (LED).** SPU prefers LED lighting applications used in new and retrofit facilities and in outdoor/indoor, wet/corrosive, and hazardous/non-hazardous areas.
- **Tube fluorescent.** T5 or T8 4-ft tubes are used in open fixtures with reflectors, with a few uplights, or in enclosed and gasketed fixtures for wet/corrosive areas.
- **Compact fluorescent (CF).** SPU uses these bulbs in most outdoor and hazardous location fixtures where instant-on lights are required.
- **High-intensity discharge (HID).** Bulbs that are either high-pressure sodium (HPS) for highest efficiency or metal halide (MH) for best color rendition are used in outdoor wall- or pole-mounted fixtures. They are also used in large and high-ceiling indoor areas. HID fixtures take several minutes to achieve full brightness.

### 9.2.3.5 Instrumentation & Control

For details on instrumentation and control (I&C), see *DSG Chapter 10, I&C (Supervisory Control and Data Acquisition [SCADA])*. I&C equipment is located on the electrical drawings and installed by an electrical contractor.

Most existing SPU SCADA systems depend on telephone lines. The electrical design engineer is usually responsible for coordinating with an SPU SCADA engineer and a local communications company to bring the service to the site and for identify and show the demarcation point.

The electrical power system supplies power for the instruments, control devices, and control panels. The power source for instruments, whether from a 120V circuit breaker panel or a main I&C control panel, is one of the early design coordination decisions. It is preferable to supply the instrument power from the control panel unless space is limited. Testing is facilitated by having both power and signal wires accessible in the same place.

It is the electrical design engineer's responsibility to translate the control requirements for the process equipment into elementary (control) diagrams. The electrical design engineer should also ensure that the necessary signals are provided among the electrical starters, I&C control panel, and SCADA system. These signals are either discrete (on/off) or analog (continuously variable over a specified range) and fall into two general categories: *status* or *alarm*. Status signals provide information about the state of something, whether ON or OFF, while alarm signals require attention. A *trouble signal* falls in between status and alarm, indicating a potential or future problem. Critical control, including safety interlock circuits and security signals, must be a fail-safe circuit.

The following are typical SCADA status signals:

- Flow rate (analog)
- Fuel tank low level
- Genset power available
- Pump fail
- Pump on/run
- Transfer switch position
- Utility power fail
- Valve closed
- Valve open
- Valve position (analog)
- Wet well level
- Flood switch
- Hazard gas LEL (analog)
- Intrusion switch

The following are typical control signals:

- START/STOP (for pump)
- OPEN/CLOSE (for valve)

### 9.2.3.6 Special Systems

#### A. Fire Alarm

Most SPU facilities do not have a distinct fire alarm system. They have fire detection devices, such as smoke detectors or heat sensors, which send alarm signals to the SCADA system via a main control panel.

If a complete fire alarm system is required, it is specified as contractor designed and Authority Having Jurisdiction (AHJ) approved. The electrical designer must show an acceptable location on the drawings for the fire alarm panel and provide power to it.

For remote monitoring services, the connection to the telephone interface board must be shown. Any auxiliary devices (duct smoke detectors or fire dampers) must be shown with power and control wiring.

#### B. Security

The basic SPU security concern is unauthorized intrusion into a facility. While access and acknowledge switches have been adequate, there is a growing need for additional measures. Some additional measures include closed-circuit television (CCTV), access control systems (ACS), and intrusion detection systems (IDS) with specialized devices. The degree of security should be coordinated with the project manager in coordination with SPU's Security and Emergency Management staff for site specific scopes. For additional details on security, see *DSG Chapter 15, Physical Security*.

#### C. Telephone and Data

Most SPU projects need at minimum a dial-up telephone line for alarm transmission and communication. SCADA also requires a dedicated telephone line or direct connection to the water or wastewater network. The electrical designer should coordinate with the Project Manager (PM) and SPU SCADA Engineer to install fiber or cellular communication where feasible, as physical telephone lines are being phased out. Specific requirements should be coordinated with I&C and Field Operations and Maintenance (O&M).

#### D. Lightning Protection

Most SPU projects do not require lightning protection. Water tanks and other elevated and exposed structures like antenna towers should be evaluated and documented if a lightning protection system is not implemented. Seattle does experience occasional severe lightning storms.

## 9.2.4 DGS Design Resources

DSG design resources include standard specifications, drawings, sample calculations, and other technical guidelines found only in the DSG. In general, specifications define the level of quality expected, while the drawings and schedules indicate quantities, dimensions, and sizes.

### 9.2.4.1 Technical Specifications

DSG standard technical specifications for electrical design describe SPU requirements for products and installation, quality control measures for checking the products, and for construction. These specifications are presented in Construction Specifications Institute Master

Format 2020 or current. Electrical specifications make up only a portion of the complete specifications for a project.

The DSG Specifications for Electrical Design are available in **Appendix 9A - Standard Specifications for Electrical Design**.

#### 9.2.4.2 Drawings

Drawings provide detailed information on quantities, size, dimensions, and relationships. Drawings and specifications form the bulk of contract documents. A cardinal rule is to avoid duplicating information in specifications and drawings to avoid discrepancies.

Electrical drawings must be consistent with and reference other related drawings. For example, conduit penetrations through concrete floors must be mentioned on the structural drawings so that the conduits are put in place before a slab is poured. Civil, mechanical, I&C, and structural drawings may all need to be referenced.

The need to reference other drawings from other disciplines makes electrical drawings susceptible to changes by others. It is one reason the electrical design engineer is often the last to complete project drawings.

For an example set of Standard SPU electrical drawings, see **Appendix 9B - Standard Drawings for Electrical Design**.

#### 9.2.4.3 Design Calculations

Design calculations establish minimum guidelines and requirements for generating electrical calculations on projects. Electrical calculations should be made for all SPU projects that include electrical components and should be filed in the project notebook (see DSG section 9.4.3.3).

Design calculations may be made either manually or using SPU-approved computer programs. The electrical design engineer must use only SPU-approved electrical analysis software. The results should be validated with a hand calculation or order of magnitude estimate. SPU-approved software tools include:

- ETAP Electrical Power Analysis Software is a basic tool for calculating short circuit, load flow, arc flash analysis, and protection and coordination.
- Cummins Power Suite for sizing emergency generators.
- CenterONE available from Rockwell Automation for laying out MCCs.
- Spreadsheets may also be used to perform basic electrical load calculations with programs such as Microsoft Excel.

For more explanation and example design calculations, see **Appendix 9C - Design Calculations for Electrical Design**.

## 9.3 GENERAL REQUIREMENTS

Electrical design engineers that work in SPU facilities must be familiar with industry standards and code requirements. If industry standards and City requirements conflict, the design engineer must discuss and document any discrepancy with the line-of-business representative, O&M manager, and owner of this DSG chapter.

## 9.3.1 Industry Codes

The principal industry codes governing the electrical components of SPU designs are the NEC and modifications to it found in the Washington state and City of Seattle codes (Table 9-1). National Fire Protection Association (NFPA) codes, such as 820 and 110, determine wastewater hazardous conditions and emergency power requirements. Appropriate codes must be verified with the project manager, architect, and local building official.

**Table 9-1**
**Electrical Codes for SPU Electrical Design**

| Designation | Code |
|---|---|
| NFPA 70 | NEC |
| | Washington State Electrical Code |
| | City of Seattle Electrical Code |
| | Washington State Energy Code |
| NFPA 820 | Standard for Fire Protection in Wastewater Treatment and Collection Facilities |
| NFPA-101-HB85 | Life Safety Code |
| | IFC |
| IEEE C2 | NESC |

Acronyms and Abbreviations
IEEE: Institute of Electrical and Electronics Engineers
IFC: International Fire Code
NEC: National Electrical Code
NESC: National Electrical Safety Code
NFPA: National Fire Protection Association

## 9.3.2 Regulations

Regulations are legal design standards that must be incorporated into design. The following regulations must be incorporated in SPU electrical design:

- Puget Sound Clean Air Agency
- U.S. Environmental Protection Agency (EPA)

## 9.3.3 Industry Standards

Industry standards are typically opinions and recommendations that form design guidelines. They are not legal in nature but describe commonly accepted standards of practice. Standards are often published by industry associations but may also be established by SPU (Table 9-2).

**Table 9-2**
**Industry Standards Organizations**

| Acronym | Organization |
|---|---|
| ANSI | American National Standards Association |
| NEMA | National Electrical Manufacturers Association |
| IEEE | Institute of Electrical and Electronics Engineers |
| OSHA | Occupational Safety and Health Administration |
| ASTM | American Society for Testing Materials |
| UL | Underwriters Laboratory |
| IES | Illuminating Engineering Society |
| NFPA | National Fire Protection Association<br>NFPA 820, Standard for Fire Protection in Wastewater Treatment and Collection Facilities |

# 9.4 DESIGN PROCESS

*DSG Chapter 1, Design Process* describes a series of steps evolved from planning through commissioning for a typical SPU project. The electrical design engineer should apply these principles to guide design decision making and evaluate possible solutions to a problem when preparing design record in the following phases:

1. **Preliminary Design.** This phase identifies basic issues that could make the project electrically unfeasible due to expense or code/regulation requirements and sets the stage for the following phases.
2. **30% Design.** The Basis of Electrical Design Memorandum (see DSG section 9.4.3.2) is introduced at this phase. Lists are started and preliminary calculations are used to produce one-line drawings.
3. **60% Design.** The electrical drawings at this phase usually appear very incomplete. However, most underlying calculations, equipment selection, and layout work has been done. Detailed electrical drawings at this stage are not required. Other disciplines will usually contribute to the electrical drawings as well.
4. **90% Design.** This phase is usually completed in two parts to allow for final coordination. The 90% design should be an attempt at 100%, understanding that some relatively minor changes are often necessary to produce the final set of documents.

## 9.4.1 Design Checklist

Checklists are used to verify that required information is included in each design phase. Table 9-3 shows approximately what is covered at the various stages of electrical design. For a detailed checklist for electrical design at SPU, see **Appendix 9D - SPU Electrical Design Checklist**.

**Table 9-3**
**Simplified Checklist for Electrical Design**

| Checklist Category | Predesign | 30% | 60% | 90% | 100% |
|---|---|---|---|---|---|
| Code Review | ✓ | ✓ | ✓ | ✓ | |
| Deliverables | ✓ | ✓ | ✓ | ✓ | ✓ |
| Design Coordination | ✓ | ✓ | ✓ | ✓ | |
| Power and Light Concepts | ✓ | ✓ | | | |
| Power Supply and Distribution | ✓ | ✓ | ✓ | ✓ | |
| Special Systems | ✓ | ✓ | | | |
| Basis of Electrical Design Memorandum | | ✓ | ✓ | ✓ | ✓ |
| Calculations | | ✓ | ✓ | ✓ | |
| Drawing List | | ✓ | ✓ | ✓ | |
| Equipment List | | ✓ | ✓ | ✓ | |
| One-Line Diagram | | ✓ | ✓ | ✓ | ✓ |
| Lighting/Facility | | | ✓ | ✓ | ✓ |
| Process/I&C | | x | ✓ | ✓ | ✓ |
| Site Electrical | | x | ✓ | ✓ | ✓ |
| Special Systems Riser Diagrams | | | ✓ | ✓ | ✓ |
| Specifications | | | ✓ | ✓ | ✓ |
| Design Fixup | | | | ✓ | |
| Project Closeout | | | | | ✓ |

Acronyms and Abbreviations
I&C: instrumentation and control

## 9.4.2 Responsibilities of Electrical Design Engineer

The electrical design engineer must take an active role in consulting with other members of the project team to identify, understand, and coordinate the electrical design needs and related needs of other design team members. The electrical designer is responsible for:

- Supplying electrical energy to utilization equipment located on the project site.
- Providing adequate illumination in all areas.
- Providing special electrical systems such as fire alarm, security, telephone, and CCTV.
- Installing conduits and conductors for power distribution and for I&C systems.
- Selecting electric motors (e.g., enclosure type and size, horsepower [hp], and configuration).
- Specifying appropriate power generation.

- Selecting alternating current (AC) variable frequency and direct current (DC) drives.
- Determining motor controls and other electrical control circuits (in conjunction with I&C group).

## 9.4.3 Electrical Design Documents

The electrical design engineer must produce a set of documents for each project. A typical set of documents for electrical design includes:

- Basis of Electrical Design memorandum
- Environmental conditions and materials application spreadsheet
- Technical specifications
- Drawings (electrical and instrument site plan, schedule for raceways and conductors, panels, and luminaries; diagrams for motor control and risers; one line diagram; and standard installation details)

### 9.4.3.1 Basis of Design Plan Sheet

The basis of design plan sheet is a general sheet that shows a plan overview and lists significant design assumptions and requirements for major design elements, including electrical design. The following are SPU standards for this sheet:

- The design engineer must include a basis of design plan sheet in the plan set.
- The sheet must be archived with the record drawings.

The basis of design plan sheet is not intended for construction and should **not** be included with the bid set. The sheet is inserted after the project has begun. See *DSG Chapter 1, Design Process*.

For electrical design, the basis of design sheet contains the information shown in Figure 9-1.

**Figure 9-1**
**Basis of Design Plan Sheet Data for Electrical Design**

**Electrical Design**

System Voltage: __________V _______Phase Available Fault Current: ________________A

Total Connected Load: _________________KVA Future Capacity Required: _____________KVA

Spare Requirement: ___________________% Largest Motor Size: ___________________hp

Equipment Redundancy Load:

Coincident: _________________KVA Non-Coincident: __________________KVA

Hazardous (Classified) Location:

Class: ______________ Division: ____________ Group: ______________

Emergency Power Requirement: (choose one)

☐ Emergency Power System

☐ Legally Required Standby Power System

☐ Optional Standby Power System

Project Specific/Special Information (Assumption included):

### 9.4.3.2 Basis of Electrical Design Memorandum

A technical memorandum is used to establish the electrical design approach and set basic electrical design criteria for a project. A Basis of Electrical Design memorandum must be prepared for each project with an electrical design component. This Basis of Electrical Design memorandum is intended to provide a reference to the original design intent, assumptions, and constraints of a project and its performance criteria for future modifications to the facility.

The memo must be located and maintained electronically in the project directory (SPU's SharePoint server), within the electrical discipline and delivery folders. Clear definition of revisions must be provided so that team members can be sure they have the latest version.

For a template for the Basis of Electrical Design memorandum, see **Appendix 9E - Basis of Electrical Design Memorandum**.

### 9.4.3.3 Design Record (Project Notebook)

Electrical design information should be kept in a project notebook. This notebook (along with the construction documents, specifications, and drawings) forms a complete record for the electrical portion of a project. The notebook must contain the following information:

| Project Information | Record of Electrical Design |
|---|---|
| Service: water, sewer, combined sewer overflow (CSO) | Basis of Electrical Design Memorandum |
| Type: pump station, lift station, etc. | Calculations |
| Location: address | Vendor specification sheets |
| Internal contacts (e.g., project manager) | Decision log |
| External contacts (e.g., SCL) | |
| Instructions (e.g., schedule, budget) | |

### 9.4.3.4 Coordination

While the electrical design process has phases, it is highly dependent on other project disciplines. The electrical design engineer must be proactive in pursuing coordination throughout the project. Table 9-4 lists the various disciplines and types of information requiring coordination with the electrical design engineer.

**Table 9-4**
**Coordination Matrix for Electrical Design**

| Discipline | To Electrical | From Electrical |
|---|---|---|
| Mechanical | Pump motors<br>Valve actuators | Motor types/accessories<br>Voltages available<br>Motor starting methods |
| Architectural | Facility layout | Equipment space requirements |

| Discipline | To Electrical | From Electrical |
|---|---|---|
| | Lighting characteristics | Luminaries and emergency lighting |
| | Occupancy ratings | Hazardous material quantities |
| Structural | Types of construction | Equipment needing support |
| | Penetration/embedment restrictions | Conduit routing requirements |
| | Seismic requirements | Equipment needing restraint |
| | Equipment pad types | Equipment needing pads |
| Process | Importance | Backup power options |
| | Sequencing/redundancy | Distribution configuration |
| | Design life | Materials choices |
| | Future capacity | |
| Instrumentation | Power requirement | Recommended source |
| | Signal type | |
| | Signal cable | Specify |
| Control | Manual/automatic | Equipment requirements |
| | Discrete, analog, network | Equipment capability/limitations |
| SCADA | Transmission medium | |
| HVAC | Heater loads | Voltages available |
| | Ventilation loads | Interlock requirements |
| | Control requirements | Indicator/monitoring |
| Odor Control | Fan loads | Voltages available |
| | Chemical equipment loads | |
| | Control requirements | |
| Sound | Noise limits | Equipment sound characteristics |
| | Attenuation methods | |
| Security | Communication bandwidth | Conduit routing requirements |
| | Load requirement | Equipment needing supports |

Acronyms and Abbreviations
HVAC: heating, ventilation, and air conditioning
SCADA: supervisory control and data acquisition

# 9.5 DESIGN GUIDE

This section describes general components of electrical design. The assembly of conductors and electric circuit protective and control equipment is called an *electrical system*. Components within the system include motor controls, lighting, and special systems such as telephone, security cameras and detectors, card readers and locks, pagers, and fire alarms.

No single electrical system is adaptable to all SPU projects. Some SPU projects have no electrical components. When a project does require an electrical component, the specific requirements must be analyzed and the electrical system designed to meet those needs. Any approach to electrical design should include several considerations that will affect overall design. The most important consideration is safety of personnel and preservation of property, followed by reliability and continuity of service.

***Note:*** *Throughout this section, the DSG specification for an electrical system component is shown in brackets, although not all components have a specification. Specifications are listed in* ***Appendix 9A - Standard Specifications for Electrical Design****.*

## 9.5.1 Reliability and Redundancy

Reliability and redundancy requirements for SPU projects are driven by the applications of facilities and determined during preliminary engineering. The design engineer must consult and determine what level of reliability is required and then evaluate alternatives to determine the most cost-effective means of supplying it. The need for increased reliability must be weighed against the increased cost of providing it.

### 9.5.1.1 Reliability

Some SPU facilities are more critical than others. For most SPU process designs, system reliability is important (e.g., water pump stations must maintain pressure). SPU recommends that ANSI/IEEE Standard 493, IEEE *Recommended Practice for Design of Reliable Industrial and Commercial Power Systems,* be used to evaluate reliability requirements. At the time of DSG publication, SPU was applying RCM principles to help determine what maintenance can be done and is worth doing so that its infrastructure assets continue to operate as intended.

### 9.5.1.2 Redundancy

One means to improve power system reliability is to increase redundancy (see Table 9-5). Redundancy can be as simple as a standby engine generator or a transfer switch for a single pump station. The electrical design engineer should use the following to determine redundancy requirements:

- ANSI/IEEE Standard 493, which contains examples of how redundancy increases reliability.
- U.S. Environmental Protection Agency's (EPA) reliability criteria: Technical Bulletin EPA-430-99-74-001, Design *Criteria for Mechanical, Electrical, and Fluid System and Component Reliability*.

The design engineer must verify the level of redundancy the utility provides. In some cases, it may be sufficient to receive power from two separate lines from the same substation. In others, the ultimate source may need to be different transmission grids. This investigation should be done during preliminary engineering, when facility reliability and redundancy requirements are established.

**Table 9-5**
**Typical Applications of Redundancy**

| Facility | Redundancy |
|---|---|
| Maintenance or Control Building | A single power supply with emergency lighting units for egress lighting and an uninterruptible power supply for computer systems |
| Water Treatment Plant | A primary selective power service from the utility, with a standby generator for critical loads such as high-service pumping and disinfection |
| Wastewater Treatment Plant | Two primary services from the utility: a secondary selective low-voltage system with a standby generator for critical loads, and an uninterruptible power supply for computer-based control systems |
| Water Booster Pump Station | A single electrical service with a standby generator and transfer switch capable of supplying the entire load at the station |
| Sewage Pump Station | A single electrical service with a standby generator and transfer switch capable of supplying the entire load at the station |

## 9.5.2 Environmental Materials and Equipment Location

This section describes SPU standards for environmental materials and locations for electrical equipment.

### 9.5.2.1 Indoor Locations

Enclosures installed indoors in dry, industrial-type areas should be NEMA 12. NEMA 1 enclosures may be used in electrical rooms, offices, and laboratory areas where flying dust and debris would not be present. NEMA 4 enclosures should be installed in indoor damp and wet areas that do not have corrosive atmospheres. Where corrosive atmospheres are also anticipated, 316 stainless steel or reinforced fiberglass NEMA 4X enclosures should be installed.

### 9.5.2.2 Outdoor Locations

Enclosures installed outdoors and/or underground vaults must be designed to meet many conditions. If the atmospheric conditions are unknown, NEMA 4X 316 stainless steel enclosures should be installed. If it is known that no corrosive atmospheric conditions can be expected, then NEMA 3R or NEMA 4 enclosures could be used. NEMA 4 enclosures should be used in process areas where wash-down can be expected. NEMA 3R can be used for disconnect switches and similar equipment, where it is located away from process equipment. Thermal management must be considered during design for outdoor enclosures with electronics like a SCADA cabinet. The electrical design engineer should consider adding an air-conditioner and sun shield for outdoor enclosures that house uninterruptable power supplies (UPS).

### 9.5.2.3 Hazardous Locations

A *hazardous location* is an area that may be subject to explosive concentrations of flammable gases or suspended combustible dust (see NFPA Fire Codes and NEC Articles 500, 501, and 502).

All electrical design must follow the NEC 500 series articles.

Equipment enclosures in hazardous locations should be classified. The two most common are:

1. NEMA 7 enclosures, for use in Class I Group A, B, C, and D locations (gaseous hazards).

2. NEMA 9, for Class II Groups E, F, and G locations (explosive amounts of dust).

The electrical design engineer must work with the process engineer, mechanical engineer, and architect to define hazardous areas. These areas must be clearly defined on the drawings and Project Manual.

For CSO reduction storage and wastewater handling facilities, NFPA 820, *Fire Protection at Wastewater Treatment and Collection Facilitie*s, should be followed to classify hazardous areas and requirements for fire protection, fire detection, and fire-fighting requirements, such as ventilation requirements and use of explosion-proof electrical equipment and conduit sealing requirements. Table 9-6 lists other standards for classifications of hazardous areas.

***Note:*** *Fire sprinkler systems are normally omitted in facility electrical rooms; hence, electrical engineer is advised to follow NFPA 13 standards and requirements for specific fire rating and protection of electrical equipment.*

**Table 9-6**
**Other Standards for Classifications of Hazardous Areas**

| Standard | Content |
|---|---|
| NFPA 13 | Standard for The Installation of Sprinkler Systems |
| NFPA 52 | Standard for Compressed Natural Gas Vehicular Fuel Systems |
| NFPA 58 | Storage and Handling of Liquefied Petroleum Gases |
| NFPA 70 | NEC |
| NFPA 497 | Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas |
| NFPA 499 | Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas |
| ANSI API (RP500) | Recommended Practice for Classification of Locations of Electrical Installations at Petroleum Facilities |
| ANSI C2 | NESC |
| NFPA 820 | Standard for Fire Protection in Wastewater Treatment and Collection Facilities |
| ANSI/ UL 913 | Standard for Safety, Intrinsically Safe Apparatus and Associated for Use in Class I, II, and III, Division 1, Hazardous (Classified) Locations |

Acronyms and Abbreviations
ANSI: American National Standard Institute
NEC: National Electrical Code
NESC: National Electrical Safety Code
NFPA: National Fire Protection Association
UL: Underwriters Laboratory

A full discussion of hazardous location design is beyond the scope of this DSG chapter. The electrical design engineer should review the latest NEC Handbook (see DSG section 9.6).

### 9.5.2.4 Equipment Enclosures

Electrical equipment enclosures must be designed for the conditions to which they will be subject when installed. ANSI/NEMA 250 defines types of enclosures and conditions for which those enclosures were designed. The most often used NEMA enclosure types are:

- **NEMA Type 1 (indoor use only).** Intended for dry indoor use primarily to provide a degree of protection against contact with the enclosed equipment.
- **NEMA Type 3R ("weatherproof").** Intended for outdoor use primarily to provide a degree of protection against falling rain, sleet, and external ice formation. This is the least expensive outdoor enclosure. It is generally galvanized/painted steel and will quickly rust in marine air environments.
- **NEMA Types 4 and 4X ("waterproof").** Intended for indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, and hose-directed water. NEMA 4X enclosures protect against corrosion. It is generally not sufficient to simply specify "NEMA 4X." NEMA does not specify a material. It is possible to certify painted steel enclosures as 4X. Premium 4X enclosures are generally stainless steel, but high-quality, non-metallic enclosures are also available.
- **NEMA Type 12 ("dust-tight").** Intended for indoor use primarily to provide a degree of protection against dust, falling dirt, and dripping, noncorrosive liquids. Similar to NEMA 1 but has no openings and gaskets on all doors and covers. Cost slightly more than NEMA 1. For variable frequency drives (VFDs) it can be very costly. Equipment located in electrical rooms with filtered air handling systems can generally be specified as NEMA 1.

### 9.5.2.5 Equipment Rooms and Buildings

Major electrical equipment (e.g., transformers, switchgear assemblies, switchboards, and MCCs) should be installed in dedicated rooms or buildings. Smaller equipment (such as individual motor starters and panelboards) could be installed in mechanical spaces that are continuously ventilated and dry. All equipment rated above 600V, except pad-mounted transformers and metal-enclosed outdoor switchgear assemblies, should be located in dedicated spaces accessible only to qualified persons.

#### A. Electrical Equipment

NEC Article 110 contains specific requirements for location of electrical equipment. NEC Table 110-26(A) defines the working space required in front of equipment rated 600V and less. With the exception of lighting panels, the article allows equipment pieces of equal depth to be mounted above each other as long as one piece of equipment does not impinge on the working space of another. The fronts of all equipment must be at the same distance from the wall, presenting a flat vertical plane up to 6.5 feet (ft) above the floor. NEC Table 110-34(A) defines the working space required in front of equipment rated above 600V. Note that the specified values are minimums and may not provide a comfortable working space.

#### B. Switchboards, Motor Control Centers, and Panelboards

NEC Article 408.18 contains additional requirements that pertain to the location of switchboards, MCCs, and panelboards. Specifically, NEC Article 110.26 (E) requires that a dedicated space (not necessarily a room) be provided. This space must span from the floor to 6 ft high or the structural ceiling of the space, whichever is lower, and equal the width and depth of the equipment. A dropped, suspended, or similar ceiling that does not add strength to a building is not a structural ceiling. Where ceiling height exceeds 6 ft, it is still advisable to maintain clear space above equipment, if possible. No equipment foreign to the electrical equipment (piping, ducts, roof drain piping, or HVAC equipment) may be allowed in this space. Rooms containing MCCs should be ventilated, not air-conditioned, so that the ambient temperatures around both the motors and their controllers are similar. Air conditioning should be considered if ventilation will not be sufficient to keep the room temperature below 40 degrees Celsius (104 degrees Fahrenheit).

## C. Transformers

NEC Article 450 contains several requirements for installation of the various types of transformers. It also contains specific requirements for construction of transformer vaults.

The need for pads should be carefully considered under MCCs, switchboards, switchgear assemblies, unit substations, and transformers. Pads are not required in dedicated electrical rooms where the floor will be dry. Installing pads under MCCs and switchboards can often require the handle of a breaker or switch to be located higher than 6 ft, 7 inches, the maximum mounting height allowed by Article 380-8.

***Tips:*** *Make sure adequately sized electrical rooms are provided early in the project before the building layout is finalized. Watch out for columns in the interior of the room that will limit usable space.*

*Working spaces with large switchboards require two exits. Check NEC Article 110.*

*Working spaces with large switchboards and switchgear require front and rear access. Do not assume a switchboard can be located against a wall unless it is verified with at least two vendors.*

*In general, transformers require little maintenance and can be located outside in most climates. Switchgear should be located indoors unless there is a compelling reason to locate it outdoors. The cost of walk-in type switchgear often exceeds the cost of placing the equipment inside. Ultimately, locating switchgear and/or transformers is designer and operator preference.*

*MCC, panelboard, and metal-clad switchgear dimensions are nearly standard across manufacturers. But low-voltage switchboard dimensions and configurations can vary dramatically. Check at least two major suppliers and size the room for the worst case.*

Table 9-7 is a master table for environmental conditions and materials for electrical design. Typical tables may be produced for specific types of SPU facilities and customized for each project.

## Table 9-7 Environmental Conditions and Materials Applications Master Table

| Water and Wastewater (Area within project) | Condition | Raceway[1,2] (Preferred) | Raceway[1,2] (Typical) | Small Box[3] (Device, Pull, Junction) | Large Box (Pull, Junction) | Enclosure (Panelboard[4]) | Enclosure[5] (Power Control[6]) | Support |
|---|---|---|---|---|---|---|---|---|
| Concealed conduit or flush panel | DRY | IMC | EMT | Steel | NEMA 1 | NEMA 1 | NEMA12 | GALV |
| Electrical room | DRY | RGS | EMT | Steel | NEMA 1 | NEMA 1 | NEMA 12 | GALV |
| Motor room – no pumps or piping | DRY | RGS | IMC | Steel | NEMA 1 | NEMA 1 | NEMA 12 | GALV |
| Motor room (drywell) – pumps and/or piping | DAMP | RGS | RGS | CAST | NEMA 12 | NEMA 12 | MENA 12 | AL, SST, GALV |
| Wastewater | HAZ1-2, WET, COR | PVC-RGS | RGS | CAST | CAST | N/A | NEMA 4X SST | AL, SST, GALV |
| Wet well | WET | PVC-RGS | PVC-RGS | CAST | CAST | N/A | NEMA 4 | SST |
| Wastewater | HAZ1-1, WET, COR | PVC-RGS | PVC-RGS | CAST | CAST | N/A | NEMA 7 | SST, FRP |
| Below-grade vault – open flow | WET | PVC-RGS | RGS | CAST | CAST | N/A | NEMA 4 | SS |
| Wastewater | HAZ1-1, WET, COR | PVC-RGS | PVC-RGS | CAST | CAST | N/A | NEMA 7 | SS, FRP |
| Below-grade vault – closed piping | DAMP | RGS | RGS | CAST | NEMA 12 | NEMA 12 | NEMA 12 | AL, SS, GALV |
| Wastewater | HAZ 1-2, DAMP | RGS | RGS | CAST | NEMA 12 | N/A | NEMA 4X SS | AL, SS, GALV |
| Interior of power/control pedestal[7] | DRY | RGS | IMC, RGS, AL | Steel | NEMA 1 | NEMA 1 | NEMA 12 | GLAV, SS |
| Chemical areas[8] | WET. COR | PVC 80 | PVC-RGS, PVC 40 | PVC, FRP | NEMA 4X FRP | N/A | NEMA 4X FRP | FRP |
| Outside | WET | RGS | PVC-RGS | CAST | NEMA 3R | NEMA 3R | NEMA 4 AL or AA | SS, FRP |
| Embedded in concrete or block above grade | DRY, COR | PVC 80 | RGS, PVC 80 | Concrete tite Steel | CAST | N/A | N/A | N/A |
| Embedded in concrete in earth or fluid contact | DAMP, COR | PVC 80 | PVC80, PVC-RGS | CAST | CAST | N/A | N/A | N/A |
| Direct-buried conduits[9,10] | WET, COR | RGS | RGS, PVC 80 | CAST | Concrete | N/A | N/A | N/A |
| Transition[11] | Buried to exposed | RGS | N/A | N/A | N/A | N/A | N/A | N/A |
| Transition[11] | Embedded to exposed | RGS | PVC-RGS | N/A | N/A | N/A | N/A | N/A |
| Transition | Other | Note 12 | | | | | | |

Notes

[1] Aluminum conduit, strut, and boxes must be separated from concrete by anti-corrosion tape or other suitable means. Recommend stainless steel strut and avoid aluminum.

[2] For all S (signal) conductors, use PVC-RGS with 40 mil PVC coating

[3] With PVC-RGS conduit, all fittings, device boxes, and small J-boxes must be PVC coated by the conduit manufacturer

[4] Includes fused disconnects and safety switches

[5] Provide NEMA 4 and 4X enclosures with breather fitting.

[6] Including outdoor pedestals: sometimes ventilated, but usually include internal heaters

[7] Adapt materials to specific chemicals. See Table 9-8.

[8] Threaded or steel compression fittings

[9] For signal (S) and data highway (D) cables, use in the following order the first allowed for this area: PVC-RGS, RGS, IMC, and EMT

[10] Conductors in buried conduits must have XHHW type insulation.

[11] Wrap RGS with anti-corrosion tape to 3 inches on either side of transition.

[12] Make transitions from one type of conduit to another only at pull points or junction boxes. Exception: from buried to exposed use at least 10 ft of PVC-RGS.

### Definitions

DRY: conditioned space, no condensation or other source of moisture
DAMP: unconditioned space, moisture due to condensation or occasional splashing
WET: subject to direct water contact
CORROSIVE: exposure to uncommon chemical action such as salt air, hydrogen sulfide or hypochlorite
CONCEALED: in a wall cavity other than block or masonry

### Acronyms and Abbreviations

AL: aluminum
COR: corrosive
EMT: electrical metallic tubing
FRP: fiberglass reinforced plastic
GALV: galvanized
HAZ #: (class) # (division)
IMC: intermediate metal conduit
N/A: not applicable
N-Met: non-metallic
PVC: polyvinyl chloride # (schedule)
PVC-RGS: PVC coated RGS
RGS: rigid galvanize steel
SS: stainless steel

### 9.5.2.6 Enclosures and Framing Channels

#### A. Material Selection for Large Enclosures and Channels

Selecting the material for enclosures and framing channels must balance cost and performance. For many applications, a NEMA 4X panel may not be adequate because it does not provide chemical resistance other than salt spray. Materials for enclosures and framing channels are selected based on their suitability for atmospheres found on each project. No material is most suitable in all applications, not even 316 stainless steel.

Materials that should be considered include galvanized steel, painted steel, polyvinyl chloride (PVC)-coated galvanized steel, 304 stainless steel, 316 stainless steel, aluminum, fiberglass, polyesters, vinyl esters, ABS plastics, and PVC. They have the following benefits:

- Galvanized steel is a low-cost metal. A galvanized steel framing channel is very suitable in dry and damp locations where corrosion is not expected.
- For some applications, painted steel is both strong and has superior, less costly corrosion protection than that of galvanized steel.
- In many applications, 304 and 316 stainless steel can be used. While 304 stainless steel is a less expensive choice, it is slightly less resistant to corrosion. For hydrogen sulfide environments, 316 stainless steel is appropriate.
- Aluminum is a lightweight material with high corrosion resistance for a moderate cost. It is not recommended for areas with acids or alkalis.
- Fiberglass and fiberglass-reinforced polyester and vinyl ester materials have superior corrosion resistance to many chemicals that cause severe corrosion of metals. SPU prefers not to use fiberglass enclosures for any control panel.

Table 9-8 shows chemical resistance for various materials.

#### B. Utility Metering Enclosures

Most SPU facilities require metered utility power. The exception is a few SCADA cabinets with low power demand (unmetered). SCL has specific requirements for metering depending on amperage, voltage, and service phase. Design engineer must comply with SCL construction standards when specifying a service raceway, handhole, or metering equipment. In general, a 200A or smaller, 120/240V, 1-phase or 3-phase service requires only a meter base while a service equal or larger than 225A requires a CT enclosure and separate meter socket. Large installations with a switchboard lineup may include incoming line and metering sections. The electrical design engineer should verify the current requirements for each project. Commercial meter socket with manual bypass block is required for new services.

#### C. Panel Penetrations

Except for dry areas, enclosures of all kinds should never have top-entry conduit penetrations. Penetrations should only be in the bottom or low on the sides and always include sealing locknuts or conduit hubs with gaskets. If using gaskets on conduits, conduit grounding integrity must be active. If top penetrations are unavoidable, conduits should be routed such that any moisture and condensation from the conduit run is diverted away from the panel and the penetration located such that it is not directly above any electrical components inside the panel.

**Table 9-8**
**Corrosion Resistance**

| Chemical | Other Name | Corrosive Agents | Rcm'd Conduit | Rcm'd Enclosures |
|---|---|---|---|---|
| Primary Treatment | | $H_2S$, High Moisture | Aluminum PVC-coated steel PVC Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Aluminum Sulfate | Alum | | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Aqueous Ammonia | Ammonium hydroxide | | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Calcium Carbonate | | | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Chlorine | | $Cl_2$ | PVC-coated steel<br>PVC<br>Fiberglass | Fiberglass |
| Chlorine Dioxide | | | PVC-coated steel<br>PVC<br>Fiberglass | Fiberglass |
| Ferric Chloride | | | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Fluorosilicic Acid | Fluoride | $H_2SiF_6$ | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Hydrochloric Acid | Muriatic acid | | PVC-coated steel<br>PVC<br>Fiberglass | Fiberglass |
| Calcium oxide | Lime | | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Ozone | | | Galv Steel Aluminum<br>PVC-coated steel<br>PVC Fiberglass | Galv Steel<br>304 SST<br>316 SST<br>Fiberglass |
| Polymer | | | Galv Steel<br>Aluminum<br>PVC-coated steel<br>PVC<br>Fiberglass | Galv Steel<br>304 SST<br>316 SST<br>Fiberglass |
| Potassium Permanganate | | | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |

| Chemical | Other Name | Corrosive Agents | Rcm'd Conduit | Rcm'd Enclosures |
|---|---|---|---|---|
| Sodium Bisulfate | | | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Sodium Carbonate | Soda ash | | PVC-coated steel<br>PVC<br>Fiberglass | Fiberglass<br>304 SST<br>316 SST |
| Sodium Chlorite | | $NaCLO_2$ | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Sodium Hydroxide | Caustic soda | NaOH | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |
| Sodium Hypochlorite | | | PVC-coated steel<br>PVC<br>Fiberglass | Fiberglass |
| Sulfuric Acid | | | PVC-coated steel<br>PVC<br>Fiberglass | 304 SST<br>316 SST<br>Fiberglass |

Notes

[1] Conduit and enclosure type may also depend on other environmental factors such as temperature, moisture, sunlight, or sea air. The electrical design engineer must account for these factors when selecting materials. SPU prefers minimal use of aluminum materials.

Acronyms and Abbreviations

PVC: polyvinyl chloride
SST: stainless steel

### 9.5.2.7 Mounting Heights

Equipment and devices should be mounted at the heights listed in Table 9-9. Exceptions are equipment and other devices, which may be mounted at other heights if only noted on the drawings and compliance with NEC.

**Table 9-9**
**Mounting Heights for SCADA Equipment and Devices**

| Equipment/Device | Mounting Height[1] | Remarks |
|---|---|---|
| Starters | 5 ft, 6 inches | |
| Safety Switches | 5 ft, 6 inches | |
| Lighting Switches | 4 ft | Except hatch entry |
| Selector Switches | 4 ft | |
| Outdoor Receptacles | 4 ft | Above grade |
| Standard Receptacles | 3 ft | 4 ft wet & damp locations |
| Clock Receptacle | 1 ft, 6 inches | Below ceiling |
| 3-Phase Receptacles | 4 ft, | |
| Telephone Outlets | 2 ft, | |

| Equipment/Device | Mounting Height[1] | Remarks |
|---|---|---|
| Emergency Lighting | 8 ft–10 ft | |
| Interior lighting | 8 ft-10 ft | |

Notes

[1] From finish floor to centerline of equipment unless otherwise noted.

### 9.5.3 Voltage

This DSG covers nominal standard system voltages of the low and medium-voltage class. Voltage considerations for SPU projects follow ANSI/IEEE Standard 141 (ANSI C84.1) for nominal standard system voltages and their tolerances. The standard defines three voltage classes:

1. **Low voltages** are used to supply utilization equipment and, by definition, are 1,000V and less.
2. **Medium voltages** are used as primary distribution voltages to supply step-down transformers to low-voltage systems and are greater than 1,000V but less than 100,000V. Medium voltages of 13,800V and less are also used to supply utilization equipment such as large motors.
3. **High voltages** are used to transmit large amounts of electrical power between transmission substations, and are higher than 100,000V. Note that the design of high-voltage systems is beyond the scope of this document.

Table 9-10 shows system voltage nomenclature used in the United States.

**Table 9-10**
**Electrical System Voltage Nomenclature (United States)**

| Name | Description |
|---|---|
| Single-number 1-phase voltage<br>Example: 120V, 1-phase | 2-wire, 1-phase system where the voltage indicated is the nominal voltage between the two wires |
| Single-number 3-phase voltage<br>Example: 480V, 3-phase | 3-wire, 3-phase system where the voltage designates the nominal voltage between any 2-phase wires |
| 2-voltage designation where smaller number is first<br>Example: 120/240V, 1-phase | 3-wire, 1-phase voltage in which the nominal voltage between phase conductors is 240V and the nominal voltage between either phase conductor and neutral is 120V |
| Designation such as 480Y/277 or 208Y/120V, 3-phase | 4-wire, 3-phase system supplied by a wye connected transformer. The first number indicates the nominal phase-to-phase voltage and the second number indicates the nominal phase-to-neutral voltage |
| Designations such as 240/120V | Generally, a 3-phase delta system, in which one phase is center-tapped, with the center tap grounded to provide 120V power. These are often referred to as "red-leg" or “wild/Hi-leg" delta systems.<br>Note: Wild-leg systems are typically used for small pump stations where little 120V power is required. They should be avoided for general use because 120V power is inherently limited. |

Typical voltage for SPU facilities is 480V, 3-phase. Where possible, SPU prefers 480Y/277V. SCL supplies most City electrical systems. SCL typically supplies 240/120V 1-phase to residential areas while industrial areas are equipped with 480V systems.

Low-voltage power for lighting, receptacles, and miscellaneous power needs should be distributed at 208Y/120V, 3-phase, 4-wire, unless some other power need dictates a different voltage. Low-voltage power should be supplied by installation of 480Y/208V, 3-phase transformers located at each load center. Instruments should be powered from a separate supply transformer and panelboard or directly from the control panel.

Many 480V systems are provided with a neutral and are rated 480Y/277V, 3-phase, 4-wire system, with the 277V line-to-neutral voltage used for lighting circuits. The use of 277V loads presents problems in ground fault protection when using double-ended substations. Small dry-type transformers rated either 480-120/240V 1-phase or 208Y/120V 3-phase are then provided to supply 120V lighting and convenience receptacles. Where several individual loads of 500 kilo-volt ampere (kVA) or more must be supplied, 4,160V or higher should be considered for this equipment.

Power distribution voltage often depends on the supply voltage available from the serving utility. In a case where the load is small and located in a concentrated area, service from the utility at 480V, 3-phase should be specified. Larger sites (where loads are spread out and a number of unit substations are required) should be supplied at a higher voltage. If the distribution system is directly connected to the incoming utility feeder, the voltage is generally 12 kilovolt (kV). If there are large motors that could be supplied at a higher voltage, distribution voltage could be 4,160V to supply the large motors without additional transformation.

**Tips:** *For facilities with total load up to about 2,500kVA, SPU prefers distribution voltage should be 480V, 3-phase system. For higher loads and/or long distances, medium voltage should be evaluated.*

*For large facilities with medium voltage distribution, keep unit substation transformer sizes at 2,500kVA or less to reduce the fault current available at 480V.*

*Except for office buildings or other commercial facilities, avoid 480Y/277V 4-wire systems.*

*Use 208/120V 3-phase, 4-wire systems for 120V system distribution whenever possible.*

*Avoid 240/120V 3-phase systems except for very small pump station applications where most of the load is 240V 3-phase. These "wild/Hi leg" systems have limitations in their ability to provide 120V 1-phase power.*

## 9.5.4 Wiring and Protection

This section describes SPU standards for wiring and protection.

> ***Note**: Throughout this and the following sections, the DSG specification for an electrical system component is shown in brackets. Not all components have a specification. A full list of specifications is available in **Appendix 9A - Standard Specifications for Electrical Design**.*

#### 9.5.4.1 Protective Devices

Electrical systems and equipment must be protected against overcurrent, phase-to-phase faults, and phase-to-ground faults. Two basic types of protective devices are the fuse and circuit breaker. A variety of devices fall within these two broad categories.

##### A. Fuses [Spec 26 28 13]

A fuse protects a circuit by fusing open its current-responsive element when an overcurrent or short circuit passes through it. A fuse combines both direct sensing and interrupting elements in a single, self-contained device. A fuse is also direct acting. That is, it responds to a combination of magnitude and duration of circuit current flowing through it. It is 1-phase, non-resettable and cannot interrupt a circuit during normal operation. A fuse must be used in conjunction with a switch for normal circuit interruption. Fuses are often used in combination with circuit breakers to provide current-limiting and increased fault- interrupting capacity.

| Advantages | Disadvantages |
|---|---|
| Low cost—generally the lowest cost option | Nonrenewable—must be replaced after operation |
| High interrupting capacity | Operates phase-independently—risk of 1-phase operation |
| Current limiting | Must be used in conjunction with switch to interrupt normal load current |
| | Generally, requires more space than comparable circuit breaker (low voltage) |
| | Can be difficult to determine whether fuse is blown |

##### B. Medium-Voltage Circuit Breakers [Spec 26 28 16]

Circuit breakers for 5-kV and 15-kV systems are similar to a molded case circuit breaker. However, medium-voltage circuit breakers are larger and more sophisticated and can interrupt much higher currents. Standard technology is the vacuum interrupter. In vacuum-type breakers, the breaker contacts are enclosed in a vacuum bottle and the arc drawn during operation is contained within this vacuum. Older medium-voltage circuit breakers use air circuit breakers in which the arc was drawn in air, then pulled into large arc chutes. Medium-voltage circuit breakers do not come with built-in overcurrent or short circuit protection. They must be specified with protective relays, typically 3-phase overcurrent relays, and one ground relay.

| Advantages | Disadvantages |
|---|---|
| Nondestructive operation—can be reused after fault interruption | Higher cost than fuses |
| Inherently 3-phase operation | Lower fault interruption capability compared with fuses |
| Combines switch and overcurrent protection in one device | Not current limiting (except for specially designed breakers) |
| Wide selection of types available | Molded case breakers must have instantaneous trip (per UL); therefore, at high fault levels, coordination with standard molded case breakers is not feasible |

## C. Low-Voltage Circuit Breakers [Spec 26 28 16]

Low-voltage circuit breakers have contacts to determine that an overcurrent condition has occurred. Two major classifications of low-voltage circuit breakers are defined in ANSI C37.100: molded case circuit breaker and low-voltage power circuit breaker. For most SPU applications, some form of molded case circuit breaker is preferred. The standard molded case circuit breaker has a thermal-magnetic trip unit with two separate functions: overload protection and short-circuit protection. More sophisticated devices are available, with solid-state (static) trip units offering much greater flexibility in breaker adjustment.

## D. Low-Voltage Ground Fault Protection

Ground fault protection should be provided on all of the following:

- Transformer secondary and service entrance breakers rated 1000A or more.
- Feeder breakers rated 800A or more that are downstream of a circuit breaker equipped with ground fault protection.
- Motor branch circuit breakers for motors of 100 hp and more.

Ground fault protection on transformer secondary and service entrance circuit breakers and feeder breakers should have adjustable time delays. Design should consider zone selective interlocking to minimize outage to the zone nearest the ground fault. Ground fault protection provided on motor circuits should be the instantaneous tripping type.

## E. Selection of Protective Devices

Selecting protective devices depends on cost, engineering preference, nature of facility, and quality of maintenance staff. Table 9-11 lists recommended protective devices.

**Table 9-11**
**Medium and Low-Voltage System Protective Devices**

| System Type | Protective Device |
|---|---|
| Medium Voltage Systems | |
| Main Switchgear—Large Facility | Medium-voltage circuit breakers (metal-clad switchgear) |
| Main Switchgear—Small Facility | Fused interrupter switches (metal-enclosed switchgear) |
| Transformer Primary | Fused interrupter switch |
| Low Voltage Systems | |
| Panelboards | Standard molded case circuit breaker (thermal-mag) |
| Switchboards ≤ 400A | Main and feeders > 100A: adjustable instantaneous molded case<br>Feeders ≤ 100A: standard molded case |
| Switchboards > 400A | Main: molded case with solid-state trip unit<br>Other—same as above |
| Switchboards > 2,000A | Main and feeders: insulated case with solid-state trip unit |
| Switchboards > 2,000A—Critical Facilities | Main feeders: low-voltage power circuit breaker with solid-state trip unit |

| System Type | Protective Device |
|---|---|
| High Fault Currents—480V | Circuit breakers up to 65,000A<br>For higher fault duties, use listed circuit breaker/fuse combination for up to 200,000 RMS |

Acronyms and Abbreviations
A: amps
RMS: root mean square
V: volt

### 9.5.4.2 Conductors and Cables [Spec 26 05 19]

Copper is used for most applications, although lower cost aluminum conductors may be considered for large feeder and service. In general, all conductors should be stranded. Solid No. 12 and No. 10 copper wire may be used for receptacle circuits, particularly with screw-type terminations.

Insulation and jacket materials distinguish one cable type from another. Cable insulations can be broken into two main categories: *thermoplastic* and *thermosetting*.

*Thermoplastic* insulation becomes softer when heated (like butter) and will flow like a liquid at high temperatures. It is generally cheaper to produce than thermosetting insulation. The most common example of thermoplastic insulation is THHN/THWN.

*Thermosetting* insulation does not soften or flow at high temperatures. It will eventually break down and decompose at high temperatures, but it will not soften. If thermoplastic insulation behaves like butter at high temperature, then thermosetting insulation behaves like a cake. It will burn, but not soften. XHHW is generally the least costly thermosetting insulation.

#### A. DSG Medium-Voltage Conductors (Above 600V)

Two types of insulation must be considered when specifying medium-voltage conductors:

- Cross-linked polyethylene (XLPE)
- Thermosetting ethylene-propylene rubber (EPR) compounds

Both have similar properties and ratings. EPR is less subject to treeing in the presence of water. All medium-voltage conductors should be shielded, EPR insulated, and jacketed in PVC or neoprene. Conductors with insulation rated 133% should be used on ungrounded and resistance grounded medium-voltage systems. Conductors with insulation rated 133% are normally specified on systems that are solidly grounded. Both 100% insulated conductors may also be used. A 5kV metal-clad cable (Okonite C-L-X) is generally provided without a shield.

For details on medium-voltage conductor construction electrical stress, see DSG Specification 26 05 19 in **Appendix 9A - Standard Specifications for Electrical Design.**

The electrical design engineer should use the NEC Article 310 ampacity tables to select conductor sizes for medium-voltage circuits. Design should consider the electrical effects of short circuit currents on the shields of these conductors. Application of each medium and high-voltage conductor should be reviewed for allowable short circuit current for the conductor size required and allowable temperature rise of the insulation before the short circuit protective device trips. Consult Chapter 11 of IEEE Standard 141 for more information. Several manufacturers have published data and graphs for selecting properly sized conductors for high fault currents.

## B. Low-Voltage Wiring Systems (600V and Below)

Low-voltage wiring systems generally should consist of insulated copper conductors installed in an approved raceway system. The minimum size conductor for power and lighting systems should be No. 12 American wire gauge (AWG). Conductors used for control circuits should be No. 14 AWG minimum. Larger conductors may be used where control circuits are long. See I&C chapter 10 for specific instrument wiring requirements.

### 1) Power Conductors and Cables

- **Conductors #8 and smaller and those used for lighting and receptacle branch circuits.** The SPU standard is PVC insulated, nylon jacket, UL listed, type THWN/THHN or XHHW.
- **Conductors #6 and larger.** The electrical design engineer should specify a cross-linked, thermosetting, polyethylene insulation such as UL type XHHW, XHHW-2, or RHH/RHW/USE. This type of insulation is required for conductors routed through open bottom handholes.
- **Power circuits to be installed in cable trays.** These should be UL listed. NEC does not allow single conductors smaller than No. 1/0 AWG in cable trays. Smaller feeder and branch circuit conductors to be installed in cable trays should be multi-conductor power cable rated type TC.

### a) Low-Voltage Conductors

Low-voltage conductors should be sized according to NEC Table 310.16 (Table 912). Conductor ampacity used in the calculations should be based on the appropriate temperature rating for the conductor and corrected for the ambient temperature that can be expected and conduit fill conditions. Because many terminals used in equipment for conductors No. 1 AWG and smaller are not UL listed above 60 °C, conductors No. 1 and smaller should be sized using their 60 °C ampacity. Where derating factors are used to calculate conductor size, either 75 °C or 90 °C ampacity, whichever is appropriate for the application, may be used as long as the ampacity calculated is equal to or less than the listed ampacity at 60 °C. Ampacity of 75 °C may be used if the equipment connected at both ends of the circuit is specified to have terminals rated for 75 °C.

**Table 9-12**
**Recommended 3-Phase Feeder Sizes for Copper Conductors**[1]

| Breaker Size | Circuit Amps | 3-phase, 3-wire Feeder Circuit | 3-phase, 4-wire Feeder Circuit | INSUL rating |
|---|---|---|---|---|
| 15 | 20 | 3/4"C-3 #12,1#14 G | 3/4"C-4 #12,1#14 G | 60 ˚C |
| 20 | 20 | 3/4"C-3 #12,1#12 G | 3/4"C-4 #12,1#12 G | 60 ˚C |
| 30 | 30 | 3/4"C-3 #10,1#10 G | 3/4"C-4 #10,1#10 G | 60 ˚C |
| 40 | 40 | 3/4"C-3 #8,1#10 G | 3/4"C-4 #8,1#10 G | 60˚ C |
| | | | | |

| Breaker Size | Circuit Amps | 3-phase, 3-wire Feeder Circuit | 3-phase, 4-wire Feeder Circuit | INSUL rating |
|---|---|---|---|---|
| 60 | 55 | 1"C-3 #6,1#10 G | 1-1/4"C-4#6, 1#10 G | 60˚ C |
| 70 | 70 | 1-1/4"C-3#4,1#8 G | 1-1/2"C- 4#4, 1#8 G | 60 ˚C |
| 80 | 75 | 1-1/2"C- 3#3, 1#8 G | 2"C- 4#3, 1#8 G | 60˚ C |
| 90 | 85 | 1-1/2"C- 3#3, 1#8 G | 2"C- 4#3, 1#8 G | 60˚ C |
| 100 | 95 | 2"C- 3#2, 1#8 G | 2"C- 4#2, 1#8 G | 60˚ C |
| 110 | 110 | 2"C- 3#1, 1#6 G | 2"C- 4#1, 1#6 G | 60˚ C |
| 125 | 125 | 2"C- 3#1/0,1#6 G | 2-1/2"C- 4#1/0,1#6 G | 75˚ C |
| 150 | 150 | 2-1/2"C- 3#1/0,1#6 G | 2-1/2"C- 4#1/0,1#6 G | 75˚ C |
| 175 | 175 | 2-1/2"C- 3#2/0,1#6 G | 3"C- 4#2/0,1#6 G | 75˚ C |
| 200 | 200 | 3"C-3#3/0,1#6 G | 3"C-4#3/0,1#6 G | 75˚ C |
| 225 | 230 | 3"C-3#4/0,1#4 G | 3-1/2"C-4#4/0,1#4 G | 75˚ C |
| 250 | 255 | 3-1/2"C-3-250 kcmil,1#4 G | 4"C-4-250 kcmil,1#4 G | 75˚ C |
| 300 | 285 | 3-1/2"C-3-300 kcmil,1#4 G | 4"C-4-300 kcmil,1#4 G | 75˚ C |
|  | 310 | 3-1/2"C-3-350 kcmil,1#4 G | 4"C-4-350 kcmil,1#4 G | 75˚ C |
| 350 | 335 | 4"C-3-400 kcmil,1#3 G | 4"C-4-400 kcmil,1#3 G | 75˚ C |
| 400 | 380 | 2[3"C-3-3/0,1#3 G]ea | 2[3"C-4-3/0,1#3 G]ea | 75˚ C |
| 450 | 420 | 2[3"C-3-4/0,1#2 G]ea | 2[3"C-4-4/0,1#2 G]ea | 75˚ C |
|  | 460 | 2[3"C-3#4/0,1#2 G]ea | 2[3"C-4#4/0,1#2 G]ea | 75˚ C |
| 500 | 510 | 2[3-1/2"C-3-250 kcmil, 1#2 G]ea | 2[4"C-4-250 kcmil, 1#2 G]ea | 75˚ C |
| 600 | 570 | 2[3-1/2"C-3-300 kcmil, 1#1 G]ea | 2[4"C-4-300 kcmil, 1#1 G]ea | 75˚ C |
|  | 610 | 2[3-1/2"C-3-350 kcmil, 1#1 G]ea | 2[4"C-4-350 kcmil, 1#1 G]ea | 75˚ C |
| 700 | 670 | 2[4"C-3-400 kcmil, 1#1/0 G]ea | 2[4"C-4-400 kcmil, 1#1/0 G]ea | 75˚ C |
| 800 | 760 | 2[4"C-3-500 kcmil, 1#1/0 G]ea | 2[4"C-4-500 kcmil,1#1/0 G]ea | 75˚ C |
|  | 820 | 2[4"C-3-600 kcmil, 1#1/0 G]ea | 2[4"C-4-600 kcmil,1#1/0 G]ea | 75˚ C |
| 1000 | 1005 | 3[4"C-3-400 kcmil, 1#2/0 G]ea | 3[4"C-4-400 kcmil, 1#2/0 G]ea | 75˚ C |
| 1200 | 1260 | 3[4"C-3-600 kcmil,1#3/0 G]ea | 3[4"C-4-600 kcmil, 1#3/0 G]ea | 75˚ C |
|  | 1240 | 4[4"C-3-350 kcmil, 1#3/0 G]ea | 4[4"C-4-350 kcmil, 1#3/0 G]ea | 75˚ C |
| 1400 | 1520 | 4[4"C-3-500 kcmil, 1#4/0 G]ea | 4[4"C-4-500 kcmil,1#4/0 G]ea | 75˚ C |
|  | 1425 | 5[3-1/2"C-3-300 kcmil,1#4/0 G]ea | 5[4"C-4-300 kcmil, 1#4/0 G]ea | 75˚ C |
| 1600 | 1680 | 4[4"C-3-600 kcmil,1#4/0 G]ea | 4[4"C-4-600 kcmil, 1#4/0 G]ea | 75˚ C |
|  | 1675 | 5[4"C-3-400 kcmil, 1#4/0 G]ea | 5[4"C-4-400 kcmil, 1#4/0 G]ea | 75˚ C |
| 2000 | 2100 | 5[4"C-3-600 kcmil,1-250 kcmil G]ea | 5[4"C-4-600 kcmil, 1-250 kcmil G]ea | 75˚ C |

| Breaker Size | Circuit Amps | 3-phase, 3-wire Feeder Circuit | 3-phase, 4-wire Feeder Circuit | INSUL rating |
|---|---|---|---|---|
| | 2010 | 6[4"C-3-400 kcmil, 1-250 kcmil G]ea | 6[4"C-4-400 kcmil,1-250 kcmil G]ea | 75° C |

Notes

[1] For long distance runs, conductor must be derated for voltage drop. All conductor sizes are based on ambient temperatures below 30° C. For higher ambient temperatures, use correction factors from NEC Table 310.16. Conduit sizes are based on THHN/THWN and XHHW insulation for phase conductors and RHW insulation for ground conductors.

### b) Larger Conductors

Terminals for larger conductors are rated for use with conductors rated 75 °C. The 90 °C ampacity of all conductors can be used in determining the size of the conductor to be used, if:

- The conductors are 90 °C rated for area of application (wet or dry).
- Derating is required due to high ambient temperatures or if the number of conductors being installed in the conduit exceeds 3.
- The resulting ampacity calculated does not exceed the 60 °C or 75 °C rating of the conductor.

### 2) Control Conductors and Cables

The minimum size conductor for control circuits should be No. 14 AWG. Larger size conductors, No. 12 AWG or 10 AWG, should be used for long circuits where voltage drop is a concern or where additional physical strength is required. The conductors should be PVC insulated, should have a nylon jacket, and should be UL type THWN/THHN/XHHW. Where multiple control conductors are required between two panels or terminal junction boxes, a multi-conductor control cable should be installed. Multi-conductor control cables should be constructed using UL type THWN/THHN/XHHW single conductors, bound together in a single assembly with a PVC jacket. The assembly should be manufactured in accordance with UL 1277 and should be UL and NEC Type TC suitable for cable tray installation.

Control conductors may be installed with motor branch circuit conductors where control devices are located at or near the motor. Individual conductors should be installed with branch circuit conductors No. 4 AWG and smaller, and multi-conductor cables should be installed where the branch circuit conductors are No. 2 AWG or larger. Where the branch circuit conductors are larger than No. 4/0 or parallel conductors are used, control conductors should be installed in a separate raceway.

### 3) Instrumentation Cables

The minimum size conductor for analog signal circuits should be No. 18 AWG and other low-voltage discrete DC circuits should be No. 16 AWG. Analog conductor should be installed as twisted shielded pairs (TSPs) and/or twisted shielded triads (TSTs) as may be required for the installation. A TSP should consist of two No. 18 stranded copper conductors with PVC insulation and a bare copper drain wire, twisted together within conducting shield and a flame-retardant jacket. A TST should be similar except that it should contain three No. 18 insulated stranded conductors. Instrumentation cables are available with both 300V and 600V insulation. Cables with 600V insulation should be used wherever equipment contains circuits that operate at above 120V to ground.

Cables with 300V insulation may be used wherever a physical separation is maintained from conductors that operate above 120V to ground. A TSP should be installed from each field-located device to the associated control-room-located instrument or panel without the use of intermediate terminal junction boxes, wherever possible. An exception is where multiple instruments (more than five) are located close to each other. In that case, a local terminal junction box may be installed to gather the single TSPs into a multi-pair cable. This cable should be made of multiple, individually jacketed, TSP conductors cabled together within an overall shield and jacket.

Where a large number of 24V discrete signals have been brought together in a terminal junction box and need to be connected to the terminals of a distributed control system or similar input/output assembly for a programmable logic controller (PLC), a multi-pair unshielded cable may be used.

## C. Metal-Clad Cables

Metal-clad cable (MC cable) is an alternative to individual conductors or multi-conductor cables installed in conduit. MC cable is a factory assembly of one or more insulated circuit conductors enclosed in a metallic sheath of interlocking tape, or in a smooth or corrugated tube. If properly specified, MC cable can be used for nearly any use. See NEC Article 330 for more on permitted uses. MC cables should be considered for large low-voltage feeders and for high-voltage feeders where they will be installed inside very large buildings. They could also be used effectively in light industrial and warehouse buildings where visual impact is not important. Cables of multiple voltages can be intermixed in the same cable tray systems without regard to cable ratings. The tray system can then be left without additional conduit protection as long as proper support is provided.

## D. Optical Fiber Cables [Spec 40 95 33.33]

Optical fiber cables are an integral part of a fiber optic communication system design. They implement analog and digital communications using light wave propagation within glass or plastic core of a fiber cable assembly. Fiber optic communication systems and optical fiber cables are designed and specified for various local and wide area systems:

- 10Mbs Ethernet
- 100Mbs fast Ethernet
- 10Gigabit Ethernet
- Token Ring
- FDDI (fiber distributed data interface)
- CATV (cable television systems)
- CCTV (closed-circuit (security) television)

### 1) Optical Fiber Cable Application and Specification

Optical fiber cables can be specified for a variety of rated applications, including aerial messenger, cable trays, plenums, riser, conduits, and direct buried. Care must be taken to ensure that manufacturers identified in the specifications can supply UL or Nationally Recognized Testing Laboratories (NRTL) listings for special applications.

Optical fiber cable specification requires selecting:

- Fiber type: Single or multi-mode
- Fiber style: Breakout or distribution
- Construction: Loose or tight buffered
- Core and cladding diameters
- Maximum attenuation dB/km
- Minimum bandwidth MHz-km
- Special application features: plenum rated, flame retardant, tray rated, direct buried, aerial messenger, etc.
- Fiber amount: 2 to 24 fibers generally

Critical elements for the selection and specification of optical fiber cables include:

- System communication and required bandwidth(s)
- System required distances
- System maximum dB levels
- System required applications: indoor, outdoor, below-grade, backbone, drops, network type, and termination requirements

### 2) Codes and Standards

NEC requirements for installation of nonconductive, conductive, and composite optical fiber cables and raceways are in Article 770 Optical Fiber Cables and Raceways. The following offer additional detail on fiber design, installation, and applications:

- IEEE 802.3, Telecommunication and Information Exchange Between Systems
- Telecommunications Industry Association (TIA) 492, Specifications for Optical Waveguide Fibers

### 3) Optical Fiber Types

Two basic types of optical fiber can be specified: single and multi-mode. They differ in operation, capability, price, ease of installation, and performance:

1. **Single mode optical fiber operation**. Consists of propagation of only one light wave within an 8.3/125/250-micron (µ) core, cladding, and coating (typical single mode core/cladding/coating diameters). Cables are not subject to modal dispersion and are not bandwidth and distance limited.
2. **Multi-mode optical fiber operation**. Consists of step index or graded index multiple light wave propagation within a 50/125-µ or 62.5/125-µ core and cladding (typical multi-mode core/cladding/coating diameters). Multi-mode optical fiber cables are subject to modal dispersion and are bandwidth and distance limited.

### 4) Optical Fiber Construction

- **Optical fiber structure.** Optical fiber consists of the basic elements of core, cladding, coating, and buffer layers. Core is the light transmission area of the fiber, constructed out of glass or plastic. Cladding surrounds the core and provides a lower refractive index at the core interface to cause reflection within the core so light waves are transmitted through the fiber. Coatings are usually multiple layers of plastic surrounding the cladding, preserving fiber strength, absorbing shock, and providing extra fiber protection.

- **Loose and tight buffered.** Loose or tight buffer construction isolates the fiber from external forces. Loose tube cables are designed to endure outside temperatures and high moisture conditions. The fibers are loosely packaged in gel-filled buffer tubes to repel water. Loose tube cable is restricted from inside building use, typically allowing entry not to exceed 50 ft per local codes. Loose buffer construction minimizes level of attenuation over a given temperature range.
- **Tight buffer or non-gelled constructions.** Able to withstand much greater crush and impact forces without fiber breakage but have an increased level of attenuation over given temperature range compared with loose tube construction.
- **Breakout and distribution style.** Contains several individual cables inside an outer jacket. Dielectric fillers are used to keep the cables positioned. A Mylar wrap containing a ripcord is contained in the jacket, allowing the cables inside to be exposed with ease to desired length when needed. Breakout design enables individual routing of fibers for termination and maintenance.
- **Distribution style (compact building cable).** Packages individual buffered fibers, reducing size and cost compared with breakout cable. The connectors may be installed directly on the 900-µm buffered fiber at the breakout box location.

## E. Splices and Terminations

Generally, SPU allows no conductor (regardless of voltage) to be spliced, but certain situations require special splices and terminations.

### 1) Low-Voltage Power Conductors

Low-voltage power conductors in lighting and receptacle circuits only may be spliced using UL-listed insulated, twist-on spring connectors (wire-nuts). Splices in conductors to process equipment, control elements, and instruments should be made with approved compression type connectors. Final terminations at motors and similar equipment where equipment will be removed for maintenance should be made with approved bolted connection. All splices and termination should be insulated with heat-shrinkable sleeves that provide insulation at least equal to that of the conductor.

Splices should not be tolerated in control and instrumentation circuit conductors. Where splices are required, they should be made on terminal strips in a junction box (terminal junction box). Control conductors and cables should be terminated at box lug type terminal blocks rated 600V. Instrumentation conductors and cables should be terminated using locking forked tongue lugs and screw type terminals.

### 2) Medium-Voltage Power Conductors

Splices should be allowed only in medium-voltage conductors where existing conductors must be extended and terminals are not available for the extension. Such splices should be made inside MHs or aboveground pedestals using pre-molded deadbreak elbows and modular splice assemblies of ethylene propylene-diene monomer (EPDM).

Terminations located indoors and in motor termination boxes should be factory pre-molded EPDM type. Terminations in pad-mounted transformers should be pre-molded EPDM loadbreak elbow type. All other medium-voltage conductor terminations should be made using factory pre-molded and skirted EPDM type or preassembled slip-on type terminators.

### F. Conductor Identification [Spec 26 05 53]

All conductors should be identified by a system of unique numbers. Circuit numbers should be keyed to the equipment to which the conductors are connected. Each conductor should be identified at each termination point and at all accessible locations, such as handholes, maintenance holes, pull-boxes, etc. Conductors should be identified by approved conductor and cable tags.

### G. Conductor Installation

Conductors and cable should be installed only in conduits and ducts that are properly sized, properly installed, and free from debris. Large conductors and cables in long conduit or duct runs or in conduit or duct runs with multiple bends should be reviewed carefully to verify they can be installed safely without damage to them. Pull-boxes should be installed to limit the number of directional changes of conduits to a total of not more than 270 cumulative degrees in any run between pull-points. Pulling tension and jam ratio calculations should be performed to determine if additional pull points or larger conduits are required.

For sample calculations for conductor installation, see **Appendix 9C - Design Calculations for Electrical Design.**

***Tip:*** *It is possible to design a conduit system that meets code but is impossible to install. This is especially true for large numbers of small wire (No. 12, No. 10) in a conduit. Even though code allows installing 35 No. 12 conductors in a 1¼-inch conduit, it is difficult to pull so many loose wires around three or four 90° bends. SPU prefers not to use standard* $90^0$ *bends. Use long sweep or minimum of 24" bend radius where possible.*

### 9.5.4.3 Grounding [Spec 26 05 26]

Electrical circuits, equipment, and equipment enclosures must be bonded and grounded as required by NEC Article 250. All process equipment including pipes, ductwork, and other structures subject to potential and current flow due to lightning, line surges, unintentional contact by higher-voltage lines, repetitive intermittent short circuit, static accumulation, or other abnormal conditions should be grounded by two ground connections. Refer to the following in designing grounding systems:

- NFPA 70—NEC
- WAC 296-46B-250 – Washington State Electrical Safety Standards
- ANSI/IEEE Standard 80—IEEE Guide for Safety in AC Substation Grounding
- IEEE Standard 142—IEEE Recommended Practices for Grounding of Industrial and Commercial Power Systems

- IEEE Standard 367-1987
- IEEE Recommended Protection for Determining Electrical Power Station Ground Potential Rise and Induced Voltage from Power Fault

Three types of grounding are discussed in IEEE Standard 142: system grounding, equipment grounding, and static and lightning protection grounding.

## A. System Grounding

Electrical distribution systems can be either ungrounded (no intentional ground) or grounded (intentionally grounded). For purposes of this DSG chapter, a *grounded system* is a system of conductors in which at least one conductor or point is intentionally grounded, either solidly or through an impedance. In other words, a system grounding is to connect a winding to the earth to provide a direct path for high frequency current to discharge in the event of overvoltage that could damage the conductor's insulation. The basic reasons for system grounding are to:

Limit the difference of electric potential between all uninsulated conducting objects in a local area

- Provide for isolation of faulted equipment and circuits when a fault occurs
- Limit over-voltages on the system under various conditions

## B. Service Entrance Grounding

SPU requires ground rod wells for all buried ground rods.

Each power supply system must be connected to a grounding electrode system meeting all requirements of NEC Article 250. Each item within the system must be bonded together by a bonding conductor sized according to NEC. When electrodes are included in the grounding electrode system, they should be 3/4-inch by 10-ft (minimum) copper-plated steel rod (copper weld or equal). NEC Article 250-52 requires that metal underground water pipes, metal frames of buildings (where effectively grounded), concrete-encased electrodes (embedded rebar), and grounding rings, in addition to any made electrodes, must be bonded together to form the grounding electrode system.

***Tip:*** *Include a grounding system connection to foundation rebar in new construction. SPU requires the grounding electrode conductor to be isolated from concrete by using a PVC sleeve to prevent from corrosion.*

## C. Medium-Voltage Grounding

Systems 2.4kV to 12kV should be low-resistance grounded. Installation of the ground grid required should be calculated using measured soil resistivity. The system grounding resistor should be sized to allow sufficient ground current to flow to provide immediate and selective clearing of the ground fault.

The zero sequence CT method should be used to monitor for ground currents because of their increased sensitivity over a residual scheme using the high-ratio phase CTs.

## D. Low-Voltage System Grounding

Low-voltage 480/277V and 208/120V, wye-connected, and 240/120V, delta-connected, 3-phase and 1-phase transformers must have their neutral solidly connected to ground. This ground connection should be short, straight, and sufficient size and have low enough impedance to effectively ground the low-voltage distribution system.

## E. Grounding Electrode Systems and Grounding Grids

A grounding electrode system should be provided for all premises' wiring systems as required by the NEC. The grounding electrode system should be used for grounding the neutral of the low-voltage power supply and the equipment ground conductors. A grounding grid should be provided at low and medium-voltage transformers and switchgear located outdoors to provide equipment grounding and system grounding, and to minimize step and touch potential.

## F. Transformer Grounding

A grounding grid should be installed at each transformer or switchgear assembly located outdoors. The first step in calculating the amount of grounding materials required is to determine system maximum available fault current and soil resistivity. Several methods are outlined in IEEE Standard 81, *IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System*. IEEE Standard 81 can be used or resistivity approximated based on soil types.

Where soil resistivity is measured, a complete grounding system design can be prepared. It is often sufficient to determine the approximate needs of the grounding system, install a system based on available data, and then verify that the system is adequate. The following grounding system should be adequate in areas where soils have reasonably low levels of resistivity:

- Supply transformers (pad-mounted or unit substation type) 1,000kVA (480 V) and with a minimum of two No. 2 bare copper ground connections to a ground mat constructed under and around the transformer.
- The ground mat should be constructed of No. 2/0 bare copper conductors and copper-clad steel ground rods in sufficient quantity to result in a measured resistance to ground of 1 ohm.
- For larger transformers, the entire grounding system, including the connections to the transformer, should be No. 2/0.

Where high-resistivity soils are encountered, a complete grounding system design should be performed according to IEEE Standard 80.

## G. Equipment Grounding

NEC Article 250 covers requirements for equipment grounding. Non-current-carrying metal parts should be ground for all fixed equipment likely to become energized. The equipment grounding connection should be provided by an equipment grounding conductor, sized according to NEC Table 250-95 and routed with phase conductors. Use of a metallic raceway system for grounding is not acceptable. All metallic segments of the raceway system must be bonded to the equipment grounding conductor installed in it.

### H. Instrumentation and Computer Grounding

Instruments should be grounded with an insulated equipment grounding conductor that can be run in the same raceway with the power conductors. A dedicated power circuit with a separate insulated grounding conductor should be used for the computer system. If the environment is electrically noisy, an isolated grounding conductor run back to the main service ground point may be necessary but is not required for most SPU projects.

### I. Surge Protective Devices Grounding

I&C design engineers specify surge protective devices (SPDs) for nearly all I&C panels located outside a building and for some equipment inside buildings. Equipment likely to be equipped with SPDs includes field-located analog instruments with or without 120V power supplies, field located control panels with 12V power supplies and analog signal connections, and packaged equipment control panels. Connection of the surge protection equipment to a low impedance ground is critical to its operation. Where multiple devices are located in close proximity, a common ground must be used to minimize potential differences between devices. Ground conductor length must be kept to a minimum and the conductor size must be the largest that is practical.

All equipment within close proximity and equipped with surge protection must be grounded by a single ground conductor (single point) and a short length of larger ground conductor (No. 6 AWG minimum) located between the single point ground and the individual surge suppressors. The equipment ground conductor in the branch circuit supplying the equipment may not provide adequate grounding if the equipment is a long distance from the power supply. If so, size needs to be increased or special grounding provided to ensure proper operation of the surge suppressor.

### J. Lightning Protection System Grounding

NFPA 780, *The Lightning Protection Code,* and IEEE Standard 142 both cover grounding requirements of a lightning protection system. Lightning is the most destructive naturally occurring event and so essential to protect people and infrastructures from its effects. This chapter does not comprehensively cover lightning protection system and installation.

Where a simple lightning protection system is installed on a building or structure, its grounding system must be installed separate from the electrical system ground, but the two grounding conductors must be interconnected to provide a common ground potential. Only a design engineer with specialization and substantial experience in these systems should design a lightning protection grounding system.

## 9.5.4.4 Surge Protective Devices [Spec 26 43 13]

The NEC distinguishes between surge arresters and SPDs, yet both provide surge protection. Surge arresters generally apply only to the *line* side of the meter or service main disconnect switch to provide a low resistance path for lightning surges to the ground. SPDs generally apply only to the *load* side to regulate the operation voltage level and protect the equipment. Some devices are listed for use in either location, but most are designed for use in only one location. A surge arrester is generally used in a large-scale protection system to discharge or bypass surge currents, while SPD shunts the current and clamps the voltage. Surge arresters are required to protect systems above 600V, while SPD primarily protects electrical systems below 600V.

## A. Primary Systems

Surge arresters are applied on power distribution systems to protect electrical equipment against the effect of over-voltages resulting from lightning, switching surges, motor surges, high-energy arc operations, faults, and other disturbances. The equipment they protect includes transformers, rotating machines, metal enclosed buses, shunt capacitor banks, protective devices, transmission lines, and power cables. A detailed discussion of primary surge arresters is beyond the scope of this document.

## B. Secondary Systems

### 1) Technologies

Several technologies exist for SPD construction:

- **Metal oxide varistor (MOV).** MOV technology is high-energy with reliable clamping voltage. Under normal operating conditions, the MOV is a high-impedance component that has a small leakage current passing through it. But when subjected to a voltage surge of 125% system nominal voltage, the MOV reacts in nanoseconds, becoming a low-impedance path to divert the surge away from the load.
- **Silicon avalanche diode (SAD).** SAD is used at the last panelboard feeding data, fire alarm, and communication systems. It is fast acting (in the picosecond range). Because of its limited energy handling, SAD is not recommended for high-exposure power applications like switchboards or distribution panelboards. A SAD/MOV hybrid SPD can provide fast-acting surge suppression through the SAD, with the MOV handling most of the surge energy. This hybrid SPD provides excellent repetitive qualities.
- **Spark-gap.** This technology uses a combination of gas-filled surge arresters, varistors, and suppressor diodes to obtain a fast-acting, high-energy suppression with good clamping voltage SPD.

### 2) Equipment Location

IEEE C62.41.1 defines three different locations of equipment that should be protected:

- **Location C** equipment includes outside equipment and service entrance. This includes service drop from the pole to the building, runs between the meter and service disconnect switch or panelboard rated for service entrance, and overhead lines to a detached building.
- **Location B** equipment encompasses feeders and short branch circuits. Items such as distribution panels and bus and feeder distribution are included in this category.
- **Location A** equipment includes the outlets and long-length branch circuits that supply the final loads.

IEC uses a similar approach to the three category locations defined by IEEE except that IEC classifies four lightning protection zones (LPZ 0 through 3). LPZ 0 designates outside equipment and service entrance and LPZ 3 designates final protected load.

For each location defined above, there are three standard surge-testing waveforms. One is the 0.5µS-100kHz ring wave (0.5µS rise time with a ringing frequency of 100kHz), which is comparable to a surge from a lightning strike. The other two waves are defined as combination waves, which are comparable to a surge from capacitors or switching on the system. The first combination wave is a 1.2µSx50µS (front time x duration) open-circuit voltage wave. The second is an 8µSx20µS (front time x duration) short-circuit current waveform. Maximum amplitude of a lightning-related surge on a facility's service entrance is a 20kV, 10kA combination wave (see IEEE C62.41).

## C. kA Ratings

SPD kA ratings are determined based on the unit's ability to repetitively suppress the ring and combination test waves. The larger the kA rating, the more times the unit can suppress the test waves before failure. For example, a 120kA SPD will suppress 12 times more test wave surges than a 10kA unit, although both provide the same level of protection (i.e. clamping voltage). The 120kA will simply last longer.

***Note:*** *The kA rating is based on the test surge waves. Some manufacturers market a unit based on a single massive surge test and then imply that this is the kA rating. Be very careful—such testing can be very inaccurate.*

## D. Grounding

For SPDs to properly function, an effective grounding system must be installed. Make sure the system impedance to ground is less than the 25 ohms (Ω) specified in the NEC. In facilities with sensitive equipment, the recommended impedance to ground is less than 5Ω.

Be sure there is protection at the facility service entrance and at all of the panels supplying power to equipment that either produce surges or are susceptible to surges. The protection with the highest current rating should be at the service entrance, as close as possible to the service entrance ground. Interior panels can have a lower ampere rating. Locate SPDs as close as possible to the equipment that produces surges and to the equipment being protected. Connect SPDs using the shortest direct leads possible. This will greatly affect SPD performance.

## E. Lightning Protection [Spec 26 41 13]

Lightning protection systems protect structures from lightning damage.  They do not protect electrical equipment. Devices such as transient voltage surge suppressors protect electrical systems. Protection for overhead transmission lines (also known as static wire) or high-voltage air insulated substations is beyond the scope of this DSG chapter.

The primary reference for lightning protection systems for structures is National Fire Protection Association (NFPA) 780, Standard for the Installation of Lightning Protection Systems.

## 1) General

Lightning will tend to strike a surface according to the tallest structure or person, surface of lowest potential, or surface with the sharpest point. Lightning, however, does not always follow these general guidelines.

A typical lightning strike can easily have a potential of 2 million V and contain a tremendous amount of energy. The lightning protection system should control this flow of energy and direct it to the ground. Although we can control and direct this flow of energy into the ground, the immediately surrounding area will be electrified at an elevated potential.

The first line of defense in a lightning protection system is the air terminal (also known as lightning rod or Franklin rod). A typical air terminal is composed of copper, threaded at the base and fashioned to a sharp point at the other end, ⅜ to ½ inch in diameter, and of varying lengths from 12 inches and greater. Each air terminal is affixed to a threaded base attached to the structure. A main conductor is bonded to each base to interconnect all air terminals. Depending on structure geometry, a series of down conductors are required to direct the energy towards a system grounding rod.

## 2) Example Building

Consider a 12-ft high, 60-by-20-ft building with a flat roof. NFPA 780 dictates Class I or Class II materials, although aluminum is not recommended as a best practice (Table 9-13).

### Table 9-13
### Class I and Class II Materials

| Class | Description | Copper | Aluminum |
|---|---|---|---|
| I (<= 75 ft) | Air terminal, solid | 3/8-inch diameter | 1/2-inch diameter |
| II (> 75 ft) | Air terminal, solid | 1/2-inch diameter | 5/8-inch diameter |
| I (<= 75 ft) | Main conductor | 17 AWG | 14 AWG |
| II (> 75 ft) | Main conductor | 15 AWG | 13 AWG |

Acronyms and Abbreviations
AWG: American wire gauge

For the example building, Class I materials are required: 3/8-inch-diameter solid copper air terminals and 17 AWG bare copper main conductor. The minimum height of air terminals is 10 inches above the surface to be protected, so a standard 12-inch height would suffice.

However, if any other objects protrude above the top of the roof (e.g., photoelectric cell), then the height of the air terminals should be increased to provide the required minimum of 10 inches above the protruding object. For the example building, the maximum allowed spacing along the edge between air terminals is 20 ft. Thus, eight air terminals are required, with four along each 60-ft edge.

Interconnecting each air terminal base is a 17 AWG bare copper stranded conductor. The main conductor should be supported or securely attached to the structure at a maximum spacing of 3 ft.

The minimum number of down conductors for any structure is two, but in no case should the distance between down conductors exceed 100 ft. Thus, the two required down conductors are placed at opposite corners across the diagonal of the building. Each down conductor should be protected from physical damage for a minimum height of 6 ft above-grade. Typically, a PVC conduit is used to provide this protection.

Although a mechanical method is acceptable when bonding the down conductor to the ground rod, an exothermically weld should be used. For the purposes of the lightning protection system, the two down conductors bonded to the two ground rods do not have to be bonded together with a bare copper conductor around the perimeter of the building. However, the ground rods can be bonded together with the perimeter ground ring as part of the power or communications grounding system.

## 9.5.5 Raceway Systems [Spec 26 05 33]

A raceway system should be installed to protect conductors for power, control, and instrumentation circuit conductors. Most SPU raceway systems include conduit systems, wireways, cable trays, and underground duct systems. For more detail on raceway systems, see DSG Specification 26 05 33 in **Appendix 9A - Standard Specifications for Electrical Design**.

### 9.5.5.1 Conduit System

#### A. Conduit Type

The raceway most often used to protect conductors is conduit. Conduit is available in many materials. SPU uses the following types:

1. Schedule 40 or Schedule 80 PVC
2. Rigid galvanized steel (RGS) conduit
3. PVC-coated galvanized rigid steel conduit
4. Intermediate metal conduit (IMC)
5. Electrical metallic tubing (EMT)
6. Liquid-tight flexible metal conduit (flex)
7. Corflex (CSA type RA90) rated for FT4, HL, and AG14

Aluminum conduit, Schedule 80 PVC, liquid-tight flexible non-metallic conduit, and flexible metal conduit (not liquid-tight) are also used for some applications.

Conduit type is project specific. PVC-coated RGS, RGS, and IMC offer superior physical protection and should be selected for applications where physical damage can be expected. PVC-coated RGS, Schedule 40 or Schedule 80 PVC, liquid-tight flexible non-metallic conduit, and aluminum conduit resist corrosion and should be selected where corrosive conditions can be expected.

### 1) Schedule 40 and Schedule 80 PVC

Schedule 40 PVC should be used where conduits are installed underground, either direct buried or concrete encased, because of its superior resistance to corrosion. Schedule 40 PVC may also be installed above-grade where a corrosive environment is anticipated, such as in a chemical room, and where the conduit can be protected from impact damage. Where PVC conduit is installed outdoors, or in areas subject to large changes in temperature, thermal expansion is a concern because the solvent-welded joints in PVC conduit installations can fail under large amounts of expansion. Expansion fittings should be specified for these installations. See NEC article 300 for information on installing conduit systems.

Schedule 80 PVC is a good selection for SPU facilities that use hypochlorite or chlorine gas. The PVC conduit should be compliant with NEMA TC 2. Schedule 80 is strong and provides excellent protection to the wires. Schedule 40 PVC is not as robust and should be used only for duct banks where the conduit is imbedded in concrete. It is very important that the glue used to weld the fittings to the pipe be either the same manufacturer as that for the PVC conduit, or the type of glue recommended by the manufacturer. PVC conduit has the same selection of PVC fittings as rigid conduit. All types of adapters, threaded ends, elbows and bushings are available.

### 2) Rigid Galvanized Steel Conduit

Rigid galvanized steel conduit should be used where conduits are exposed, subject to physical damage or concealed above ground. Rigid metal conduit must be used in hazardous locations. Rigid steel conduit should be hot-dipped and conform to ANSI C80.1. Rigid aluminum conduit should not be used. Rigid metal conduit and fittings can be used for water and wastewater applications in a non-corrosive environment.

### 3) PVC-Coated Rigid Galvanized Steel

PVC-coated RGS is preferred for conditions where conduits turn up out of a corrosive soil or pass through the interface between concrete and either the soil or a wet condition is exposed to the air. PVC-coated RGS conduit must be used in hazardous and corrosive locations, such as wet wells, or environments containing hypochlorite, or chlorine gas. PVC coated conduit is rigid steel conduit with external 40 mil 0.1 mm PVC coating permanently bonded to hot-dipped galvanized rigid steel conduit and internal galvanized surface. It complies with NEMA RN1 and is much stronger than standard PVC conduit. However, it can still corrode if not properly installed and can be damaged by being struck or scraped.

### 4) Electrical Metallic Tubing and Intermediate Metal Conduit

The galvanized coating of EMT resists corrosion well, but the walls are so thin that it does not resist physical damage well. EMT should be used in dry areas above the level where physical damage is likely to occur and should be concealed in walls for lighting, receptacle, and HVAC circuits.

IMC is not commonly used in industrial settings. IMC can be found in commercial buildings where high-voltage or high-current conductors are run in walls and above suspended ceilings. The fittings are compression type and do not seal out moisture and contaminants. The standards for conduits and fittings do not support the use of IMC and EMT in any SPU facility, including the Operations Control Center.

### 5) Aluminum

Although aluminum conduit is an excellent choice for corrosive environments, it cannot be installed in direct contact with concrete. Aluminum conduit must be installed on conduit spacers or other means when installed along a concrete wall that may be damp. If aluminum conduit must pass through a concrete wall, it should be installed through a PVC sleeve large enough to allow the sleeve to be sealed with an approved compound. SPU does not generally allow aluminum conduit (prefers PVC or RGS).

### 6) Liquidtight Flexible Conduit and Fittings

Liquidtight conduit is a flexible steel conduit composed of a single strip interlocked type steel strip, galvanized on both interior and exterior surfaces and is made liquid-tight by being covered with an extruded PVC jacket. The flexible conduit should conform to the requirements of the current Federal Specification No. WW-C-566, Conduit: Steel, Flexible. Be sure the NEC grounding requirements for using flexible conduit are followed. Where currents exceed a specific level for the size of conduit, a separate ground conductor must be installed and bonded to each end of the flexible conduit. The connectors for liquid tight conduit should be grounding type. PVC fittings for flexible conduit should not be allowed. Refer to manufacturer specifications and ratings if installation of flexible conduit is specified in a wastewater Class 1 Division 1 Group D hazardous environment.

***Tips:*** *Conduits run under floor slabs supported by piling must be tied to the floor system to avoid settlement problems.*

*Exposed conduit in process areas should be RGS not EMT. Non-electrical construction inspectors should be advised to make sure that RGS is used; there is little visual difference between rigid steel and EMT.*

*Non-metallic raceways should not be used to route instrumentation cables with 4-20mA DC signals due to the noise problems.*

## B. Conduit Size

For individual conduits to devices or loads, the minimum size of any exposed conduit should be ¾ inch in diameter. Although the NEC contains a listing for ½-inch-diameter conduits, standard engineering practice dictates use of ¾ inch in diameter as a minimum. The incremental cost is negligible for material and labor to install a ¾-inch conduit versus a ½-inch conduit.

However, whenever individual conduits are installed underground or below-grade, the minimum size of any conduit should be increased to 1 inch in diameter. Because it is more costly to install conduits underground, particularly beneath paved areas, larger size conduits allow the future addition of conductors. The proper method of installing new conductors into a conduit with existing conductors is to remove the existing conductors, swab the conduit clean, then pull all new and existing conductors into the conduit at once.

While NEC lists many sizes of conduits ranging from ½ inch to 6 inches in diameter, depending on type, SPU recommends that several conduit sizes be standardized within a project. The following sizes are recommended as standard: ¾, 1, 1½, 2, 2½, 3 and 4 inch.

## C. Duct Bank

When a project includes many conductors traversing from one exterior point to another, then an underground duct bank (concrete-encased or backfilled by other means) is the raceway method of choice. The most common conduit size is 4 inches in diameter, even when a smaller size conduit would suffice (except when used to feed a specific device or load). The incremental cost is negligible for material and labor for 4-inch conduits. In addition, the bank of conduit in the duct should simulate the look of a matrix. The most common duct bank configurations are 2-by-2, 3-by-3, 2-by-4, or 4-by-2 matrices. Larger matrices of duct banks are possible (e.g., 4-by-4 or 5-by-5), but derating of conductor ampacity must be considered because of the heating effects of all current-carrying conductors.

### 1) Fill Factor

The most important guide to minimum sizing of conduits is to maintain a fill factor within the limits of NEC Chapter 9, Table 1. Fill factor refers to the ratio of the cross-sectional area of all conductors installed in a conduit to the cross-sectional area defined by the inner diameter of the conduit. For most applications, maximum FF is 40% and specifically applies to three or more conductors installed in a single conduit. If only two conductors are installed in a conduit, then the maximum FF is 31%. If a single conductor is installed in a conduit, then the maximum FF is 53%.

#### a) Calculating Fill Factor

It is important to remember two key points when calculating FF:

1. Grounding conductors are included in the FF calculation.
2. Inner diameter of a conduit does not always match its trade size name.

For instance, the inner diameter of a trade size 2-inch rigid metal conduit is 2.083 inches, while the same trade size for a PVC Schedule 80 conduit is 1.913 inches. Refer to NEC Chapter 9, Table 4 for a list of conduits and internal diameters.

#### b) Exceptions

For conduits or nipples not exceeding 24 inches and installed between boxes, cabinets, and similar enclosures, the maximum allowable FF is 60%. In addition, the NEC-required ampacity deratings for current-carrying power conductors (e.g., 80% for four to six conductors and 70% for seven to nine conductors) do not apply these to short conduits or nipples.

Standard engineering practice dictates exceeding the NEC minima for two key reasons. First, specifying larger conduits (or, conversely, calculating lower FFs) will make it easier for a contractor to pull the wires into the conduit, thereby minimizing damage to the conductor insulation. Second, larger conduits allow the addition of more future conductors.

### 2) Conduit Bends

For the design of conduit runs, the NEC limits the total angle of bends to 360˚ between pull points, conduit bodies, junction boxes, pull boxes, and maintenance holes. These conduit bends can be composed of four 90˚, or eight 45˚, or 16 22.5˚ bends, or any combination totaling 360˚. However, standard engineering practice is to limit the total conduit bends to 270˚, of any combination. The intent of the 270˚ limit is to minimize the potential damage to conductors during installation by contractors.

***Tip:*** *Back-to-back bends in opposite directions, such as two 45˚ bends used for an offset, create greatest stress on conductors as they are pulled into a conduit. It is recommended you avoid this design.*

### 3) Pulling Tension and Jam Ratio Calculations

*Pulling tension* refers to using either a pulling eye or a basket grip and is directly related to the size of the conduit used, among other factors, with or without conductor pulling lubricants. *Jam ratio* refers to the ratio of the conduit inner diameter to the single conductor outer diameter. Bigger is not always better for conduits when jam ratio is concerned. Jam ratio becomes a potential issue only when several conductors of large outer diameter are pulled into a single conduit. Conductors can easily become jammed or wedged in the conduit during pulling, damaging the conductor. Thus, while FF may be acceptable for a particular conduit size, the jam ratio may still prove unacceptable. According to conductor manufacturer, Okonite, jamming is not likely to occur when the jam ratio is less than 2.8 or greater than 3.2 (i.e. the critical range to avoid is from 2.8 to 3.2). To mitigate the pulling tension, SPU prefers to use long sweep bend radii and to avoid the use of standard 90° bends for all sizes.

## D. Conduit Fitting

Conduit fittings should conform to ANSI/NEMA FB 1 and be threaded. Almost all of the available fittings are compliant with the ANSI/NEMA standard. In general, the fittings and conduit should conform to the specifications listed below:

- Provide a minimum of one spare conduit in each run for all underground conduit installations. The spare conduit must be the same size and type as the smallest conduit used. Where electrical service and telephone service are available from a single utility pole, provide one spare conduit of the same size and type as the signal (telephone) conduit.
- All fittings for rigid steel conduit must be rust-proofed and threaded for conduit connection. Couplings, nipples, bushings, connectors, etc. for general use must be made of galvanized steel.
- All boxes and fittings used with PVC-coated conduit must be furnished with a PVC coating bonded to the metal, the same thickness as used on the coated steel conduit.
- Cast or malleable iron boxes and fittings must have cadmium-zinc finish with cast covers and stainless-steel screws.
- Steel elbows and couplings must be hot-dipped galvanized. Elbows and couplings used with PVC-coated conduit must be furnished with a PVC coating bonded to the steel, the same thickness as used on the coated steel conduit.
- Cable tray conduit clamps must be malleable iron, hot dip galvanized, sized to suit the conduit to be clamped, and attachable at any angle.
- Fittings with covers must be equipped with neoprene gaskets, except for explosion-proof fittings, which are not designed to accept gaskets.

- Field wiring of intrinsically safe circuits in wastewater applications is to be segregated from non-intrinsically safe wiring by use of suitable barriers, separate wireways or trays.
- Where conduit crosses under roadways and railroad tracks, a spare conduit must be provided for power and control as a provision for future upgrade or in the event of original conduit failure. Install to SPU standards.

## E. Embedded Conduit Systems

Embedding conduits on a project should be considered carefully. It is often necessary because of a routing impediment, such as an overhead crane, but is just as often a design engineer's choice as the shortest route. Most projects use a combination of embedded and surface routing.

| Advantages | Disadvantages |
|---|---|
| Less expensive materials – PVC40 (unless magnet shielding is required) vs. RGS | Need to locate boxes while construction is incomplete – mistakes more likely |
| Generally, requires less labor to install | Cannot adjust location of devices or lights |
| Often provides shorter route – fewer materials | Can be difficult to transition between embedded and exposed routing |
| Outlets already located | Cannot expand boxes for more devices |
| No straps or anchors required (does need support in concrete form) | Cannot trace conduits visually |
| Does not clutter surfaces – more space for equipment | Need to coordinate carefully with building structure |
| Cleaner appearance | Embedding conduit in structural concrete requires careful planning and coordination. Each design must consider the structural design while making it possible for a contractor to install the conduit system as designed |

The electrical design engineer should be aware of several requirements:

- Embedding conduit in concrete is allowed only with approval of the responsible PE (PE's seal on structural drawings).
- Embedding conduit must not be larger or smaller than the outside conduit. Embedded conduits should be limited to 1 inch in diameter unless a larger size is coordinated with the structural engineer.
- Rigid steel or PVC conduit must not be spaced closer than one diameter of its neighboring conduit. Embedding conduits in structure slaps must be coordinated and approved by the responsible structure engineer for acceptable spacing.
- All conduits, including crossovers, must be located in the middle 1/3 of a structural member.
- Conduits must be located with a minimum cover of 2 inches, including fittings.
- Conduit must be fabricated and installed to require no change in reinforcing steel location or configuration.

- Coordinate with the structural engineer for conduit dimensions, acceptable spacing of embedded conduit, and minimum slab thickness for embedment of conduits.

### 9.5.5.2 Wireway

Wireways with conduit nipples may be used to interconnect electrical equipment where many separate enclosures are located close to each other. The wireway provides an ideal pathway between the enclosures and space for tapping of conductors. It makes it easy to group conductors from the various enclosures into conduits leaving the area. Wireways should not be used in critical applications where a single failure within the wireway could cause process failure or downtime. Refer to NEC Articles 376 and 378 on application of wireways.

### 9.5.5.3 Cable Tray System [Spec 26 05 36]

*Cable tray* refers to an assembly of sections and associated fittings forming a rigid structural system used to securely fasten or support cables and raceways. Cable trays provide support and safe transport for raceways, insulated conductors, and cables through and across buildings, facilities, and industrial premises. Cable tray systems are rare in SPU. Most SPU projects do not require high-density wiring installations.

### 9.5.5.4 Duct Bank System

A *duct bank system* consists of a number of handholes or maintenance holes interconnected by direct-buried or concrete-encased conduits. The conduits are grouped and routed along a single corridor to minimize space.

#### A. General

Duct banks should be constructed using PVC conduit, with appropriate spacers to maintain the NEC-required spacing. Consideration should be given to the use of separate duct banks for low-voltage (600V and less) and medium-voltage circuits.

The largest ducts should be installed at the bottom of each duct bank, with all of the spare ducts provided at the top of the duct bank. Even though different sizes of ducts may be required by the conductors and cables, the number of sizes being installed should be kept to a minimum. Each row in the duct bank should be the same size throughout its width. The minimum size to be installed should be 2 inch. Duct banks should be concrete encased where they do the following:

- Connect to buildings, structures, handholes, and maintenance holes
- Pass under roadways and parking areas
- Pass through areas where future underground work can be expected
- Provide color code, such as fluidized thermal backfill

Duct banks in other areas may be installed without concrete encasement.

### B. Communication System Duct Bank Not Required

If a communication system duct bank is not required, instrumentation cables rated 600V may also be installed in the duct bank if the cables are:

- Installed in galvanized rigid steel conduit through the duct bank
- Kept separate.
- Wrapped with fireproof tape through the handholes and maintenance holes

### C. Communication System Duct Bank Required

A separate duct bank should be provided for communication system cables, or those circuits must be contained in a conduit system where they pass through maintenance holes and handholes. Where a duct bank for a communication system is installed, it should also be used for routing instrumentation cables.

### D. Duct Bank Settlement

For projects where buildings and structures are supported by piling, it is important to consider the problem of duct bank settlement. In some cases, this differential settlement could be as much as 18 inches. In extreme situations, it may be necessary to pile-support duct banks and maintenance holes to reduce differential settlement. Always consult with the geotechnical and structural engineers on the project regarding settlement problems.

## 9.5.5.5 Fiber Optic Cable Raceway Systems

The electrical design engineer usually specifies and designs raceway systems that support optical fiber cable installations. Approved raceway systems for optical fiber cables include NEC Chapter 3 Raceways (rigid metallic conduit [RMC], IMC, rigid non-metallic conduit [RNC], EMT, and cable trays), optical fiber raceways (innerduct and multi-cellular).

### A. Codes and Standards

Refer to NEC Article 770 Optical Fiber Cables and Raceways for general requirements for installation of nonconductive, conductive, and composite systems.

NEC Article 770.9 identifies three types of optical fiber cables (not to be confused with *single mode* and *multi-mode* types, as typically identified by manufacturers of optical fiber cables):

- **Nonconductive.** Cables containing optical fiber only; no metallic members and no other electrically conductive materials.
- **Conductive (Armored).** Cables containing optical fibers and non-current-carrying conductive members, such as metallic strength members; no other electrically conductive materials.

- **Compost (Hybrid).** Cables containing optical fibers and current-carrying conductive electrical conductors, and which are permitted to contain non-current-carrying conductive members such as metallic strength members and metallic vapor barriers. Composite optical fiber cables are classified as electrical cables in accordance with the type of electrical conductors. Composite cables support transmitting telephone voice or video and high-speed data within the same cable.

### B. Raceway Fill

In general, raceway fill tables of NEC Chapters 3 and 9 do not apply when optical fiber cables are installed within raceways without current-carrying conductors.

Where optical fiber cables are installed within raceways with electrical conductors, the raceway fill tables of NEC Chapters 3 and 9 apply.

### C. Innerduct and Multi-Cellular Raceways

Standard optical fiber raceway system design for direct bury and concrete encasement applications consists of the following:

- Placement of innerducts within separately installed raceway(s)
- Multi-cellular raceway(s) with pre-installed innerducts.

Innerduct and multi-cellular raceway systems facilitate the installation of multiple optical fiber or other communication specialty cables inside common conduit, minimizing potential for cable damage.

When specifying and designing raceway systems for optical fiber cables, the following information should be coordinated with the originator of optical cable specifications and with cable manufacturers:

- Optical fiber type (reference NEC Article 770.9)
- Optical fiber amount and dimensions
- Optical fiber construction (weight, tensile strength, impact resistance, flexing and bending, riser ratings)
- Optical fiber raceway lengths (determining maximum pull tensions)
- Optical fiber minimum bend radius
- Optical fiber applications (reference NEC Article 770.154)

## 9.5.5.6 Terminal, Junction, and Pull Boxes [Spec 26 05 33]

Terminal boxes, junction boxes, and pull boxes should be sheet steel or fiberglass (fiberglass in hypochlorite facilities). Boxes must be galvanized and have continuously welded seams. Welds should be ground smooth and galvanized. Box bodies must be flanged and must not have holes or knockouts. The boxes commonly found in commercial buildings with pre-punched but still attached knockouts are unacceptable. Box bodies should not be less than 14-gauge metal and covers should not be less than 12-gauge metal. Covers must be gasketed and fastened with stainless steel screws. Boxes and fittings for wastewater must be rated for Class 1, Division 1, Group D hazardous environments.

Junction boxes and pull boxes should facilitate combining multiple circuits into a single conduit and the pulling of conductors and cables. The boxes should be sized to NEC requirements to accommodate the conductors and cables being installed and constructed of material suitable for their location. For more information on junction and pull boxes, see DSG Specification 26 05 33 in **Appendix 9A - Standard Specifications for Electrical Design**.

Two sizes of boxes are discussed here: device boxes used as junction and pull boxes, and boxes that must be larger than device boxes. Junction boxes should be shown on the drawings as required in the conduit system to group conductors, terminate cables, etc. Pull boxes may or may not be shown, depending on the project. Even if pull boxes are not shown, the specifications require the Contractor to install them to limit the number of bends in a conduit section to not more than three 90° equivalent bends. Note that while the NEC allows four bends, SPU specifications take precedence.

## A. Indoor Locations

Indoor locations vary from dry to wet and can include corrosive and hazardous atmospheres. The boxes used in indoor locations must withstand physical abuse, stand up to the environment, and keep water out of the raceway system.

Boxes used in dry areas may be either sheet steel or cast metal. Small boxes (4-by-4-inch) that may be subject to physical damage should be cast metal. Larger boxes in the same locations should be sheet steel. Small boxes located 4 ft above finished floor in lighting, as well as receptacle circuits and concealed boxes in all raceways, should be sheet steel.

Small boxes to be installed in damp or wet locations should be cast metal. Larger boxes may be cast metal, epoxy-coated sheet metal with stainless steel hardware and neoprene gaskets, 316 stainless steel, 5052-H32 aluminum with stainless steel hardware, or gasketed reinforced fiberglass with stainless steel hardware rated NEMA 4.

Cast metal conduit fittings such as conduits may be used as junction boxes in both dry and wet areas if the box contains no splices. Large device boxes should be used wherever splices are necessary.

## B. Outdoor Locations

Boxes to be installed in outdoor locations that have noncorrosive atmospheres should be installed using the same criteria as for indoor wet areas. Boxes should be installed to protect them from physical abuse or vandalism, either by locating them out of harm's way or installing them behind a removable barrier. Concrete pull boxes should be installed in underground runs of conduits where the number of conduits passing through them does not justify installation of either a handhole or a maintenance hole.

## C. Corrosive Locations

Boxes to be installed in corrosive locations should be rated NEMA 4X and should be a material suitable for the corrosive environment. These boxes should be located away from corrosive materials as much as possible. Acceptable materials include 316 stainless steel, reinforced fiberglass, and PVC. PVC may be used only in small sizes.

### D. Hazardous Locations

Boxes installed in hazardous locations should be UL listed for use in an area with a hazard classification—if a standard exists. Where a standard does not exist, the boxes should be designed to meet NEC articles 500 and NEMA 7 or 9 requirements as a minimum.

### E. Terminal Junction Boxes

Terminal junction box is a term applied to junction boxes that contain terminal strips for the termination of control, power, or instrumentation conductors. They should be constructed using a junction or pull-box suitable for the environmental designated areas and should contain terminal strips that allow termination of the conductors.

## 9.5.5.7 Maintenance Holes and Handholes

Maintenance holes and handholes are similar in construction except for size and are used for different purposes. Handholes are smaller and used as pull points and locations to redirect circuits in low-voltage and communication conduit systems in places where it is reasonable to work with the conductors from above ground. Maintenance holes are much larger and are used as pull points and locations to redirect circuits in medium-voltage duct banks and in low-voltage duct banks where the conductors are too large to work from above ground. Maintenance holes are constructed with enough depth to allow a worker to climb down into them. Because a worker must move within the maintenance hole without contacting the low and medium-voltage conductors that pass through it, the horizontal dimensions of the maintenance hole must be larger than that of a handhole.

### A. Handholes

Handholes should be precast concrete, should contain knockouts on all four sides (or bottomless for conduit entry), and should have a circular or rectangular covers suitable for a minimum of H-20 loading. Rectangular openings should be equipped with a hinged door suitable for the handhole size and location. Regardless of size, handholes located in vehicular areas must be equipped with covers rated for HS-25 loading, including those installed in driveways, parking areas, or other areas where vehicle travel can be expected.

Handholes smaller than 4-by-4 ft need not be equipped with cable racks and insulators.

Handholes installed in high groundwater locations where the inside of the handhole must be dry should not have knockouts and should have solid concrete walls with a gravity drainpipe routed to nearest cast basin and core drill holes with link-seal devices for all penetrations. Structure Buoyancy should be considered.

Handholes should be installed in low-voltage or communication systems as follows:

- At all 90-degree bends
- Adjacent to every building and/or structure where large numbers of ducts enter the duct bank system
- As necessary to limit pulling tension required for installation of conductors and cable to within safe limits

### B. Maintenance Holes

Maintenance holes should be precast concrete, should contain knockouts on all four sides and should have a round opening in the top. The top opening should be equipped with a 24-inch minimum cast metal circular cover suitable for H-20 loading. The maintenance hole should be a minimum height of 6 ft, 6 inches to allow a worker to stand fully erect within the maintenance hole.

Maintenance holes should be equipped with heavy-duty inserts and cable racks to provide support for conductors and cables that pass through them. All conductors and cables should be trained around the perimeter of the maintenance hole and should be tied into place with suitable wire ties or similar banding material.

Maintenance holes with electronics or electrical components installed inside should be equipped with a depressed area for installation of a portable sump pump or at minimum to support installation of a gravity drainpipe.

> ***Note:** In high groundwater areas, buoyancy may be sufficient to lift the maintenance hole out of the ground. It may be necessary to provide a drain in the bottom of the maintenance hole to allow the level of the water in the maintenance hole to rise and fall with the groundwater level.*

Maintenance holes for pull boxes should be used in all medium-voltage duct bank systems and in low-voltage duct bank systems where conductor size makes it impossible to work from above ground. They should be installed at all 90˚ bends and as necessary to limit the pulling tension required for conductor or cable installation to within safe limits.

## 9.5.6 Emergency and Standby Power Systems

This section describes standards for SPU emergency and standby power systems.

### 9.5.6.1 General

Emergency power systems are required by law or code for life safety. Standby systems are required for continuous operation of a plant or a process should the normal power source be interrupted. Typically, standby systems are installed by owner choice.

Emergency and standby power systems use the same equipment and often serve the same purpose.[1]

### 9.5.6.2 Emergency Power Systems

*Emergency power system* refers to an independent reserve source of electric energy. The emergency system, upon failure or outage of the normal source, automatically provides reliable

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[1] NEC defines two types of standby systems: legally required and optional. For NEC, legally required standby systems are those required by local, state, federal, and other codes to supply power to facilities where interruption of normal electrical supply could create a hazard or hamper rescue or fire-fighting operations. ANSI/IEEE Standard 446, IEEE Recommended Practices for Emergency and Standby Power Systems for Industrial and Commercial Applications, is an excellent reference on the subject of emergency and standby power systems.

electric power within a specified time to critical devices and equipment. Critical equipment is that whose failure to operate satisfactorily would jeopardize the health and safety of personnel or damage property.

Emergency power systems should meet all applicable requirements of NEC Article 700. Where large amounts of emergency power are required, the need could be supplied by an on-site diesel-driven engine-generator. Where emergency power is required only for emergency lighting and egress illumination, unit equipment as defined in Article 700 should be used.

#### 9.5.6.3 Legally Required Standby Power System

A *standby power system* is an independent reserve source of electric energy that, upon failure or outage of the normal source, provides electric power of acceptable quality and quantity so that the user's facilities may continue in satisfactory operation.

Legally required standby systems must meet all applicable requirements of NEC Article 701. Where large amounts of power are required, diesel-driven engine-generators should be installed on-site. Lighting requirements should be provided by unit type equipment defined in Article 701.

#### 9.5.6.4 Optional Standby Systems

Standby power supply equipment should be installed as necessary for safe egress from all buildings, continuous operation of critical control and monitoring functions, and continuous operation of process elements required during normal power. A diesel- or gas-driven engine-generator system can supply power for large power requirements. Unit type equipment, as defined in NEC Article 700, should be provided to supply supplemental and egress lighting requirements. An uninterruptible power supply system should be provided for all computer-based control and monitoring equipment that may not have integral battery backup capability.

#### 9.5.6.5 Engine-Generators [Spec 26 32 13]

Engine-generators are the most widely used on-site emergency or standby power. They can be powered by diesel, natural gas, gasoline, or even propane. To be used as an emergency or legally required standby power supply, the NEC requires on-site storage of sufficient fuel for two hours of full load operation. Therefore, natural gas engines are not often used. Because of fuel volatility, gasoline engines are seldom used except in very small sizes. Synchronous generators should be used for all applications.

#### 9.5.6.6 Diesel-Driven Engine-Generator

SPU prefers the diesel-driven engine-generator for emergency and legally required standby power. A diesel engine starts up to full speed much faster than other fuel engines. For optional standby power, the natural-gas-driven engine-generator should be given first consideration because it burns cleaner and longer. Gasoline and propane-driven engine-generators should not be used unless other sources of fuel are not available.

#### 9.5.6.7 Generator Ratings

Engine-generators are available in ratings from less than 1 kW to several thousand kW, with both diesel and natural gas available in most ratings.

### 9.5.6.8 Generator Sizing

Engine-generator sizing must be based on the needs of the system electrical load and starting requirements of the larger motors on the system. Generator-sizing computer software available from most manufacturers can be used to make the initial selection. The manufacturer should be consulted to verify proper generator selection.

Selection should be made once a complete list of loads and their sequence of application has been completed. Either one large motor or several smaller motors equal in total hp and started simultaneously will have the same impact on generator sizing. Soft starter vs across the line starter methods also impacts generator sizing. If several motors must start when the generator is connected to the load bus, all motor starters should be equipped with a time delay relay. A relay allows automatic sequencing, thus limiting an initial inrush.

Voltage drop during motor starting should be limited to 15% or less unless it can be verified that the motor will start satisfactorily at lower voltages and all other equipment operate as intended.

Generator fuel tanks, except for sub-base fuel tanks, should comply with environmental and fire codes per local jurisdictions having authorities.

### 9.5.6.9 Considerations for Load Types

Special consideration must be given to sizing a generator when the electrical system being supplied includes loads such as VFD systems, uninterruptible power supplies, and similar solid-state power equipment.

### 9.5.6.10 Unit Equipment

Unit type emergency lighting units should consist of a sealed lead acid or lead calcium battery, two 6-watt (minimum) lamps, a battery charger, and appropriate indicating lights and test switches, all contained in a single, compact case. The unit should meet all applicable requirements of NEC Article 700-7 and NFPA 101.

Unit equipment should be installed as required to provide egress lighting. Units must be powered from the branch circuit that supplies normal lighting in the area where it is to be installed as required by NEC Article 700-12(f). The connection to the branch circuit must be made ahead of all local switches.

### 9.5.6.11 Uninterruptible Power Supplies [Spec 26 33 53A]

For most SPU projects, relatively small DC UPS are required to keep the programmable automation controller (PAC)/SCADA system operational while the facility switches to emergency or standby power. The I&C design engineer should specify UPS needs for specific site requirements. Alternatively, the electrical engineer can size and write the technical specifications of the UPS used for backup power to motor/actuator operated gates. For example, UPS locates inside a roadside electrical cabinet in direct sunlight should require a thermal control system, such as an air conditioner and/or sunshield panels, to maintain the operating temperature of UPS batteries and electronics. Using offline UPS or line interactive UPS for less-than-critical equipment is recommended, where possible.

***Note:*** *The need for this special editing is that the electrical specification is intended for larger units and extended duration backup power, or large load support, rather than the substantially smaller I&C UPS.*

## 9.5.7 Transfer Switches [Spec 26 63 00]

The *transfer switch* refers to a switch used to transfer a load from one power source to another. It is a fundamental component of any emergency or standby power system. Most transfer switches are automatic to minimize the time a load is non-operational. Where there is either continuous supervision or operation of the load is discretionary, a manual transfer switch may be used. Manual switches are only used at sites that do not require a standby power system and are optional for mobile power sources.

### 9.5.7.1 Automatic Transfer Switches

Automatic transfer switches must be sized to handle the total load connected to them, whether a part of the load operates on emergency power or not. The switch capacity should be matched to the rating of the largest directly connected upstream protective device. Such a situation usually exists when an entire facility is switched from utility to generator power.

The basic design choice for the electrical engineer is whether to switch the neutral in a power system. Switching the neutral eliminates parallel paths for ground fault currents. It is essential in systems with ground fault protection circuits. While the NEC requires ground-fault protection on solidly grounded 480/277V wye services rated 1,000A or more, SPU requires more stringent recommendations (see DSG section 9.5.4.1C Low-voltage Ground Fault Protection). If ground-fault protection exists upstream of the ATS, the neutral should be switched (i.e. a 4-pole switch should be specified for a 3-phase system).

An ATS may operate with or without a delay-in-neutral position unconnected to either power source for an adjustable length of time. ATSs that transfer without a delay are required for emergency systems and used in-phase monitors to retransfer to utility power from generator power and usually require load-shedding before retransfer. A *delay in-neutral* ATS is the simplest to operate since all operating loads lose power, motors spin down, and the facility reconnects to the utility with minimum disturbance. Either mode of operation must be coordinated with the facility control system.

Most ATSs are equipped with standard voltage and phase sensors, and with adjustable timers. The electrical design engineer should carefully coordinate with the process, mechanical, and I&C design engineers to determine how the emergency/standby power system should function. For instance, it may be desirable to control when the facility transfers back to utility power. In that case, a retransfer inhibit function should be specified. A more common option is an “elevator module,” which produces a warning signal before the ATS retransfers to utility power. This signal allows time for the facility control system to shut down large loads before retransfer thus reducing sudden demand on the utility and voltage dip.

A 4-pole ATS must be used for a separately derived system, see NEC Articles 445.11 & 250.26 for code requirements.

## 9.5.8 Lighting Systems [Specs 26 51 00 & 26 56 00]

For SPU, three different lighting systems apply: (1) general illumination; (2) emergency/standby; and (3) exit signing. AGI32 Lighting Design Software, by Lighting Analysts, Inc. may be used to calculate and design both interior and exterior illumination.

### 9.5.8.1 General Illumination

*General illumination* refers to the lighting needed for visual tasks in and around a facility, see NEC table 220.12 General Lighting Loads by Occupancy and Table 220.42 Lighting Load Demand Factors for design calculations. Lighting for general illumination can be provided by various sources depending on the visual tasks anticipated, lighting levels required, mounting height of the luminaires, and frequency of use. Illumination should be supplied by a source that provides the highest light output (lumens) per watt of input power (efficacy), and reasonable color rendition for the tasks in the area.

### 9.5.8.2 Recommended Illumination Levels

In 1979, the Illumination Engineering Society (ISA) established recommended illuminance categories from A (the lowest) to I (the highest). Most SPU facilities fall into categories C, D, and E (Table 9-14).

**Table 9-14**
**Illuminance Categories**

| Category | Description | Level (footcandles) |
|---|---|---|
| A | Public spaces | 3 fc (30 lux) |
| B | Simple orientation for short visits | 5 fc (50 lux) |
| C | Working space where simple visual tasks are performed | 10 fc (100 lux) |
| D | Performance of visual tasks of high contrast and large size | 30 fc (300 lux) |
| E | Performance of visual tasks of high contrast and small size, or tasks of low contrast and large size | 50 fc (500 lux) |
| F | Performance of visual tasks of low contrast and small size | 100 fc (1000 lux) |
| G | Performance of visual tasks of critical importance | 300 – 1,000 fc<br>(3,000 – 10,000 lux) |

Acronyms and Abbreviations
fc: footcandles
lux: lumen per square meter

For more information on illumination, see the IESNA *Lighting Handbook*.

Washington State Energy Code applies to a very limited number of SPU projects because most of a facility’s areas are exempt. These exempt areas only require that the lighting meet a specified energy budget (watts/square ft) and have automatic controls, and other mandatory requirements. However, reducing lighting energy requirements is a design consideration for all SPU projects. Specify energy-efficient fixtures to reduce lighting energy requirements. All lighting should be LED; exterior lighting must use photocells and timeclocks. Interior lighting should use occupancy sensors with 10-60 minutes timeouts, depending on the space. Lighting should always be designed to minimize light spills and automate operating times. Lighting fixtures must be selected to reduce glare and provide full cut-off/down lighting to reduce spill upward (Dark Sky). Security lighting should be shielded and directed downward toward areas that require illumination and should not adversely affect adjacent properties. Lighting should always be designed to minimize light spill and automate operating times.

### 9.5.8.3 Luminaires

Many types of luminaires are available. SPU prefers those described here.

### A. LED

#### 1) General

LED bulbs should be most preferred for indoor and outdoor lighting applications, including hazardous classified areas. The keys to LED lighting are its energy savings and overall cost reductions. An LED can cut energy use by more than 80 percent compared to conventional incandescent lights and last more than 25 times longer than traditional light bulbs.

Like fluorescent lighting, SPU uses color temperatures: 2700 Kelvin (K)–3200K for warm white, 4000K–4500K for natural white, and 5500K–6000K for day white. Although 5500K lamps produce a higher light output per watt, 4500K–5600K lamps are recommended for most LED applications because they provide good to very good color (color rendition index [CRI] ≥ 70) with high efficiency.

#### 2) Design Considerations

The typical LED lighting fixture is straightforward for traditional lighting applications in nonhazardous environments. However, LEDs used in areas classified as hazardous have a variety of models depending on wattages and budgets. For example, a typical Crouse-Hinds Class I Division I light is about $1,200–$1,800 and weighs up to 53–90 lbs. An electrical engineer must always use caution when editing electrical specifications such as lumens, color temperatures, and heat dissipation requirements in hazardous environments.

### B. Fluorescent

#### 1) General

Fluorescent lamps should be used for indoor locations if LED lighting cannot fit in a project's requirements. Fluorescent lamps are available in several types and each has very specific characteristics. Because of their relatively long-life expectancy, these lamps are often used in 48-inch, 32-watt, T8, T5, and various CF type lamps. Consider using CF types for hazardous locations.

SPU uses fluorescent lamps with 3000K, 3500K, and 4100K color temperatures. Although 5000K lamps produce a higher light output per watt that approximates noon-time sunlight, 4100K lamps are recommended for most applications because they provide good to very good color with high efficiency.

#### 2) Design Considerations

Fluorescent luminaires used indoors should be one of four basic types:

1. Recessed type with a lens (or parabolic louver)
2. Surface type with a lens (or parabolic louver)
3. Open-chassis type
4. Enclosed and gasketed

All lenses should be 100% clear acrylic. All fluorescent luminaires should be specified with electronic ballasts.

**Recessed fluorescent luminaires.** Recessed fluorescent luminaires with lenses or parabolic louvers should normally be used in office areas, laboratories, and control rooms. The luminaires specified must be coordinated with the type of ceiling. A luminaire to be recessed in a lay-in ceiling cannot be installed in a plasterboard ceiling and vice versa. Two-lamp luminaires are preferred, but 3 and 4-lamp luminaires should be used where higher foot-candle levels are required and/or two-level switching is desired. Where 3 and 4-lamp luminaires are installed in office and control room areas, two-level switching should be provided. Be sure to check for local energy codes regarding fixture, lamp, and ballast requirements (see Seattle and Washington energy codes).

**Surface-mounted fluorescent luminaires.** Surface-mounted fluorescent luminaires with lenses may be substituted for recessed luminaires in areas where plasterboard ceilings are being installed.

**Areas with cathode ray tubes.** In areas that contain equipment with cathode ray tube (CRT) screens, selection of the lenses or parabolic louvers is specialized to avoid interference with CRT display. High-angle brightness (glare) must be controlled to avoid discomfort and fatigue of occupants. Proper selection of lenses, parabolic louvers, or indirect lighting can substantially reduce this brightness and thus improve the work environment.

**Open-chassis luminaires.** If they can be mounted at a height of 15 ft or less, open-chassis fluorescent luminaires should be specified for all industrial areas where moisture is not a problem. For higher mounting heights, consider low-wattage MH or HPS lamps. Open-chassis luminaires with reflectors should normally be used. Where the luminaires are to be suspended, a minimum of 10% uplight should be provided. In situations where surface mounting is necessary, no uplight is required and an open-chassis luminaire without a reflector may be used. All open-chassis luminaires specified should be industrial, heavy-duty type.

**Enclosed and gasketed luminaires.** Enclosed and gasketed luminaires should be specified for damp and wet locations. They should be UL listed as suitable for the type of area in which they will be installed. Luminaires should be manufactured of molded, high-impact resistant ABS plastic or reinforced fiberglass with a diffuser of high-impact resistant acrylic.

Hazardous location fluorescent fixtures can be used, but they should be evaluated first because of the higher fixture costs.

## C. High Pressure Sodium

### 1) General

HPS lamps are preferred for outdoor and high-bay indoor locations if LED lamps are not applicable to project environment. HPS lamps are available in a variety of wattages and are suitable for any orientation. Even though their color rendition is poorer than that of LEDs and fluorescents, their cost, generally good efficiency (lumens per watt) and relatively long life may make them an appropriate choice for outdoor, indoor industrial, and hard-to-re-lamp indoor areas. One characteristic of all HID lamps (HPS and MH) is that they require a warm-up and restrike time; they do not turn on at full brightness as does a fluorescent or incandescent lamp. The warm-up time for an HPS can be as much as three to four minutes, during which time the light output is greatly reduced. The restrike time for an HPS is usually one minute or less. Where immediate light output is necessary on re-energization, an auxiliary quartz lamp can be provided by some luminaire manufacturers. Improved CRI HPS lamps should be specified, if possible.

## 2) Design Considerations

### a) Indoor Applications

HPS luminaires installed indoors should be either open or enclosed and gasketed depending on the area where they are to be installed. Open luminaires should be installed in dry low and high-bay areas where they will be suspended and uplight is required. They should be installed in areas where the ceiling height exceeds 15 ft. Enclosed and gasketed HPS luminaires should be installed in all damp and wet areas where the mounting height exceeds 12 ft. Luminaires should be installed suspended and should be constructed using an acrylic or glass refractor that completely houses the lamp.

### b) Outdoor Applications

HPS lamps should be used for all lighting applications outdoors except where LEDs are not suitable for decorative lighting, such as at the entrances of administration buildings.

All exterior applications should use cutoff type luminaries, including full cutoff, cutoff, semi-cutoff, and non-cutoff, as deemed appropriate.

Security lighting should be provided on the outside of buildings and at entrances by wall-mounted HPS luminaires that use cutoff type optics and a prismatic glass or acrylic refractor to direct the light over a broad horizontal area.

Illumination should be provided at underground facilities by pole-mounted cutoff optic type luminaires. Mounting heights should not exceed 30 ft, and lamp size should be at least 150 watts. IES Type IV or V luminaires provide the best lighting for broad areas. A combination of distribution types can be used as needed. Luminaire manufacturers can assist in pole layout and computer analysis of illumination levels or the use of AGi32 can produce excellent results.

## D. Metal Halide

For high-bay, high-wattage, and for low-bay, low-wattage applications where high-accuracy color rendition is critical, MH lamps may be the appropriate choice. MH lamps can be used in the same areas where HPS lamps have been recommended.

## E. Incandescent

Incandescent lamps have very low efficacy and short life, but they turn on immediately when energized and have very low installation costs. They may have applications in places and where low temperatures, or hazardous environments exclude using other sources.

### F. Emergency/Standby Lighting

*Emergency lighting* refers to the minimum illumination needed for a means of egress to safely exit an area if normal power fails. For this section, the term emergency lighting is specific to those lighting systems required by NFPA 101 for protection of human life when the normal power supply fails. The term “standby lighting” is specific to auxiliary lighting systems not required by code but required for safety reasons should the normal power supply fail. The same equipment may be used for both lighting systems.

Emergency/standby lighting in office, lab, and control room areas may be provided by either recessed emergency lighting units or emergency lighting units that are integral to the fluorescent luminaires. In either case, sufficient units should be installed in all areas to provide adequate egress lighting for all building occupants. Units supplied must provide the minimum minutes of light required by UL 924.

Emergency/standby lighting in enclosed process areas should be provided by 12V unitized lighting units. At least one unit should be installed in each area where motors or other process equipment exist. Another unit should be installed in each electrical room that houses switchboards, unit substation, or MCCs. Lighting units may also be installed in other areas where the exit-way may be blocked by equipment or materials and a hazard may exist. Each lighting unit should be located to provide maximum illumination on the normal exit-way.

The NEC requires that all unit type emergency lighting systems be supplied power from the circuit that normally supplies the lighting in the area where the unit is to be located. Where more than one circuit supplies the area, the one that supplies the largest part of the traveled area should be selected as the power source.

### 9.5.8.4 Exit Signs

Exit signs and lighting should be provided in the administration building where the public and persons unfamiliar with the building may have access. Exit signs must provide clear direction to the exits. Rooms that have a single door that does exit to the outdoors need not be equipped with an exit sign. In addition, process buildings that contain multiple rooms so that the means of egress is not obvious should be equipped with a series of exit signs that direct a person to the nearest building exit. All exit signs that are electrically powered must contain an integral battery, charger, and LED lamp source to provide uninterrupted illumination should the normal power supply fail. The Life Safety Code (NFPA 101) defines the need for exit signing and lighting as well as design and installation requirements

## 9.5.9 Special Systems

This section describes standards for special SPU electrical systems such as those for fire alarm, security, and telecommunications.

### 9.5.9.1 Fire Alarm

Fire alarm system design is highly specialized and dependent upon jurisdiction. Contractor must coordinate with local fire marshals for detailed designs; however, the project design team is responsible for determining the general needs of a fire alarm system. Often, for small SPU facilities and installations, only smoke detectors are required; however, it is required that these smoke alarms connect to SCADA systems for monitoring. The electrical design engineer is responsible for delineating and classifying hazardous areas and shall comply with NFPA 820 for design and installation. One such area is around enclosed wastewater wet well odor control fans where both a combustible gas detector monitor and a Fire Detection System are required.

#### 9.5.9.2 Security

An electronic security system is only one part of physical security for access control, intrusion detection, and assessment. As security technologies are constantly evolving, it is important to develop the specific objective and comprehensive strategy before determining the required equipment. The electrical design engineer should work with the project owner and consult SPU security officers to provide the necessary power and infrastructure required for later installation of the security system.

For detail security system requirements, see *DSG Chapter 15, Physical Security*.

#### 9.5.9.3 Telephone and Data

The telecommunications industry is a fast-moving industry with constant changes. The most common telecommunications design considerations for construction projects include transmission media and telecommunications spaces. Offices that do significant telecommunications work should consider purchasing the BICSI Telecommunications Distribution Design Manual. The electrical engineer should consult with SPU SCADA engineers for determining the preferred method and concurrent standards for SPU network communication link.

##### A. Transmission Media

Life expectancy of telecommunications wiring is 15 to 20 years, depending on facility types and system bandwidth. SPU generally relies on copper, fiber, or wireless transmission media on construction projects. The right choice for a project depends on the situation and user.

Copper wiring may include UTP, STP, coaxial cable, or outside plant cabling. UTP is the most commonly used cable for serving outlets inside a building. The most commonly used exterior cables are gel-filled twisted pair cables.

##### 1) UTP Cable

UTP cable of the latest ratified category should be used for all data and voice applications. At a minimum, SPU projects should use Category 5e (but Category 6 is recommended, for both voice and data networks. Many companies sell category 6e and 6a, which are based on proposed 10G Ethernet standards. The current Category 6 standard may only be able to support future 10G Ethernet over 60m, which may be suitable for most projects. However, for longer distances the electrical design engineer should consider Category 6a cables because they are more likely to fully support 10G at 100m.

***Tip:*** *Be careful with conduit sizing for Category 6a cabling because it is considerably bigger than 6e. Minimum conduit sizing to outlet boxes is 1 inch but may need to be larger.*

##### 2) Voice-Over IP Cable

Acceptance of voice-over IP (VOIP) has led to some fundamental changes in the approach to voice cabling. New designs should treat voice cabling the same as data networks. In the future, most telephone handsets will be connected to Ethernet switches similar to personal computers. For this reason, all voice and data cabling should be terminated at patch panels instead of terminal blocks.

Backbone cabling between telecommunications closets needs to be fiber-optic cable due to emerging technologies and the unavailability of Category 6 backbone cable. Therefore, copper wiring will need to be run to the main communications room for voice. This will take the form of bundles of Category 6 cables. Copper wiring telecommunication technology is old and phasing out, hence fiber or wireless transmission networks should be utilized for SPU projects, where feasible.

#### 3) Wireless Systems

Wireless systems are also becoming more common for user flexibility and as security concerns are addressed by the industry. There is a common misconception that these systems require no wire, but this is incorrect. Wireless systems require multiple access points throughout a facility to provide adequate service. Help from manufacturer's representatives should be sought, as this is the fastest changing aspect of the industry. Items to consider are:

- Obstructions (particularly block walls).
- Number of users (access points share bandwidth; therefore, a 100MB/sec access point will provide only about 10MB/sec speed to each of 10 users).
- Future proofing: Access points will need to be replaced more often than cabling to upgrade speed.

As a rule, wireless systems supplement wired systems by providing access at locations where a wired system is difficult to install.

The current standard fiber-optic cable is 50µ laser optimized fiber. Where possible, SPU should consult with the SCADA engineer and the City of Seattle IT Department to get 62.5µ cable installed on new projects. The 62.5µ fiber offers limited support for 10G Ethernet.

Exterior copper cabling entering a building must be protected by a primary building protector assembly with a fusible stub. The exterior cable should terminate at a splice closure inside the main communications room and be connected to the fusible stub that is supplied with the primary protector assembly. This primary protection is required by the NEC and must be located within 50 linear ft of the cable being exposed.

## 9.5.10 Major Electrical Equipment

This section describes major electrical equipment installed on SPU infrastructure. SPU water quality equipment and pump stations use a great deal of medium-voltage switchgear.

### 9.5.10.1 Medium-Voltage Switchgear (4.16 kV–13.8 kV)

*Switchgear* refers to switching and interrupting devices alone or in combination with other associated control, metering, protective, and regulating equipment. A *power switchgear assembly* is a complete assembly of one or more of these devices and main bus conductors, interconnecting wiring, accessories, supporting structures, and enclosures.[2] Two types of medium-voltage switchgear are available:

- Metal-clad switchgear (circuit breakers)
- Metal enclosed Fused Load interrupter switchgear (fused switches)

Both are available for either indoor or outdoor installation.

## A. Metal-Clad Switchgear

*Metal-clad switchgear* is an assembly of drawout vacuum circuit breakers, auxiliary equipment, metering equipment, and insulated copper bus bars enclosed in a rigid metal assembly. Each compartment in the assembly is isolated from all other others by grounded metal barriers.

The circuit breakers are horizontal drawout type on rails. The breakers are operated by a motor-charged, spring-stored energy mechanism. The mechanism is front accessible and is charged by a universal electric motor and (in an emergency) by a manual handle. Each circuit breaker contains three vacuum interrupters operated by a common linkage. A source of control power must be provided to the circuit breakers. For utility and other critical installations, this control power is generally 48V to 125V DC and provided by station batteries. Control power of 120V and 240V AC can also be used, with each breaker provided with a small capacitive or other stored-energy device to ensure tripping power.

Metal-clad switchgear should be provided as the service entrance equipment for all medium-voltage distribution systems that require more than one main device and more than two feeder devices downstream of each main device. Metal-clad switchgear should also be provided where large motors are served directly from the medium-voltage distribution system.

## B. Metal-Enclosed Fused Load Interrupter

Metal-enclosed fused load interrupter switchgear includes interrupter switches, power fuses, bare bus and connections, instrument and control power transformers, and all necessary wiring and accessories.

Metal-enclosed interrupter switchgear is used for all medium-voltage distribution systems not using metal-clad switchgear. Where circuit requirements are 600A or less and 15,000V or less, pad-mounted interrupter switchgear should be used to make transformer taps and dual-source selective switching at pad-mounted transformers.

***Tips:*** *At 5kV and 15kV, fused switches are much less expensive than circuit breakers and require far less space. Use them for noncritical applications, where little switching will occur.*

*Medium-voltage circuit breakers offer much greater flexibility and reliability than fused switches. They can be used with a wide variety of protective relaying and provide automatic and/or remote operation.*

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[2] See Chapter 9 of ANSI/IEEE Standard 141 and ANSI/IEEE C37.20-1, C37.20-2, C37.20-3, C37.100, NEMA SG5, and NEMA SG6 for additional information on switchgear.

### 9.5.10.2 Low-Voltage Switchgear (Power Distribution) [Spec 26 24 13]

Two types of low-voltage enclosed switchgear are used in power distribution systems: metal-enclosed, low-voltage power circuit switchgear, and power switchboards. Panelboards are used for multiple small 480V loads. Most panelboards provide 120/240V 1-phase or 3-phase power.

#### A. Metal-Enclosed Switchgear

Metal-enclosed low-voltage power circuit switchgear is constructed according to ANSI C37.20-1 and meets the requirements of UL Standard 1558. It features individually mounted air break power circuit breakers in drawout construction. Power circuit breakers both with and without current limiting fuses are available. Circuit breakers are equipped with solid-state tripping systems and offer a wide range of adjustability. For more details on switchgear, see DSG Specification 26 24 13 in **Appendix 9A - Standard Specifications for Electrical Design.**

Metal-enclosed, low-voltage power circuit switchgear should be used where the available fault current exceeds 50,000A symmetrical at 480V or 65,000A symmetrical at 208V or 240V.

#### B. Switchboards

Power switchboards are available in either group or individually mounted configurations. The group-mounted configuration is normally used for small boards and in commercial construction. Both are constructed according to UL 891 and NEMA PB-2.

The main circuit protective devices in group-mounted switchboards are either fixed or drawout-mounted, but the branch devices are all fixed-mounted. The main device is a molded case circuit breaker, a molded case circuit breaker with solid-state trip units, an air brake power circuit breaker, or a bolted pressure switch. The branch devices are either molded case circuit breakers, with or without solid-state trip units, or fused switches. The standard short circuit rating for group-mounted switchboards is 50,000A RMS (root mean square) symmetrical, but higher ratings are available. For more details on switchboards, see DSG Specification 26 24 16 in **Appendix 9A - Standard Specifications for Electrical Design.**

Both the main and feeder circuit protective devices should be drawout type in individually mounted configurations. The standard short circuit rating for switchboards with individually mounted drawout circuit breakers is 50,000A RMS symmetrical, but higher ratings are available.

Switchboards with group-mounted circuit protective devices should be used where:

- Main bus rating is 800A or less.
- Fault current available is less than 50,000A RMS symmetrical.
- Feeder and/or branch circuit protective devices are all 225A or less.

Where the main bus rating must be greater than 800A and feeder breakers of 400A or larger are required, switchboards with individually mounted circuit protective devices should be used if the fault current available is 50,000A RMS symmetrical or less.

Where higher fault currents are available, metal-enclosed, low-voltage power circuit switchgear should be used.

## C. Panelboards [Spec 26 24 16]

Power distribution panelboards are usually 480V or 240V, 3-phase, 3-wire with 3-pole breakers serving small loads such as gate operators or automatic valves. If 277V power is needed, usually for lighting in commercial buildings, then a 4-wire panelboard should be installed.

Otherwise, panelboards should be installed as necessary to provide power to the 120V, 1-phase and 208V, 3-phase loads shown on the drawing. Branch circuit breakers must be sized in accordance with NEC Articles 210, 220, 225, and 430. Where NEC Article 220 allows the use of demand factors, they should be used with caution. Demand factors may be used for feeder and transformer sizing calculations, but not for branch circuit calculations.

Panelboards must have a rating not less than the minimum feeder capacity required for the calculated load. The maximum load connected to the panelboard should not exceed 80 percent ampacity of 100 percent rated panel capacity. Series rated panels must have the same magnitude short circuits rating to main breaker and panel and be UL Tested and labeled as Series Rated Equipment.

Where more circuits are required than can be provided by a single panelboard, provide a subfeed breaker in the transformer panelboard to supply a second panelboard. The second panelboard may be located remote from the first panelboard. All panelboards supplied from a transformer must have a main circuit breaker (transformer secondary breaker) sized in accordance with NEC Article 450.

The load on branch circuits that supply lighting and receptacles must be limited to 80% of the rating of the branch circuit protective device, per NEC Article 220-3 because lighting and receptacle loads must be considered "continuous." SPU recommends that the load on these circuits be limited further to 1,800-volt amperes (VA) to limit voltage drop on these circuits.

Branch circuit breakers for instruments or instrumentation panels where the exact load is unknown but is small should be sized at 15A to allow installation of multiple conductors in the same conduit without the need for derating. In addition, these circuits often pass through an instrument panel and become No. 14 AWG control conductors.

A separate branch circuit should be provided for each instrument and instrumentation panel unless several instruments are located at the same location, are all associated with the same flow stream or process, and monitor different parameters. In the above case, a toggle switch should be located adjacent to each instrument to disconnect it from the branch circuit.

Branch circuits for HVAC equipment rated 120V or 208V should be supplied power from the lighting and power panelboards. Branch circuit protective devices should be rated 15A minimum unless a larger size is required to supply the load.

The electrical design engineer should attempt to group circuits that perform a common function within a panelboard (i.e. all lighting together and all receptacles together). In addition, 3- and 4-wire branch circuits should be shown on the drawings wherever appropriate to minimize the amount of conduit that is required. These circuits should be connected to adjacent circuit breakers in the panelboard.

Where a common neutral is used for multi-wire branch circuits, the neutral conductor should be appropriately sized to account for third-harmonic neutral current generated by nonlinear loads such as computers. SPU prefers separate neutral conductor for every nonlinear load due to third-harmonic problem.

***Tip:*** *Provide ample extra space and spare breakers in all 120-V panelboards.*

## D. Receptacles

Duplex receptacles should be located throughout each facility to provide a ready power supply for portable tools. These receptacles should be located such that no item of process equipment is located more than 40 ft from a receptacle, whether inside or outside a building. Additional receptacles should be provided in areas where portable tools may need to be used and where the above criteria do not require one in the area. These receptacles should all be in addition to receptacles for connection of portable process equipment.

NEC Article 210-63 requires a 15A or 20A, 125V, 1-phase receptacle to be located on the same level and within 25 ft of heating, air conditioning, and refrigeration equipment on rooftops and in attics. Use NEC Article 220.44 and Table 220.44 Demand Factors for Dwelling Receptacles Loads for receptacle load calculations.

Inside an administration or maintenance building designed primarily for personnel, coordinate the location of receptacles with the architect. In office areas, provide outlets on at least three walls. In laboratory areas, multiple outlets should be located at workstations. Coordinate these locations with the laboratory designer. Duplex receptacles should be NEMA configuration 5-20R unless requirements dictate otherwise (e.g., hazardous location). All receptacles should be installed per current NEC. Receptacles located outdoors, or in places subject to washdown where they cannot be protected by mounting height (4-ft minimum above finished floor), should have a weatherproof cover.

Receptacles suitable for installation in Class I, Division 1 or 2, or Class II locations are often required for power tools. Specification of a dead front, interlocked, circuit-breaking receptacle similar to Crouse Hinds-type ENR is recommended.

Ground fault interrupter outlets should be installed in all locker rooms, bathrooms, rooftops, indoor wet areas, and other outdoor locations.

Receptacles to be installed in underground structures, and in areas where a corrosive atmosphere can be expected, should be manufactured of corrosion-resistant materials.

In many facilities, it is desirable to provide heavy-duty receptacles for use by welding machines. These are typically 480V, 3-phase receptacles rated 30A to 60A, but the receptacle type must be coordinated to match existing equipment.

### 9.5.10.3 Transformers [Spec 26 22 00]

Dry-type transformers are available in either ventilated or non-ventilated construction for both indoor and outdoor applications. However, temperature rating for dry-type transformers is more complex than that for liquid-filled transformers. The insulated system class system for dry-type transformers is made up of three elements of temperature:

1. Ambient rating
2. Winding rise
3. Hot spot

The ambient temperature represents the average temperature to which the transformer can be subjected. Ambient temperature is always 40 °C.

The winding rise temperature represents the actual temperature of the windings inside the transformer, averaged over the entire transformer. The winding rise temperature represents the ability of the materials and construction of the transformer to deliver rated output at a certain temperature. One of the methods used by transformer manufacturers to increase the efficiency of transformers is to increase the size of the coil conductors, which in turn lowers the operating temperature and results in lower energy costs. The four standard winding rise temperatures are 55 °C, 80 °C, 115 °C, and 150 °C. There is a vast difference in the construction and materials between a transformer rated with a winding rise of 55 °C versus 150 °C. The 55 °C is a typical rating for liquid-filled and more costly transformer because it is constructed to deliver rated output at only 55 °C.

The hot spot temperature represents some fictitious point inside the transformer coils having the longest thermal paths to the outside air. Theoretically, this point would be at the very first few windings of the transformer coil around the core. This hot spot temperature differential is determined by the manufacturer on prototype units. The three standard hot spot temperatures are 10 °C, 25 °C, and 30 °C.

Table 9-15 summarizes insulation system classification for standard transformers (from General Electric's *Electrical Distribution and Control*). Various combinations are available from different manufacturers (e.g., 80 °C or 115 °C winding rise with a 220 °C insulation system).

**Table 9-15**
**Insulation System Classification**

| Ambient + | Winding Rise + | Hot Spot = | Insulation System |
|---|---|---|---|
| 40 °C | 55 °C | 10 °C | 105 °C |
| 40 °C | 80 °C | 30 °C | 150 °C |
| 40 °C | 115 °C | 25 °C | 180 °C |
| 40 °C | 150 °C | 30 °C | 220 °C |

It is important to understand the proper terminology and ratings when specifying dry-type transformers. The temperature rating of 150 °C shows in both the winding rise column and the insulation system column. Thus, when specifying a high-efficiency transformer and a 150 °C insulation system with a corresponding 80 °C winding rise rating, the electrical design engineer may be specifying a lower efficiency 220 °C insulation system with a corresponding 150 °C winding rise rating. Table 9-16 lists feeder and breaker sizing for low-voltage transformers.

### Table 9-16
### Low-Voltage Transformer Feeder and Breaker Sizing for Copper Conductors (3-Phase, 480V Primary and 208Y/120V Secondary)

| | Primary | | | Secondary | | |
|---|---|---|---|---|---|---|
| kVA | Primary FLA | Breaker | Primary Feeder | FLA | Breaker | Secondary Feeder |
| Single Phase -- 480V Primary, 120/240V Secondary | | | | | | |
| 9 | 11 | 20 | 3/4"C- 3#12, 1#12 G | 25 | 35 | 3/4"C-4#8, 1#8 G |
| 15 | 18 | 30 | 3/4"C- 3#10, 1#10 G | 42 | 60 | 1"C- 4#6, 1#8 G |
| 30 | 36 | 60 | 1"C- 3#6, 1#10 G | 83 | 110 | 1-1/2"C-4#1, 1#6 G |
| 45 | 54 | 80 | 1-1/4"C- 3#3, 1#8 G | 125 | 175 | 2"C-4#2/0, 1#4 G |
| 75 | 90 | 150 | 1-1/2"C- 3#1/0, 1#6 G | 208 | 300 | 3"C-4-300 kcmil, 1#2 G |
| 112.5 | 135 | 200 | 2"C- 3#3/0, 1#6 G | 313 | 400 | 3-1/2"C- 4-500 kcmil, 1#1/0 G |
| 150 | 180 | 300 | 2-1/2"C- 3-300 kcmil, 1#4 G | 417 | 500 | 2[2-1/2"C-4-250 kcmil,1#1/0 G]ea |
| 225 | 270 | 400 | 3"C- 3-500 kcmil, 1#3 G | 625 | 800 | 2[3-1/2"C-4-500 kcmil,1#2/0 G]ea |
| Single Phase -- 480V Primary, 120/240V Secondary | | | | | | |
| 5 | 10 | 20/2 | 3/4"C- 2#12, 1#12 G | 21 | 30/2 | 3/4"C- 3#10, 1#8 G |
| 7.5 | 16 | 30/2 | 3/4"C- 2#10, 1#10 G | 31 | 40/2 | 3/4"C- 3#8, 1#8 G |
| 10 | 21 | 40/2 | 3/4"C- 2#8, 1#10 G | 42 | 60/2 | 1"C- 3#6, 1#8 G |
| 15 | 31 | 50/2 | 3/4"C- 2#8, 1#10 G | 63 | 80/2 | 1-1/4"C- 3#3, 1#8 G |
| 25 | 52 | 80/2 | 1"C- 2#3, 1#8 G | 104 | 150/2 | 1-1/2"C- 3#1/0, 1#6 G |
| 50 | 104 | 150/2 | 1-1/2"C- 2#1/0, 1#6 G | 208 | 250/2 | 2"C- 3#4/0, 1#2 G |
| 75 | 156 | 225/2 | 2"C- 2#4/0, 1#4 G | 312 | 400/2 | 3"C- 3-500 kcmil, 1#1/0 G |
| 100 | 208 | 300/2 | 2-1/2"C- 2-300 kcmil, 1#3 G | 416 | 500/2 | 2[2"C- 3-250 kcmil, 1#1/0 G]ea |

Notes

[1] Primary feeder breaker sized at 150% (+-) of primary full-load amps (FLA), see NEC 450.3(B) for rules that apply.

[2] Secondary breaker sized at 125% (to next standard size) of secondary full load amps.

[3] Primary ground conductors sized using Table 250.122, secondary using Table 250.66 assuming breaker remote from transformer.

[4] Conduit sized based on NEC chapter 9 Tables 4 and 5 for THHN/THWN and XHHW insulation.

[5] Copper conductor sizes, using 60 ˚C ampacity for #1 AWG and smaller, and 75 ˚C ampacity for larger than #1 AWG.

[6] The exceptions allowed by NEC 240.4 have been applied in sizing conductors.

Acronyms and Abbreviations

kcmil: thousands of circular mils
kVA: kilovolt amperes
FLA: full-load amps

### 9.5.10.4 Motors

Most SPU infrastructure does not require large motors. For specific information not discussed in this section, see *Motor Applications and Maintenance Handbook*. For information on construction and testing of all types of motors, see NEMA standard MG 1 Motors and Generators.

#### A. Basic Motor Types

SPU uses three basic types of motors in its facilities: induction, synchronous, and DC. Most induction motors fall into one of the following classifications: low-voltage 1-phase, low-voltage 3-phase, or medium-voltage 3-phase.

#### B. Design Considerations

When specifying a motor, the most important characteristics are the torque speed characteristics of the motor and its load, operating speed, thermal protection, and the environmental protection provided by the enclosure and the insulation system.

#### C. Motor Voltage Rating

Most electrical utilization equipment has a nameplate voltage that matches the nominal supply voltage for which the equipment is designed. Motors are the exception. Motors intended to operate on a 208V system should be nameplated at 200V. Motors designed for connection to a 480V, 3-phase system are rated 460V 3-phase. Similar differences are found in the ratings for motors designed for operation on 120V, 208V, 240V, and 4,160V systems.[3]

***Tip:*** *When specifying or reviewing submittals for 208V system motors, watch out for so-called "triple-rated" motors. This motor is nameplated for operation at 208/230/460V. But it will not operate up to specifications at 208V, especially if the supply voltage is less than 208V.*

#### D. Motor Torque

*Torque* is the force that produces a turning motion in an electrical motor. It is expressed in terms of force and distance to represent the turning moment. The basic types of torque are:

- **Locked rotor torque.** The minimum torque developed by the motor at all angular positions of the rotor at the instant of rated-power application to the motor primary winding circuit. This torque is sometimes referred to as *breakaway starting* torque.
- **Full-load torque.** The torque necessary to produce rated speed with rated-power input.
- **Breakdown torque.** The maximum torque developed at rated-power input without an abrupt change in speed.

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[3] See Table 7 in Chapter 3 of ANSI/IEEE Standard 141 for the nameplate voltages of motors as specified in NEMA MG1.

- **Accelerating torque.** The torque developed with rated-power input during the period from standstill to full rated speed. It is the positive torque available beyond the requirements of the load.

Torque capabilities of a motor itself must be compared with torque requirements of the machine load to verify a motor can operate. This comparison is often done by the driven equipment supplier, typically by plotting a torque curve of the motor and the load torque on the same graph from zero speed to synchronous speed of the motor. It is recommended that the engineer use torque characteristics of NEMA Design for specifying speed-torque-slip relationships of various motor applications.

## E. Motor Speed

Motor speed is designated as revolutions per minute (rpm). For synchronous and induction motors, speed directly relates to frequency of the power source. The following are useful terms:

- **Full-load speed** is the rated speed at which rated full-load torque is delivered with rated-power input.
- **Constant speed** indicates that the normal operating speed is constant, or practically constant, for a specified range of torque.
- **Synchronous speed** indicates that the motor speed is in synchronism with the frequency of the power supply. For AC motors, synchronous speed can be found by using the following formula:

  $$srpm = \frac{120\ \times F}{P}$$

  Where*:*

  srpm = synchronous revolutions per minute

  120 = constant

  F = supply frequency

  P = number of winding poles
- **Slip speed** is the difference between synchronous speed and actual rotor speed.
- **Variable speed** indicates that the speed may be varied gradually over a considerable range but remains practically unaffected by load at each adjustment.

Numbers of poles in a motor are in pairs. The synchronous speed of an AC motor is directly related to that number, which limits the motor speeds available. Motors are specified for *full-load speed*, where full-load speed is the synchronous speed minus the slip speed, which varies between 0.5 and 5% at full load. Full-load speed applies only to induction motors because synchronous motors operate at synchronous speed. With variable-frequency controllers, it is now possible to continuously adjust AC motor speed because the frequency can be continuously varied. Speeds (srpm) can be 3,600, 1,800, 1,200, 900, 600, 514, 450, 400, 360, 327, 300, 277, 257, 240, and 225.

A single motor can be operated at up to four different constant speeds, depending on the motor design. A single-winding induction motor can be wound to operate at either of two speeds by reconnecting the windings within the motor. The low speed must be

50% of the high speed. A two-winding motor can operate at any of the normally available speeds, and the low speed does not need to be ½ of the high speed. Therefore, a single motor designed with two sets of windings, each designed for 2-speed operation, can operate at four speeds. Because a 2-speed single-winding and a 2-speed 2-winding motor require different controllers, the type of motor should be coordinated with the controller. When switching from high to low-speed operation, a time delay must be provided before the low-speed contactor is closed to allow the motor residual voltage to decay to a safe level.

## F. Motor Thermal Protection

Thermal protection must be provided to prevent uneconomical and excessive rates of electrical insulation system deterioration caused by excessive temperatures. Severe overheating may result in immediate motor burnout. Typical sources of burnout include sustained overload, low or unbalanced supply voltage, high ambient temperature, and loss of ventilation, failure of electrical elements, and failure of mechanical components.

Several methods can be employed to protect a motor against thermal damage. In some cases, it is best to provide a combination of elements to provide protection against several possible causes. In every case, thermal overload protection needs to be included as part of the motor controller. Where high ambient temperatures are anticipated, an insulation system with a higher temperature rating should be specified. Integral winding overheating protection should be provided for:

- All motors 50 hp and larger
- Motors 25 hp and larger driven by a VFD for continuous operation application
- Motors 40 hp and larger driven by a VFD
- Most motors located in wet wells (submersible motors) or other locations where continuous cooling cannot be ensured

Integral thermostat devices are adequate for small motors, but larger motors with higher investment costs should be protected by thermistors or resistance temperature devices (RTDs). Thermistors should be used for motors 100 hp and larger at 480V, and RTDs should be used for all medium-voltage motors.

The need for special protection schemes must be evaluated for each other possible cause of motor overheating. The larger the motor, the higher the operating temperature is. The more critical the drive, the more likely that special protection should be provided.

## G. Motor Enclosures

Different types of motor enclosures are offered that provide varying degrees of physical protection. Following is a brief list of those enclosures most often needed in water and wastewater treatment plants:

- **Open-drip-proof enclosure (ODP)** is an open enclosure with ventilating openings. The openings prevent liquid or solid particles that fall on the machine from an angle of 15˚ or less from vertical from entering the machine.

- **Weather-protected Type I (WP-I)** enclosure is an open enclosure whose ventilating passages are constructed and arranged to minimize contact of rain, snow, and airborne particles with live and rotating parts.
- **Weather-protected Type II (WP-II)** enclosure has ventilation passages at both intake and discharge arranged such that high-velocity air and airborne particles blown into the machine can be discharged without entering the internal ventilation passages.
- **Totally enclosed fan-cooled (TEFC)** enclosure is designed to prevent free exchange of air between the inside and outside of the enclosure and includes an integral fan external to the enclosure to provide cooling.
- **Chemical industry severe duty TEFC (CISD-TEFC)** enclosure is a special TEFC motor with corrosion-resistant features.
- **Totally enclosed non-ventilated enclosure (TENV)** is designed to prevent free exchange of air between the inside and outside of the enclosure and includes no external provisions for cooling the enclosed parts. The motor is cooled by heat radiating from the surface to the surrounding atmosphere.
- **Explosion-proof** motor is designed for use in areas subject to explosive concentrations of combustible gases, such as methane. The motor should be UL listed for use in the appropriate Group (D for methane) in a Class 1, Division 1 location. AC induction motors to be installed in Class 1, Division 2 areas do not require explosion-proof classification.

Motors larger than 5 hp that are located in indoor dry areas should be specified to have drip-proof enclosures. Totally enclosed fan-cooled enclosures should be specified for motors smaller than 5 hp in all locations and for larger motors located outdoors and in wet areas, except for the following two exceptions. Very small motors may also be specified to have totally enclosed non-ventilated enclosures when these are the standard of the manufacturer supplying the equipment. Motors 200 hp and larger that are installed outdoors should be specified to have weather-protected Type I or Type 2 enclosures. All motors to be located outdoors and in wet and/or corrosive indoor locations should be specified to have sealed winding insulation.

## H. Medium-Voltage Induction Motors

Medium-voltage induction motors should be used for all constant-speed applications where the motor size exceeds 400 hp, unless only one will be required and the size required is available at 480V 3-phase. Medium-voltage motors may be used for smaller motors, down to 300 hp, if medium-voltage motor control is being provided for other drive motors. For variable-frequency applications, economics generally lead to use of 480V motors up to 800 hp.

All medium-voltage motors should include integral overheating protection provided by RTDs embedded in the coils of the motor and in the bearing housings. Provide a multichannel system to monitor the temperature at each RTD location and a contact operation to stop the motor if the temperature at any location exceeds a preset value.

## I. Low-Voltage Single-Phase Induction Motors

Single-phase motors should be specified for nonessential process loads less than ¾ hp and in HVAC system equipment where they are manufacturer's standard. Single-phase motors must be equipped with some type of starting device to cause motor rotation. Because this starting device often includes a centrifugal switch and a capacitor, which can be points of failure, use of this motor is limited.

Single-phase motors are available for operation at 115V, 200V, or 230V 1-phase, which will allow their connection to most low-voltage systems.

***Tip:*** *For proper operation on a 208V system, motors should be nameplated for 200V.*

## J. Low-Voltage Three-Phase Induction Motors

Three-phase induction motors should be specified for most low-voltage process applications. Apart from the motor controller, 3-phase induction motors do not require any type of auxiliary equipment for starting. Thus, they offer the highest reliability available. Low-voltage 3-phase motors are available from ¼ to 600 hp but should not be specified above 400 hp except in special situations. Larger motors (above 400 hp or so) should be medium voltage. The determination of when to use medium-voltage motors depends on the number of motors involved, the existing distribution system, and the ability to maintain them.

NEMA classifies five design types for low-voltage 3-phase induction motors: A, B, C, D, and F. The main difference among them is torque characteristics. Design B motors should be specified for HVAC fans, blowers, and pump applications unless the load has special torque requirements and a special motor.

These motors are capable of being driven as constant-speed motors by a full-voltage or reduced-voltage motor controller, or at variable speed by a speed-control system. A variable-frequency-controlled speed drive system can be used to operate a normal induction motor, whereas a wound-rotor motor is required if a wound-rotor motor controller is to be used. Except where special circumstances require otherwise, variable-speed motors should be inverter-duty, 3-phase induction type with pulse width modulated (PWM) variable-frequency controllers.

***Tip:*** *For proper operation on a 480-V system, motors should be nameplated for 460V.*

## K. Synchronous Motors

Synchronous motors are similar to induction motors and require similar controls except that they need more complex control equipment. Synchronous motors are available from fractional to many thousands of hp. They are typically used where large loads are operated continuously and power factor improvement is required because these motors can be a source of reactive power when overexcited.

The synchronous motor must be protected for the same conditions that apply to a large induction motor. Many additional types of protection are also required: pull-out, loss-of-field, starting winding, and incomplete sequence.

## L. DC Motors

DC motors have limited applications for SPU facilities. DC motors offer a wide speed range, with essentially stepless variation in speed setting. They can be accelerated and decelerated quickly and result in very accurate speed control. DC motors should be specified to drive chemical feed pumps where precise control is required. The most common application is positive-displacement pumps, such as chemical metering pumps, and progressive-cavity (Moyno) type pumps.

DC motors should be powered from the low-voltage AC power system using DC-SCR drive units. Units 5 hp and less should be supplied power at either 120V or 240V 1-phase. Isolation transformers are generally required for DC-SCR drive systems. The DC-SCR is low-cost drive for controlling DC motors. It uses a special type of power transistor called an SCR.

## M. Motor Efficiency and Power Factor

For large facilities, motors require the most electric power. Their efficiency is a major design focus. The efficiency of a motor can be improved by a combination of factors: size of winding wire, winding material, air gap tolerance, and iron and steel quality. Increasing efficiency generally requires a trade-off. The most common is power factor. Energy-efficient motors have lower power factors and higher starting current than do standard motors.

Motor specifications should include the minimum requirements for efficiency and power factor. NEMA MG1 standards include minimum efficiencies for energy-efficient and NEMA Premium efficient motors.

Keep in mind that specified efficiencies are guaranteed *minimum efficiencies*. This means that any production run motor furnished will have an *actual efficiency* at least as high as this specified number. This differs from a nominal efficiency value often contained in manufacturer's data and on the motor nameplate. *Nominal efficiency* is the average value achieved by any type of motor from a particular manufacturer. The efficiency of the actual motor may be higher or lower than this value, within a range specified by NEMA MG1. The nominal efficiency will always be higher than the guaranteed minimum. If you know the nominal efficiency for a NEMA MG1 motor, you can determine its minimum efficiency. SPU should always request documentation from the manufacturer on the guaranteed efficiency and ensure it meets the Washington State Energy Code requirements.

***Tip:*** *Specify energy-efficient or premium-efficient motors for virtually all applications.*

### 9.5.10.5 Motor Control Equipment

*Motor control equipment* is a general term for a range of voltage and hp ratings and innumerable combinations of equipment arrangements and operational functions (Table 9-17). All such equipment is designed and produced according to NEMA Standards Publication *Industrial and Control Systems*. See Section 9.6 of ANSI/IEEE Standard 141 for more detailed information on motor controller selection.

## A. Medium-Voltage Induction Motor Control

Protection of an AC motor is a function of its type, size, speed, voltage rating, application, location, and type of service. Medium-voltage motor control equipment (controllers) is similar to low-voltage motor starters and rated for systems from 2,300V to 4,800V. Circuit breakers in metal-clad switchgear equipment may be used (with proper relays) to directly control medium-voltage motors, but it is more costly than medium-voltage controllers. Above 4,800-V, switchgear must be used.

Medium-voltage motors should be controlled by medium-voltage motor starters specifically designed for that motor and should have a hp rating equal to or greater than the motor. Motor starters should be NEMA Class E-2, as described in ANSI/NEMA ICS 2.

Each motor starter should consist of current-limiting power fuses, a contractor, instrument and control power transformers, instrumentation, and appropriate protective relay functions for the type of motor being supplied. Two types of contactors are available: *vacuum* and *air brake*. The vacuum contactor type should be selected. Motor protection is discussed in detail in ANSI/IEEE Standard 242. Manufacturers of medium-voltage motor control equipment also offer recommendations. The protective, metering, and control functions should be provided by using a multipurpose microprocessor-based module such as the GE Multi-Lin 269, 369, 469, or similar equipment.

Each starter should be completely self-contained and pre-wired with all components in place. Where multiple starters are required in a single location, an assembly of medium-voltage motor starters with a common supply bus, grounded metal barriers, and drawout mounting assemblies for each motor starter should be provided. As in low-voltage starters, medium-voltage starters are available in reversing and reduced-voltage configurations.

***Tip:*** *Full-voltage medium-voltage starters are generally available in a "two-high" construction where two starters can be placed in a single section. In this configuration, there is little additional space available in the starter cubicle for accessories or optional features. For space planning, allow a full vertical section for each starter.*

### Table 9-17 Motor Control and Feeder Data (460V, 3-Phase, 60 Hz Motors)

| Motor Data |  |  | Starter |  |  |  |  |  |  | VFD Feeder |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Motor (hp) | NEC FLA | FLA x 1.25 | Mag-Only Breaker | Thermal Breaker | NEMA Starter | Recommended Conduit | Phase Cond | Ground Cond | Maximum Distance | Thermal Breaker | Recommended Conduit | Phase Cond | Ground Cond |
| 0.5 | 1.1 | 1.375 | 3/M |  | 1 | 3/4" | #12 | #12 | 2667 | 15 | 3/4" | #12 | #12 |
| 0.75 | 1.6 | 2 | 3/M |  | 1 | 3/4" | #12 | #12 | 2667 | 15 | 3/4" | #12 | #12 |
| 1 | 2.1 | 2.625 | 7/M |  | 1 | 3/4" | #12 | #12 | 2667 | 15 | 3/4" | #12 | #12 |
| 1.5 | 3 | 3.75 | 7/M |  | 1 | 3/4" | #12 | #12 | 1412 | 15 | 3/4" | #12 | #12 |
| 2 | 3.4 | 4.25 | 7/M |  | 1 | 3/4" | #12 | #12 | 1412 | 15 | 3/4" | #12 | #12 |
| 3 | 4.8 | 6 | 7/M |  | 1 | 3/4" | #12 | #12 | 1000 | 15 | 3/4" | #12 | #12 |
| 5 | 7.6 | 9.5 | 15/M |  | 1 | 3/4" | #12 | #12 | 632 | 15 | 3/4" | #12 | #12 |
| 7.5 | 11 | 13.75 | 15/M |  | 1 | 3/4" | #12 | #12 | 436 | 20 | 3/4" | #12 | #12 |
| 10 | 14 | 17.5 | 30/M |  | 1 | 3/4" | #12 | #12 | 343 | 25 | 3/4" | #10 | #10 |
| 15 | 21 | 26.25 | 30/M |  | 2 | 3/4" | #10 | #10 | 361 | 35 | 3/4" | #8 | #10 |
| 20 | 27 | 33.75 | 50/M |  | 2 | 3/4" | #8 | #10 | 444 | 40 | 3/4" | #8 | #10 |
| 25 | 34 | 42.5 | 50/M |  | 2 | 1" | #6 | #10 | 529 | 50 | 1" | #6 | #10 |
| 30 | 40 | 50 | 50/M |  | 3 | 1" | #6 | #10 | 450 | 60 | 1" | #6 | #10 |
| 40 | 52 | 65 | 100/M |  | 3 | 1-1/4" | #4 | #8 | 533 | 80 | 1-1/4" | #4 | #8 |
| 50 | 65 | 81.25 | 100/M |  | 3 | 1-1/4" | #3 | #8 | 426 | 100 | 1-1/4" | #3 | #8 |
| 60 | 77 | 96.25 | 100/M | 125 | 4 | 1-1/2" | #1 | #6 | 668 | 125 | 1-1/2" | #1 | #6 |
| 75 | 96 | 120 | 225/M | 150 | 4 | 1-1/2" | #1 | #6 | 536 | 150 | 1-1/2" | #1/0 | #6 |
| 100 | 124 | 155 | 225/M | 175 | 4 | 2" | #2/0 | #6 | 611 | 200 | 2" | #3/0 | #6 |
| 125 | 156 | 195 | 225/M | 250 | 5 | 2" | #3/0 | #4 | 577 | 250 | 2" | #4/0 | #4 |
| 150 | 180 | 225 | 400/M | 300 | 5 | 2" | #4/0 | #3 | 615 | 300 | 3" | 300 kcm | #4 |
| 200 | 240 | 300 | 400/M | 350 | 5 | 3" | 350 kcm | #3 | 632 | 400 | 3" | 500 kcm | #3 |
| 250 | 302 | 377.5 |  | 400 | 6 | 3" | 500 kcm | #3 | 492 | 450 |  |  |  |

| Motor Data | | | Starter | | | | | | | VFD Feeder | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Motor (hp) | NEC FLA | FLA x 1.25 | Mag-Only Breaker | Thermal Breaker | NEMA Starter | Recommended Conduit | Phase Cond | Ground Cond | Maximum Distance | Thermal Breaker | Recommended Conduit | Phase Cond | Ground Cond |
| 300 | 361 | 451.25 | | 600 | 6 | 2-2" | 2-#4/0 | 2-#1 | 492 | 600 | | | |
| 350 | 414 | 517.5 | | 600 | 6 | 2-3" | 2-300 kcm | 2-#1 | 630 | 600 | | | |
| 400 | 477 | 596.25 | | 700 | 6 | 2-3" | 2-350 kcm | 2-#1/0 | 630 | 700 | | | |
| 450 | 515 | 643.75 | | see note 3 | 7 | 2-3" | 2-400 kcm | 2-#2/0 | | see note 3 | | | |
| 500 | 590 | 737.5 | | see note 3 | 7 | 2-3" | 2-500 kcm | 2-#2/0 | | see note 3 | | | |

## Notes

[1] Motor FLA based on 2005 NEC. FLA may be higher for slow speed motors.

[2] Motor branch conductor size 125% x motor FLA based on 60°C insulation up through #1, and 75°C for larger sizes.

[3] Review with manufacturer; not a standard size.

[4] Conduit size from NEC Tables 4 and 5. Areas based on THHN/THWN up to size #1 & XHHW above size #1.

[5] Motor circuit from starter size is based on 125% of motor full-load current.

[6] VFD circuit breaker size based on 150% of motor full load current; feeder size based on breaker size.

[7] For separate starter breaker size, use 250% of motor full load current.

[8] All ground conductor sizes are based on NEC table 250.122.

[9] Maximum distance to motor based on allowed voltage drop of 3% calculated using IEEE Red Book.

## Acronyms and Abbreviations

kcmil: thousands of circular mils
kVA: kilovolt amperes
FLA: full-load amps
IEEE: Institute of Electrical and Electronics Engineers
NEC: National Electrical Code
NEMA: National Electrical Manufacturers Association
VFD: variable frequency drives

## B. Low-Voltage Motor Control [Specs 26 24 19 and 26 29 13]

In AC motor controls, contactors are normally used for controlling the power supply to the motor. The contactor, when applied in conjunction with an overload relay, is called a *motor starter*. The starter is then applied in combination with fuses, a magnetic-only circuit breaker, or a thermal magnetic circuit breaker, and is called a *combination motor starter*. The overload relay—traditionally a thermal relay but now often solid state—protects the motor from long-term overloads. The fuses or circuit breaker provide short-circuit protection. The disconnect switch or circuit breaker provides a disconnecting means within sight of the starter, as required by NEC Article 430.[4] The standards for magnetic controllers rated 115V through 575V are summarized in ANSI/NEMA ICS 2.

For projects with more than a few motors, the motor starters are generally mounted together in a common assembly called an MCC. An MCC contains a common horizontal bus that connects to a vertical bus in each section. The combination starters are pre-wired and installed in assemblies (units or buckets) that slide into the MCC and plug onto the vertical bus. An MCC may also include feeder breakers and other components. With a suitable main breaker or fused disconnect, an MCC can be service entrance equipment. UL listings should be specified.

Motor starters can be divided into two categories: full-voltage and reduced-voltage.

### 1) Full-Voltage (“Across-the-Line”) Starting

Full-voltage starting (also called “across-the-line”), refers to instantaneous application of full line voltage to a motor through a contactor. Full voltage is the most common starting method and should be used whenever possible. The disadvantages of full-voltage starting include high inrush current to the motor (causing voltage dip and motor heating) and high torque to the motor and load during acceleration.

Several types of low-voltage starters are available:

- **Manual motor starter.** This is a manually operated switch rated for control of induction loads. It includes thermal overload protection. The manual starter may not provide under voltage protection and does not allow remote control. It is available in 1-phase and 3-phase.
- **Magnetic, non-reversing motor starter.** This provides full-voltage (across-the-line) starting for motors that must be started frequently. It is suitable for remote control devices such as push-buttons, selector switches, or similar pilot devices. The magnetic, non-reversing motor starter provides overload protection and under-voltage protection if momentary contact controls are provided.
- **Magnetic, reversing motor starter.** Control is provided by two contactors wired so that reversing the phases provides the reversing function. In all other respects, control is the same as for magnetic, non-reversing motor starters. Mechanical and electrical interlocks are provided to prevent both contactors from being energized simultaneously, which would result in a short circuit.

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[4] The need for and location of disconnecting means for motors are widely misunderstood portions of the NEC. The electrical design engineer should read that section carefully.

A complete description of these motor starters can be found in either ANSI/IEEE Standard 141 or in the *Switchgear and Control Handbook*.

### 2) Reduced-Voltage Starters

In a reduced-voltage starter, various methods are used to start a motor at lower-than-normal voltage, then switching to full voltage as it accelerates. The purpose of a reduced-voltage starting is to reduce the voltage drop experienced by the rest of the electrical system when the motor starts and to reduce stress on the motor itself during starting. These starters include the basic components of a combination motor starter, with a means to reduce inrush current to the motor to some level below full voltage. Generally, this is done by introducing a means to reduce the voltage applied to the terminals of the motor. Reduced-voltage starting also reduces torque. In fact, the torque varies with the square of voltage, so that if 70% voltage is applied, only 49% of normal torque is available. The following are five widely available types of reduced-voltage starters:

1. **Autotransformer type (both open transition and closed transition).** An autotransformer is used to reduce the voltage being applied to the motor windings. The starting torque will vary almost directly with the variation in motor current. To minimize the short-duration, high-inrush current that would occur during an open transition from start to run, the closed transition connection momentarily uses the autotransformer as a series reactor to minimize current surge. The autotransformer type reduced-voltage starter offers the highest starting torque in foot-pound of torque per kVA of inrush. It is a good choice for reduced-voltage starting of high-inertia loads but is also the most expensive reduced-voltage starter. SPU prefers not to utilize Autotransformer reduce voltage starters unless there is a specific, large-hp application that requires it.
   **Primary resistor type reduced-voltage starter.** The motor inrush current is limited by the value of resistance placed in the primary circuit. Because starting torque is a function of the square of the voltage, if the voltage applied to the motor is only 50% of rated voltage, the starting torque is reduced to only 25% of normal. This type of starter should be used only with low-inertia loads where the low starting torque provided is sufficient for the connected load. This type of starter provides the smoothest acceleration of the load possible and is usually the least expensive. SPU prefers not to use resistor type reduced-voltage starters.
2. **Part-winding motor starter.** This starter requires a special motor wired for part-winding starting and two magnetic motor starters. It should only be used on light or low-inertia loads. It is fourth in terms of smooth acceleration of the load and is normally open transition. SPU prefers not to use this starter method.
3. **Wye-delta type motor starter.** This starter initially energizes the motor windings in a wye configuration and then transitions (either open transition or closed transition are available) when load approaches full speed. Because wye-delta starters provide only 33% of normal starting torque, they should be used only where the drive equipment can be started unloaded. This starter requires a special motor, and both ends of each motor winding must be brought back to the motor starter. The wye-delta starter is useful for long accelerations (e.g., centrifuges, chillers, and elevators).

4. **Solid-state motor starters.** This starter can control the starting cycle and provide reduced voltage starting for conventional AC motors. The solid-state electronics provide a smooth and adjustable acceleration rate that limits inrush current surges and reduces sudden torque surges to the motor. Solid-state motor starters should be considered for smooth acceleration and imitation of inrush current.

***Tips:*** *Use full-voltage starting whenever possible. Where reduced-voltage starting is required, use solid-state reduced voltage starters or autotransformer-type or wye-delta type.*

*Avoid the trap of arbitrary hp limits for reduced-voltage starting. The primary reason for reduced-voltage starting is to reduce voltage dip on the power system. When a dip is the justification for reduced-voltage starting, each motor must be evaluated individually. The impact on the electrical system when starting a 500-hp motor with reduced-voltage startup is the same as starting a 250-hp motor across-the-line. Simply installing reduced-voltage starters will not automatically solve the voltage drop problem.*

*For projects with more than two or three motors above ½ hp, use an MCC. MCCs should be specified in a full 20-inch depth, with front mounting only. On large projects, limit MCCs to a maximum horizontal bus rating of 1,200A.*

*Separately mounted motor starters should be combination-type, preferably utilizing a magnetic-only breaker.*

*For large MCCs used as service entrance equipment, make certain that utility metering is coordinated. Most utilities will not accept the standard 20-inch-deep MCC section for metering.*

## C. Motor Branch Circuit Protection

The branch circuit device provided in a combination motor starter must be carefully selected. If an upstream device provides short circuit protection, then a simple disconnect switch may suffice. In MCC applications, the branch circuit device must provide both disconnect and short circuit protection.

Short circuit protection can be provided by either fuses or circuit breakers. For low voltage MCC applications, SPU prefers the use of circuit breakers. Two types of circuit breakers are available for motor branch circuit protection: magnetic only and thermal magnetic breaker. Each functions differently. When a motor branch circuit protective device is used in combination with a motor starter, it may be selected to provide both overcurrent and short circuit protection, or only short circuit protection.

A properly selected and sized fuse provides both overcurrent (overload or short circuit protection for a motor branch circuit. Some fuses can limit let-through current during a fault and thereby reducing damage. If fuses are used, they should be dual element fuses in most industrial-type applications, where higher fault currents are likely. The NEC allows dual element fuses to be sized at 175% of motor full-load amps (FLA) in most situations. This sizing offers short circuit protection but not overload protection. When dual element fuses are used, follow the manufacturer's recommendations for sizing.

A fuse is a one-time device. Once it has interrupted a fault current, it must be replaced. In addition, it is a 1-phase device. It interrupts the current only in the phase or phases that exceed the time current characteristics of the fuse. Although fuses offer superior protection, they can cause secondary single-phasing problems when a single fuse blows. An adequate stock of fuses must be kept as replacements after a fault has occurred. Fuses are especially useful in material handling applications where jamming of the equipment is possible. The fuses can be sized to operate more quickly than the overload relay, providing better protection for the motor.

Two types of circuit breakers are used in low-voltage motor control, magnetic-only and thermal magnetic.

### 1) Magnetic-Only Circuit Breakers or MCPs

Motor circuit protectors (MCPs) are often used in combination motor starters. They can be used only in combination with a motor starter because they do not offer any overload protection. The NEC allows MCPs to be sized up to 800% of motor FLA and set up to 1,300% of motor FLA. In most situations, selection of the proper MCP should be left to the motor starter manufacturer. It should be sized so that its range of adjustment allows it to be set between 8- and 13-times motor FLA. MCPs are less expensive than thermal magnetic circuit breakers and clear short circuit currents faster. For motors 50 hp and larger, they may provide less protection than a properly sized thermal magnetic circuit breaker.

### 2) Thermal Magnetic Circuit Breakers

*Thermal magnetic circuit breakers* are commonly used as overcurrent protection devices in motor branch circuits. They provide both short circuit and overload protection. Depending on the type of motor being protected, NEC allows thermal magnetic circuit breakers to be sized at as much as 250% of motor FLA. Thermal magnetic breakers 70A and larger with an adjustable magnetic trip unit can be sized for the magnetic trip assembly to provide adequate short circuit protection for the motor branch circuit. Smaller breakers with only fixed magnetic trip units cannot be sized small enough so that the instantaneous trip point is between 7- and 13-times motor FLA and will not be tripped by motor running current.

Where the convenience of a circuit breaker is desired but available fault current exceeds the rating of a motor starter with a magnetic-only circuit breaker, a current limiter should be added to the breaker to increase the rating of the assembly. A current limiter is similar in construction and characteristics to a current-limiting fuse.

***Tip:*** *Circuit breakers offer convenience, trip all three phases, and adequately protect the motor. They should be used for motor branch circuit protection unless a special condition exists. For 480V applications, combination motor starters size 3 and smaller should be provided with magnetic-only circuit breakers. Larger starters should be equipped with thermal magnetic breakers with adjustable magnetic trip units because energy-efficient motors tend to have higher inrush currents. It is impossible in some cases to set magnetic-only circuit breakers at less than 1,300% of motor FLA. This limitation is not a factor when applying thermal magnetic breakers.*

## D. Starter Control Power

The contactor used in a magnetic motor starter requires a source of power to operate. Although it is possible to use 480V or 240V directly from the starter supply power, most U.S. starters operate at 120V AC. This is referred to as the *control power voltage* for the starter. The 120V power can be brought from an external source, but the commoner recommended approach is to use a control power transformer mounted in the starter to derive 120V, 1-phase from the 480V supply.

***Tip:*** *Control power transformers (CPTs) should be provided in all motor starters to provide 120V control circuit power. CPTs should be provided with two primary fuses, one on each side of the transformer, and one secondary fuse on the ungrounded side of the transformer. CPTs should be sized to carry at least the total connected load of the control circuit plus an additional 25VA.*

## E. Variable-Speed Drives

AC induction motors are inherently single speed, with the nominal speed a function of the frequency of the applied power.

However, several controllers have been developed for controlling the speed of induction motors. The most widely used today is the VFD, which is an outgrowth of the development of solid-state power electronics. Variable-frequency drives (often called adjustable-frequency drives) are available for 460V motors up to 1,000 hp, and for medium-voltage motors 400 hp and up.

Variable-speed drives reduce the motor’s ability to dissipate heat during low-speed operation. This is mostly a concern when an existing constant-speed motor is to be used with a variable-frequency drive. New installations should be specified with inverter duty motors that will handle heat and harmonic issues.

### 1) Variable Frequency Drives [Spec 26 29 23]

VFDs are widely used. They are easily applied to standard squirrel cage induction motors and offer increased efficiency and better speed control than do wound rotor type controllers, especially at reduced speeds. Solid-state power electronics have improved reliability, simplicity, and maintenance. Because standard squirrel cage induction motors can be used, VFDs are also retrofitted to existing installations also. The primary disadvantages of VFDs are increased complexity/cost, and the introduction of harmonic distortion into the power system.

DSG specification 26 29 23 (Variable Frequency Motor Controllers) requires that the supplier of the drive calculate the anticipated harmonic distortion that will be created by the drive. This specification also requires that the supplier take steps to ensure that the distortion is less than the specified maximum limit based on the current publication of IEEE Standard 519 (see DSG section 9.6).

Application of VFDs, especially large-hp units, requires careful consideration of potential harmonic distortion and proper motor operation. For more detail on application of VFDs, contact a manufacturer’s representative.

Three basic types of VFDs are available, as described in this section:

1. **PWM inverter.** This drive closely approximates a sinusoidal output waveform for small-motor applications by generating multiple variable-width pulses at varying frequency. The PWM drive is generally more economical to manufacture than other types of drives, and it offers high efficiency and high-power factor. The requirement for fast output switching has limited the size of PWM drives because of the limited capabilities of the solid-state electronic devices required to achieve the fast-switching rates. The maximum size of PWM drives for 480V motors is 800 hp. Disadvantages of the PWM drives include an increase in audible noise at the motor (especially at low speeds) and evidence of high-voltage stress in the motor due to the high carrier frequency employed in a PWM drive.
2. **Forced-commutated inverter.** This consists of a 3-phase AC/DC converter, a capacitive filter, and a six-step SCR inverter filter. The advantage of the forced-commutated inverter is that it is independent of the connected load and thus can be connected to drive any motor or group of motors up to its capacity. The forced-commutated inverter is commonly known as a voltage source (or variable voltage inverter [VVI] drive).
3. **Sequentially commutated inverter.** This is usually referred to as *the current source inverter (CSI)* or constant-current drive and consists of a 3-phase AC/DC converter, an inductive filter, and a six-step inverter. Although the bridge circuitry of the constant-current inverter drive is simpler than that of the force-commutated inverter, the inverter must be matched to the drive motor. The main advantage of the constant-current drive is its ability to completely control motor current, which results in complete torque control.

Advances in solid-state electronics have resulted in drive systems that have high reliability and low maintenance and are easily applied with standard squirrel cage induction motors. In addition, the cost of these drives has decreased while the cost of electrical energy has increased. PWM systems are the easiest to apply with existing or off-the-shelf motors and should be given first consideration.

***Tips:*** *Use low-voltage PWM technology for all small motor applications in the range of 400 to 600 hp. Above this size, use medium-voltage PWM technology. Use CSI-or VVI-type for special applications only.*

*It is recommended that an engineer concentrate on good performance specs before selecting a specific technology.*

*If possible, require that all drives on a project be the end product of a single manufacturer.*

*Watch out for application of VFDs with standby generators. The lower capacity of the generator compared with the normal source can amplify harmonic distortion of the drive significantly.*

*Avoid application of power-factor correction capacitors on, or even on the same bus with, VFDs. The drives produce distorted sine waves with significant high-frequency content. These high-frequency currents see the power-factor capacitors as extremely low impedances, resulting in potential overloading and/or resonant conditions. If* *capacitors must be used, they must be equipped with trapping filters to filter out high frequencies.*

*Use VFD cable or route VFD power output cable in a dedicated steel conduit between the drive and motor. For PWM drives, keep lead length from drive to motor as short as practical and separate power and control cables.*

*Locate VFD enclosures in a controlled, filtered environment. Specify NEMA 1 enclosures when installing drives in controlled environments.*

*Use of isolation transformers ahead of drives is not a "cure all" for harmonic problems. A reactive filter or 18-pulse (or more) drive may be a better solution. Most vendors do not require the use of an isolation transformer for standard 6-pulse drives.*

## F. Power Factor Correction

Power factor improvement should be provided only when the electric utility rates include a requirement or penalty for low power factor and the projected power factor of the facility will be less than the minimum allowed within the rate. A power factor improvement capacitor bank is recommended for motors ≥25 hp and powered by full-voltage starters. Power factor correction should not be used with VFD applications. The electrical design engineer must discuss and present power factor correction benefits and make economic recommendations with and to the design team and facility owner for motors greater than 75 hp. The capacitor banks should be connected between the motor starter contacts and the overload relays so that overload relay heaters can be sized in accordance with motor nameplate currents.

For calculations for sizing capacitors, see **Appendix 9C - Design Calculations for Electrical Design**. They should not be larger than the maximum size recommended by the motor manufacturer.

## G. Power Monitor Devices

**H.** Power monitoring devices are used for monitoring various power quality parameters of a power system. This includes power consumption, current and volts, phase imbalances, Power factor, harmonics, and alarms. The device must have a Modbus communication protocol via serial RS-485 interface. The electrical engineer should coordinate with the facility owner and with operation crews to specify the operational requirements of the devices per specific facility operations.

## I. Control Circuit Devices

All control circuit devices should meet NEMA ICS2-125 Standards. Devices that contain contacts and are used in 120V control circuits should have contacts with the designation Class A300 or A600. Devices with contacts having the designation A600 should be used where control circuit voltage will be greater than 120V. Contacts with these designations are capable of carrying 10A continuously, making a circuit requiring 7,200VA, and breaking a circuit carrying 720VA. Devices covered by this rating include:

- Momentary and maintained-contact push-button and control switches
- Push-to-test pilot lights
- Limit switches

- Snap action switches in temperature, pressure, and similar switches
- Control relays
- LOR switch on motor controller panel

All push buttons, selector switches, and pilot lights should be heavy-duty oil-tight or corrosion resistant type. Standard-duty type should not be used. In addition, all snap action switches and control relays should be of the quick-make quick-break type.

# 9.6 RESOURCES

## Documents

- *Consulting Applications Catalog,* Eaton/Cutler Hammer (Continuation of the old Westinghouse applications information and still very useful)
- *Switchgear and Control Handbook*, edited by Robert W. Smeaton, McGraw Hill Book Co.
- *Motor Application & Maintenance Handbook*, edited by Robert W. Smeaton, McGraw Hill Book Co.
- *Industrial Power Systems Handbook*, Donald Beeman, editor, McGraw Hill Book Co.
- *Electrical Systems Analysis and Design for Industrial Plants*, Irwin Lazar, editor, McGraw Hill Book Co.
- *Standard Handbook for Electrical Engineers*, Fink and Carroll, editors, McGraw Hill Book Co.
- *IES Lighting Handbook*, Illuminating Engineering Society
- IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

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