Installation of Electric Services

26209-05

Steven F. Udvar-Hazy Center
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Chantilly, Virginia
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Installation of Electric Services

Topics to be presented in this module include:

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Overview

Commercial power becomes the responsibility of the customer at the electric service. Electricians install the electric service but do not generally make the connections at the point where the commercial power connects. This is usually the job of the electric utility provider.

If the commercial power connects to the electric service overhead, the incoming service supply is referred to as a service drop. On the other hand, if the lines are supplied underground, the service supply is said to be a service lateral. The *National Electrical Code*® regulates the installation of both service drops and service laterals, including minimum requirements related to overhead conductor heights, burial depths, raceways, and other installation conditions.

Building an electric service at the consumer's location requires knowledge of materials and service installation skills. If the service supply is a service drop, the service conductors enter the service raceway through a service head or weatherhead, which is designed to keep rain out of the service equipment. Separate service-entrance conductors are usually installed in the service raceway and these connect to the service drop at the point of attachment to the service raceway. The service equipment includes the electrical meter enclosure, service disconnecting means, main circuit breaker panelboard, and grounding system.

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Objectives

When you have completed this module, you will be able to do the following:

1. Describe various types of electric services for commercial and industrial installations.
2. Read electrical blueprints and diagrams describing service installations.
3. Calculate and select service-entrance equipment.
4. Explain the role of the *NEC®* in service installations.
5. Install main disconnect switches, panelboards, and overcurrent protection devices.
6. Identify the circuit loads, number of circuits required, and installation requirements for distribution panels.
7. Explain the types and purposes of service grounding.
8. Explain the purpose and required location(s) of ground fault circuit interrupters.
9. Describe single-phase service connections.
10. Describe both wye- and delta-connected three-phase services.

Trade Terms

Delta-connected	Service equipment
Load center	Service lateral
Service	Service raceway
Service conductors	Substation
Service drop	Wye-connected
Service entrance	

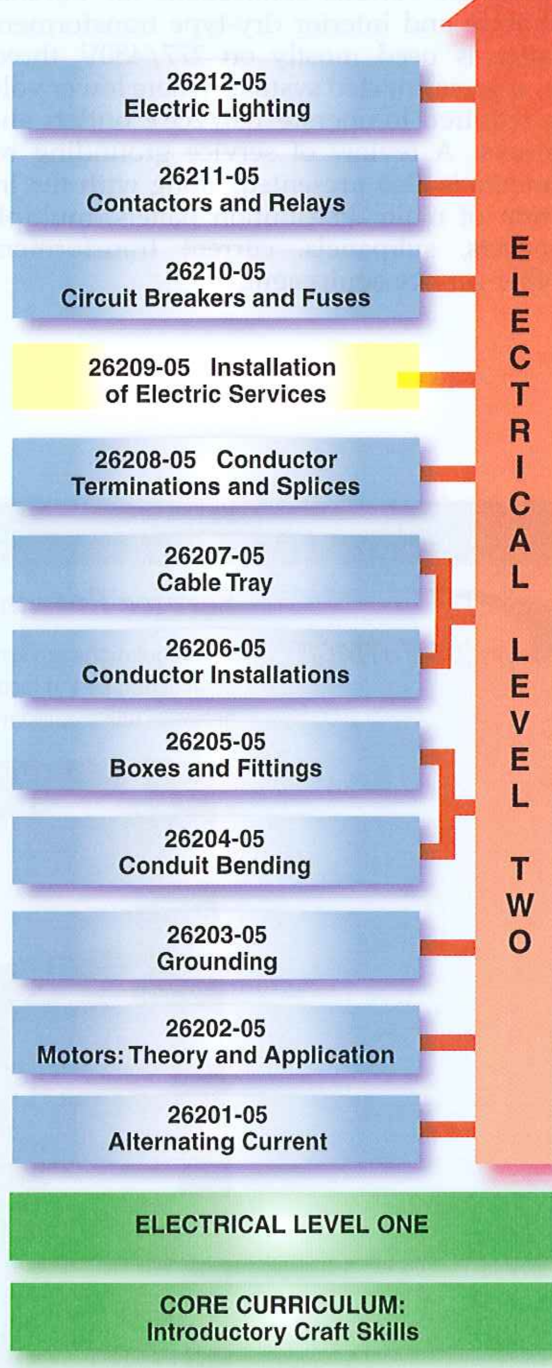
Required Trainee Materials

1. Pencil and paper
2. Appropriate personal protective equipment
3. Copy of the latest edition of the *National Electrical Code®*

Prerequisites

Before you begin this module, it is recommended that you successfully complete *Core Curriculum; Electrical Level One; Electrical Level Two,* Modules 26201-05 through 26208-05. You should also read *NEC Article 230.*

This course map shows all of the modules in *Electrical Level Two.* The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map. The local Training Program Sponsor may adjust the training order.



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1.0.0 ◆ INTRODUCTION

This module is designed to cover most electric **service** applications that will be encountered by electricians working on commercial and industrial projects. Detailed installation techniques are also presented for secondary systems up to 600V, including the various connections for outdoor distribution and interior dry-type transformers; the latter is used mostly on 277/480V, three-phase, **wye-connected** systems where lower voltage is required to operate 120/208V outlets and equipment. A review of service grounding requirements is also presented, along with the installation of main distribution panels, multiple disconnects, subpanels, current transformers, and other service equipment.

Electric services can range in size from a small 120V, single-phase, 15A service, which is the minimum allowed by *NEC Section 230.79(A)*, for a roadside vegetable stand, to huge industrial installations involving **substations** dealing with thousands of volts and amperes. Regardless of the size, all electric services are provided for the same purpose: to deliver electrical energy from the supply system to the wiring system on the premises served. Consequently, all establishments containing equipment that utilizes electricity require an electric service.

INSIDE TRACK

Service Entrances

The regulations governing the method of bringing the electric power into a building are established by the local utility company. These regulations can vary considerably between utility companies and regional areas.

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Figure 1 shows the basic components of a typical commercial electric service. In this illustration, note that the high-voltage lines terminate on a power pole near the building being served. A bank of transformers is mounted on the pole to reduce the transmission voltage to a usable level (in this case, 120/208V, three-phase, wye-connected).

The remaining sections are:

- *Service drop* – The overhead conductors through which electrical service is supplied between the last power company pole and the point of their connection to the service-entrance conductors located at the building or other support used for the purpose.
- *Service entrance* – All components between the point of termination of the overhead service drop or underground **service lateral** and the building's main disconnecting device, except for metering equipment.
- *Service conductors* – The conductors between the point of termination of the overhead service drop or underground service lateral and the main disconnecting device in the building or on the premises.
- *Service equipment* – The necessary equipment, usually consisting of a circuit breaker or switch and fuses and their accessories, located near the point of entrance of supply conductors to a building and intended to constitute the main control and cutoff means for the electric supply to the building.

When the service conductors to the building are routed underground, as shown in *Figure 2*, these conductors are known as the service lateral, which are the underground conductors through which service is supplied between the power company's distribution facilities and the first point of their connection to the building or area service facilities located at the building or other support used for the purpose.

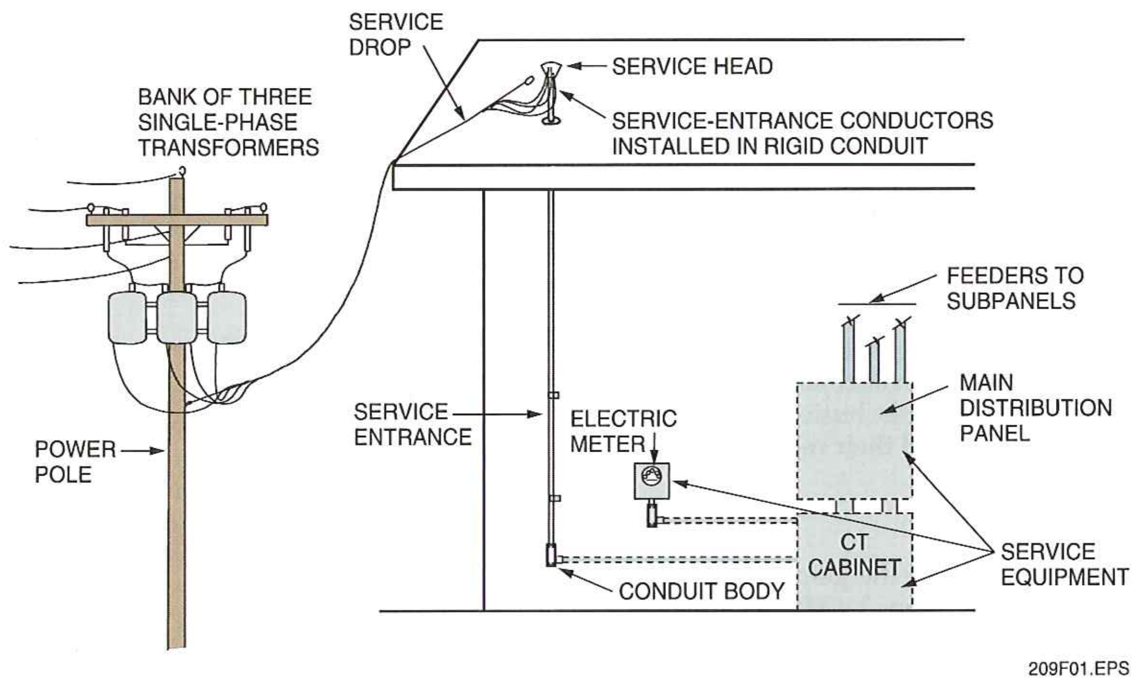

Figure 1 ◆ Typical three-phase overhead service.

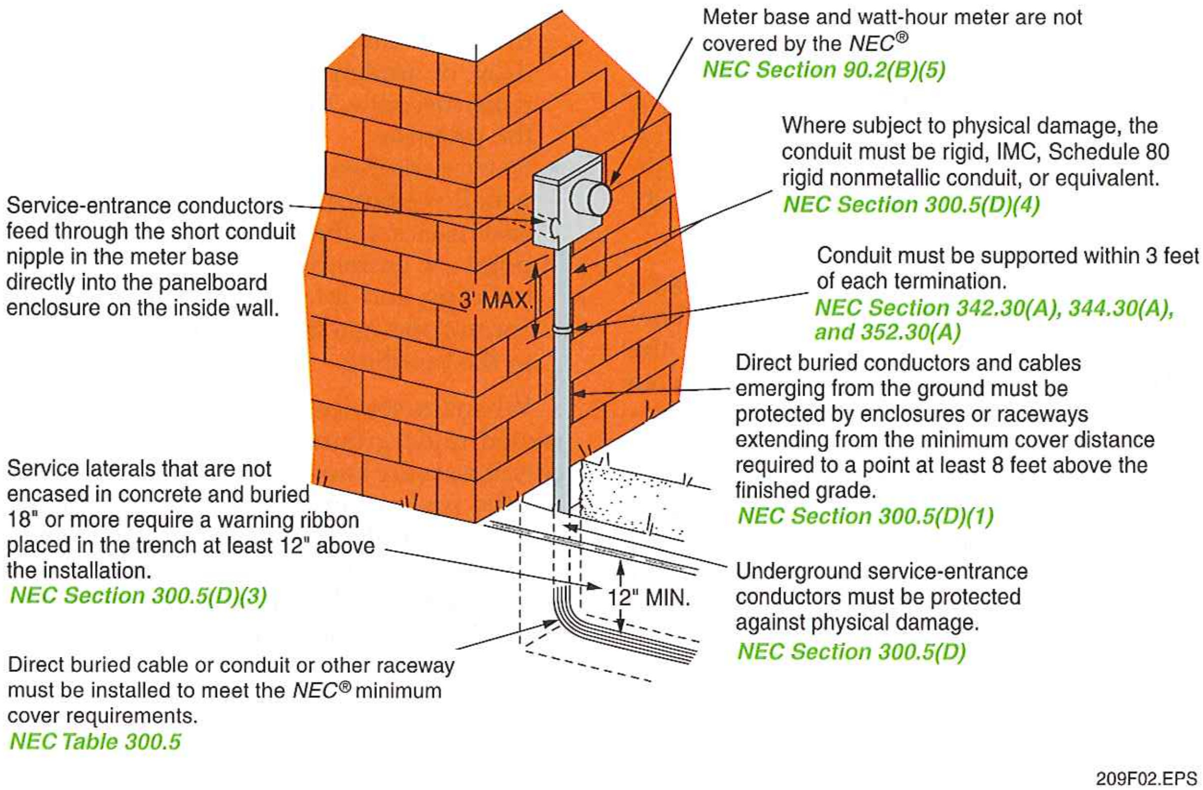

Figure 2 ◆ Single-phase underground service lateral for small commercial building.

2.0.0 ◆ ELECTRICAL GENERATION AND DISTRIBUTION

A review of electrical distribution systems is the best foundation for understanding alternating current and the purpose of electric services.

The essential elements of an AC electrical system capable of producing useful power include generating stations, transformers, substations, transmission lines, and distribution lines. *Figure 3* shows these elements and their relationships.

2.1.0 Generation

Electricity is produced at the generating plant at voltages ranging between 2,400V and 13,200V. Transformers are also located at the generating plant to step up the voltage to hundreds of thousands of volts for transmission.

Electricity is transported from one part of the system to another by cables made up of many strands of wire. The continuous system of conductors through which electricity flows is called the distribution circuit.

2.2.0 Transmission

The system for moving high-voltage electricity is called the transmission system. Transmission lines are interconnected to form a network of lines. Should one line fail, another will take over the load. Such interconnections provide a reliable system for transporting power from generating plants to communities.

Most transmission lines installed by power companies utilize three-phase current—three separate streams of electricity traveling on separate

THINK ABOUT IT

Electrical Utilities

Is the equipment installed and operated by an electrical utility required to comply with the *NEC*®?

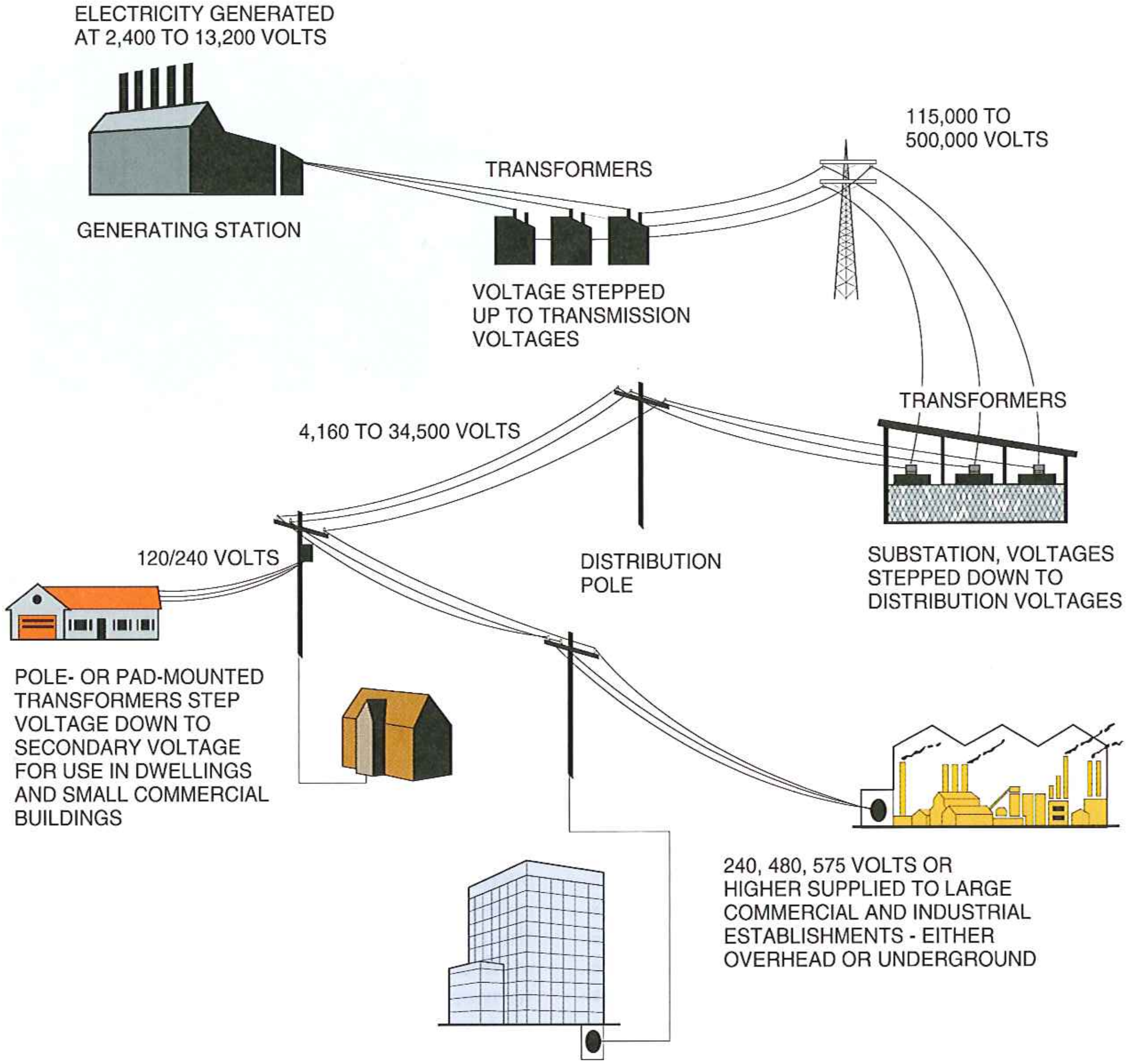

Figure 3 ◆ Parts of a typical electrical distribution system.

conductors. This is an efficient way to transport large quantities of electricity. At various points along the way, transformers step down the transmission voltage at facilities known as substations.

2.3.0 Substations

Substations can be small buildings or fenced-in yards containing switches, transformers, and other electrical equipment and structures. Substations are convenient places to monitor the system and adjust circuits. Devices called regulators, which maintain system voltage as the demand for electricity changes, are also installed in substations. Another device, which momentarily stores energy, is called a capacitor, and is sometimes installed in substations; this device reduces energy losses and improves voltage regulation. Within the substation, rigid tubular or rectangular bars, called busbars or buses, are used as conductors.

At the substation, the transmission voltage is stepped down to voltages below 35,000V, which feed into the distribution system.

The distribution system delivers electrical energy to the user's energy-consuming equipment (i.e., lighting, motors, machines, and appliances).

Conductors called feeders radiate in all directions from the substation, carrying the power from the substation to various distribution centers. At key locations in the distribution system, the voltage is stepped down by transformers to the level needed by the customer. Distribution conductors on the high-voltage side of a transformer are called primary conductors or primaries; those on the low-voltage side are called secondary conductors or secondaries.

Transformers are actually smaller versions of substation distribution transformers that are installed on poles, on concrete pads, or in transformer vaults throughout the distribution system.

Distribution lines carry either three-phase or single-phase current. Single-phase power is normally used for residential and small commercial occupancies, while three-phase power serves most of the other users.

2.4.0 Underground

Most power companies now utilize transmission systems that include both overhead and underground installations. In general, the terms and devices are the same for both. In the case of the underground system, distribution transformers are installed at or below ground level. Those mounted on concrete slabs are called padmounts (*Figure 4*), while those installed in underground vaults are called submersibles.

Buried conductors (cables) are insulated to protect them from soil chemicals and moisture. Many overhead conductors do not require such protective insulation.

When underground transmission or distribution cables terminate and connect with overhead conductors at buses or on the tops of poles, special devices called potheads or cable terminators are employed. See *Figure 5*. These devices prevent moisture from entering the insulation of the cable and also serve to separate the conductors to prevent arcing between them. The cable installation along the length of the pole is known as the cable riser.

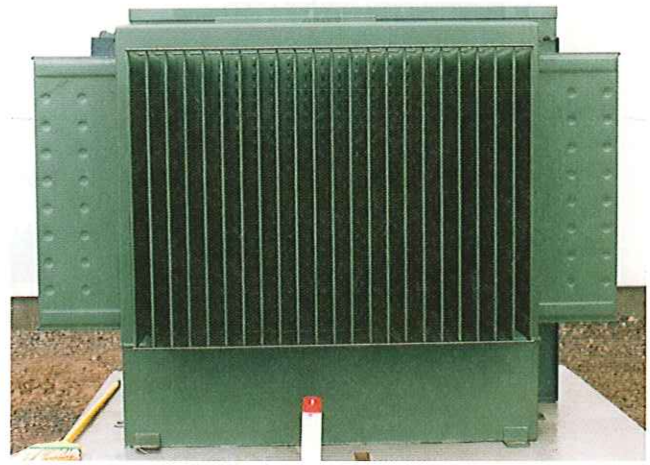

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Figure 4 ◆ Padmount transformer.

2.5.0 Secondary Systems

From a practical standpoint, most of your work will be involved with the power supply on the secondary (usage) side of the transformer.

Two general arrangements of transformers and secondaries are in common use. The first arrangement is the sectional form, in which a unit of load, such as one city street or city block, is served by secondary conductors, with the transformer located in the middle. The second arrangement is the continuous form, in which the primary is installed in one long continuous run, with transformers spaced along it at the most suitable points to form the secondaries. As the load grows or shifts, the transformers spaced along it can be moved or rearranged, if desired. In a sectional

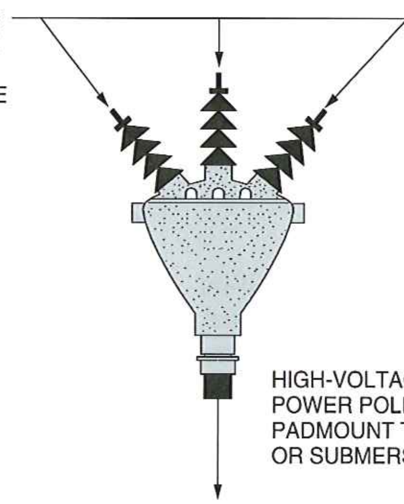

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Figure 5 ◆ Typical pole-mounted pothead.

arrangement, such a load can be increased only by changing to a larger size of transformer or installing an additional unit in the same section.

One of the greatest advantages of the secondary bank is that the starting currents of motors are divided among transformers, reducing voltage drop and diminishing the resulting lamp flicker at the various outlets.

Power companies all over the United States and Canada are now trying to incorporate networks into their secondary power systems, especially in areas where a high degree of service reliability is necessary. Around cities and industrial applications, most secondary circuits are three-phase, either 120/208V or 277/480V, and are wye-connected. Usually, two to four primary feeders are run into the area and the transformers are alternately connected to them. The feeders are interconnected in a grid or network so that if any feeder goes out of service, the load is still carried by the remaining feeders.

The primary feeders supplying networks are run from substations at the usual primary voltage for the system, such as 4,160V, 4,800V, 6,900V, or 13,200V. Higher voltages are practical if the loads are large enough to warrant them.

2.6.0 Common Power Supplies

The most common power supply used for residential and small commercial applications is 120/240V, single-phase, three-wire service; it is used primarily for light and power, including single-phase motors up to about 7½ horsepower (hp). A diagram of this service is shown in *Figure 6*.

Four-wire, **delta-connected** secondaries (*Figure 7*) and four-wire, wye-connected secondaries (*Figure 8*) are common in industrial and commercial applications.

The characteristics of the electric service and the equipment connected to the service must match. Also, the characteristics of an electric service will often dictate those for the electrical equipment or vice versa.

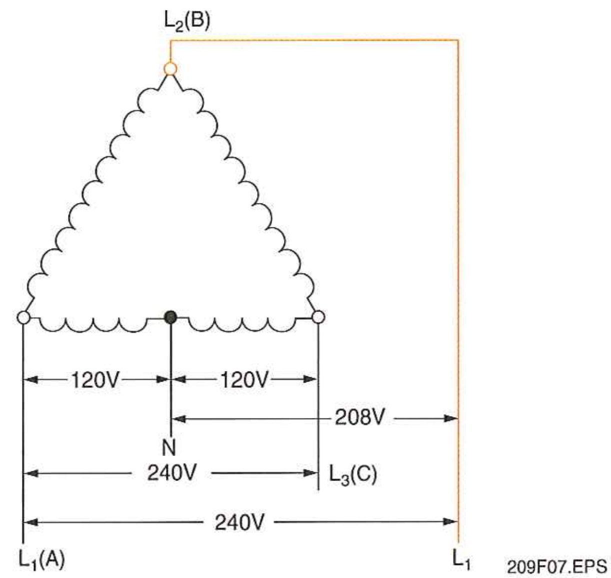

Figure 7 ◆ Three-phase, four-wire, delta-connected secondary.

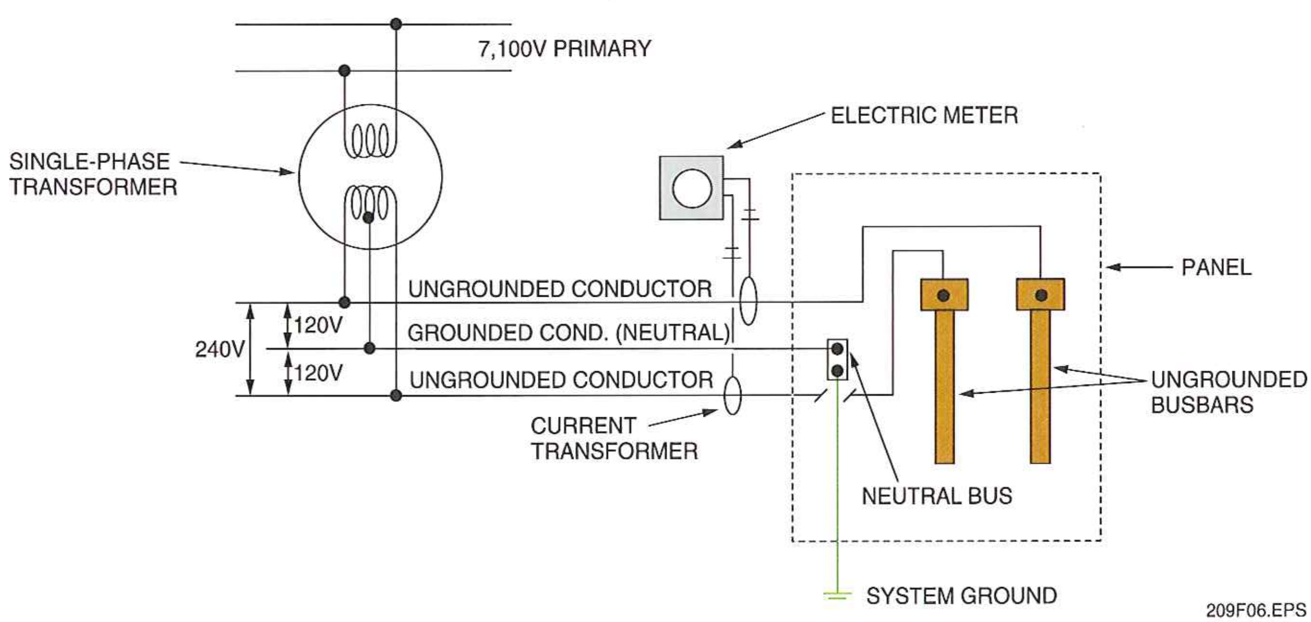

Figure 6 ◆ Single-phase, three-wire, 120/240V electric service.

Referring again to the three-phase, wye-connected service in *Figure 8*, note that the voltage between any one of the three conductors (legs L_1, L_2, and L_3) and the grounded (neutral or N) conductor is 120V. Consequently, you might assume that the voltage between any two of the phase conductors would be 240V. However, this is not the case. When dealing with any three-phase wye system, a factor—the square root of 3 ($\sqrt{3}$ or 1.73)—must be applied to determine the phase-to-phase voltage. Therefore, to find the voltage between any two phase conductors, multiply the voltage of one phase conductor to ground (120V) by the square root of 3:

$$120 \times \sqrt{3} = 207.84\text{V (approx. 208V)}$$

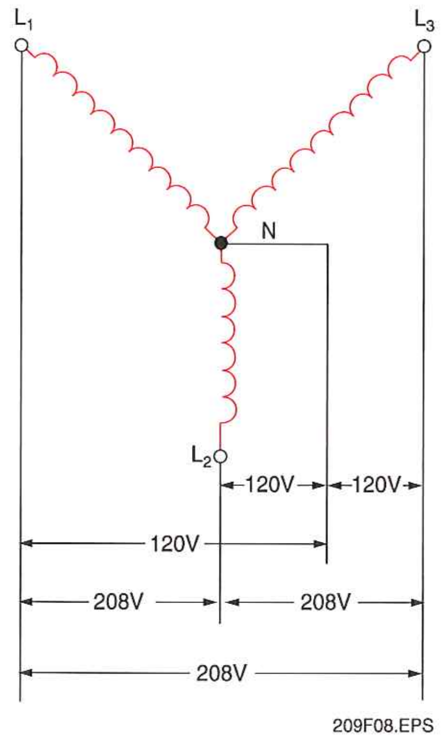

Figure 8 ◆ Four-wire, wye-connected secondary.

Therefore, feeder and branch circuits connected to 120/208V, three-phase, four-wire systems can supply the following loads:

- 120V, single-phase, two-wire
- 208V, single-phase, two-wire
- 208V, three-phase, three-wire
- 120/208V, three-phase, four-wire

The 120/208V, three-phase, four-wire system yields an electrical supply for loads rated at 120/208V, such as HVAC equipment, cooking units, washers, and dryers.

Another popular wye-connected system is the three-phase, four-wire, 277/480V system.

Feeder and branch circuits connected to 277/480V, three-phase, four-wire systems can supply the following loads:

- 277V, single-phase, two-wire
- 480V, single-phase, two-wire
- 480V, three-phase, three-wire
- 277/480V, three-phase, four-wire

The delta-connected system in *Figure 9* operates a little differently. While the wye-connected system is formed by connecting one terminal from three equal voltage transformer windings together to make a common terminal, the delta-connected system has its windings connected to

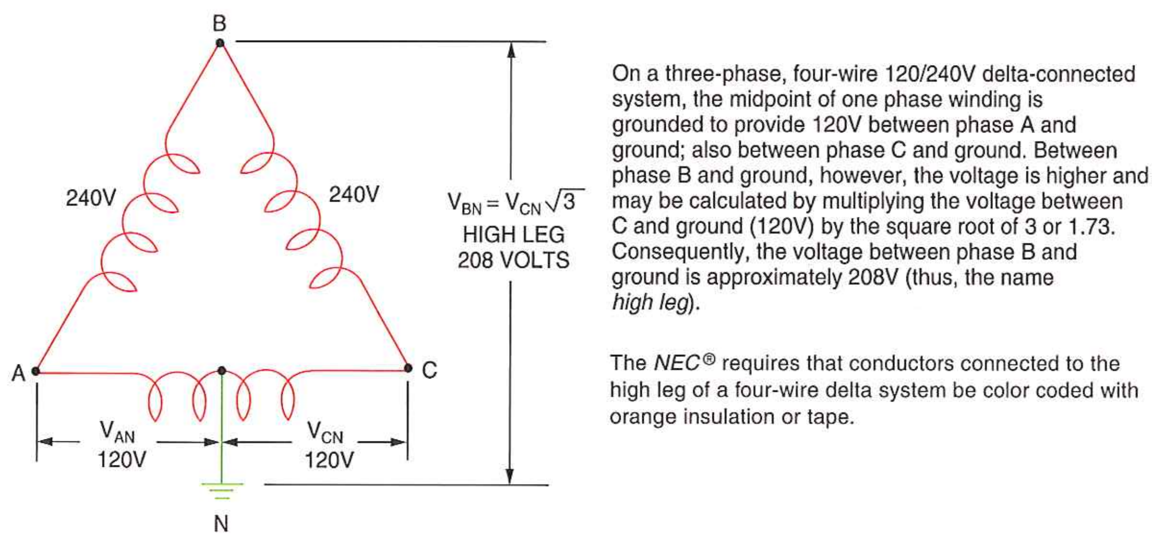

Figure 9 ◆ Characteristics of a center-tap, delta-connected system.

THINK ABOUT IT

Four-Wire, Delta-Connected Secondary

You are connecting 120V lighting branch circuits in a panelboard equipped with a neutral bus. One of the conductors feeding the panel has an orange finish. Can a bus connected to this feeder be used in conjunction with the neutral to supply a 120V branch lighting circuit?

form a triangle or the Greek delta symbol Δ. Note in *Figure 9* that a center-tap terminal is used on one winding to ground the system. On a 120/240V system, 120V is available between the center-tap terminal and each ungrounded terminal on either side, while 240V is available across the full winding of each phase.

Refer again to *Figure 9*. Point B is known as the high leg or wild leg. This high leg has a higher voltage to ground than the other two phases. The voltage of the high leg can be determined by multiplying the voltage to ground of either of the other two legs by the square root of 3. Therefore, if the voltage between phase A and ground is 120V, the voltage between phase B and ground may be determined as follows:

$$120 \times \sqrt{3} = 207.84\text{V (approx. 208V)}$$

From this, it should be obvious that no single-pole breakers should be connected to the high leg of a center-tapped, four-wire, delta-connected system. In fact, *NEC Sections 230.56 and 408.3(E)* state that the phase busbar or conductor having the higher voltage to ground must be permanently marked by an outer finish that is orange in color. This prevents future workers from connecting 120V single-phase loads to this high leg, which would probably result in damaging any equipment connected to the circuit. Remember the color orange: No 120V loads are to be connected to this phase.

3.0.0 ◆ SERVICE COMPONENTS

Electricians who work mostly on commercial projects will be involved with the service installation from the power company's point of attachment to the building's service equipment, including all wiring and components in between, with the possible exception of the electric meter.

To understand the function of each part of an electric service, we will examine an actual installation—a commercial retail store. Assume that you are in charge of the project and this is your first day on the job. The contractor's superintendent stops by the project site and hands you a set of working drawings and written specifications. It is up to you to determine how the service is to be installed. Furthermore, you will be required to compile a materials list and order all the necessary items to complete the service installation.

This particular project consists of a rectangular building that is a part of a shopping center complex. The concrete block walls have been erected and the building is under roof. The concrete floor will not be poured until all electrical and plumbing work has been installed. However, the permanent electric service is to be installed immediately to provide temporary power for the workers. The remaining wiring in the building will be installed later.

3.1.0 Consulting the Construction Documents

The first order of business is to consult the working drawings and then read the appropriate sections in the written specifications. The floor plan of the building appears as shown in *Figure 10*. Note that the standard panel symbol is used (a solid rectangle) to indicate the location of Panel *A*, the only power panel used on this project. The panel symbol indicates that the panel is to be surface-mounted on the inside rear wall of the building in the storage area. The electric meter, as well as a time clock for controlling night and outside lighting, are also shown on this floor plan. The meter is installed on the outside rear wall, while the time clock is installed on the inside rear wall, next to Panel *A*.

Notes and callout arrows on this floor plan refer to a power-riser diagram and also a panelboard schedule on the same drawing sheet; these appear in *Figures 11* and *12*, respectively. This drawing sheet showing the floor plan, power-riser diagram, and panelboard schedule provides most of the required information so that the service can be installed to meet the project specifications.

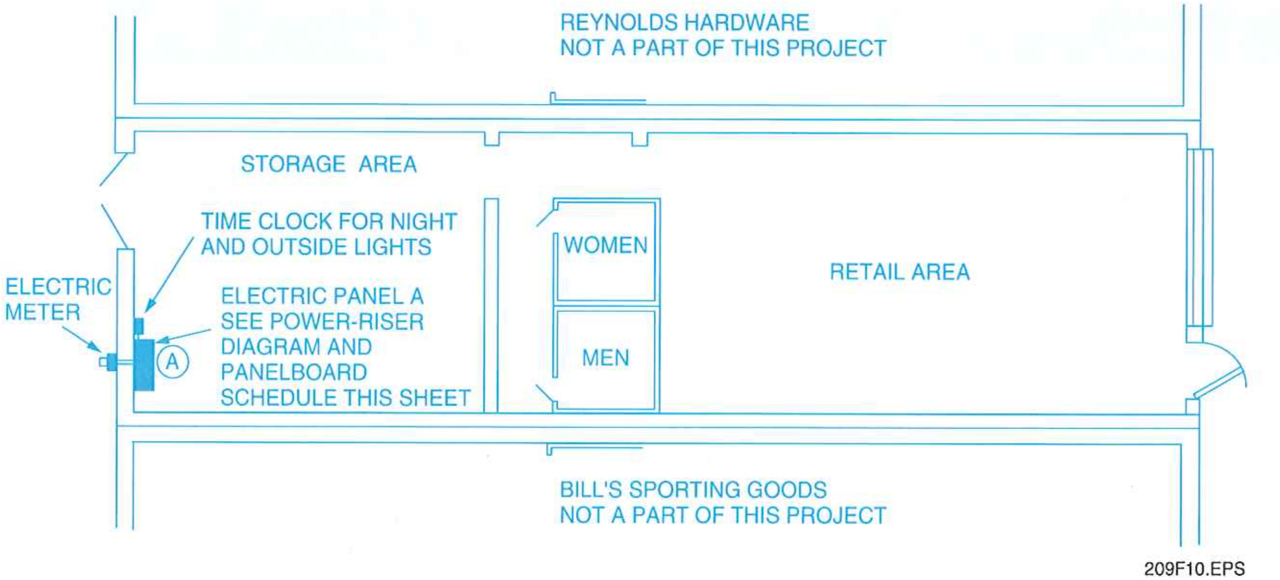

Figure 10 ◆ Floor plan of an example commercial facility.

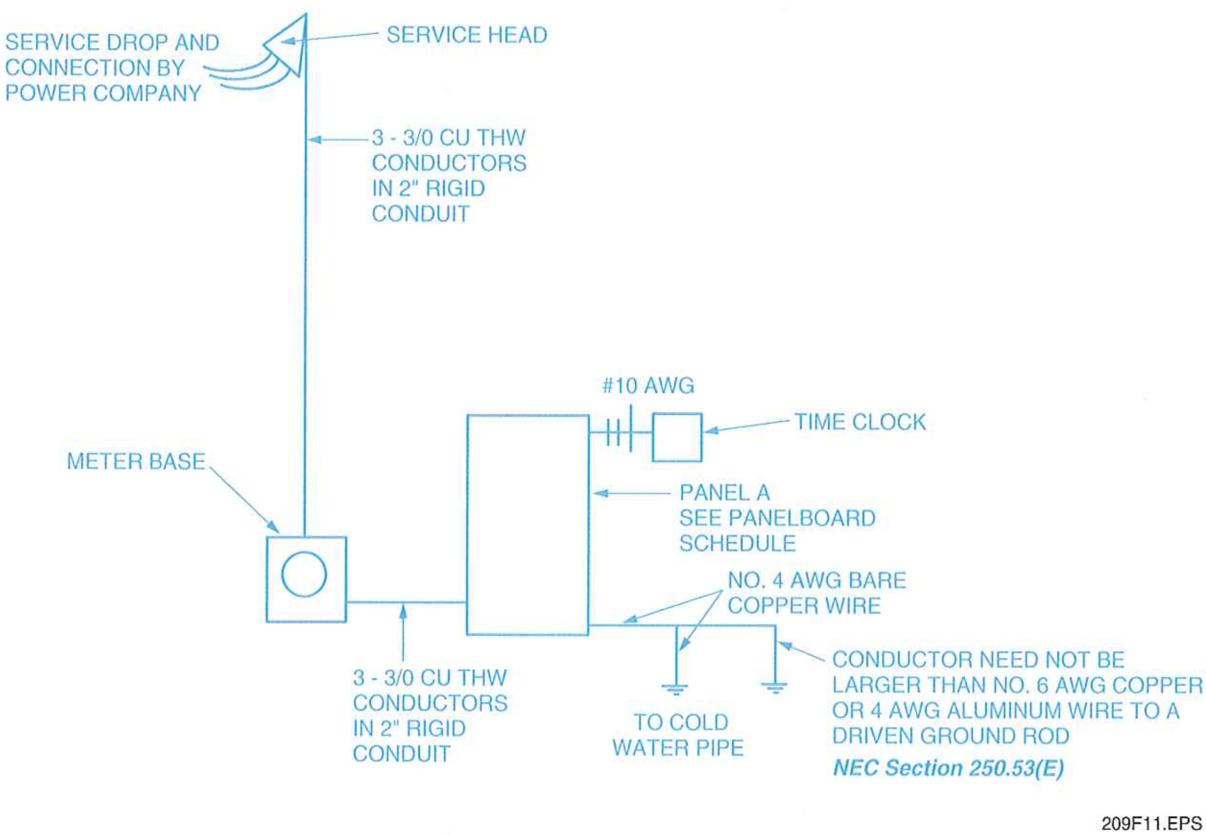

Figure 11 ◆ Power-riser diagram for sample facility.

In most cases, electrical workers are not required to design electrical systems; rather, they are required to interpret the engineer's designs. Consequently, panelboard schedules will vary with each designer. However, once you have a feel for interpreting electrical working drawings, you should have little difficulty in reading schedules.

The written specifications should also be read to make certain that no conflicts exist, and to further verify the information found on the working drawings. A sample specification appears in *Figure 13*.

PANELBOARD SCHEDULE										
PANEL NO.	CABINET TYPE	PANEL MAINS								ITEMS FED OR REMARKS
		AMPS	VOLTS	PHASE	1P	2P	3P	PROT.	FRAME	
A	SURFACE	200A	120/240	1φ, 3 - W	12	-	-	20A	70A	LTS., RECEPTS, W.C.
					-	1	-	60A	100A	CONDENSING UNIT
					-	1	-	30A	70A	WATER HEATER
					-	1	-	20A	70A	AIR-HANDLING UNIT
					-	2	-	20A	70A	TOILET HEATERS
					8	-	-	-	70A	PROVISIONS ONLY

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Figure 12 ◆ Panelboard schedule for sample facility.

From the information obtained from the drawings and specifications, we know that the service for this project is single-phase, three-wire, 120/240V, 200A. The main panel (Panel A) is a surface-mounted Square D Type NQO (or equivalent) with a 200A main circuit breaker. Furthermore, we can determine the number of spaces required in the panel by totaling the number of circuit breakers listed in the panelboard schedule as follows:

12 single-pole, 20A breakers = 12 spaces

1 two-pole, 60A breaker = 2 spaces

1 two-pole, 30A breaker = 2 spaces

3 two-pole, 20A breakers = 6 spaces

8 provisions only = 8 spaces

Total = 30 spaces

Therefore, a surface-mounted panel (Square D and type NQO with 200A main circuit breaker and provisions for 30 spaces) can be ordered. The required circuit breakers should also be ordered and installed at the same time. This will meet with the project specifications.

3.2.0 Service Head

Referring again to *Figure 11,* start at the top of the service riser. The first item shown is the service head, sometimes called the weatherhead. *NEC Section 230.54(A)* requires the **service raceway** in our example to be equipped with a raintight service head at the point of connection to the service drop conductors.

A service head (*Figure 14*) is a fitting that prevents water from entering the service raceway. This is accomplished by bending the service conductors contained in the raceway downward as they exit from the service head so that any water or moisture will drip from the outside conductors before entering the service head. These conductors are also protected by a plastic or fiber strain insulator or bushing placed at the entrance of the service head to separate the service conductors as required by *NEC Section 230.54(E).* Two types of service heads are in common use: one type has internal threads that enable the service head to be screwed directly onto the conduit; the other type utilizes a clamp with retaining screws. In the latter type, the service head is placed on top of the service raceway and the clamp is tightened with the retaining screws.

Further protection from water and moisture is provided by drip loops, as specified in *NEC Section 230.54(F).* Service heads are required to be located above the service drop attachment. Drip loops are then formed where the service drop conductors are connected to the service conductors, and these drip loops must be located below the service head. *Figure 14* shows how drip loops prevent water from entering the service raceway; that is, water will not flow uphill into the service head, so the water drips from the conductors at the lowest point of the drip loop.

The service-entrance conductors must have a minimum length of 3½' after they leave the service head. This is to ensure a good drip loop and to provide adequate length for splicing onto the service drop.

NOTE

Some states allow a shorter minimum length after leaving the service head. Always check and follow local codes.

PANELBOARDS-CIRCUIT BREAKER

A. GENERAL:

Furnish and install circuit breaker panelboards as indicated in the panelboard schedule and where shown on the drawings. The panelboard shall be a dead-front safety-type equipped with molded case circuit breakers and shall be the type as listed in the panelboard schedule. Service-entrance panelboards shall include a full capacity box bonding strap and be approved for service entrance. The acceptable manufacturers of the panelboards are ITE, General Electric, Cutler-Hammer, and Square D, provided that they are fully equal to the type listed on the drawings. The panelboard shall be listed by Underwriters' Laboratories and bear the UL Label.

B. CIRCUIT BREAKERS:

Provide Type NQO circuit breakers of frame, trip rating, and interrupting capacity as shown on the schedule. Also, provide the number of spaces for future circuit breakers as shown in the schedule. The circuit breakers shall be quick-make, quick-break, thermal-magnetic, trip indicating, and have a common trip on all multipole breakers with internal tie mechanisms.

C. WIRING TERMINALS:

Terminals for feeder conductors to the panelboard mains and neutral shall be suitable for the type of conductor specified. Terminals for branch circuit wiring, both breaker and neutral, shall be suitable for the type of conductor specified.

D. CABINETS AND FRONTS:

The panelboard bus assembly shall be enclosed in a steel cabinet. The size of the wiring gutters and gauge of steel shall be in accordance with NEMA Standards. The box shall be fabricated from galvanized steel or equivalent rust-resistant steel. Fronts shall include door and have flush, brushed stainless steel, spring-loaded door pulls. The flush lock shall not protrude beyond the front of the door. All panelboard locks shall be keyed alike. Fronts shall not be removable with the door in the locked position.

E. DIRECTORY:

On the inside of the door of each cabinet, provide a typewritten directory which will indicate the location of the equipment or outlets supplied by each circuit. The directory shall be mounted in a metal frame with a nonbreakable transparent cover. The panelboard designation shall be typed on the directory card and panel designation stenciled in 1-1/2" high letters on the inside of the door.

F. PANELBOARD INSTALLATION

(1) Before installing panelboards check all of the architectural drawings for possible conflict of space and adjust the location of the panelboard to prevent such conflict with other items.

(2) When the panelboard is recessed into a wall serving an area with accessible ceiling space, provide and install an empty conduit system for future wiring. All 1-1/4" conduit shall be stubbed into the ceiling space above the panelboard and under the panelboard if such accessible ceiling space exists.

(3) The panelboards shall be mounted in accordance with *NEC Article 312.* The Electrical Contractor shall furnish all material for mounting the panelboards.

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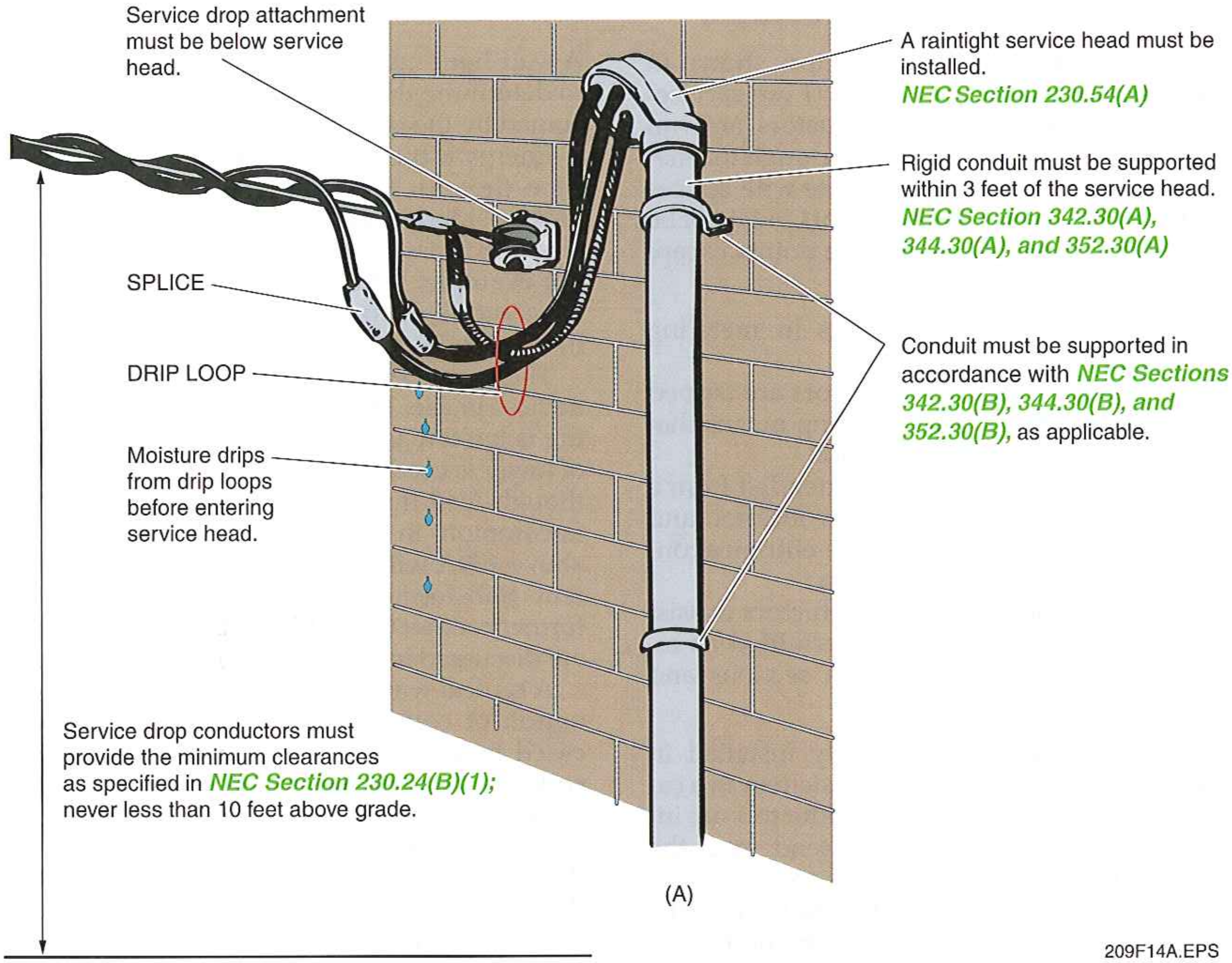
Figure 13 ◆ Sample panelboard specifications.



(A)

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209F14B.EPS

(B)

Figure 14 ◆ Service head and related components.

3.3.0 Service-Entrance Conductors

The 3/0 AWG, Type THW conductors shown in the power-riser diagram in *Figure 11* are service-entrance conductors. These conductors are run from the main disconnect breaker through the meter to the service head and terminate with splices onto the service drop. The conductors must not be spliced at any place between these points except for the following:

- Clamped or bolted connections in metering equipment
- Where service-entrance conductors are tapped to supply two to six disconnecting means that are grouped at a common location
- Where service conductors are extended from a service drop to an outside meter location and returned to connect to the service-entrance conductors of an existing installation
- Where the service-entrance conductors consist of a busway, connections are permitted as required to assemble the various sections and fittings

Service conductors are normally installed in two different ways: in a raceway system or in a cable assembly. In our sample, the conductors are installed in 2" rigid conduit and extend from the service head down to the threaded weatherproof hub on top of the meter base. The *NEC®* permits the conductors to be spliced at this point, that is, connected to the bolted terminals on the meter base. However, no splices are permitted from the service head to the meter base.

3.4.0 Service Equipment

Equipment and components falling under the heading of service equipment include the main disconnect switch or breaker, circuit breakers, fuses, and other items necessary to control and disconnect the power supply.

3.4.1 Metering Equipment

A watt-hour meter is used by the power company to determine the amount of electrical energy consumed by the customer.

Energy is the product of power (kilowatts) and time (hours). The type of meter connected to most residential and small commercial occupancies provides a reading in kilowatt-hours (kWh). For example, if the meter reads a usage of 500W for a period of six hours, it would register 3kWh ($0.5 \times 6 = 3$).

There are several different types of metering devices in use. The type used in our sample building is known as the feed-through type. This type of meter is used mostly for services up to 200A, although feed-through meters up to 400A are not uncommon in many locations. Services rated above 400A will almost always use separate current transformers enclosed in a current transformer cabinet (CT cabinet). Current transformers are discussed in greater detail later in this module.

A typical watt-hour meter consists of a combination of coils, conductors, and gears—all encased in a housing, as shown in *Figure 15*. The coils are constructed on the same principle as a split-phase induction motor, in that the stationary current coil and the voltage coil are placed so that they produce a rotating magnetic field. A disc near the center of the meter is exposed to the rotating magnetic field. The torque applied to the disc is proportional to the power in the circuit, and the braking action of the eddy currents in the disc makes the speed of the rotation proportional to the rate at which the power is consumed. The disc, through a train of gears, moves the pointers on the register dials to record the amount of power used directly in kilowatt-hours.

Most watt-hour meters use five dials (see *Figure 15*). The dial farthest to the right on the meter counts the kilowatt hours singly. The second dial

INSIDE TRACK

Service Mast Installations

NEC Sections 342.30(A) and 344.30(A) do not require above-the-roof terminations of metal conduit service masts to be secured within 3' of the service head.

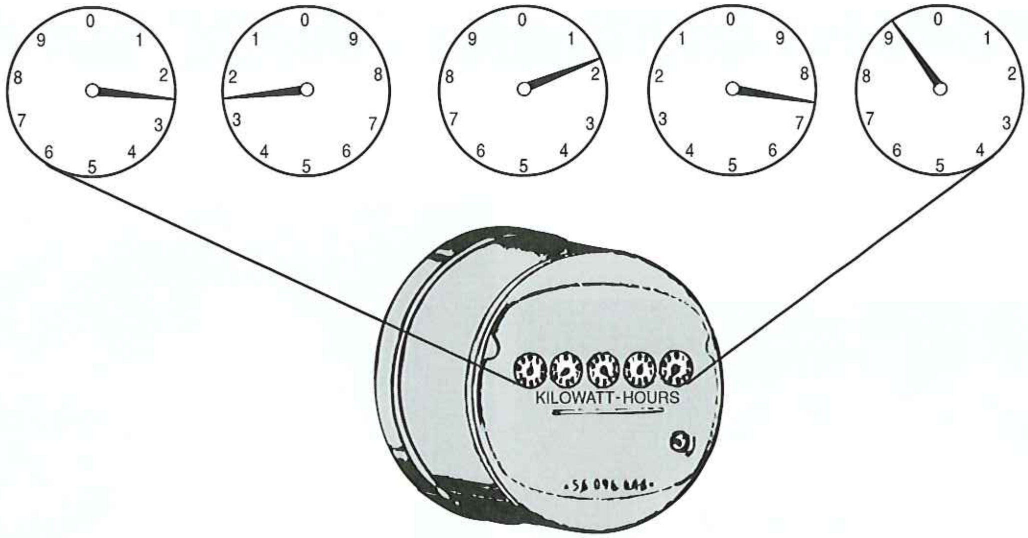

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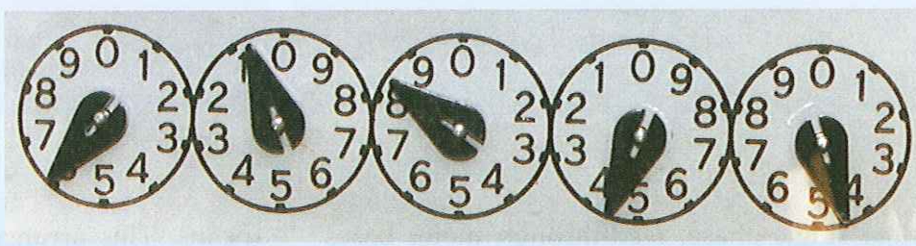
Figure 15 ◆ Typical watt-hour meter.

THINK ABOUT IT

Reading a Watt-Hour Meter

What is the reading on this meter?



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from the right counts by tens, the third dial by hundreds, the fourth dial by thousands, and the left-hand dial by ten-thousands. The dials may seem a little strange at first, but they are actually very simple to read. The number which the dial has passed is the reading. For example, look at the dial on the far left. Note that the pointer is about halfway between the number 2 and the number 3. Since it has passed the number 2, but has not yet reached 3, the dial reading is 2. The same is true of the second dial from the left; that is, the pointer is between 2 and 3. Consequently, the reading of this dial is also 2. Following this same procedure, the complete reading for the meter in *Figure 15* is 22,179 kilowatt-hours.

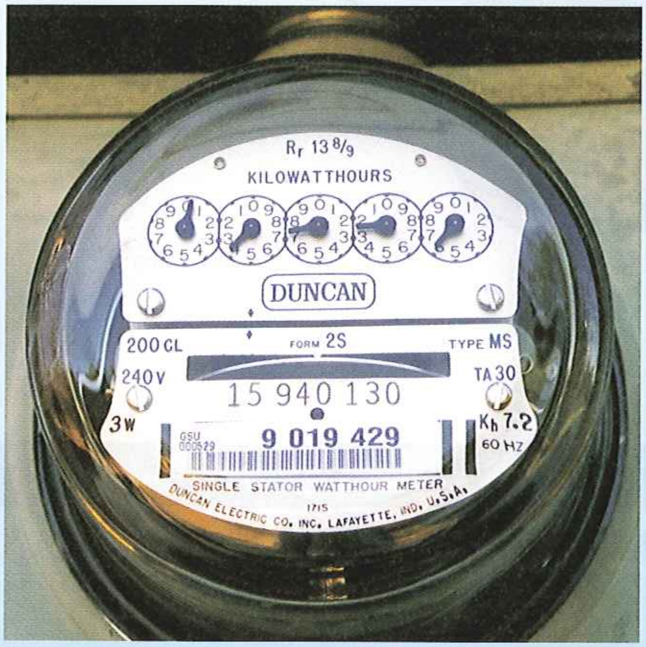
Although knowing how to read an electric meter is interesting, most electricians will be involved only with installing the meter base and making the connections therein. Once these connections are made and inspected, the local power company will install and seal the meter.

Meter bases should be installed securely with anchors sufficient to hold the weight of the meter as well as the raceway system resting upon the meter base. In our example, this base must support the 2" conduit, service head, and copper conductors. Although the conduit will be supported with conduit straps, most of the weight will rest upon the meter base; the straps are used mainly to keep the conduit from moving sideways.

INSIDE TRACK

Meter Types

Watt-hour meters are available in both analog and digital forms, as shown here.



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(A) ANALOG

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(B) DIGITAL

Most single-phase, feed-through meter bases are arranged as shown in *Figure 16*. The ungrounded service conductors from the service drop terminate in the top terminals. These conductors are once again picked up from the bottom terminals. Clips are provided on these terminals to clamp in the meter itself, allowing current from the ungrounded conductors to pass through the meter for a reading. Since the grounded conductor (neutral) is not metered, one terminal is provided for both the incoming and outgoing conductors.

3.4.2 Service Disconnecting Means

A service disconnecting means is a device that enables the electric service from the power company to be disconnected from the building or premises. Several different configurations are possible. In our sample building, a single panel with a 200A main circuit breaker acts as the disconnecting means. This arrangement and another possible service configuration for the same project appear in *Figure 17*.

Service switches, **load centers**, or main distribution panelboards are normally installed at the point where the service-entrance conductors enter the building. Branch circuits and feeder panelboards (as well as the main service panel, when required) are usually grouped together at one or more centralized locations to keep the length of the branch circuit conductors at a practical minimum and to lower the initial installation costs.

Distribution panelboards are generally intended to carry and control electrical current, but are not intended to dissipate or use energy. The requirements of *NEC Article 230, Part VI* must be met for service disconnects. In addition, the following factors influence the selection of distribution equipment:

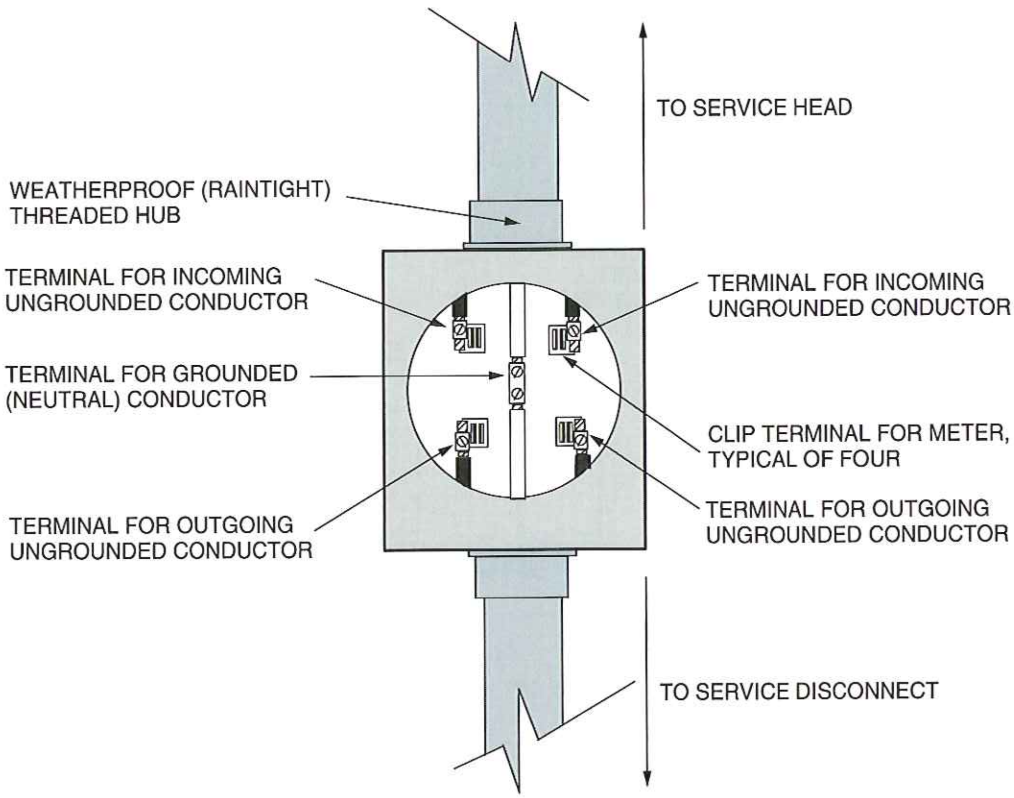

Figure 16 ◆ Arrangement of conductors in a typical single-phase meter base.

INSIDE TRACK

Meter Enclosure Location

The meter enclosure (base) should be mounted in an easily accessible place. The mounting location and height used with meter enclosures must always comply with local and/or electric utility company requirements. Typical mounting heights can range between 4' (minimum) and 7' (maximum) above ground level.

- *Codes and standards* – Suitability for installation and use, in conformity with the provisions of the *NEC*® and all local codes, must be considered. Suitability of equipment may be evidenced by listing or labeling.
- *Mechanical protection* – Mechanical strength and durability, including the adequacy of the protection provided, must be considered.
- *Wiring space* – Wire bending and connection space is provided according to UL standards in all distribution equipment. When unusual wire arrangements or connections are to be made, then extra wire bending space, gutters, and terminal cabinets should be investigated for use.
- *Electrical insulation* – All distribution equipment carries labels showing the maximum voltage level that should be applied. The supply voltage should always be equal to or less than the voltage rating of distribution equipment.
- *Heat* – Heating effects under normal conditions of use and also under abnormal conditions likely to arise in service must be constantly considered. Ambient heat conditions, as well as wire insulation ratings, along with the heat rise of the equipment, must all be evaluated during selection.
- *Arcing effects* – The normal arcing effects of overcurrent protective devices must be considered when the application is in or near combustible materials or vapors. Enclosures are selected to prevent or contain fires created by the equipment.

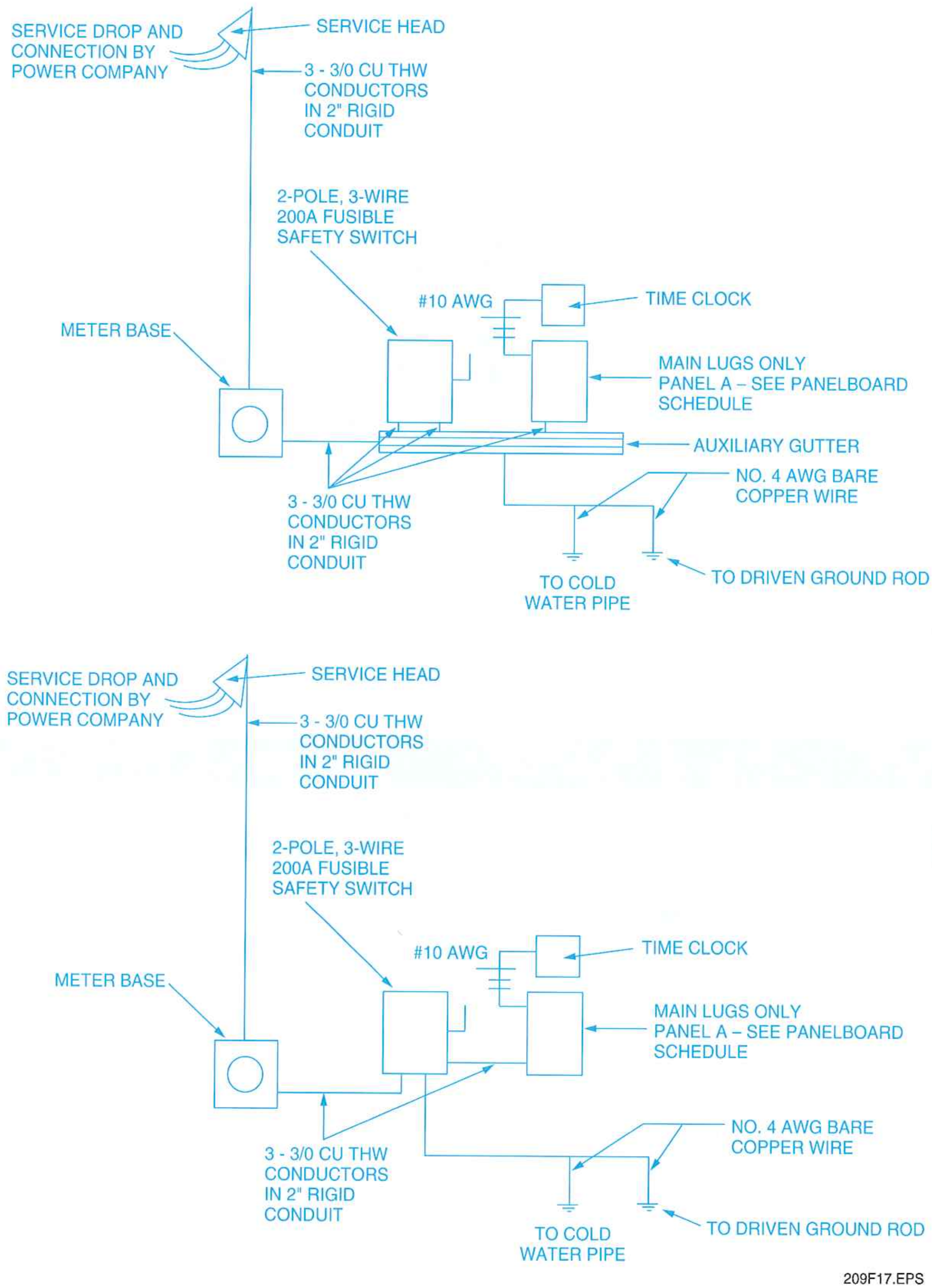

Figure 17 ◆ Two possible service configurations for the sample facility.

Inside Track: Dual Services

Some large installations have two services. Dual services are provided with separate disconnects, as shown here.

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Inside Track: Service Disconnects

Some local codes allow service-entrance conductors to be run within a building up to a specified length to terminate at the service disconnect. Depending on the specific state or locality, the allowable length can vary anywhere from one or two feet to several feet. When service conductors are run inside a building, they should always be kept to a minimum length, because power utilities provide limited overcurrent protection and, in the event of a fault, the service conductors could ignite nearby combustible materials.

- *Classification* – Classification according to type, size, voltage, current capacity, interrupting capacity, and specific use must be considered when selecting distribution equipment. Loads may be continuous or noncontinuous, and the demand factor must be determined before distribution equipment can be selected.
- *Personal protection* – Other factors that contribute to the practical safeguarding of a person using or likely to come in contact with the equipment must be considered. The equipment selected for use by qualified persons may be different from the equipment used or applied where unqualified people may come in contact with it.

In electrical wiring installations, overcurrent protective devices, consisting of fuses or circuit breakers, are sometimes factory-assembled in a metal cabinet; the entire assembly is commonly called a panelboard. At other times, the panelboards will be delivered unassembled, consisting of an enclosure (can), the interior busbars, and the trim. Circuit breakers are then installed as the project dictates.

Sometimes the main service disconnecting means will be made up on the job by assembling individually enclosed fused switches or circuit breakers on a length of metal auxiliary gutter, as shown in one of the views in *Figure 17*.

3.5.0 Grounding and Bonding

NEC Article 250 covers the requirements for grounding and bonding electric services. In general, the *NEC®* requires that a premises' wiring system supplied by an AC service be grounded by a grounding electrode conductor connected to a grounding electrode. The grounding electrode conductor must be bonded to the grounded service conductor (neutral) at any accessible point from the load end of the service drop or service lateral up to and including the terminal bus to which the grounded service conductor is connected at the service disconnecting means. A grounding connection must not be made to any grounded circuit conductor on the load side of the service disconnecting means.

Most applications require the grounded service conductor to be bonded to one or more electrodes according to *NEC Section 250.50.*

Table 1 gives the required sizes of grounding conductors for various sizes of electric services. Referring to this table, since the service in our sample building is 200A, requiring 3/0 THW copper conductors, a No. 4 AWG copper or No. 2 AWG aluminum wire must be used for the grounding electrode conductor. Refer to *Figure 18* and the module on grounding for additional details on grounding electric services.

4.0.0 ◆ MATERIAL TAKEOFF

After reviewing the details of construction and the *NEC®* requirements so far, all the necessary information required for a complete material takeoff of the service installation has been gathered, with the exception of the height of the service raceway. Our sample building has a flat, built-up gravel roof with a parapet wall around the roof perimeter. The height of the back wall where the service raceway will be installed, along with other details of construction, are shown on the architect's elevation views of the building. If no plans are available, the wall height can be measured, or since 8" high concrete blocks are used for the construction of the wall, one column of blocks may be counted and the height of the wall determined by the following equation:

$$\frac{\text{Number of blocks} \times 8}{12} = \text{total feet}$$

A rear elevation view of our sample building is shown in *Figure 19*.

Note that the total height of the rear wall from ground level is 20', including the parapet wall. However, a loading platform is 4' above grade, and since the meter can be read from this platform, the meter can be installed 4' above the loading dock grade or 8' above ground level.

Table 1 Sizes of Grounding Electrode Conductors for AC Systems

Size of Largest Service-Entrance Conductor or Equivalent for Parallel Conductors		Size of Grounding Electrode Conductor	
Copper	**Aluminum or Copper-Clad Aluminum**	**Copper**	**Aluminum or Copper-Clad Aluminum**
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250 kcmil	4	2
Over 3/0 through 350 kcmil	Over 250 kcmil through 500 kcmil	2	1/0
Over 350 kcmil through 600 kcmil	Over 500 kcmil through 900 kcmil	1/0	3/0
Over 600 kcmil through 1,100 kcmil	Over 900 kcmil through 1,750 kcmil	2/0	4/0
Over 1,100 kcmil	Over 1,750 kcmil	3/0	250 kcmil

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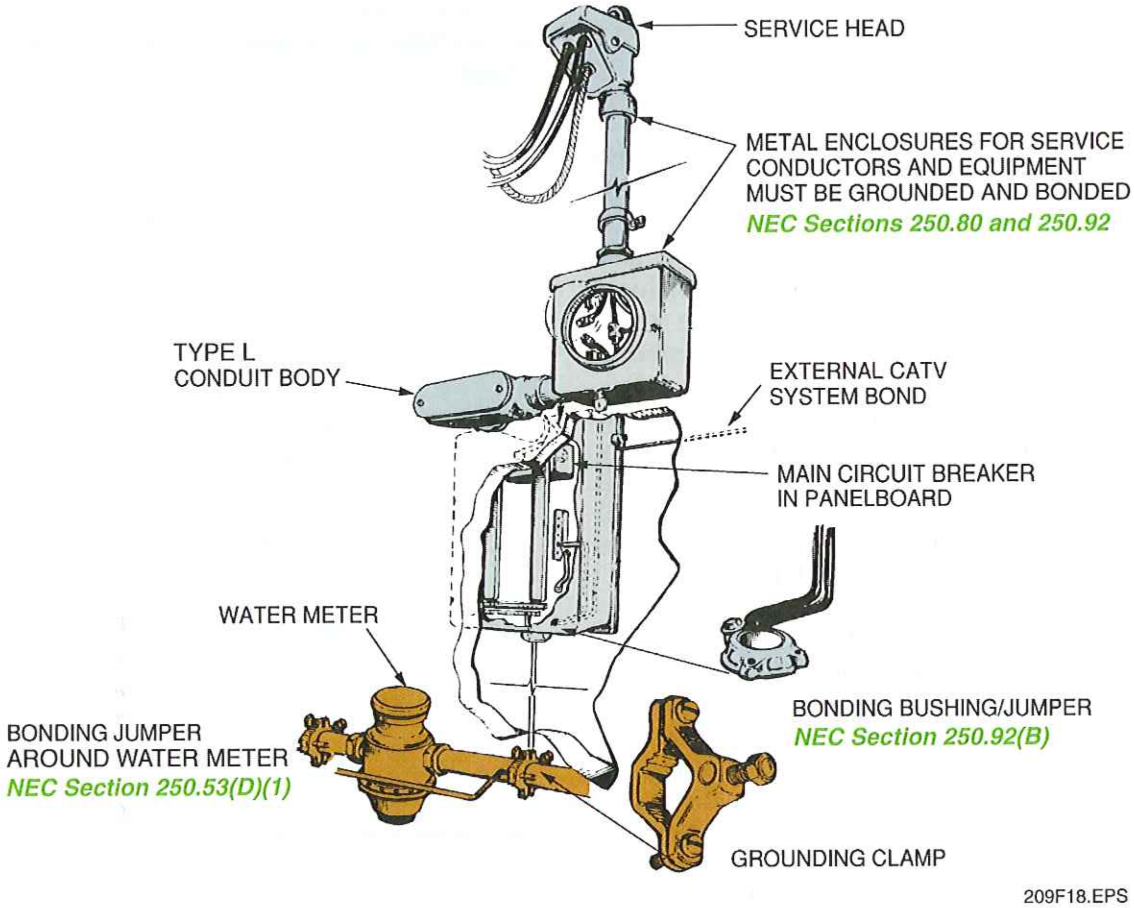

Figure 18 ◆ Summary of *NEC*® service grounding regulations.

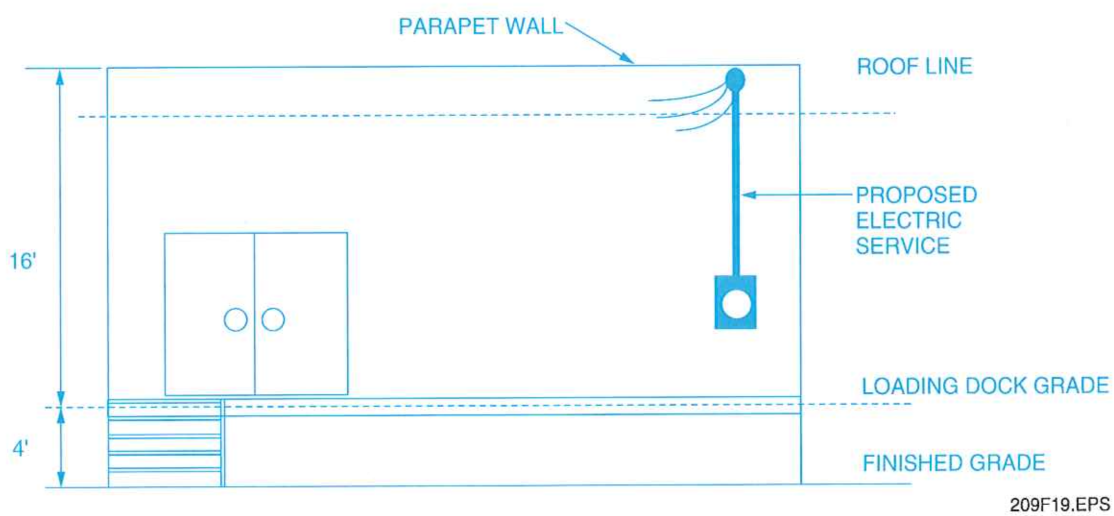

Figure 19 ◆ Rear elevation of sample building.

Consequently, one 10' length of 2" conduit will put the service raceway and service head at the very top of the wall, leaving plenty of room for the power company to connect the service drop below the service head to comply with *NEC Section 230.54(C).* Furthermore, the service drop will be more than 10' above the deck—complying with *NEC Sections 230.24 and 230.26.*

Once the service configuration has been laid out, it is best to verify the layout with the local power company. This is also a good time to request the meter base that will have to be installed by the electrician on the job.

This is also a good time to start thinking about the tool requirements. Since the service raceway extends 16' above the loading dock, workers will need a 24' extension ladder. A rotary hammer will be needed to drill the holes for the lead anchors and to penetrate the concrete block to insert the 2" nipple between the meter base and the panelboard on the inside wall. Cable cutters will speed up the work when cutting the 3/0 service conductors and a bucket of wire-pulling lubricant will facilitate the installation of the 3/0 conductors into the 2" conduit. For this short length of pull, no special cable-pulling apparatus should be required. The conductors are merely cut to length, and then two workers feed these conductors from the top of the service raceway down to the meter base for connection to the meter base terminals. The same is true of the short run between the meter base and the panelboard on the opposite wall.

Much time can be saved on any project if careful planning is exercised before beginning any work. Even if the material is already on the job site, as taken from the electrical estimator's list, the electricians on the job must know how to utilize this material to its best advantage. Traditionally, more time has been wasted on electrical jobs because of material or tool shortages than any other causes. Therefore, before a project is started, make sure that all the necessary materials and tools are at hand. If not, order them immediately. Any time saved on any project, in most cases, means a savings to someone.

Before continuing with this module, complete the takeoff list in *Table 2*. The purpose of this exercise is to prepare a complete list of materials for the service described for our sample commercial building. Since grounding details have not been covered, the items required to ground the system have been listed. In general, two 1" grounding clamps and a bonding jumper are required around the water meter.

Another 1" grounding clamp is required to connect the grounding electrode conductor to the 1" water pipe, and a ⅝" grounding clamp is required to connect the grounding electrode conductor to a driven ground rod. This requires 20' of No. 4 AWG bare copper wire. Also refer to *Figure 18* to better visualize exactly what is required for the grounding of this service.

Table 2 Material Takeoff Exercise

Quantity	Item
1	2" service head
—	2" rigid conduit
—	2" rigid conduit strap(s)
—	200A meter base (obtain from power company)
—	Raintight hub(s) for meter base
—	2" Type L conduit body
—	2" conduit nipple(s) (10" long)
—	4" chase nipple(s) (from meter hub to Type L conduit body)
—	2" locknut(s)
—	Grounding bushing(s)
—	Square D NQO panelboard(s)
—	One-pole, 20A circuit breaker(s)
—	Two-pole, 60A circuit breaker(s)
—	Two-pole, 30A circuit breaker(s)
—	Two-pole, 20A circuit breaker(s)
—	¼-20 lead anchor(s) and ¼-20 machine screw(s) 1½" long
—	No. 3/0 THW copper wire
3	Grounding clamp(s) for 1" pipe
1	Grounding clamp(s) for ⅝" ground rod
20'	No. 4 AWG bare copper wire
1	⅝" copperweld grounding rod(s), 8' in length

5.0.0 ◆ THREE-PHASE SERVICES

Most services encountered on commercial and industrial projects will consist of three-phase systems with voltage ratings as low as 120/208V to as high as perhaps 4,160V or more.

In single-phase current, only one voltage curve is generated, while three-phase current indicates that there are three voltage curves present on the system simultaneously. There is very little difference between installing a single-phase service (just described) and a three-phase service. The main difference is that there is an extra service conductor for a three-phase, four-wire system, requiring that the service head have four openings instead of three. Of course, the panelboard will also have to be arranged for a three-phase system—requiring an extra ungrounded busbar. Other than these changes, the installation process is essentially the same as that described for the single-phase system.

To illustrate, *Figure 20* shows the power-riser diagram for a 1,200A, three-phase, wye-connected

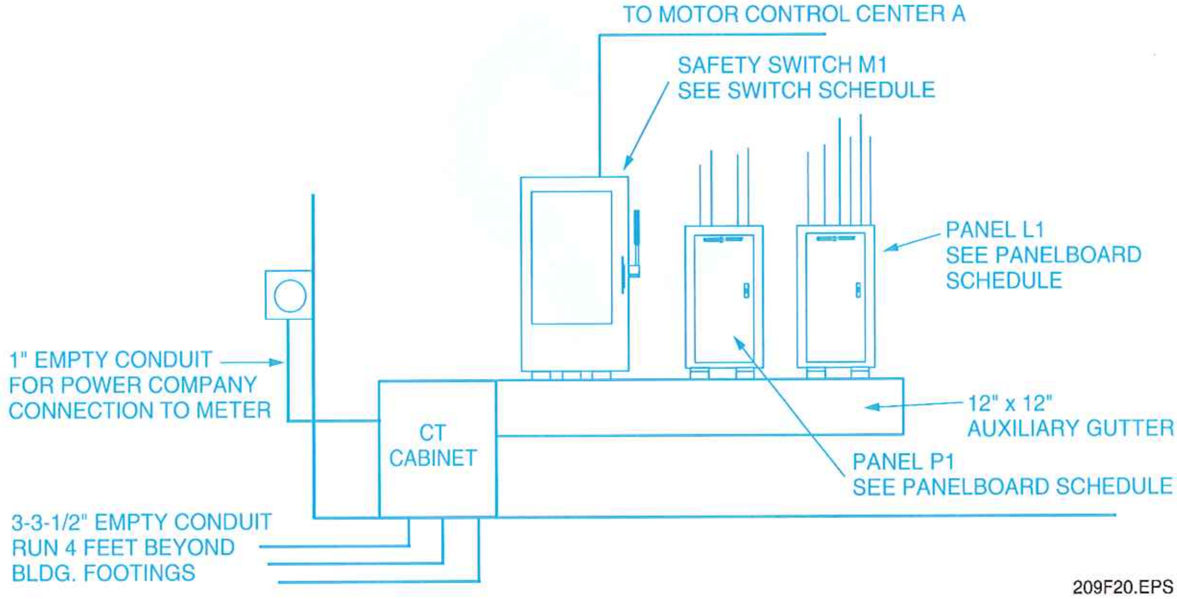

Figure 20 ◆ Power-riser diagram for a three-phase, four-wire, 1,200A service.

service. Note that the service lateral consists of three 3½" empty conduit runs to be installed from the CT (current transformer) cabinet to 4' beyond the building's footings. These are provided for the power company's service lateral.

The service conductors continue through the CT cabinet and terminate in an auxiliary gutter. Three service equipment taps are made in this gutter to feed the following:

- One 800A fusible safety switch, which feeds a motor control center
- One 200A power panel with a main circuit breaker
- One 200A lighting panel with a main circuit breaker

We will take a look at the individual components for this service.

5.1.0 Current Transformers

Meters used by power companies to record the amount of current used by customers usually respond to a current that varies from 0A to 5A. To respond to the actual current of the service, each meter is provided with current transformers. If the peak demand of the service is 100A, a 100:5 current transformer is used. If the peak current demand is expected to be 200A, a 200:5 current transformer is used.

Services above 400A usually utilize a group of current transformers, one for each ungrounded conductor or set of conductors. There are two basic types of current transformers: the busbar type and the doughnut type. The doughnut-type current transformer encircles the ungrounded conductors in the system to read the current flow, much the same as a clamp-on ammeter. See *Figure 21*. The busbar-type current transformer has each transformer connected in series with a busbar and does not encircle the conductor.

Current transformers are normally enclosed in a CT cabinet. *Figure 22* shows a typical CT cabinet with current transformers and their related wiring. In some cases, the current transformers may be mounted exposed on overhead conductors, but this is more the exception than the rule.

Power companies have different requirements for sizes of CT cabinets, but the dimensions shown in *Table 3* are typical for several service sizes.

Power companies also have different specifications for the location and wiring of CTs and CT cabinets, depending on the locale. The following are the requirements of one power company. However, always check the local requirements.

- The meter base and meter may be located on either the side or top of the current transformer cabinet, or they may be located at a distance away, if approved by the power company and as long as the conduit containing the instrument wiring is run exposed.
- In no instance shall more than one set of conductors terminate in the instrument transformer cabinet. Subfeeders and branch circuits are to terminate at the customer's distribution panel. The instrument transformer cabinet shall not be used as a junction box.

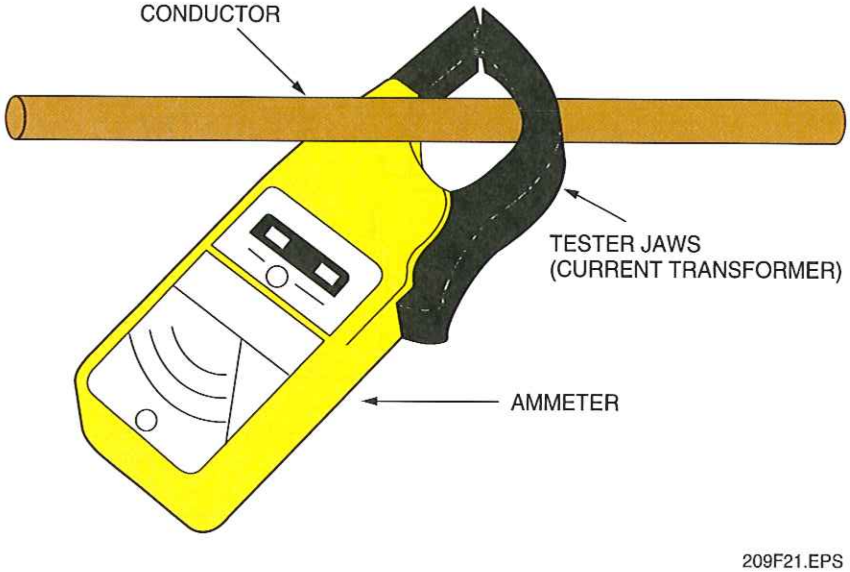

Figure 21 ◆ Clamp-on ammeters operate on the same principle as doughnut-type current transformers.

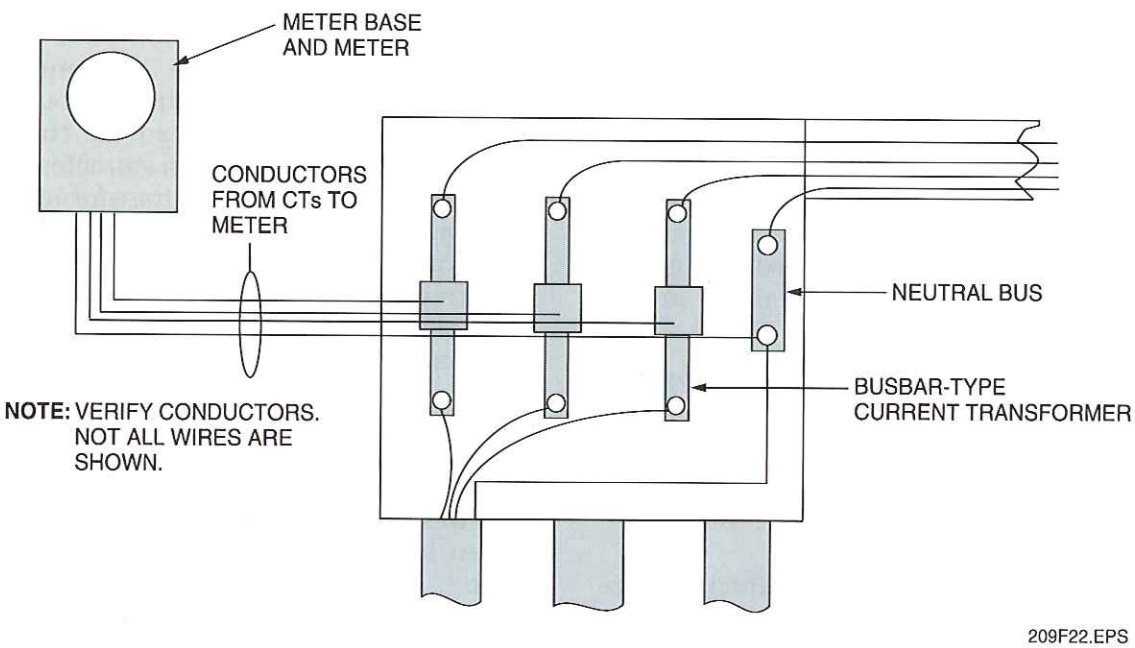

Figure 22 ◆ Typical CT cabinet arrangement.

Table 3 Typical CT Cabinet Sizes

Phase	Service Characteristics	Cabinet Size
Single-phase	120/240V, three-wire	10" × 24" × 32"
Three-phase	120/240V, four-wire	10" × 36" × 42"
Three-phase	120/208V, four-wire	10" × 36" × 42"
Three-phase	480V, three-wire	10" × 36" × 42"
Three-phase	277V/480, four-wire	10" × 36" × 48"

- When service-entrance conductors enter or leave through the back of the cabinet, the size of the CT cabinet must be increased to provide additional working space.
- For services at higher voltages, additional space must be provided in the transformer cabinet for mounting potential transformers. Consult the local power company for dimensions.
- If recording demand instruments are required, increase the height of the meter mounting from 36" to 48".

5.2.0 Gutters

Auxiliary gutters are used to route the service conductors and to provide an enclosure for tapping these conductors for safety switches and panels. In this type of arrangement, appropriate connectors are normally used to make the taps. However, many electrical contractors have found that a bussed gutter saves labor and provides for a neater installation.

A bussed gutter is an assembly of busbars in an enclosure. The enclosure may be rated for outdoor (weatherproof) or indoor installations. Busbars installed in the gutter may be made of aluminum or copper and must have an ampacity rating for the application; that is, if the service conductors are rated for 1,200A (as in our sample building), the busbars must be rated for at least the same ampacity. Furthermore, they must be UL listed.

From an installation or a maintenance/modification viewpoint, bussed gutters are one of the most common types of wiring methods for use with multiswitch services. One advantage of a bussed gutter is the ease of installation and modification. Adding disconnect switches or changing switches is relatively easy. No connectors have to be untaped and reconnected, as with systems using wire connectors on the conductors for taps.

In our example, with a service conductor ampacity of 1,200A, the rating of the busbars in bussed gutters must also be 1,200A if bussed gutters are to be used. See *Figure 23*. Furthermore, the bussed gutter must be rated for the available fault current and must have sufficient wire bending space per *NEC Sections 110.3(A)(3) and 312.(A) through (C).*

5.2.1 Bus Bracing

One characteristic of fault currents is an induced torque in conductors carrying the fault. Because of this torque, the busbars in a bussed gutter must be attached to the enclosure in such a manner as to prevent their being dislodged and/or making contact with the gutter frame during the fault. When busbars are attached in such a manner as to withstand the torque created by the available amount of fault current, they are said to be *braced* for that amount of current. For instance, busbars may be braced for 20,000A, 30,000A, or whatever level of fault current is required, up to 200,000A. The bussed gutter must be labeled by the manufacturer for the amount of fault current the buses are braced to withstand.

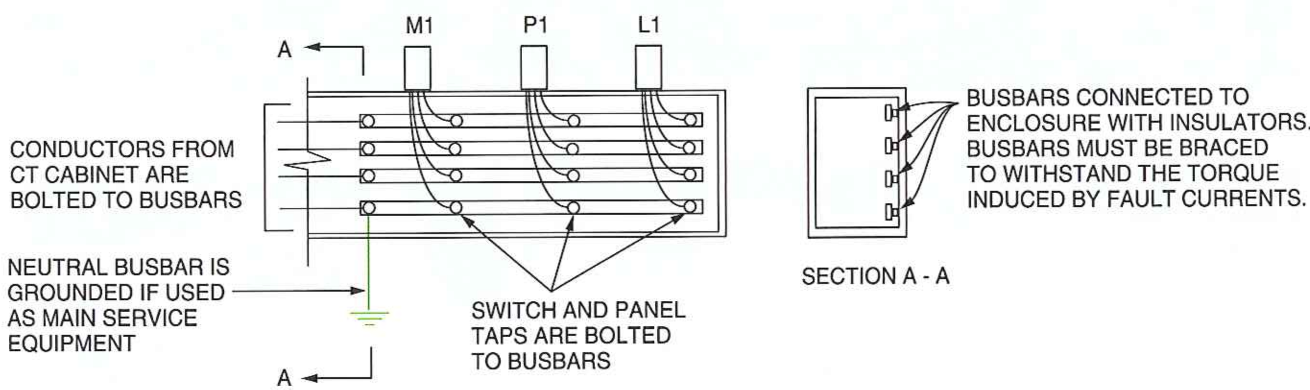

Figure 23 ◆ Three-phase bussed gutter.

INSIDE TRACK

Three-Phase Busduct

Three-phase busduct is a modular type of power distribution system that provides power directly through a set of system busbars rather than using power cable. It allows for easy system expansion because whenever a new piece of equipment is added, a new switch can simply be plugged into place and the equipment supplied without the need to run additional power cable through the plant.

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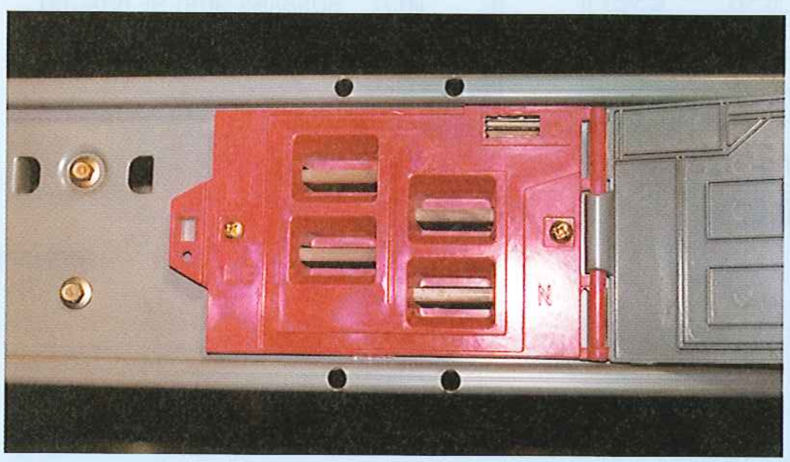

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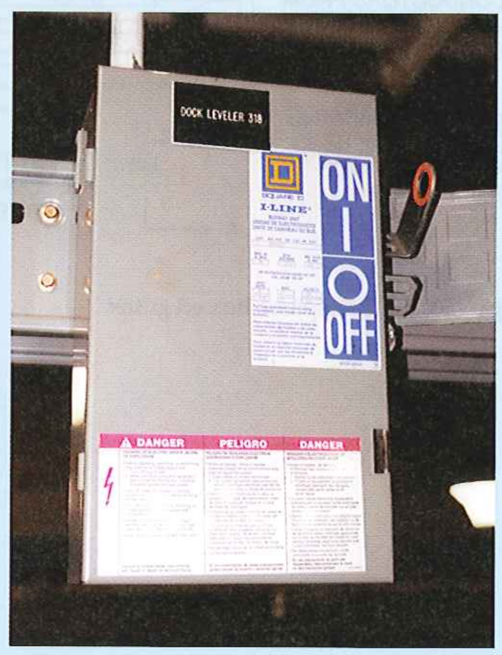

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6.0.0 ◆ 277/480V SERVICES

Wye-connected, 277/480V services are common in medium to large commercial projects. This type of service is also frequently used in industrial applications to power motors for driving machinery and other apparatus. Such installations frequently use switchgear enclosures such as the one shown in *Figure 24*. Service equipment of this type is made up of vertical sections that connect to a common bus system within the enclosure. These sections contain fusible switches or circuit breakers, metering equipment, or other devices related to the electric service.

NEC Section 230.71(A) allows a maximum of six service disconnecting means per service grouped in any one location. If there are more than six switches or circuit breakers in the switchboard, then a main switch or circuit breaker must be provided to disconnect all service conductors in the building or structure from the power supply.

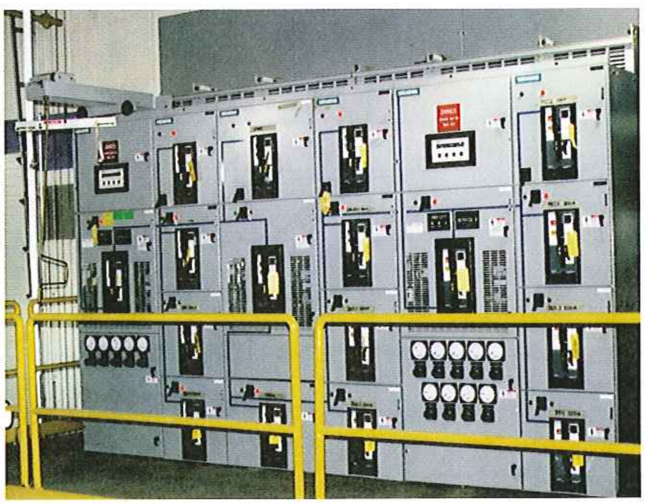

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Figure 24 ◆ Typical switchgear.

Typically, the metering equipment (CTs, potential transformers, etc.) is installed in the same enclosure as the main disconnecting means; additional space is usually provided in the switchgear for this equipment. Furthermore, taps are normally provided in the main bus in a barriered section for connection to emergency switches, such as for fire alarm systems, emergency lighting, etc., as allowed by *NEC Section 230.82(5)*.

6.1.0 Practical Applications

Figure 25 shows a plot plan of a shopping center facility that utilizes a 277/480V, wye-connected, three-phase service to supply numerous tenant areas. In general, a padmount transformer installed on the property perimeter reduces the distribution voltages to 277/480V. An underground service is installed from this padmount transformer to a switchgear room in one section of the shopping center. A single-line diagram of the electrical system for this project is shown in *Figure 26*. Note that there are only six fusible switches in the main switchgear, so no main disconnecting means is necessary. Each of these six feeders supplies a bussed gutter system (discussed previously), each of which contains six meter bases and a fused safety switch that feeds a 277/480V panel for lighting and HVAC equipment. This latter panel also feeds a 480V to 120/208V dry transformer, which in turn furnishes power to a 120/208V panel for feeding tenant receptacles and display lighting.

In general, this system records the amount of power used by each tenant so that tenants may be billed accordingly. A 277V fluorescent lighting system provides general illumination, which is fed from the 277/480V panel in each tenant space. However, some 120V display lighting is employed. It is fed from the 120/208V panel.

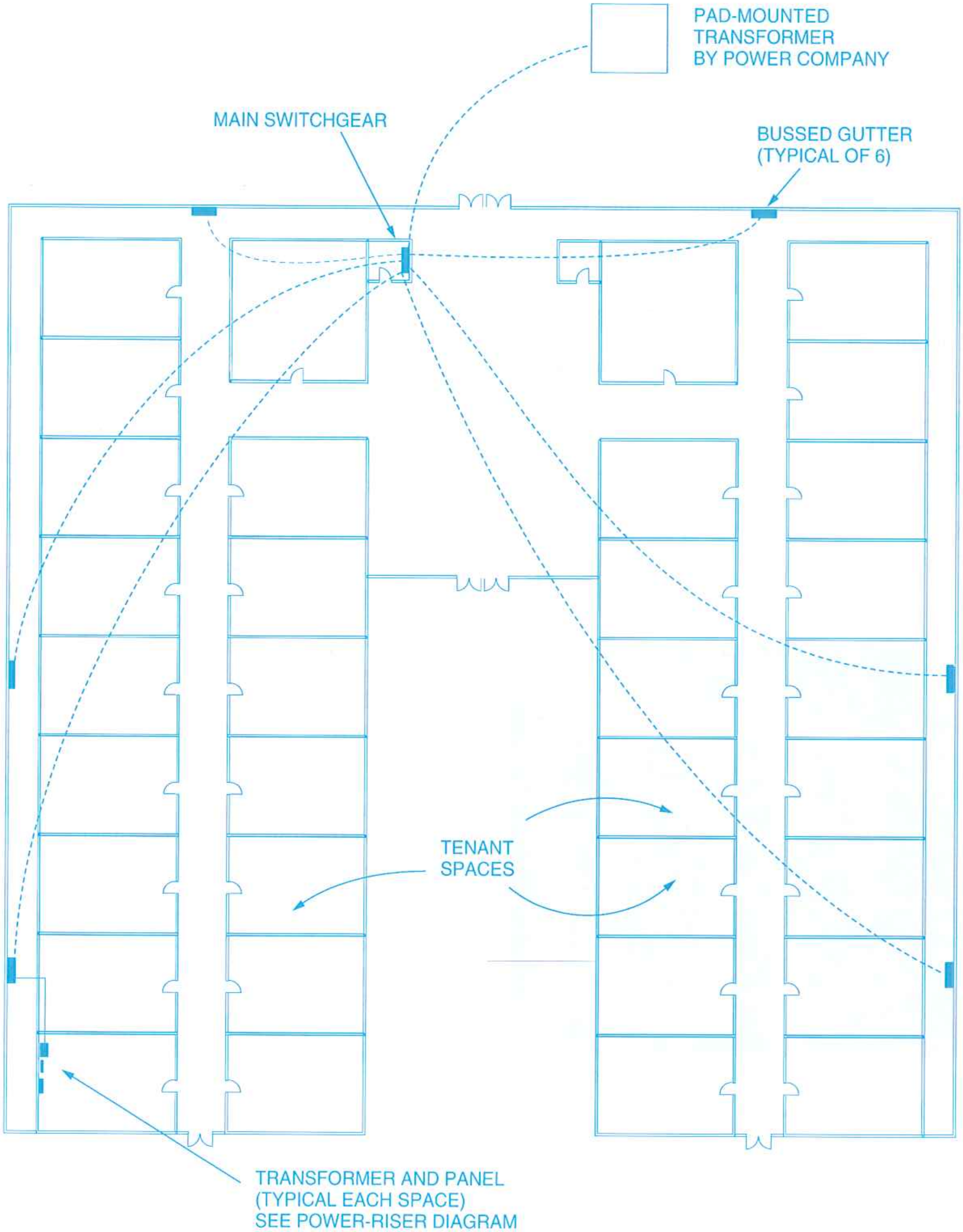

Figure 25 ◆ Plot plan of shopping center installation.

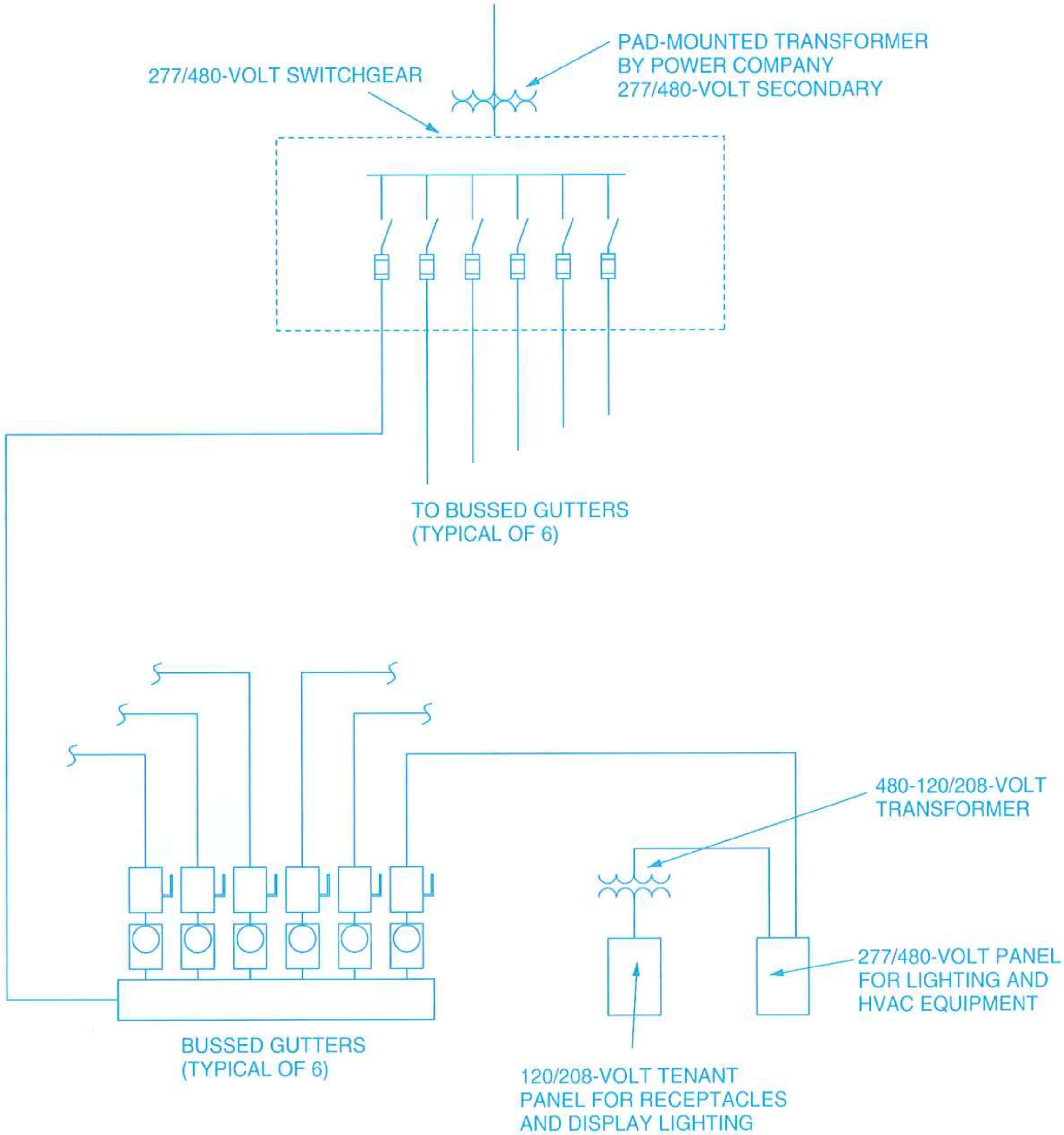

Figure 26 ◆ Power-riser diagram for shopping center installation.

7.0.0 ◆ SWITCHES, PANELBOARDS, AND LOAD CENTERS

Panelboards consist of assemblies of overcurrent protection devices in a metal cabinet, with or without disconnecting devices. The cabinet includes a cover or trim with one or two doors to allow access to the overcurrent and disconnecting devices and, in some types, access to the wiring space in the panelboard.

There is some confusion concerning the differences between load centers and panelboards. Typically, **load centers** are fuse or circuit breaker cabinets used on residential or small commercial projects. They are preassembled units with the interior buses installed at the factory. Upon installation, the required number of plug-in circuit breakers or fuse holders are installed, the circuit conductors terminated, and the front cover installed.

Many electricians classify panelboards as enclosures for overcurrent protection devices that are used on larger commercial and industrial installations. Furthermore, the can or housing usually consists of unpainted galvanized metal. Frequently, the circuit breakers are factory-installed using bolt-in circuit breakers.

You would probably be correct in calling all load centers panelboards, but remember, not all panelboards are load centers.

Panelboards fall into two mounting classifications: flush mounting (*Figure 27*), wherein the trim extends beyond the outside edges of the cabinet to provide a neat finish with the wall surface; and surface mounting (*Figure 28*), wherein the edge of the trim is flush with the edge of the cabinet.

Panelboards fall into two general classifications with regard to overcurrent devices: circuit breaker types and fusible types. Small circuit breaker and fusible panelboards, commonly referred to as load centers, are manufactured for use in residential, small commercial, and small industrial occupancies.

7.1.0 Panel Installation

Prior to installing a panel, the selected location must be examined to verify that proper clearances exist and that the environment is proper for the panel installation.

In general, all panelboards must have a rating of not less than the minimum feeder capacity required for the load computed in accordance with *NEC Article 220*. Panelboards must be durably marked by the manufacturer with the voltage and current rating and the number of phases for which they are designed. They must also include the manufacturer's name or trademark in such a manner as to be visible after installation without disturbing the interior parts or wiring. All panelboard circuits and circuit modifications shall be legibly identified as to purpose or use on a circuit

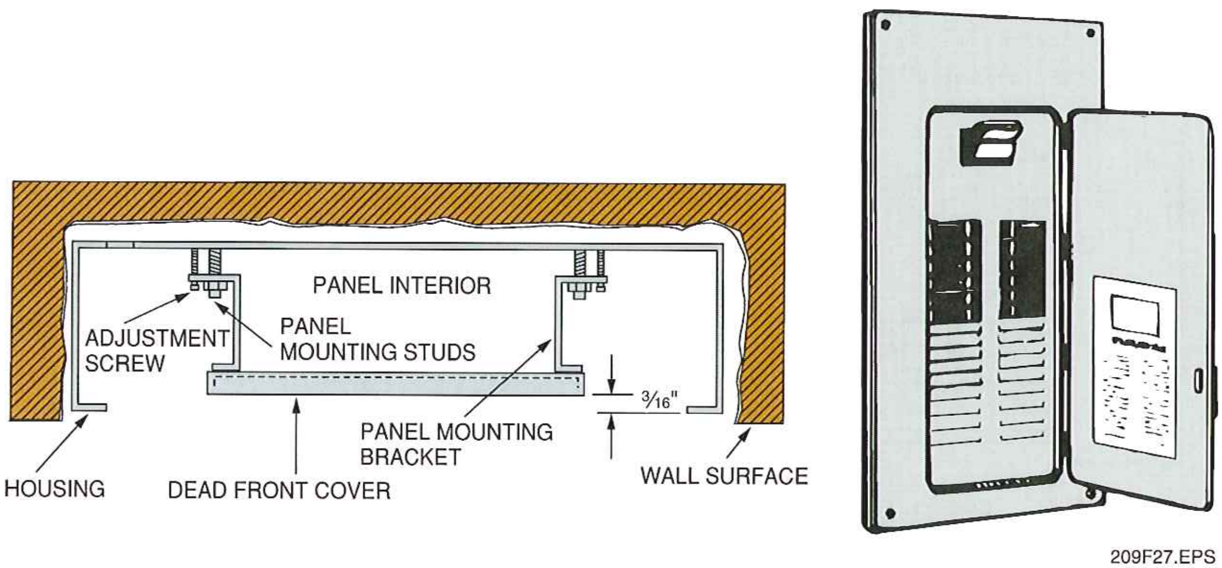

Figure 27 ◆ Flush-mounted panelboard.

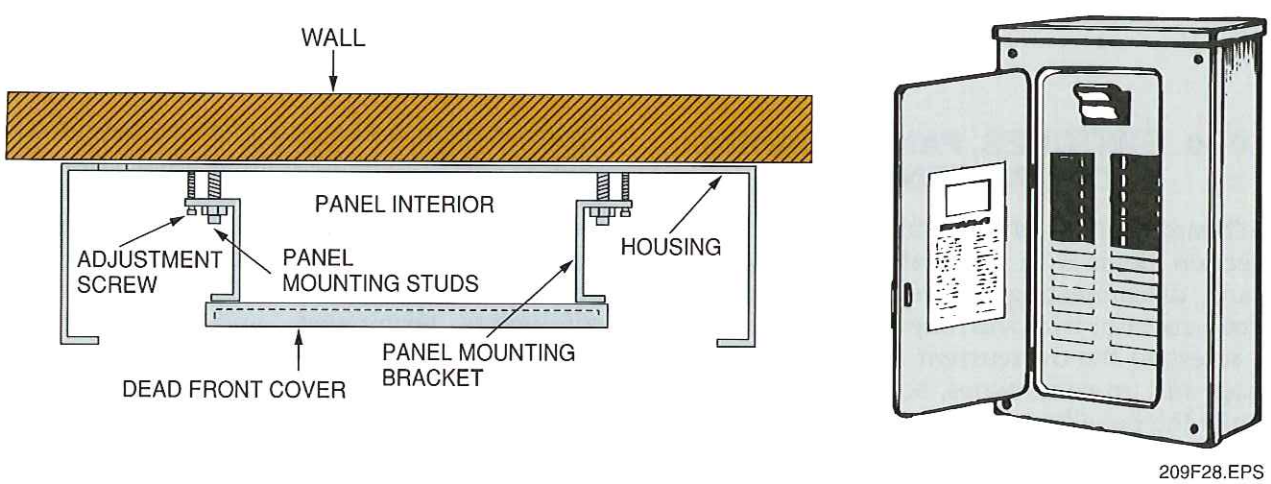

Figure 28 ◆ Surface-mounted panelboard.

directory located on the face or on the inside of the panel doors (*NEC Section 408.4*). The working height near panelboards is 6.5'. See *Figure 29*.

Once a proper location has been determined, the panel is removed from its packing boxes, assembled, and installed. When removing the panel from its packing, verify that all necessary components have been delivered and make sure that any stray packing material has been removed from the panel. Check to make sure that the right panel is to be installed. A checklist might include the following items:

- Is the panel to be top fed or bottom fed? This information should be obtained from the drawings or from the project supervisor.
- Check to verify that the voltage rating of the panel is as specified in the drawings.
- Check to verify that the ampacity of the panel is as specified in the drawings.
- Check to verify that the phase and number of conductors is as specified in the drawings.
- Verify that the panel was not damaged during shipping.
- Verify that the lugs supplied with the panel will fit the conductors being installed.

7.1.1 Installing Flush-Mounted Enclosures

Flush-mounted enclosures installed in noncombustible material must be mounted so that the front edge of the enclosure is not set back farther than ¼" from the finished surface. If installed in other than noncombustible walls, the panel edge must be flush with the finished wall (*NEC Section 312.3*).

7.1.2 Installing Surface-Mounted Enclosures

Surface-mounted enclosures must be securely fastened in place. If the wall structure offers little structural support, as in the case of ¼" wood paneling or ½" gypsum board, the enclosure must be located so that it may be attached to framing members inside the wall covering. In some cases, a framing structure will have to be built to support the panel.

7.1.3 Installing the Panel Interior

Prior to installing the panel interior, check to verify that the enclosure is securely fastened in place and is free of all foreign material. Obtain and study the specifications and instructions that are included with the panel. If no instructions are available, the following is a general installation procedure that may be used:

Step 1 Mount the interior to the enclosure using the four mounting studs installed on the enclosure back.

Step 2 Adjust the depth of the interior with the adjustment screws. The dead front cover should be no farther than 3/16" from the wall surface for a flush panel, or the same distance from the enclosure face for a surface-mounted panel.

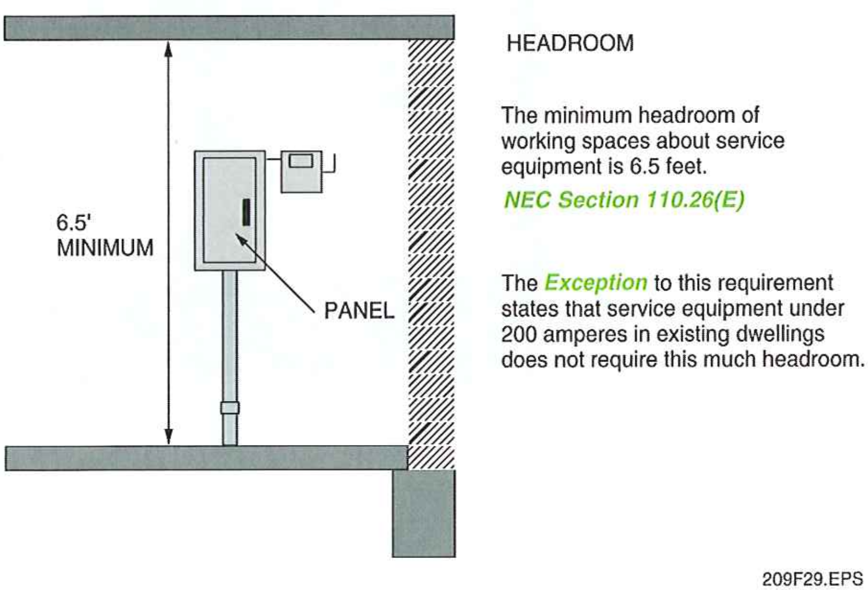

Figure 29 ◆ *NEC*® headroom requirements.

INSIDE TRACK

Panelboards

The selection of the components used in a panelboard is based on the following criteria:

- Feeder voltage and amperage
- Phase (single or three-phase) and number of conductors
- Type of busbar material (copper or aluminum)
- Number of required spaces or blanks
- Whether the panelboard is configured as a main breaker type of panel or main-lugs only (MLO) type of panel

NOTE

MLO panels do not have a MAIN circuit breaker.

After the panelboard is assembled, the appropriate number and type of circuit breakers must be ordered separately and installed in the panel.

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7.1.4 Knockouts

A series of concentric or eccentric circular partial openings are usually cut in the top, bottom, and sides of both load center and panelboard housings; some may also be cut in the back. These openings are cut in such a manner that they may be removed by tapping (knocking) them out, usually with a screwdriver blade or punch and hammer, just as you would in a device or fixture box (*Figure 30*).

The direction from which the knockouts can be removed alternates from inside the enclosure to outside the enclosure; that is, ½" knockouts are knocked outward from inside the enclosure; ¾" knockouts are knocked inward from outside the enclosure; 1" knockouts are knocked outward from inside the enclosure, etc. See *Figure 31*.

In most cases, raceways connected to panelboards using the concentric knockout openings have poor equipment grounding connections. Consequently, *NEC Section 250.92(B)* requires bonding jumpers to be used around concentric or eccentric knockouts that are punched or otherwise formed so as to impair the electrical connection to ground. This is accomplished by using a grounding locknut or bushing and then connecting a bonding jumper either to another grounding locknut or bushing, or else to the equipment grounding terminal inside the panelboard.

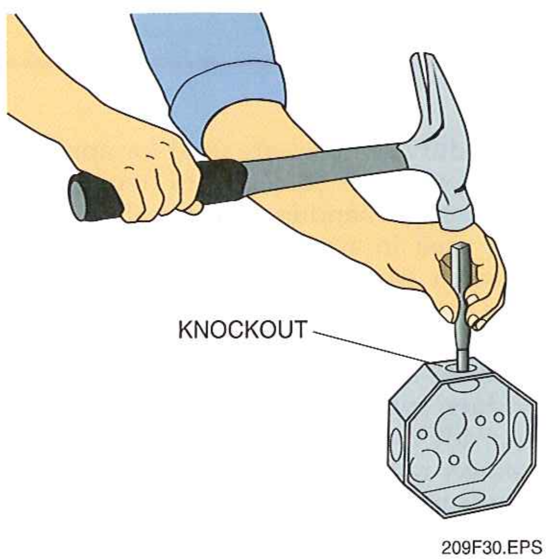

Figure 30 ◆ Removing knockouts.

7.2.0 Panel Connections

Electrical connections in a panelboard fall under two categories:

- Line connections, including termination and routing of service and feeder conductors
- Load connections, including termination and routing of branch circuit and feeder conductors

WARNING!

Even though the main breaker handle is in the OFF position, the line side of the switch is still energized.

Prior to terminating aluminum conductors, verify that the lugs are stamped CU-AL or a label inside the panel states that the connection of aluminum conductors is permitted.

NEC Section 408.3(E) requires the phase arrangement on three-phase buses to be A, B, and C from front to back, top to bottom, or left to right, as viewed from the front of the panel. The B phase must be the phase with the highest voltage to ground on a three-phase, four-wire, delta-connected system. See *Figure 32*.

7.3.0 Enclosures

The majority of overcurrent devices (fuses and circuit breakers) are used in some type of enclosure (i.e., panelboards, switchboards, motor control centers, individual enclosures, etc.).

NEMA has established enclosure designations because individually enclosed overcurrent protection devices are used in so many different types of locations, weather and water conditions, dust

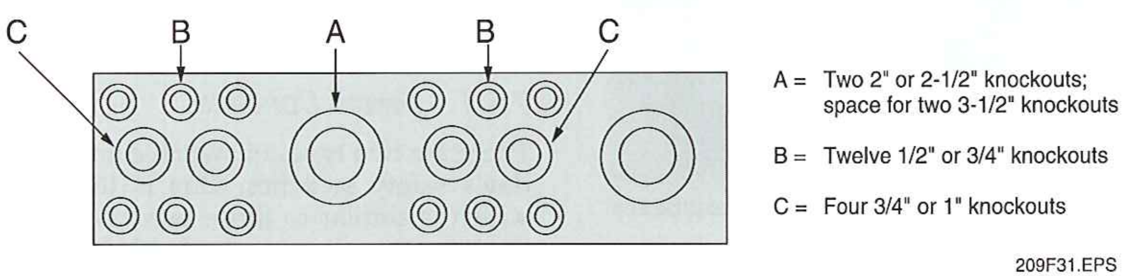

Figure 31 ◆ Typical knockouts in top of panelboard.

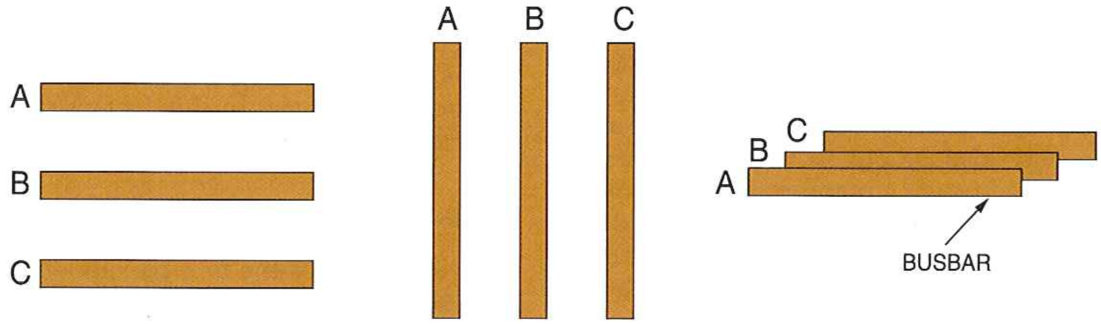

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Figure 32 ◆ *NEC®*-approved phase arrangements.

and other contaminating conditions, etc. The NEMA designations were recently revised to obtain a clearer and more precise definition of the enclosure needed to meet various standard requirements.

For example, a NEMA Type 12 enclosure can now be substituted in many installations in place of a NEMA Type 5 enclosure. The advantage of this substitution is that the NEMA Type 12 enclosure is much less expensive than the NEMA Type 5 enclosure. *Figure 33* shows two types of NEMA enclosures and *Table 4* provides a brief explanation of NEMA enclosure specifications.

7.4.0 Safety Switches

Most manufacturers of safety switches have at least two complete lines to meet industrial, commercial, and residential requirements. Both types usually have visible blades and safety handles. With visible blades, the contact blades are in full view so you can clearly see their position. Safety handles are always in complete control of the switch blades, so whether the cover is open or closed, when the handle is in the OFF position, the switch is always OFF, that is, on the load side of the switch. See *Figure 34.*

209F33A.EPS (A)   209F33B.EPS (B)

Figure 33 ◆ NEMA enclosures. (A) General-duty safety switch. (B) Heavy-duty safety switch.

> **WARNING!**
> Even though a safety switch handle is in the OFF position, the line side of the switch is still energized.

Heavy-duty switches are used for applications where the switch is subjected to frequent operation and rough handling. Heavy-duty switches are also used in atmospheres where a general-duty switch would be unsuitable. Heavy-duty switches are widely used by most heavy industrial applications; motors and HVAC equipment will also be controlled by such switches. Most heavy-duty switches are rated at 30A through 1,200A, 240V to 600V (AC-DC). The switches with horsepower ratings are able to interrupt approximately six times the full-load, motor current ratings. When equipped with Class J or Class R fuses, many heavy-duty safety switches are UL listed for use on systems with up to 200,000A available fault current. Heavy-duty switches are available with NEMA Types 1, 3R, 4, 5, 7, 9, and 12 enclosures.

7.4.1 Switch Contacts

There are two types of switch contacts used in today's safety switches. One is the butt contact, which is similar to those used in circuit breaker devices; the other is a knife blade and jaw type. The knife blade type is considered to be superior to other types on the market.

Table 4 NEMA Enclosure Specifications

Enclosure	Explanation
NEMA Type 1 General Purpose	To prevent accidental contact with enclosed apparatus. Suitable for use indoors where not exposed to unusual service conditions.
NEMA Type 3 Weatherproof (Weather Resistant)	Protects against specified weather hazards. Suitable for use outdoors.
NEMA Type 3R Raintight	Protects against entrance of water from rain. Suitable for general outdoor applications not requiring protection against sleet.
NEMA Type 4 Watertight	Designed to exclude water applied in the form of a hose stream. Protects against stream of water during cleaning operations.
NEMA Type 5 Dusttight	Constructed so that dust will not enter the enclosed area. Being replaced in some equipment by NEMA Type 12.
NEMA Type 7 Hazardous Locations A, B, C, or D Class I–air break letter(s) following type number indicate particular groups of hazardous locations per the *NEC®*.	Designed to meet application requirements of the *NEC®* for Class I, hazardous locations (explosive atmospheres). Circuit interruption occurs in the air.
NEMA Type 9 Hazardous Locations E, F, or G Class II–letter(s) following type number indicate particular groups of hazardous locations per the *NEC®*.	Designed to meet application requirements of the *NEC®* for Class II hazardous locations (combustible dusts, etc.).
NEMA Type 12 Industrial Use	For use in those industries where it is necessary to exclude dust, fibers, and filings, or oil or coolant seepage.

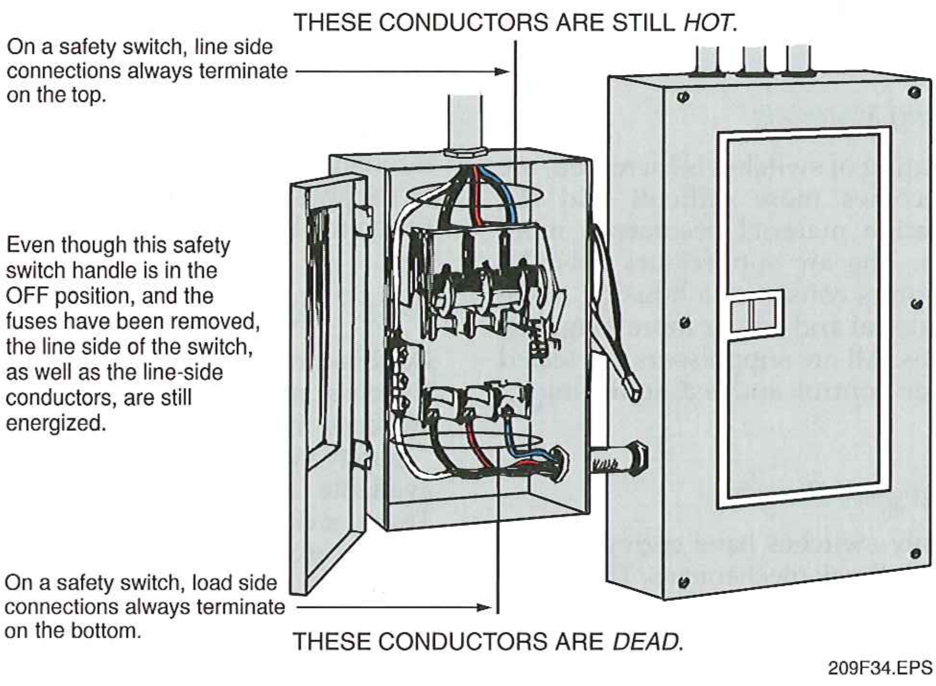

Figure 34 ◆ Using a safety switch as a panelboard disconnect.

All current-carrying parts of safety switches are usually plated with tin, cadmium, or nickel to reduce heating by keeping metal oxidation at a minimum. The switch blade and jaws are made of copper for high conductivity. With knife blade construction, the jaws distribute a uniform clamping pressure over the entire blade-to-jaw contact surface. In the event of a high current fault, the electromagnetic forces that develop tend to squeeze the jaws tightly against the blade. In the butt-type contact, these forces tend to force the contacts apart, causing them to burn severely.

INSIDE TRACK

Safety Switches

When selecting a safety switch for a particular application, always check the manufacturer's product literature to determine if any switch accessories are required for use with the switch. Safety switches often must be equipped with accessories for certain applications. For example, when used with service equipment, they must be labeled as *SUITABLE FOR USE AS SERVICE EQUIPMENT* and a main bonding jumper must be installed. Similarly, when installing NEMA Type 3R, 4, 5, and/or 12 enclosures, the use of bolt-on rainproof or watertight hubs is often required.

Fuse clips are also plated to control corrosion and keep heating to a minimum. All heavy-duty fuse clips have steel reinforcing springs to increase their mechanical strength and provide a firmer contact pressure. As a result, fuses will not work loose due to vibration or rough handling.

7.4.2 Insulating Materials

As the voltage rating of switches is increased, arc suppression becomes more difficult and the choice of insulation material becomes a more critical problem. The arc suppressors used by many manufacturers consist of a housing made of insulation material and one or more magnetic suppressor plates. All arc suppressors are tested to ensure proper control and extinguishing of arcing.

7.4.3 Operating Mechanism

Heavy-duty safety switches have spring-driven, quick-make, quick-break mechanisms. The quick-break action is necessary if a switch is to be safely switched to OFF under a heavy load. The spring action, in addition to making the operation quick-make, quick-break, firmly holds the switch blades in an ON or OFF position. The operating handle is an integral part of the switching mechanism, so if the springs should fail, the switch can still be operated. When the handle is in the OFF position, the switch is always OFF.

A one-piece crossbar is usually employed to offer direct control over all blades simultaneously. The one-piece crossbar provides stability and strength, plus proper alignment for uniform blade operation.

Dual cover interlocks are also standard on all heavy-duty switches. The dual interlock prevents the enclosure door from being opened when the switch is ON and also keeps the switch from being turned ON while the door is open.

7.4.4 General-Duty Safety Switches

General-duty switches are for residential and light commercial applications where the price of the device is a limiting factor. General-duty switches are meant to be used where operation and handling are moderate and where the available fault current is less than 10,000A. Some examples of general-duty switch applications include: residential HVAC equipment, light-duty fan coil circuit disconnects for commercial projects, and the like.

General-duty switches are rated up to 600A at 240V (AC only) in general-purpose (NEMA Type 1) and rainproof (NEMA Type 3R) enclosures. These switches are horsepower-rated and capable of opening a circuit with approximately six times a motor's full-load current rating.

All current-carrying parts of general-duty switches are plated with either tin or cadmium to reduce heating. Switch jaws and blades are made of plated copper for high conductivity. A steel reinforcing spring increases the mechanical strength of the jaws and ensures firm contact pressure between the blade and jaw.

7.4.5 Double-Throw Safety Switches

Double-throw switches are used as transfer switches and are not intended as motor circuit switches; therefore, they are not horsepower-rated.

Safety switches are manually operated and are available as either fused or unfused devices. These switches have quick-make, quick-break action, plated current-carrying parts, a key-controlled interlock mechanism, and screw-type lugs. Arc suppressors are supplied on all switches rated above 250V.

7.5.0 Main Lugs

Main lugs load centers provide distribution of electrical power where a main disconnect with overcurrent protection is provided separately from the load center. All terminals are suitable for aluminum or copper conductors.

Many main-lugs only (MLO) load centers rated at 125A and up have interiors that are reversible for either top or bottom feed. The cover does not need to be reversed when the interior is reversed. Load centers of 125A and above are commonly available in 14" wide boxes for more wire bending space. Some single-phase, three-wire load centers are also approved for three-phase grounded B-type systems at 240VAC. A main lugs load center can also be converted to a main breaker load center provided that it has approved breakers. Follow the manufacturer's instructions.

7.6.0 Main Breaker Load Centers

Main breaker load centers typically have the following characteristics:

- The main breakers are factory-installed, cutting installation costs. There are no lugs to remove; no screws, nuts, or washers to misplace; and no expensive main breakers to lose. Factory-assembled main disconnects also ensure a proper and safe electrical connection.
- Boxes that are 14" wide are available in 100A to 225A main breaker load centers. This offers more side gutter space for wiring and permits flush load center installation between 16" centered studs without an extra mounting support to hold the box in place.
- The line side terminals of the main breakers are suitable for use with copper or aluminum conductors.

7.7.0 Panelboards

Switchgear manufacturers offer complete lines of lighting and distribution panelboards, most of which are available either unassembled from distributor stock or factory-assembled. All types should be UL listed and meet *Federal Specification WP-115a.*

NQO panelboards are rated for use on the following AC services: 120/240V, single-phase, three-wire; 240V, three-phase, three-wire delta; 240V, three-phase delta with grounded B phase; and 120/208V, three-phase, four-wire wye. They carry no DC rating. NQO panelboards are available either factory-assembled or unassembled.

This type of panelboard is suitable for use in industrial buildings, schools, offices, and commercial buildings and institutions in which the largest branch breaker does not exceed 150A and the system voltage is not greater than 240VAC.

NQO panelboards have maximum ratings of 400A (main breaker or main lugs). Branch circuit breakers may be catalog prefix QO, QO-H, QH, Q1, or Q1-H, and one-, two-, or three-pole—having a maximum rating of 150A and featuring plug-in bus connections. QO and Q1 circuit breakers are standard with 10,000 amperage interrupting capacity (AIC) rating and QH breakers with 65,000 AIC rating. Other ratings for specific applications are also available.

Branch circuit breakers with ground fault circuit interruption may also be supplied in Type NQO panelboards. Rated 10,000 AIC symmetrical, these devices provide GFCI ground fault protection as well as overload and short circuit protection for branch circuit wiring.

NQO unassembled panelboards are available as follows:

- Branch breakers
- Interior with solid neutral
- Box (14" wide × 4" deep, 14" wide × 5¾" deep, or 20" wide × 5¾" deep)
- Mono-flat front with door and flush lock
- Accessories

NQO factory-assembled panelboards are identical in construction to the unassembled type. Main ratings and branch circuits are the same. Unlike unassembled panelboards, however, the branches are factory-installed.

Assembled and unassembled NQO boxes are constructed of galvanized steel. Several types of knockouts are provided in each end wall. Interiors having a maximum main lugs rating of 225A are available in 14" × 4", 14" × 5¾", or 20" × 5¾" boxes. 14" × 5¾" or 20" × 5¾" boxes are required for panelboards having a main circuit breaker. Boxes for interiors having 400A mains (breakers or lugs) are 20" × 5¾".

Interiors for standard-width panelboards having a maximum rating of 225A are of the single-bus construction. In this construction, one-, two-, and three-pole catalog prefix Q1 breakers extend the full width of the panelboard and cannot be mounted opposite each other. QO, QO-H, and QH circuit breakers twin-mount on the bus assembly. In other words, a three-pole QO requires three-pole spaces, but a three-pole Q1 requires six QO spaces.

Interiors of 400A panelboards utilize a double-row bus construction. This type of construction consists of two sets of busbars mounted on a single pan. The respective phase buses of each set are paralleled with each other by means of insulated, solid connectors. QO and Q1 breakers mount on a one-for-one basis (i.e., a three-pole QO requires the same spaces as a three-pole Q1).

All current-carrying parts are plated for maximum corrosion resistance and minimum heating at contact surfaces. Main lugs are UL listed for use with either copper or aluminum cable. Main lugs may be replaced by the appropriate crimp lug, when required. Lug catalog numbers and crimping tools are called out on the panelboard wiring diagram. Box-type lugs for circuits on both branch breakers and the solid neutral permit maximum convenience and speed in wiring and are also UL listed for use with either copper or aluminum cable.

8.0.0 ◆ MAINTENANCE

The first requirement in a satisfactory maintenance program for electrical panelboards and switches is safety, including the use of the proper lockout/tagout procedures.

The second is good equipment that has been properly installed. No one can do a good maintenance job on equipment that is not appropriate for the job or that has been installed haphazardly with no eye to future maintenance requirements. If such conditions exist, they should be brought to the attention of the proper party and corrected, rather than trying to establish a maintenance program for them.

The third requirement for a good maintenance program is proper maintenance personnel. Persons who must maintain equipment should have a thorough knowledge of the equipment's operation and have the ability to make thorough inspections and minor repairs of that equipment.

The fourth requirement of a good maintenance program is the establishment of preventive maintenance. This is an all-inclusive phrase for the continuing inspection of equipment, the report and recording of the condition of the equipment, and the repair of the equipment.

The term preventive maintenance has come to mean a system of routine inspections of equipment that is properly recorded for future reference on some type of inspection records. More specifically, the term stands for the heading-off of future equipment problems by making minor repairs in advance of major operating difficulties. In electrical panelboards and switches, a simple tightening of a lug early on can prevent a serious short circuit or a heated terminal later. Due to the aspect of recording all such inspections, some electricians believe that preventive maintenance is merely a system of records. Actually, the records supplement the inspection and are designed to take the place of the maintenance technician's memory. In such extreme cases where only one maintenance worker services a particularly small plant or building, records might be entirely disregarded, although this is not recommended. However, where a number of maintenance personnel are servicing large systems, records are vital to the proper operation of the maintenance inspection routine.

Electrical equipment is more prone to damage by operating conditions than almost any other piece of equipment. Water, dust, heat, cold, humidity, vibration, and countless other conditions can affect the proper operation of electrical equipment. Because of this, there are three cardinal rules to follow in maintaining electrical apparatus. These are:

- Keep it clean.
- Keep it dry.
- Keep it tight.

One of the greatest problems existing in panelboards, switchgear, load centers, and the like are loose connections at both the main lugs and at circuit breakers and/or fuse blocks. Loose connections cause overheating and eventual failure of the terminals and/or conductors. This condition is especially prevalent where aluminum conductors are used. Therefore, periodic checks should be made to ensure that all connections are tight.

CASE HISTORY

Improper Maintenance Procedures Can Be Dangerous

A group of electricians were performing maintenance on AC switchgear. The equipment was placed in the maintenance mode by opening the primary 20kV interrupter switch. This switch was housed in the upper compartment of a two-compartment cabinet. Each compartment had its own door. One of the electricians was assigned to clean the lower compartment, but he began to clean the upper compartment as well. He sprayed cleaning fluid from an aerosol can onto the circuitry. When the aerosol spray contacted the line side of the primary switch, it provided a conductive plasma for the current. The current passed through the spray, spray can, and the electrician's body, which had apparently made contact with one of the switch blades, causing him to be electrocuted and badly burned.

The Bottom Line: This accident could have been prevented if proper safety and maintenance procedures had been followed. No electrician should attempt to work on any equipment, regardless of voltage, without first getting permission from the supervisor and only after having received proper training for the task at hand. This includes training in the use of special tools and safety equipment required for the task.

THINK ABOUT IT

Putting It All Together

Examine the service at your home or workplace. Is the service entrance properly installed and protected? Is the service-entrance cable cracked or frayed? What about the electrical panel? Are the breakers properly labeled? Is there a main service disconnect switch?

Review Questions

1. Which of the following best describes the components between the service drop and the building's main disconnecting device?
   a. Wye connection
   b. Service entrance
   c. Service union
   d. Service lateral

2. The most common electric service for residential and small commercial applications is _____.
   a. single-phase, 120V, two-wire service
   b. single-phase, 120/240V, three-wire service
   c. three-phase, 208/120V, four-wire service
   d. three-phase, 277V/480, four-wire service

3. The approximate voltage between ground and the high leg of a 120/240V delta-connected service with a center tap is _____.
   a. 120V
   b. 163V
   c. 208V
   d. 240V

4. What is used in conjunction with a watt-hour meter to measure the power used in services over 400A?
   a. An autotransformer
   b. A current transformer
   c. An ohmmeter
   d. An ammeter

5. Which of the following is used on most working drawings to give details of the panelboards and overcurrent protective devices used on the project?
   a. A panelboard schedule
   b. An appliance schedule
   c. A cross-sectional detail drawing
   d. A site plan

6. How must overhead service-entrance conductors be arranged from the point where they leave the service head to the point where they are connected to the service drop?
   a. They must be absolutely straight with no sag.
   b. They must terminate in a pothead.
   c. A drip loop must be provided.
   d. They must be color-coded yellow, green, and orange.

7. A(n) _____ is used to determine the amount of electricity consumed by the customer.
   a. ammeter
   b. wattmeter
   c. watt-hour meter
   d. ohmmeter

8. The minimum size copper grounding electrode conductor allowed when used with copper service-entrance cables No. 2 AWG or smaller is _____.
   a. No. 2
   b. No. 4
   c. No. 6
   d. No. 8

9. When a metal water pipe is used as a grounding electrode, a _____ must be provided at the water meter.
   a. bonding jumper
   b. floor drain
   c. grounding locknut
   d. grounding bushing

10. Which of the following is considered to be a part of the metering equipment in a 277/480V, wye-connected service?
    a. Subpanels
    b. Service-entrance conductors
    c. Potential transformers
    d. Autotransformers

Summary

Regardless of the size or complexity, all electric services serve the same purpose: to deliver electrical energy from the supply system to the wiring system on the premises served. The basic components of a commercial electric service include a transformer to convert the transmission voltage to a usable level; a service drop, which includes the conductors that are used to connect the service from the power pole to the service facilities at the building; a service entrance, which includes all components between the termination of the overhead service drop and the building's main disconnecting device, except for the metering equipment; service conductors, which are the conductors used in the service entrance; and service equipment, which provides overcurrent protection, a means of disconnect, and a point of attachment for the metering equipment. *NEC Article 230* covers the requirements for electric services.

Notes

Trade Terms Introduced in This Module

Delta-connected: A three-phase transformer connection in which the terminals are connected in a triangular shape like the Greek letter delta (Δ).

Load center: A specific type of panelboard designed for light-duty, single- or three-phase applications, such as residential or light commercial installations.

Service: The electric power delivered to the premises.

Service conductors: The conductors between the point of termination of the overhead service drop or underground service lateral and the main disconnecting device in the building or on the premises.

Service drop: The overhead conductors through which electrical service is supplied between the last power company pole and the point of their connection to the service-entrance conductors located at the building or other support used for the purpose.

Service entrance: All components between the point of termination of the overhead service drop or underground service lateral and the building's main disconnecting device, except for metering equipment.

Service equipment: The necessary equipment, usually consisting of a circuit breaker or switch and fuses and their accessories, located near the point of entrance of supply conductors to a building and intended to constitute the main control and cutoff means for the electric supply to the building.

Service lateral: The underground service conductors between the street main, including any risers at a pole or other structure or from transformers, and the first point of connection to the service-entrance conductors in a terminal box, meter, or other enclosure with adequate space, inside or outside the building wall.

Service raceway: The rigid conduit, IMC, or other raceway that encloses the service-entrance conductors.

Substation: An installation or area where an assembly of devices and apparatus are used to monitor, control, transform, or modify electrical power. Substations are normally installed at a point on the system where transmission voltages are reduced to distribution voltages.

Wye-connected: A three-phase transformer connection in which all three phases are connected at a central point, forming a Y configuration.

Additional Resources

This module is intended to present thorough resources for task training. The following reference works are suggested for further study. These are optional materials for continued education rather than for task training.

American Electrician's Handbook, Latest Edition. New York: Croft and Summers, McGraw-Hill.

National Electrical Code® Handbook, Latest Edition. Quincy, MA: National Fire Protection Association.