ELECTRICAL WIRING INDUSTRIAL

Based on the 2014 National Electrical Code®

15TH EDITION

STEPHEN L. HERMAN

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Preface

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INTENDED USE AND LEVEL

Electrical Wiring—Industrial is intended for use in industrial wiring courses at two-year community and technical colleges. The text walks the reader step by step through an industrial building, providing the basics on installing industrial wiring systems. An accompanying set of plans at the back of the book allows the student to proceed step by step through the wiring process by applying concepts learned in each chapter to an actual industrial building, in order to understand and meet requirements set forth by the *National Electrical Code*® (*NEC*®).

SUBJECT AND APPROACH

The fifteenth edition of *Electrical Wiring—Industrial* is based on the 2014 *NEC*. The *NEC* is used as the basic standard for the layout and construction of electrical systems. To gain the greatest benefit from this text, the learner must use the *NEC* on a continuing basis.

> In addition to the *NEC*, the instructor should provide the learner with applicable state and local wiring regulations as they may affect the industrial installation.

In addition to the accurate interpretation of the requirements of the *NEC,* the successful completion of any wiring installation requires the electrician to have a thorough understanding of basic electrical principles, a knowledge of the tools and materials used in installations, familiarity with commonly installed equipment and the specific wiring requirements of the equipment, the ability to interpret electrical construction drawings, and a constant awareness of safe wiring practices.

Electrical Wiring—Industrial builds upon the knowledge and experience gained from working with the other texts in the Delmar Cengage Learning electrical wiring series and related titles. The basic skills developed through previous applications are now directed to industrial installations. The industrial electrician is responsible for the installation of electrical service, power, lighting, and special systems in new construction; the changeover from old systems to new in established industrial buildings; the provision of additional electrical capacity to meet the growth requirements of an industrial building; and periodic maintenance and repair of the various systems and components in the building.

FEATURES

An introduction to *plans and sitework* is the topic of the first chapter in the book, providing explanations of identifying symbols and interpreting the plans in order to help orient the student to the industrial job site. *Examples* are integrated into the text and take the student step by step through problems, to illustrate how to derive solutions using newly introduced mathematical formulas and calculations. *Industrial building drawings* are included in the back of the book, offering students the opportunity to apply the concepts that they have learned in each chapter as they step through the wiring process. *Review questions* at the end of each chapter allow students to test what they have learned and to target any sections that require further review.

NEW TO THIS EDITION

- Updated to the 2014 *National Electrical Code*
- New information concerning grounding and bonding
- Extended coverage of service-entrance connections
- New information concerning the maintenance of transformers
- New information on timing relays
- Additional coverage of multispeed squirrel-cage motors
- Added information concerning motor nameplate data
- Additional coverage of power factor
- New information concerning 3-phase power and connections

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This edition of *Electrical Wiring—Industrial* was completed after all normal steps of revising the *NEC* NFPA 70 were taken and before the actual issuance and publication of the 2014 edition of the *NEC*. These steps include the following:

- The National Fire Protection Association (NFPA) solicits proposals for the 2014 *NEC*.
- Interested parties submit proposals to the NFPA.
- Proposals are sent to Code-Making Panels (CMPs).
- CMPs and the Technical Correlating Committee review proposals.
- Report on Proposals document is published.
- Interested parties submit comments on the proposals to the NFPA.
- CMPs and Technical Correlating Committee review comments.
- Report on comments document is published.
- Review of all Proposals and Comments is conducted at the NFPA Annual Meeting.
- New motions are permitted to be made at the NFPA Annual Meeting.
- Finally, the Standard Council meets to review actions made at the NFPA Annual Meeting and to authorize publication of the *NEC*.

Every effort has been made to be technically correct, but there is the possibility of typographical errors or appeals made to the NFPA board of directors after the normal review process that could result in reversal of previous decisions by the CMPs.

If changes in the *NEC* do occur after the printing of this book, these changes will be incorporated in the next printing.

The NFPA has a standard procedure to introduce changes between *Code* cycles after the actual *NEC* is printed. These are called *Tentative Interim Amendments,* or TIAs. TIAs and corrected typographical errors can be downloaded from the NFPA website, http://www.nfpa.org, to make your copy of the *Code* current.

SUPPLEMENTS

The Instructor Resources CD contains an Instructor Guide as a PDF with answers to all review questions included in the book, as well as an ExamView test-bank, chapter presentations, and a topical presentation in PowerPoint. (order #: 978-1-2850-5440-7).

Visit us at http://www.delmarelectric.com, now LIVE for the 2014 Code cycle!

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ABOUT THE AUTHOR

Stephen L. Herman has been both a teacher of industrial electricity and an industrial electrician for many years. He received his formal education at Catawba Valley Technical College in Hickory, North Carolina. After working as an industrial electrician for several years, he became the Electrical Installation and Maintenance instructor at Randolph Technical College in Asheboro, North Carolina. After nine years, he returned to industry as an electrician. Mr. Herman later became the lead Electrical Technology instructor at Lee College in Baytown, Texas. After serving 20 years at Lee College, he retired from teaching and now lives with his wife in Pittsburg, Texas. Mr. Herman has received the Halliburton Education Foundation's award for excellence in teaching. He has been a guest speaker at professional organizations and has three times been a judge for the national motor control competition at Skills USA.

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CHAPTER 1

Plans and Sitework

OBJECTIVES

After studying this chapter, the student should be able to

- read site plans to determine the location of the specific items.
- select materials for electrical sitework.
- identify underground wiring methods.
- perform International System of Units (SI) to English and English to SI conversions.
- calculate metric measurements.

CONSTRUCTION PLANS

An electrician who has previously wired a residence or a commercial building is familiar with electrical floor plans and symbols. Although the electrical plans and symbols are basically similar for an industrial building project, additional emphasis is often placed on the sitework. The electrician must continually coordinate and work with the general foreman who is employed by the general contractor.

After the contract for the project is awarded, the electrical contractor must inspect the site plans to determine the approximate location of the industrial building on the site, as well as the locations of underground wiring, raceways, and manholes. The contractor then moves a trailer to the site and locates it so that it will require a minimal amount of relocation during construction. This trailer is used to store materials and tools during the construction of the building.

Building Location

The building location is given on the site plan by referring to existing points such as the centerline of a street. If the electrical contractor and the crew arrive on the site before the general contractor arrives, they are not required to "stake out" (locate) the building. However, they should be able to determine its approximate location. A site plan, such as the one given on Sheet Z-1 of the industrial building plans included in this text, shows the property lines and the centerlines of the street from which the electrician can locate the building and other site improvements.

EXPLANATION OF PLAN SYMBOLS

Contour Lines

Contour lines are given on the site plan to indicate the existing and the new grading levels. If the required underground electrical work is to be installed before the grading is complete, trenches must be provided with enough depth to ensure that the installations have the proper cover after the final grading. The responsibility of who does the ditch-work (general contractor or electrician) is usually agreed upon before the contract is awarded.

Figure 1-1 gives the standard symbols used on construction site plans for contour lines and other features.

Benchmark

The benchmark (BM), as given on the site plan, is the reference point from which all elevations are located. The benchmark elevation is established by the surveyor responsible for the preliminary survey of the industrial site. This BM elevation is related to a city datum or to the mean sea level value for the site. The elevation is usually given in feet and tenths of a foot. For example, an elevation of 123.4 ft is read as "one hundred twenty-three and four-tenths feet." Table 1-1 is used in making conversions from tenths of a foot to inches.

Elevations

The electrician must give careful attention to the elevations of the proposed building. These details are shown on Sheet Z-1 of the enclosed plans for the industrial building. These drawings provide valuable information concerning the building construction. Measurements on the elevations may be a plus or a minus reference to the BM elevation as given on the site plan.

Invert Elevation (INV)

When an invert elevation (INV) is given, this quantity indicates the level of the *lower* edge of the inside of a conduit entering the manhole (this conduit is usually the lower one in an installation). Refer ahead to Figure 1-19.

Site Plan Scales

Residential site plans generally are drawn to the same scale as is used on the building plans; that is, $\frac{1}{8}'' = 1'\text{-}0''$ or $\frac{1}{4}'' = 1'\text{-}0''$. However, industrial building site

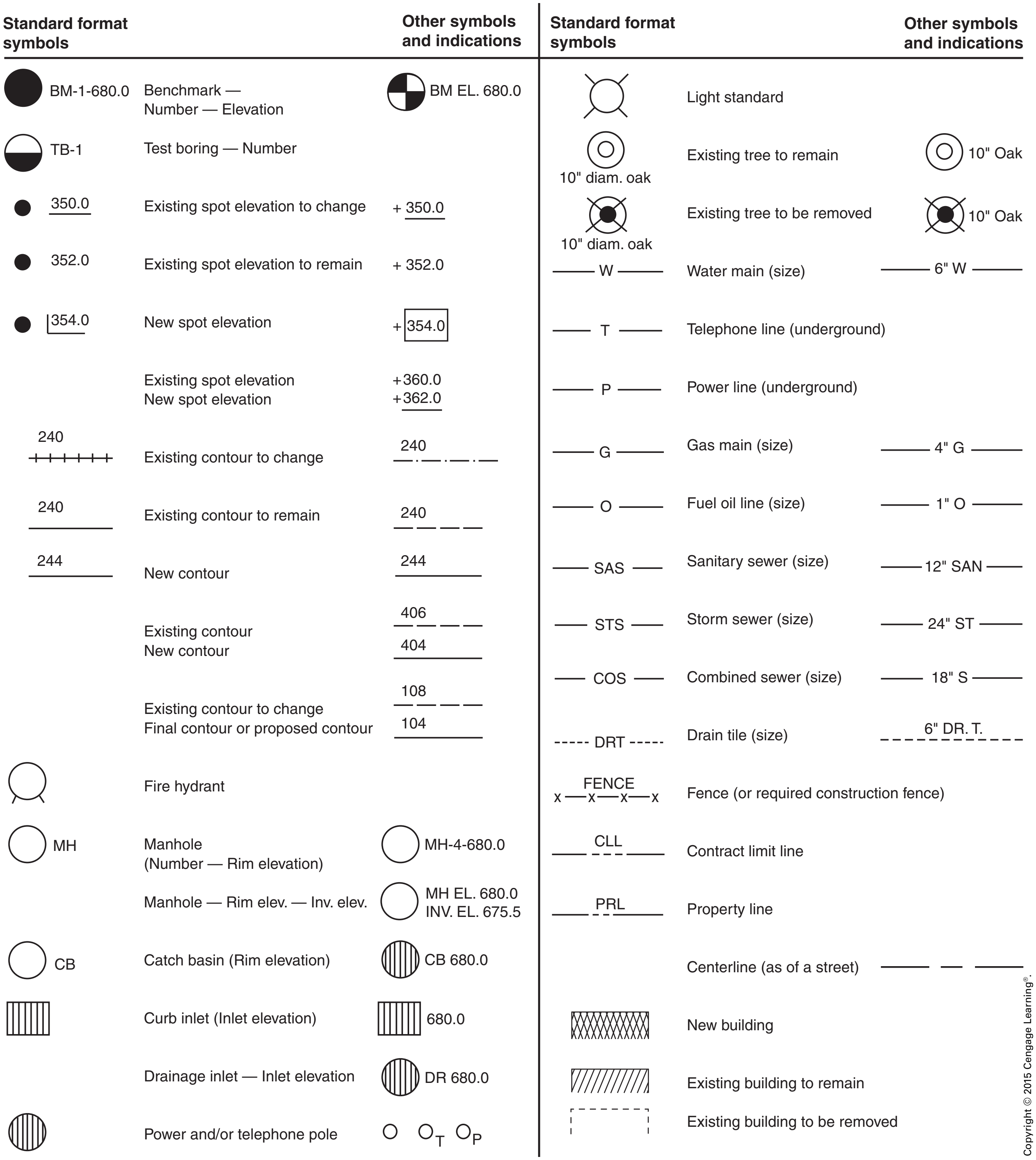

FIGURE 1-1 Site plan symbols.

TABLE 1-1

Conversions of tenths of a foot to inches.

TENTHS	DECIMAL	FRACTIONAL
0.1 ft	1.2 in.	$1\frac{3}{16}$ in.
0.2 ft	2.4 in.	$2\frac{3}{8}$ in.
0.3 ft	3.6 in.	$3\frac{5}{8}$ in.
0.4 ft	4.8 in.	$4\frac{13}{16}$ in.
0.5 ft	6 in.	6 in.
0.6 ft	7.2 in.	$7\frac{3}{16}$ in.
0.7 ft	8.4 in.	$8\frac{3}{8}$ in.
0.8 ft	9.6 in.	$9\frac{5}{8}$ in.
0.9 ft	10.8 in.	$10\frac{13}{16}$ in.

plans typically use scales ranging from 1″ = 20′ and 1″ = 30′ up to 1″ = 60′. It is recommended that the electrician use a special measuring device, called a scale, to measure the site plans, Figure 1-2.

SITEWORK

There may be requirements for several different types of electrical systems to be installed on the site apart from the building itself. The electrician should review the plans and specifications carefully to be aware of all requirements. It is then the responsibility of the electrical contractor/electrician to ensure that these requirements are met and that installations are made at the most advantageous time and in a fashion that will not conflict with sitework being carried out by other trades.

TESTING THE SITE FOR GROUNDING REQUIREMENTS

When determining the site for a building, one of the most important considerations is the system ground. Proper grounding helps protect against transient currents, electrical noise, and lightning strikes. Several methods can be used to test the electrical grounding system. The effectiveness of the grounding system greatly depends on the resistivity of the earth at the location of the system ground. The resistivity of the earth varies greatly throughout the world and even within small areas. Many factors affect the earth's resistivity such as soil type (clay, shell, sand, etc.), moisture content, electrolyte content (acids, salts, etc.), and temperature.

In theory, the system ground is considered to have a resistance of zero because it is connected to system grounds everywhere, via the neutral conductor, Figure 1-3. In actual practice, however, the current carrying capacity of the grounding system can vary greatly from one area to another.

Testing

There are different methods for determining the resistivity of the grounding system. An old method used by electricians for many years is to connect a 100-watt lamp between the ungrounded (hot) conductor and the grounding conductor, Figure 1-4. To perform this test, the grounding conductor must be disconnected from the neutral bus in the panel. The brightness of the lamp gives an indication of the effectiveness of the grounding system. Although this

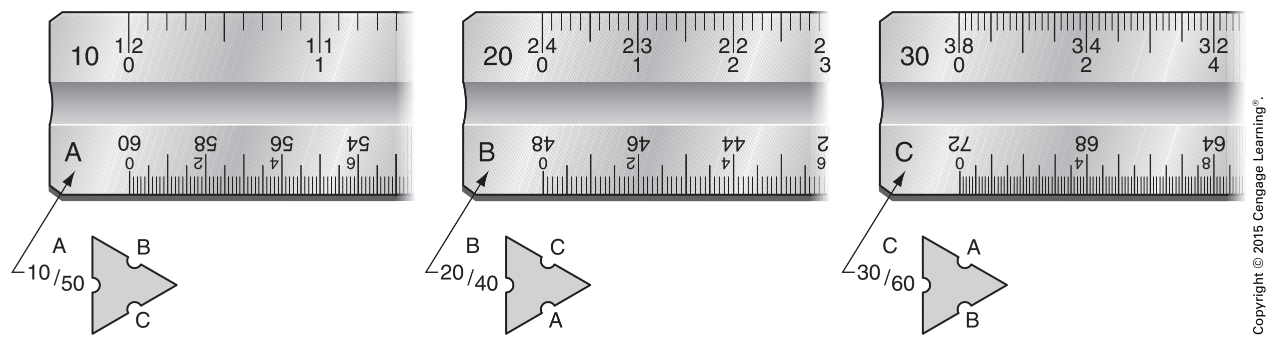

FIGURE 1-2 Scale.

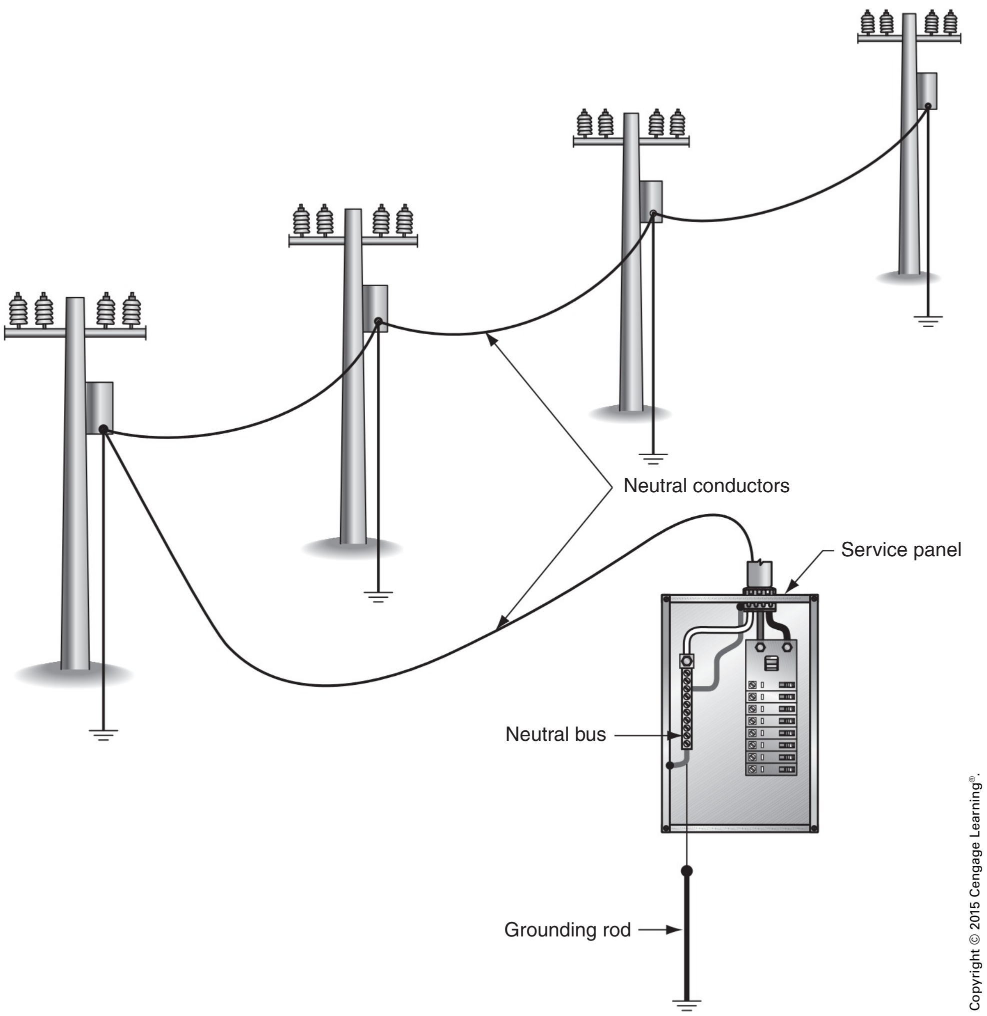

FIGURE 1-3 All neutral conductors are bonded together, forming a continuous grounding system.

test indicates whether the grounding system works, it does not indicate the actual resistance of the system. To measure the actual resistance of the grounding system requires the use of special equipment such as a ground resistance tester, Figure 1-5. There are three main tests used to measure ground resistance: the Wenner four-point test, the three-point fall-of-potential test, and the clamp-on ground resistance test.

The Wenner Four-Point Method

The Wenner four-point test is generally performed before building construction begins. This method measures the ground resistance over a wide area. The results are used in designing the grounding system to ensure that it performs properly. This test requires the use of a 4-pole ground resistance meter, four metal rods, and conductors. The four rods are driven into the ground in a straight line, with equal space between each rod, Figure 1-6. To perform this test, the ground resistance tester produces a known amount of current between rods C1 and C2, producing a voltage drop across rods P1 and P2. The amount of voltage drop is proportional to the amount of current and ground resistance. Readings are generally taken with probes C1 and C2 spaced 5, 10, 15, 20, 30, 40, 60, 80, and 100 feet apart. If possible, it is recommended to perform the test with the probes spaced 150 feet apart.

The calculated soil resistance is the average of the soil resistance from the surface to a depth equal to the space between the probes. If the probes are set 30 feet apart, for example, each probe will provide an average resistance measurement from the surface to a depth of 30 feet. The tests should not only be made with the

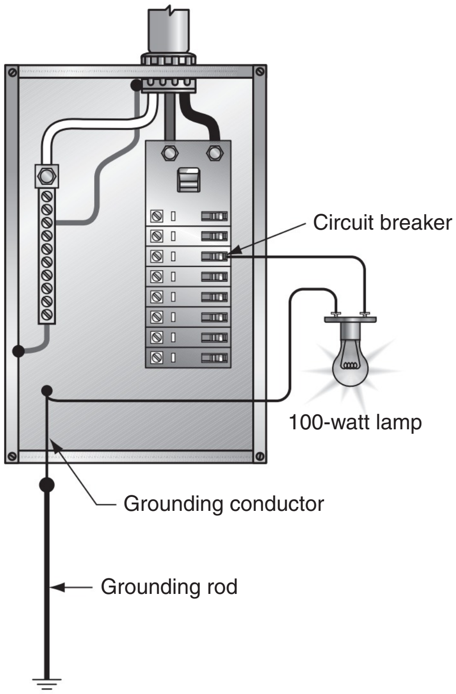

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FIGURE 1-4 A 100-watt lamp is used to test the grounding system.

Courtesy of AEMC® Instruments

FIGURE 1-5 Ground resistance tester.

probes spaced different distances apart but also with the probes in different directions from a central point. If the site is large enough, it is generally recommended to perform the test along at least two sides, generally from one corner to the other. It should be noted that underground structures such as metal water pipes can influence the readings. The best results will be obtained by gathering as much data as possible.

Three-Point Fall-of-Potential Test

The fall-of-potential test requires the use of a ground resistance meter. It is performed after the installation of the grounding system and should be done annually to ensure the quality of the grounding system. Annual testing provides protection against the degradation of the system before damage to equipment and performance problems occur.

In the three-point fall-of-potential test, the three points of ground contact are

1. the system ground (grounding rod) (point A);
2. a current probe placed some distance from the grounding rod (point B); and
3. a voltage probe that is inserted at various distances between the grounding rod and the current probe (C). The voltage probe is placed in a straight line between the grounding rod and the current probe.

Ideally, the current probe (B) should be placed at a distance that is at least 10 times the length of the grounding rod (A), Figure 1-7. If the grounding rod is 8 feet in length, the current probe should be placed at least 80 feet from the grounding rod.

To perform this test, the grounding rod must be disconnected (electrically isolated) from the neutral bus in the service panel. Failure to do so will completely invalidate the test. The meter provides a known amount of current that flows from the current probe and back to the meter through the system grounding rod. The resistance of the earth causes a voltage drop that is measured between the current probe and the voltage probe. The amount of voltage drop is proportional to the amount of current flow and the ground resistance. Resistance readings should be taken at several locations by moving the voltage probe a distance equal to 10% of the distance between the system grounding rod and the current probe. If performed properly, the

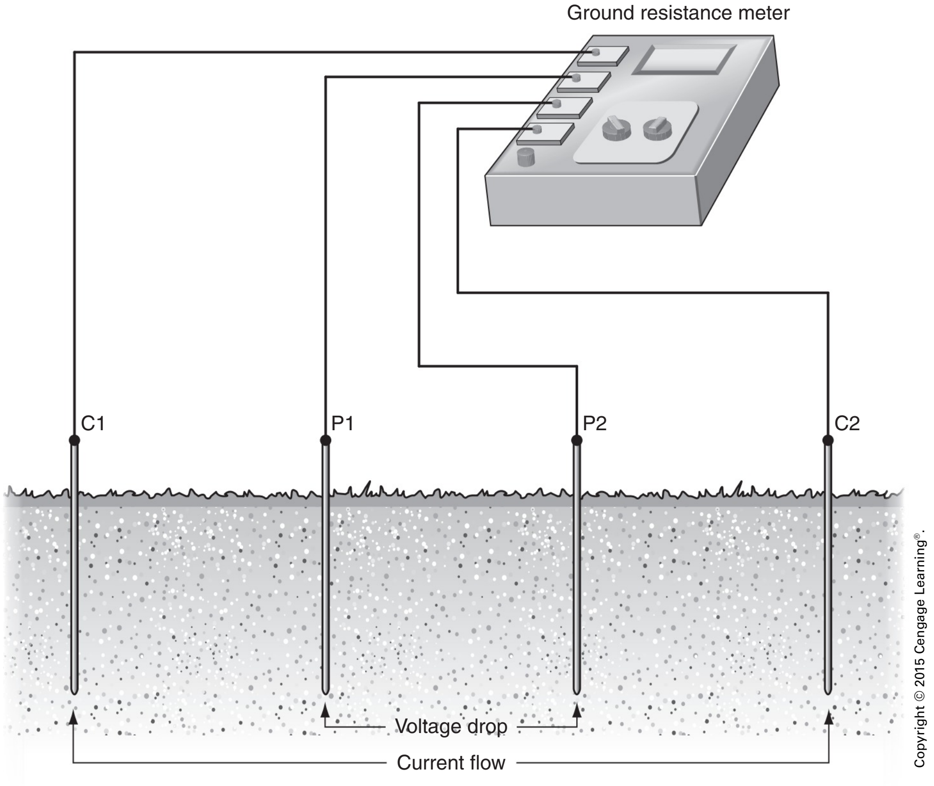

FIGURE 1-6 The Wenner four-point test.

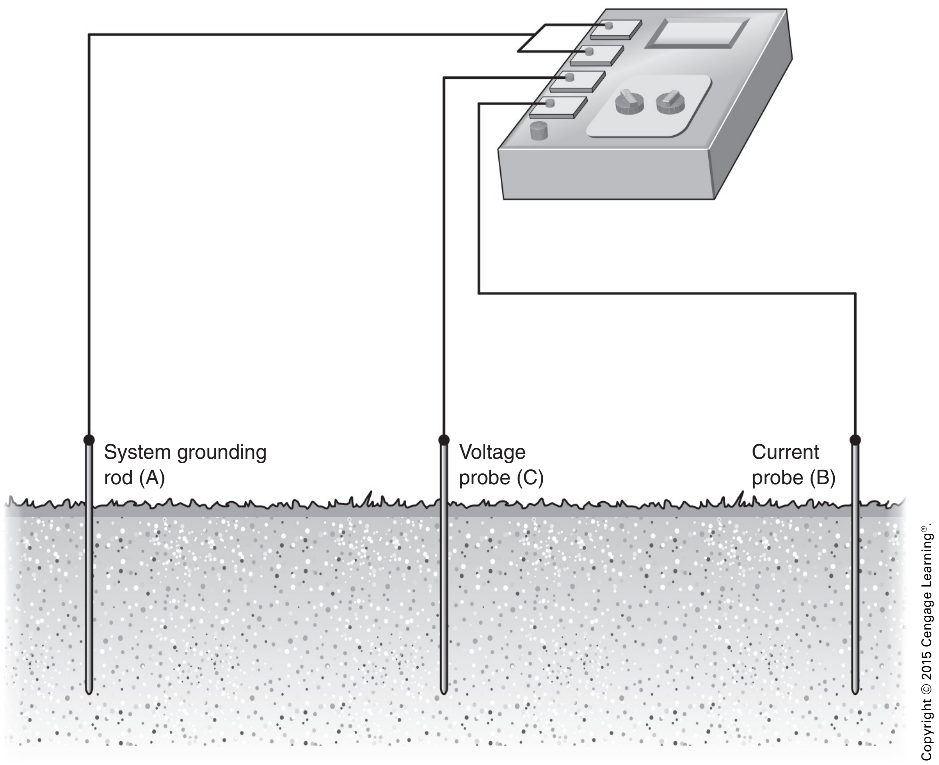

FIGURE 1-7 The three-point fall-of-potential test.

three-point ground resistance test is the most accurate method of determining ground resistance.

The Clamp-On Ground Resistance Test

The clamp-on ground resistance test requires the use of a special clamp-on ground resistance meter. This test has several advantages over the three-point fall-of-potential test.

1. The service grounding system does not have to be disconnected and isolated from the neutral bus.
2. There are no probes that have to be driven into the ground or long connecting conductors.
3. The neutral conductor supplied by the utility company ties innumerable grounds together in parallel. The clamp-on ground tester measures the effective resistance of the entire grounding system.
4. Because this test is performed by a clamp-on meter, there are no connections that have to be broken or reconnected, resulting in a safer procedure, Figure 1-8.

The clamp-on ground resistance tester, Figure 1-9, contains two transformers. One transformer induces a small fixed voltage at approximately 2 kHz on the grounding conductor. If a path exists, the voltage will result in a current flow. The path is provided by the grounding system under test, the utility neutral, and the utility grounding system. The second transformer inside the meter senses the amount of current at the unique frequency provided by the first transformer. The amount of current is proportional to the induced voltage and the resistance of the grounding system. The meter uses the two known electrical quantities to calculate the resistance of the grounding system.

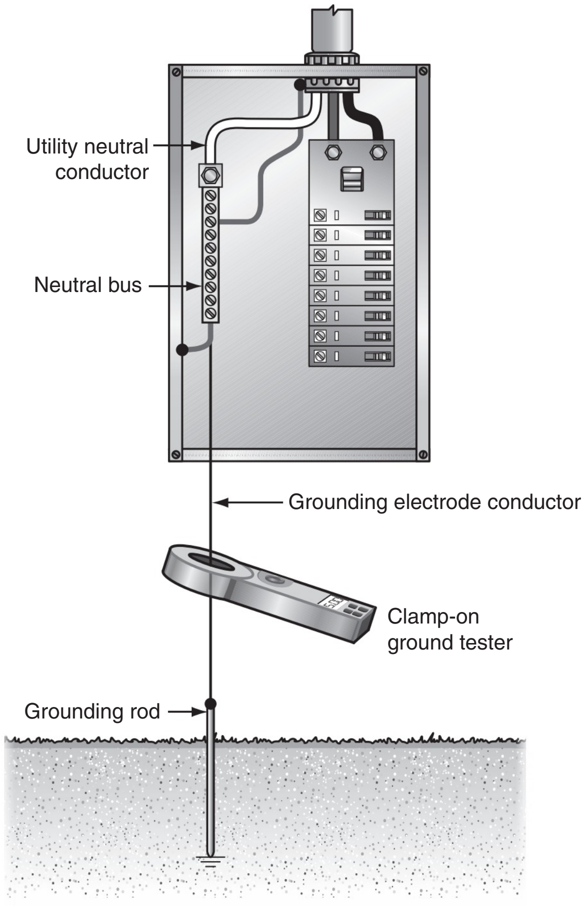

FIGURE 1-8 The clamp-on ground resistance test.

FIGURE 1-9 Ground resistance tester.

Grounding and Bonding Considerations

Many technicians and electricians pay little attention to grounding and know only the basic requirements specified by the *National Electrical Code*. However, grounding is one of the most important parts of any electrical installation. Proper grounding protects circuits and equipment from destruction and personnel from injury. Grounding is generally thought of as connecting a system to earth via a grounding electrode, as shown in Figure 1-8. In reality, grounding is connecting a circuit to a common point of reference. Almost all grounded systems are connected to earth, which is a common point of reference, but the earth generally does not provide the low-impedance path necessary to protect against ground-fault currents. *NEC 250.4(A)(5)* states, The earth shall not be considered an effective ground-fault current path.

Grounding not only provides a low-impedance path for fault currents, but it also provides a common point of reference for different electrical systems and voltages, Figure 1-10. A low-impedance path exists from the alternator supplying power to the last device connected to the circuit. The alternator has an output of 13.8 kV, which is stepped up to 138 kV for transmission. The voltage is stepped back down to 13.8 kV at a unit substation. The plant substation steps the voltage down to 480 volts to feed the plant bus system. Other 3-phase and single-phase transformers are powered by the plant bus. A battery backup system is used by an uninterruptable power supply. All of these different power systems and voltages are connected together via grounding conductors. Grounding is also used to protect against lightning, static electricity, and the influence of high frequency. It should be noted, however, that the grounding requirements listed in the *National Electrical Code* are intended for direct current and 60-hertz AC systems. These requirements may not provide an effective ground for high frequency. Alternating current systems are subject to skin effect, which is the tendency of electrons to move toward the surface of a conductor, Figure 1-11.

The higher the frequency, the greater the skin effect. At a frequency of 10 MHz, a 6 AWG copper conductor may exhibit a resistance of several thousand ohms. High-frequency circuits must be grounded with a conductor that contains a large surface area, such as braided cable or wide copper tape.

Safety

Besides providing a common point of connection for different systems and voltages, grounding plays

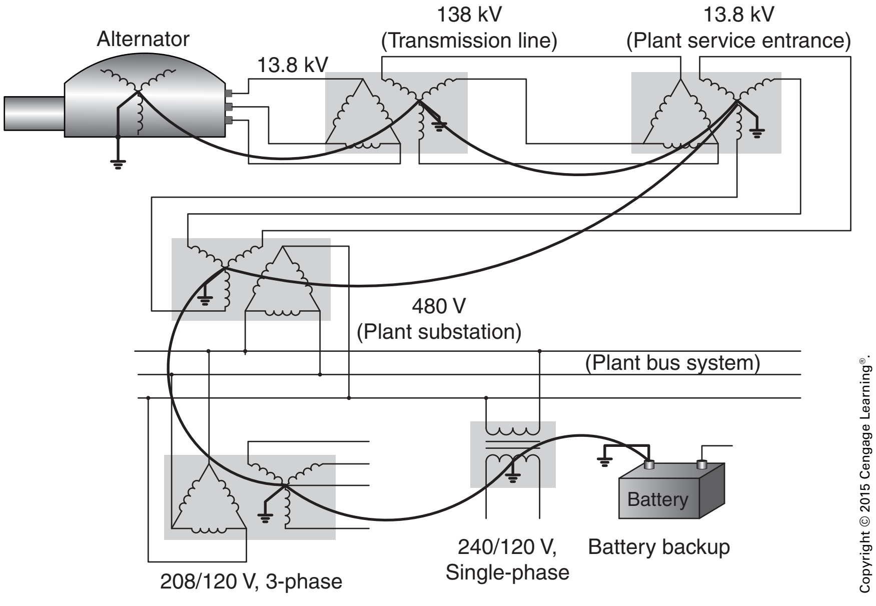

FIGURE 1-10 A low-impedance ground is connected throughout the system.

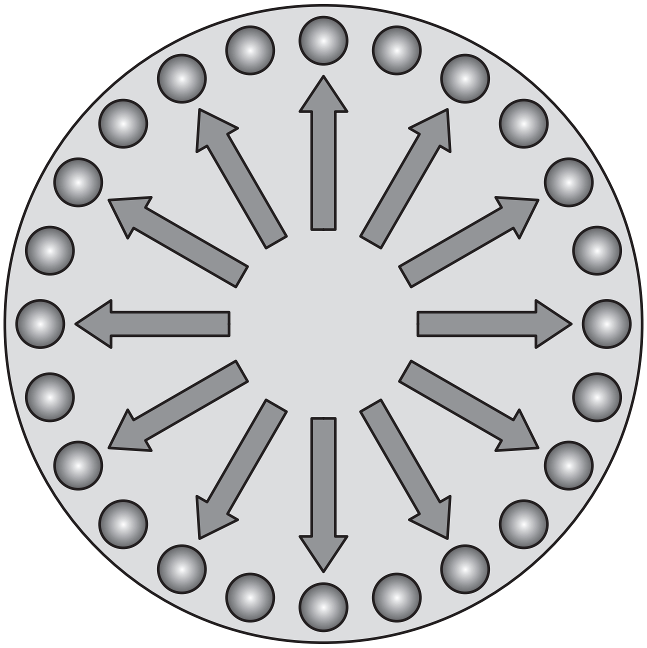

FIGURE 1-11 Alternating current causes electrons to move toward the surface of the conductor. This action is called skin effect.

a large part in the safety of equipment and personal. When the grounding system is properly installed and maintained, it provides a low-impedance path to ground. A common saying among people in the electrical trades is that current follows the path of least resistance. There is some truth to that idea, but it is not the whole truth. Current will behave in the manner dictated by Ohm's law. Assume that a 3-phase, 480-volt motor is protected by a 30-ampere circuit breaker. Also assume that the stator windings have an impedance of 20 ohms. If the stator windings are connected in wye, Figure 1-12, each winding will have an applied voltage of 277 volts (480/1.732).

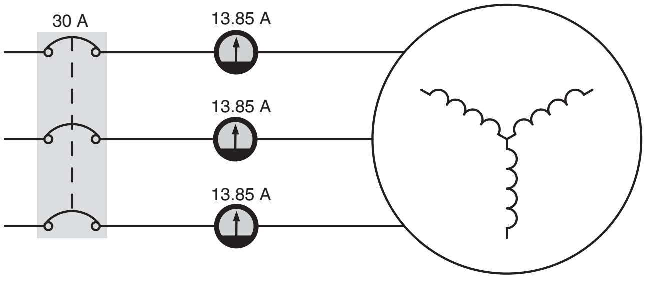

FIGURE 1-12 A 3-phase motor is connected to 480 volts.

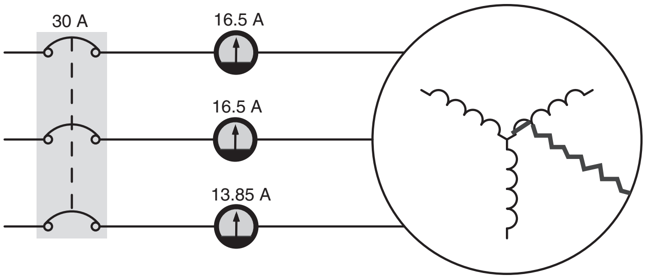

FIGURE 1-13 One-stator windings develop a short to the case of the motor.

The phase current will be 13.85 A (277/20). Because the stator windings are connected in wye, the line current will be the same as the phase current. Now assume that one of the phase windings develops a shorted winding to ground. If only part of the winding is shorted, the motor may still operate with an increase of current on two of the lines, and the current may not be sufficient to cause the circuit breaker to open, Figure 1-13.

If the case of the motor is not grounded, there is no complete circuit for current flow, which causes the case of the motor to exhibit a voltage of approximately 277 volts to ground. Anyone touching the motor is in danger of electrocution. The resistance of the human body can vary from as low as 500 ohms to as high as 600,000 ohms. Assume that a person touching the motor has a resistance of 1000 ohms to ground. That would produce a current flow of approximately 277 mA, which is about three times the amount necessary to cause death.

If the motor is properly grounded, Figure 1-14, the grounding conductor will provide a very low-impedance path to ground. The low-impedance

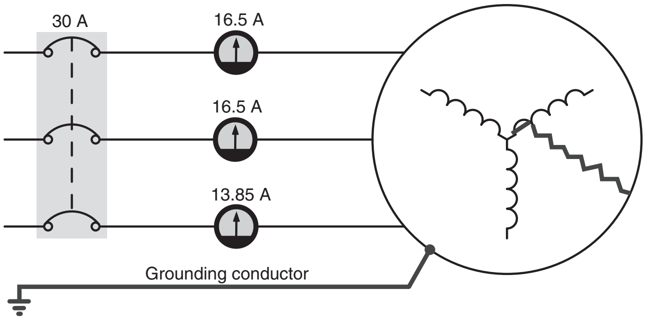

FIGURE 1-14 A grounding conductor provides a low-impedance path to ground.

grounding conductor forces the motor case to exist at ground potential, and the shock hazard is eliminated. Also, the current path to ground will very likely cause enough current flow for the circuit breaker to open. It should be noted that grounding conductors should be installed in the same conduit as circuit conductors; otherwise, the impedance of the grounding conductor may increase due to inductance.

Bonding

Bonding is used to connect the metal parts of equipment or building structure to the grounding system. The *NEC* states that Bonding shall be provided where necessary to ensure electrical continuity and the capacity to conduct safely any fault current likely to be imposed. *Article 250* of the *NEC* lists the requirements and specifications for the bonding of equipment. Bonding jumpers are lengths of wire used to connect the equipment to the grounding system. Some examples of where bonding jumpers are required are around impaired connections such as reducing washers or oversized, concentric, or eccentric knockouts. Metallic boxes, raceways, cable trays, cable sheath, armored cable, metal water pipes, and exposed parts of metal buildings are also required to be bonded, Figure 1-15.

INTERPRETING THE SITE PLAN

Notations that do not normally appear on a site plan have been added to plan Z1 of the plans located in the back of the text. These notations are aids used to locate specific spots on the plan. The notations are

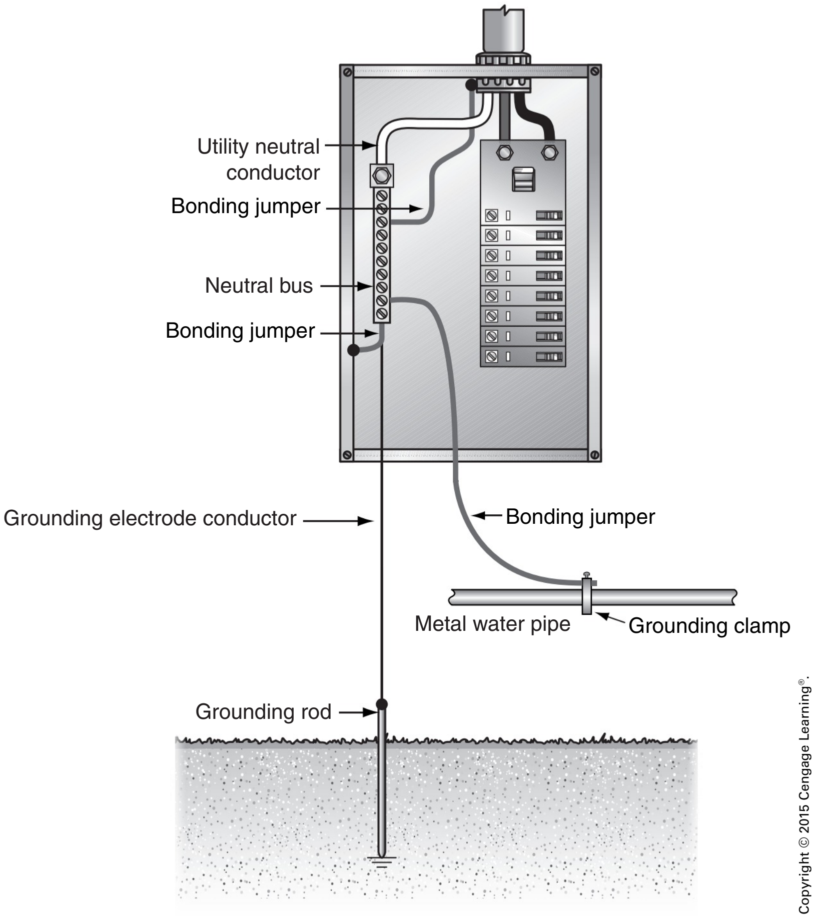

FIGURE 1-15 Bond jumpers are used to connect electrical parts to ground.

identified by an asterisk followed by a number such as **1*, **2*, and so on.

Refer to the Composite Site Plan. Note the benchmark located in the southeast quadrant of the plan. This is the point at which the surveyor began measuring the elevations seen on the plan. Notice that some of the elevation lines have crossing hash marks. The hash marks indicate that that section of the elevation is to be changed. Locate the contour lines for 748 and 749. Parts of these lines have crossing hash marks and parts do not. Only the sections denoted with hash marks are to be changed.

The new elevations are shown with dark heavy lines. These dark heavy lines are shown to connect at some point with the existing contour lines. The elevation of the connecting contour line indicates what the new elevation is intended to be. At position **1*, located in the upper southwest quadrant, a heavy dark line connects with the 749 elevation line. The area indicated by the new contour line is to be 749. Locate the new contour line connecting with the 749 contour line at **2*. Trace this line to the point where it intersects with the layout of the building. Notice that the entire building is positioned in an area marked by these two new contour lines. This indicates that the building site is to be changed to a uniform 749 ft in preparation for pouring the concrete slab.

New spot elevations are used to indicate an elevation different from that marked by the plot plan. For example, locate the new contour line at **3*. This new contour line connects to the 747 contour line. Now locate the new spot elevation at position **4*. The arrow points to the curb inlet drain. The curb inlet drain is located in an area that is indicated to be 747 ft. The new spot elevation, however, shows that the curb inlet drain is to be 0.3 ft (90 mm) lower than the surrounding area.

Telephone Service

Telephone service is provided by conduit that runs from the telephone pole. The conduit runs underground at a minimum depth of 18 in. (450 mm) and then is run up the telephone pole for a distance of 8 ft (2.5 m), Figure 1-16. A temporary standard pole cap is installed to protect the equipment from water until the cables are pulled in. The telephone company later removes this cap and extends the conduit up the pole to the point of connection. The conduit is then sealed with a special telephone fitting or with a compound known as *gunk*. A long sweep conduit elbow or quarter bend is installed at the base of the pole. At the lowest point of this fitting, a small V-groove is cut or a ⅜ in. (9.5 mm) hole is drilled for moisture drainage. This drainage hole is known as a *weep hole*. A small dry well is then constructed below the weep hole and is filled with rocks. A pull wire (fish wire) is installed in the raceway from the pole to the junction box at the point where it enters the building. In general, 12-gauge galvanized wire is used as the fish wire, but a nylon string will do as well.

Direct Burial Wiring

The electrician may have a choice of several methods of installing underground wiring. The selection of the method to be used depends on the type of materials available and whether provisions are to be made for replacing the conductors. If direct burial cable is used, Figure 1-17, care must be taken to protect the cable from damage. For example, the cable can be installed in the ground to a greater depth than that at which normal digging takes place. Added protection is obtained by placing a treated board over the cable to provide a shield against digging and probing near the cable. The cable should also be surrounded by a layer of sand to prevent any abrasion of the cable by sharp stones and other objects in the soil.

Underground Raceways

Although underground raceways are more expensive to install, they provide many advantages that direct burial installations do not, such as permitting the removal of the original conductors and/or the installation of new conductors with higher current or voltage ratings. Underground raceways are available in a number of different materials, including rigid metal conduit and rigid nonmetallic conduit.

Rigid metal conduit can be installed directly in the soil if (*300.5 and 300.6 of the National Electrical Code* [*NEC*]):

- ferrous conduits (iron or steel) do not rely solely on enamel for corrosion protection;

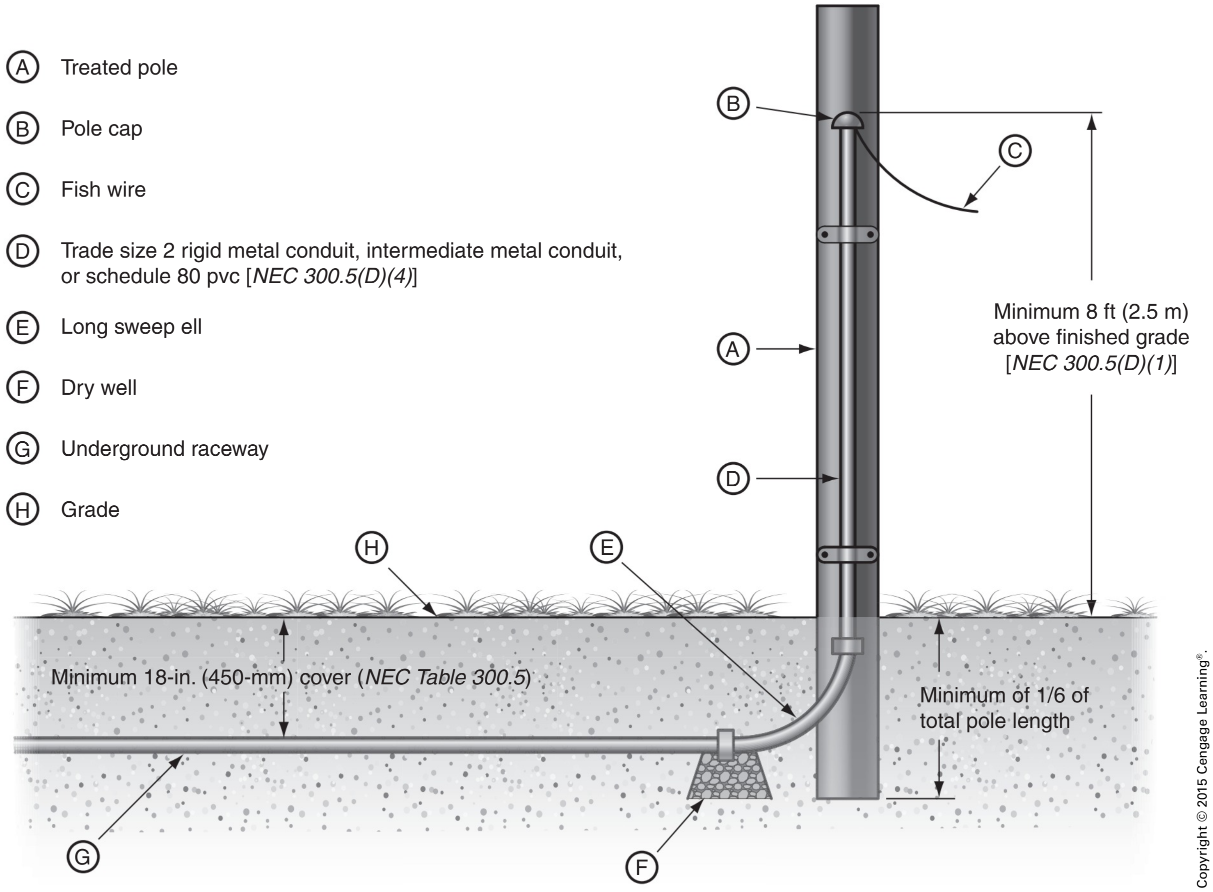

FIGURE 1-16 Telephone service installation.

- the conduit is made of a material judged suitable for the condition; and
- the conduit is not placed in an excavation that contains large rocks, paving materials, cinders, large or sharply angular substances, or corrosive material.

Special precautions should be taken when using nonferrous conduit (aluminum) to prevent the conduit

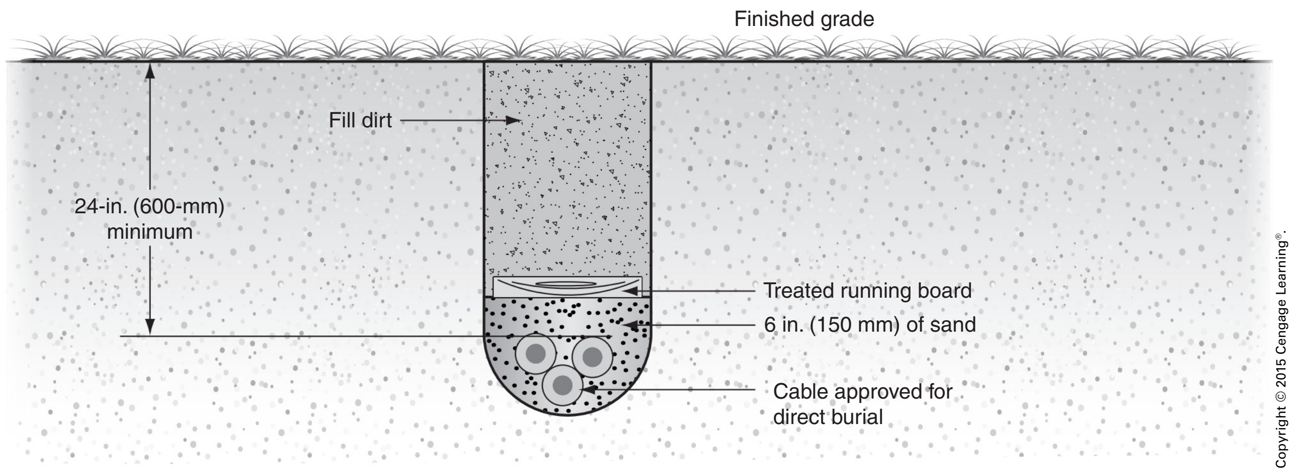

FIGURE 1-17 An installation of direct burial cable.

from contacting sodium chloride (salt) mixtures. Concrete mixes often use such mixtures to lower the freezing temperature of the green concrete. The chemical reaction between the aluminum and the salt may cause the concrete to fracture or spall (chip or fragment). When protection is desired or required for the type of raceway used, concrete is poured around the conduit, as shown in Figure 1-18, with at least 2 in. (50 mm) of cover in compliance with *NEC Table 300.5*.

The use of rigid polyvinyl chloride conduit type PVC is covered in *NEC Article 352*. These conduits may be used:

- concealed in walls, floors, and ceilings;
- under cinder fill;
- in locations subject to severe corrosive conditions;
- in dry and damp locations;
- exposed where not subject to physical damage; and
- underground.

If the electrical system to be installed operates at a potential higher than 600 volts, the nonmetallic conduit must be encased in not less than 2 in. (50 mm) of concrete.

NEC Article 344 gives the installation requirements for rigid metal conduit and *NEC Article 352* covers rigid polyvinyl chloride conduit type PVC.

The minimum requirements for the installation of conduit and cables underground are given in *NEC Table 300.5*. The general installation requirements are as follows.

For direct burial cables:

- the minimum burial depth is 24 in. (600 mm);
- where necessary, additional protection is to be provided, such as sand, running boards, or sleeves;
- a residential exception permits cable burial to a depth of only 12 in. (300 mm) with GFCI protection; *NEC Table 300.5,* column 4.

For rigid polyvinyl chloride conduit type PVC:

- the minimum burial depth is 18 in. (450 mm);
- a 12 in. (300 mm) burial depth is permitted if a 2 in. (50 mm) concrete cover is provided over conduit;

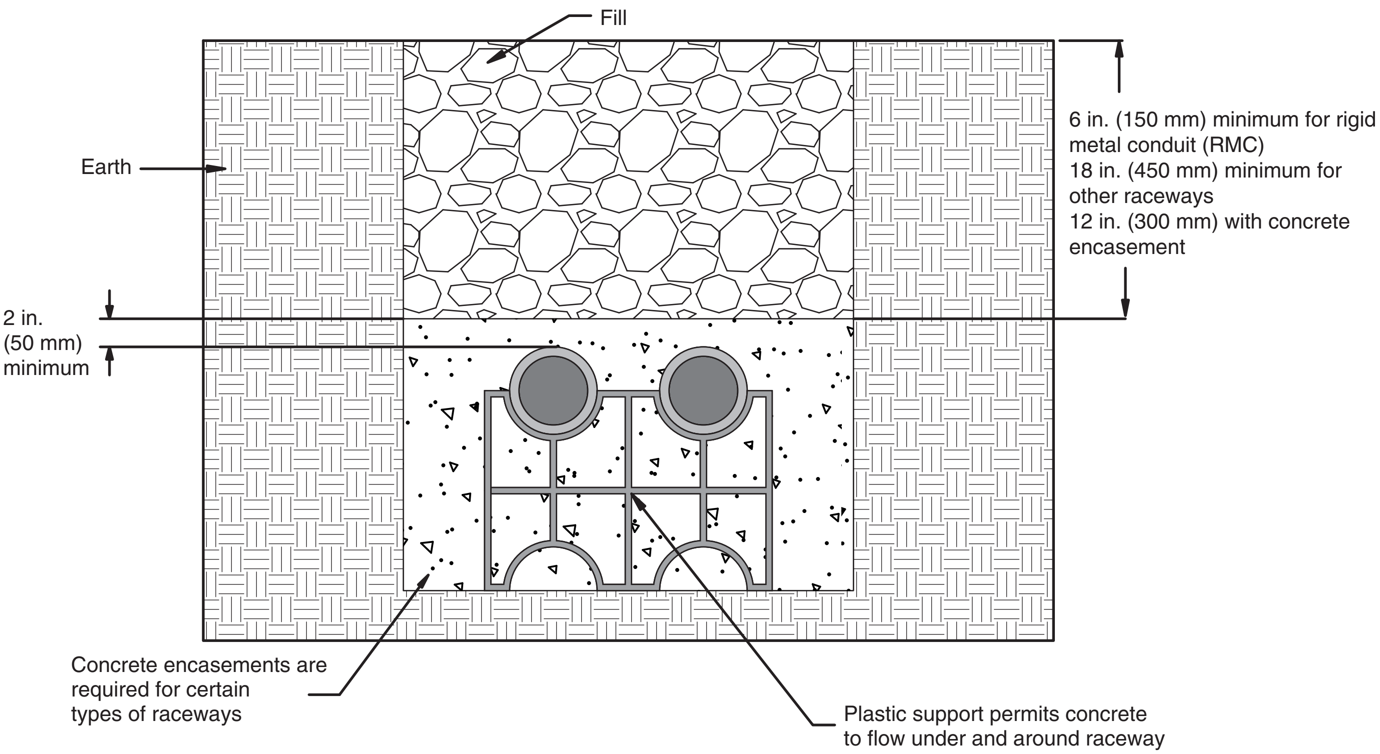

FIGURE 1-18 Concrete encasement of raceways.

- a 24 in. (600 mm) burial depth is required in areas subjected to heavy vehicular traffic.

For rigid conduit:

- the minimum burial depth is 6 in. (150 mm);
- a 24 in. (600 mm) burial depth is required in areas subjected to heavy vehicular traffic.

Manholes

Underground raceways terminate in underground manholes similar to the one shown in Figure 1-19. These manholes vary in size depending on the number and size of raceways and conductors that are to be installed. The drain is an important part of the installation because it removes moisture and allows the manhole to remain relatively dry. If a storm sewer is not available for drainage, the installation of a dry well is an alternate choice.

Lighting Standards

Most types of area lighting standards require the installation of a concrete base, Figure 1-20. The manufacturer of the lighting standard should provide a template for the placement of the anchor bolts. If

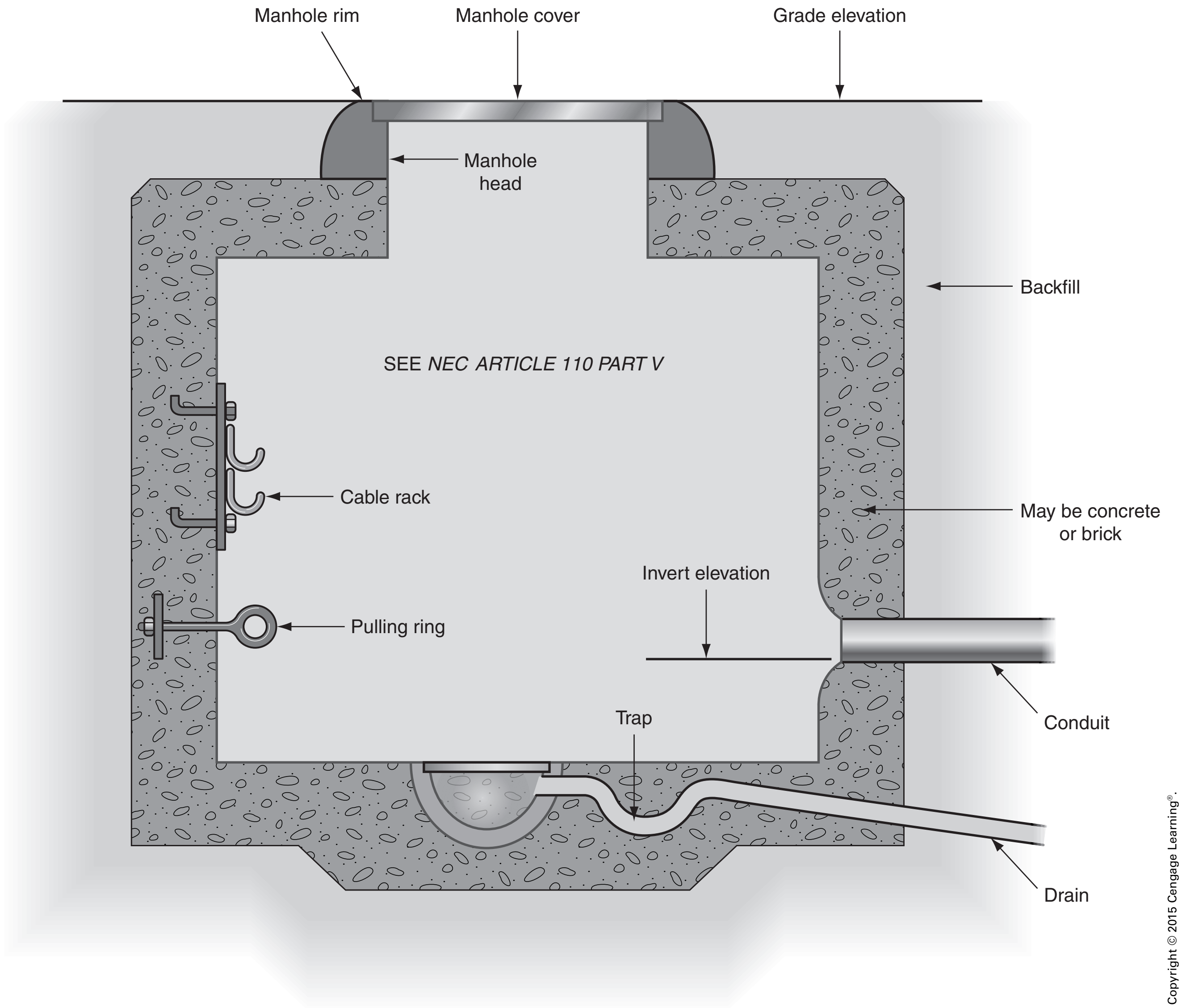

FIGURE 1-19 Typical manhole.

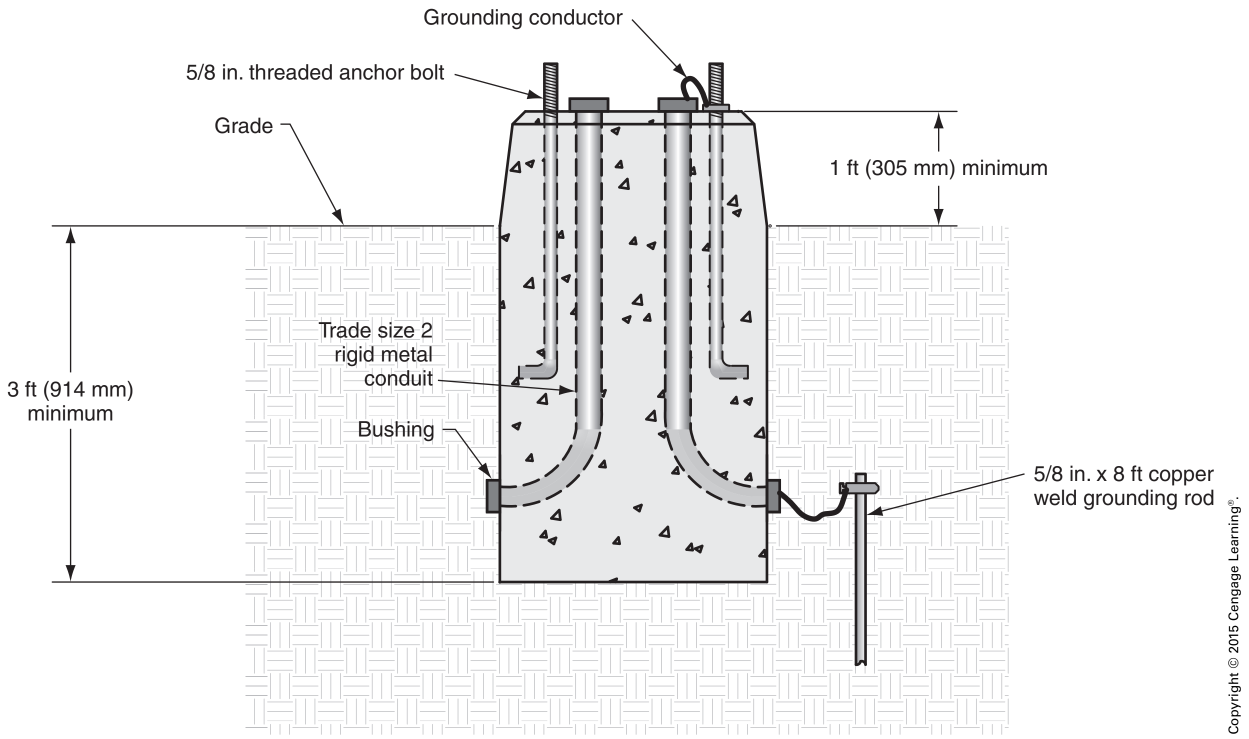

FIGURE 1-20 Typical concrete base for area lighting standard.

the manufacturer fails to provide a template for the placement of anchor bolts, the electrician should supply the general contractor with the template. The conduit installed in the base should be supplied with bushings on the ends to protect the cables. It is important that proper grounding be achieved at each lighting standard. A grounding conductor shall be installed with the supply conductors as the earth cannot be the sole grounding path; see *250.54*. This section also permits the installation of supplementary grounding electrodes as shown in Figure 1-20. It is mandatory that all conductive parts, including the grounding electrode, base, bolts, and conduits, be bonded together to achieve comprehensive grounding. See *250.2*, *250.134*, and *250.54*.

METRICS (SI) AND THE *NEC*

The United States is the last major country in the world not using the metric system as the primary system. We have been very comfortable using English (U.S. Customary) values, but this is changing. Manufacturers are now showing both inch-pound and metric dimensions in their catalogs. Plans and specifications for governmental new construction and renovation projects started after January 1, 1994, have been using the metric system. You may not feel comfortable with metrics, but metrics are here to stay. You might just as well get familiar with the metric system.

Some common measurements of length in the English (Customary) system are shown with their metric (SI) equivalents in Table 1-2.

The *NEC* and other National Fire Protection Association (NFPA) Standards are becoming international standards. All measurements in the 2014 *NEC* are shown with metrics first, followed by the inch-pound value in parentheses—for example, 600 mm (24 in.).

In *Electrical Wiring—Industrial*, ease in understanding is of utmost importance. Therefore, inch-pound values are shown first, followed by metric values in parentheses—for example, 24 in. (600 mm).

TABLE 1-2

Customary and metric comparisons.

CUSTOMARY UNITS	*NEC* SI UNITS	SI UNITS
0.25 in.	6 mm	6.3500 mm
0.5 in.	12.7 mm	12.7000 mm
0.62 in.	15.87 mm	15.8750 mm
1.0 in.	25 mm	25.4000 mm
1.25 in.	32 mm	31.7500 mm
2 in.	50 mm	50.8000 mm
3 in.	75 mm	76.2000 mm
4 in.	100 mm	101.6000 mm
6 in.	150 mm	152.4000 mm
8 in.	200 mm	203.2000 mm
9 in.	225 mm	228.6000 mm
1 ft	300 mm	304.8000 mm
1.5 ft	450 mm	457.2000 mm
2 ft	600 mm	609.6000 mm
2.5 ft	750 mm	762.0000 mm
3 ft	900 mm	914.4000 mm
4 ft	1.2 m	1.2192 m
5 ft	1.5 m	1.5240 m
6 ft	1.8 m	1.8288 m
6.5 ft	2.0 m	1.9182 m
8 ft	2.5 m	2.4384 m
9 ft	2.7 m	2.7432 m
10 ft	3.0 m	3.0480 m
12 ft	3.7 m	3.6576 m
15 ft	4.5 m	4.5720 m
18 ft	5.5 m	5.4864 m
20 ft	6.0 m	6.0960 m
22 ft	6.7 m	6.7056 m
25 ft	7.5 m	7.6200 m
30 ft	9.0 m	9.1440 m
35 ft	11.0 m	10.6680 m
40 ft	12.0 m	12.1920 m
50 ft	15.0 m	15.2400 m
75 ft	23.0 m	22.8600 m
100 ft	30.0 m	30.4800 m

A *soft metric conversion* is when the dimensions of a product already designed and manufactured to the inch-pound system have their dimensions converted to metric dimensions. The product does not change in size.

A *hard metric measurement* is where a product has been designed to SI metric dimensions. No conversion from inch-pound measurement units is involved. A *hard conversion* is where an existing product is redesigned into a new size.

In the 2014 edition of the *NEC*, existing inch-pound dimensions did not change. Metric conversions were made, then rounded off. Please note that when comparing calculations made by both English and metric systems, slight differences will occur as a result of the conversion method used. These differences are not significant, and calculations for both systems are therefore valid. Where rounding off would create a safety hazard, the metric conversions are mathematically identical.

For example, if a dimension is required to be 6 ft, it is shown in the *NEC* as 1.8 m (6 ft). Note that the 6 ft remains the same, and the metric value of 1.83 m has been rounded off to 1.8 m. This edition of *Electrical Wiring—Industrial* reflects these rounded-off changes. In this text, the inch-pound measurement is shown first—for example, 6 ft (1.8 m).

Trade Sizes

A unique situation exists. Strange as it may seem, what electricians have been referring to for years has not been correct!

Raceway sizes have always been an approximation. For example, there has never been a ½ in. raceway! Measurements taken from the *NEC* for a few types of raceways are shown in Table 1-3.

TABLE 1-3

Trade size of raceways vs. actual inside diameter.

TRADE SIZE	INSIDE DIAMETER (I.D.)
½ Electrical Metal Tubing	0.622 in.
½ Electrical Nonmetallic Tubing	0.560 in.
½ Flexible Metal Conduit	0.635 in.
½ Rigid Metal Conduit	0.632 in.
½ Intermediate Metal Conduit	0.660 in.

TABLE 1-4

This table shows the metric designator for raceways through trade size 3.

METRIC DESIGNATOR AND TRADE SIZE

METRIC DESIGNATOR	TRADE SIZE
12	⅜
16	½
21	¾
27	1
35	1¼
41	1½
53	2
63	2½
78	3

TABLE 1-5

This table compares the trade size of a knockout with the actual measurement of the knockout.

TRADE SIZE KNOCKOUT	ACTUAL MEASUREMENT
½	⅞ in.
¾	1³⁄₃₂ in.
1	1⅜ in.

You can readily see that the cross-sectional areas, critical when determining conductor fill, are different. It makes sense to refer to conduit, raceway, and tubing sizes as trade sizes. The *NEC in 90.9(C)(1)* states that where the actual measured size of a product is not the same as the nominal size, trade size designators shall be used rather than dimensions. Trade practices shall be followed in all cases. This edition of *Electrical Wiring—Industrial* uses the term *trade size* when referring to conduits, raceways, and tubing. For example, instead of ½ in. electrical metal tubing (EMT), it is referred to as trade size ½ EMT.

The *NEC* also uses the term *metric designator*. A ½ in. EMT is shown as *metric designator 16 (½)*. A 1 in. EMT is shown as *metric designator 27 (1)*. The numbers 16 and 27 are the metric designator values. The (½) and (1) are the trade sizes. The metric designator is the raceways' inside diameter—in rounded-off millimeters (mm). Table 1-4 shows some of the more common sizes of conduit, raceways, and tubing. A complete table is found in the *NEC, Table 300.1(C)*. Because of possible confusion, this text uses only the term *trade size* when referring to conduit and raceway sizes.

Conduit knockouts in boxes do not measure up to what we call them. Table 1-5 shows trade size knockouts and their actual measurements.

Outlet boxes and device boxes use their nominal measurement as their *trade size*. For example, a 4 in. × 4 in. × 1½ in. does not have an internal cubic-inch area of 4 in. × 4 in. × 1½ in. = 24 cubic inches. *Table 314.16(A)* shows this size box as having an area of 21 in.^{3} This table shows *trade sizes* in two columns—millimeters and inches.

Table 1-6 provides the detailed dimensions of some typical sizes of outlet and device boxes in both metric and English units.

In practice, a square outlet box is referred to as 4 × 4 × 1½-inch square box, 4″ × 4″ × 1½″ square box, or trade size 4 × 4 × 1½ square box. Similarly, a single-gang device box might be referred to as a 3 × 2 × 3-inch device box, a 3″ × 2″ × 3″-deep device box, or a trade size 3 × 2 × 3 device box. The box type should always follow the trade size numbers.

Trade sizes for construction material will not change. A 2 × 4 is really a *name*, not an actual dimension. A 2 × 4 stud will still be referred to as a 2 × 4 stud. This is its *trade size*.

In this text, measurements directly related to the *NEC* are given in both inch-pound and metric units. In many instances, only the inch-pound units are shown. This is particularly true for the examples of raceway calculations, box fill calculations, and load calculations for square foot areas, and on the plans (drawings). To show both English and metric measurements on a plan would certainly be confusing and would really clutter up the plans, making them difficult to read.

Because the *NEC* rounded off most metric conversion values, a calculation using metrics results in a different answer when compared with the same

NEC® **TABLE 1-6**

Table 314.16(A) Metal Boxes

Box Trade Size			Minimum Volume		Maximum Number of Conductors* (arranged by AWG size)						
mm	in.		cm³	in.³	18	16	14	12	10	8	6
100 × 32	(4 × 1¼)	round/octagonal	205	12.5	8	7	6	5	5	5	2
100 × 38	(4 × 1½)	round/octagonal	254	15.5	10	8	7	6	6	5	3
100 × 54	(4 × 2⅛)	round/octagonal	353	21.5	14	12	10	9	8	7	4
100 × 32	(4 × 1¼)	square	295	18.0	12	10	9	8	7	6	3
100 × 38	(4 × 1½)	square	344	21.0	14	12	10	9	8	7	4
100 × 54	(4 × 2⅛)	square	497	30.3	20	17	15	13	12	10	6
120 × 32	(4¹¹⁄₁₆ × 1¼)	square	418	25.5	17	14	12	11	10	8	5
120 × 38	(4¹¹⁄₁₆ × 1½)	square	484	29.5	19	16	14	13	11	9	5
120 × 54	(4¹¹⁄₁₆ × 2⅛)	square	689	42.0	28	24	21	18	16	14	8
75 × 50 × 38	(3 × 2 × 1½)	device	123	7.5	5	4	3	3	3	2	1
75 × 50 × 50	(3 × 2 × 2)	device	164	10.0	6	5	5	4	4	3	2
75 × 50 × 57	(3 × 2 × 2¼)	device	172	10.5	7	6	5	4	4	3	2
75 × 50 × 65	(3 × 2 × 2½)	device	205	12.5	8	7	6	5	5	4	2
75 × 50 × 70	(3 × 2 × 2¾)	device	230	14.0	9	8	7	6	5	4	2
75 × 50 × 90	(3 × 2 × 3½)	device	295	18.0	12	10	9	8	7	6	3
100 × 54 × 38	(4 × 2⅛ × 1½)	device	169	10.3	6	5	5	4	4	3	2
100 × 54 × 48	(4 × 2⅛ × 1⅞)	device	213	13.0	8	7	6	5	5	4	2
100 × 54 × 54	(4 × 2⅛ × 2⅛)	device	238	14.5	9	8	7	6	5	4	2
95 × 50 × 65	(3¾ × 2 × 2½)	masonry box/gang	230	14.0	9	8	7	6	5	4	2
95 × 50 × 90	(3¾ × 2 × 3½)	masonry box/gang	344	21.0	14	12	10	9	8	7	4
min. 44.5 depth	FS — single cover/gang (1¾)		221	13.5	9	7	6	6	5	4	2
min. 60.3 depth	FD — single cover/gang (2⅜)		295	18.0	12	10	9	8	7	6	3
min. 44.5 depth	FS — multiple cover/gang (1¾)		295	18.0	12	10	9	8	7	6	3
min. 60.3 depth	FD — multiple cover/gang (2⅜)		395	24.0	16	13	12	10	9	8	4

*Where no volume allowances are required by 314.16(B)(2) through (B)(5).

calculation done using inch-pounds. For example, load calculations for a residence are based on 3 volt-amperes per square foot or 33 volt-amperes per square meter.

For a 40 ft × 50 ft dwelling:

$$3\,\text{VA} \times 40\,\text{ft} \times 50\,\text{ft} = 6000\,\text{volt-amperes}.$$

In metrics, using the rounded-off values in the *NEC*:

$$33\,\text{VA} \times 12\,\text{m} \times 15\,\text{m} = 5940\,\text{volt-amperes}.$$

The difference is small, but nevertheless, there is a difference.

To show calculations in both units throughout this text would be very difficult to understand and would take up too much space. Calculations in either metrics or inch-pounds are in compliance with *90.9(D)*. In *90.9(C)(3)* we find that metric units are not required if the industry practice is to use inch-pound units.

It is interesting to note that the examples in *Chapter 9* of the *NEC* use inch-pound units, not metrics.

Guide to Metric Usage

The metric system is a *base-10* or *decimal* system in that values can be easily multiplied or divided by 10 or powers of 10. The metric system as we know it today is known as the International System of Units (SI) derived from the French term *le Système International d'Unités.*

In the United States, it is the practice to use a period as the decimal marker and a comma to separate a string of numbers into groups of three for easier reading. In many countries, the comma has been used in lieu of the decimal marker, and spaces are left to separate a string of numbers into groups of three. The SI system, taking something from both, uses the period as the decimal marker and the space to separate a string of numbers into groups of three, starting from the decimal point and counting in either direction. For example, 12345.789 99. An exception to this is when there are four numbers on either side of the decimal point. In this case, the third and fourth numbers from the decimal point are not separated. For example, 2015.1415.

In the metric system, the units increase or decrease in multiples of 10,100,1000, and so on. For instance, one megawatt (1,000,000 watts) is 1000 times greater than one kilowatt (1000 watts).

By assigning a name to a measurement, such as a watt, the name becomes the unit. Adding a prefix to the unit, such as kilo-, forms the new name *kilowatt*, meaning 1000 watts. Refer to Table 1-7 for prefixes used in the numerical systems.

Certain prefixes shown in Table 1-7 have a preference in usage. These prefixes are *mega-, kilo-*, the unit itself, *centi-, milli-, micro-*, and *nano-*. Consider that the basic metric unit is a meter (one). Therefore, a kilometer is 1000 meters, a centimeter is 0.01 meter, and a millimeter is 0.001 meter.

The advantage of the SI metric system is that recognizing the meaning of the proper prefix lessens the possibility of confusion.

In this text, when writing numbers, the names are often spelled in full, but when used in calculations, they are abbreviated. For example: m for meter, mm for millimeter, in. for inch, and ft for foot. It is interesting to note that the abbreviation for inch is followed by a period (12 in.), but the abbreviation for foot is not followed by a period (6 ft). Why? Because ft. is the abbreviation for fort.

SUMMARY

As time passes, there is no doubt that metrics will be commonly used in this country. In the meantime, we need to take it slow and easy. The transition will take time. Table 1-8 shows useful conversion factors for converting English units to metric units.

TABLE 1-7

Numerical system prefixes.

NAME	EXPONENTIAL	METRIC (SI)	SCRIPT	CUSTOMARY
mega	(10^6)	1 000 000	one million	1, 000, 000
kilo	(10^3)	1 000	one thousand	1000
hecto	(10^2)	100	one hundred	100
deka		10	ten	10
unit		1	one	1
deci	(10^{-1})	0.1	one-tenth	1/10 or 0.1
centi	(10^{-2})	0.01	one-hundredth	1/100 or 0.01
milli	(10^{-3})	0.001	one-thousandth	1/1000 or 0.001
micro	(10^{-6})	0.000 001	one-millionth	1/1,000,000 or 0.000,001
nano	(10^{-9})	0.000 000 001	one-billionth	1/1,000,000,000 or 0.000,000,001

TABLE 1-8

Useful conversions and their abbreviations.

inches (in.) × 0.0254 = meter (m)	square centimeters (cm^2) × 0.155 = square inches ($in.^2$)
inches (in.) × 0.254 = decimeters (dm)	square feet (ft^2) × 0.093 = square meters (m^2)
inches (in.) × 2.54 = centimeters (cm)	square meters (m^2) × 10.764 = square feet (ft^2)
centimeters (cm) × 0.3937 = inches (in.)	square yards (yd^2) × 0.8361 = square meters (m^2)
millimeters (mm) = inches (in.) × 25.4	square meters (m^2) × 1.196 = square yards (yd^2)
millimeters (mm) × 0.039 37 = inches (in.)	kilometers (km) × 1 000 = meters (m)
feet (ft) × 0.3048 = meters (m)	kilometers (km) × 0.621 = miles (mi)
meters (m) × 3.2802 = feet (ft)	miles (mi) × 1.609 = kilometers (km)
square inches ($in.^2$) × 6.452 = square centimeters (cm^2)	

REVIEW QUESTIONS

All answers should be written in complete sentences, and calculations should be shown in detail.

1. In a set of construction drawings, where would an electrician find information about the location and placement of a building? ______________________________

2. From information on the Composite Site Plan, where is the lowest area on the site and what is the elevation? ______________________________

3. Using a scale, what is the length, in feet, of the "footprint" of the industrial building? ______________________________

4. What would be the elevation, at the pole, of the bottom of a trench being dug to install telephone service using rigid nonmetallic conduit? ______________________________

5. Raceways are specified for use under sidewalks and drives for the installation of the underground cable serving the site lighting. How many feet of raceway should be ordered for this installation? ______________________________

6. What is the difference, in SI units, between the lowest and the highest contours? _____

____

____

To answer the following questions, examine the composite site plan, the north and west elevations, the site plan symbols, and the *NEC*.

7. What is the elevation of the manhole rim where the benchmark is established? _____

____

____

8. What is the elevation of the first floor of the industrial building? _______________

____

____

9. What is the vertical distance from the manhole rim to the first floor of the industrial building? (Measure in decimal feet.) _______________

____

____

10. What is the vertical distance from the manhole rim to the first floor of the industrial building, measured in feet and inches accurate to 1⁄16 inch? _______________

____

____

11. Where is the preferred area for location of the construction trailer? Why did you choose that area? _______________

____

____

12. It was determined that the rigid nonmetallic conduit for the telephone service could be installed in a trench with a bottom elevation of 743.65 ft. If the conduit is allowed to rise a distance of 1 ft, how deep is the trench at the building? _______________

____

____

13. The distance from the first floor of the office wing to the second floor is how many meters? _______________

____

14. A cable containing two insulated conductors and a bare grounding wire is installed to a lighting standard mounted on a base similar to the one shown in Figure 1-20. Assume

you are the electrician in charge. What instruction would you give to a first-year apprentice who will make up the grounding connection? ________________________

____

____

15. Why is it necessary to have a good grounding system for the building? ____________

____

____

16. What are the three most common methods of determining ground resistance? _______

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____

CHAPTER **2**

The Unit Substation

OBJECTIVES

After studying this chapter, the student should be able to

- define the functions of the components of a unit substation.
- select the proper size of high-voltage fuse.
- explain how to set transformer taps.
- describe how a ground detector operates.
- identify the proper metering connections.
- discuss the differences between wye and delta 3-phase connections.
- calculate line and phase values of voltage and current for wye and delta 3-phase connections.
- discuss different types of service-entrance connections.

Utility companies generally supply 3-phase power to industrial customers. The requirements of the industrial location determine the type of service-entrance connection, voltage, and current capacity. To understand the difference between single-phase and 3-phase power, imagine a single-phase winding and a rotating magnetic field, Figure 2-1.

The rotating magnet produces a single sine wave. Three-phase power is produced by placing three different phase windings 120° apart. The rotating magnetic field produces three separate sine waves 120° apart, Figure 2-2.

There are two major types of 3-phase connections: the wye, or star, and the delta. The wye connection is made by connecting one end of each phase winding together at a central point, Figure 2-3.

In this example, it is assumed that the finish end of each phase winding is connected together. The start end of each winding is the point of connection

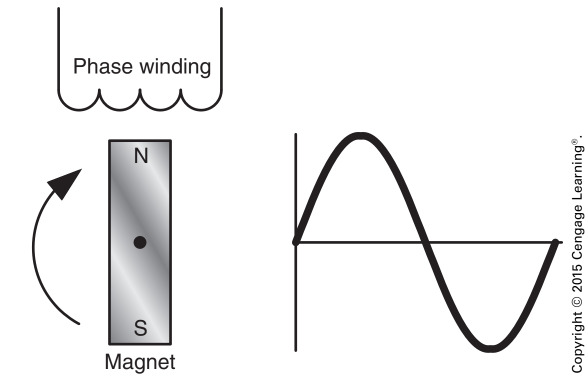


FIGURE 2-1 Single-phase power is produced by rotating a magnetic field across a single winding.

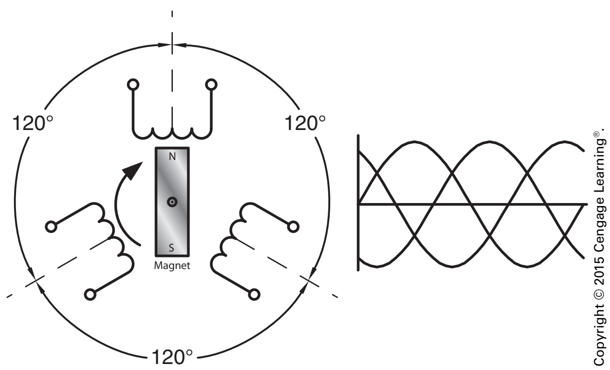


FIGURE 2-2 Three-phase power is produced by placing three phase windings 120° apart.

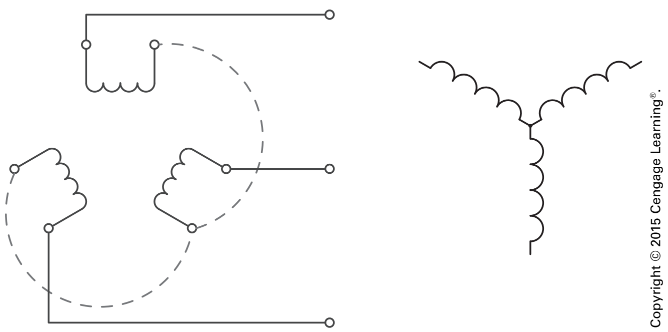


FIGURE 2-3 The wye connection is made by connecting one end of each phase winding together.

to the outside circuit. Schematically, the connection looks like the letter Y or a three-point star.

The delta connection is formed by connecting the finish end of a winding to the start end of another winding, Figure 2-4.

If the connection is drawn schematically, it looks like the Greek letter delta (Δ). Each of these connections exhibits different characteristics. Three-phase connections have two different values for voltage and current. One is the line-to-line value, generally called the line value, and the other is the phase value. In the wye connection, the line voltage and line-current values are the values associated with the connected lines. The phase values of voltage and current are the values associated with each individual phase winding, Figure 2-5.

In a wye connection, the phase voltage is less than the line voltage by a factor of the square root of 3. In the example shown, a wye-connected load is supplied by a 208-volt, 3-phase power source.

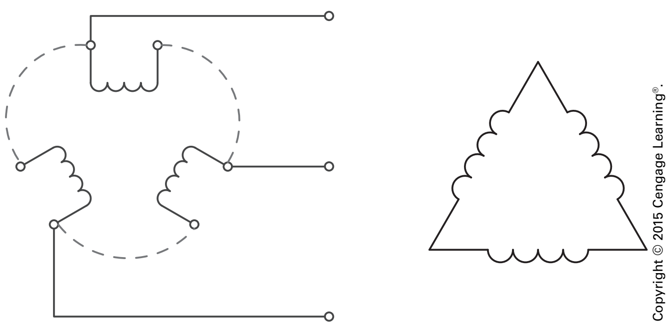


FIGURE 2-4 The delta connection is made by connecting the finish end of one phase winding to the start end of another.

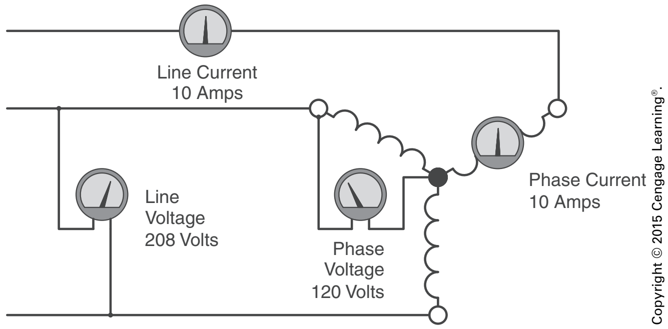


FIGURE 2-5 In a wye connection, the phase voltage is less than the line voltage by a factor of the square root of 3. The line current and phase current are the same.

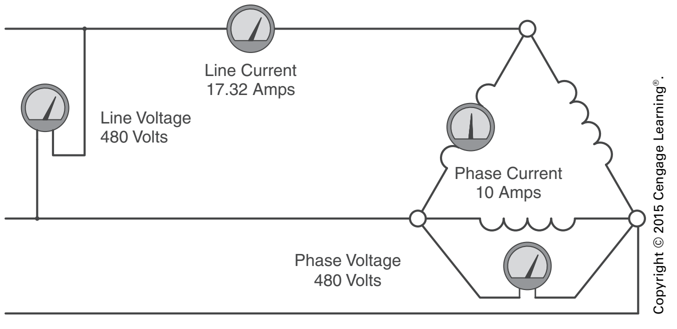


FIGURE 2-6 In a delta connection, the phase voltage and line voltage are the same. The phase current is less than the line current by a factor of the square root of 3.

The voltage across each phase winding, however, is 120 volts.

$$E_{(Phase)} = \frac{E_{(Line)}}{\sqrt{3}}$$
$$E_{(Phase)} = \frac{208}{1.732}$$
$$E_{(Phase)} = 120\,V$$

In a wye connection, the line voltage is greater than the phase voltage by a factor of the square root of 3. Assume that a wye-connected load has a phase voltage of 277 volts. The line voltage connected to the load is 480 volts.

$$E_{(Line)} = E_{(Phase)} \times \sqrt{3}$$
$$E_{(Line)} = 277 \times 1.732$$
$$E_{(Line)} = 480\,V$$

In a wye connection, the line current and phase current are the same.

$$I_{(Line)} = I_{(Phase)}$$

In the delta connection, the phase current is less than the line current by a factor of the square root of 3, Figure 2-6. In the example shown, a 3-phase delta load is connected to 480 volts. The line current supplying the load is 17.32 amperes. The phase current is only 10 amperes.

$$I_{(Phase)} = \frac{I_{(Line)}}{\sqrt{3}}$$
$$I_{(Phase)} = \frac{17.32}{1.732}$$
$$I_{(Phase)} = 10\,A$$

In a delta connection the line current is greater than the phase current by a factor of the square root of 3.

$$I_{(Line)} = I_{(Phase)} \times \sqrt{3}$$

In a delta connection the line voltage and phase voltage are the same.

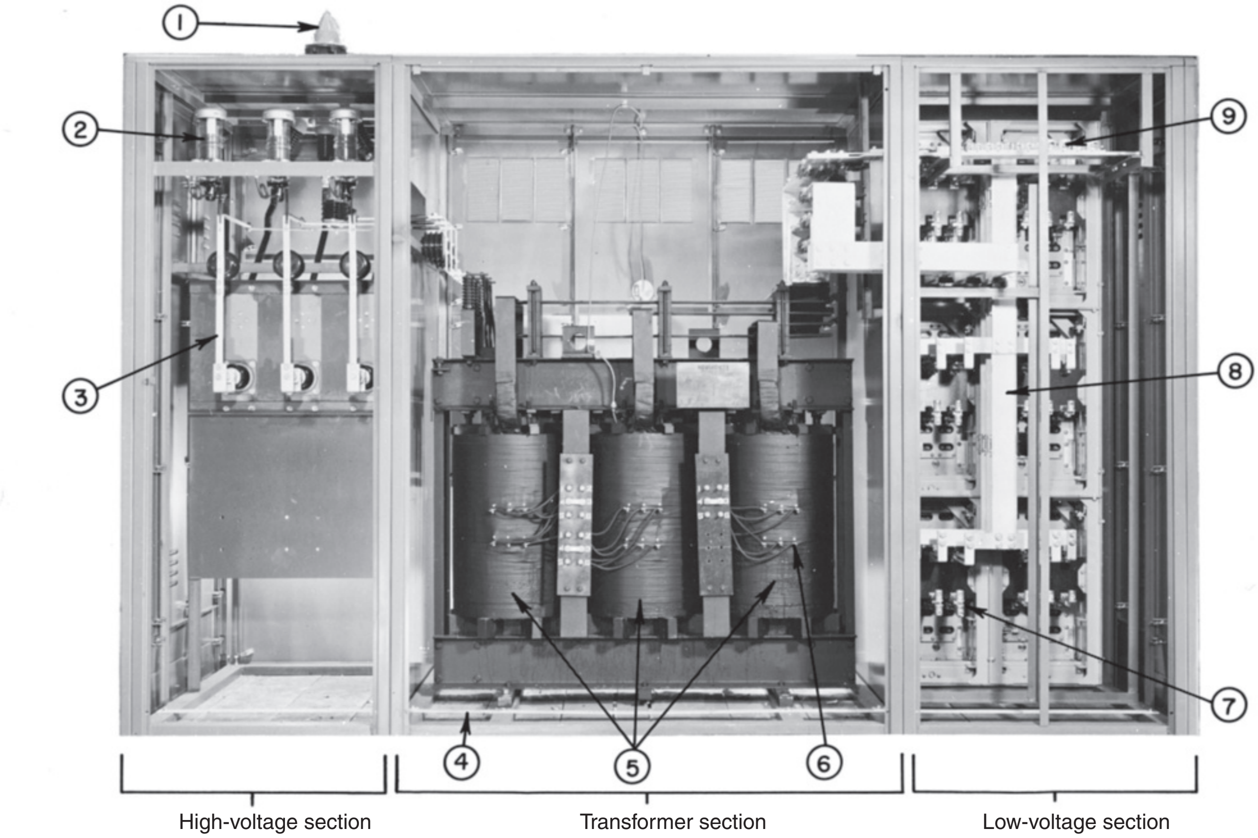
$$E_{(Line)} = E_{(Phase)}$$

Power companies commonly supply high-voltage service to large commercial or industrial buildings and complexes. The customer owns the step-down transformers, metering, and switching equipment necessary to supply the low-voltage loads. This equipment is housed in a *unit substation*, Figure 2-7. The unit substation consists of three compartments: the high-voltage section, the transformer section, and the low-voltage section.

THE HIGH-VOLTAGE SECTION

The Pothead

The high-voltage section must include a means by which the incoming line can be terminated. A device called a *pothead* provides a reliable method of terminating a high-voltage cable, Figure 2-7 and Figure 2-8. To connect the incoming lead-covered cable at the pothead, the cable is opened and the conductors are bared for several inches. The wiping sleeve of the pothead is cut off until the opening is the correct size to receive the cable. The cable is then inserted until the lead sheath is inside the sleeve.



① Pothead ② Lightning arrester ③ High-voltage fused switch ④ Grounding bus ⑤ Transformer ⑥ Taps ⑦ Load-side terminals ⑧ Secondary bus ⑨ Neutral connections

FIGURE 2-7 Unit substation.

The following steps are then completed in the order given: (1) The cable conductors are connected to the terminals at the end of the porcelain insulators; (2) the lead cable is wiped (soldered) to the wiping sleeve; and (3) the pothead is filled with a protective and insulating compound (usually made from an asphalt or resin base). The pothead installation is now ready for the external connections. Several precautions should be observed when the pothead is filled with the selected compound. First, the correct compound is heated to a specified temperature (usually between 250°F and 450°F). The pothead is then filled according to the manufacturer's instructions. Extreme care must be taken to ensure that voids do not occur within the pothead where moisture can accumulate.

Lightning Arresters

Lightning arresters, Figure 2-9, are installed on buildings in areas where lightning storms are common. These devices are designed to provide a *low-impedance* path to ground for any surge currents such as those resulting from a lightning strike. Surge arresters installed in accordance with the requirements of *NEC Article 280* shall be installed on each ungrounded overhead service conductor. See *230.209*. The internal components of the arrester vary according to the type of arrester and the specific application. The electrician must ensure that a good ground connection is made to the arrester.

TIP: If the transformer section of the unit substation is to be given a megohmmeter test, the line connection to the arrester must be disconnected during the test to prevent a false ground reading. ●

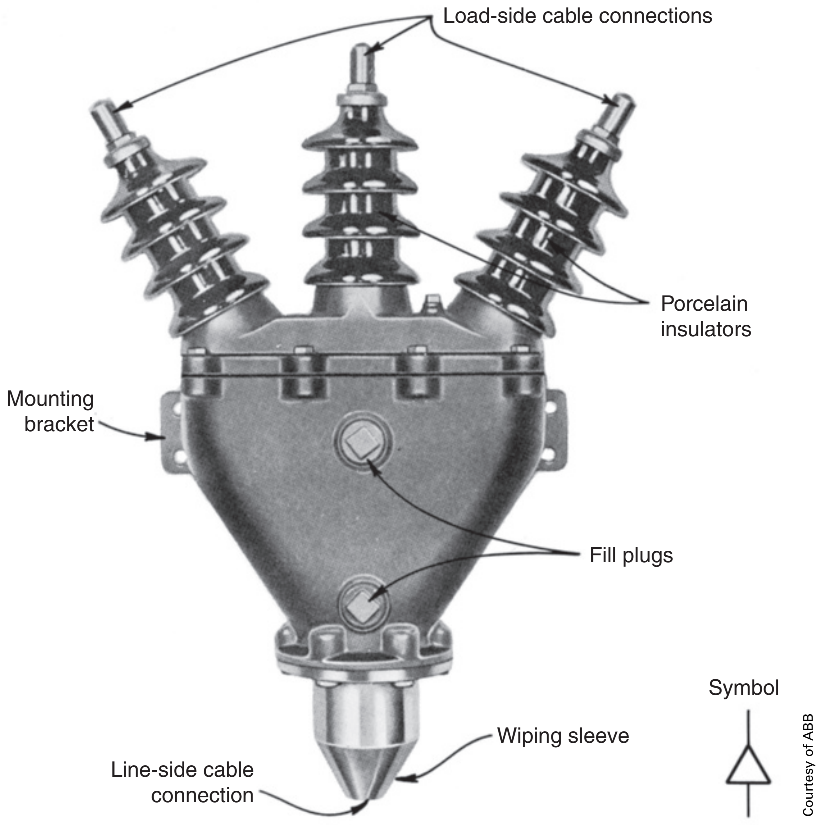


FIGURE 2-8 Pothead.

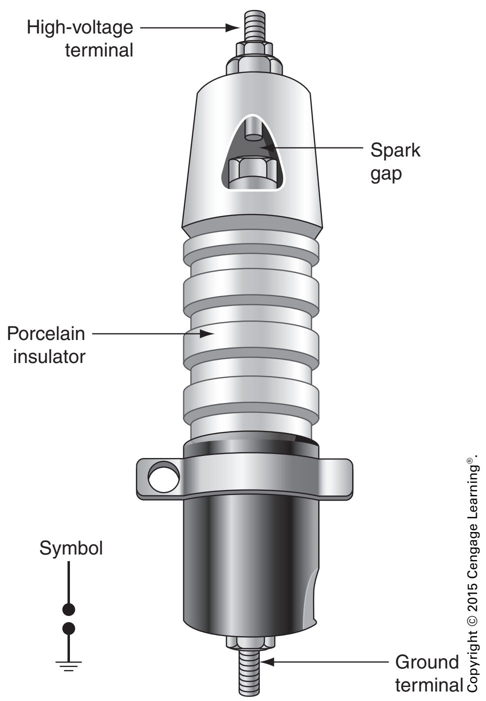


FIGURE 2-9 Lightning arrester.

High-Voltage, Current-Limiting Fuses

High-voltage, current-limiting fuses are installed as protective devices in power distribution systems such as the one installed in the industrial building. The selection of the proper fuse is based on several factors, including the continuous current rating, voltage rating, frequency rating, interrupt rating, and coordination. The fuse selected for a particular installation must meet the predetermined voltage and frequency requirements listed. Fuses are available for both 25- and 60-hertz systems and for voltage ratings of 2400 volts and up, Figure 2-10.

Continuous Current Rating

High-voltage fuses are available with either an N or an E rating. These ratings indicate that certain standards established by the Institute of Electrical and Electronic Engineers, Inc. (IEEE) and National

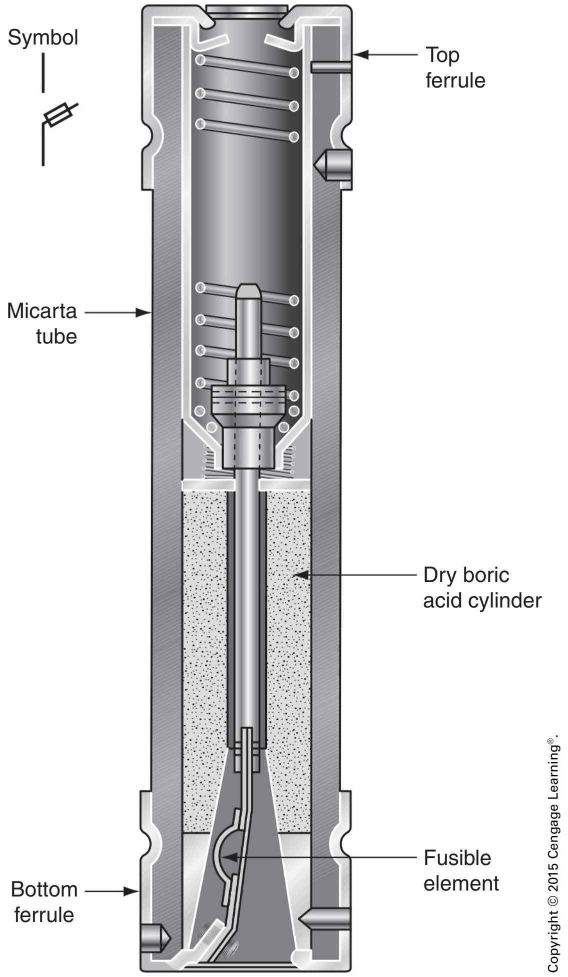


FIGURE 2-10 Cutaway view of high-voltage fuse.

Electrical Manufacturers Association (NEMA) have been met. The N rating represents an older set of standards and indicates that a cable-type fuse link will open in less than 300 seconds at a load of 220% of its rated current.

An E-type fuse rated at 100 amperes or less will open in 300 seconds at a current of 200% to 240% of its rating. Above 100 amperes, an E-rated fuse will open in 600 seconds at a current of 220 to 264% of its rated current. The electrician should note, however, that an E-rated fuse does not provide protection in the range of one to two times the continuous load current rating.

The selection of the fuse with the correct continuous current rating to provide transformer protection is based on the following recommendations:

- select a fuse with the lowest rating that has a minimum melting time of 0.1 second at 12 times the continuous current rating of the transformer;
- select a fuse with a continuous current rating of 1.6 times the continuous current rating of the transformer;
- select a fuse that complies with *NEC Article 450*.

TRANSFORMER PROTECTION

In general, fuses are selected for high-voltage protection because they are less expensive than other types of protection, are extremely reliable, and do not require as much maintenance as do circuit breakers. The protection will be further enhanced if the protective device has the proper interrupt rating.

The minimum interrupt rating permitted for a fuse in a specific installation is the maximum symmetrical fault current available at the fuse location. Power companies will provide the information when requested and will recommend a fuse rating in excess of this value.

OVERCURRENT PROTECTION

Interrupt Rating

As stated earlier, the maximum rating of overcurrent devices for transformers rated at 1000 volts or higher is set forth in *NEC Table 450.3(A)*. To use this table, the *percent impedance* (%Z) of the transformer must be known. This value is stamped on the nameplate of transformers rated 25 kVA and larger. See *450.11*. The actual impedance of a transformer is determined by its physical construction, such as the gauge of the wire in the winding, the number of turns, the type of core material, and the magnetic efficiency of the core construction. Percent impedance is an empirical value that can be used to predict transformer performance. It is common practice to use the symbol %Z to represent the percent impedance. Percentages must be converted to a decimal form before they can be used in a mathematical formula.

When this conversion has been made, the symbol •Z will be used to represent the decimal impedance, that is, the percent impedance in decimal form. The percent value is converted to a numerical value by moving the decimal point two places to the left; thus, 5.75% becomes 0.0575. This value has no units, as it represents a ratio.

When working with any transformer, it is important to keep in mind the full meaning of the terms *primary* and *secondary* and *high-voltage* and *low-voltage*. The primary is the winding that is connected to a voltage source; the secondary is the winding that is connected to an electrical load. The source may be connected to either the low-voltage or the high-voltage terminals of the transformer. If a person inadvertently connects a high-voltage source to the low-voltage terminals, the transformer would increase the voltage by the ratio of the turns. A 600-volt to 200-volt transformer would become a 600-volt to 1800-volt transformer if the connections were reversed. This would not only create a very dangerous situation but could also result in permanent damage to the transformer because of excessive current flow in the winding. Always be careful when working with transformers, and never touch a terminal unless the power source has been disconnected.

The percent impedance is measured by connecting an ammeter across the low-voltage terminals and a variable voltage source across the high-voltage terminals. This arrangement is shown in Figure 2-11. The connection of the ammeter is short-circuiting the secondary of the transformer. An ammeter should be chosen that has a scale with about twice the range of the value to be measured so that the reading will be taken in the middle of the range. If the current to be measured is expected to be about 30 amperes, a meter with a 0- to 60-ampere range would be ideal. Using a meter with a range under 40 amperes or over 100 amperes may not permit an accurate reading.

After the connections have been made, the voltage is increased until the ammeter indicates the rated full-load current of the secondary (low-voltage winding). The value of the source voltage is then used to calculate the decimal impedance (•Z). The •Z is found by determining the ratio of the source voltage as compared to the rated voltage of the high-voltage winding.

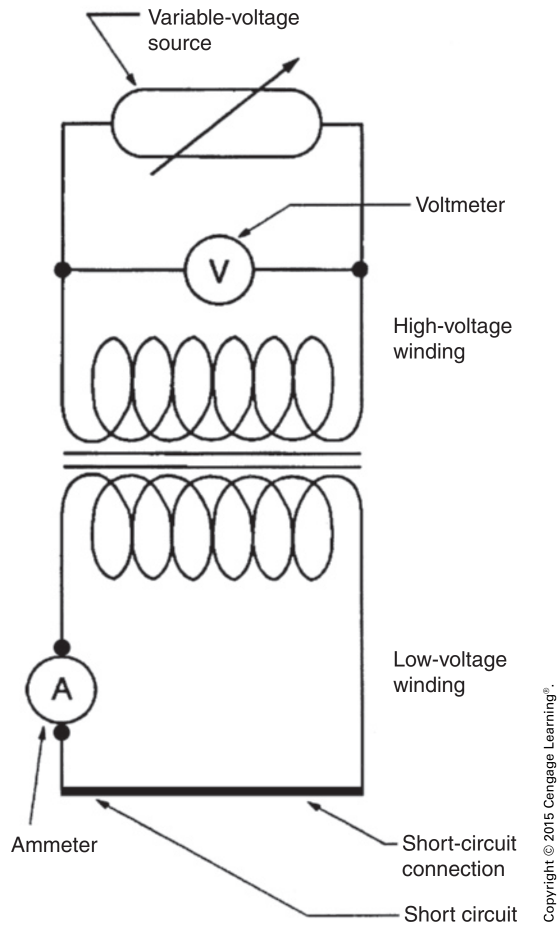


FIGURE 2-11 Determining transformer impedance.

EXAMPLE

Assume that the transformer shown in Figure 2-11 is a 2400/480-volt, 15 kVA transformer. To determine the impedance of the transformer, first calculate the full-load current rating of the secondary winding. Given the transformer rating in VA, and the secondary voltage E, the secondary current I can be calculated:

$$I = \frac{VA}{E} = \frac{15{,}000}{480} = 31.25\,\text{amperes}$$

Next, increase the source voltage connected to the high-voltage winding until there is a current of 31.25 amperes in the low-voltage winding. For the purpose of this example, assume that voltage value to be 138 volts. Finally, determine the ratio of source voltage as compared to the rated voltage.

$$\bullet Z = \frac{\text{Source voltage}}{\text{Rated voltage}}$$
$$= \frac{138}{2400} = 0.0575$$

To change the decimal value to %Z, move the decimal point two places to the right and add a % sign. This is the same as multiplying the decimal value by 100.

$$\%Z = 5.75\%$$

Transformer impedance is a major factor in determining the amount of voltage drop a transformer will exhibit between no load and full load and in determining the current in a short-circuit condition. When the transformer impedance is known, it is possible to calculate the maximum possible short-circuit current. This would be a worst-case scenario, and the available short-circuit current would decrease as the length of the connecting wires increases the impedance. The following formulas can be used to calculate the short-circuit current value when the transformer impedance is known.

$$\text{(Single-phase) } I_{SC} = \frac{VA}{E \times \bullet Z}$$

$$\text{(3-phase) } I_{SC} = \frac{VA}{E \times \sqrt{3} \times \bullet Z}$$

The equation $I = VA/\bullet Z$ is read "amperes equals volt-amperes divided by the decimal impedance." This equation is not an application of Ohm's law because decimal impedance is not measured in ohms. The purpose of the equation is to determine the current in a circuit when the transformer capacity (volt-amperes) and the percent impedance are given.

The equation for calculating the rated current for a single-phase transformer is

$$I = \frac{VA}{E}$$

The equation for calculating the rated current for a 3-phase transformer is

$$I = \frac{VA}{E \times \sqrt{3}}$$

The short-circuit current can be determined by dividing the rated secondary current by the decimal impedance of the transformer:

$$I_{SC} = \frac{I_{SECONDARY}}{\bullet Z}$$

The short-circuit current for the transformer in the previous example would be

$$I_{SC} = \frac{31.25}{0.0575}$$
$$= 543.5 \text{ amperes}$$

DETERMINING TRANSFORMER FUSE SIZE

The transformer impedance value is also used to determine the fuse size for the primary and secondary windings. It will be assumed that the transformer shown in Figure 2-11 is a step-down transformer and the 2400-volt winding is used as the primary and the 480-volt winding is used as the secondary. *NEC Table 450.3(A)* indicates that the fuse size for a primary over 1000 volts and having an impedance of 6% or less is 300% of the rated current. The rated current for the primary winding in this example is

$$I = \frac{15{,}000}{2400}$$
$$= 6.25 \text{ amperes}$$

The fuse size will be

$$6.25 \times 3.00 = 18.75 \text{ amperes}$$

NEC Table 450.3(A) Note 1 permits the next higher fuse rating to be used if the calculated value does not correspond to one of the standard fuse sizes listed in *240.6*. The next higher standard fuse size is 20 amperes.

NEC Table 450.3(A) indicates that if the secondary voltage is 1000 volts or less, the fuse size will be set at 125% of the rated secondary current. In this example, the fuse size will be

$$31.25 \times 1.25 = 39.06 \text{ amperes}$$

A 40-ampere fuse will be used as the secondary short-circuit protective device, Figure 2-12.

Transformers Rated 1000 Volts or Less

Fuse protection for transformers rated 1000 volts or less is stipulated by *450.3(B)*. If the rated primary current is less than 9 amperes, the overcurrent protective device can be set at **not more than** 167% of this value. If the primary current is less than 2 amperes, the short-circuit protective device can be set at **not more than** 300% of this value.

Notice that if the primary current is 9 amperes or more, it is permissible to increase the fuse size to the next highest standard rating. If the primary current is less than 9 amperes, the next lowest fuse size must be used.

NEC 450.3(B) addresses only transformers that have short-circuit protection in both the primary and secondary windings. If the secondary winding is protected with an overcurrent protective device that is not rated more than 125% of the rated secondary current, the primary winding does not have to be provided with separate overcurrent protection if the feeder it is connected to is protected with an overcurrent protective device that is not rated more than than 250% of the primary current.

EXAMPLE

Assume that a transformer is rated 480/120 volts, and the secondary winding is protected with a fuse that is not greater than 125% of its rated current. Now assume that the rated primary current of this transformer is 8 amperes. If the feeder supplying the primary of the transformer is protected with an overcurrent protective device rated at 20 amperes or less ($8 \times 2.50 = 20$), the primary of the transformer does not require separate overcurrent protection, Figure 2-13. The *Code* further states in *450.3(B)* that if the transformer is rated at 1000 volts or less and has been provided with a thermal overload device in the primary winding by the manufacturer, no further primary protection is required if the feeder overcurrent protective device is not greater than six times the primary current for a transformer with a rated impedance of not more than 6%, and not more than four times the primary rated current for a transformer with a rated impedance greater than 6% but not more than 10%.

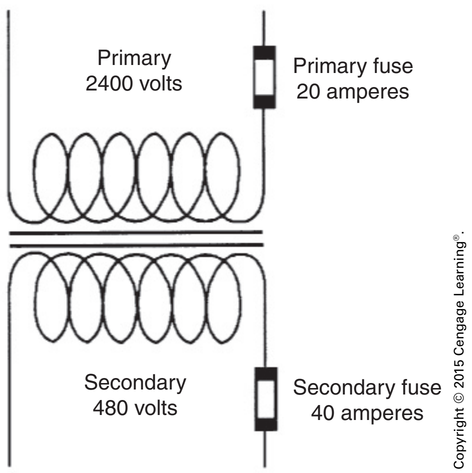


FIGURE 2-12 Transformer fusing.

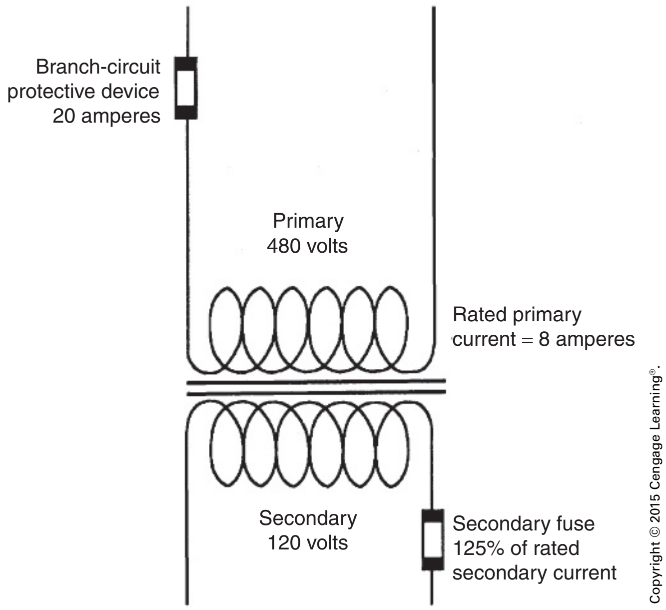


FIGURE 2-13 Transformer overcurrent protection.

EXAMPLE

Assume that a transformer has a primary winding rated at 240 volts and is provided with a thermal overload device by the manufacturer. Also assume that the primary has a rated current of 3 amperes and an impedance of 4%. To determine whether separate overcurrent protection is needed for the primary, multiply the rated primary current [*NEC Table 450.3(B), Note 3*] by 6 ($3 \times 6 = 18$ amperes). If the branch-circuit protective device supplying power to the transformer primary has an overcurrent protective device rated at 18 amperes or less, no additional protection is required. If the branch-circuit overcurrent protective device is calculated greater than 18 amperes, a separate overcurrent protective device for the primary is required.

If separate overcurrent protection is required, it is calculated at 167% of the primary current rating because the primary current is less than 9 amperes but greater than 2 amperes. In this example, the primary overcurrent protective device should be rated at

$$3 \times 1.67 = 5.01\,\text{amperes}$$

A 5-ampere fuse would be used to provide primary overcurrent protection.

Coordination

Coordination is the process of selecting protective devices so that there is a minimum of power interruption in case of a fault or overload. In other words, for a particular situation, a value of high-voltage fuse should be selected that ensures that other protective devices between it and the loads can react to a given condition in less time.

Coordination studies require that the time-current characteristic of the different protective devices be compared and that the selection of the proper devices be made accordingly. Problems in the coordination of high-voltage fusing occur most frequently when

1. circuit breakers are used as secondary protective devices, and
2. a single main protective device is installed on the secondary side of the transformer.

THE TRANSFORMER SECTION

There is little difference between the transformer in a unit substation and any other power transformer (see the connection diagram in Figure 2-14). However, the topic of transformer taps should be explained in some detail.

Taps

Although voltage systems are generally classified by a voltage value, such as a 2300-volt or a 4160-volt system, this exact value is rarely the voltage provided at the transformer. To compensate for this probable voltage difference, taps are built into the transformer, Figure 2-15. These taps are usually provided at 2½% increments above and below the standard rated voltage. For example, taps on a 4160/480-volt transformer may provide for voltages of 3952, 4056, 4160, 4264, and 4368 volts. Connections at the proper voltage levels will provide the desired 480 volts on the secondary.

THE LOW-VOLTAGE SECTION

After the incoming voltage is reduced to the desired value, it is taken by busbars into the low-voltage section. Here, protective devices are installed to distribute the voltage throughout the area to be served. Numerous variations in the arrangements of these devices are possible depending upon the needs of the installation. A main device can be installed to interrupt the total power, or any combination of main and feeder devices can be used.

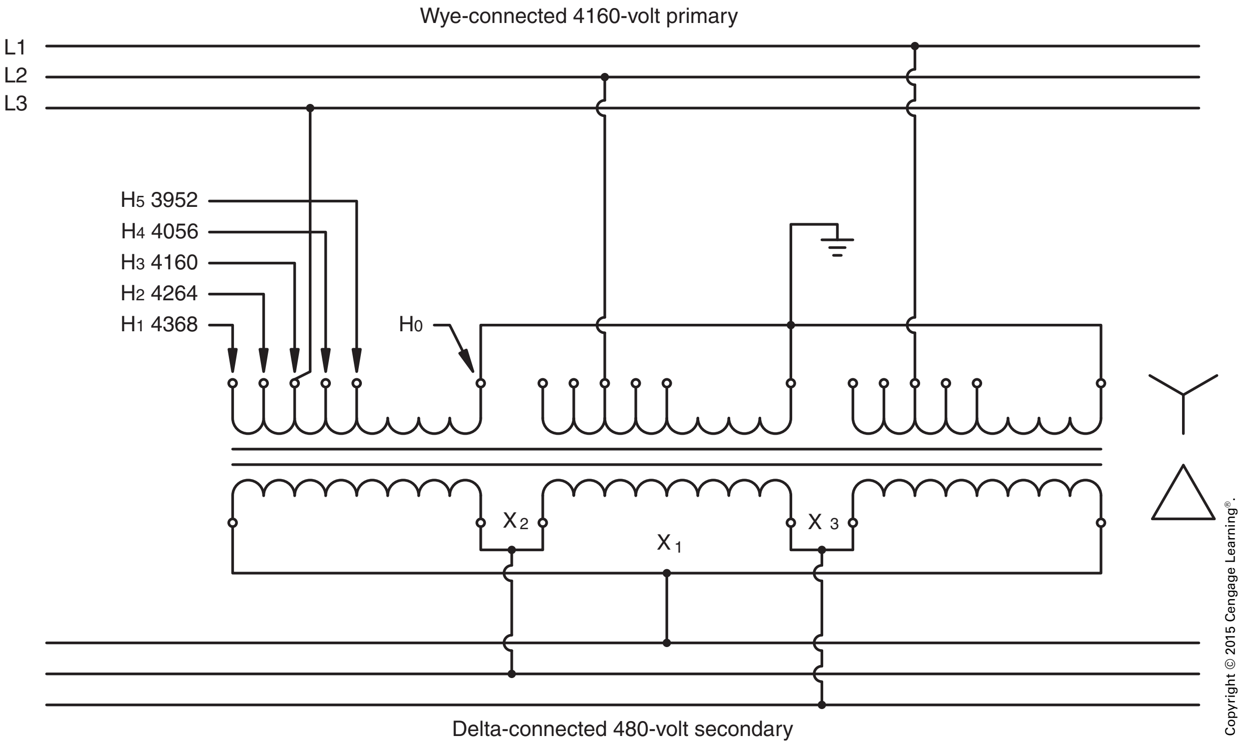


FIGURE 2-14 Three-phase power transformer with a wye-connected primary and delta-connected secondary.

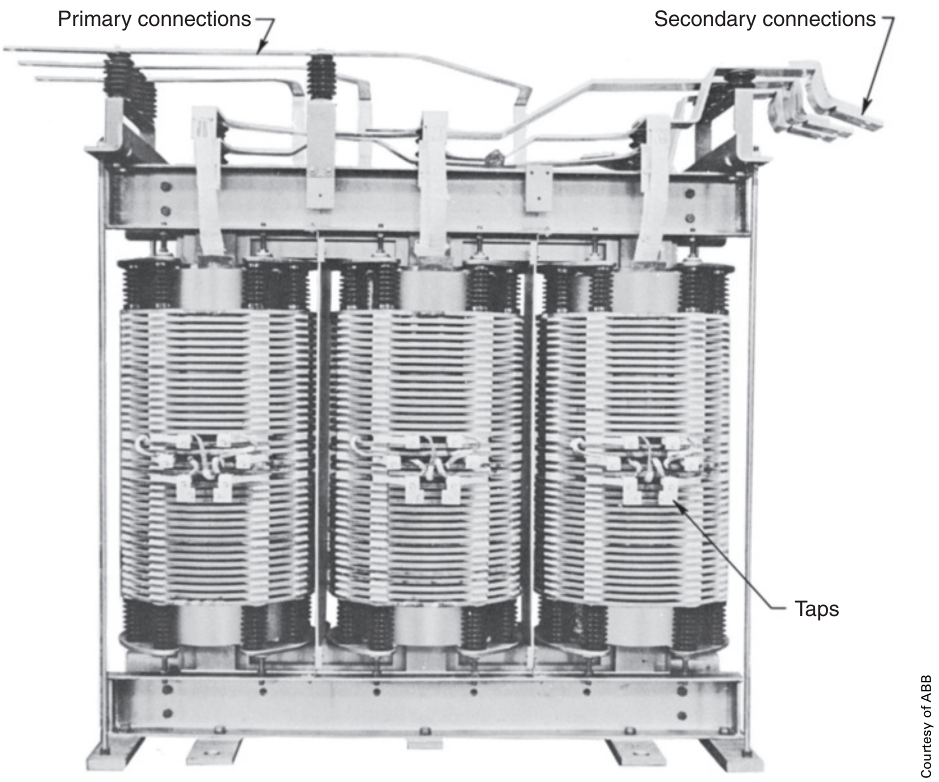


FIGURE 2-15 Taps built into a transformer.

Grounding

The majority of the connections to ground are made in the low-voltage section. However, the electrician should be aware that a grounding bus usually runs the entire length of the unit substation. This bus provides the means for a positive ground connection between the compartments, as well as a convenient place to make other ground connections. Two types of grounding connections are of special interest. The system grounding connection is used to connect a phase or the neutral of the transformer secondary to ground. This grounding electrode conductor is sized according to *NEC 250.66* and *Table 250.66*.

The second grounding connection of special interest is the connection of all the incoming metal raceways to the grounding system. There are no problems in grounding when the raceways enter the substation through the metal structure. However, when a raceway enters through the base of the unit, a grounding connection must be installed between the conduit and the grounding system. This conductor is sized according to *NEC 250.122* and *Table 250.122*.

Ground Detectors

A careful inspection of Figure 2-14 reveals that there are two grounding connections, one on the center tap of the 3-phase wye, high-voltage connection and another to X2 on the 3-phase delta secondary. The decision as to whether the high side is to be grounded is made by the utility company. The general rule, however, is to ground the wye system as shown in this figure. The grounding of the secondary system is optional when the system is a 480-volt delta-connected type, according to *250.26(4)*. If the phase is grounded, then special attention should be given to *240.22*. This section says that if fuses are used for overcurrent protection, they should be installed only in the ungrounded conductors.

An alternative to grounding the secondary is to let it *float*; that is, the secondary remains ungrounded. If this design is selected, ground detectors should be installed, Figure 2-16, to detect any unintentional system grounding. See *250.21(B)*. It should be noted that if a conductor makes contact with ground at any point, the entire system is grounded. However, such a ground may not be an effective ground connection, and serious equipment damage may result when a second ground connection occurs on another phase.

The ground detector system in Figure 2-16 consists of three lamps connected as shown. The lamps used have the same voltage ratings as for the line-to-line voltage. The lamps light dimly when there are no grounded conductors. If any phase becomes grounded, however, the lamp connected to that phase dims even more or goes out entirely, whereas the other two lamps become brighter. Thus, a quick visual check by maintenance personnel can determine whether a ground has developed. Ground detectors are shown on the riser diagram on Sheet E-1 of the plans for the industrial building.

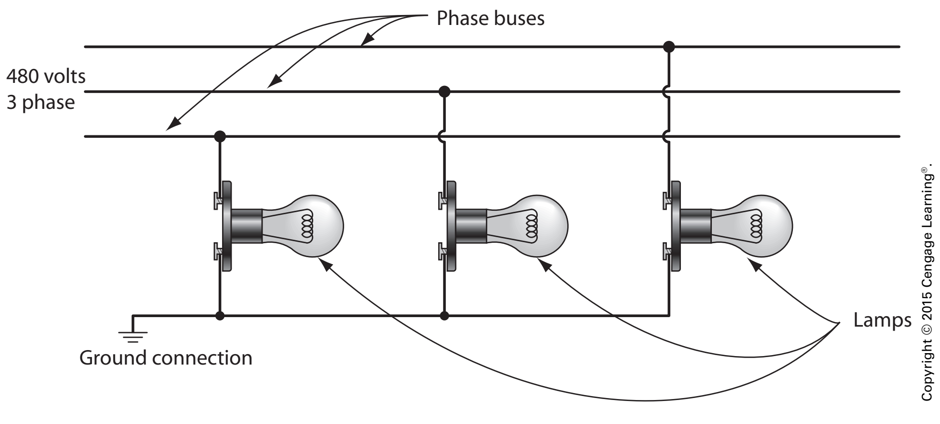


FIGURE 2-16 Ground detectors for ungrounded systems.

THE HIGH-VOLTAGE METERING EQUIPMENT

The specifications for the industrial building indicate that to provide for energy use measurements, two ¾-inch conduits must be run from the high-voltage section of the unit substation to a cabinet located in a caged section of the loading platform behind the unit substation, Figure 2-17. Current and potential transformers located in the high-voltage section (4160 volts) are an integral part of the substation as assembled at the factory. (The ratio of the potential transformers is 40:1, and the ratio of the current transformers is 400:1.) The metering cabinet is provided with meter test blocks and an instrument autotransformer.

A double 3-phase meter socket trough must be installed above the metering cabinet. This socket trough is connected to the cabinet with conduit nipples. Connections between the current and potential transformers in the high-voltage section of the unit substation and the autotransformer and meter sockets in the cabinet are made with size 12 American Wire Gauge (AWG) wire. The autotransformer is designed to provide voltage components of the proper magnitude and at the correct phase angles to the potential coils of the reactive meter (to be described shortly). These voltage components are 90° out of phase with the line voltage. The left-hand meter socket is wired to receive a standard socket-type watt-hour meter that measures active kilowatt hours. The right-hand meter socket will receive a reactive var-hour (volt-amperes-reactive) meter, Figure 2-18. This second meter measures reactive kilovar-hours.

The two meters are provided with 15-minute demand attachments. The local power company furnishes these meters, which are installed by power

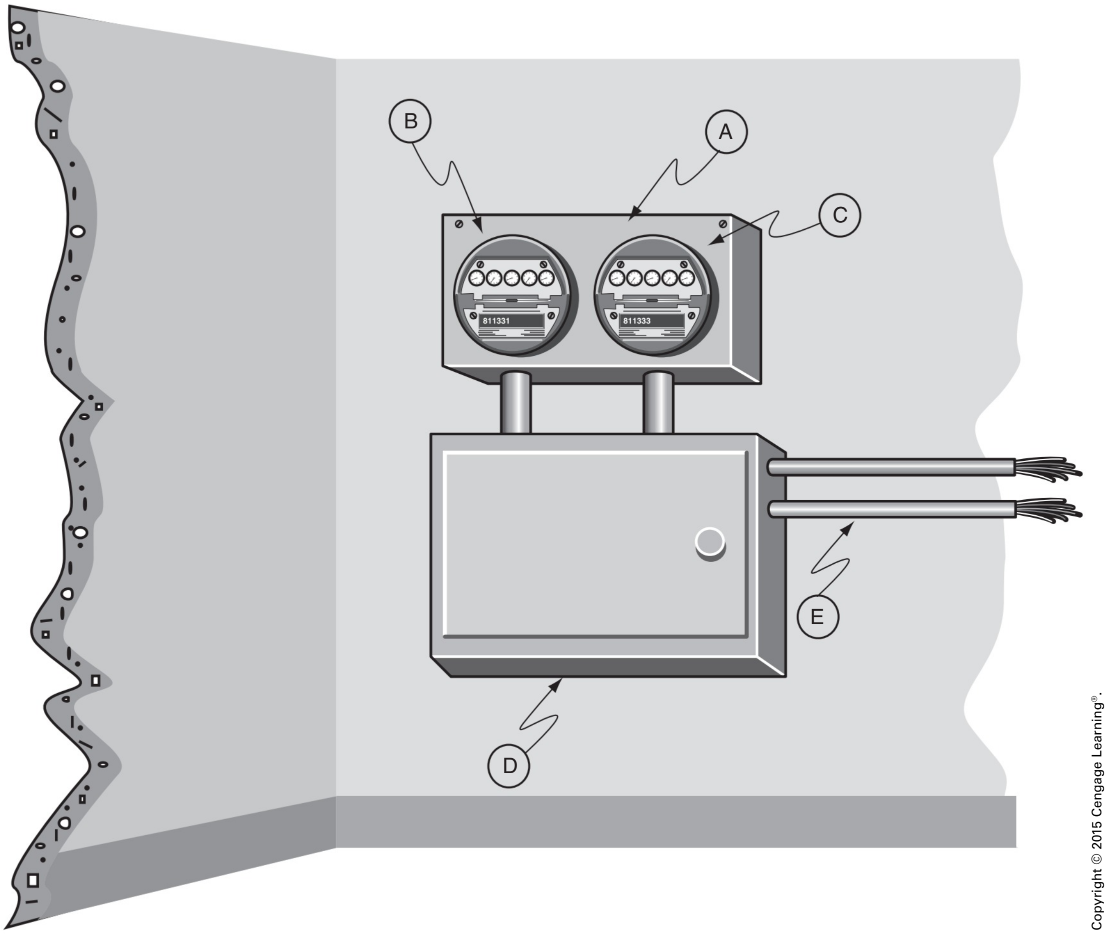


FIGURE 2-17 Meter installation in a caged section of an alcove at the end of the loading platform.

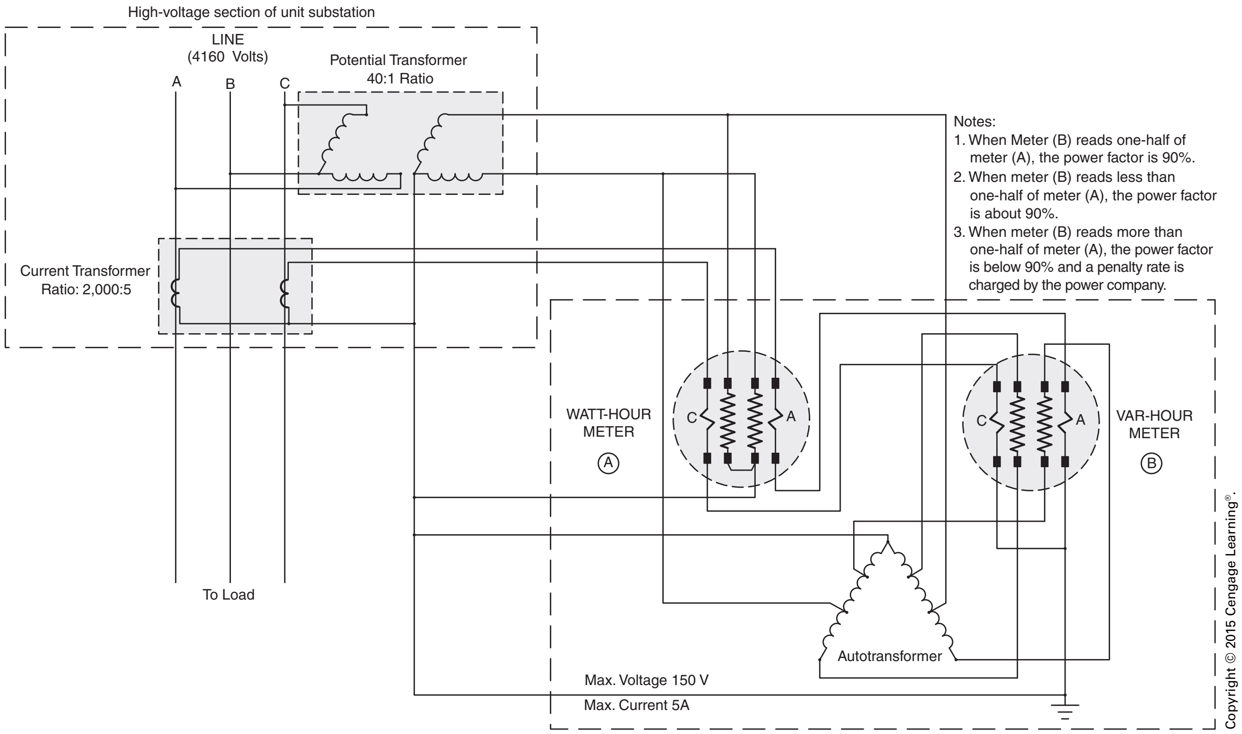


FIGURE 2-18 Connections for high-voltage metering of watt-hours and var-hours.

company personnel. The meters each have two elements and maximum ratings of 150 volts and 5 amperes. The two demand attachments (not shown) register the demand in kilowatts and kilovars for the respective meters if the demand is sustained for a period of more than 15 minutes at any one time.

Industrial Power Rates

The rates charged by the power company for the energy used are based on the readings of the meter registers and the maximum demand indicators. Some power companies charge a penalty if the power factor falls below a certain level, as indicated in the example shown in Figure 2-18, Note 3. Assume that the reactive meter reading is one-half the kilowatt-hour reading. Thus, the tangent of the phase angle is $5/10$, or 0.5, and the cosine of the phase angle is 0.9. As a result, no penalty is imposed by the power company because the power factor is 90%.

Preferential rates are given when the power transformer is owned by the customer. Further rate reductions are made when the metering measurements are taken on the high-voltage side of the transformer. Both of these conditions for preferential rates are present in the industrial installation being considered in this text.

If the power factor is unity (1.00), it is evident that the reactive meter (var-hour meter) indicating disk is stationary. However, if the power factor falls below unity, then the var-hour meter disk will rotate in one direction for a lagging current and in the opposite direction for a leading current.

In the industrial building, two 350-kVAR synchronous condensers furnish leading current as desired to raise and correct the power factor. (Synchronous condensers are described in Chapter 10.) Simple adjustments of these machines minimize the kVAR-hours, as registered on the reactive meter.

SERVICE ENTRANCES

Page E1 of the plans indicates that the incoming power for this installation is a wye-delta 3-phase transformer rated at 1500 kVA. The transformer primary is protected by 300 A fuses. The drawing is a one-line diagram that shows the feeder busways and power supplies throughout the building. One-line diagrams are a very common method used for this application. The unit substation is drawn as shown in Figure 2-19.

A wiring diagram of this installation would show a 3-phase fused disconnect, a 3-phase transformer bank, a 1000 A circuit breaker with disconnect that protects feeder busway 1, and a 1600 A circuit breaker with disconnect that protects feeder busway 2, Figure 2-20.

Most 3-phase transformer connections have a delta connection as either the primary or secondary. The delta connection stabilizes the voltage in the event of an unbalanced condition. A schematic diagram of the unit substation connection is shown in Figure 2-21.

This connection is often referred to as a floating delta connection because it is not grounded. Although floating delta connections are common, they can experience some unpredictable voltage transients relative to ground. These transients can cause insulation failure and other concerns.

Installations that do not require a large kVA capacity are generally supplied by pole-mounted, single-phase transformers that are connected to form a 3-phase bank, Figure 2-22.

Connections of this type have an advantage in that if one transformer fails, only one transformer has to be replaced. Installations that require a large amount of power are generally supplied by a pad-mounted, 3-phase transformer, Figure 2-23.

Three-phase transformers have an advantage in that they are more efficient than a 3-phase bank composed of single-phase transformers. A 3-phase transformer contains three separate transformers that share the same core material, which improves the magnetic coupling among the transformers. Common output voltages for a delta-connected secondary are 240 volts and 480 volts. Some installations may use a voltage of 560 volts, but they not as common as the 240- or 480-volt connections.

Although the wye-delta transformer connection used in this installation is very common in industry, it is not the only connection employed for industrial and commercial applications.

Grounded Delta Connection

Another common industrial connection is the grounded delta connection. This connection is referred to as the B phase ground system because the B phase of the delta secondary is grounded, Figure 2-24.

Grounding one phase of the transformer does reduce problems with transient voltages and makes troubleshooting simpler because there is a true reference to ground. B phase ground systems can be identified by the fact that only two fuses are required

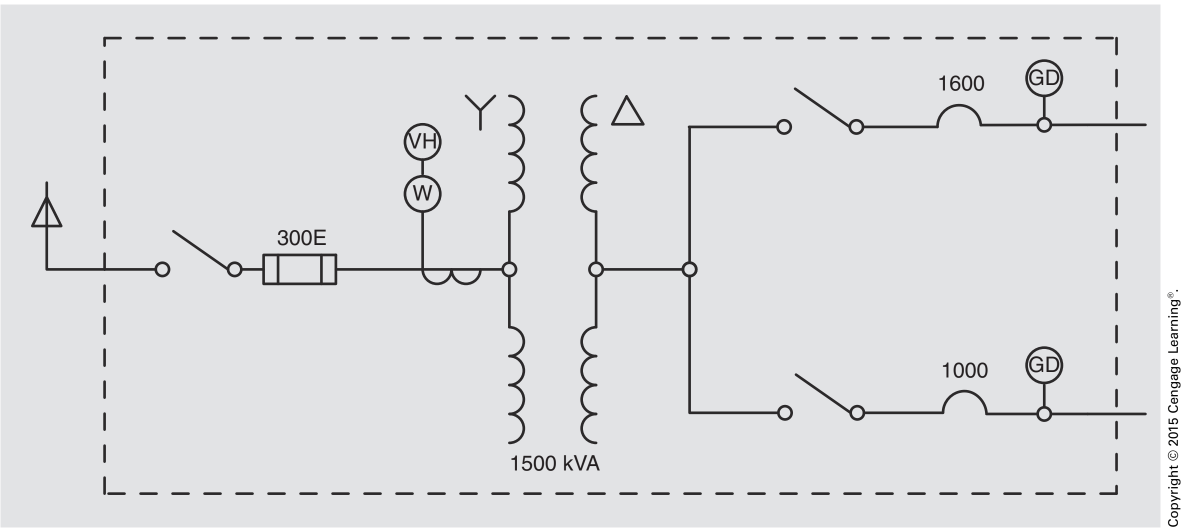


FIGURE 2-19 One-line diagram of the unit substation.

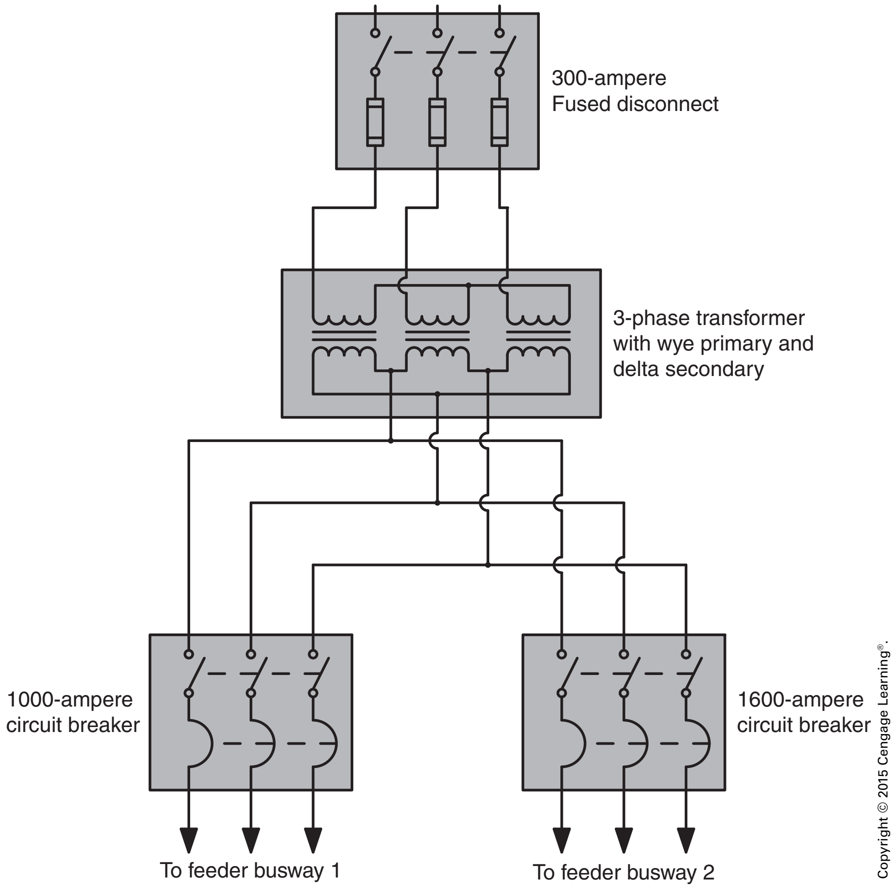


FIGURE 2-20 Schematic diagram of the unit substation.

to protect the circuit. Overcurrent protection is not required for grounded conductors.

Open Delta Connection

Open delta connections are used for installations that do not have a large kVA requirement. The advantage of the open delta connection is that it requires only two transformers to supply 3-phase power, Figure 2-25.

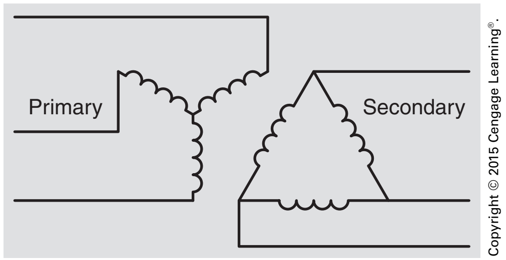


FIGURE 2-21 Schematic drawing of a wye-delta transformer connection.

FIGURE 2-22 Single-phase transformers mounted on a pole and connected to form a 3-phase bank.

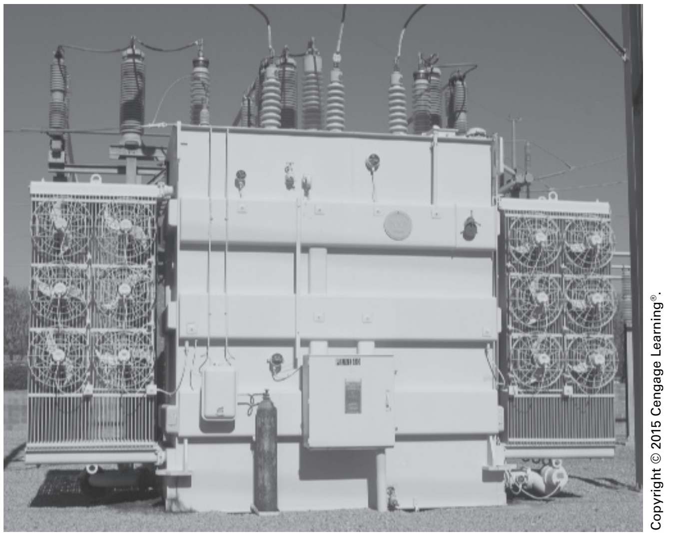


FIGURE 2-23 Three-phase, pad mounted transformer.

Although only two transformers are required for the connection, they must have a larger kVA capacity than a closed delta connection with three transformers. For example, if an installation required a total kVA capacity of 600 kVA, the three transformers of a closed delta connection would need a capacity of 200 kVA each (200 kVA $\times$ 3 = 600 kVA). An open delta connection can supply only 86.6% of the total capacity of the two transformers. Therefore, the total kVA capacity of the two transformers would need to be 692.8 kVA (600 kVA/0.866 = 692.8 kVA). Each transformer would need a minimum kVA capacity of 346.4 kVA (692.8 kVA/2 = 346.4 kVA). As with closed delta connections, common output voltages for the open delta connection are 240 and 480 volts.

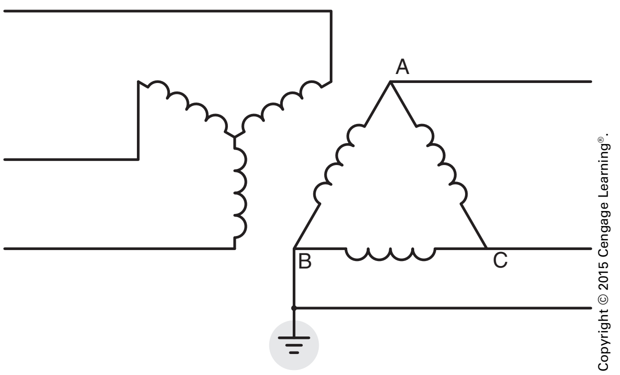


FIGURE 2-24 Delta secondary with B phase grounded.

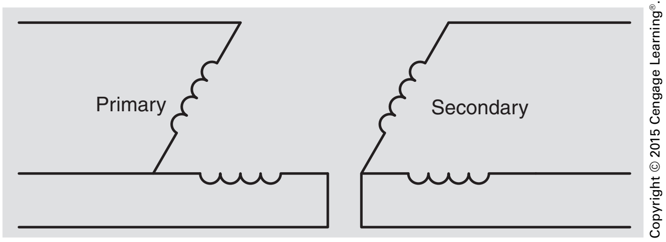


FIGURE 2-25 Open delta connections require only two transformers.

Open Delta Connection with Ground

Open delta connections often ground the center tap of one transformer, Figure 2-26.

This connection is used when the installation requires both single-phase and 3-phase power. The output voltage is generally 240 volts between phases. The center tap of one transformer is grounded to provide a neutral conductor. This connection is referred to as a high-leg connection, because the voltage between the neutral conductor and the phase conductor of the transformer that was not center tapped is 208 volts (120 volts $\times$ 1.732 [square root of 3]). The voltage between the neutral and the phase conductors of the transformer that is center tapped is 120 volts. Because one transformer must supply all the single-phase load and part of the 3-phase load it must have a larger kVA capacity than the transformer that does not supply any of the single-phase load. This connection can be identified by the fact that one transformer will be larger than the other, Figure 2-27.

Assume that a business requires 50 kVA of single-phase load and 30 kVA of 3-phase load. First determine the minimum size transformers that would supply the 3-phase load.

$$30{,}000\,\text{VA}/0.866 = 34{,}642\,\text{VA}$$

$$34{,}642\,\text{VA}/2 = 17{,}321\,\text{VA}$$

Each transformer must have a minimum capacity of 17,321 to supply the needed 3-phase load. One transformer, however, must also supply the entire single-phase load.

$$17{,}321 + 50{,}000 = 67{,}321\,\text{VA}$$

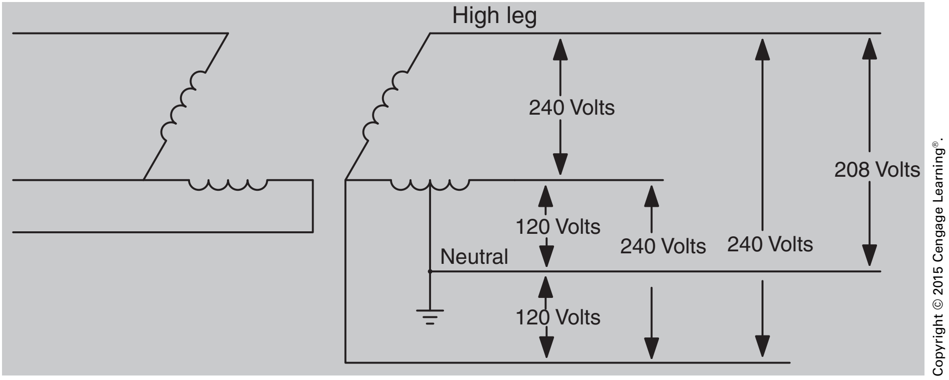


FIGURE 2-26 Open delta connection with ground.

FIGURE 2-27 One transformer is larger than the other.

Delta-Wye Connection

To make this connection, the primary windings are connected in delta, and the secondary windings are connected in wye, Figure 2-28.

The delta-connected primary provides a stable voltage for the wye-connected secondary. The center point of the secondary is often grounded to provide a neutral conductor, Figure 2-29. A very common voltage for this type connection is 208/120 volts. A voltage of 208 volts is provided between any of the phase conductors and a voltage of 120 volts exists between any phase conductor and neutral. The 208/120-volt connection is commonly used for apartment complexes and schools.

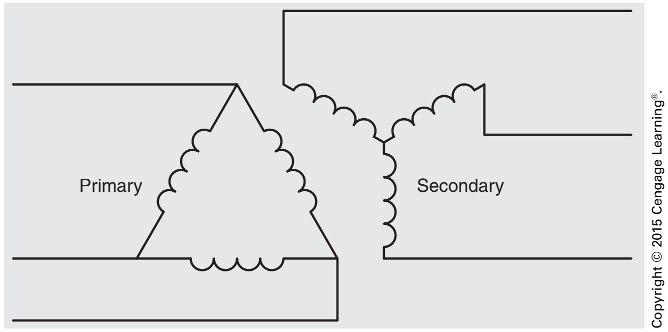


FIGURE 2-28 Delta-wye connection.

Another common voltage for the grounded wye is 480/277. A voltage of 480 volts exists between any two phase conductors, and a voltage of 277 volts exists between any phase conductor and neutral (480/1.732). This connection is common in large department stores and office buildings.

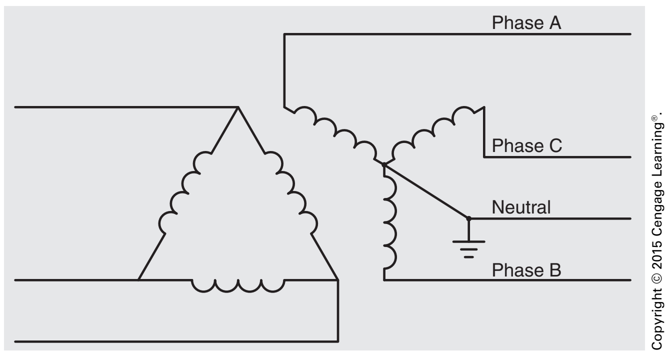


FIGURE 2-29 The mid-point of the secondary is grounded to form a neutral conductor.

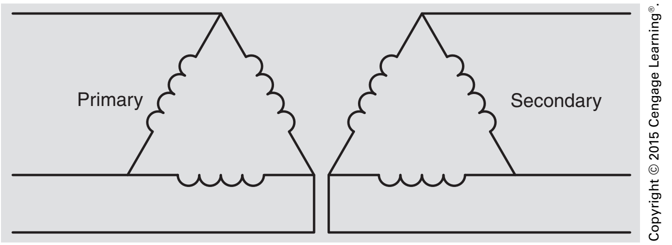


FIGURE 2-30 Delta-delta connection.

Many commercial lighting systems operate on 277 volts. Air conditioning and heating systems are powered by 480 volts.

Delta-Delta Connection

Delta-delta connections are made by connecting both the primary and secondary of the transformers in a delta, Figure 2-30.

The delta-delta connection exhibits the same basic characteristics as the wye-delta connection discussed previously. One of the secondary windings of the delta-delta is often center tapped and grounded to produce a neutral connection. Like the open delta with one transformer having a grounded center tap to supply single-phase loads, this connection will also produce a high leg. The transformer supplying the single-phase load will have a greater kVA capacity that the other two transformers.

EXAMPLE

An installation requires a 3-phase load of 75 kVA and an additional single-phase load of 50 kVA. Two of the transformers would have a minimum rating of 25 kVA (75 kVA/3 = 25 kVA). The third transformer that supplies the single-phase load would have a minimum rating of 75 kVA (25 kVA + 50 kVA = 75 kVA), Figure 2-31.

Wye-Wye Connection

Wye-wye connections, Figure 2-32, are seldom employed because they can exhibit extremely unstable voltages between phases if the line currents should become unbalanced. When a wye-wye

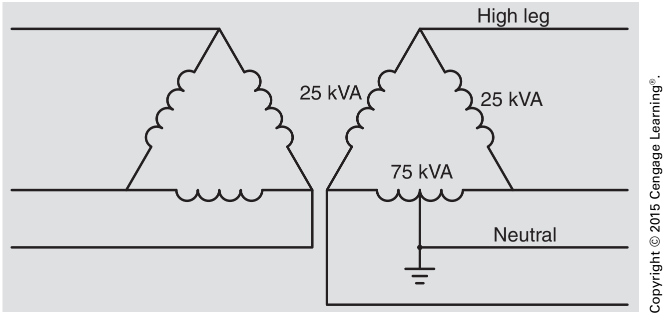


FIGURE 2-31 Delta-delta connection with one transformer secondary center tapped and grounded.

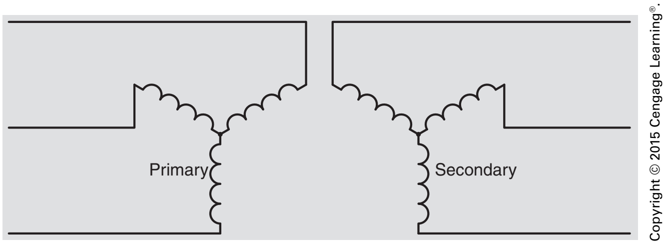


FIGURE 2-32 Wye-wye connection.

connection is used, the utility company generally connects a grounded (neutral) conductor to the center connection of the primary, Figure 2-33.

Grounding the center point of the primary greatly increases the voltage stability of the connection. It is also common practice to connect the center points of both the primary and secondary windings together to help improve voltage stability, Figure 2-34. Doing this, however, does have the disadvantage of losing line isolation between the primary and secondary windings.

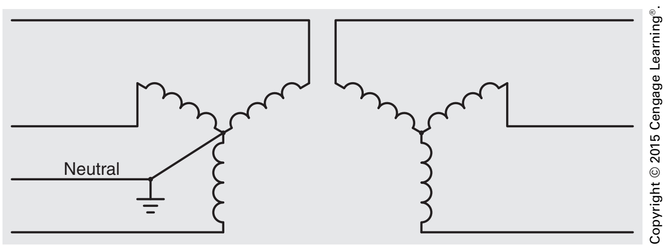


FIGURE 2-33 The utility company connects a grounded conductor to the center point of the primary.

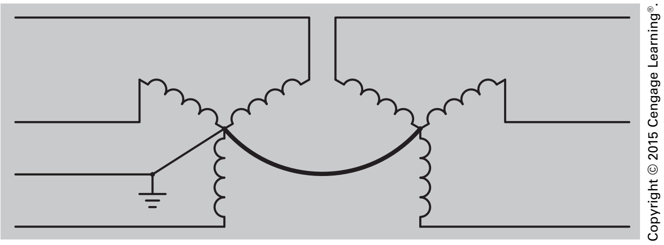


FIGURE 2-34 The center points of both primary and secondary are connected together to help improve voltage stability.

TRANSFORMER MAINTENANCE

Regardless of the type of service-entrance connection, it is generally necessary to perform regular transformer maintenance. Transformers are usually thought of as being stationary objects with no moving parts. Because of this misconception, transformers are often neglected and left out of routine preventive maintenance schedules. This could prove to be a very expensive omission. Transformers must be inspected and maintained on a regular schedule in order to get maximum performance and life from them. This applies to all transformers no matter how large or small they are. Environmental conditions such as changing temperatures caused by varying loads and changing ambient temperature affect the operation and life of the transformer. Dust, moisture, and corrosive chemicals in the air surrounding the transformer greatly affect its operation and life. The type of maintenance procedures and intervals between procedures are governed by the type, size, location, and application of the transformer.

Safety Procedures

As with any electrical equipment, the primary consideration when working on or near transformers must be the safety of personnel. Before working on any transformer, establish whether it is energized and whether the work can be done safely with power on the transformer. Most maintenance procedures require that power be disconnected and locked or tagged out. On larger transformers with high-voltage connections, it is usually advisable to prepare a written switching procedure detailing each step of the process of de-energizing the equipment. By following a written procedure and initialing each step as it is taken, errors in switching can be avoided.

In many larger installations, grounds are placed on each side of the transformer after it is de-energized, to protect the workers. If these grounds are not removed before the transformer is energized, the windings could be severely damaged. A written switching procedure includes the placement and removal of these grounding connections. This helps avoid energizing a transformer with the grounds still in place.

After the power to the transformer has been disconnected and before doing any work, it is advisable to test all exposed connections for voltage. Be sure to use the proper test instrument with a voltage rating at least as high as the voltage rating of the connection. This is especially important when there is more than one source of power, as in a double-ended substation, Figure 2-35.

Double-ended substations permit power to be supplied from another source in the event of equipment failure. Although the circuit kVA capacity is reduced, power can be maintained until the defective equipment is repaired or replaced. This can, however, cause a backfeed to the secondary side of a transformer that has the primary disconnected. Extreme care must be taken when working with double-ended systems to ensure that power is not being applied to either the primary or secondary windings.

Entering a Transformer Tank

In some of the maintenance procedures, it is necessary to enter a transformer tank. When this is part of the maintenance procedure, the atmosphere in the tank must be tested for the presence of combustible and/or toxic gases and also for the presence of sufficient oxygen. Oxygen is normally present in the atmosphere at about 21.2%. If this concentration is less than about 20%, it could be a health threat to the worker. If there are dangerous gases present or if there is insufficient oxygen in the tank, it must be ventilated with fresh air until safe conditions are met. When anyone is inside the tank, there must be a person outside the entrance to observe the worker in the tank and be alert for any problems encountered.

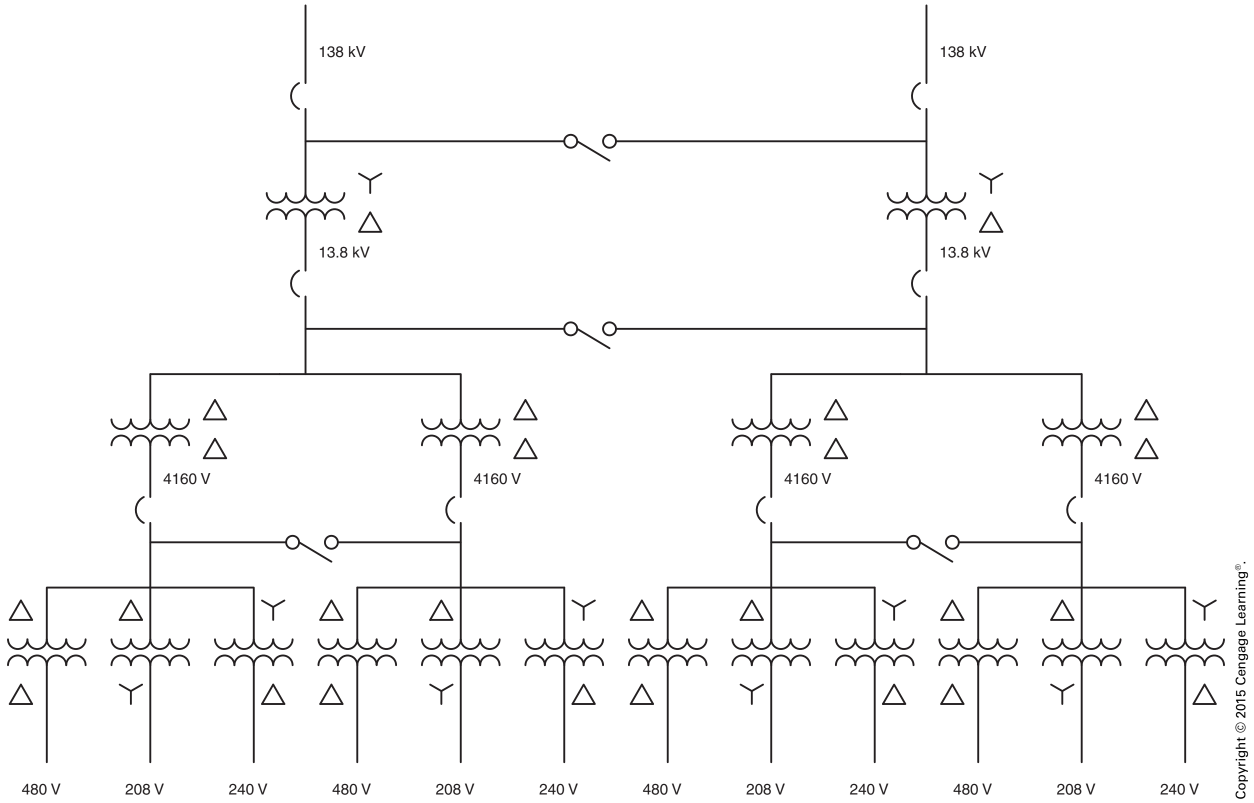


FIGURE 2-35 Double-ended substations.

Preventive Maintenance

The first step in any preventive maintenance procedure is inspection of the equipment. Inspection of the transformer will reveal the presence of rust or corrosion. Dirt or dust buildup or rust and corrosion should be noted at this time.

Cleaning

The outside of the transformer should be cleaned with an approved solvent or cleaner. Rust and corrosion should be removed and the housing painted if necessary.

Tightening

All connections and mounting bolts should be tightened. Any corroded connections should be replaced.

Testing

These small transformers should be tested for short circuits and grounds annually. A megger test between the primary and secondary windings will test the insulation between windings, Figure 2-36. A megger test from each winding to the housing or core will show any insulation weakness in this area, Figure 2-37.

Use a megger with voltage ratings close to the rating of the transformer winding; for example, a 500-volt megger would be used to test the insulation on a transformer with a 480-volt rated winding.

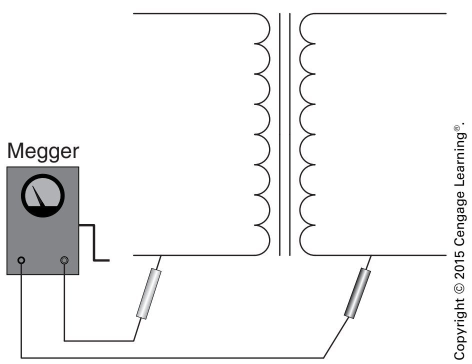


FIGURE 2-36 Testing for shorts between the primary and secondary windings with a megger.

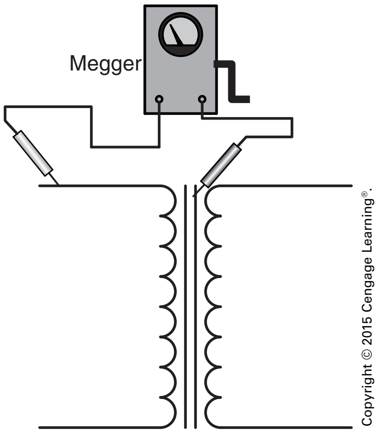


FIGURE 2-37 Testing for grounds.

After testing the windings with a megger, each winding should be tested for continuity with an ohmmeter, Figure 2-38.

This can be accomplished by connecting the ohmmeter leads across the terminals or leads connected to the ends of each winding. This test will determine whether any of the windings are open, but it will probably not determine whether they are shorted. In some instances, the insulation of the wire breaks down and permits the turns to short together. When this occurs, it has the effect of reducing the number of turns for that winding. If these shorted windings do not make contact with the case or core of the transformer, a megger test will not reveal the problem. This type of problem is generally found by connecting the transformer to power and measuring the current and voltage values. Excessive current draw or a large deviation from the rated voltage of a winding is a good indicator of a shorted winding. When making this test, however, be aware that it is not uncommon for the secondary voltage to be higher than the rated value under a no load condition. Voltage ratings are listed for full load, not no load. It would not be uncommon for a transformer winding rated at 24 volts to measure 28 or 30 volts with no load connected.

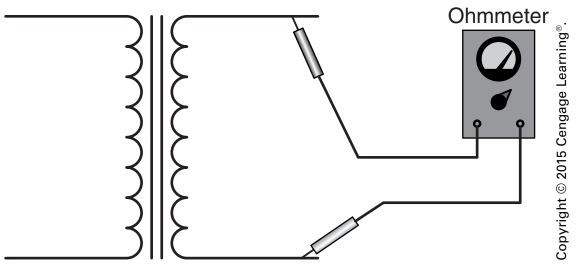


FIGURE 2-38 An ohmmeter is used to test for continuity.

Pad-Mounted Oil-Cooled Transformers

External Inspection The first step in maintaining these transformers is a thorough external inspection. Look for evidence of leaks in the housing or cooling radiators. Inspect the housing for rust, corrosion, or damage, and note the general condition of the paint. Inspect the bushings for cracks or chips. Look for loose, corroded, or discolored connections. Inspect the housing ground connection. Make sure it is tight and free of corrosion. Most pad-mounted transformers are contained in vaults, Figure 2-39. Many are equipped with temperature and pressure gauges to measure the coolant temperature and the pressure inside the transformer.

Cooling Equipment If the transformer utilizes external cooling fins, make sure that they are free of debris and clean, Figure 2-40.

FIGURE 2-39 Pad-mounted transformers are generally contained in vaults.

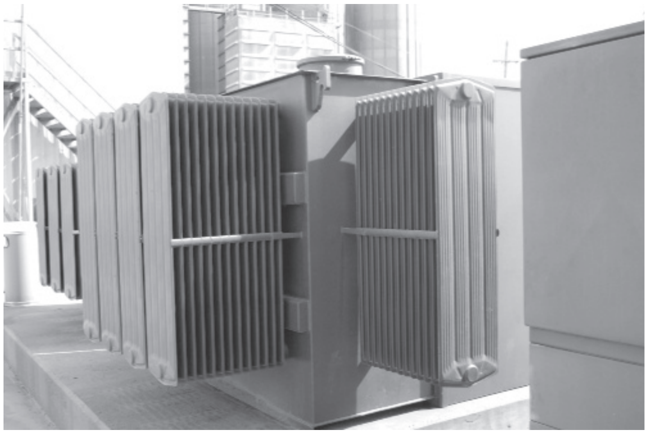


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FIGURE 2-40 Pad-mounted transformer with external cooling fins.

If the transformer is equipped with auxiliary cooling equipment, it should be checked for proper operation. Check radiator connections to the tank for leaks, and make necessary repairs. Automatic cooling fans should be operated manually to be sure they work. Temperature and pressure switches and gauges are removed and calibrated once a year to ensure their proper operation. On transformers with a gas blanket (usually dry nitrogen) over the oil, the gas pressure should be checked at least once a week. These transformers often have external temperature and pressure gauges because the transformer is in a sealed container, Figure 2-41. The pressure regulator and gauges should be removed and calibrated once a year.

Transformer Protective Relaying

Transformers that have a gas blanket on top of the insulating oil have pressure switches that actuate an alarm system if the gas pressure on the blanket drops below a certain point. These switches should be tested frequently along with any temperature or pressure alarm devices on the transformer windings or tank. Protective relaying usually includes

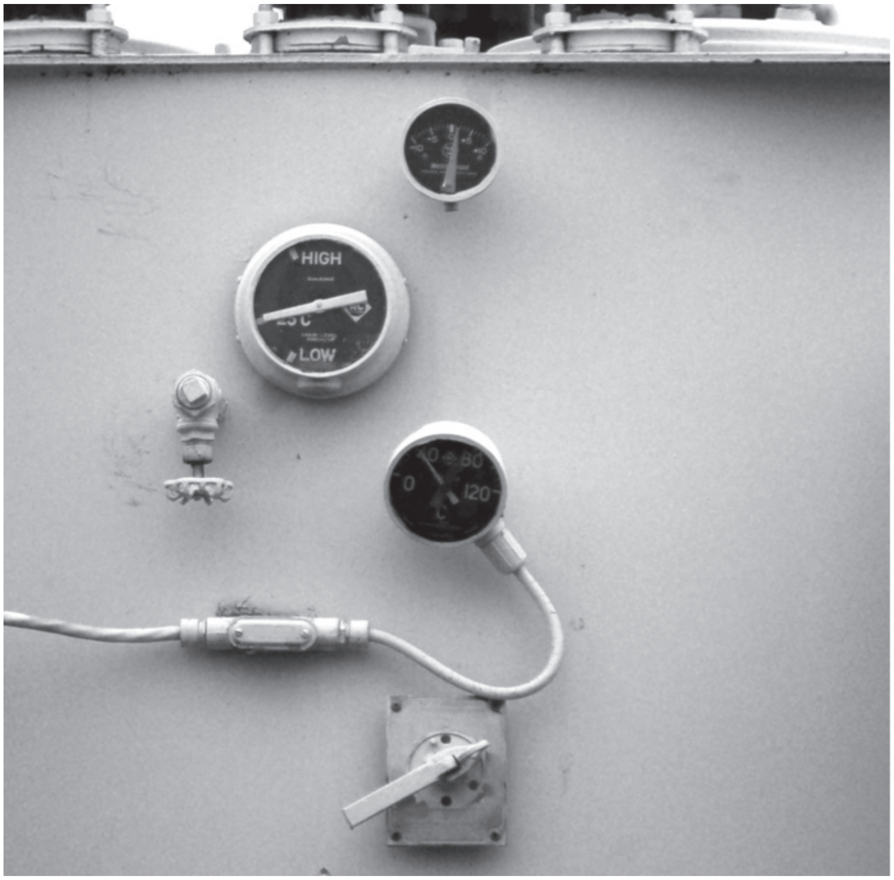

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FIGURE 2-41 Large pad-mounted transformers often contain external temperature and pressure gauges because they contain a sealed gas blanket over the dielectric oil.

overcurrent relays, sudden pressure relays, reverse-current relays, and winding and oil over temperature relays of various types. These devices should be tested and calibrated by qualified technicians on a regularly scheduled basis, but at least once a year.

Internal Inspection and Maintenance

On larger transformers, it is necessary to open manholes or inspection covers to determine the condition of the windings, connections, and other parts inside the housing. Before removing any covers, it is advisable to have new gaskets available for replacement when the opening is reclosed. Relieve any internal pressure in the transformer before loosening flange bolts. It is very important that no tools or equipment be left inside the housing. Inventory all tools, parts, and equipment brought to the work area before opening the transformer and also before reclosing it. Anything left in the transformer could cause a short circuit or interfere with the normal circulation of the cooling medium, and destroy the transformer. Make sure all safety precautions are followed, and atmosphere is tested before entering the transformer.

Look for loose, corroded, or discolored connections; distorted or damaged windings; and broken or missing spacers between windings. Check the general condition of the insulation for deterioration. Clean and tighten connections where necessary. Be sure to follow manufacturer's recommendations for torque when tightening any connections. Check and tighten any mounting bolts. Look for deposits of sludge on windings core material or other structures. Sludge deposits indicate contamination of the oil and reduce the dielectric strength of the insulation. Sludge can also act as thermal insulation, thus decreasing the transfer of heat from the internal parts to the cooling oil. While inspecting the internal parts of the transformer, it is good practice to look for any evidence of rust on the inside of the housing or covers. This might indicate condensation of moisture on these parts, which could be caused by a leaky gasket that allows ambient air to be admitted to the housing.

Insulation Testing

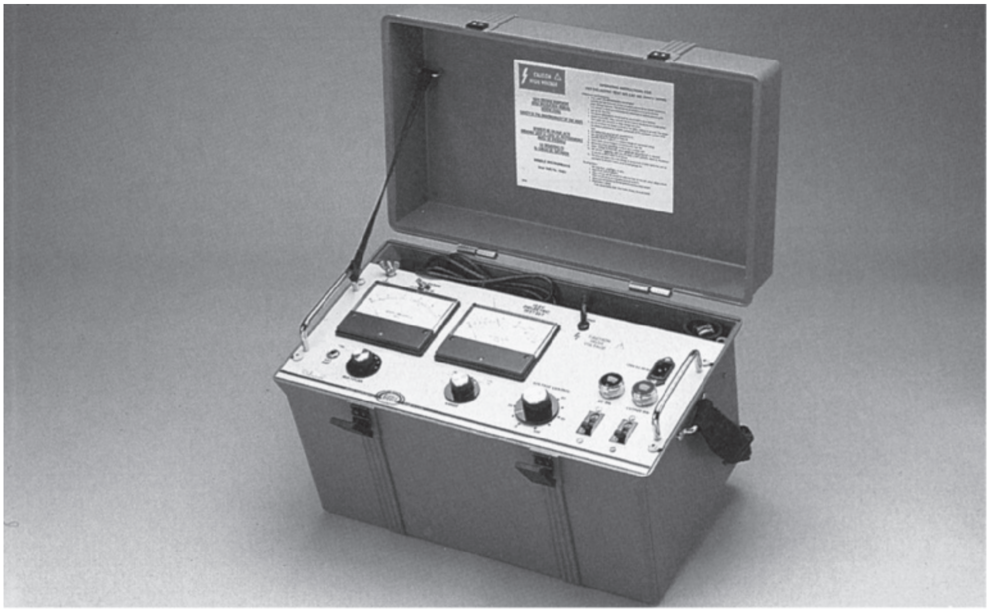
As with any other transformer, the dielectric strength of the insulation must be tested at least once a year. Megger testing can be done on the lower voltage transformers. Hand crank and battery-operated meggers are shown in Figure 2-42. Special high-voltage equipment is necessary to test the insulation on higher-voltage units. A high-voltage tester, generally referred to as a "HiPot," is shown in Figure 2-43. This unit develops a high voltage and measures any leakage current caused by weak or defective insulation.

For voltages above 13,800 volts, it is usually advisable to contract high-voltage insulation tests to a company that specializes in this type of tests and

Courtesy of Megger®

Courtesy of Megger®

FIGURE 2-42 Meggers used to test transformer windings.



Courtesy of Megger®

FIGURE 2-43 High-voltage tester.

has trained technicians and the proper equipment available. As with any insulation testing a record should be kept of test results in order to establish any trends in insulation dielectric strength.

Oil Testing

Transformer oil testing should be conducted at least once a year, and more frequently in cases of frequent overloads, or if there is a history of marginal oil test results. Oil samples are drawn into clean dry containers. Label each container with the identity of the transformer. After the sample is drawn, it should be allowed to stand for a short period of time to allow any free water to settle to the bottom of the sample. If glass containers are used, it will be easier to see any free water in the sample.

Testing for dielectric strength is done in a special device that has a cup for the sample, and electrodes placed 0.1 inch apart. Thoroughly clean and dry the sample cup, and then rinse it with a portion of the sample. Fill the cup and allow it to settle for at least three minutes to eliminate air bubbles. Turn the device on and gradually increase the voltage until it arcs across the sample. Record the voltage and repeat the test five times on each of three samples from each transformer. Calculate the average of the fifteen tests done in this manner to get the representative dielectric strength of the oil. An average dielectric strength of 26 kV to 29 kV is considered usable. 29 kV to 30 kV is good. Less than 26 kV is poor, and the oil should be replaced or filtered to increase dielectric strength. Special equipment is required to filter transformer oil, and the transformer must be de-energized. This process is usually contracted to companies specializing in transformer maintenance.

Other tests conducted on transformer oil include water content, gas content, and color. A water content of less than 25 parts per million is usually acceptable for units operating at voltages up to 228 kV. Excess water can come from condensation or leaks in the housing or cooling system, and it reduces the dielectric strength of the insulation and oil. Filtering removes excess water from the oil.

Arcing or overheating can cause combustible gases such as acetylene, hydrogen, methane, and ethane to be formed in the oil. The presence of these gases can only be detected by specialized test equipment and should be done by qualified technicians. Samples should be sent to laboratories specializing in this type of testing. Most transformer consulting firms prefer to have their technicians collect the samples in order to ensure uniform sampling procedures. In most cases the companies doing this type of testing submit a report listing the conditions found, probable causes, suggested remedies, and suggested frequency of retesting.

REVIEW QUESTIONS

All answers should be written in complete sentences, and calculations should be shown in detail.

The three main components of a unit substation follow. For each component, name the principal parts and identify their function(s). The parts are listed in Figure 2-7.

1. High-voltage section ____
____
____

2. Transformer section ____
____
____

3. Low-voltage section ____
____
____

The remaining questions are related to the equipment that is associated with the unit substation.

4. Explain the operation of ground detectors and identify the situation that would require their use. ____
____

5. Explain the reasoning for installation of the two meters. ______________________
____
____

6. Two current coils are installed. What is their function and why was it not necessary to install three coils? ____
____
____

7. If the secondary is ungrounded (such as that shown in Figure 2-11), what connections would likely be made to the grounding bus? ____________________________
____
____

8. If the secondary is grounded, what connection(s), in addition to those listed in problem 7, would be made to the grounding bus? __________________________________
____
____

9. What type of 3-phase connection requires only two transformers? ____________________

10. An installation requires a capacity of 86 kVA. The utility company intends to set two transformers as an open delta to supply this installation. What is the minimum kVA capacity of each transformer? ____________________

11. Why do most 3-phase transformer connections have at least one side (primary or secondary) connected in delta? ____________________

12. What type of 3-phase connection requires overcurrent protection in only two of the three phases? ____________________

13. List some of the protective relays found with large transformers. ____________________

14. What material should be available before opening manholes on large transformers?
____

15. Why is it important to inventory tools and equipment before and after working inside a transformer? ____________________

16. What are the two major types of 3-phase connections? ____________________

17. In what type of 3-phase connection are the line current and phase current the same?
____

18. In what type of 3-phase connection are the line voltage and phase voltage the same?
____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CHAPTER 3

Feeder Bus System

OBJECTIVES

After studying this chapter, the student should be able to

- set forth the benefits of using busways.
- identify common applications of busways.
- list the components of busways.
- describe various support systems.

FEEDER DUCTS

Modern industrial electrical systems use several methods to transport electrical energy from the source of supply to the points within the plant where panelboards or switchboards are located. These methods may include the use of heavy feeder conductors or cables run in troughs or trays, or heavy busbars enclosed in ventilated ducts. For the industrial building covered in this text, busbars in a ventilated enclosure are specified and shown on the plans. The proper name for this assembly is a busway; however, most electricians and others call the assembly a bus duct. *NEC Article 368* contains the provisions for the installation of busways.

The source of electrical energy in this case is the unit substation located at the rear of the industrial building. Two ventilated feeder busways originate at the unit substation.

Feeder busway sections are available in standard 10 ft (3 m) lengths and in other lengths on special order. Numerous fittings can be used to make branches, turn corners (in both the edgewise and the flat types of installation), and in general follow the contours of a building.

The enclosure containing the buses is constructed of two identical ventilated steel halves. When these halves are bolted together, they form a complete housing for the busbars. The copper busbars are supported on insulators inside the enclosure, Figure 3-1.

The enclosure contains six busbars that are connected together in pairs to form a 3-conductor system. The busbars are machine wrapped with varnished cambric insulating tape, except where connections are to be made.

The connection of the busway to enclosures such as unit substations is accomplished with flanged end connections. In addition, these connections are used to transpose the positions of the buses connected to the same phase, Figure 3-2. This transposition reduces the impedance of the total length of the busway. Because each phase is located at two places (or more in larger busways), the effects of the magnetic field are reduced, and the opposition to the current flow is also reduced. See *300.20* in the *NEC* for installation requirements related to induced currents.

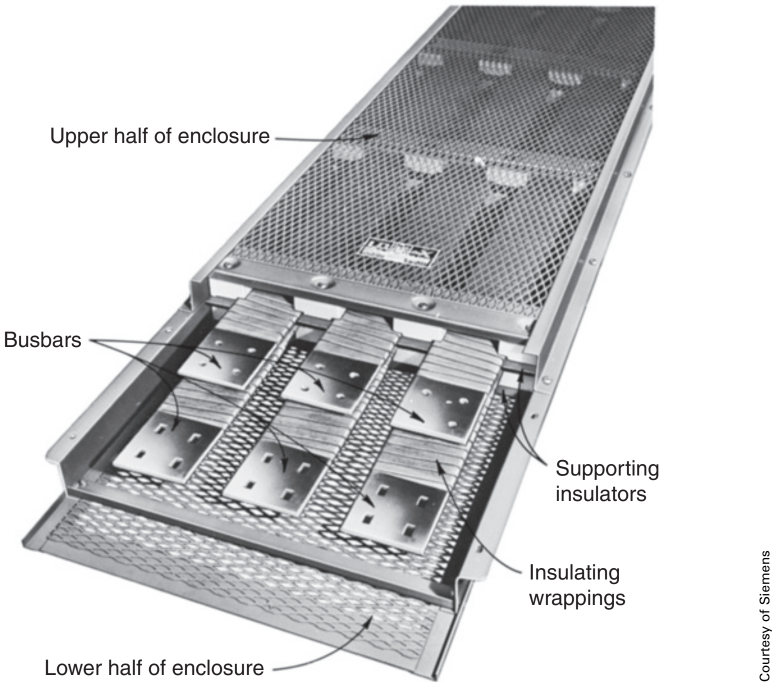


FIGURE 3-1 Feeder busway section.

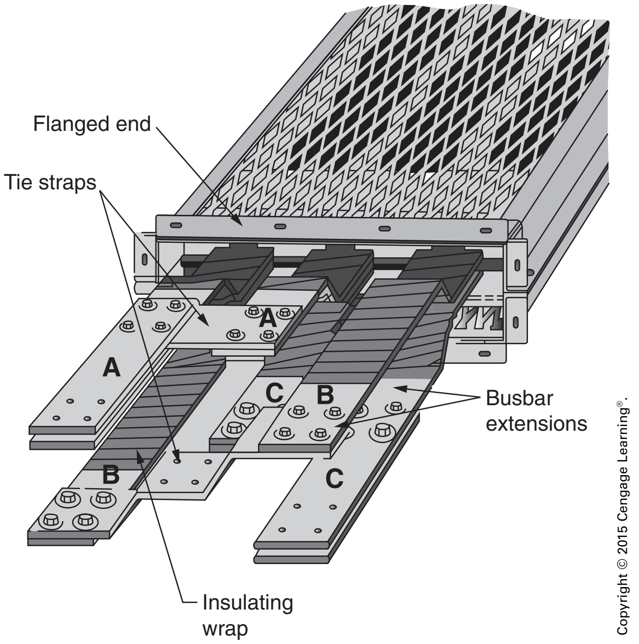


FIGURE 3-2 Busway showing cross connections of phases.

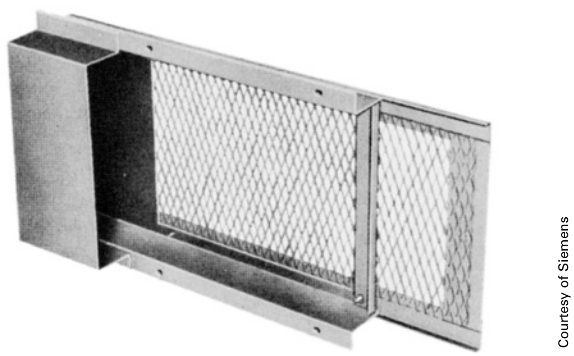


FIGURE 3-3 End closure for ventilated busway.

Feeder Busway No. 1

Feeder busway No. 1 of the industrial building has a 600-volt and 1000-ampere rating. It starts at the low-voltage section of the unit substation and rises vertically for almost 8 ft (2.5 m). At this point, a tee section is installed to carry the busway in an edgewise, double-branch formation in both directions along the east wall of the main structure (toward the north and south walls of the building).

When the two busway branches meet the north and south walls of the building, edgewise ells change the direction of the branches. The branches of feeder busway No. 1 continue in an edgewise installation along the north and south walls of the manufacturing area at a height of about 16 ft (4.9 m) above the floor. The feeder busway runs along the south ends at approximately the midpoint of the wall.

The branch of the feeder busway running along the north wall extends to the west wall of the manufacturing area. An edgewise ell installed at this point changes the direction of the busway once again. It now continues along the west wall of the building and ends before reaching the southwest corner of the manufacturing area. End closing sections, Figure 3-3, are used at the termination of each of the busway runs, *NEC 368.10*.

Power can be tapped from the feeder busway at any *handhole opening*. The handhole openings are located at every joint in the enclosure. For standard lengths, the joints and the handhole openings are 10 ft (3 m) apart. Cable tap boxes are used for cable or conduit tapoff or feed-ins at any handhole opening, Figure 3-4A. Tap box cable lugs and straps, Figure 3-4B, are provided with each tap box. Fusible switch adapters (cubicles) and circuit-breaker cubicles are available for use when it is necessary to connect loads to the feeder, *NEC 368.17(C)*.

Feeder Busway No. 2

Much of the information presented for the ventilated feeder busway No. 1 also applies to feeder busway No. 2. This feeder also begins at the low-voltage section of the unit substation and rises vertically to a point slightly below the overhead roof structure of the building. An elbow section is installed at this point to change the direction of the busway while positioning it so that it runs horizontally to form a flat type of installation. The busway runs in a westerly direction down the center of the manufacturing area until it reaches the approximate center of the area where a tee section is installed. As a result, branches of the same feeder duct run north and south and extend as far as the two outside plug-in busways, Figure 3-5.

Feeder busway No. 2 is designed to carry large current values with a minimum power loss and at a

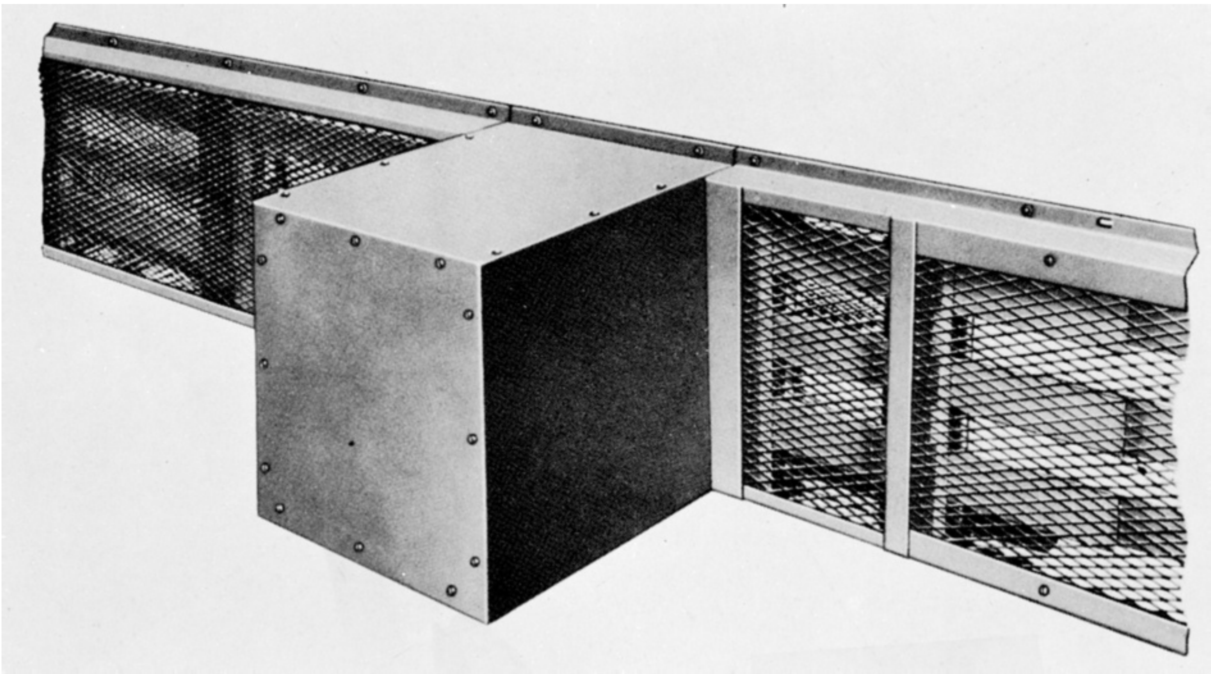


FIGURE 3-4A Busway with cable tap box.

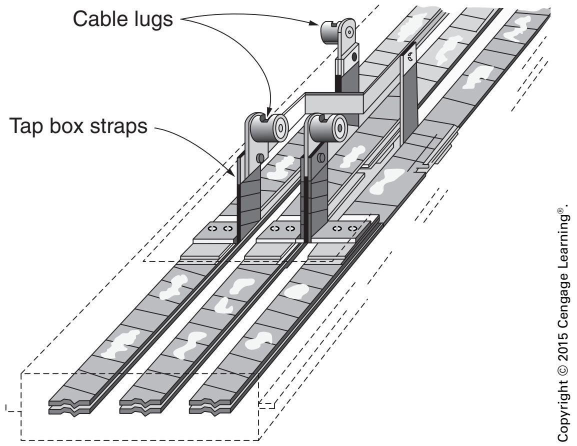


FIGURE 3-4B Bus extension to facilitate cable connections.

low operating temperature. The busway is rated at 1600 amperes and 600 volts.

Feeder busway No. 2 is constructed of flat, closely spaced, completely insulated, paired-phase busbars enclosed in a ventilated steel casing similar to that of busway No. 1. Straight sections, elbows, tees, and crosses are standard components available for use so that the duct can be installed horizontally or vertically, edgewise or flat, and can meet any turn or elevation requirements. The casing ends of adjacent sections overlap and are bolted together to form a rigid scarf-lap joint, Figure 3-6.

The flat busbars overlap in the same manner as for the casing. The busbars are bolted together with spring washers, cap screws, and splined nuts furnished with the sections. Vinyl plastic snap-on covers insulate the bolted busbar sections. There are two busbars per phase, for a total of six bars. Each bar measures 2¼ in. by 2⁷⁄₁₆ in. (6 mm by 58 mm).

Each busbar has a cross-sectional area of 0.61 in.^{2} (394 mm^2); thus, the total area per phase is 1.22 in.^{2} (788 mm^2). Because the assembly is rated for 1600 amperes, the current density in the busbars is

$$\frac{1600\,\text{A}}{1.22\,\text{in.}^2} = \begin{array}{l}1311\,\text{amperes/in.}^2\\ \text{(of cross-sectional area)}\end{array}$$

$$\frac{1600\,\text{A}}{788\,\text{mm}^2} = 2\ \text{amperes/mm}^2$$

When this is compared with a standard density value of 1000 amperes per square inch (1.55 amperes per square millimeter), the value of transposing the buses to reduce the impedance is evident.

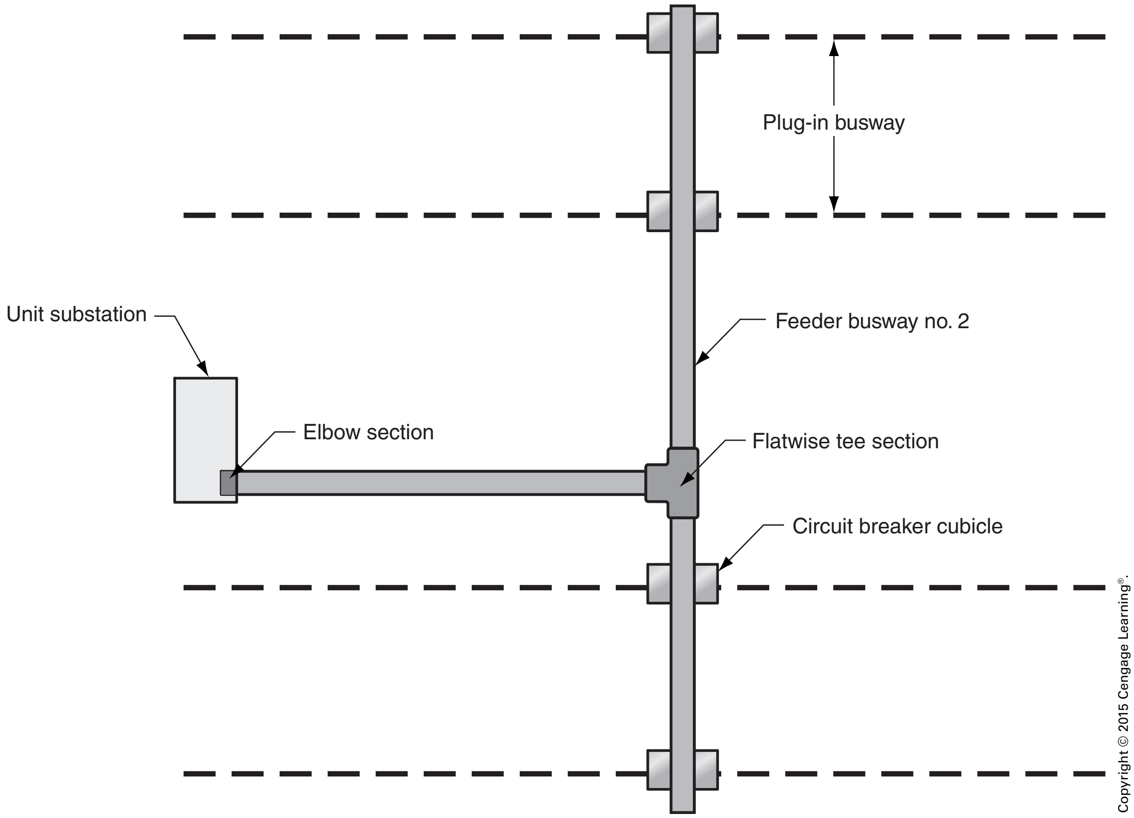


FIGURE 3-5 Feeder busway No. 2.

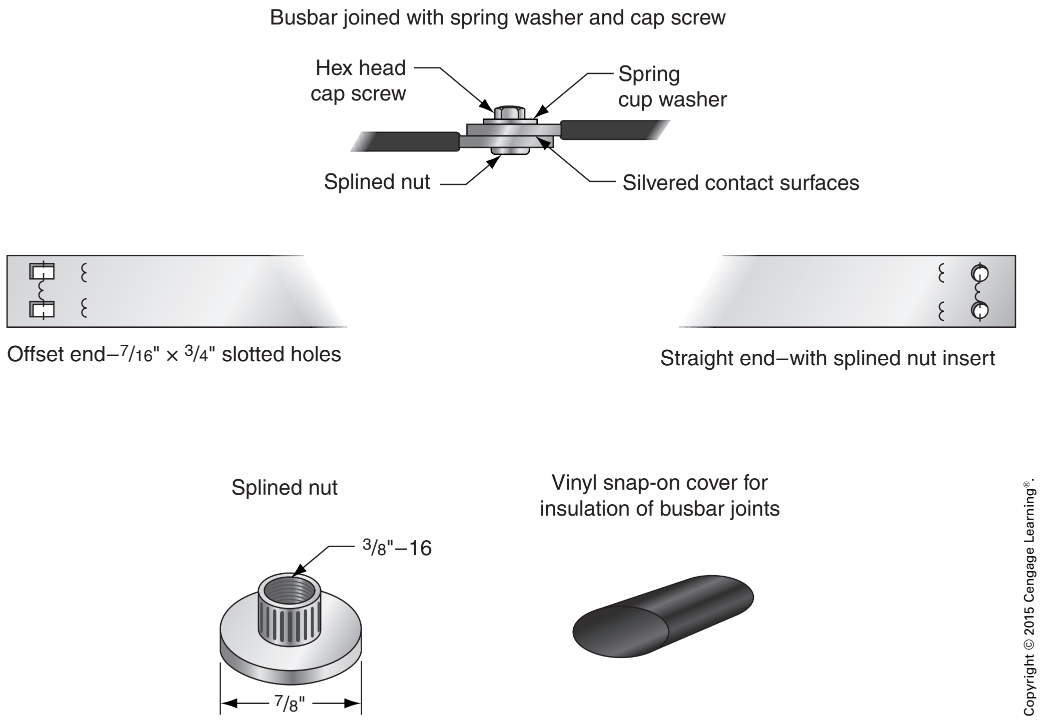


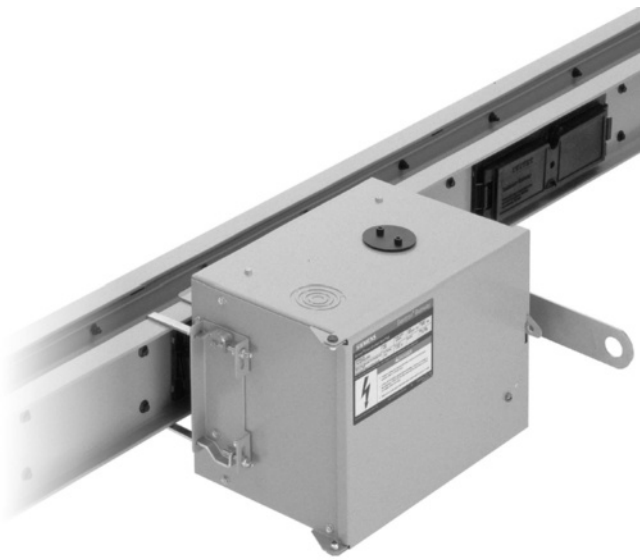
FIGURE 3-6 Busbar accessories.

The pairs of busbars are joined together at the flanged ends located at the substation. End closers are installed at the two dead-end sections of the feeder.

THE CIRCUIT-BREAKER CUBICLES

Circuit-breaker cubicles are used to connect the No. 2 feeder busway to the 225-ampere, plug-in busway runs, Figure 3-7. There are ten of these runs in the industrial building; thus, five double circuit-breaker cubicles are required.

The circuit-breaker cubicle consists of a cube-shaped steel housing. This housing can be attached to the lower side of the ventilated feeder duct. Two 225-ampere circuit breakers are provided in a single housing. Openings in the sides of the cubicle permit the attachment of a plug-in busway. This busway runs in opposite directions at right angles to the feeder (review Figure 3-5). The circuit breakers protect the plug-in duct from overloads, as required by *368.17(C)*. This section of the *Code* requires that a means such as chains, ropes, or sticks be provided so that the disconnecting means can be operated from the floor. In this installation, a rope is to be connected to each operating handle and extended to within 7 ft (2.1 m) of the floor.



Courtesy of Siemens

FIGURE 3-7 Circuit-breaker cubicle.

PLUG-IN BUSWAY

The plug-in busway is actually a subfeeder taken from the No. 2 ventilated feeder. According to the layout shown on the plans, the plug-in busway makes 3-phase, 480-volt power available to all parts and at any point of the manufacturing area of the plant.

The busbars in the busway are coated with silver at each connection point. Silver is unequaled as an electrical conductor. In addition, silver is less subject to pitting (corrosion) than is copper. Thus, when the bus plug fingers contact the silver coating of the busbars, a high-conductivity connection is ensured. Standard plug-in sections are 10 ft (3 m) in length and consist of two identical formed steel halves that are bolted together to form the complete outside housing, Figure 3-8. This housing also provides the scarf-lap feature, which permits two adjacent duct sections to overlap each other by 12 in. (300 mm). The resulting lap simulates an interlocked joint and provides high rigidity and strength to the assembly, Figure 3-9.

The busway specified for the industrial building is 3-phase duct and is rated at 225 amperes and 480 volts. Although ells, tees, and cross sections (or fittings) are not required for the industrial building installation, such fittings are available for use when specified by the design or layout. Some of these fittings are shown in Figure 3-10.

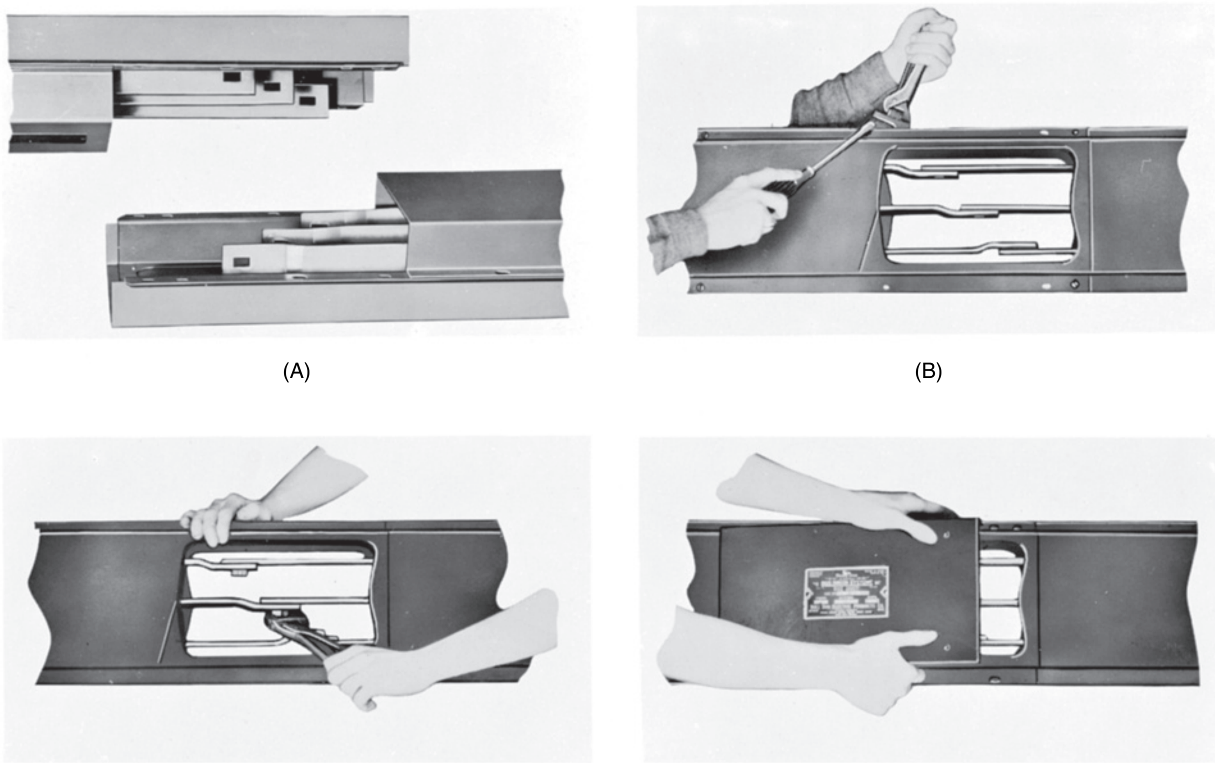
Power takeoff plug-in openings are spaced at convenient intervals on alternate sides of the enclosure. (Each side has the same number of openings.) Bus plugs can be inserted into any one of these openings. In this manner, branch circuits can be dropped to any item of equipment requiring electric power. The design of the bus plugs is such that they ground against the enclosure before the plug fingers contact the busbars. Additional safety is provided by this design during plug insertion, Figure 3-11.

A plug-in busway is used to provide a flexible tapoff means for motor branch circuits. In other words, the plug-in busway transports electrical energy from the ventilated feeder to the locations of the production machines. Tapoff openings every 10 in. (250 mm) along the busway mean that there is always a convenient location to connect a machine.

FIGURE 3-8 Plug-in busway.

The plug-in busway is much like a panelboard extending through a complete load area. However, the busway system is much more flexible. If a machine is to be moved from one location to another, it is a simple matter to unplug the circuit-protective device, move it and the machine to the new location, and plug the protective device back into the busway system. A move of this type can be made without shutting off power to the system or disrupting production in any way. Figure 3-12 shows a typical power distribution system.

The ten separate runs of the plug-in busway in the industrial building start at the circuit-breaker cubicles and extend for a distance of approximately 96 ft (29 m) in either direction (east-west). The runs are about 32 ft (9.6 m) apart on centers with a lesser distance between the outside runs and the walls of the structure. The ends of each run are fitted with end closer fittings.



(A) (B) (C) (D)

FIGURE 3-9 Joining plug-in bus duct sections.

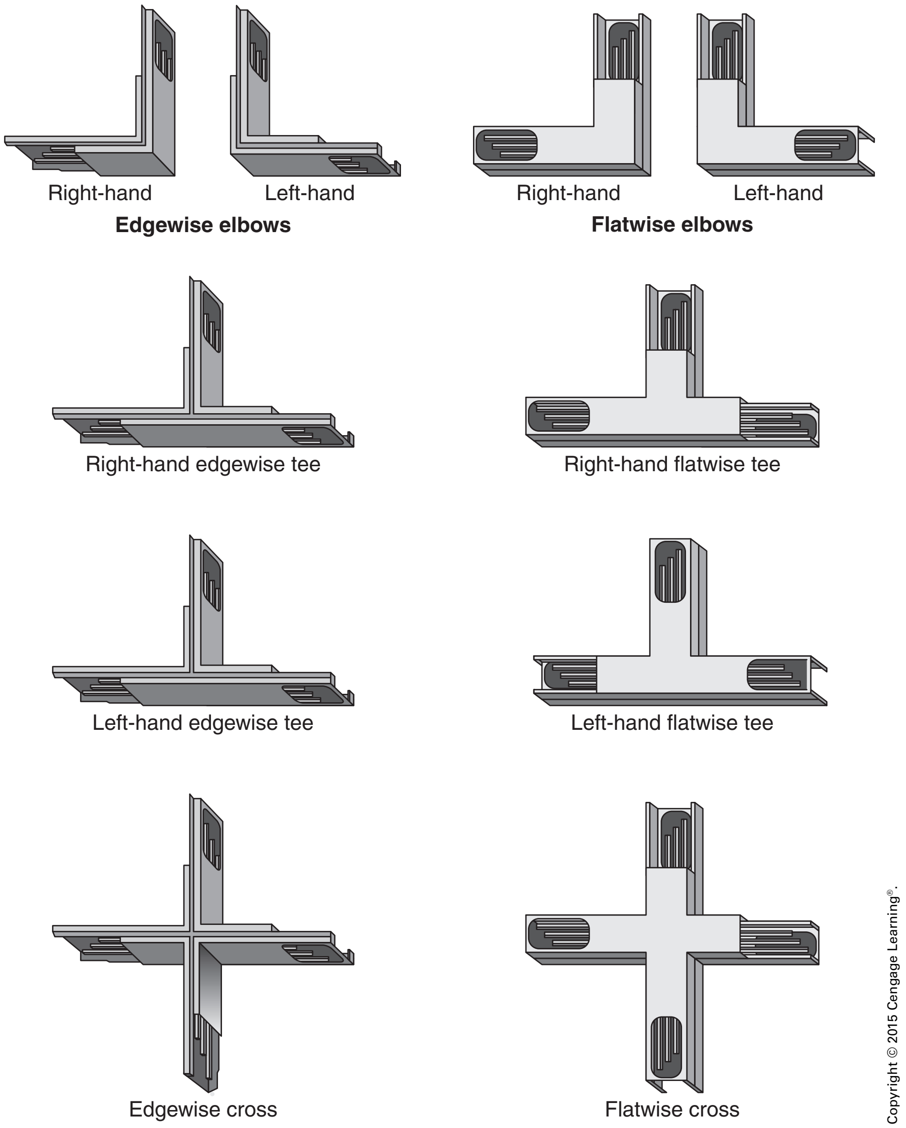


FIGURE 3-10 Plug-in busway fittings.

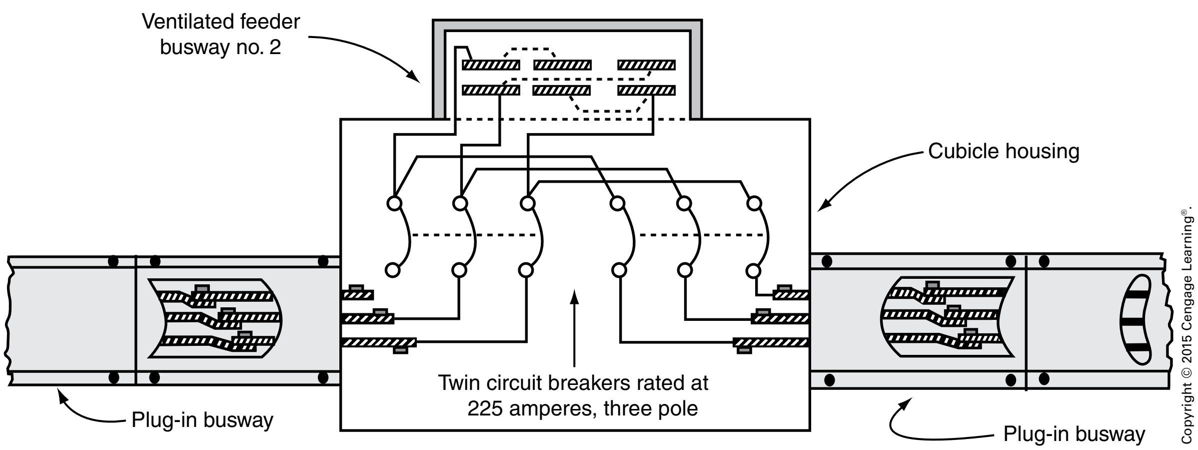


FIGURE 3-11 Plug-in busway.

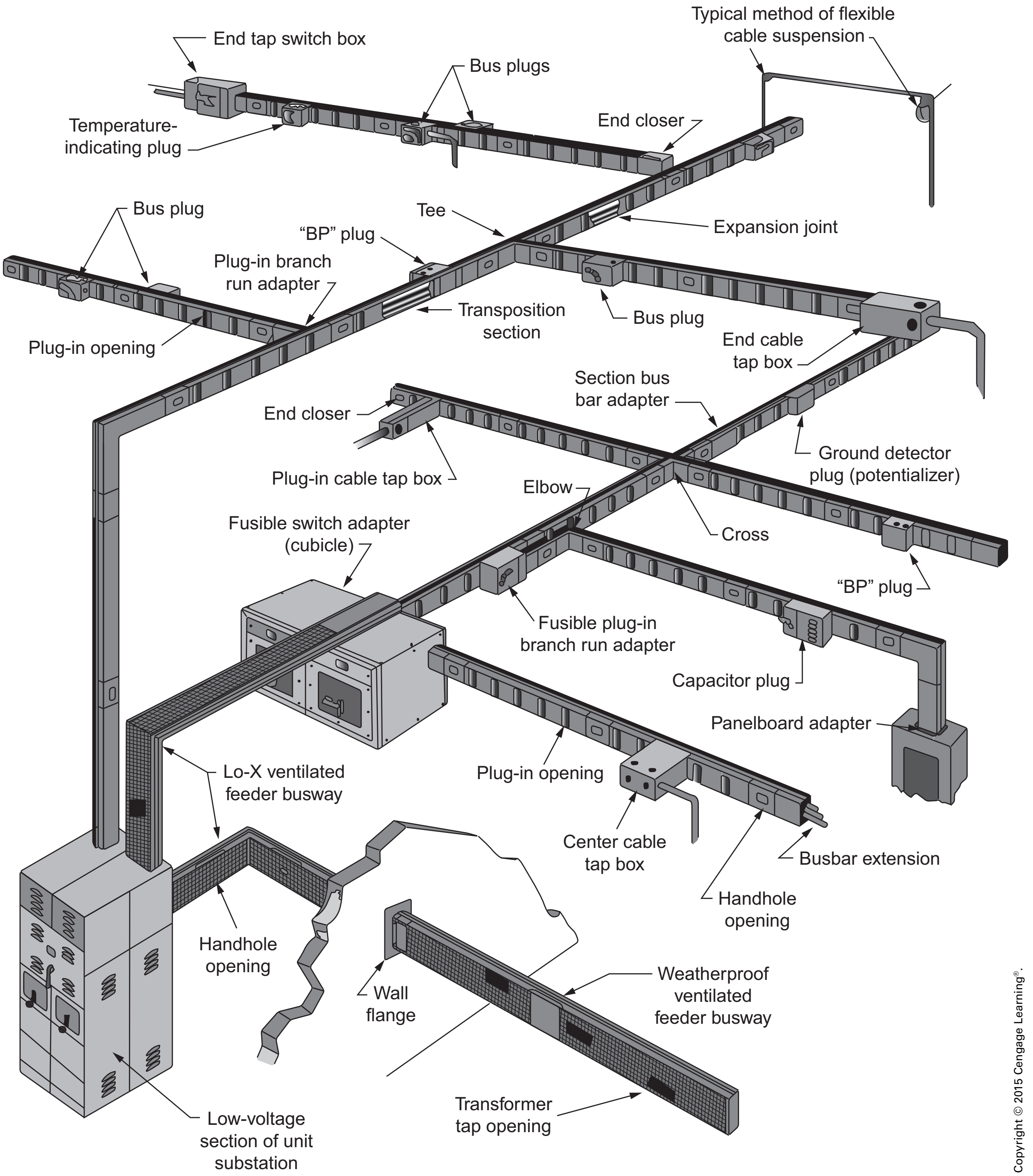


FIGURE 3-12 Power distribution system.

Method of Suspension

There is an almost unlimited selection of methods for hanging or supporting the plug-in busway. Support arrangements are shown in Figure 3-13 to illustrate some of the more common methods of hanging sections using clamp hangers. Prefabricated clamp hangers eliminate the drilling, cutting, or bending generally associated with hangers constructed on the job. Clamp hanger halves are slipped over the duct casing and are bolted together. Support arrangements shown include bracket supports, strap hangers, rod hangers, and messenger cable suspension.

The busway used in the industrial building is supported by rods and messenger cables. These cables, in turn, are supported from the overhead

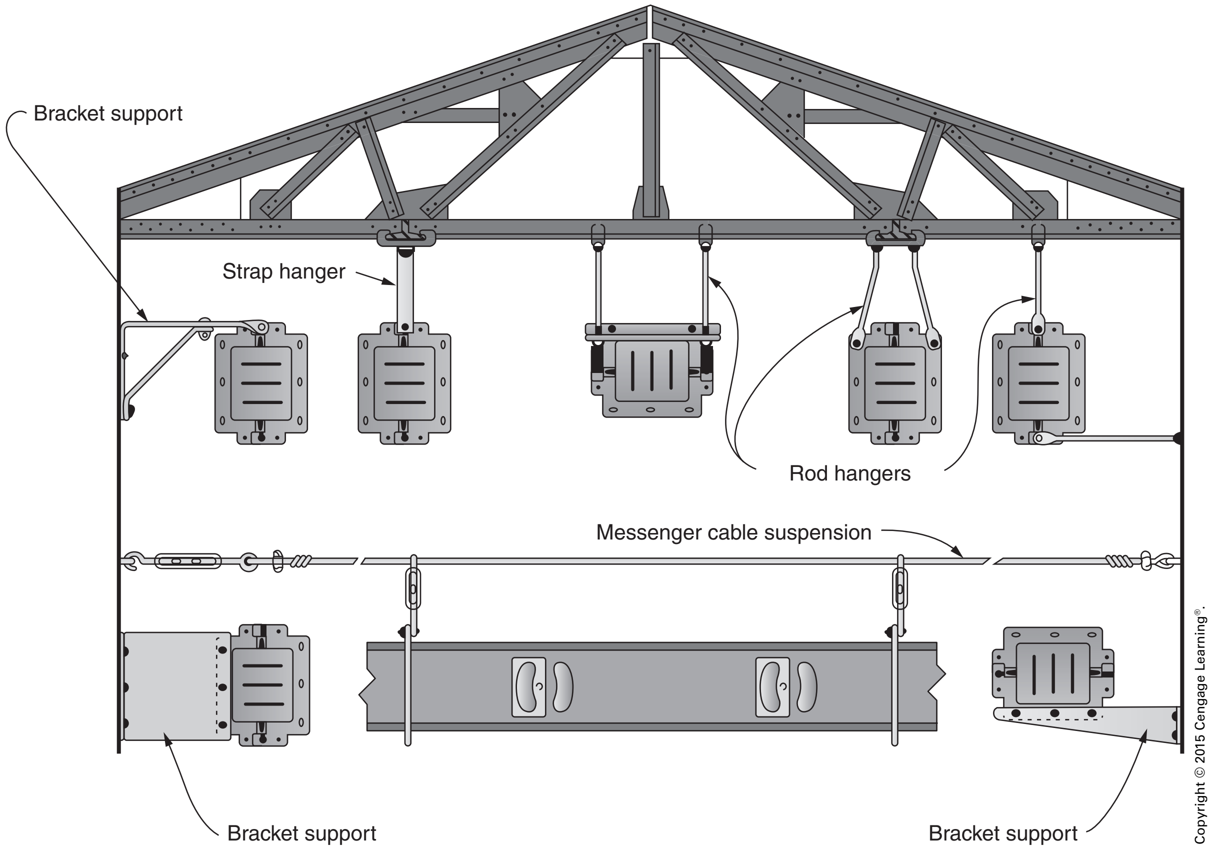


FIGURE 3-13 Support methods for busway.

structure. The busways are all supported at intervals of 5 ft (1.5 m) or less, in accordance with *368.30*.

BUS PLUGS

One bus plug, Figure 3-14, must be furnished for each machine in the manufacturing area of the plant. According to the plans and specifications for the industrial building, there are 111 machines to be supplied with power from the plug-in system. The number and size of the bus plugs required are summarized in Table 3-1.

The bus plugs provide branch-circuit protection for each of the machines and must be selected according to the specific requirements of the individual machines. The plug-in devices are identified on Sheet E-2 of the plans with regard to the type of machine tool to be supplied. More detailed information is given

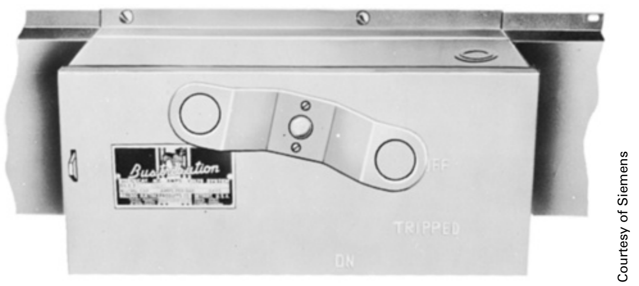


FIGURE 3-14 Bus plug.

TABLE 3-1

Number and size of required bus plugs.

NUMBER OF BUS PLUGS REQUIRED	PROTECTIVE DEVICES RATING, AMPERES	SWITCH RATING, AMPERES
47	15	30
26	20	30
30	30	30
3	60	60
5	90	100

in the specifications. One advantage of the fusible plug-in unit is that a minimum number of sizes are needed. The plug-in unit size is based on the switch ampere rating. In addition, the protective device rating can be easily changed. Where such devices are located out of reach of the machine operators, suitable means must be provided for operating the disconnect means. See *368.17(C)*.

REVIEW QUESTIONS

All answers should be written in complete sentences. Calculations should be shown in detail, and *Code* references should be cited when appropriate.

1. The current density of the 1600-ampere busway was calculated to be 1313 amperes per square inch. Compare this with the allowable current density of a 500 kcmil (thousand circular mils)–type THWN conductor. ____________________

2. Would it be permissible to cut six openings in the top of the unit substation, with each busbar installed through an individual opening? Why or why not? ____________________

3. Describe what is meant by transposing the buses and what is achieved. ____________________

4. Describe when it is appropriate to use busways and when plug-in busways are preferred. ____________________

5. Describe at least four support methods, and give examples of when their use would be appropriate. ____________________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CHAPTER **4**

Panelboards

OBJECTIVES

After studying this chapter, the student should be able to

- identify panelboard types.
- select and adjust circuit breakers.
- make feeder connections to panelboards.

PANELBOARDS

Circuit control and overcurrent protection must be provided for all circuits and the power-consuming devices connected to these circuits. Lighting and power panelboards located throughout the building being supplied with electrical energy provide this control and protection. Fifteen panelboards are provided in the industrial building to feed electrical energy to the various circuits, Table 4-1.

All of the required panelboards are listed in the specifications and are shown on the plans or are referred to on the riser diagram. These panelboards distribute the electrical energy and protect the circuits supplying outlets throughout the building. The schedule in Table 4-1 shows that eleven of the fifteen panelboards listed supply lighting and receptacle circuits. As a general rule, a panelboard for which more than 10% of its overcurrent devices are rated at 30 amperes or less, and for which neutral connections are provided, is defined as a lighting and appliance branch-circuit panelboard. Throughout this text, this type of panelboard will be called a *lighting panelboard*. Panelboards not meeting these requirements are known as power or distribution panelboards.

Lighting and Appliance Panelboards

The basic requirements for panelboards are given in *408.36*. Panelboards P-1 through P-10 and P-12 are considered as lighting and appliance panelboards (Table 4-1).

For these panelboards, follow these requirements:

- The panelboard shall have a rating of not less than the minimum feeder capacity as calculated according to *NEC Article 408*.
- The panelboard must be protected using an overcurrent protective device with a trip setting not exceeding the rating of the panelboard.
- The total 3-hour load shall not exceed 80% of the panelboard rating except when specifically rated for 100% continuous duty.

Panelboards are available with standard main ratings of 100, 225, 400, 600, 800, and 1200 amperes.

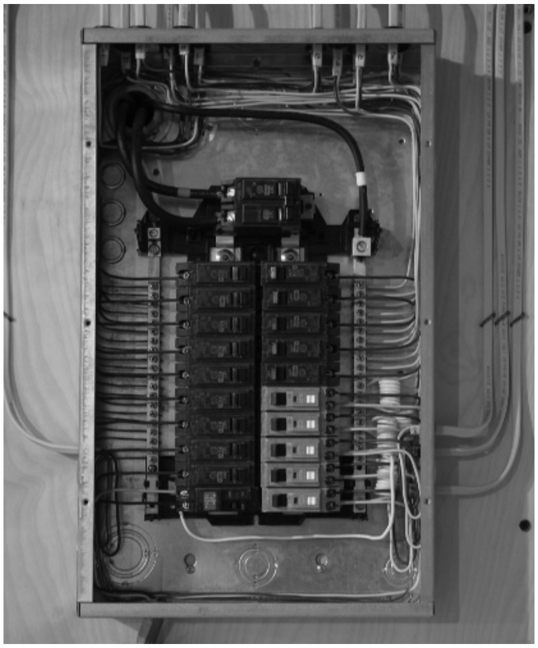


FIGURE 4-1 Lighting and appliance panelboard with main breaker.

These panelboards may be installed without a main protective device and can be connected directly to a feeder protected at not more than the rating of the panelboard. Individual protection is required on lighting and appliance panelboards when these panelboards are connected to the secondary of a transformer having only primary protection, Figure 4-1.

When a subfeeder, such as the one from transformer TA (as shown on Sheet E-1 of the working drawings), serves more than one panelboard, then connections must be made in the subfeeder for each of the panelboards. These connections can be made either by tapping the conductor or by using subfeed lugs in the panelboards, Figure 4-2.

If subfeed lugs are used, the electrician must ensure that the lugs are suitable for making multiple connections, as required by *110.14(A)*. In general, this means that a separate lug is to be provided for each conductor being connected, Figure 4-3.

When connections of this type are employed, it is very important to make certain that the connections are tightened properly. Loose or poor connections are one of the leading causes of electrical fires and damaged equipment. The damage caused by

TABLE 4-1

Schedule of electric panelboards for the industrial building.

PANELBOARD NO.	LOCATION	MAINS	VOLTAGE RATING	NO. OF CIRCUITS	BREAKER RATINGS	POLES	PURPOSE
P-1	Basement	Breaker	208/120 V	19	20 A	1	Lighting and
	N. Corridor	100 A	3 ϕ, 4 W	2	20 A	2	Receptacles
				5	20 A	1	Spares
P-2	1st Floor	Breaker	208/120 V	24	20 A	1	Lighting and
	N. Corridor	100 A	3 ϕ, 4 W	2	20 A	2	Receptacles
				0			Spares
P-3	2nd Floor	Breaker	208/120 V	24	20 A	1	Lighting and
	N. Corridor	100 A	3 ϕ, 4 W	2	20 A	2	Receptacles
				0			Spares
P-4	Basement	Breaker	208/120 V	24	20 A	1	Lighting and
	S. Corridor	100 A	3 ϕ, 4 W	2	20 A	2	Receptacles
				0			Spares
P-5	1st Floor	Breaker	208/120 V	23	20 A	1	Lighting and
	S. Corridor	100 A	3 ϕ, 4 W	2	20 A	2	Receptacles
				1	20 A	1	Spares
P-6	2nd Floor	Breaker	208/120 V	22	20 A	1	Lighting and
	S. Corridor	100 A	3 ϕ, 4 W	2	20 A	2	Receptacles
				2	20 A	1	Spares
P-7	Mfg. Area	Breaker	208/120 V	5	50 A	1	Lighting and
	N. Wall E.	100 A	3 ϕ, 4 W	7	20 A	1	Receptacles
				2	20 A	1	Spares
P-8	Mfg. Area	Breaker	208/120 V	5	50 A	1	Lighting and
	N. Wall W.	100 A	3 ϕ, 4 W	7	20 A	1	Receptacles
				2	20 A	1	Spares
P-9	Mfg. Area	Breaker	208/120 V	5	50 A	1	Lighting and
	S. Wall E.	100 A	3 ϕ, 4 W	7	20 A	1	Receptacles
				2	20 A	1	Spares
P-10	Mfg. Area	Breaker	208/120 V	5	50 A	1	Lighting and
	S. Wall W.	100 A	3 ϕ, 4 W	7	20 A	1	Receptacles
				2	20 A	1	Spares
P-11	Mfg. Area	Lugs only	208 V	6	20 A	3	Blowers and
	East Wall	225 A	3 ϕ, 3 W				Ventilators
P-12	Boiler	Breaker	208/120 V	10	20 A	1	Lighting and
	Room	100 A	3 ϕ, 4 W				Receptacles
				4	20 A	1	Spares
P-13	Boiler	Lugs only	208 V	6	20 A	3	Oil Burners
	Room	225 A	3 ϕ, 3 W				and Pumps
P-14	Mfg. Area	Lugs only	208 V	3	175 A	3	Chillers
	East Wall	400 A	3 ϕ, 3 W	2	70 A	3	Fan Coil Units
				1	40 A	3	Fan Coil Units
P-15	Mfg. Area	Lugs only	208 V	5	100 A	3	Trolley Busway
	West Wall	600 A	3 ϕ, 3 W				and Elevator

Note: Where a two-pole circuit breaker is used, the space required is the same as for two single-pole breakers.

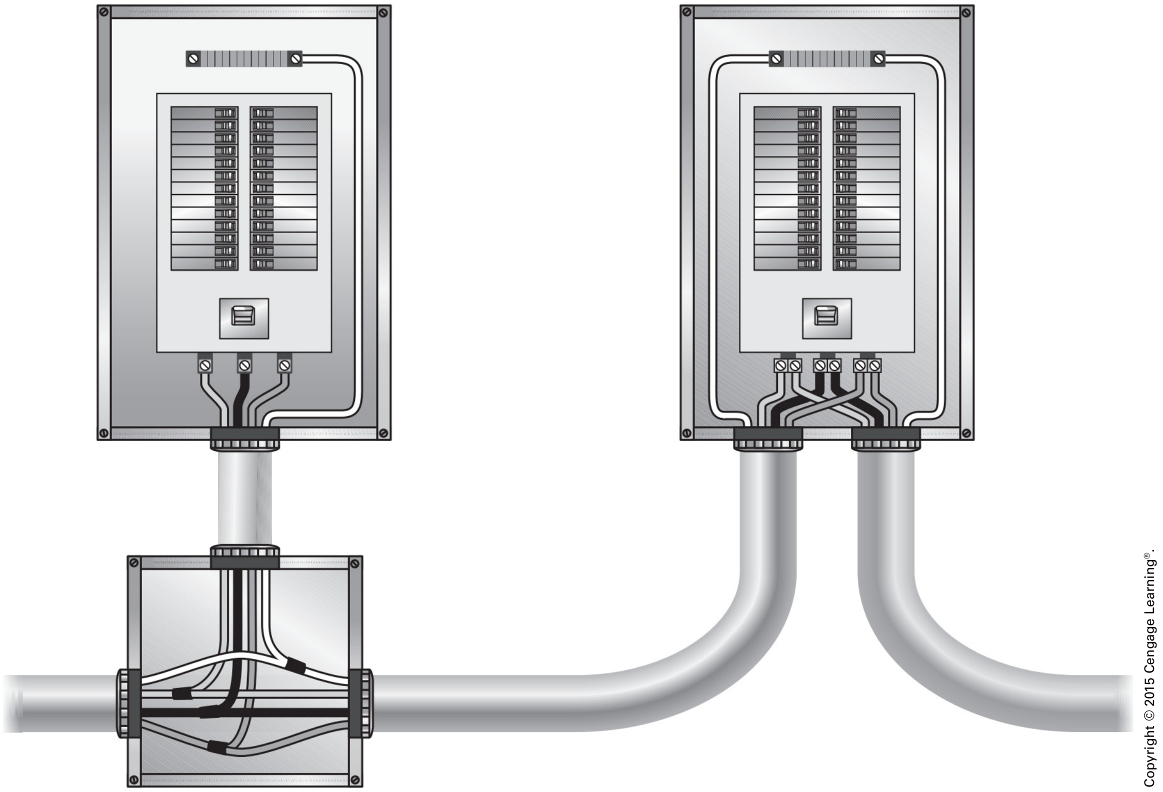


FIGURE 4-2 Methods of connecting panelboards.

a poor connection on a relay terminal is shown in Figure 4-4. The damaged conductor and terminal are shown in Figure 4-5. Many manufacturers provide torque specifications. When this is the case, a torque wrench should be used to properly tighten the connections, Figure 4-6.

If taps are made to the subfeeder, they may be reduced in size according to *240.21*. This specification is very useful in cases such as that of panelboard P-12. For this panelboard, a 100-ampere main breaker is fed by a 350 kcmil conductor. Within the distances given in the section, a conductor with a 100-ampere rating

FIGURE 4-3 Cable connectors.

FIGURE 4-4 Overheating caused by a poor connection.

FIGURE 4-5 Burned conductor and terminal caused by a poor connection.

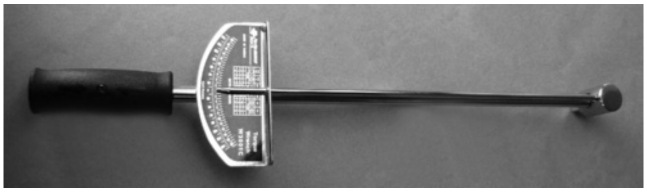


FIGURE 4-6 Torque wrenches are used to tighten nuts and bolts to a specific tightness.

FIGURE 4-7 Single-pole breaker.

FIGURE 4-8 Double-pole breaker.

may be tapped to the subfeeder and connected to the 100-ampere main breaker in the panelboard.

The temperature rating of conductors must be selected and coordinated so as not to exceed the lowest temperature rating of any connected termination, conductor, or device [*110.14(C)*].

BRANCH-CIRCUIT PROTECTIVE DEVICES

The schedule of panelboards for the industrial building, Table 4-1, shows that lighting panelboards P-1 through P-6 have 20-ampere circuit breakers, including two double-pole breakers (to supply special receptacle outlets). Two single-pole breakers, Figure 4-7, require the same installation space as for a double-pole breaker, Figure 4-8.

For a 3-pole circuit breaker such as the one shown in Figure 4-9, three poles are required for each breaker used. When the panelboards are purchased, the interiors are specified by the total number of poles required; the circuit breakers are ordered separately.

FIGURE 4-9 A 3-pole breaker.

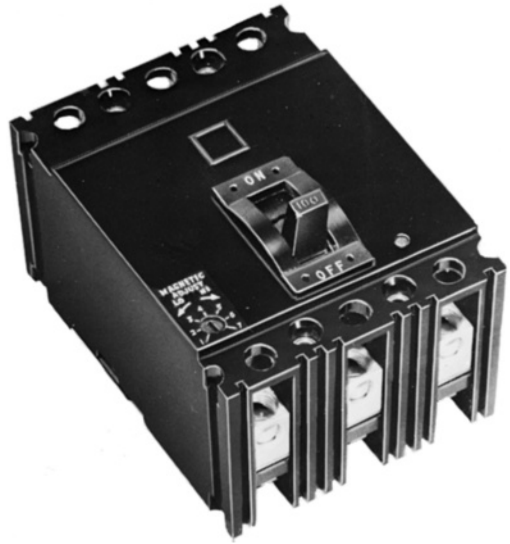


FIGURE 4-10 Circuit breaker with adjustable magnetic trip.

PANELBOARD PROTECTIVE DEVICE

The main for a panelboard may be either a fuse or a circuit breaker. Because the *Electrical Wiring–Commercial* text discusses the use of fuses in detail, this text will concentrate on the use of circuit breakers. The selection of the circuit breaker should be based on the necessity to

- provide the proper overload protection;
- ensure a suitable voltage rating;
- provide a sufficient interrupt current rating;
- provide short-circuit protection; and
- coordinate the breaker(s) with other protective devices.

The choice of the overload protection is based on the rating of the panelboard. The trip rating of the circuit breaker cannot exceed the ampacity of the busbars in the panelboard. The number of branch-circuit breakers generally is not a factor in the selection of the main protective device except in a practical sense. It is a common practice to have the total amperage of the branch breakers exceed the rating of the main breaker by several times.

The voltage ratings of the breakers must be higher than that of the system. Breakers are usually rated at 250 or 600 volts.

The importance of the interrupt rating is covered in detail in *Electrical Wiring–Commercial*. The student should recall that if there is any question as to the exact value of the short-circuit current available at a point, a circuit breaker with a high interrupt rating is to be installed.

Many circuit breakers used as the main protective device are provided with an adjustable magnetic trip, Figure 4-10. Adjustments of this trip determine the degree of protection provided by the circuit breaker if a short circuit occurs. The manufacturer of this device provides exact information about the adjustments to be made. In general, a low setting may be ten or twelve times the overload trip rating. Two rules should be followed whenever the magnetic trip is set:

- The lower setting provides the greater protection.
- The setting should be lower than the value of the short-circuit current available at that point.

POWER PANELBOARDS

The panelboard schedule in Table 4-1 shows that four panelboards in the industrial building are power panelboards. A typical power panelboard is shown in Figure 4-11. A common interior arrangement for a 3-wire, fusible panelboard is shown in Figure 4-12. The panelboard is supplied from a major source such as a transformer. The panelboard then provides circuits to individual loads, as shown in Figure 4-13.

Courtesy of Square D Company

FIGURE 4-11 A typical power panelboard.

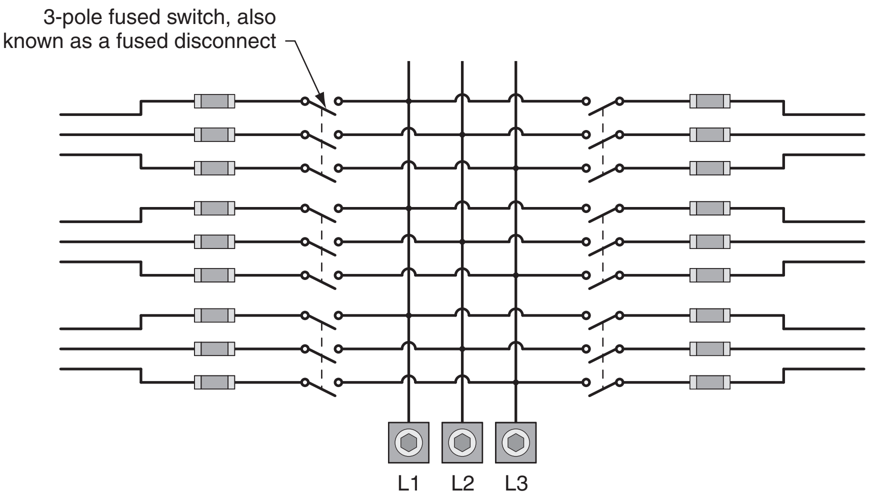


FIGURE 4-12 Fusible power panelboard.

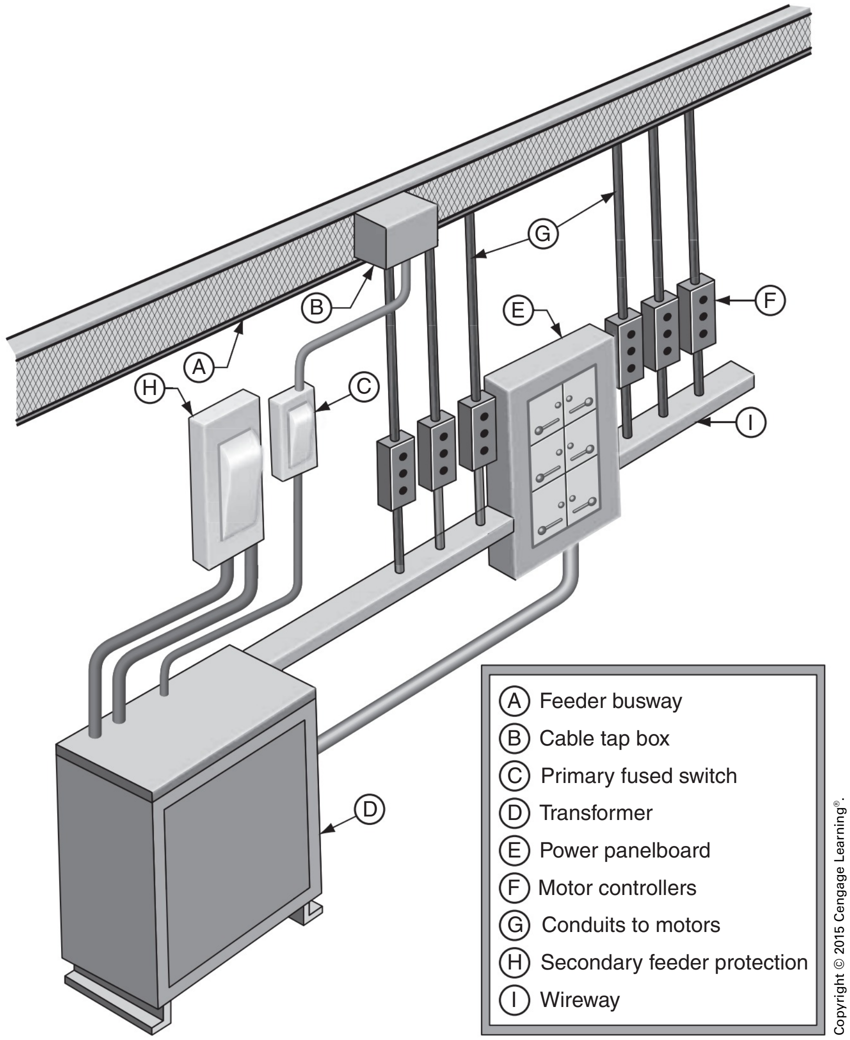


FIGURE 4-13 Floor-mounted transformer supplying power panelboard.

REVIEW QUESTIONS

All answers should be written in complete sentences. Calculations should be shown in detail, and *Code* references should be cited when appropriate.

1. The schedule of panelboards is given in Table 4-1. How many of these are power panelboards, and how are they different from the others? ______________________________

____

____

____

2. Three-phase, 4-wire panelboards are usually constructed with an even number of spaces available for each phase; thus, the total number of spaces would be in increments of 6, such as 12, 18, 24, 30, 36, or 42. How many spaces would be available for the later addition of circuit breakers in panelboard P-1 after the panelboard has been equipped as scheduled? ____

____

____

3. Figure 4-2 illustrates two methods of feeding a panelboard from a feeder that continues on to serve other loads. Compare the two methods and indicate your preference.

____

____

____

4. Describe in detail what is illustrated in Figure 4-13. ______________________

____

____

____

____

____

5. How would you adjust the magnetic trip on a circuit breaker? ________________

____

____

____

CHAPTER 5

Trolley Busways

OBJECTIVES

After studying this chapter, the student should be able to

- identify features of a trolley busway installation.
- identify features of a lighting trolley busway and installation.
- select components to support cord drops.

THREE-PHASE TROLLEY BUSWAY

Many modern industrial plants use systems of mobile trolley outlets that move along specially constructed busways. The industrial trolley bus is a 100-ampere, enclosed busbar electrical system. Such a trolley bus provides a continuous outlet system for feeding electrical energy to portable electric tools, cranes, hoists, and other electrical loads.

When the trolley system is installed over production and assembly lines, it provides current to equipment through trolleys that move along with the particular object being assembled. Because the busbars are totally enclosed in a steel casing, there are no exposed live parts to provide hazards to worker safety. This system eliminates the need for and the hazards of portable cords plugged into fixed outlets at the floor level.

THE TROLLEY BUSWAY RUNS

Sheet E-2 of the industrial building plans shows the layout of the four trolley busway runs to be installed. The specifications provide more detailed information about the trolley busway system. The four runs as shown on Sheet E-2 are labeled A, B, C, and D. These runs are 68 ft (20.7 m), 131 ft (40 m), 96 ft (29 m), and 106 ft (32.3 m) long, respectively.

The trolley systems are constructed of straight sections joined end to end, Figure 5-1. The standard section is 10 ft (3 m) long, but sections of less than 10 ft (3 m) in length are available so that a run can be made to exact dimensions. Curved sections and other fittings are also available.

Trolley Busway Run A

Trolley run A consists of straight busway extending for 68 ft (20.7 m). One 3-phase drop-out section is installed at the approximate midpoint of the run. A drop-out section provides the means for removing or inserting the trolleys, Figure 5-2. As shown in Figure 5-2, the drop-out section contains two hinged doors that open when a lever is raised. When the lever is in the down position, the doors are firmly closed and the trolleys move past this section smoothly. Blocking straps ensure that a trolley cannot be placed in the duct incorrectly. This feature also ensures that the polarity is always correct after the trolleys are inserted. Drop-out sections are available in lengths of 10 ft (3 m), and one drop section must be installed in each run.

The trolley busway is to be suspended 8 ft (2.5 m) above the floor according to the specifications and is supported by standard hangers. These hangers also serve as a means for joining adjacent sections and automatically aligning the busbars. The hangers are formed from 12-gauge steel. However, the only tool needed to join the industrial-type trolley duct is a screwdriver.

Intermediate-type hangers are used at the midpoint of each standard 10 ft (3 m) section to give extra support. The intermediate hangers fit snugly around the duct sections but do not interfere with the free passage of the trolleys. The combination of the standard hangers and the intermediate hangers supports the busway at 5 ft (1.5 m) intervals, resulting in a very rigid and secure installation, Figure 5-3. The standard and intermediate hangers are attached to the overhead structure by rod or strap-type supports, Figure 5-4.

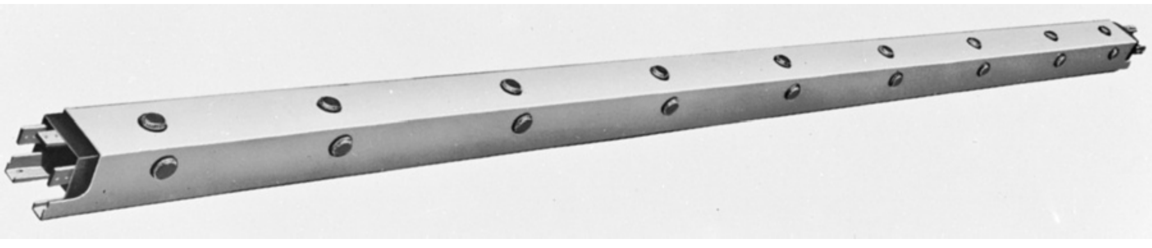


FIGURE 5-1 Standard 10 ft (3 m) section of trolley busway.

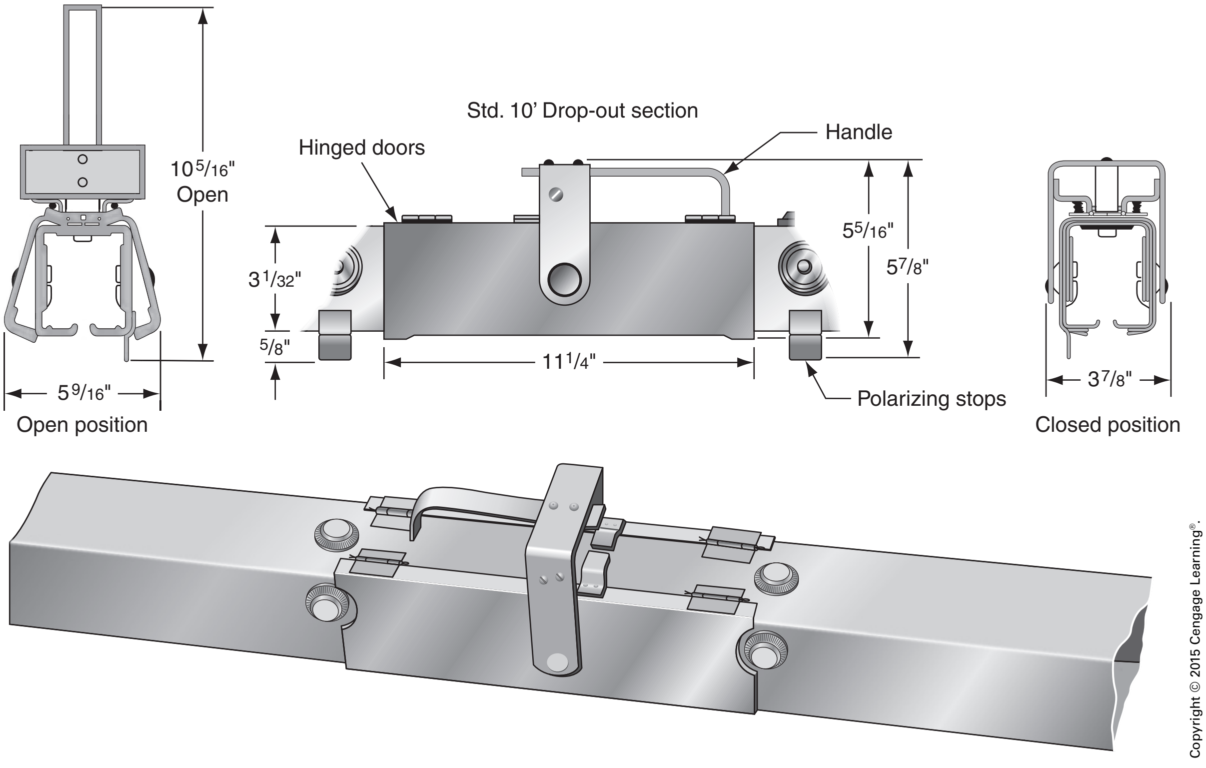


FIGURE 5-2 Standard drop-out section.

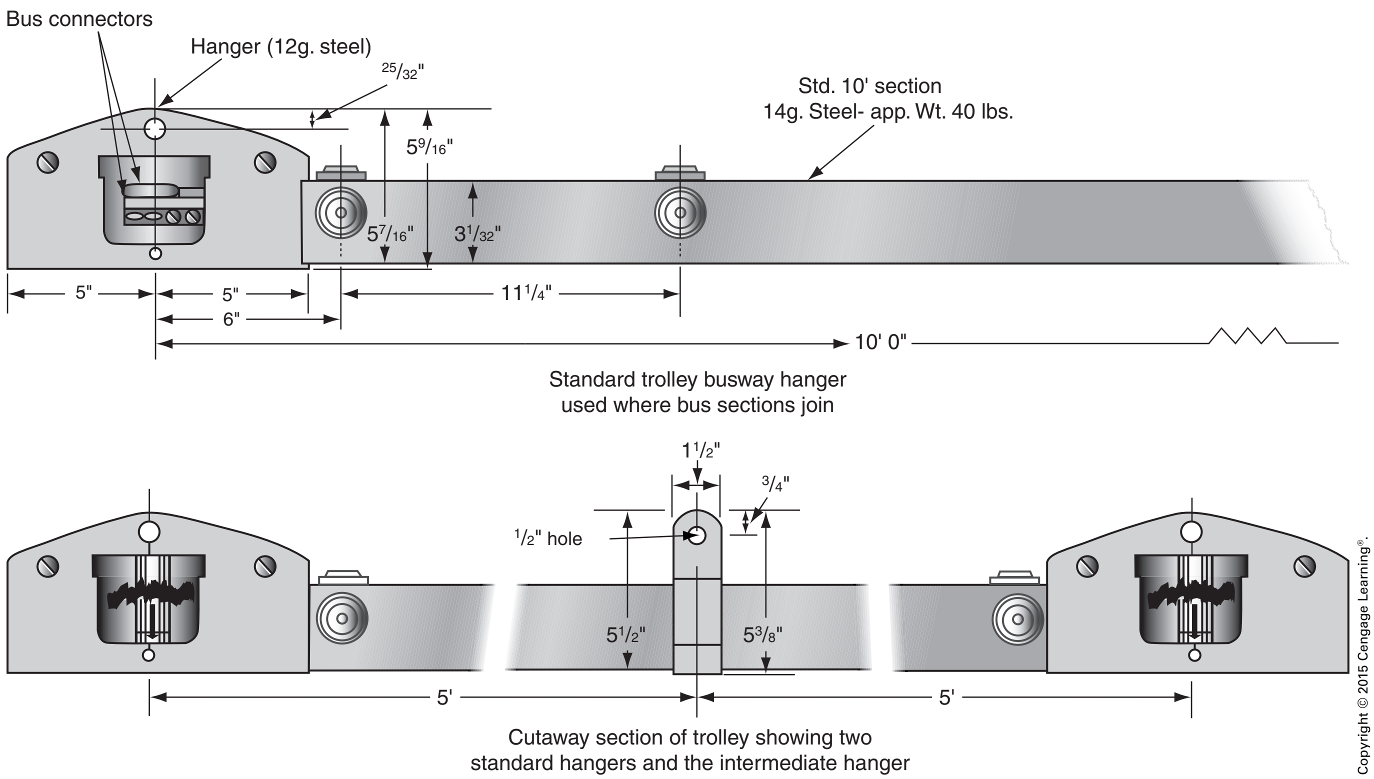


FIGURE 5-3 Supporting trolley busway.

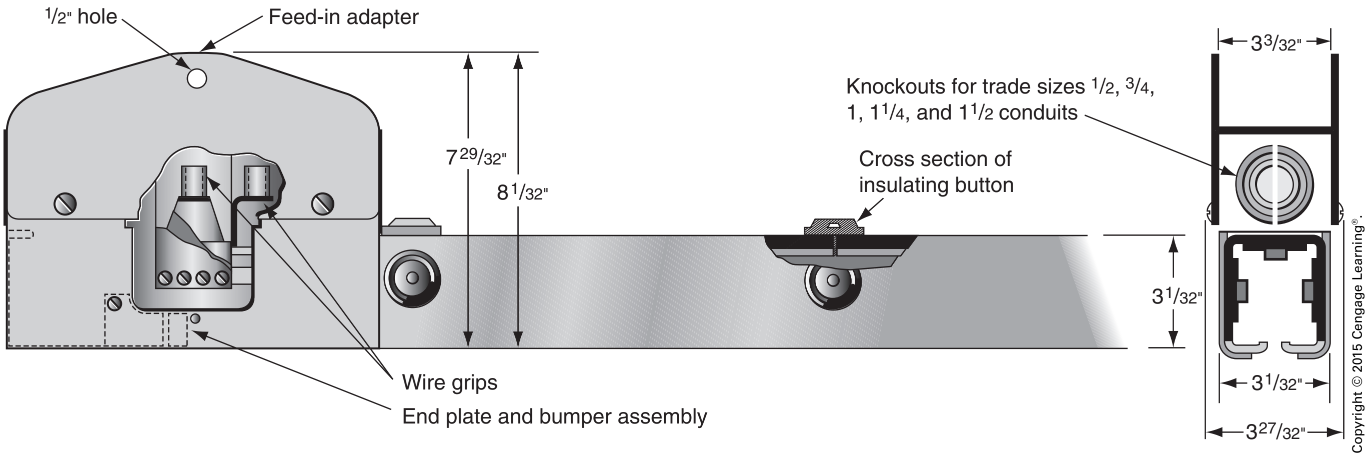


FIGURE 5-4 Trolley busway section with feed-in adapter and end plate with bumper.

Each end of the busway is capped with an end plate and bumper assembly. This device closes the ends of the busway run and acts as a bumper for any trolley reaching the end of the busway. The bumper absorbs shock and protects the trolley from damage.

Feed-in Adapter

The power supply from the panelboard is fed into the busway run through a *feed-in adapter*, Figure 5-4. The feed-in adapter has pressure-type wire terminals. This adapter can be used at the end of a run, or it can be installed in the center of the busway to provide center feed for the connection of the conduit or cable from the panelboard. Conduit must be installed between the power panelboard and the feed-in adapter to bring power to the trolley busway. A 100-ampere circuit will run in this conduit from panelboard P-15.

The Trolleys

Several types of both fused and unfused trolleys are available. The trolley specified for the industrial building is a fusible, box-type tool hanger with a heavy-duty rating. The box tool hanger, Figure 5-5, has a hinged cover and is provided with puller-type fuse cutouts, plug receptacles, and cord clamps. For the industrial building, cutouts for 0- to 30-ampere fuses are provided. The trolley has eight wheels and four side thrust rollers to ensure smooth movement along the busway.

The trolleys have six graphite bronze shoes. These shoes make contact with the busbars and provide a path that continues through the fuse cutout and receptacle to the heavy-duty, 4-wire rubber cord. This cord is used to attach the various portable tools such as electric drills, buffers, grinders, and other equipment to the busway system, Figure 5-6.

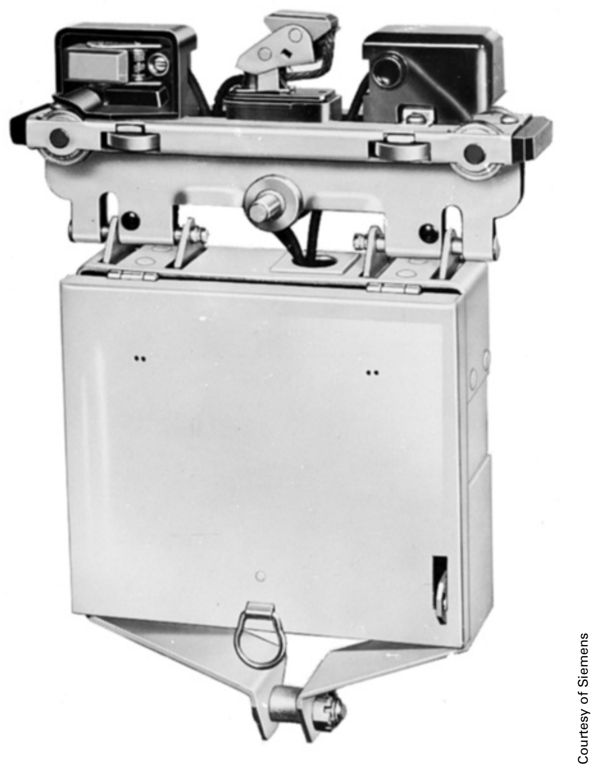
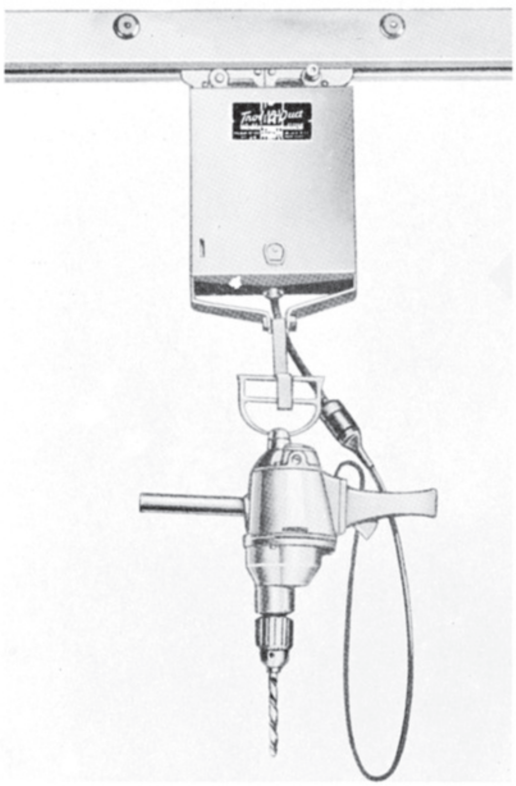


FIGURE 5-5 Trolley with box tool hanger.



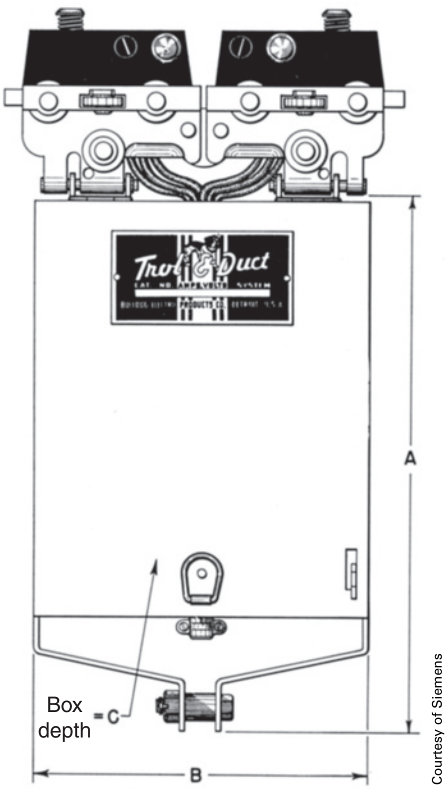


FIGURE 5-6 Heavy-duty trolley with box tool hanger.

The 4-wire rubber cord provides three conductors to operate the 3-phase portable tools used on the job. The fourth conductor (green in color) is used to ground the equipment (*400.23* and *400.24*).

One end of the grounding conductor must be attached securely to the trolley, and the other end to the housing of the portable tool. The cord must be approved for heavy-duty usage and may be a type SJ containing 12 AWG conductors. The fuses in the trolley are rated at 20 amperes, Figure 5-7.

The specifications for the industrial building call for the use of one trolley for each 15 ft (4.5 m) or fraction thereof of trolley busway. Thus, for run A (68 ft [20.7 m] long), the contractor must furnish five trolleys. Figure 5-8 shows a typical installation of trolley busway.

The Conduit Run

Conduit must be installed from the feed-in adapter to the power panelboard to bring electrical energy to the duct runs. A 100-ampere feeder circuit will run in this conduit from panelboard P-15.

Trolley Busway Run B

As shown on the plans, trolley busway run B extends 131 ft (40 m) in length. The information supplied for busway run A also applies to trolley runs B, C, and D. The location of run B is shown on Sheet E-2. As is the case for run A, conduit must be installed to power panelboard No. 15. The conduit runs must be routed to conform with the structure of the building. Nine trolleys are required for trolley run B.

Trolley Run C

Trolley run C is a straight run extending 96 ft (29 m) (see Sheet E-2 of the plans). This run is connected to power panelboard No. 15 by conduit from the feed-in adapter located at the end of the run. Six trolleys are required for trolley run C.

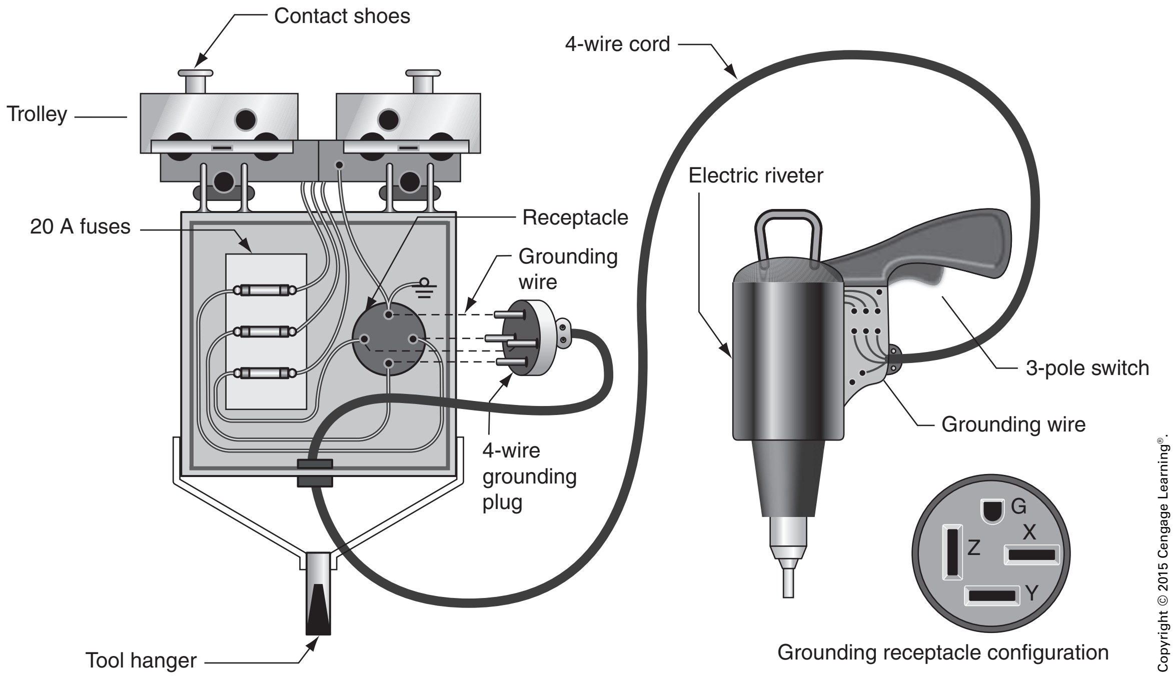


FIGURE 5-7 Details of trolley box-type tool hanger showing grounding connections.

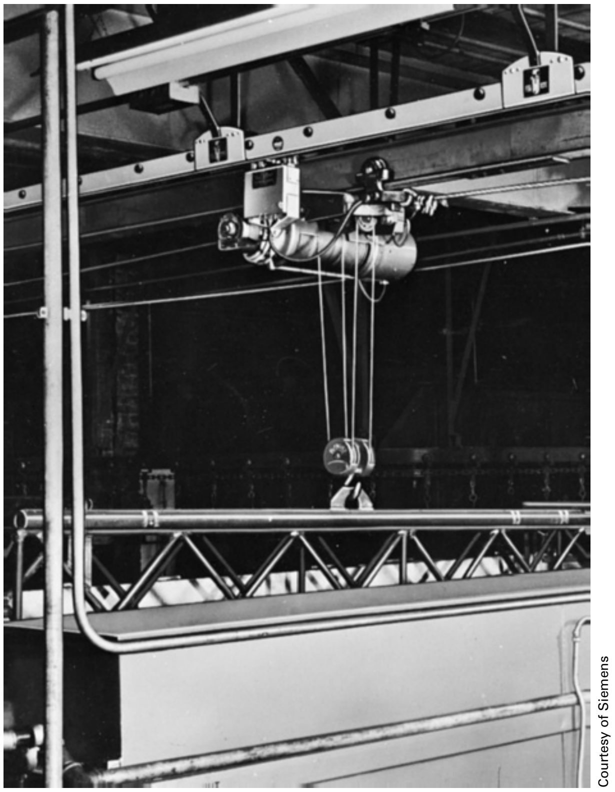


FIGURE 5-8 Trolley busway may be used to feed power to hoisting equipment.

Trolley Run D

Trolley run D is 106 ft (32.3 m) long. The installation methods and parts used for this run are the same as those used in the other runs. Panelboard P-15 (located on the west wall of the manufacturing area) again supplies electrical energy to the run. According to the specifications, run D requires eight trolleys including tool hangers to be installed, one for every 15 ft (4.5 m) or fraction thereof of busway.

Each of the four trolley systems (A through D) is a 3-phase system and is rated at 208 volts and 100 amperes. The equipment attachment plugs used with the duct system are polarized. This feature eliminates several problems when portable tools having 3-phase motors are used. For example, reversed phases and the resulting reversal in the direction of rotation of the portable tools are eliminated.

These trolley systems have several advantages. The runs follow the production and assembly lines of the plant. This convenience tends to increase the amount of work that can be completed. A neater and safer production area is maintained because the tools the worker commonly uses are not scattered over the floor but rather are suspended directly over the working area.

LIGHTING IN THE MANUFACTURING AREA

The general illumination system for the manufacturing area of the plant consists of 180 fluorescent luminaires suspended from a system of 50-ampere lighting trolley busways. This type of lighting system is in wide use in industrial applications because of the mobility provided by the system, Figure 5-9. For example, in modern industry, production lines and machine layouts can be changed when so required by the introduction of new products or manufacturing methods. A lighting system composed of fixed outlets and a fixed conduit system is not easily adaptable to such changing requirements.

On the other hand, a system of luminaires suspended from a trolley system can be readily shifted from one location to another as desired. It is not necessary to take down or replace heavy conduit systems as would be required to change a fixed lighting outlet system. If extensive alterations or a major plant changeover requires the removal of the lighting trolley duct, the duct sections are completely reusable.

The lighting trolley busways are rated at 50 amperes. Thus, 50-ampere lighting circuits are available, as compared with the 15- or 20-ampere branch circuits used in conventional lighting systems. The 50-ampere lighting circuits used in the trolley systems are approved by the Underwriters Laboratories, Inc. (UL).

The trolley lighting circuits in the industrial building consist of twenty 50-ampere branch circuits. These branch circuits, in turn, are composed of 20 trolley runs constructed of standard 10 ft (3 m) lengths and special lengths as necessary. Each run is about 96 ft (29.3 m) long. The runs are suspended by special clips from messenger wires stretched tightly below the roof structure trusswork. These messenger wires are adjusted for tension by turnbuckles located at the ends of the runs. Intermediate supports for the messenger cables, Figure 5-10, must be attached to

Courtesy of Siemens

FIGURE 5-9 Typical trolley busway lighting system.

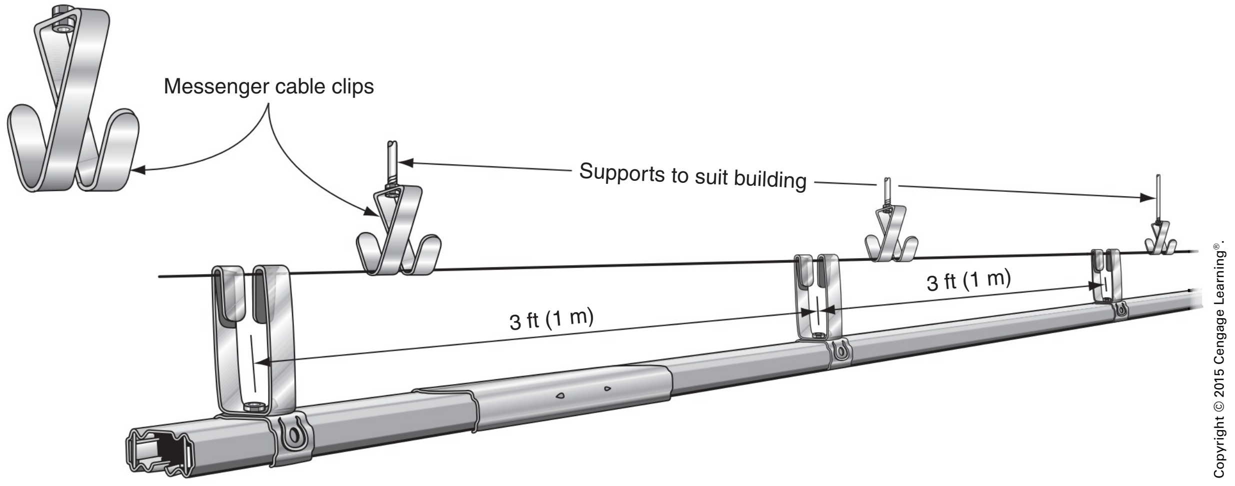


FIGURE 5-10 Messenger cable suspension.

the overhead structure at appropriate intervals to prevent any sagging of the lighting system.

The lighting trolley is available in 5 ft (1.5 m) and 10 ft (3 m) sections. These sections are joined by plain couplings. The ends of the sections contain trolley entrance end caps. The plain couplings make a positive connection, electrically and mechanically, between two duct sections and permit free passage of the trolleys along the duct runs. The trolley entrance and caps serve two purposes: They close the ends of the duct runs and they provide an entrance point for the insertion or removal of the trolleys, Figure 5-11.

Other trolley entrance couplings are used at the midpoint (approximately) of each duct run. This arrangement is an additional convenience when removing or inserting trolleys. To prevent arcing, trolleys should not be inserted or removed while they are under load.

Center feed-in boxes are used to bring the electrical supply cables to the trolley busway. Each box

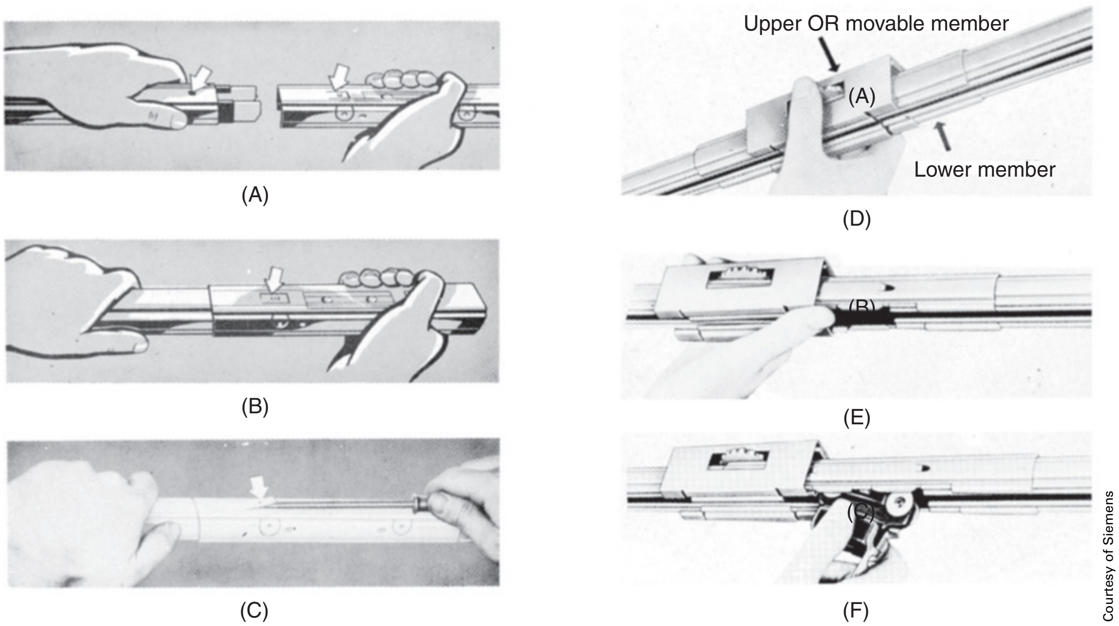


FIGURE 5-11 Plain and trolley entrance couplings.

has two adjustable couplings (one on each end of the box) connected by removable flexible jumper wires. In addition, the feed-in box has two sets of concentric knockouts that provide a means of bringing the feeding conduits into the duct system, Figure 5-12.

The Busbars

The trolley busway is equipped with two copper busbars. Each bar has a cross-sectional area of 30,557 circular mils and is rated by UL at 50 amperes and 250 volts, Figure 5-13.

FIGURE 5-12 Feed-in box.

The Trolleys

Several types of trolleys are available for use with the lighting trolley busway. The trolley specified for the industrial building is equipped with a cord clamp and grounding screw. The trolley has metal wheels and rolls freely along the busway from one position to another. Two heavy-duty, weight-supporting devices are used with the trolley when heavy luminaires are to be suspended from it as is the case with the industrial building, Figure 5-14.

The twenty 50-ampere trolley busway branch lighting circuits in the manufacturing area run east and west from the twenty center feed-in boxes (see Sheet E-3 of the plans). These circuits form ten lines of trolley busway suspended lighting. Each circuit has nine trolleys, and an industrial-type, 96 in. long (2.5 m long) fluorescent luminaire is suspended from each trolley.

The luminaires used in the manufacturing area are industrial-type fluorescent luminaires. Each luminaire uses two F96T12/CW/VHO lamps rated at 215 watts each. However, the power losses in the ballasts increase this value to 450 volt-amperes per luminaire. The fluorescent ballasts used are all of

FIGURE 5-13 Busbar section.

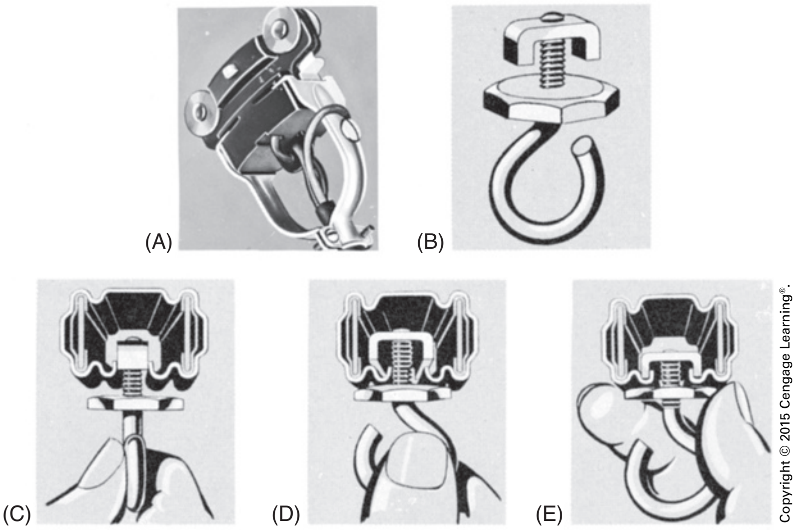


FIGURE 5-14 Heavy-duty weight supports.

the high power factor type, with individual fusing provided in accordance with *368.17*.

The luminaires are also equipped with *lead-lag adders*, which cause the lamps to fire at different times. In other words, the current wave crest of one lamp occurs nearly one-half cycle before the second lamp receives the wave crest. This arrangement eliminates most of the stroboscopic effect that occurs if individual lamps are used or if the lead-lag system is not used.

The luminaires are supported at the center by the trolley attachment and by two additional supports near the ends of each luminaire. Of the 180 luminaires installed in the industrial building, 45 are fed from each of the four panelboards.

In addition to the lighting, several receptacle outlets are also supplied with power from each of the panelboards. According to the plans and the Schedule of Receptacle Outlets included in the specifications, each of the four lighting panelboards in the manufacturing area of the plant contains seven 20-ampere circuit breakers feeding fifteen duplex grounding receptacles. Two or three receptacle outlets are assigned to each of these 120-volt circuits.

LIGHTING IN THE BOILER ROOM

Panelboard P-12 is located in the boiler room of the plant. This panelboard supplies the lighting and receptacle needs in this area. There are sixteen lighting outlets in the boiler room connected to four separate circuits so that there are four outlets on each circuit. The luminaires used in the boiler room are the same as those used in the manufacturing area. However, these sixteen luminaires are suspended by chains from fixed outlet boxes.

The Cord Drops (*NEC Article 400*)

The specifications call for the use of 4-conductor type SJ rubber cord to connect the various machines in the manufacturing area to the busway system. These cords are rated for heavy-duty usage. The colors of the individual conductors of the cord are black, white, red, and green.

The green conductor is reserved for equipment grounding. One end of this conductor is connected to the steel housing of the bus plug. The other end of the conductor is connected to the steel housing of the motor control equipment on the machine.

The drop from the overhead busway system to supply power to the machines located at various points on the floor is usually made by either of two methods.

One method involves the use of rigid or thinwall conduit to extend from the bus plug to the machine that it will serve. The conduit may be run horizontally with or without bends to a point directly over the machine to be supplied and then dropped vertically.

The resulting system is a rigid raceway assembly that must be supported by appropriate hangers. The ungrounded conductors are pulled into the conduit, which serves as the equipment ground.

One disadvantage of this method is its inflexibility when the layout of the machines being served must be rearranged. In such a case, the conduit assemblies must be taken down, the wire removed, and the conduit disassembled. Then, the entire run must be rebuilt to fit the new location using new wire and new conduit for part or all of the assembly.

The second method is to use rubber cord drops from the bus plug to the machine being served, Figure 5-15. This method is flexible in terms of making changes and thus is commonly used. The industrial building uses the rubber cord drop method.

Strain Reliefs

Strain relief grips are used in the cord drop method of supplying equipment to comply with *400.10*. The strain relief type of grip is designed for use at the terminals or ends of the rubber cord drop where it enters or leaves a knockout opening in the bus plug, in the disconnecting switch, or in a motor controller.

The bus drop grips are used at or near the ends of the rubber cord runs and also where the cord changes direction from the horizontal to the vertical, Figure 5-15 and Figure 5-16.

Figure 5-17 shows that the cord grips are constructed in a basketweave pattern. The grips are tubular in shape and are made from strands of galvanized plow steel wire. Grips are available in a

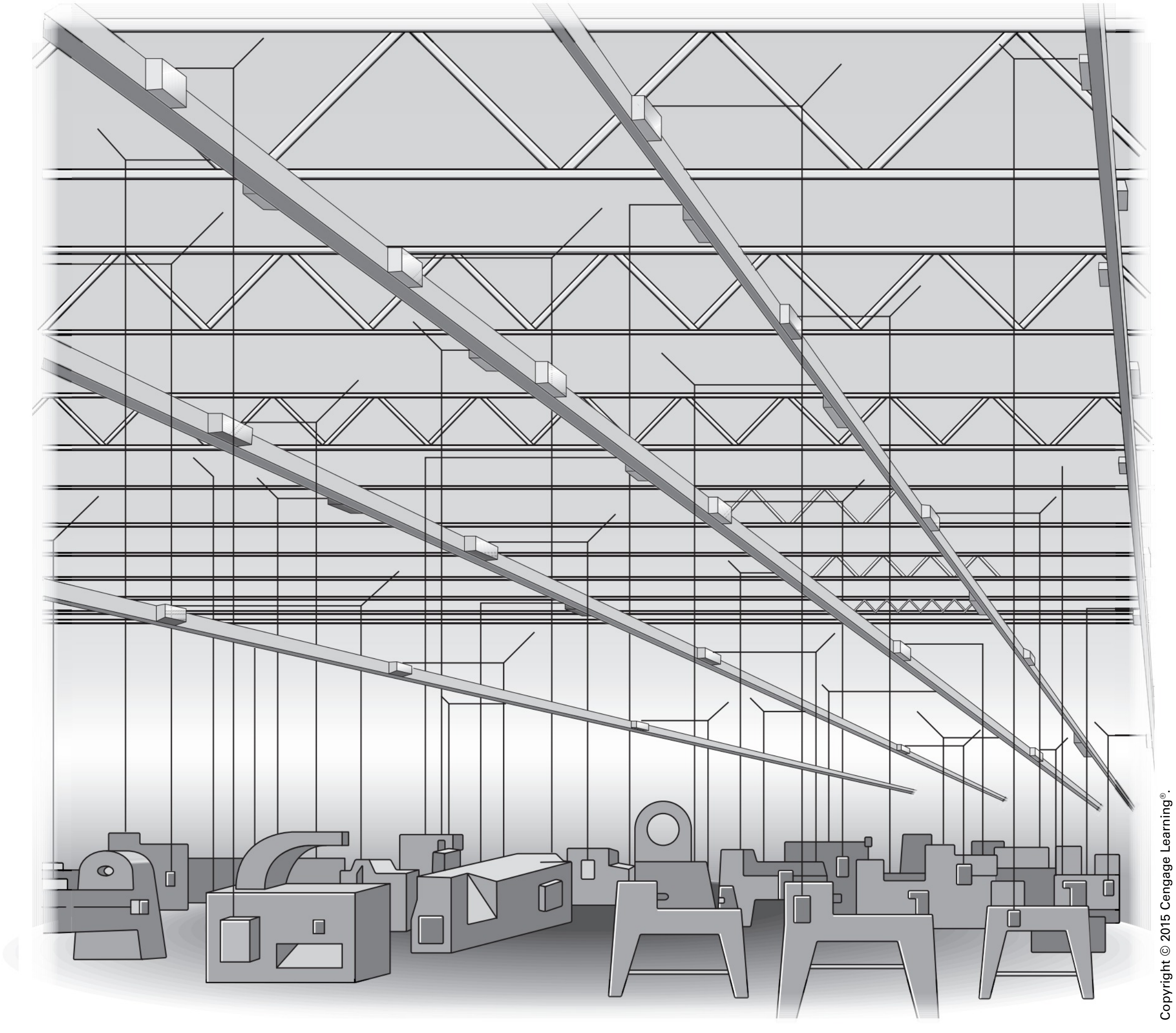


FIGURE 5-15 Machines supplied by rubber cords from overhead busway.

variety of sizes to fit most cables or cords. When strain or tension is placed on the rubber cord so that it is pulled taut, the basket structure of the cord grip contracts to apply a stronger grip on the cord.

Bus drop safety springs are used to maintain the proper tension on the horizontal and vertical cord runs. These springs are available with 40-, 80-, and 150-pound (18.14, 36.28, and 68 kg) ratings. The selection of the proper spring depends upon the weight and length of the cord being supported, Figure 5-18.

Several different ways of using cord grips are shown in Figure 5-19.

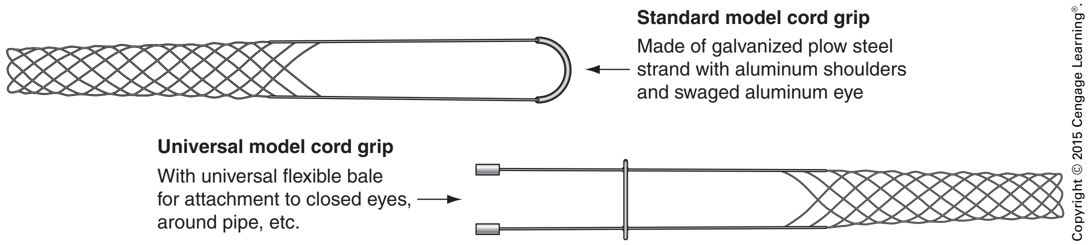


FIGURE 5-16 Cord grip models.

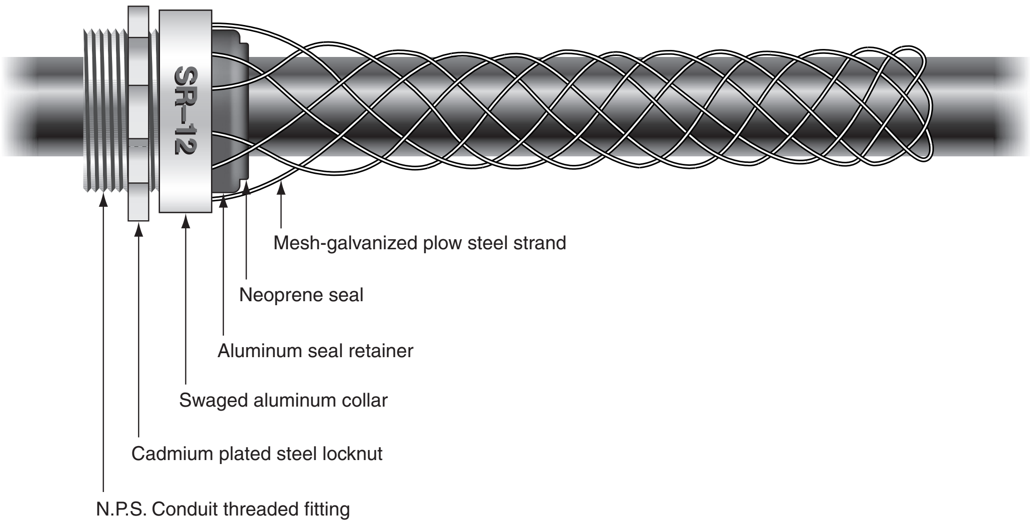
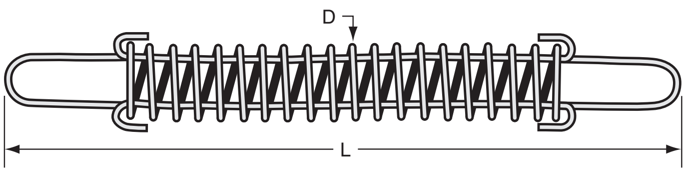


FIGURE 5-17 Bus drop and strain relief cord grip.



Catalog number	Maximum deflection	Breaking strength	No load length	Diameter
40 lb.	2.875 in. @ 45 lb. 73.0 mm @ 20.4 kg	500 lb. 227 kg	7.25 in. 184 mm	0.75 in. 19 mm
80 lb.	2.62 in. @ 110 lb. 66.5 mm @ 50 kg	850 lb. 385 kg	8.25 in. 209 mm	1 in. 25 mm
150 lb.	2.38 in. @175 lb. 60.5 mm @ 79 kg	850 lb. 385 kg	8.25 in. 209 mm	1.125 in. 28 mm

FIGURE 5-18 Bus drop safety spring.

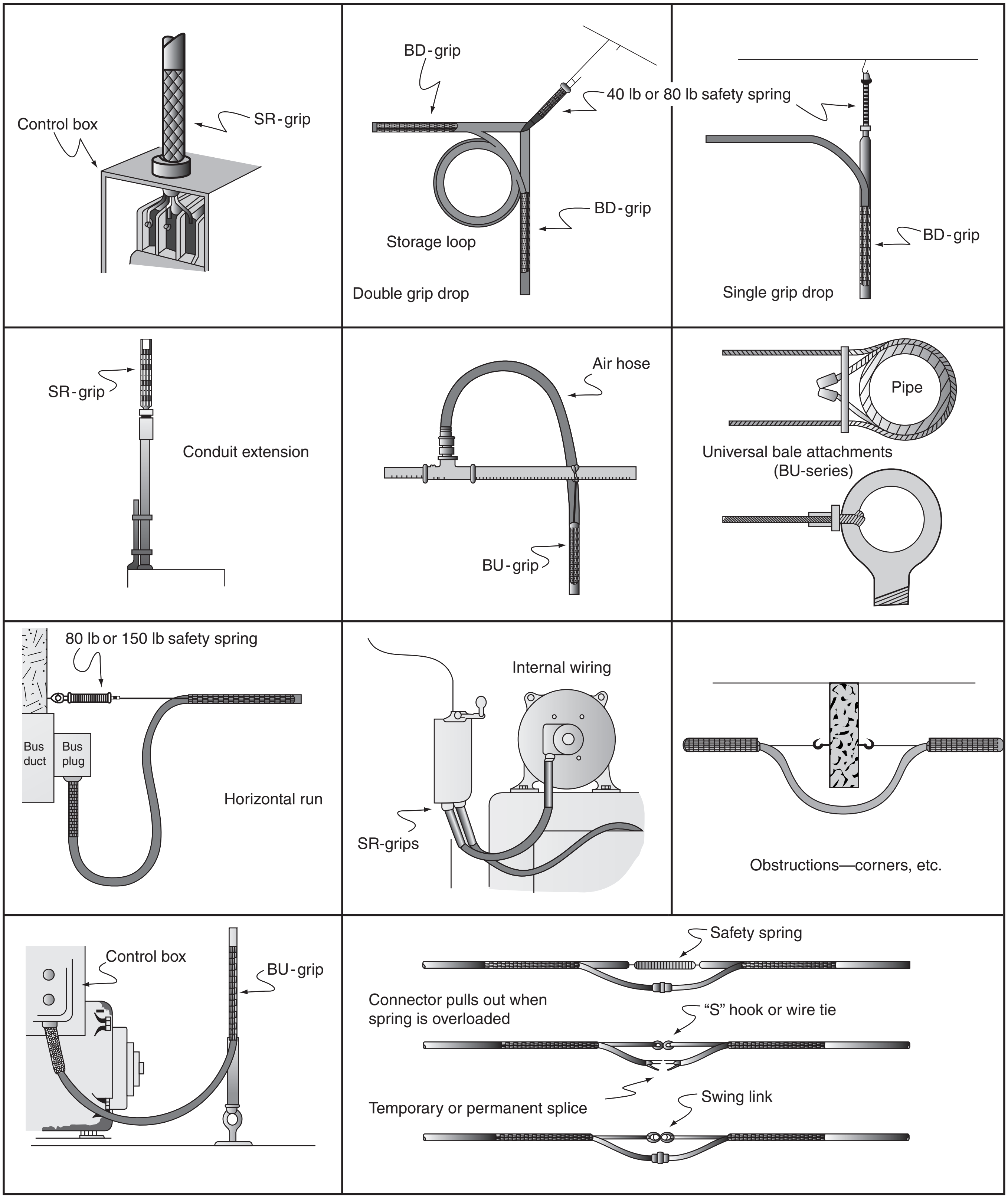


FIGURE 5-19 Applications of bus drop and strain relief cord grips.

REVIEW QUESTIONS

All answers should be written in complete sentences. Calculations should be shown in detail, and *Code* references should be cited when appropriate.

1. What advantages are there to having a trolley busway installed? ___________________

2. Is the trolley busway considered to be a feeder or a branch circuit? ___________________

3. What features does a trolley box–type hanger provide? ___________________

4. Describe the operation of strain relief grips and identify their basic function. ________

5. What are some of the advantages of installing the lighting on a busway? ___________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CHAPTER **6**

Using Wire Tables and Determining Conductor Sizes

OBJECTIVES

After studying this chapter, the student should be able to

- select a conductor from the proper wire table.
- discuss the different types of wire insulation.
- determine insulation characteristics.
- use correction and adjustment factors to determine the ampacity of conductors.
- determine the resistance of long lengths of conductors.
- determine the proper wire sizes for loads located long distances from the power source.
- list the requirements for using parallel conductors.
- discuss the use of a megohmmeter for testing insulation.

CONDUCTORS

- *NEC Article 310* addresses conductors for general wiring.
- *NEC Table 310.104(A)*, reproduced in this chapter as Table 6-1, lists the conductor application and gives specific information about each insulation type.

NEC® TABLE 6-1

Table 310.104(A) Conductor Applications and Insulations Rated 600 Volts[1]

Trade Name	Type Letter	Maximum Operating Temperature	Application Provisions	Insulation	Thickness of Insulation: AWG or kcmil	Thickness of Insulation: mm	Thickness of Insulation: mils	Outer Covering[2]
Fluorinated ethylene propylene	FEP or FEPB	90°C 194°F	Dry and damp locations	Fluorinated ethylene propylene	14–10 8–2	0.51 0.76	20 30	None
		200°C 392°F	Dry locations — special applications[3]	Fluorinated ethylene propylene	14–8	0.36	14	Glass braid
					6–2	0.36	14	Glass or other suitable braid material
Mineral insulation (metal sheathed)	MI	90°C 194°F 250°C 482°F	Dry and wet locations For special applications[3]	Magnesium oxide	18–16[4] 16–10 9–4 3–500	0.58 0.91 1.27 1.40	23 36 50 55	Copper or alloy steel
Moisture-, heat-, and oil-resistant thermoplastic	MTW	60°C 140°F 90°C 194°F	Machine tool wiring in wet locations Machine tool wiring in dry locations. Informational Note: See NFPA 79.	Flame-retardant, moisture-, heat-, and oil-resistant thermoplastic	 22–12 10 8 6 4–2 1–4/0 213–500 501–1000	(A) (B) 0.76 0.38 0.76 0.51 1.14 0.76 1.52 0.76 1.52 1.02 2.03 1.27 2.41 1.52 2.79 1.78	(A) (B) 30 15 30 20 45 30 60 30 60 40 80 50 95 60 110 70	(A) None (B) Nylon jacket or equivalent
Paper		85°C 185°F	For underground service conductors, or by special permission	Paper				Lead sheath
Perfluoroalkoxy	PFA	90°C 194°F 200°C 392°F	Dry and damp locations Dry locations — special applications[3]	Perfluoro-alkoxy	14–10 8–2 1–4/0	0.51 0.76 1.14	20 30 45	None
Perfluoroalkoxy	PFAH	250°C 482°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus (nickel or nickel-coated copper only)	Perfluoro-alkoxy	14–10 8–2 1–4/0	0.51 0.76 1.14	20 30 45	None
Thermoset	RHH	90°C 194°F	Dry and damp locations		14–10 8–2 1–4/0 213–500 501–1000 1001–2000	1.14 1.52 2.03 2.41 2.79 3.18	45 60 80 95 110 125	Moisture-resistant, flame-retardant, nonmetallic covering[2]
Moisture-resistant thermoset	RHW	75°C 167°F	Dry and wet locations	Flame-retardant, moisture-resistant thermoset	14–10 8–2 1–4/0 213–500 501–1000 1001–2000	1.14 1.52 2.03 2.41 2.79 3.18	45 60 80 95 110 125	Moisture-resistant, flame-retardant, nonmetallic covering
	RHW-2	90°C 194°F						

NEC® TABLE 6-1

Table 310.104(A) *Continued*

Trade Name	Type Letter	Maximum Operating Temperature	Application Provisions	Insulation	Thickness of Insulation: AWG or kcmil	Thickness of Insulation: mm	Thickness of Insulation: mils	Outer Covering[2]
Silicone	SA	90°C 194°F 200°C 392°F	Dry and damp locations For special application[3]	Silicone rubber	14–10 8–2 1–4/0 213–500 501–1000 1001–2000	1.14 1.52 2.03 2.41 2.79 3.18	45 60 80 95 110 125	Glass or other suitable braid material
Thermoset	SIS	90°C 194°F	Switchboard and switchgear wiring only	Flame-retardant thermoset	14–10 8–2 1–4/0	0.76 1.14 2.41	30 45 55	None
Thermoplastic and fibrous outer braid	TBS	90°C 194°F	Switchboard and switchgear wiring only	Thermoplastic	14–10 8 6–2 1–4/0	0.76 1.14 1.52 2.03	30 45 60 80	Flame-retardant, nonmetallic covering
Extended polytetra-fluoroethylene	TFE	250°C 482°F	Dry locations only. Only for leads within apparatus or within raceways connected to apparatus, or as open wiring (nickel or nickel-coated copper only)	Extruded polytetra-fluoroethylene	14–10 8–2 1–4/0	0.51 0.76 1.14	20 30 45	None
Heat-resistant thermoplastic	THHN	90°C 194°F	Dry and damp locations	Flame-retardant, heat-resistant thermoplastic	14–12 10 8–6 4–2 1–4/0 250–500 501–1000	0.38 0.51 0.76 1.02 1.27 1.52 1.78	15 20 30 40 50 60 70	Nylon jacket or equivalent
Moisture- and heat-resistant thermoplastic	THHW	75°C 167°F 90°C 194°F	Wet location Dry location	Flame-retardant, moisture- and heat-resistant thermoplastic	14–10 8 6–2 1–4/0 213–500 501–1000 1001–2000	0.76 1.14 1.52 2.03 2.41 2.79 3.18	30 45 60 80 95 110 125	None
Moisture- and heat-resistant thermoplastic	THW	75°C 167°F 90°C 194°F	Dry and wet locations Special applications within electric discharge lighting equipment. Limited to 1000 open-circuit volts or less. (size 14–8 only as permitted in 410.68)	Flame-retardant, moisture- and heat-resistant thermoplastic	14–10 8 6–2 1–4/0 213–500 501–1000 1001–2000	0.76 1.14 1.52 2.03 2.41 2.79 3.18	30 45 60 80 95 110 125	None
	THW-2	90°C 194°F	Dry and wet locations					
Moisture- and heat-resistant thermoplastic	THWN	75°C 167°F	Dry and wet locations	Flame-retardant, moisture- and heat-resistant thermoplastic	14–12 10 8–6 4–2 1–4/0 250–500 501–1000	0.38 0.51 0.76 1.02 1.27 1.52 1.78	15 20 30 40 50 60 70	Nylon jacket or equivalent
	THWN-2	90°C 194°F						
Moisture-resistant thermoplastic	TW	60°C 140°F	Dry and wet locations	Flame-retardant, moisture-resistant thermoplastic	14–10 8 6–2 1–4/0 213–500 501–1000 1001–2000	0.76 1.14 1.52 2.03 2.41 2.79 3.18	30 45 60 80 95 110 125	None

(*Continues*)

NEC® TABLE 6-1

Table 310.104(A) *Continued*

Trade Name	Type Letter	Maximum Operating Temperature	Application Provisions	Insulation	Thickness of Insulation			Outer Covering[2]
					AWG or kcmil	mm	mils	
Underground feeder and branch-circuit cable — single conductor (for Type UF cable employing more than one conductor, see Article 340.)	UF	60°C 140°F 75°C 167°F[5]	See Article 340.	Moisture-resistant Moisture- and heat-resistant	14–10 8–2 1–4/0	1.52 2.03 2.41	60[6] 80[6] 95[6]	Integral with insulation
Underground service-entrance cable — single conductor (for Type USE cable employing more than one conductor, see Article 338.)	USE	75°C 167°F[5]	See Article 338.	Heat- and moisture-resistant	14–10 8–2 1–4/0 213–500 501–1000 1001–2000	1.14 1.52 2.03 2.41 2.79 3.18	45 60 80 95[7] 110 125	Moisture-resistant nonmetallic covering (See 338.2.)
	USE-2	90°C 194°F	Dry and wet locations					
Thermoset	XHH	90°C 194°F	Dry and damp locations	Flame-retardant thermoset	14–10 8–2 1–4/0 213–500 501–1000 1001–2000	0.76 1.14 1.40 1.65 2.03 2.41	30 45 55 65 80 95	None
Moisture-resistant thermoset	XHHW	90°C 194°F 75°C 167°F	Dry and damp locations Wet locations	Flame-retardant, moisture-resistant thermoset	14–10 8–2 1–4/0 213–500 501–1000 1001–2000	0.76 1.14 1.40 1.65 2.03 2.41	30 45 55 65 80 95	None
Moisture-resistant thermoset	XHHW-2	90°C 194°F	Dry and wet locations	Flame-retardant, moisture-resistant thermoset	14–10 8–2 1–4/0 213–500 501–1000 1001–2000	0.76 1.14 1.40 1.65 2.03 2.41	30 45 55 65 80 95	None
Modified ethylene tetrafluoroethylene	Z	90°C 194°F 150°C 302°F	Dry and damp locations Dry locations — special applications[3]	Modified ethylene tetrafluoro-ethylene	14–12 10 8–4 3–1 1/0–4/0	0.38 0.51 0.64 0.89 1.14	15 20 25 35 45	None
Modified ethylene tetrafluoroethylene	ZW	75°C 167°F 90°C 194°F 150°C 302°F	Wet locations Dry and damp locations Dry locations — special applications[3]	Modified ethylene tetrafluoro-ethylene	14–10 8–2	0.76 1.14	30 45	None
	ZW-2	90°C 194°F	Dry and wet locations					

[1] Conductors can be rated up to 1000 V if listed and marked.
[2] Some insulations do not require an outer covering.
[3] Where design conditions require maximum conductor operating temperatures above 90°C (194°F).
[4] For signaling circuits permitting 300-volt insulation.
[5] For ampacity limitation, see 340.80.
[6] Includes integral jacket.
[7] Insulation thickness shall be permitted to be 2.03 mm (80 mils) for listed Type USE conductors that have been subjected to special investigations. The nonmetallic covering over individual rubber-covered conductors of aluminum-sheathed cable and of lead-sheathed or multiconductor cable shall not be required to be flame retardant. For Type MC cable, see 330.104. For nonmetallic-sheathed cable, see Article 334, Part III. For Type UF cable, see Article 340, Part III.

- *NEC Tables 310.15(B)(16)* through *310.15(B)(19)* are used to determine a conductor size according to the requirements of a circuit. *NEC Tables 310.15(B)(16)* and *310.15(B)(17)* are reproduced in this chapter as Tables 6-2 and 6-3, respectively.
- Table 6-2 (*NEC Table 310.15(B)(16)*) lists allowable ampacities for not more than three

NEC® TABLE 6-2

Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

	Temperature Rating of Conductor [See Table 310.104(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
Size AWG or kcmil	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			Size AWG or kcmil
18**	—	—	14	—	—	—	—
16**	—	—	18	—	—	—	—
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	350	420	475	285	340	385	600
700	385	460	520	315	375	425	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	445	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	525	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	555	665	750	470	560	630	2000

*Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).
**Refer to 240.4(D) for conductor overcurrent protection limitations.

NEC® **TABLE 6-3**

Table 310.15(B)(17) (formerly Table 310.17) Allowable Ampacities of Single-Insulated Conductors Rated Up to and Including 2000 Volts in Free Air, Based on Ambient Temperature of 30°C (86°F)*

Size AWG or kcmil	Temperature Rating of Conductor [See Table 310.104(A).]						Size AWG or kcmil
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			
18	—	—	18	—	—	—	—
16	—	—	24	—	—	—	—
14**	25	30	35	—	—	—	—
12**	30	35	40	25	30	35	12**
10**	40	50	55	35	40	45	10**
8	60	70	80	45	55	60	8
6	80	95	105	60	75	85	6
4	105	125	140	80	100	115	4
3	120	145	165	95	115	130	3
2	140	170	190	110	135	150	2
1	165	195	220	130	155	175	1
1/0	195	230	260	150	180	205	1/0
2/0	225	265	300	175	210	235	2/0
3/0	260	310	350	200	240	270	3/0
4/0	300	360	405	235	280	315	4/0
250	340	405	455	265	315	355	250
300	375	445	500	290	350	395	300
350	420	505	570	330	395	445	350
400	455	545	615	355	425	480	400
500	515	620	700	405	485	545	500
600	575	690	780	455	545	615	600
700	630	755	850	500	595	670	700
750	655	785	885	515	620	700	750
800	680	815	920	535	645	725	800
900	730	870	980	580	700	790	900
1000	780	935	1055	625	750	845	1000
1250	890	1065	1200	710	855	965	1250
1500	980	1175	1325	795	950	1070	1500
1750	1070	1280	1445	875	1050	1185	1750
2000	1155	1385	1560	960	1150	1295	2000

*Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).
**Refer to 240.4(D) for conductor overcurrent protection limitations.

insulated, copper conductors in a raceway, based on an ambient air temperature of 86°F (30°C).

- If the ambient temperature is above 86°F (30°C), a correction factor must be applied. These factors are given in *Table 310.15(B)(2)(a)* reproduced in this chapter as Table 6-4.
- If there are four or more conductors in the raceway, an adjustment factor shall be applied. These factors are given in *NEC Table 310.15(B)(3)(a)*, reproduced in this chapter as Table 6-5.

INSULATION TYPE

A factor that determines the amount of current a conductor is permitted to carry is the type of insulation used. The insulation is the nonconductive covering

NEC® **TABLE 6-4**

Table 310.15(B)(2)(a) Ambient Temperature Correction Factors Based on 30°C (86°F)

For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities specified in the ampacity tables by the appropriate correction factor shown below.				
Ambient Temperature (°C)	**Temperature Rating of Conductor**			**Ambient Temperature (°F)**
	60°C	**75°C**	**90°C**	
10 or less	1.29	1.20	1.15	50 or less
11–15	1.22	1.15	1.12	51–59
16–20	1.15	1.11	1.08	60–68
21–25	1.08	1.05	1.04	69–77
26–30	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	132–140
61–65	—	0.47	0.65	141–149
66–70	—	0.33	0.58	150–158
71–75	—	—	0.50	159–167
76–80	—	—	0.41	168–176
81–85	—	—	0.29	177–185

NEC® **TABLE 6-5**

Table 310.15(B)(3)(a) Adjustment Factors for More Than Three Current-Carrying Conductors

Number of Conductors[1]	**Percent of Values in Table 310.15(B)(16) through Table 310.15(B)(19) as Adjusted for Ambient Temperature if Necessary**
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

[1]Number of conductors is the total number of conductors in the raceway or cable, including spare conductors. The count shall be adjusted in accordance with 310.15(B)(5) and (6). The count shall not include conductors that are connected to electrical components but that cannot be simultaneously energized.

around the wire, as shown in Figure 6-1. Some types of insulation can withstand more heat than other types. The voltage rating of the conductor is also determined by the type of insulation. The amount of voltage a particular type of insulation can withstand without breaking down is determined by the type of material from which it is made and its thickness. Table 6-1 [*NEC Table 310.104(A)*] lists different types of insulation and certain specifications about each one.

The table is divided into seven main columns. The first column lists the trade name of the insulation; the second lists its identification code letter; the

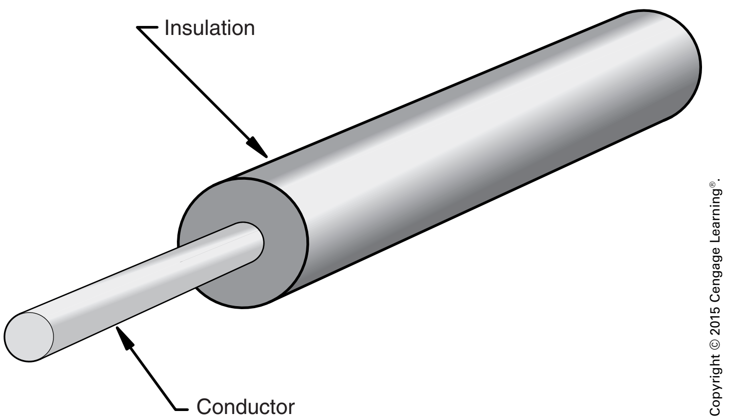

FIGURE 6-1 An insulated conductor.

third column lists its maximum operating temperature; and the fourth shows its applications and where it is permitted to be used. The fifth column lists the material from which the insulation is made; the sixth states its thickness; and the last column lists the type of outer covering over the insulation.

PROBLEM 1: Find the maximum operating temperature of type TW insulation. Refer to Table 6-1.

● **Solution:** The eighteenth data row of Table 6-1 gives the specifications for type TW conductors. The third column gives the maximum operating temperature as 60°C, or the equivalent 140°F. ●

PROBLEM 2: Can type THHN insulation be used in wet locations?

● **Solution:** Locate type THHN insulation in Table 6-1. The fourth column indicates that this insulation can be used in dry and damp locations. This type of insulation cannot be used in wet locations. For an explanation of the difference between damp and wet locations, consult "locations" in *NEC Article 100*. ●

Conductor Metals

Another factor that determines the allowable ampacity of the conductor is the type of metal used for the wire. Table 6-2 (*NEC Table 310.15(B)(16)*) lists the current-carrying capacity of both copper and aluminum or copper-clad aluminum conductors. A study of the table reveals that a copper conductor is permitted to carry more current than an aluminum conductor of the same size and insulation type. An 8 AWG copper conductor with type TW insulation has an allowable ampacity of 40 amperes. An 8 AWG aluminum conductor with type TW insulation has an allowable ampacity of 30 amperes.

CORRECTION FACTORS

One of the main conditions that determines the current a conductor is permitted to carry is the ambient, or surrounding, air temperature. Table 6-2 lists the allowable ampacity of not more than three conductors in a raceway. These allowable ampacities are based on an ambient air temperature of 86°F, or 30°C. If these conductors are to be used in a location with a higher ambient temperature, the ampacity of the conductor must be reduced.

The correction factor chart located in *Table 310.15(B)(2)(a)*, Table 6-4, provides the necessary factors for ambient temperatures from 50°F to 437°F (10°C to 225°C). This table is divided into columns that list the temperature rating of different types of insulation. To use this table, find the column that list the temperature rating of the conductor in question. Then find the correction factor listed for the ambient temperature where the conductor is located.

NOTE: After reduction, the current-carrying capacity of a conductor is referred to as the ampacity, not the allowable ampacity. ●

PROBLEM 1: What is the ampacity of a 4 AWG copper conductor with type THWN insulation that will be used in an area with an ambient temperature of 43°C?

● **Solution:** Determine the allowable ampacity of a 4 AWG copper conductor with type THWN insulation. Type THWN insulation is located in the 75°C column of Table 6-2. The table lists an allowable ampacity of 85 amperes. Refer to the Correction Factors shown in Table 6-4. In the left-hand column, select a temperature range that includes 43°C. The table lists a correction factor of 0.82 in the 75°C column. The ampacity is to be multiplied by the correction factor. ●

$$85 \times 0.82 = 69.7 \text{ amperes}$$

PROBLEM 2: What is the ampacity of a 1/0 AWG copper-clad aluminum conductor with type RHH insulation when the conductor is installed on insulators in free air, in an area with an ambient air temperature of 100°F?

Solution: In Table 6-3, locate the column that contains type RHH copper-clad aluminum. RHH insulation is located in the 90°C column. The table indicates an allowable ampacity of 205 amperes. Determine the correction factor from the 90°C column in Table 6-4. Fahrenheit degrees are located in the far right hand column of *Table 310.15(B)(2)(a)*. The 100°F temperature is between 97°F and 104°F. The correction factor for this temperature is 0.91. Multiply the ampacity of the conductor by this factor.

$$205 \times 0.91 = 187 \text{ amperes}$$

MORE THAN THREE CONDUCTORS IN RACEWAY

Table 6-2 (*NEC Table 310.15(B)(16)*) and *NEC Table 310.15(B)(18)* list allowable ampacities for three conductors in a raceway. If a raceway is to contain more than three conductors, the allowable ampacity of the conductors must be derated. This is because the heat from each conductor combines with the heat dissipated by the other conductors to produce a higher temperature inside the raceway. Table 6-5 [*NEC Table 310.15(B)(3)(a)*] lists the adjustment factors. If the raceway is used in a space with a greater ambient temperature than that listed in the appropriate wire table, the temperature correction formula also shall be applied.

- When conductors are of different systems, or where installing the conductors in a cable tray, *310.15(B)(3)* should be reviewed.
- Adjustment is not required for raceways size 24 (600 mm) or less in length.

PROBLEM: Twelve 14 AWG copper conductors with type RHW insulation are to be installed in conduit in an area with an ambient temperature of 110°F. What will be the ampacity of these conductors?

Solution: First, determine the allowable ampacity of a 14 AWG copper conductor with type RHW insulation. Type RHW insulation is located in the 75°C column of Table 6-2. A 14 AWG copper conductor has an allowable ampacity of 20 amperes. The next step is to use the correction factor for ambient temperature. A correction factor of 0.82 is appropriate.

$$20 \times 0.82 = 16.4 \text{ amperes}$$

Next, an adjustment factor located in Table 6-5 shall be applied. The table indicates a factor of 50% where 10 through 20 conductors are installed in a raceway.

$$16.4 \times 0.50 = 8.2 \text{ amperes}$$

A 14 AWG, Type RHW conductor where installed in a raceway, with a group of twelve conductors, in a 110°F ambient has an ampacity of 8.2 amperes.

UNDERGROUND CONDUCTORS

NEC Tables 310.60(C)(81) through *310.60(C)(84)* list ampacities and temperature correction factors for conductors with voltage ratings from 2001 to 35,000 volts and intended for direct burial. *NEC Tables 310.60(C)(77)*, *310.60(C)(78)*, and *310.60(C)(79)* list conductors that are to be buried in electrical duct banks. An electrical duct can be a single metal or nonmetallic conduit. An electrical duct bank is a group of electrical ducts buried together, as shown in *NEC Figure 310.60*. When a duct bank is used, the center point of individual ducts should be separated by a distance of no less than 7.5 in. (190 mm).

CALCULATING CONDUCTOR SIZES AND RESISTANCE

Although the wire tables in the *NEC* are used to determine the proper wire size for most installations, there are instances in which these tables are not used. One example of this is the formula shown in 310.60(C). This formula may be used under engineering supervision.

$$I = \sqrt{\frac{T_c - (T_a + \Delta T_d)}{R_{dc}(1 + Y_c)R_{ca}}} \times 10^3 \textit{ amperes}$$

where

T_c = conductor temperature (°C)
T_a = ambient temperature (°C)
ΔT_d = dielectric loss temperature rise
R_{dc} = DC resistance of conductor at temperature T_c

Y_c = component AC resistance resulting from skin effect and proximity effect

R_{ca} = effective thermal resistance between conductor and surrounding ambient

LONG WIRE LENGTHS

It also becomes necessary to calculate wire sizes instead of using the tables in the *Code* when the length of the conductor is excessively long. The listed ampacities in the *Code* tables assume that the length of the conductor will not significantly increase the resistance of the circuit. When the wire length becomes extremely long, however, it is necessary to calculate the size of wire needed.

All wire contains resistance. As the length of wire is increased, it has the effect of adding resistance in series with the load. There are four factors that determine the resistance of a length of wire:

1. The material from which the wire is made. Different types of material have different wire resistances. A copper conductor will have less resistance than an aluminum conductor of the same size and length. An aluminum conductor will have less resistance than a piece of iron wire the same size and length.
2. The diameter of the conductor. The larger the diameter, the less resistance it will have. The diameter of a wire is measured in mils. One mil equals 0.001 inch. The circular mil area of a wire is the diameter of the wire in mils squared.

EXAMPLE

Assume a wire has a diameter of 0.064 inch. Converting to mils:

$$0.064\,\text{in.} \times 1000\,\text{mil per in.} = 64\,\text{mils}$$

The area in circular mils is

$$64^2 = (64 \times 64) = 4096\,\text{cmil}$$

3. The length of the conductor. The longer the conductor, the more resistance it will have. Adding length to a conductor has the same effect as connecting resistors in series.
4. The temperature of the conductor. As a general rule, most conductive materials will increase their resistance with an increase of temperature. Some exceptions to this rule are carbon, silicon, and germanium. If the coefficient of temperature for a particular material is known, its resistance at different temperatures can be calculated. Materials that increase their resistance with an increase of temperature have a *positive* coefficient of temperature. Materials that decrease their resistance with an increase of temperature have a *negative* coefficient of temperature.

In the customary system of measurement, a standard value of resistance is the mil foot. It is used to determine the resistance of different lengths and sizes of wire. A mil foot is a piece of wire 1 foot long and 1 mil in diameter, Figure 6-2. The resistances of a mil foot of wire at 20°C for different materials are shown in Table 6-6. Notice the wide range of

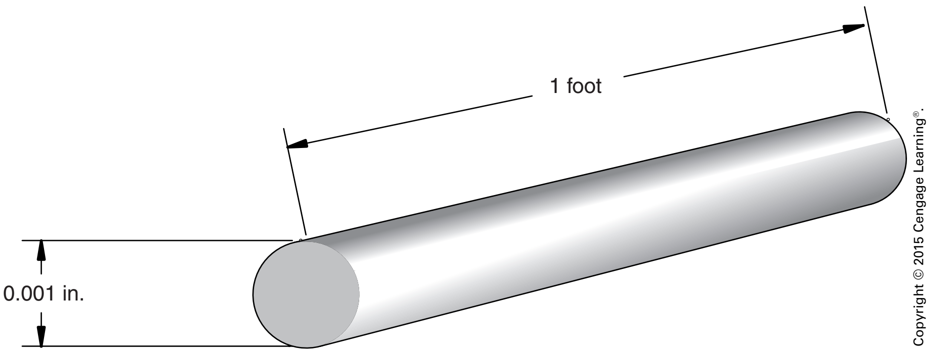

FIGURE 6-2 Mil foot.

TABLE 6-6

Resistivity of materials.

MATERIAL	K (OHMS PER CMIL FOOT @ 20°C)	TEMPERATURE COEFFICIENT (OHMS PER °C)
Aluminum	17	0.0040
Carbon	22,000	–0.0004
Constantan	295	0.000,002
Copper	10.4	0.0039
Gold	14	0.0040
Iron	60	0.0055
Lead	126	0.0043
Mercury	590	0.000,88
Nichrome	675	0.0002
Nickel	52	0.0050
Platinum	66	0.0036
Silver	9.6	0.0038
Tungsten	33.8	0.0050

resistances for different materials. The temperature coefficient of the different types of conductors is also listed. The temperature of a conductor can greatly affect its resistance. Table 6-6 lists the ohms per mil foot at 20°C. The resistance of material is generally given at 20°C because it is the standard used in the *American Engineers Handbook*. The temperature coefficient of the material can be used to determine the resistance of a material at different temperatures.

PROBLEM: What is the ohms per mil foot at 75°C?

Solution: Use the formula:

$$R = R_{ref}[1 + \alpha(T - T_{ref})]$$

where

R = Conductor resistance at temperature "T"
R_{ref} = Conductor resistance at reference temperature (20°C in this example)
α = Coefficient of resistance for the conductor material
T = Conductor temperature in °C
T_{ref} = Reference temperature at which α is specified for the conductor material

$$R = 10.4[1 + 0.0039(75 - 20)]$$
$$R = 10.4[1 + 0.0039(55)]$$
$$R = 10.4[1 + 0.2145]$$
$$R = 10.4[1.2145]$$
$$R = 12.63$$

At a temperature of 75°C, copper would have a resistance of 12.63 ohms per mil foot.

CALCULATING RESISTANCE

Now that a standard measure of resistance for different types of materials is known, the resistance of different lengths and sizes of these materials can be calculated. The formula for calculating resistance of a certain length, size, and type of wire is

$$R = \frac{K \times L}{cmil}$$

where

R = resistance of the wire
K = ohms per mil foot
L = length of wire in feet
cmil = circular mil area of the wire

This formula can be converted to calculate other values in the formula such as size, length, and area of wire used.

To find the size of wire, use

$$cmil = \frac{K \times L}{R}$$

To find the length of wire, use

$$L = \frac{K \times cmil}{K}$$

To find the type of wire, use

$$K = \frac{R \times cmil}{L}$$

PROBLEM 1: Find the resistance of 6 AWG copper wire 550 feet long. Assume a temperature of 20°C. The formula to be used is

$$R\,(ohms) = \frac{K\,(ohms\ per\ mil\ ft) \times L\,(ft)}{cmil}$$

Solution: The value for K can be found in Table 6-6, where the resistance and temperature coefficient of several types of materials are listed. The table indicates a value of 10.4 ohms per cmil foot for a copper conductor. The length (L) was given at 550 feet, and the area of 6 AWG wire is listed at 26,240 cmil, as shown in Table 6-7.

$$R = \frac{10.4 \times 550}{26,240} = 0.218 \text{ ohm}$$

PROBLEM 2: An aluminum wire 2250 feet long cannot have a resistance greater than 0.2 ohm. What is the minimum size wire that may be used?

Solution: To find the size of wire, use

$$\text{cmil} = \frac{\text{K (ohms per mil ft)} \times \text{L (ft)}}{\text{R (ohms)}}$$
$$= \frac{17 \times 2250}{0.2}$$
$$= 191,250$$

The standard size conductor for this installation can be found in Table 6-7. Because the resistance cannot be greater than 0.2 ohm, the conductor cannot be smaller than 191,250 circular mils. The smallest acceptable standard conductor size is 4/0 AWG.

Good examples of when it becomes necessary to calculate the wire size for a particular installation can be seen in the following problems.

PROBLEM 3: A workshop is to be installed in a facility separate from the main building. The workshop is to contain a small arc welder, air compressor, various power tools, lights, and receptacles. It is determined that a 100-ampere, 120/240-volt, single-phase panelboard will be needed for this installation. The distance between the buildings is 206 ft (62.79 m). An extra 10 ft (3.05 m) of cable is to be added for connections, making a total length of 216 ft (65.84 m). The maximum current will be 100 amperes. The voltage drop, at full load, is to be kept to a maximum of 3%, as recommmended by *210.19(A), Informational Note No. 4*. An ambient temperature of 68°F (20°C) is assumed. What size copper conductors should be used for this installation?

Solution: The first step is to determine the maximum amount of resistance the conductors can have without producing a voltage drop greater than 3% of the applied voltage.

The maximum voltage drop can be determined by multiplying the applied voltage by the decimal equivalent of 3%.

$$240 \times 0.03 = 7.2 \text{ volts}$$

Ohm's law can now be used to determine the resistance that will permit a voltage drop of 7.2 volts at 100 amperes.

$$R = \frac{E}{I} = \frac{7.2 \text{ volts}}{100 \text{ ampere}} = 0.072 \text{ ohm}$$

The length of cable between the main building and the workshop is 216 ft (66 m). Because current exists in two conductors at the same time, it is the same as having the conductors connected in series, which effectively doubles the length of the conductor. Therefore, the conductor length will be 432 ft (132 m).

$$\text{cmil} = \frac{\text{K (ohms per mil ft)} \times \text{L (ft)}}{\text{R (ohms)}}$$
$$= \frac{10.4 \times 432}{0.072} = 62,400$$

A 2 AWG copper conductor may be used.

PROBLEM 4: This problem concerns conductors used in a 3-phase system. It is to be assumed that a motor is located 2500 ft (762 m) from its power source and operates on 560 volts. When the motor starts, the current will be 168 amperes. The voltage drop at the motor terminals shall not be greater than 5% of the source voltage during starting. What size aluminum conductors should be used for this installation?

Solution: First, find the maximum voltage drop that can be permitted at the load by multiplying the source voltage by 5%.

$$E = 560 \times 0.05 = 28 \text{ volts}$$

The second step is to determine the maximum amount of resistance of the conductors. To calculate

NEC® TABLE 6-7

Table 8 Conductor Properties

Size (AWG or kcmil)	Conductors									Direct-Current Resistance at 75°C (167°F)					
	Area		Stranding			Overall				Copper				Aluminum	
				Diameter		Diameter		Area		Uncoated		Coated			
	mm²	Circular mils	Quantity	mm	in.	mm	in.	mm²	in.²	ohm/km	ohm/kFT	ohm/km	ohm/kFT	ohm/km	ohm/kFT
18	0.823	1620	1	—	—	1.02	0.040	0.823	0.001	25.5	7.77	26.5	8.08	42.0	12.8
18	0.823	1620	7	0.39	0.015	1.16	0.046	1.06	0.002	26.1	7.95	27.7	8.45	42.8	13.1
16	1.31	2580	1	—	—	1.29	0.051	1.31	0.002	16.0	4.89	16.7	5.08	26.4	8.05
16	1.31	2580	7	0.49	0.019	1.46	0.058	1.68	0.003	16.4	4.99	17.3	5.29	26.9	8.21
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003	10.1	3.07	10.4	3.19	16.6	5.06
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004	10.3	3.14	10.7	3.26	16.9	5.17
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005	6.34	1.93	6.57	2.01	10.45	3.18
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006	6.50	1.98	6.73	2.05	10.69	3.25
10	5.261	10380	1	—	—	2.588	0.102	5.26	0.008	3.984	1.21	4.148	1.26	6.561	2.00
10	5.261	10380	7	0.98	0.038	2.95	0.116	6.76	0.011	4.070	1.24	4.226	1.29	6.679	2.04
8	8.367	16510	1	—	—	3.264	0.128	8.37	0.013	2.506	0.764	2.579	0.786	4.125	1.26
8	8.367	16510	7	1.23	0.049	3.71	0.146	10.76	0.017	2.551	0.778	2.653	0.809	4.204	1.28
6	13.30	26240	7	1.56	0.061	4.67	0.184	17.09	0.027	1.608	0.491	1.671	0.510	2.652	0.808
4	21.15	41740	7	1.96	0.077	5.89	0.232	27.19	0.042	1.010	0.308	1.053	0.321	1.666	0.508
3	26.67	52620	7	2.20	0.087	6.60	0.260	34.28	0.053	0.802	0.245	0.833	0.254	1.320	0.403
2	33.62	66360	7	2.47	0.097	7.42	0.292	43.23	0.067	0.634	0.194	0.661	0.201	1.045	0.319
1	42.41	83690	19	1.69	0.066	8.43	0.332	55.80	0.087	0.505	0.154	0.524	0.160	0.829	0.253
1/0	53.49	105600	19	1.89	0.074	9.45	0.372	70.41	0.109	0.399	0.122	0.415	0.127	0.660	0.201
2/0	67.43	133100	19	2.13	0.084	10.62	0.418	88.74	0.137	0.3170	0.0967	0.329	0.101	0.523	0.159
3/0	85.01	167800	19	2.39	0.094	11.94	0.470	111.9	0.173	0.2512	0.0766	0.2610	0.0797	0.413	0.126
4/0	107.2	211600	19	2.68	0.106	13.41	0.528	141.1	0.219	0.1996	0.0608	0.2050	0.0626	0.328	0.100
250	127	—	37	2.09	0.082	14.61	0.575	168	0.260	0.1687	0.0515	0.1753	0.0535	0.2778	0.0847
300	152	—	37	2.29	0.090	16.00	0.630	201	0.312	0.1409	0.0429	0.1463	0.0446	0.2318	0.0707
350	177	—	37	2.47	0.097	17.30	0.681	235	0.364	0.1205	0.0367	0.1252	0.0382	0.1984	0.0605
400	203	—	37	2.64	0.104	18.49	0.728	268	0.416	0.1053	0.0321	0.1084	0.0331	0.1737	0.0529
500	253	—	37	2.95	0.116	20.65	0.813	336	0.519	0.0845	0.0258	0.0869	0.0265	0.1391	0.0424
600	304	—	61	2.52	0.099	22.68	0.893	404	0.626	0.0704	0.0214	0.0732	0.0223	0.1159	0.0353
700	355	—	61	2.72	0.107	24.49	0.964	471	0.730	0.0603	0.0184	0.0622	0.0189	0.0994	0.0303
750	380	—	61	2.82	0.111	25.35	0.998	505	0.782	0.0563	0.0171	0.0579	0.0176	0.0927	0.0282
800	405	—	61	2.91	0.114	26.16	1.030	538	0.834	0.0528	0.0161	0.0544	0.0166	0.0868	0.0265
900	456	—	61	3.09	0.122	27.79	1.094	606	0.940	0.0470	0.0143	0.0481	0.0147	0.0770	0.0235
1000	507	—	61	3.25	0.128	29.26	1.152	673	1.042	0.0423	0.0129	0.0434	0.0132	0.0695	0.0212
1250	633	—	91	2.98	0.117	32.74	1.289	842	1.305	0.0338	0.0103	0.0347	0.0106	0.0554	0.0169
1500	760	—	91	3.26	0.128	35.86	1.412	1011	1.566	0.02814	0.00858	0.02814	0.00883	0.0464	0.0141
1750	887	—	127	2.98	0.117	38.76	1.526	1180	1.829	0.02410	0.00735	0.02410	0.00756	0.0397	0.0121
2000	1013	—	127	3.19	0.126	41.45	1.632	1349	2.092	0.02109	0.00643	0.02109	0.00662	0.0348	0.0106

Notes:
1. These resistance values are valid **only** for the parameters as given. Using conductors having coated strands, different stranding type, and, especially, other temperatures changes the resistance.
2. Equation for temperature change: $R_2 = R_1 [1 + \alpha (T_2 - 75)]$ where $\alpha_{cu} = 0.00323$, $\alpha_{AL} = 0.00330$ at 75°C.
3. Conductors with compact and compressed stranding have about 9 percent and 3 percent, respectively, smaller bare conductor diameters than those shown. See Table 5A for actual compact cable dimensions.
4. The IACS conductivities used: bare copper = 100%, aluminum = 61%.
5. Class B stranding is listed as well as solid for some sizes. Its overall diameter and area are those of its circumscribing circle.

this value, the maximum voltage drop will be divided by the starting current of the motor.

$$R = \frac{E}{I} = \frac{28}{168} = 0.166 \text{ ohm}$$

The third step is to calculate the length of the conductors. In the previous example, the length of the two conductors was added together to find the total amount of wire resistance. In a single-phase system, each conductor must carry the same amount of current. During any period of time, one conductor is supplying current from the source to the load, and the other conductor completes the circuit by permitting the same amount of current to flow from the load to the source.

In a balanced 3-phase circuit, there are three currents that are 120° out of phase with each other, Figure 6-3. These three conductors share the flow of current between source and load. In Figure 6-3, two lines labeled A and B have been drawn through the three current waveforms. Notice that at position A, the current in line 1 is maximum and in a positive direction. The currents in lines 2 and 3 are less than maximum and in a negative direction. This condition corresponds to the example shown in Figure 6-4. Notice that the maximum current exists in only one conductor.

Observe the line marking position B in Figure 6-3. The current in line 1 is zero, and the currents in lines 2 and 3 are in opposite directions and less than maximum. This condition is illustrated in Figure 6-5. Notice that only two of the three phase lines are conducting current, and that the current in each line is less than maximum.

Because the phase currents in a 3-phase system are never maximum at the same time, and at other times the current is divided between two phases, the total conductor resistance will not be the sum of two conductors. To calculate the resistance of conductors in a 3-phase system, a demand factor of 0.866 is used.

In this problem, the motor is located 2500 ft (762 m) from the source. The effective conductor length (Le) will be calculated by doubling the length of one conductor and then multiplying by 0.866.

$$Le = 2500 \text{ ft} \times 2 \times 0.866 = 4330 \text{ ft}$$

$$(= 762 \text{ m} \times 2 \times 0.866 = 1320 \text{ m})$$

Now that all the factors are known, the size of the conductor can be calculated using the formula:

where K = 17 (ohms per mil foot for aluminum)

$$\text{cmil} = \frac{K \times L}{R} = \frac{17 \times 4330}{0.166} = 443{,}434$$

Three 500 kcmil conductors will be used.

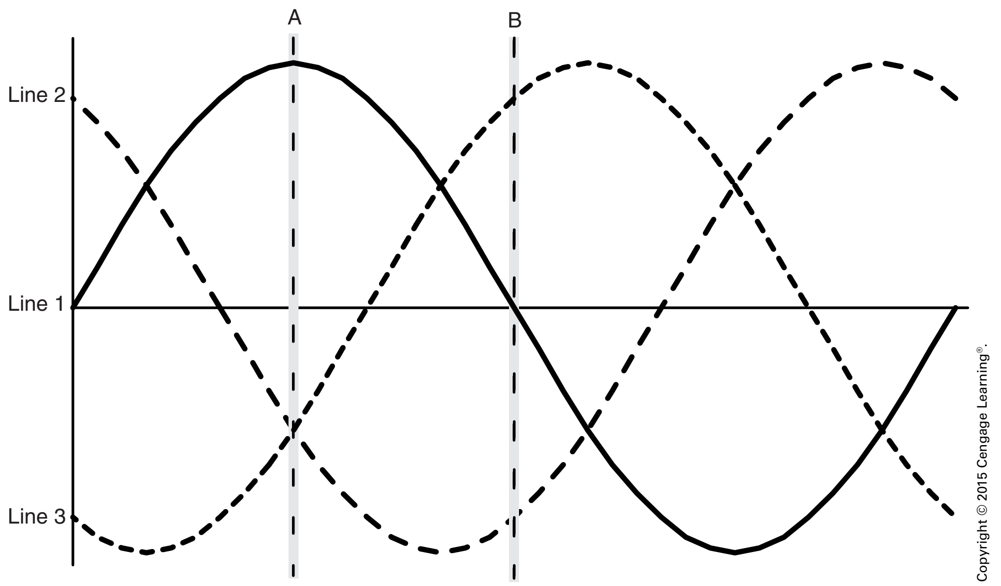

FIGURE 6-3 Currents of a 3-phase system are 120° out of phase with each other.

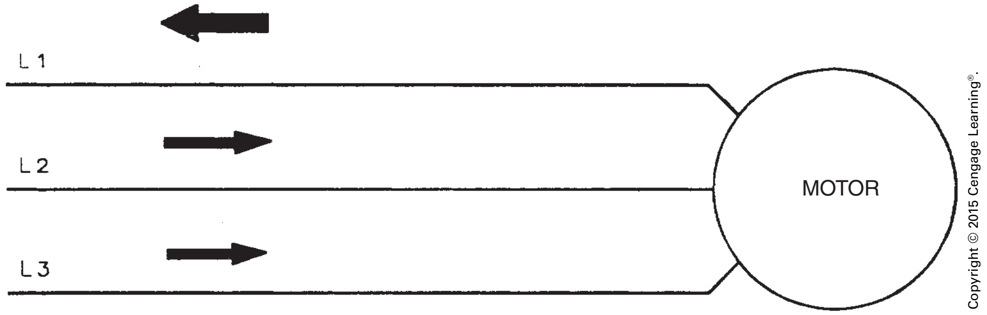

FIGURE 6-4 Current is maximum in one conductor and less than maximum in two conductors.

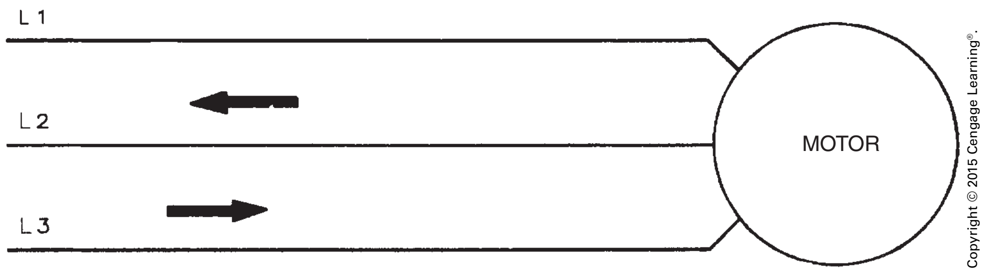

FIGURE 6-5 Currents in only two conductors.

PARALLEL CONDUCTORS

Under certain conditions, it may become necessary or advantageous to connect conductors in parallel. One example of this condition is when conductor size is very large, as is the case in problem 4 in the previous section. In that problem, it was calculated that the conductors supplying a motor 2500 ft from its source would have to be 500 kcmil. A 500 kcmil conductor is very large and difficult to handle. For this reason, it may be preferable to use parallel conductors for this installation. The *NEC* lists five conditions that must be met when conductors are connected in parallel (*310.10(H)*):

1. The conductors must be of the same length.
2. The conductors must be made of the same material. It is not permissible to use copper for one conductor and aluminum for the others.
3. The conductors must have the same circular mil area.
4. The conductors must use the same type of insulation.
5. The conductors must be terminated and connected in the same manner.

In the previous problem, the actual conductor size needed was calculated to be 443,434 circular mils. This circular mil area could be obtained by connecting two 250 kcmil conductors in parallel for each phase, or three 3/0 AWG conductors in parallel for each phase.

> **NOTE:** Each 3/0 AWG conductor has an area of 167,800 circular mils. This is a total of 503,400 circular mils. ●

Another example of when it may be necessary to connect wires in parallel is when conductors of a large size must be run in conduit. The conductors of a single phase are not permitted to be run in metallic conduit, as shown in Figure 6-6 (*300.5(I)* and *300.20*). The reason for this is that when current exists in a conductor, a magnetic field is produced around the conductor. In an alternating current circuit, the current continuously changes direction and magnitude, which causes the magnetic field to cut through the wall of the metal conduit. This cutting

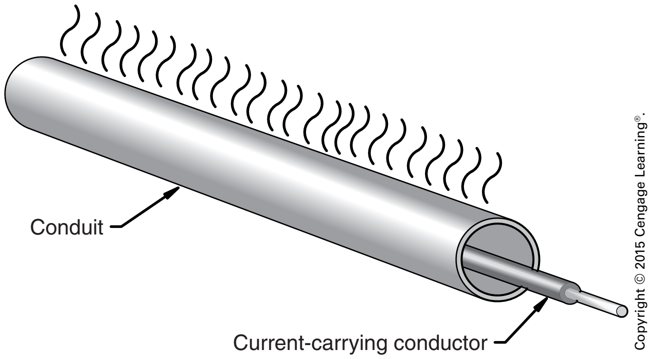

FIGURE 6-6 The current in the conductor induces eddy currents in the conduit causing the conduit to become hot.

action of the magnetic field induces a current called an eddy current into the metal of the conduit. Eddy currents can produce enough heat in high-current circuits to melt the insulation surrounding the conductors. All metal conduits can have eddy current induction, but conduits made of magnetic materials such as steel have an added problem with hysteresis loss. Hysteresis loss is caused by molecular friction. As the direction of the magnetic field reverses,

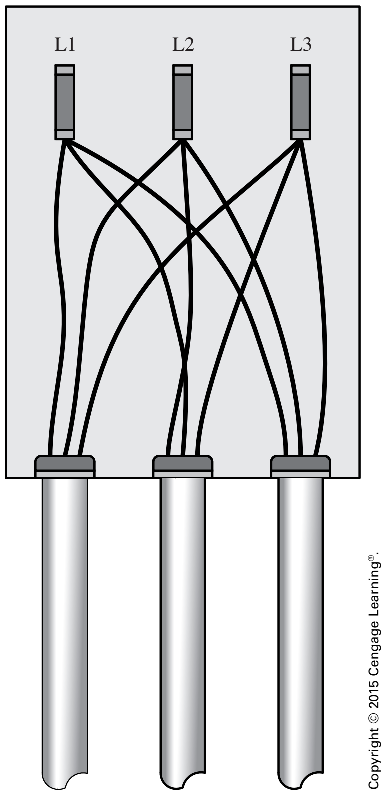

FIGURE 6-7 Each conduit contains a conductor from each phase.

the molecules of the metal are magnetized with the opposite polarity and swing to realign themselves. This continuous aligning and realigning of the molecules produces heat due to friction. Hysteresis losses become greater with an increase in frequency.

To correct this problem, a conductor of each phase must be run in each conduit, Figure 6-7. When all three phases are contained in a single conduit, the magnetic fields of the separate conductors cancel each other, resulting in no current being induced in the walls of the conduit.

TESTING WIRE INSTALLATIONS

After the conductors have been installed in conduits or raceways, it is accepted practice to test the installation for grounds and shorts. This test requires an ohmmeter, which not only can measure resistance in millions of ohms but also can provide a high enough voltage to ensure that the insulation will not break down when rated line voltage is applied to the conductors. Most ohmmeters operate with a maximum voltage that ranges from 1.5 to about 9 volts, depending on the type of ohmmeter and the setting of the range scale. To test wire insulation, a megohmmeter is used with a voltage from about 250 to 5000 volts, depending on the model of the meter and the range setting. One model of a megohmmeter is shown in Figure 6-8. This instrument contains a hand crank that is connected to the rotor of a brushless DC generator. The advantage of this particular instrument is that it does not require the use of batteries. A range selector switch permits the meter to be used as a standard ohmmeter or as a megohmmeter. When it is used as a megohmmeter, the selector switch permits the test voltage to be selected. Test voltages of 100, 250, 500, and 1000 volts can be obtained.

A megohmmeter can also be obtained in battery-operated models, as shown in Figure 6-9. These models are small, lightweight, and particularly useful when it becomes necessary to test the dielectric of a capacitor.

Wire installations are generally tested for two conditions: shorts and grounds. Shorts are current paths that exist between conductors. To test an installation for shorts, the megohmmeter is connected across two conductors at a time, as shown in Figure 6-10. The circuit is tested at rated voltage or slightly higher.

FIGURE 6-8 Hand-cranked megohmmeter.

FIGURE 6-9 Battery-operated megohmmeter.

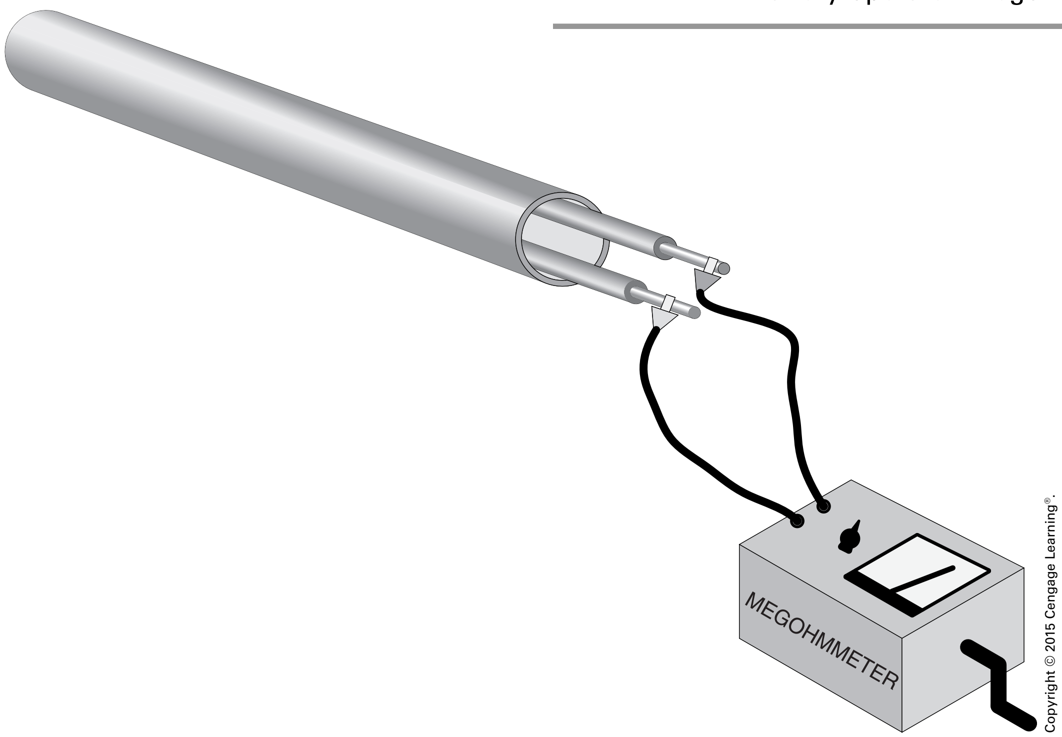

FIGURE 6-10 Testing for shorts with a megohmmeter.

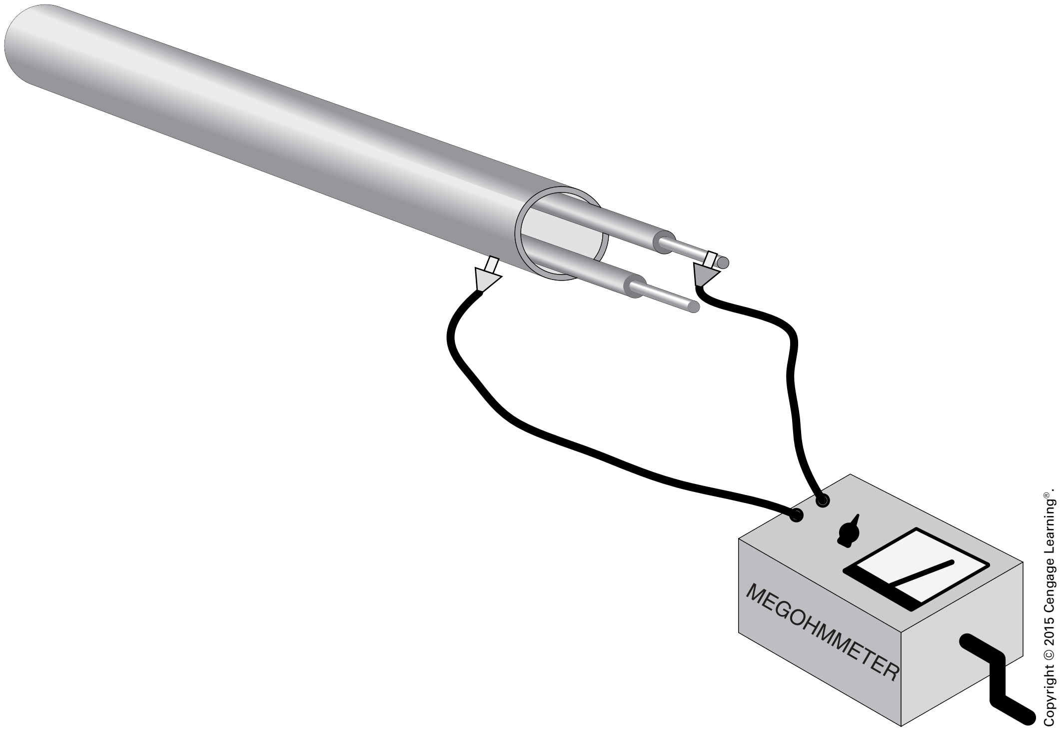

FIGURE 6-11 Testing for grounds with a megohmmeter.

The megohmmeter indicates the resistance between the two conductors. Because both conductors are insulated, the resistance between them should be extremely high. Each conductor should be tested against every other conductor in the installation.

To test the installation for grounds, one lead of the megohmmeter is connected to the metallic raceway, as shown in Figure 6-11. The other meter lead is connected to one of the conductors. The conductor should be tested at rated voltage or slightly higher. Each conductor should be tested.

THE AMERICAN WIRE GAUGE (AWG)

The American Wire Gauge was standardized in 1857 and is used mainly in the United States for the diameters of round, solid, nonferrous electrical wire. The gauge size is important for determining the current-carrying capacity of a conductor. Gauge sizes are determined by the number of draws necessary to produce a given diameter or wire. Electrical wire is produced by drawing it through a succession of dies, Figure 6-12. Each time a wire passes through a die, it is wrapped around a draw block several times. The draw block provides the pulling force necessary to draw the wire through the die. A 24 AWG wire would be drawn through 24 dies, each having a smaller diameter. In the field, wire size can be determined

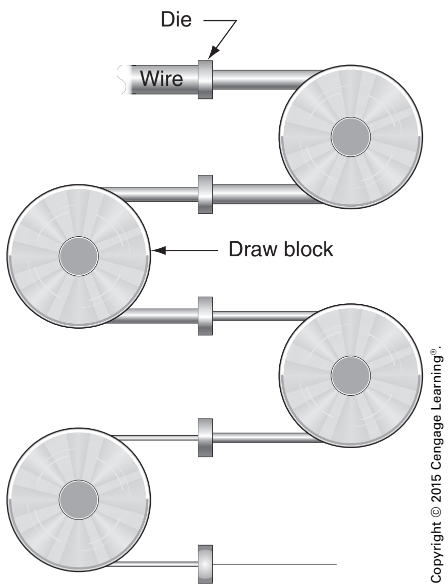

FIGURE 6-12 Electrical wire is made by drawing it through a succession of dies.

with a wire gauge, Figure 6-13. One side of the wire gauge lists the AWG size of the wire, Figure 6-14. The opposite side of the wire gauge indicates the diameter of the wire in thousandths of an inch, Figure 6-15. When determining wire size, first remove the insulation from around the conductor. The slots in the wire gauge, not the holes behind the slots, are used to determine the size, Figure 6-16.

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FIGURE 6-13 Typical wire gauge used to determine wire size.

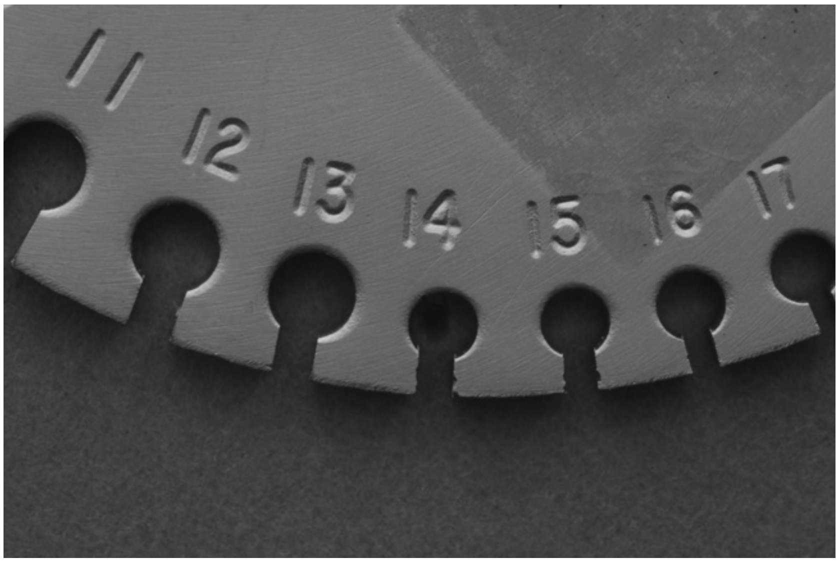

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FIGURE 6-14 One side of the wire gauge lists the AWG size of wire.

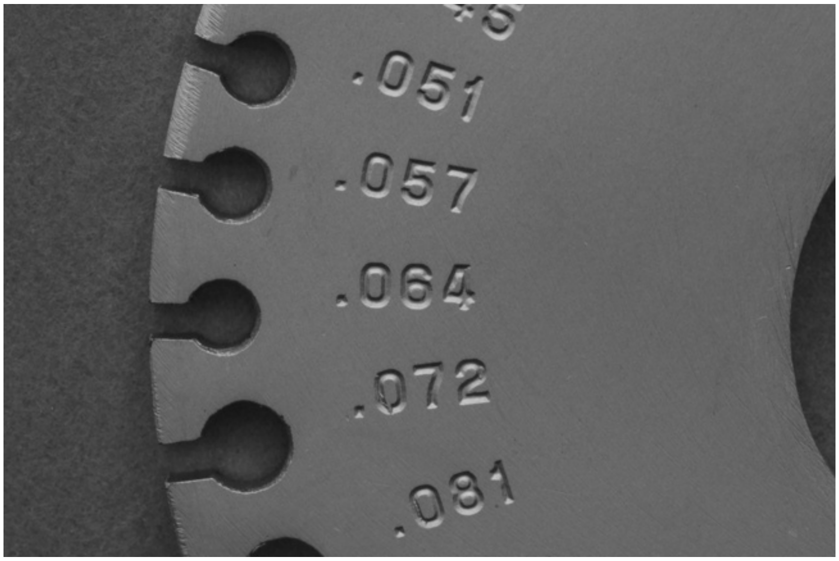


FIGURE 6-15 The opposite side of the wire gauge lists the diameter of the wire in thousandths of an inch.

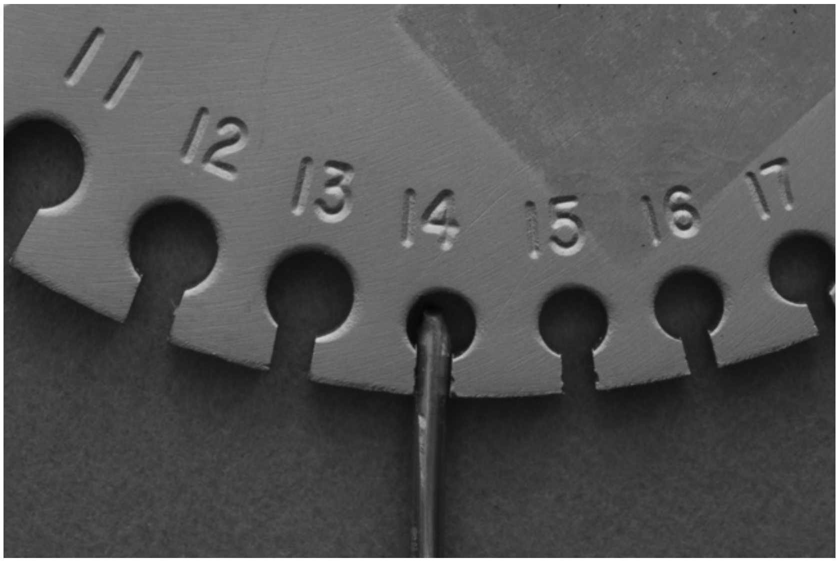


FIGURE 6-16 The slot, not the hole behind the slot, determines the wire size.

REVIEW QUESTIONS

All answers should be written in complete sentences. Calculations should be shown in detail, and *Code* references should be cited when appropriate.

Unless specified otherwise, the ambient temperature is 86°F (30°C); the location is dry; the termination has a temperature rating equal to or greater than that of the conductor; and the wire is copper. Where the term *allowable ampacity* is used, it refers to a value taken from one of the tables. Where the term *ampacity* is used, it refers to the allowable ampacity as corrected and adjusted and in compliance with *110.14(C)*.

1. What is the temperature rating of a type XHHW conductor where used in a wet location?

2. What types of conductors are approved for direct burial?

3. What types of conductors are approved for underground use?

4. Three 10 AWG, type THW conductors are to be installed between poles on individual insulators. What will the conductor ampacity be?

5. Motor feeders consisting of six 1/0 AWG type THHN aluminum conductors are to be installed in a rigid metal conduit in an ambient temperature of 100°F (38°C). What will be the conductor ampacity? What will be the circuit ampacity?

6. Explain what it means to install "conductors in parallel," and give five conditions that must be satisfied where this is done.

7. What is the size of the largest solid (not stranded) conductor approved for installation in raceways?

8. How is a 4 AWG grounded conductor in a flat multiconductor cable identified?

9. What insulation colors are reserved for special uses?

10. A single-phase, 86-ampere load is located 2800 ft (853 m) from the 480-volt electrical power source. What size aluminum conductors should be installed if the voltage drop cannot exceed 3%?

11. A 3-phase, 480-volt motor with a starting current of 235 amperes is located 1800 ft (550 m) from the power source. What size copper conductors should be used to ensure that the voltage drop will not exceed 6% during starting?

12. What is the maximum noncontinuous load that can be connected to a 2 AWG, type THHN conductor?

13. What is the maximum continuous load that can be connected to a 2 AWG, type THHN conductor?

14. Calculations made in accord with *NEC Article 220* indicate 110 amperes of continuous load and 40 amperes of noncontinuous load on a single-phase, 240/120-volt feeder. What is the minimum conductor size?

CHAPTER 7

Signaling Systems

OBJECTIVES

After studying this chapter, the student should be able to

- describe and install the master clock.
- describe and install the program system.
- describe and install the paging system.
- describe and install the fire alarm system.

A signaling circuit is any electric circuit that energizes signaling equipment. A signaling system may include one or more signaling circuits. For example, in the industrial building, there are several electrical systems that give recognizable visual and audible signals and are classified as signaling systems:

- a master clock;
- a program system;
- a paging or locating system; and
- a fire alarm system.

Courtesy of ESE

FIGURE 7-1 Clock system display unit.

THE MASTER CLOCK

The master clock is a clock designed to drive some number of units that display the time. The display units are not actually clocks themselves, but depend for their operation on signals received from the master clock. A display unit is shown in Figure 7-1. This type of display unit uses light-emitting diodes (LEDs) to indicate the time, rather than an analog display using numbers and hands. These types of displays are generally designed to accommodate large-size LEDs that can be seen from a long distance. If a display with a number larger than about 0.55 in. (14 mm) is desired, it will generally use a planar gas discharge display rather than an LED display. A diagram showing a master clock with several display units attached is shown in Figure 7-2.

Several methods can be used to sense time in the master clock unit. One of the most common methods for many years was to use a single-phase synchronous motor. The speed of the synchronous motor is proportional to its number of poles and the line frequency. This method uses the 60-hertz line frequency to measure time. This is the same method often used to operate electric clocks in the home. Sensing the line frequency is relatively accurate. Clocks using this method to sense time

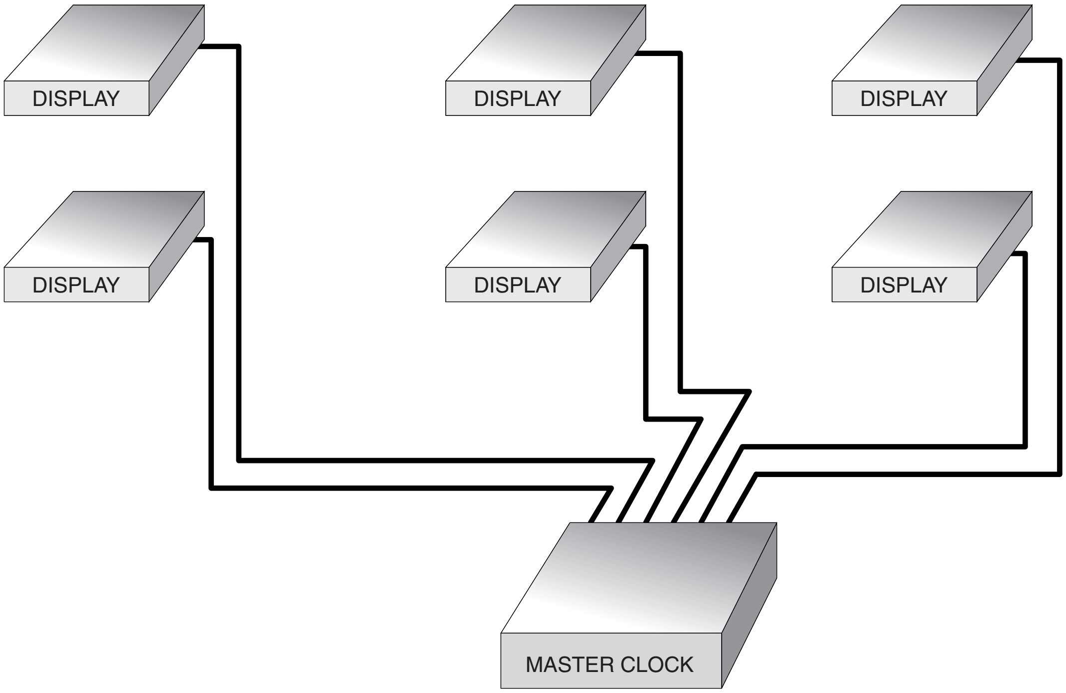


FIGURE 7-2 Master clock system.

are generally accurate to within a couple of minutes per month.

Another method that has become popular is the sensing of vibrations produced by a piece of quartz crystal. When an AC voltage is impressed across two faces of the crystal, it will resonate at some specific frequency. This resonant frequency is extremely constant and therefore can be used to accurately measure time. The frequency at which the quartz will resonate is inversely proportional to the size of the crystal. The smaller the crystal, the higher the resonant frequency will be. The shape of the crystal also plays a part in determining the resonant frequency. Quartz clocks are generally accurate to within 1 second per month.

The clock in this installation is shown in Figure 7-3. This master clock senses time by receiving a radio signal from WWV, a radio station that broadcasts time pulses. WWV is operated by the National Bureau of Standards and is used as a time standard throughout the United States. A cesium beam atomic clock is used to produce the pulses that are transmitted. WWV can be received on frequencies of 18, 20, and 60 kHz, and on frequencies of 2.5, 5, 10, 15, 20, and 25 MHz. At the beginning of each minute, a 1000 Hz signal is transmitted, except at the beginning of each hour, when a 1500 Hz signal is transmitted. The clock in this installation contains a radio receiver capable of receiving WWV pulses. The timing of the clock depends on the pulses received, and in this way, the time clock is continually updated each minute.

The clock also contains a battery and battery charger. The battery is used to provide power to the clock in the event of a power failure. The battery can operate the clock for a period of at least 12 hours. During this time, the displays will be turned off to conserve battery power, but the clock continues to operate. The master clock also can be set to operate in a 12- or 24-hour mode.

THE PROGRAM SYSTEM

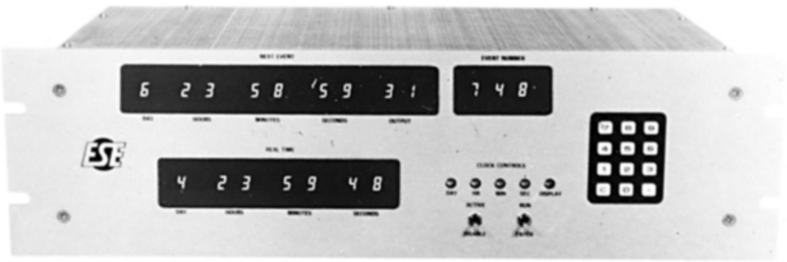
The program system is used to provide automatic signals for the operation of horns, bells, and buzzers. These devices are used in industry to signal the beginning and ending of shifts, lunch periods, and breaks. Different parts of the plant operate on different time schedules. Office workers, for example, begin and end work at different times than employees who work in the manufacturing area of the plant. Lunch and coffee break times also vary. For this reason, the program control system must be capable of providing different signals to different parts of the plant at the proper times.

The program controller used in this installation is shown in Figure 7-4. This controller is a microprocessor-based programmable timer. This unit has thirty-two separate output channels and can be programmed for up to 1000 events. Each channel contains a normally open reed relay. Each relay can be operated by momentary contact or latching, or the unit can be set so that there can be sixteen of each. A simple modification will permit sixteen double-pole relays to be used instead of thirty-two single-pole relays. The 1000 events can be entered into the unit randomly as opposed to entering them in chronological order. Cyclic events can be programmed to occur every minute, hour, day, or week, or in any combination desired. Any of the thirty-two output channels can be turned on at the same time.

Programming is done with a twelve-button keyboard located on the front of the unit. The keyboard contains numbers 0 through 9, and

Courtesy of ESE

FIGURE 7-3 Master clock.



Courtesy of ESE

FIGURE 7-4 Programmable timer.

CLEAR and ENTER buttons. Two toggle switches, also located on the front of the panelboard, are used to provide active/disable and run/enter functions. These switches permit programmed events to be viewed without interrupting the program. Once the timer has been programmed, it is possible to save the program on a cassette tape. This is done by connecting a cassette tape recorder to a jack provided on the rear of the timer. If for some reason the timer should have to be replaced, the same program can be loaded into the new unit from the cassette tape. This saves the time of having to reprogram the unit.

The program timer also contains a digital clock. The clock is operated by an internal crystal oscillator. A battery and battery charger are provided with the unit in case of power failure. With the addition of a serial time code generator, the program timer also can be used as a master clock. The time code generator gives the unit the capability of driving up to 100 display units.

THE PAGING SYSTEM

In many industrial installations, it is important to convey messages to all areas of the plant. When selecting a paging system, several factors should be taken into consideration, such as these:

1. What is the amount of area to be covered and the number of paging units needed?
2. The design of the system should permit expansion as the plant increases in size.
3. Should the paging system be voice, tone, or a combination of both?
4. Do areas of the plant require explosionproof or weatherproof equipment?
5. What is the ambient noise level of the plant?

A very important consideration when choosing the type of equipment to be used is the ambient, or surrounding, noise level. The chart shown in Figure 7-5 illustrates different levels of noise measured in decibels (dB). For a signal or voice to be heard, it should be at least 5 decibels louder than the surrounding noise level at the workstation. Another important consideration is the distance of the speaker from the workstation. As a general rule, sound decreases by 6 decibels each time the distance from the speaker is doubled.

Reaction	dB	Source Comparison
Uncomfortably loud (possible ear pain)	195	Circular saw at 2 ft (0.61 m)
	140	Jackhammer at 2 ft (0.61 m)
	120	Thunder (near)
Very loud	90 to 100	Industrial plant Wire mill boiler factory
Loud	80 to 90	Foundry factory Press room
Moderate	70 to 75	Normal conversation in office at 3 ft (0.91 m)
Quiet	40 to 55	Hospital room
Very quiet	30 to 35	Whisper at 2 ft (0.61 m)

FIGURE 7-5 Comparable sounds.

PROBLEM: A speaker is rated to produce 110 decibels at a distance of 10 ft (3 m). The ambient noise level at the workstation is measured at 80 decibels. If the speaker is mounted 160 ft (49 m) away from the workstation, will the worker be able to clearly hear the messages?

● **Solution:** Figure 7-6 illustrates the amount of sound decrease with distance. Notice that the chart starts with a value of 110 decibels at a distance of 10 ft (3 m), and decreases 6 decibels each time the distance is doubled. At a distance of 160 ft (49 m), the sound level should be 86 decibels. This is loud enough to permit the worker to hear the voice or tone.

The paging system chosen for this plant is manufactured by Audiosone Inc. It has the capability of producing both voice and tone signals. Two types of paging units will be used. The first type can be used to send voice messages only. The second type, shown in Figure 7-7, can send both voice and tone messages. Each paging unit contains its own

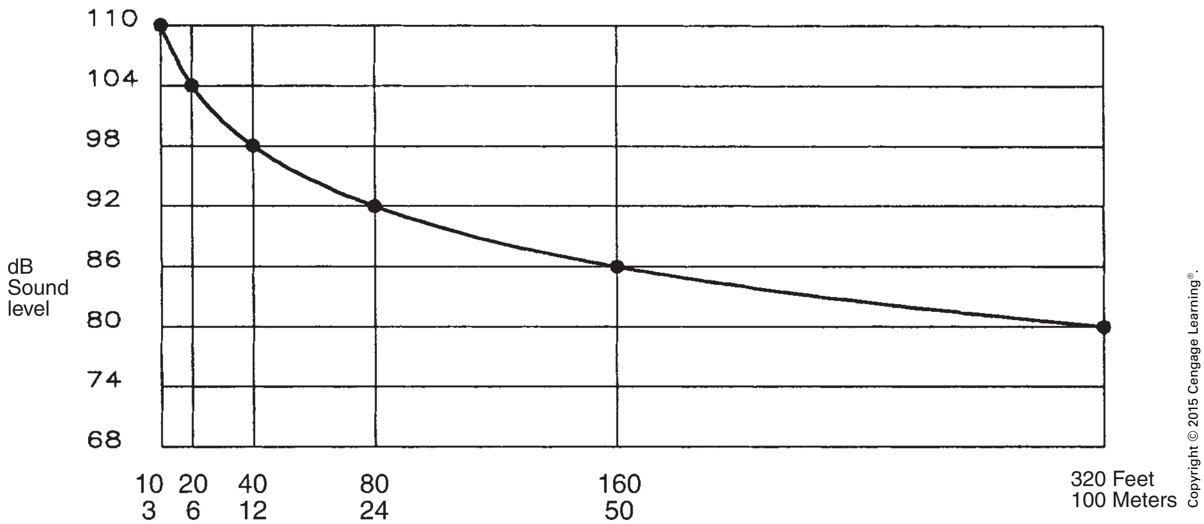


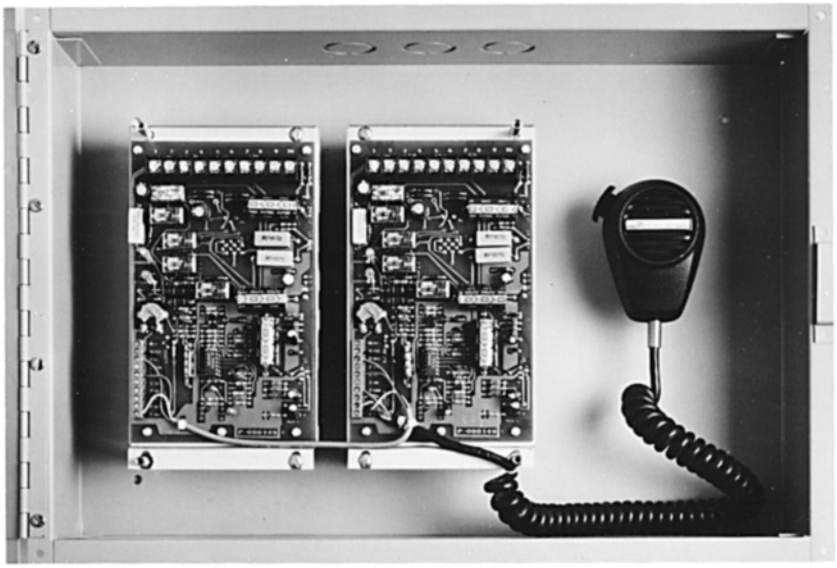
FIGURE 7-6 Effects of sound relating to distance.

FIGURE 7-7 Unit used to send voice and tone messages.

amplifier, Figure 7-8. This permits an almost unlimited number to be used where they are connected in parallel to a 4-conductor circuit. The system also can be expanded to use a voice evacuation alarm, shown in Figure 7-9. This unit permits taped messages to be used, which can instruct employees as to the nature of the emergency.

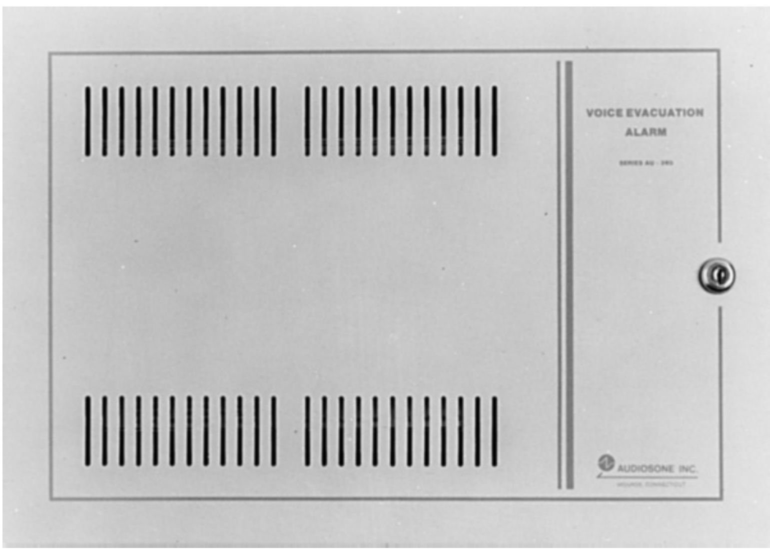
Four separate tones can be generated:

1. WAIL: conventional siren
2. HI-LO: alternating high and low (European siren)
3. WHOOP: ascending low to high, repeated
4. HORN: steady tone



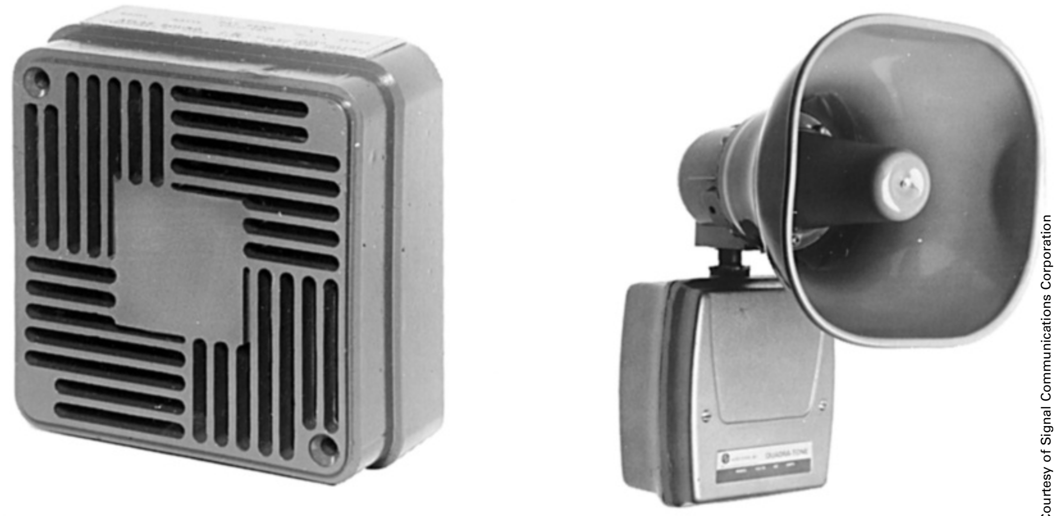
Courtesy of Signal Communications Corporation

FIGURE 7-8 Each unit contains an amplifier.



Courtesy of Signal Communications Corporation

FIGURE 7-9 Voice evacuation alarm.



Courtesy of Signal Communications Corporation

FIGURE 7-10 Speakers used with paging system.

The tones are to be used to announce different conditions. One is to be used as a fire signal and will be connected to the fire alarm system. The other three tones can be used to announce such conditions as plant evacuation, shift change, and so on. Two types of speakers will be used, Figure 7-10. These speakers will be located at strategic points throughout the plant.

THE FIRE ALARM SYSTEM

The fire alarm is part of a digital automation and control system manufactured by Jensen Electric Co. This system was chosen because of its flexibility and expansion capability. The central control unit (CCU) is a modern desktop computer. The processor, Figure 7-11, provides communication interface between the CCU and the system controllers. This system permits any number of processors (up to 100) to be connected to the CCU. The power equipment of the processor is 24 volts DC, which is provided by an uninterruptible power supply, Figure 7-12. The uninterruptible power supply produces a regulated 24 volts DC from a 120-volt AC, 60-hertz supply line. Two 12-volt lead acid storage batteries are contained inside the power supply. If the incoming AC power should fail, the lead acid batteries continue to provide power to the system. This ensures that control power to critical systems is maintained during a power failure.

The controller, Figure 7-13, is an intelligent device that provides interface between the control modules and the processor. Each processor can handle up to 100 controllers. Each controller can

Courtesy of ABB

FIGURE 7-11 Processor unit.

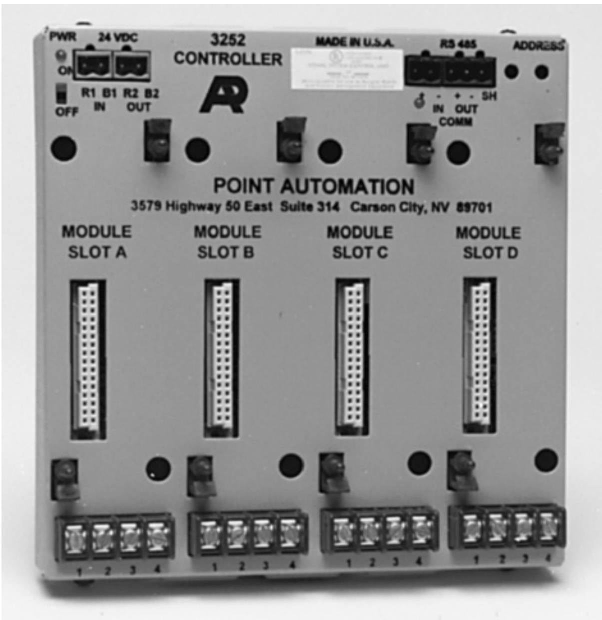
Courtesy of ABB

FIGURE 7-12 Power supply.

contain up to four interface modules, Figure 7-14. This system can operate with only one input/output (I/O) point or with as many as 640,000.

The type of interface module used determines the system control function. Modules can be obtained that permit the system to be used for motor control, burglar alarm, ground-fault detection, or to interface with television cameras. Some modules permit analog input and output signals that operate from 0 to +5 volts DC, or 4 to 20 milliamps DC. The fire alarm input and output modules are shown in Figure 7-15.

Each fire alarm module contains a momentary contact switch located on the front cover. This switch permits the alarm to be operated automatically or manually, or to be tested. Each module contains three LEDs. The green LED indicates normal circuit operation. A red LED indicates that a fire has been detected, and a yellow LED indicates trouble



Courtesy of ABB

FIGURE 7-13 Programmable controller.

Courtesy of ABB

FIGURE 7-14 Controller with interface modules.

Courtesy of ABB

FIGURE 7-15 Fire alarm modules.

Courtesy of ABB

FIGURE 7-17 Fire alarm pull handles.

with the system. The conductor sizes and types for the alarm system are sized to meet the requirements of *725.1* (Informational note), and conduit size is determined in accordance with *725.31(B)*.

The fire alarm system uses a combination of smoke detectors, Figure 7-16, and manual pull handles, Figure 7-17. Once the manual pull handles have been used, they must be reset with a key. The smoke detector, manufactured by Whelen Engineering Co., is powered by a separate 120-volt AC source and contains an internal horn that produces 86 decibels at 10 ft (3 m). This permits the smoke detector to be used in office areas without the addition of a separate audible alarm. An LED located on the front cover flashes every 4 seconds to indicate the detector is in working order. If smoke is detected, the LED will emit a steady glow.

Courtesy of Whelen Engineering

FIGURE 7-16 Smoke detector.

When a fire condition is detected, two alarm devices are activated. The first is one of the tones produced by the paging system. The second is a high-intensity strobe light that produces 75 flashes per minute, Figure 7-18. The strobe light is powered directly by the smoke detector in office areas. The fire alarm system is programmed so that when a fire is detected, all of the audible alarms produced by the paging system are activated. Not all of the strobe lights are activated, however. Only the strobe lights located in the area of the detected fire are permitted to flash. A basic line drawing of the fire alarm system is shown in Figure 7-19.

FIGURE 7-18 High-intensity strobe light.

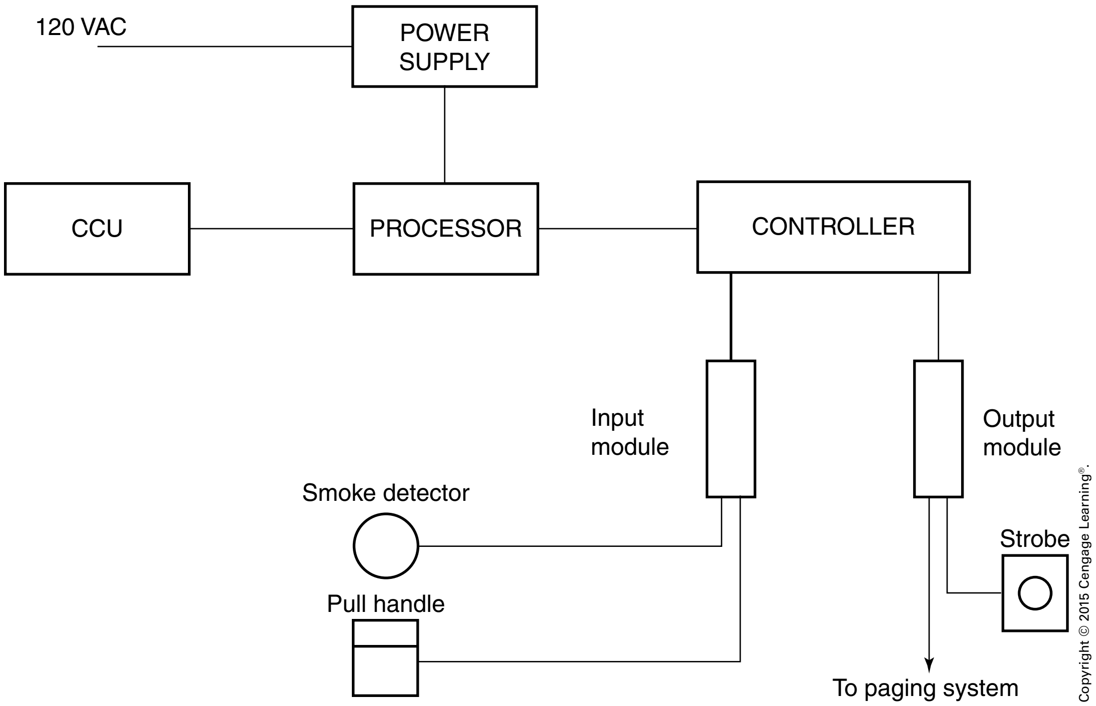


FIGURE 7-19 Basic fire alarm system.

REVIEW QUESTIONS

All answers should be written in complete sentences. Calculations should be shown in detail, and *Code* references should be cited when appropriate.

1. What is a signal circuit? ______________________________

2. Where is the definition of a signal circuit found in the *NEC*? ______________________________

3. Are the display units used in this installation actually clocks? ______________________________

4. What is WWV? ______________________________

5. What type of clock is used to provide the pulses broadcast by WWV? ______________________________

6. What type of clock is used to operate the program timer? ______________________________

7. How many separate events can be programmed in the program timer? ______________________________

8. How many output channels are provided with the program timer? ______________________________

9. What is the primary purpose of the paging system? ______________________________

10. Name five factors that should be taken into consideration when selecting a paging system.

____

____

____

11. Assume the surrounding noise level in a certain area of the plant is 80 decibels. If a message is to be clearly heard, what should be the minimum sound level of the message?

____

____

____

12. How many tones can be generated by the paging system? ______________________

____

____

13. What is used as the central control unit for the fire alarm system? ________________

____

____

14. What is the function of the processor?______________________________________

____

____

15. What is the maximum number of processors that can be connected to the CCU?_____

____

____

16. What voltage is supplied to the processor? ____________________________________

____

____

17. What supplies power to the system if the incoming AC power should fail? _________

____

____

18. What is the function of the controller?______________________________________

____

____

19. How many control modules can be connected to each controller? ________________

____

____

20. What is the purpose of the switch located on the front of the fire alarm module?_____

____

____

21. What condition is indicated by each of the three LEDs located on the front of the fire alarm module?

Green ____

Red ____

Yellow____

22. What two devices are used to indicate the presence of a fire?____________________

____

____

23. Each smoke detector contains a separate internal horn. What is the sound level of this internal horn? ____

____

____

24. What two alarm devices are activated when a fire is detected? ___________________

____

____

25. When a fire is detected, do all the strobe lights throughout the plant flash?__________

____

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CHAPTER 8

Basic Motor Controls

OBJECTIVES

After studying this chapter, the student should be able to

- describe differences between contactors and motor starters.
- describe the different functions of fuses and overloads.
- list different types of overload relays and explain how they operate.
- connect basic control circuits using a schematic diagram.
- describe the differences between schematic and wiring diagrams.
- discuss the differences between schematic or ladder diagrams and wiring diagrams.

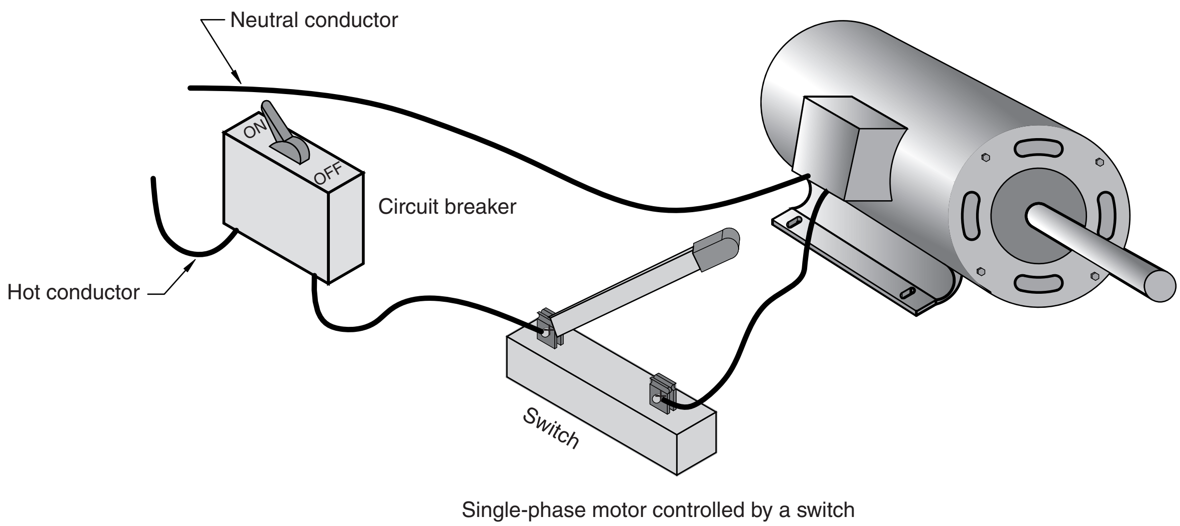
Anyone working as an electrician in industry should be able to connect and troubleshoot basic motor control circuits. Control circuits are used to start, stop, accelerate, decelerate, and protect motors. They may also consist of a number of sensing devices such as limit switches, float switches, push buttons, flow switches, pressure switches, temperature switches, and so on, that tell the circuit what action is to be performed. Motor control circuits can be divided into two major categories: 2 wire and 3 wire.

TWO-WIRE CONTROLS

Two-wire control circuits are the simplest. Two-wire controls basically consist of a switch used to connect or disconnect power to the motor, Figure 8-1. Many manual-type starters are designed as 2-wire controllers. Motor starters contain both a means to connect and disconnect the motor to and from the power source and also provide overload protection for the motor. Overload protection should not be confused with fuse or circuit protection. Fuses and circuit breakers protect the circuit from some types of high-current condition such as shorts and grounds. Overload protection is designed to protect the motor from an overload condition. Assume, for example, that a motor has a full-load current rating of 10 amperes. Also assume that the motor is connected to a 20-ampere circuit. If the motor should become overloaded and the current increase to 15 amperes, the circuit breaker would never trip or the fuse never blow because the current draw is below the 20-ampere rating. The motor, however, will probably be damaged or destroyed because of the excessive current. Overloads are intended to open the circuit when the current exceeds the full-load current rating of the motor by 115% to 125%.

A single-phase manual starter with overload protection is shown in Figure 8-2. The starter resembles a single-pole switch with the addition of overload protection. A schematic diagram of the single-phase manual starter is shown in Figure 8-3.

A 3-phase manual starter, Figure 8-4, operates in a similar manner to the single-phase manual starter except that it provides three sets of contacts and three overloads. The starter is so designed that an overload on any phase of the 3-phase system will cause all three contacts to open. A schematic diagram of a 3-phase manual starter is shown in Figure 8-5.



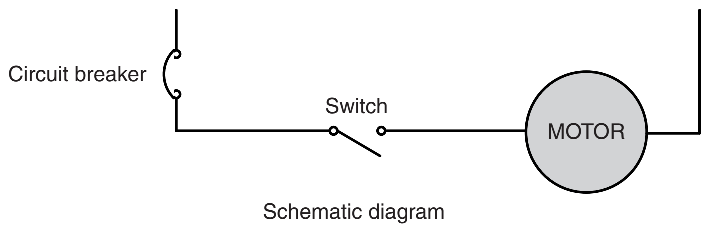


FIGURE 8-1 Pictorial and schematic diagram of a single-phase motor controlled by a switch.

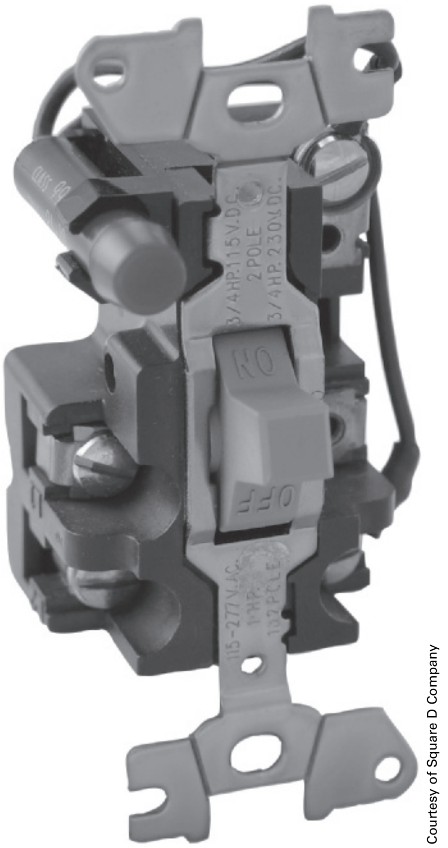


FIGURE 8-2 Single-phase manual motor starter with overload protection.

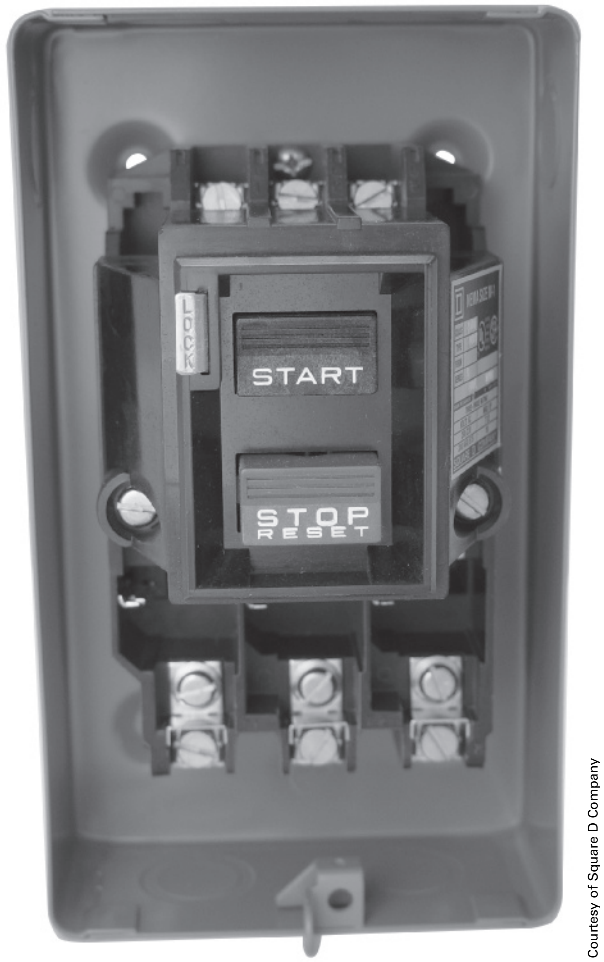


FIGURE 8-4 Three-phase manual starter.

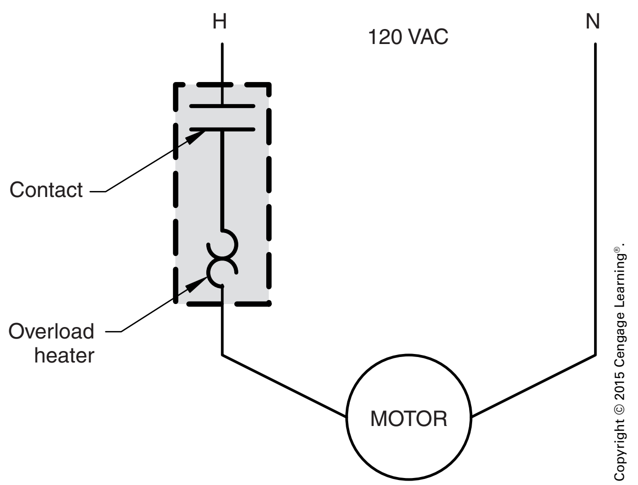


FIGURE 8-3 Schematic diagram of a single-phase manual starter.

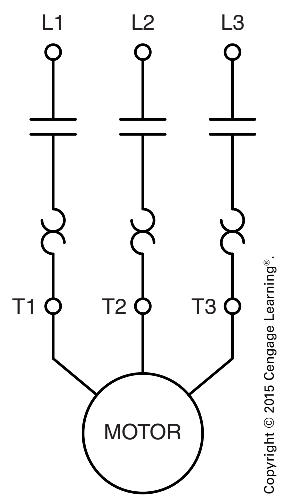


FIGURE 8-5 Schematic diagram of a 3-phase manual starter.

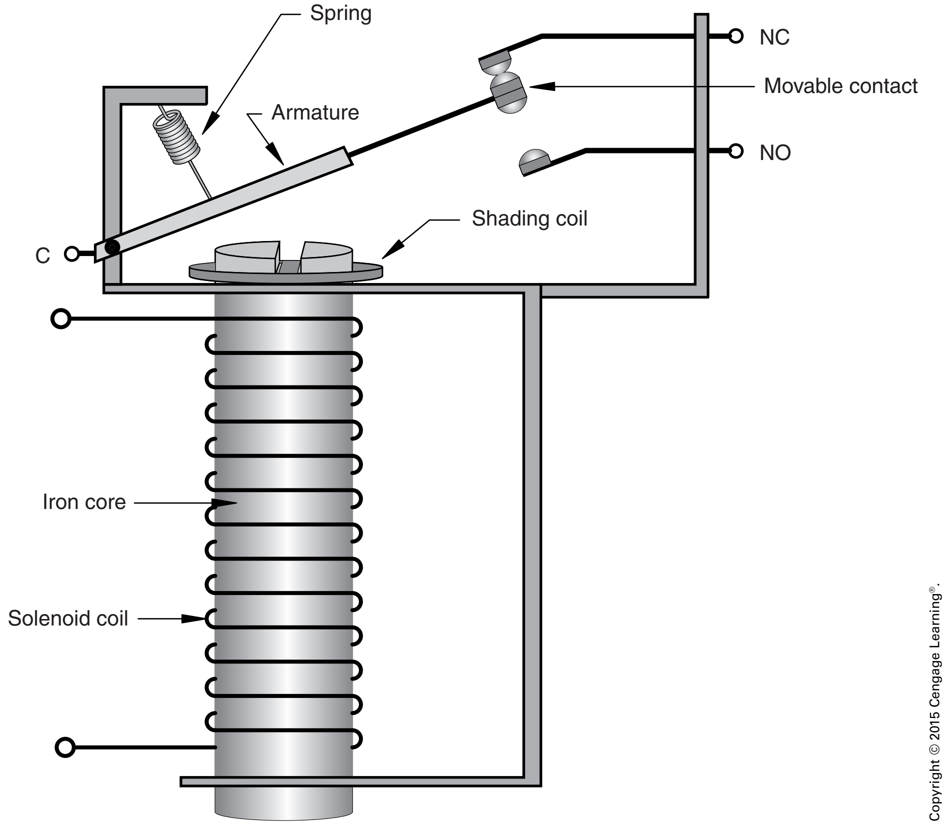


FIGURE 8-6 A magnetic relay is basically a solenoid with movable contacts attached.

THREE-WIRE CONTROLS

The designation *3-wire control* comes from the fact that three wires are run from a set of start–stop push buttons to a motor starter. Three-wire controls are characterized by the fact that they use magnetic contactors and starters. A magnetic contactor or relay is basically an electrical solenoid that closes a set of contacts when the coil is energized, Figure 8-6. A relay similar to the one illustrated in Figure 8-6 is shown in Figure 8-7. The terms used to describe motor control components can often be confusing. The term *relay* refers to a magnetically operated switch that contains small or auxiliary contacts. Auxiliary contacts are used as part of the control circuit and are not intended to connect a load to the line. *Contactors* contain large load contacts that are intended to handle large amounts of current. Load contacts are used to connect loads such as motors or other high-current devices to the power line. Contactors may or may not also contain auxiliary

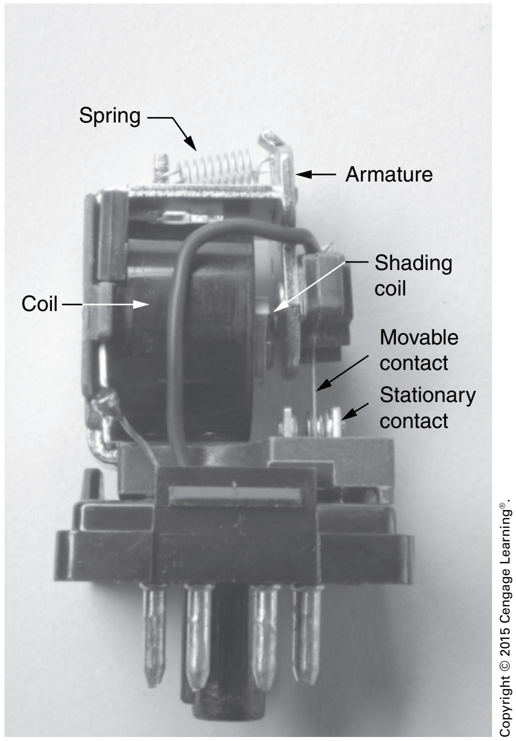


FIGURE 8-7 Eight-pin control relay.

FIGURE 8-8 Motor starters contain load contacts and overload protection for motors.

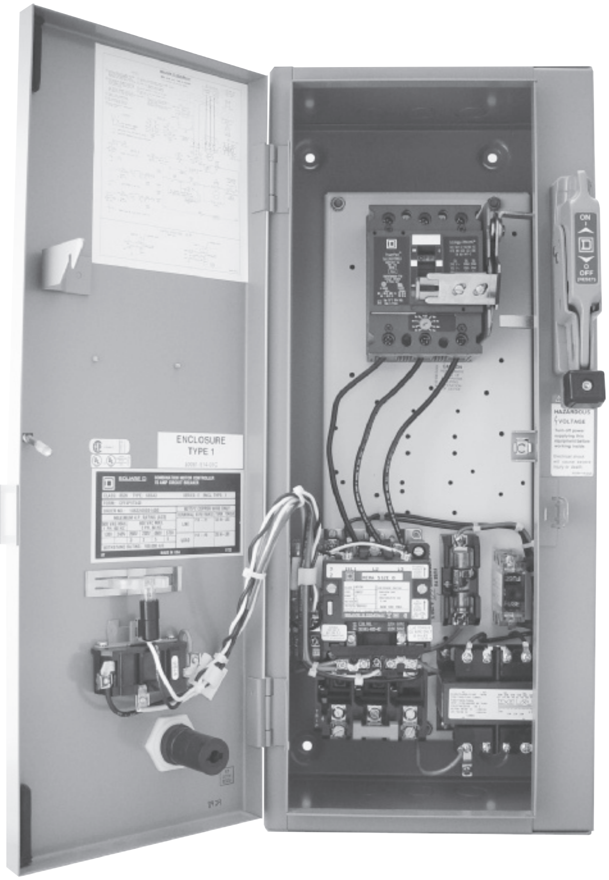


FIGURE 8-9 Combination starters contain the fused disconnect or circuit breaker, control transformer, and motor starter in one enclosure.

contacts. *Motor starters* are contactors that are equipped with overload protection for a motor, Figure 8-8. *Combination starters* contain the fused disconnect or circuit breaker, control transformer, and motor starter in one enclosure, Figure 8-9.

SCHEMATIC SYMBOLS

Schematic and wiring diagrams are the written language of motor controls. To understand these drawings, it is helpful to understand some of the symbols employed when control diagrams are drawn. Although there is no set standard for drawing motor control symbols, the most commonly accepted are those used by the National Electrical Manufacturers Association (NEMA). When reading control schematics, all switch and contact symbols are drawn to indicate their position when the circuit is turned off or not operating. This is called the *normal* position for that contact or switch.

Switch contacts can be drawn as normally open (NO), normally closed (NC), normally open held closed (NOHC), or normally closed held open (NCHO). When a switch is to be shown as normally open, it is drawn so that the movable contact is shown below and not touching the stationary contact, Figure 8-10A. If the contact is to be drawn normally closed, it is drawn so that the movable contact is above and touching the stationary contact, Figure 8-10B. There are some instances where a contact must be connected normally open, but when the circuit is not in operation, the contact is being held closed. A good example of this is the low-pressure switch on many air-conditioning circuits. The pressure in the system holds the contact closed. If the refrigerant should leak out, the reduced pressure will cause the switch to reopen and stop the operation of the compressor. A normally open held closed switch is drawn with the movable contact below but touching the stationary contact, Figure 8-10C. The switch is normally open because the movable contact is drawn below the stationary contact. It is held closed because the movable contact is touching the stationary contact.

A normally closed held open switch can be drawn in a similar manner, Figure 8-10D. The

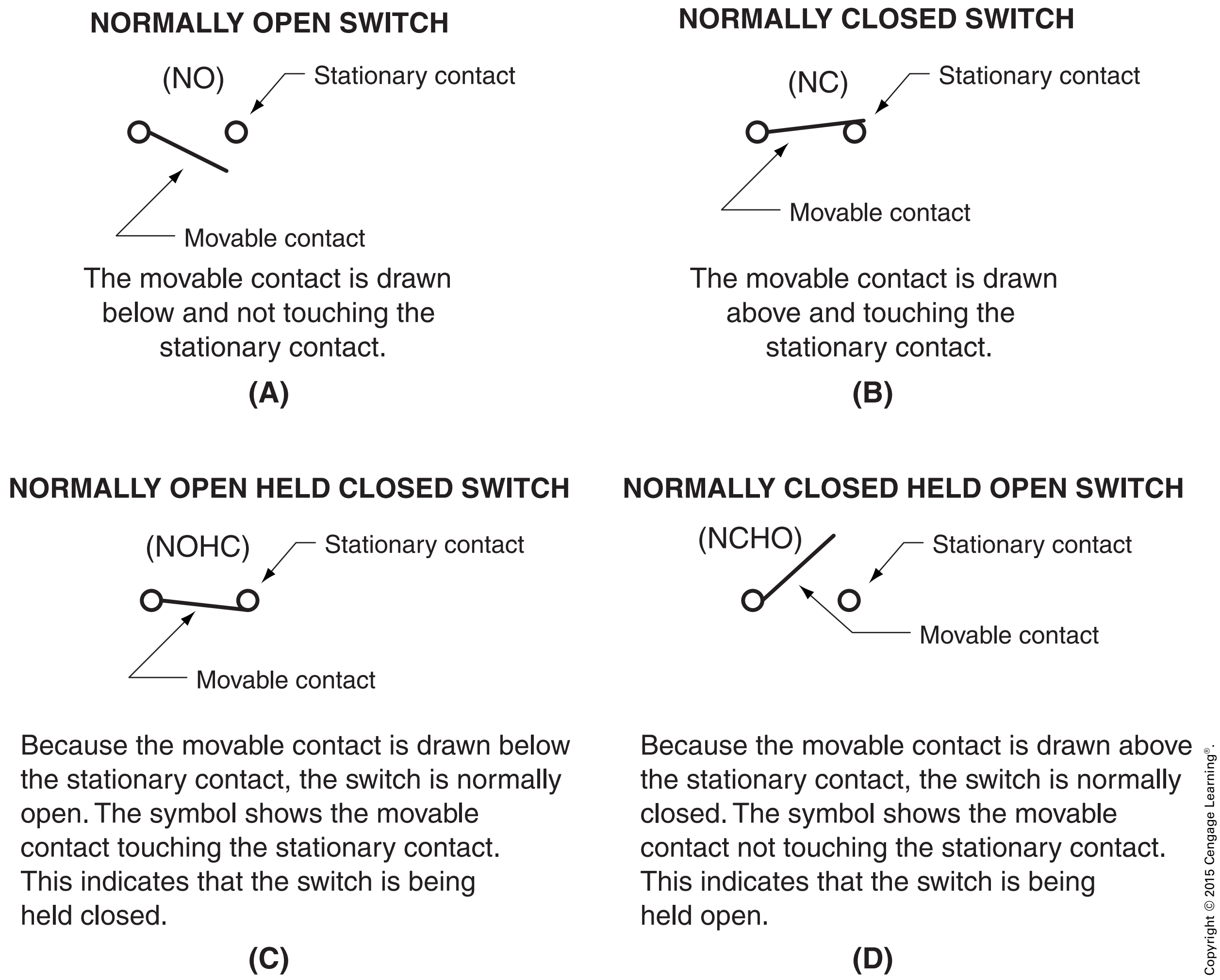


FIGURE 8-10 Switches can be drawn as normally open, normally closed, normally open held closed, or normally closed held open.

switch is normally closed because the movable contact is shown above the stationary contact. It is being held open because the movable contact is not touching the stationary contact.

Other symbols are added to switch symbols to indicate a particular type of switch. A limit switch, for example, is shown with a wedge drawn below the movable contact. The wedge represents the bumper arm of the limit switch. Limit switch symbols are shown in Figure 8-11. Other symbols are used to indicate different types of switches (Figure 8-12). A float switch, for example, uses a circle drawn on the bottom of a line. The circle represents a ball float. A flow switch uses a flag drawn on a line to represent the paddle that detects air or liquid flow. A pressure switch is drawn by connecting a semicircle to a line. The flat portion of the symbol represents a diaphragm used to sense pressure. A temperature switch or thermostat is indicated by drawing a zigzag line that represents a bimetal helix that expands and contracts with a change of temperature.

Normally open contact symbols are shown as parallel lines with connecting wires, Figure 8-13. Normally closed contact symbols are the same, with the exception that a diagonal line is drawn through the two parallel lines. Contacts are always shown in the de-energized or off position.

Another very common schematic symbol is the push button. Normally open push buttons are shown with the movable contact above and not touching the two stationary contacts, Figure 8-14. The symbol indicates that when finger pressure is applied

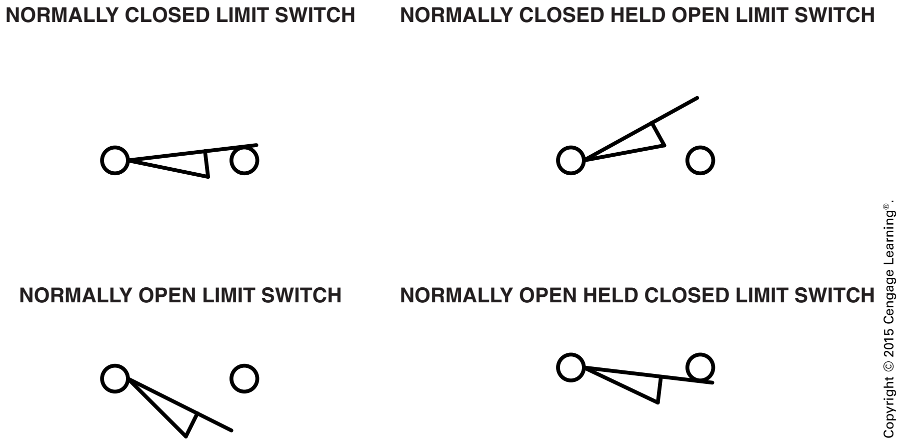


FIGURE 8-11 Limit switches are indicated by drawing a wedge shape below the movable contact of a switch symbol.

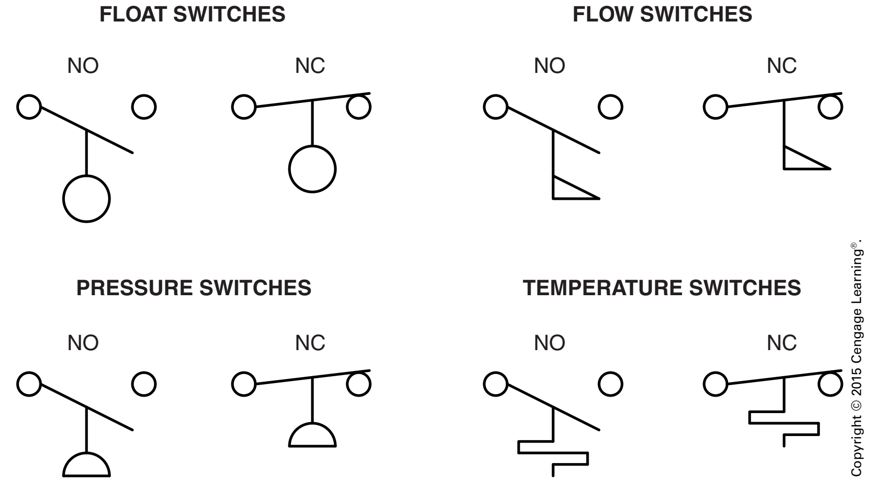


FIGURE 8-12 Symbols used to represent different types of switches.

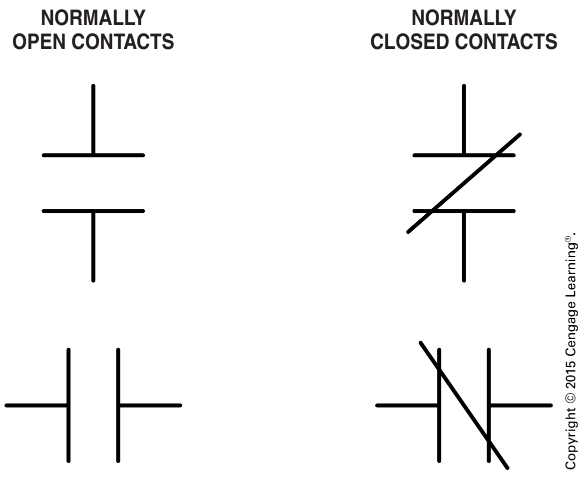


FIGURE 8-13 Normally open and normally closed contact symbols.

to the movable contact, it travels downward and bridges the gap between the two stationary contacts. Normally closed push-button symbols are drawn with the movable contact below and touching the stationary contacts. When pressure is applied to the movable contact, it travels downward and breaks the connection between the two stationary contacts. Another very common push-button symbol is the double-acting push button. Double-acting push buttons contain both normally open and normally closed contacts with one movable contact, Figure 8-15.

Control circuits often require push buttons that contain multiple contacts. When this is the case, a stacked push button can be employed. Stacked push buttons are so designed that different contact sets can be connected that are controlled by a single push

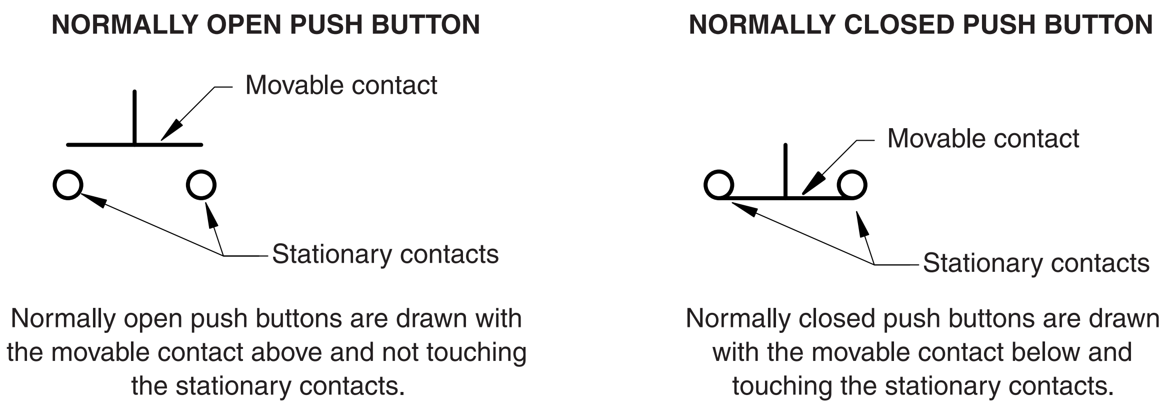


FIGURE 8-14 NEMA standard push-button symbols.

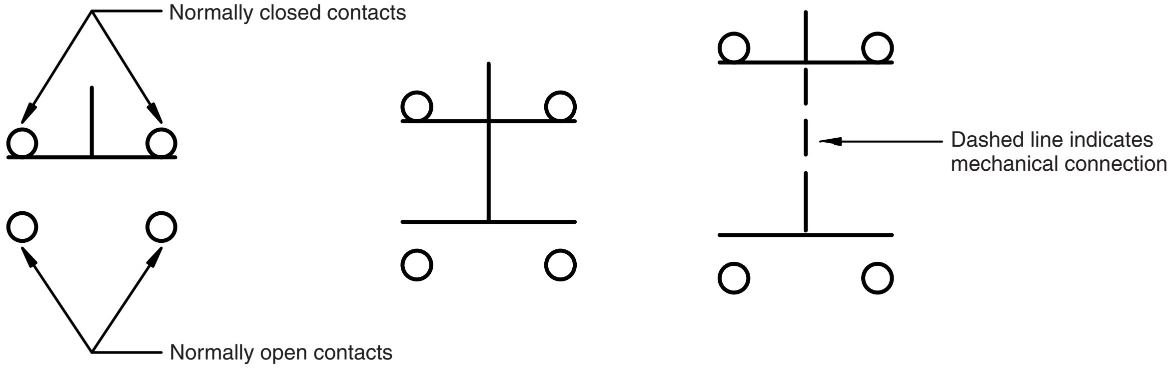


FIGURE 8-15 Different symbols used to represent double-acting push buttons.

button. These contact sets may contain normally open or normally closed contacts. A stacked push button is shown in Figure 8-16. A chart showing common electrical and control symbols is shown in Figure 8-17.

Relay, contactor, and starter coils are generally indicated by a circle. A number and/or letter is placed inside the circle to designate a particular coil. Coils with the letter M generally mean motor starter. The letters TR indicate a timer relay and the letters CR generally indicate a control relay.

OVERLOAD RELAYS

Overload relays are designed to protect the motor from an overload condition. All overload relays contain two separate sections: the current-sensing section and the control contact section. The overload relay does not disconnect the motor from the power line when

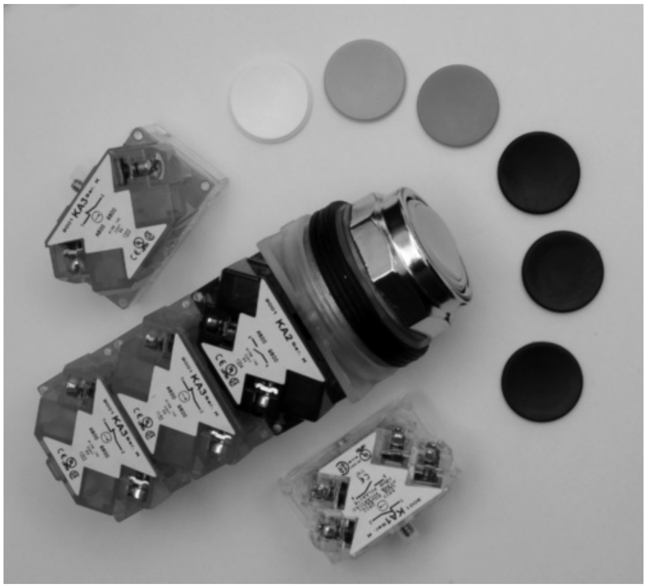


FIGURE 8-16 A stacked push button may contain numerous sets of contacts.

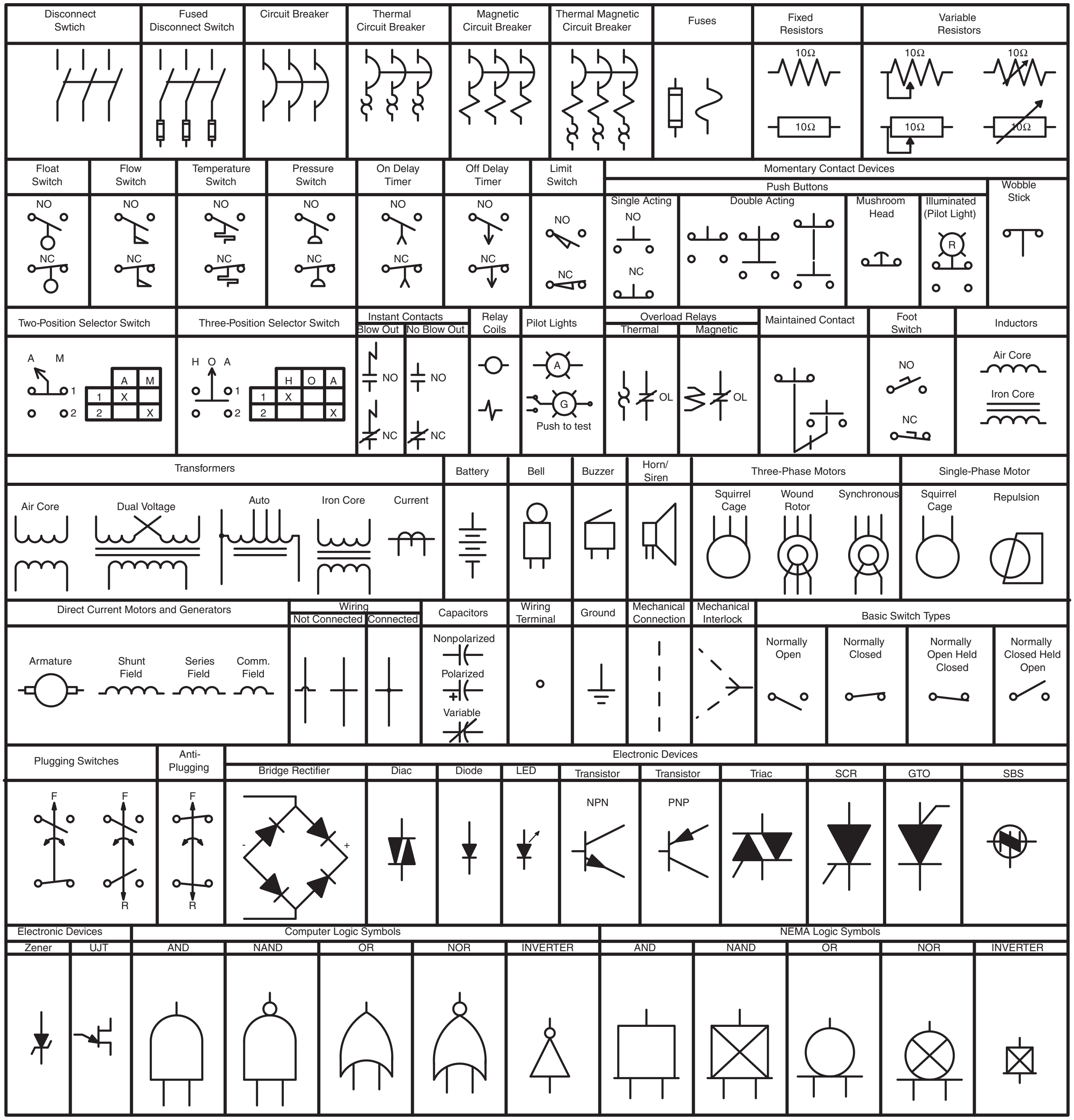


FIGURE 8-17 Common control and electrical symbols.

an overload condition occurs. The overload relay contains a set of normally closed auxiliary contacts that are connected in series with the coil of the motor starter. If an overload condition occurs, the contacts open and disconnect power to the coil of the motor starter. This causes the load contacts on the starter to open and disconnect the motor from the power line.

The current-sensing section of the overload relay can be magnetic, electronic, or thermal. Magnetic overload relays operate by connecting a current coil in series with the motor, Figure 8-18. If the motor current should become excessive, the magnetic field will become strong enough to cause the normally closed auxiliary contacts to open and de-energize the coil of the motor starter.

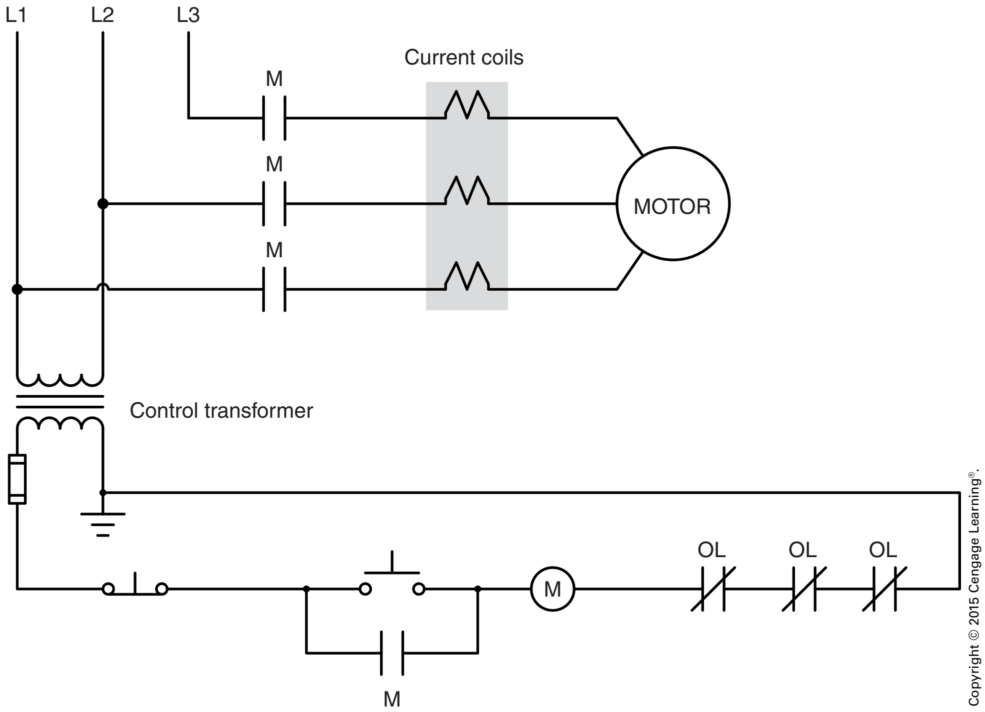


FIGURE 8-18 Magnetic overload relays sense motor current by connecting a current coil in series with the motor.

Electronic overload relays sense motor current by placing a current-carrying wire through a toroid transformer, Figure 8-19. The transformer measures the magnetic field strength of the conductor in much the same way that a clamp-on-type ammeter measures the current in a conductor. If the current becomes excessive, the normally closed auxiliary contacts open and disconnect power to the motor starter coil.

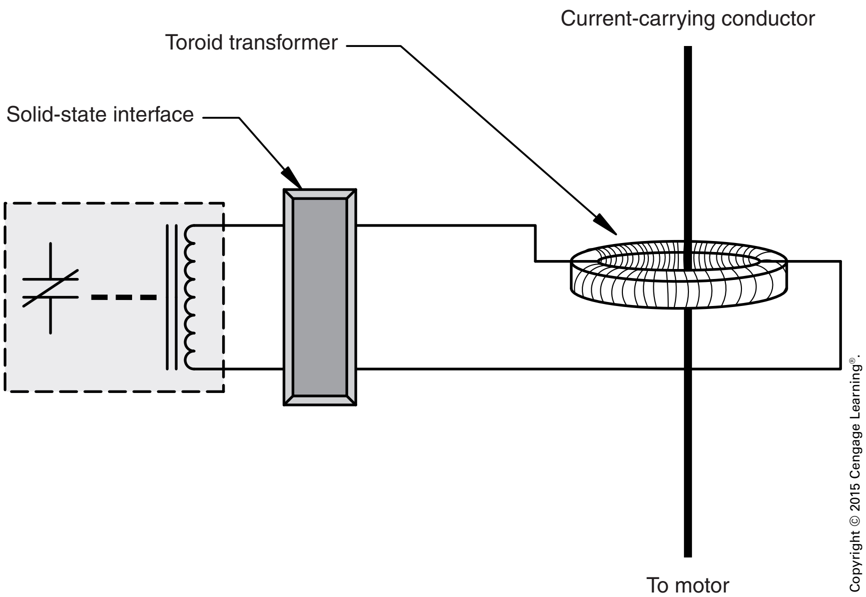


FIGURE 8-19 Electronic overload relays sense motor current by measuring the magnetic field strength around the conductor supplying power to the motor.

Thermal overload relays are by far the most common. Thermal overload relays operate by connecting a heater element in series with the motor, Figure 8-20. The temperature of the heater is dependent on motor current and the ambient temperature. There are two types of thermal overload relays, the solder pot type and the bimetal strip type.

The solder pot–type overload relay works by placing a brass shaft inside a brass tube. A serrated wheel is attached to the brass shaft, Figure 8-21. Solder is used to bond the brass shaft to the brass tube. A lever arm between the contacts and serrated wheel holds the contacts in place, Figure 8-22. If the motor current becomes excessive, the heater will melt the solder and permit the serrated wheel to turn, causing the normally closed auxiliary contacts to open.

The bimetal strip–type overload uses a bimetal strip to open the normally closed auxiliary contacts if the motor current becomes excessive, Figure 8-23. There are other differences between the solder pot–type and bimetal strip–type overload relay. Bimetal

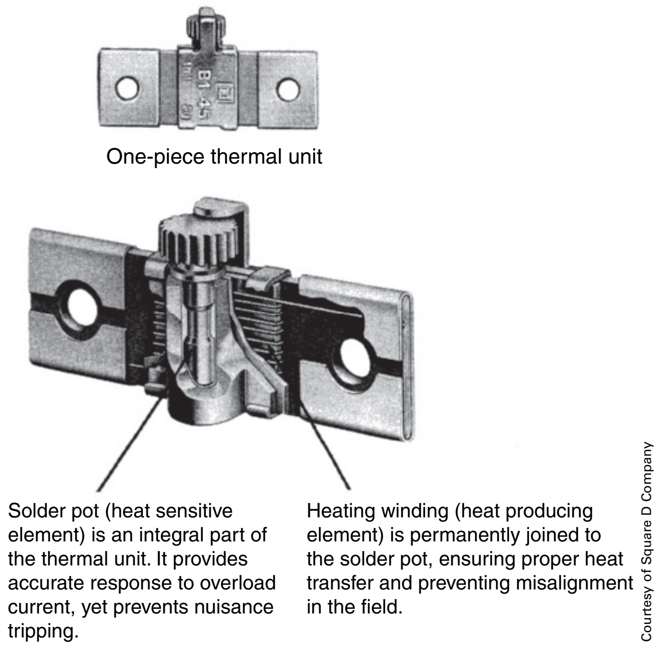


FIGURE 8-20 Thermal overload relays operate by connecting a heating element in series with the motor.

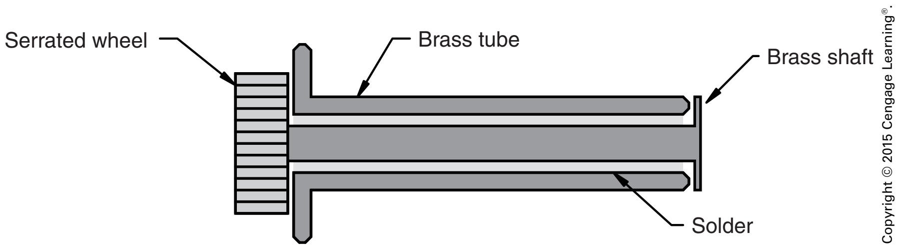


FIGURE 8-21 Construction of a typical solder pot overload.

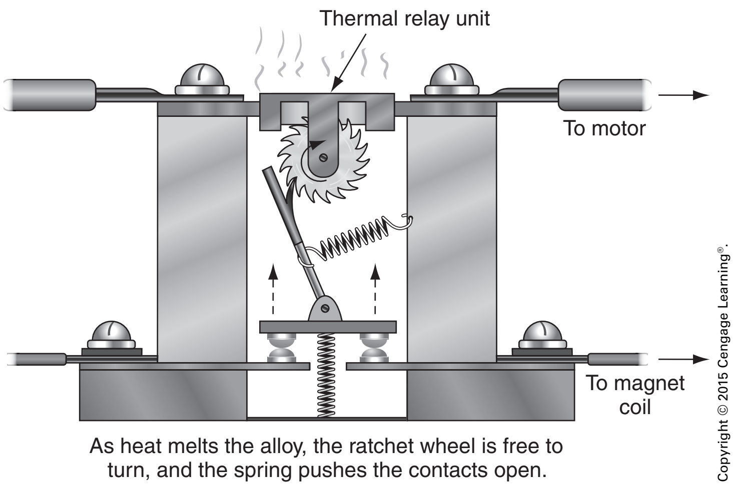


FIGURE 8-22 Basic solder pot overload relay.

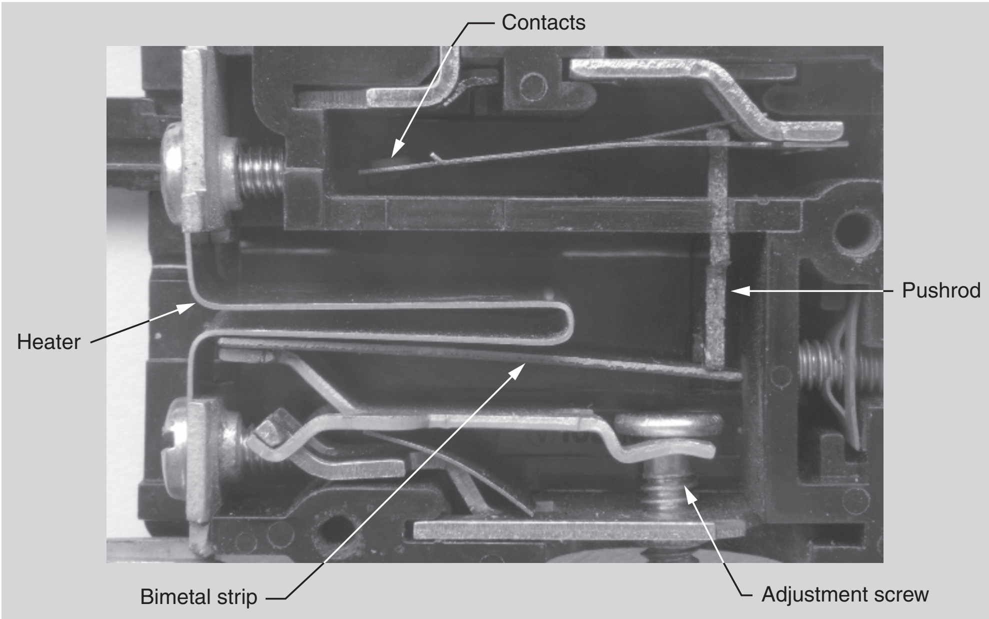


FIGURE 8-23 Bimetal-type overload relay.

strip–type overload relays generally permit the trip current to be adjusted to between 85 and 115% of the heater rating, Figure 8-24. Another difference is that bimetal strip–type overloads can generally be set to permit the contacts to reset automatically or manually after the bimetal strip has cooled sufficiently, Figure 8-25. Generally, the relay is adjusted for manual reset. Automatic reset should be used only if the sudden starting of a motor will not cause danger to personnel or damage equipment.

Regardless of the type of thermal overload relay used, the trip current of the relay is set by the size of the heater used with the relay. Manufacturers make different-sized heaters that are designed to open the contacts at different current levels. A chart provided by the manufacturer of the relay can be used to select the proper heater for a particular application.

When three single-phase overload relays are employed to protect a 3-phase motor, the three auxiliary overload contacts are connected in series, as shown in Figure 8-26. With this type of connection, if one relay should trip, the motor starter coil is disconnected from the power line. Three-phase overload relays, Figure 8-27, contain three separate heaters

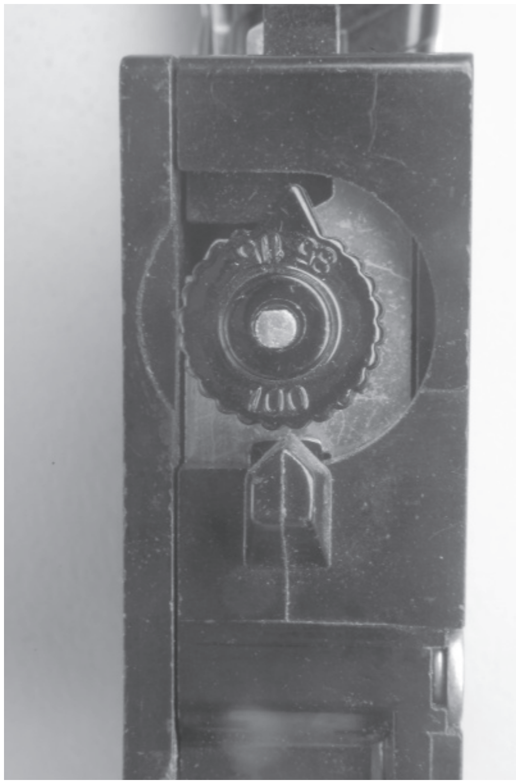


FIGURE 8-24 Bimetal strip–type overloads generally permit adjustment of the trip current.

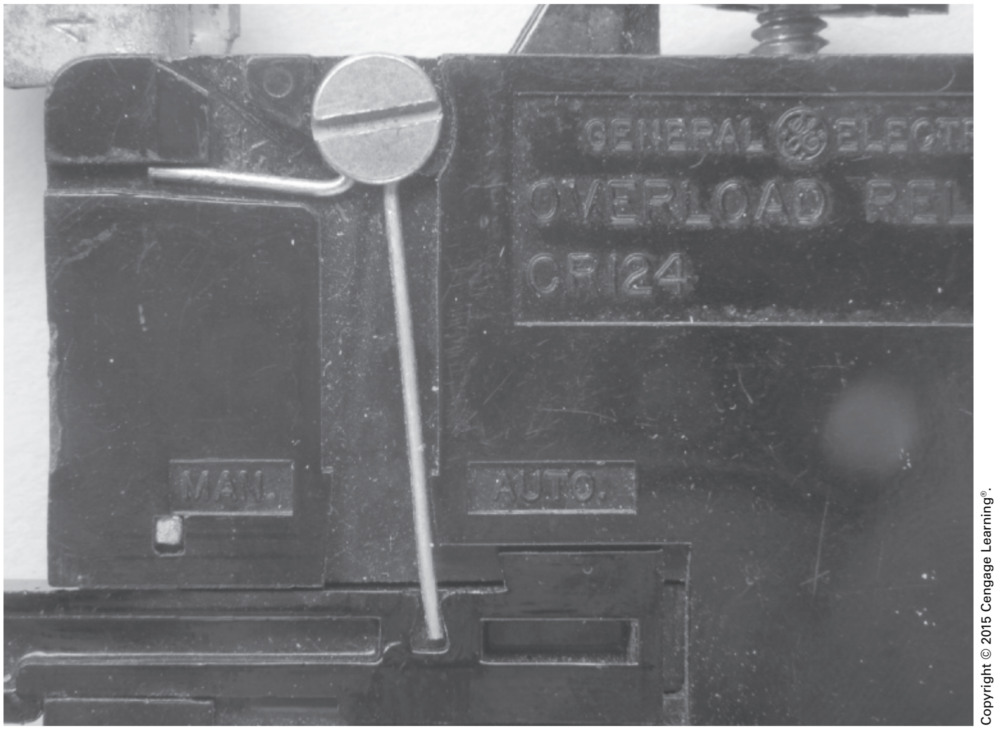


FIGURE 8-25 Bimetal strip overload relays can generally be set to permit automatic or manual reset of the auxiliary contacts.

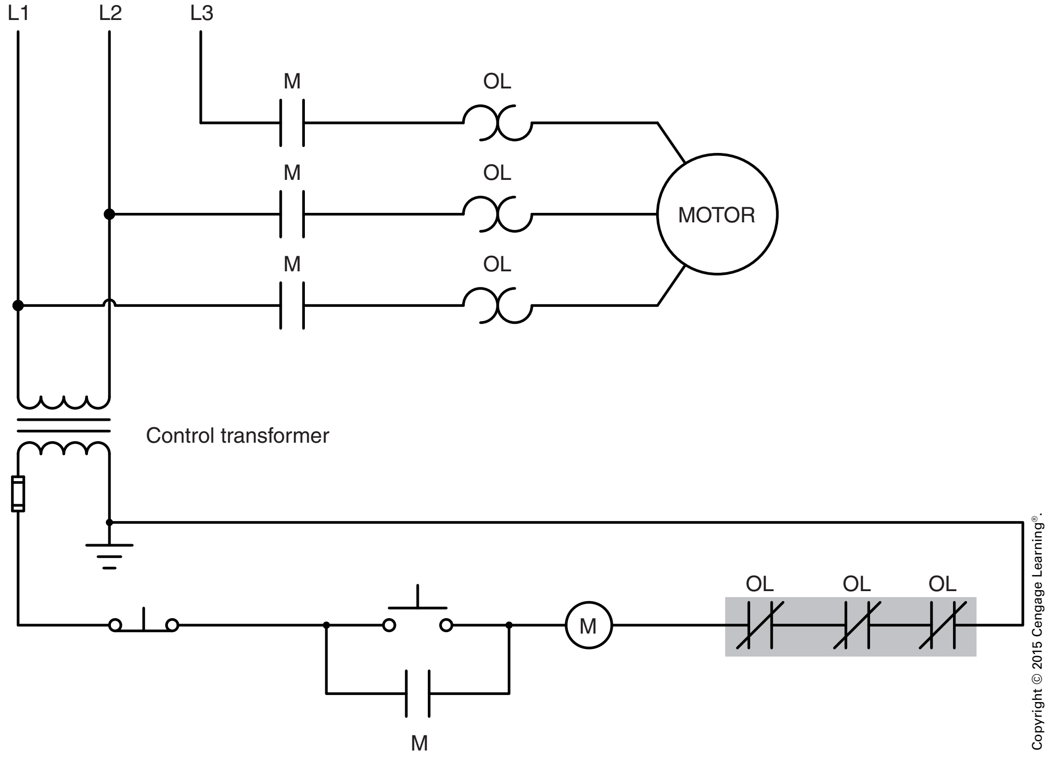


FIGURE 8-26 When three single overload relays are employed to protect a 3-phase motor, all normally closed overload contacts are connected in series.

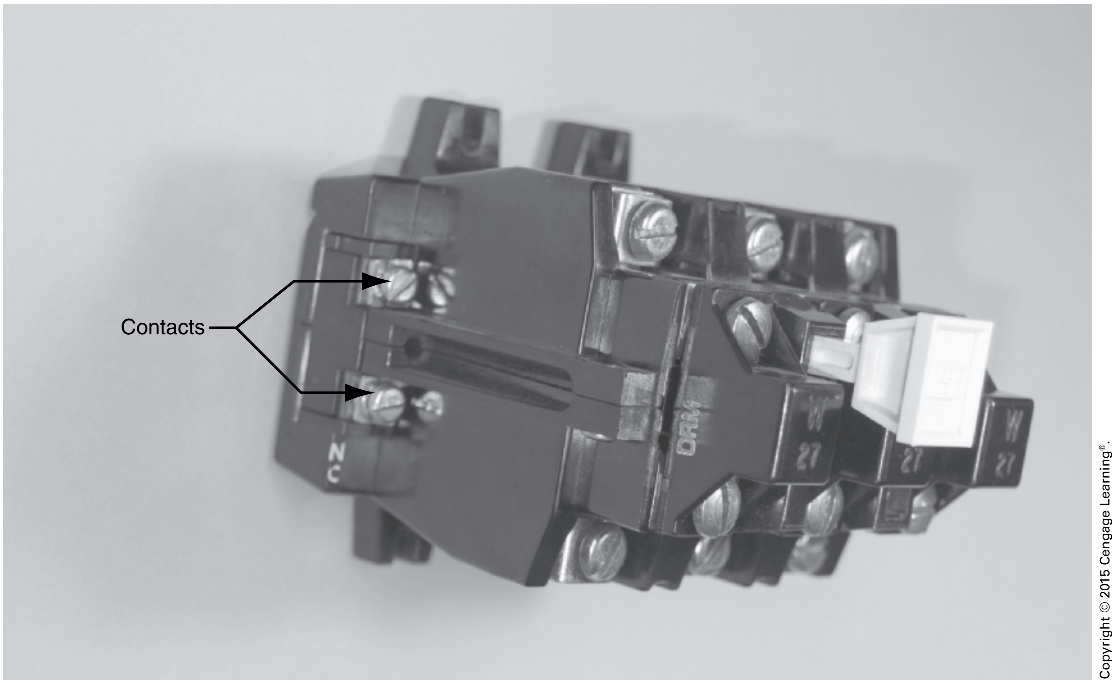


FIGURE 8-27 A 3-phase overload relay contains three separate heaters but only one set of normally closed contacts.

but only one set of overload contacts. If an overload occurs on any phase, it will open the normally closed contacts. When a 3-phase overload relay is used, only one set of normally closed contacts is connected in series with the starter coil, Figure 8-28.

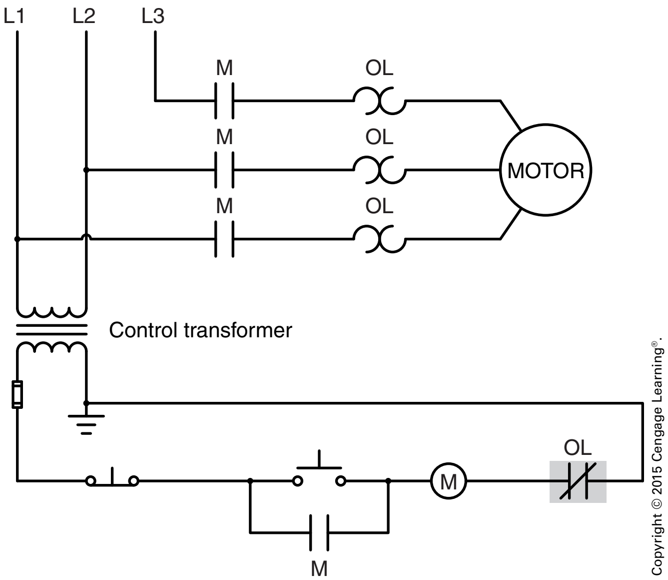


FIGURE 8-28 A 3-phase overload relay contains three heaters but only one set of normally closed contacts.

Although all overload relays contain a set of normally closed contacts, some manufacturers include a set of normally open contacts as well. There are two arrangements for normally open overload relay contacts. One arrangement contains two separate contacts, one normally open and the other normally closed. The second is basically a single-pole double-throw switch. The contacts contain a common terminal, a normally closed terminal, and a normally open terminal. The normally open terminal is sometimes labeled in some manner other than normally open. The overload relay shown in Figure 8-29 contains three terminals labeled COM. (common), OL. (overload), and ALAR. (alarm). The common terminal is connected to one side of the power supply for the control circuit. The overload terminal is connected in series with the coil of the motor starter, and the alarm terminal is connected to a pilot lamp, Figure 8-30. The pilot lamp indicates that the overload relay has tripped.

Another common method used for the normally open contacts is to supply power to the coil of a small control relay, Figure 8-31. The contact of the control relay can provide power to the input of a programmable logic controller. If the overload relay should trip, a signal is provided to the PLC to inform the circuit that the motor has tripped on overload.

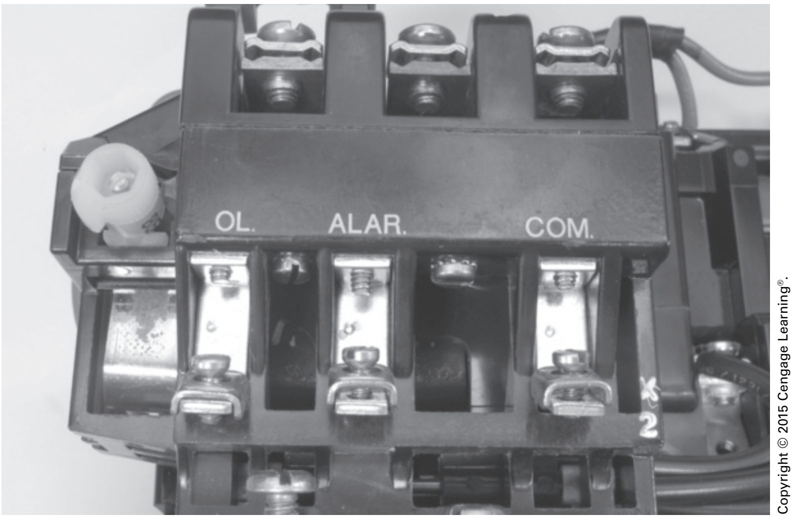


FIGURE 8-29 Overload relay with a common terminal, a normally closed terminal, and a normally open terminal.

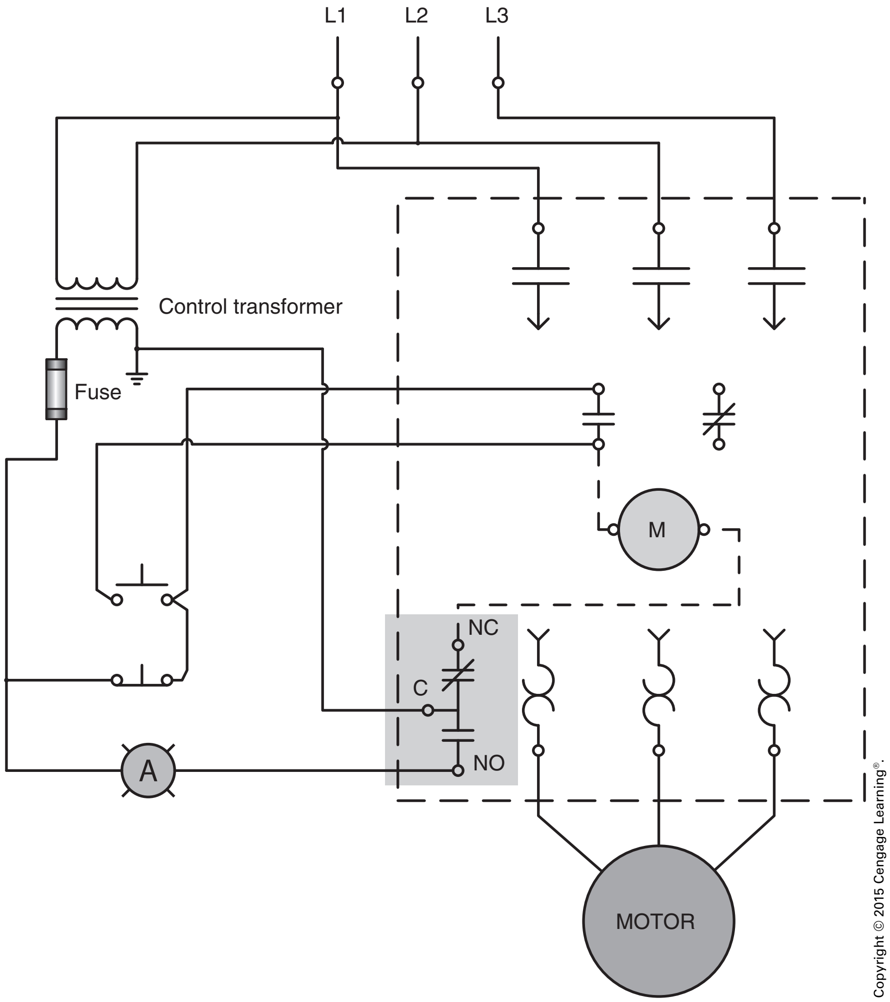


FIGURE 8-30 The normally open contact supplies power to a pilot warning lamp.

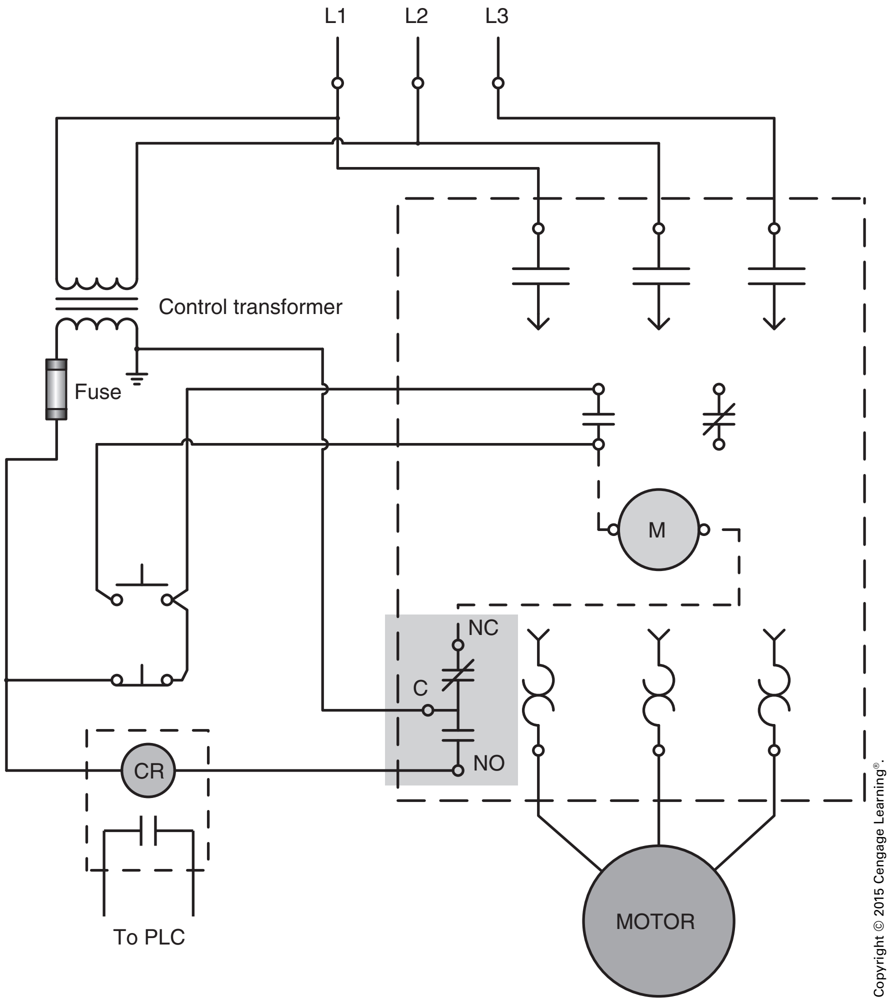


FIGURE 8-31 The normally open contact supplies power to the coil of a control relay.

Interposing relays are used to prevent more than one power source from entering the control system either at the motor starter or at the PLC.

SCHEMATICS AND WIRING DIAGRAMS

Schematic or ladder diagrams and wiring diagrams both show electrical connections, but they differ greatly in appearance. The drawing in Figure 8-32 shows a schematic or ladder diagram and a wiring diagram of a start–stop push-button control. Although both of these circuits are identical electrically, they are different in appearance. Schematic diagrams show components in their electrical sequence without regard for physical location. Wiring diagrams show a pictorial representation of the components with connecting wires. Schematic diagrams are by far the more widely used in industry. There are several rules that should be followed when reading a schematic diagram:

- All electrical components are shown in their off or de-energized position.
- Schematics should be read like a book, from top to bottom and from left to right.
- Contacts that contain the same letter or number as a coil are controlled by that coil regardless of where they are located in the drawing.
- When a circuit is completed to a coil, that coil will energize, and all contacts controlled by that coil will change position. All normally open contacts will close and all normally closed contacts will open.

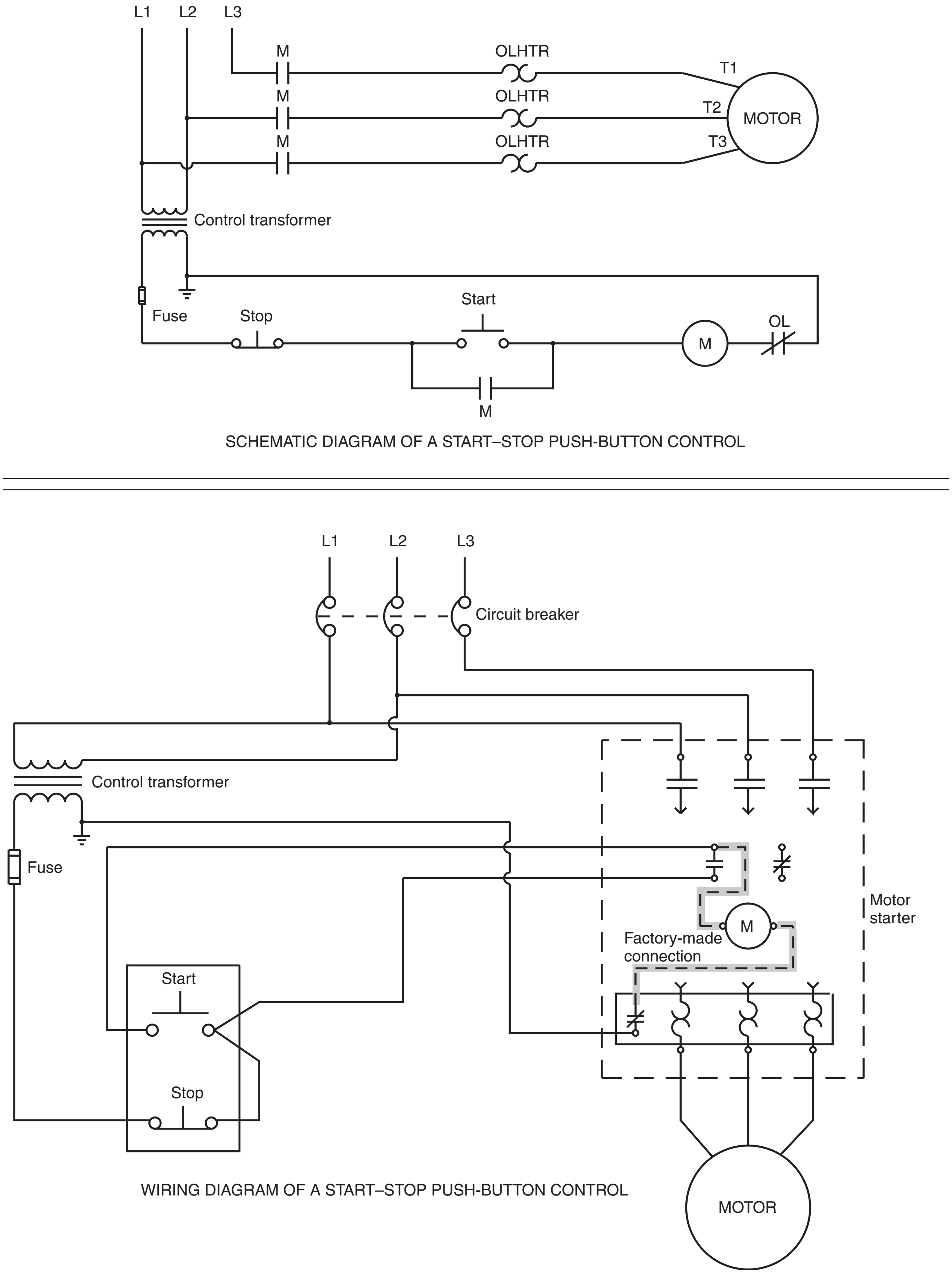


FIGURE 8-32 Schematic and wiring diagrams of a start–stop push-button control.

START–STOP PUSH-BUTTON CONTROL CIRCUIT

The start–stop push-button control circuit is often the beginning of more complex circuits. This circuit is often referred to as the basic circuit. To understand the operation of the circuit, refer to the schematic shown in Figure 8-33. Note that there are four normally open contacts labeled with the letter M. Also note that the coil of the motor starter is labeled with the letter M. This indicates that all the contacts that are labeled with an M are controlled by the coil labeled M. When the start button is pressed, Figure 8-34, a circuit is completed to M coil. When coil M energizes, all M contacts change from open to closed, Figure 8-35. The small auxiliary M contact connected in parallel with the start push button closes to maintain the circuit to the coil when the push button is released. This contact is generally referred to as a hold, sealing, or maintaining contact, because it holds the circuit closed after the start button is released. The three load contacts labeled M close and connect the motor to the power line. The circuit will remain in operation until the stop button is pressed or an overload should occur, causing the normally closed overload contacts to open, breaking the circuit to M coil, Figure 8-36. When coil M de-energizes, all M contacts return to their open position, and the circuit is back to its original de-energized state.

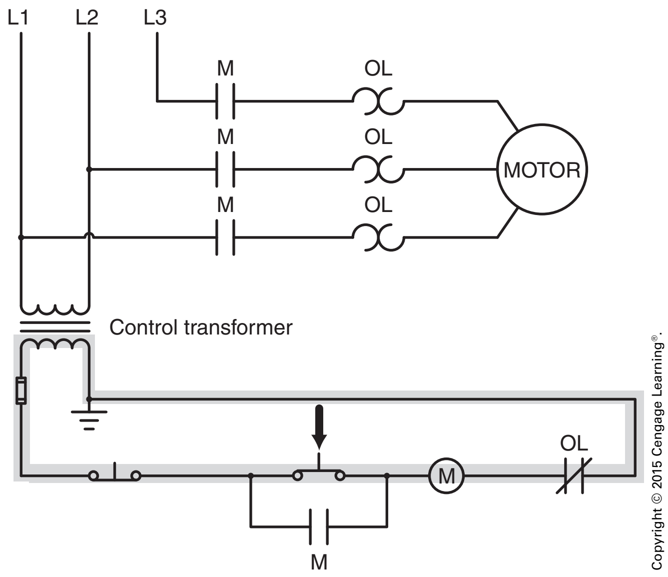


FIGURE 8-34 When the start button is pressed, a circuit is completed to coil M of the motor starter.

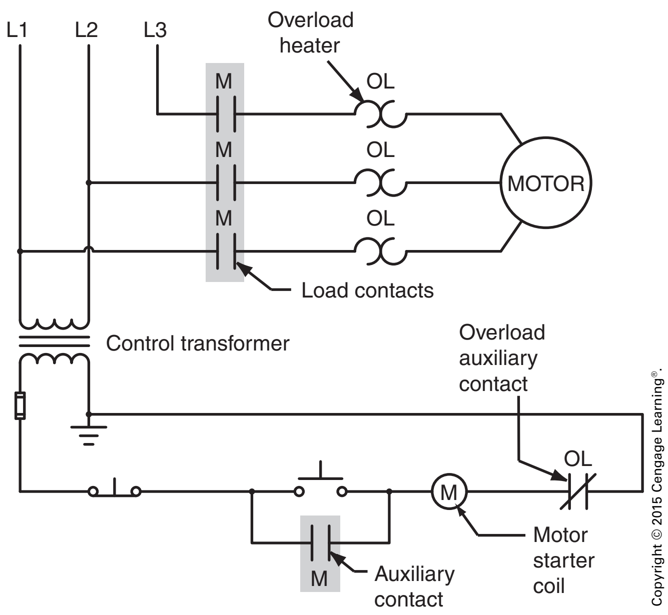


FIGURE 8-33 Basic start–stop push-button control circuit.

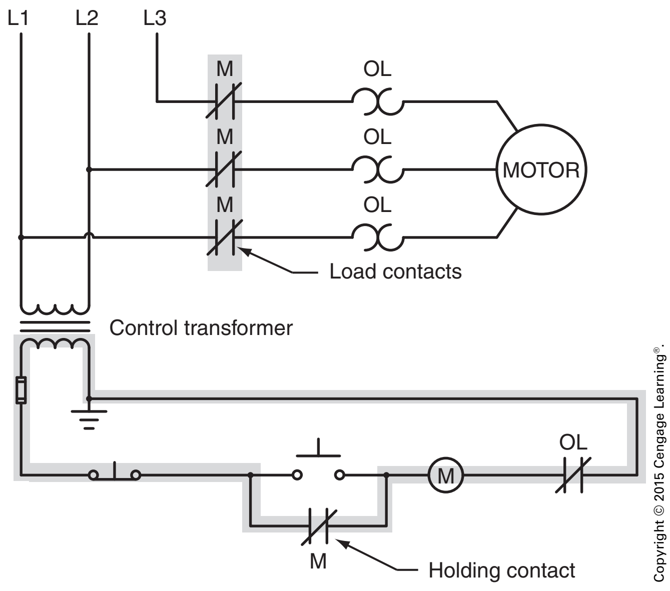


FIGURE 8-35 All contacts labeled M change position when the coil is energized.

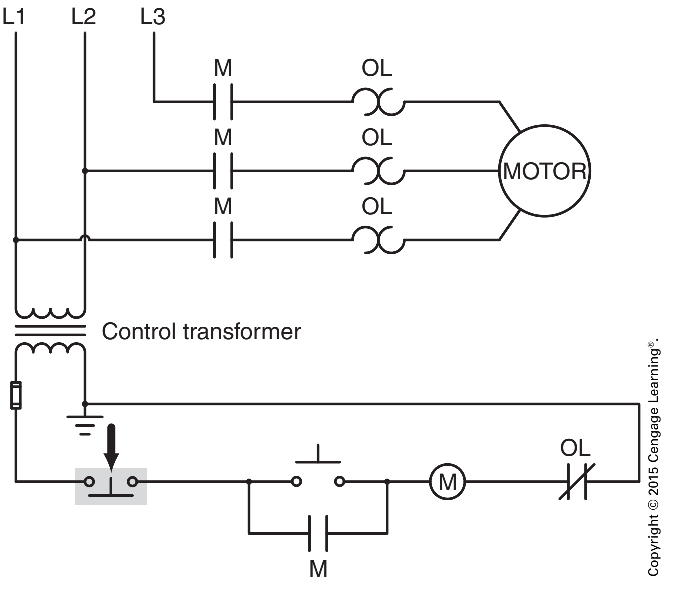


FIGURE 8-36 Pressing the stop button breaks the connection to the coil of M starter.

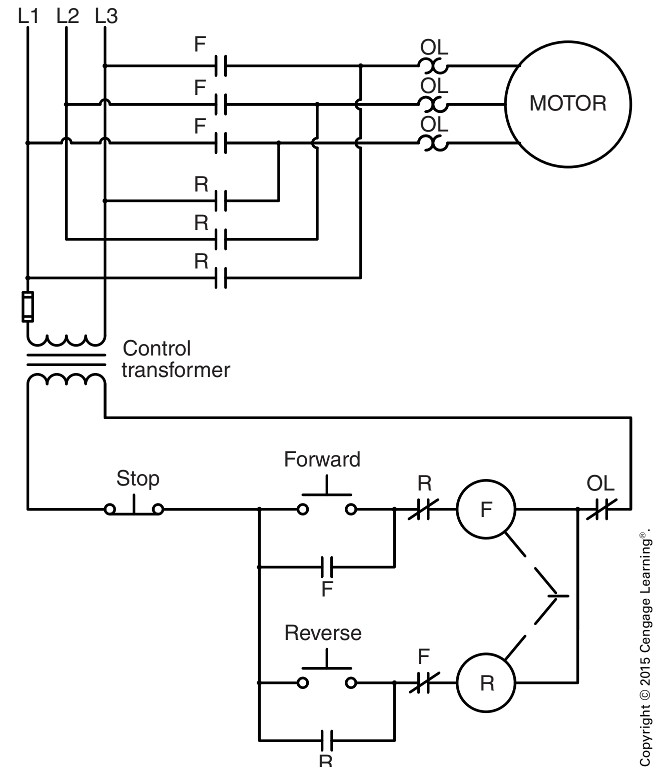


FIGURE 8-37 Basic forward–reverse control circuit.

FORWARD–REVERSE CONTROL

Another very common control circuit found throughout industry is the forward–reverse control. Three-phase motors can be reversed by changing any two stator leads. Forward–reverse controls also employ interlocking to prevent both the forward and reverse coils from being energized at the same time. A typical forward–reverse control is shown in Figure 8-37. The dashed lines drawn from the F and R coils to a single line indicate mechanical interlocking. Mechanical interlocks are used to prevent both forward and reverse contactors from being energized at the same time. When one contactor is energized, a mechanism prevents the other from being able to close its contacts even if the coil should be energized. Electrical interlocking is accomplished by using the two normally closed auxiliary contacts connected in series with F and R coils, Figure 8-38. Note that the normally closed F contact is connected in series with the R contactor coil, and the normally closed R contact is connected in series with the F contactor coil.

When the forward push button is pressed, a circuit is completed through the normally closed R contact to the F coil. When F coil energizes, all F contacts change position, Figure 8-39. The three

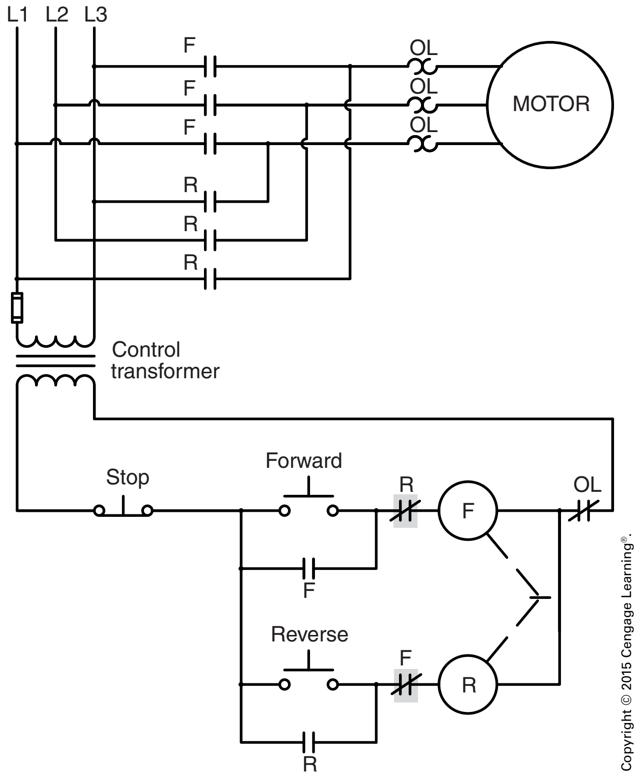


FIGURE 8-38 Normally closed auxiliary contacts are used to provide electrical interlock for the circuit.

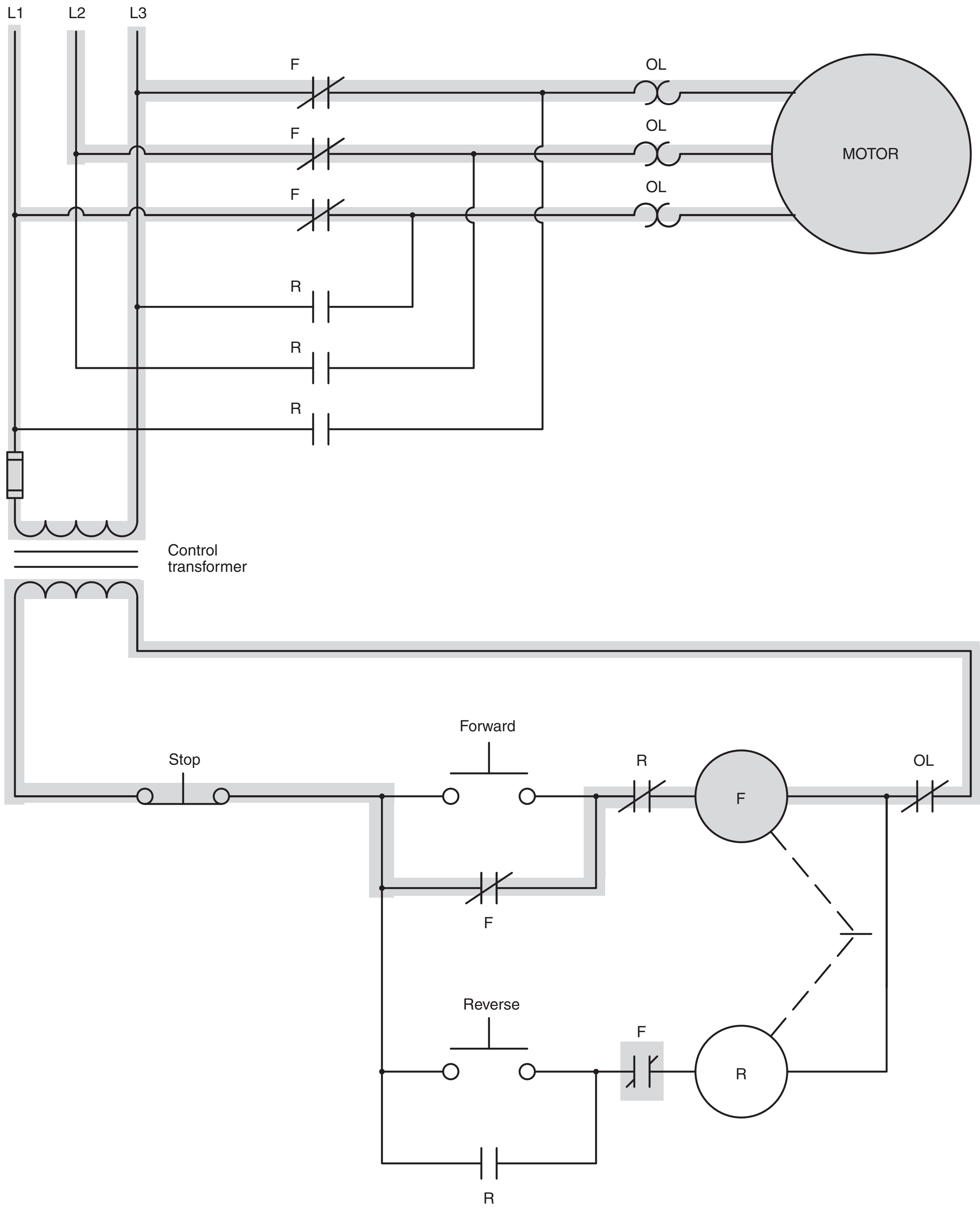


FIGURE 8-39 Motor operating in the forward direction.

F load contacts close and connect the motor to the power line, causing the motor to run in what is considered the forward direction. The normally open F auxiliary contact connected in parallel with the forward push button closes to maintain the circuit when F push button is released. The normally closed F contact connected in series with R coil opens. This would prevent R coil from energizing if the reverse push button were to be pressed.

Before the motor can be operated in reverse, the stop push button must be pressed to break the circuit to F coil. When F coil de-energizes, all F contacts return to their normal positions, as shown in Figure 8-37. When the reverse push button is pressed, a circuit is completed through the now closed F auxiliary contact to R coil. When R coil energizes, all R contacts change position, Figure 8-40. The three R load contacts close and connect the motor to the power line. Note that the connections for L1 and L3 that go to the motor have been reversed. This causes the motor to operate in the reverse direction. Also note that the normally closed R auxiliary contact connected in series with F coil is now open, preventing a circuit from being established to F coil if the forward push button should be pressed. The wiring diagram of a forward–reverse control circuit with electrical interlocks is shown in Figure 8-41.

BASIC AIR-CONDITIONING CIRCUIT

A basic circuit for a central air-conditioning system is shown in Figure 8-42. The circuit ensures that the condenser fan is in operation before the compressor is permitted to start. A flow switch is used to sense the airflow caused by the condenser fan. The compressor is also protected from low pressure and high pressure by pressure switches. Both the condenser fan and compressor are also protected from overload by overload relays. A thermostat is used to control the operation of the circuit. A transformer is used to step the 240 volts of line voltage down to 24 volts for operation of the control circuit.

TIMING RELAYS

One of the basic control components found in many control circuits is the timing relay. Timing relays can be divided into two general types, on delay and off delay. On-delay relays are sometimes noted as DOE (delay on energize), and off-delay times are sometimes noted as DODE (delay on de-energize). The contact symbols for on- and off-delay timers are shown in Figure 8-43. The arrow on the symbol points in the direction that the contacts will move after the delay period.

On-Delay Timers

The contacts of an on-delay timer delay changing their position after the timer has been energized. The contacts return to their normal position immediately when the timer is de-energized. Refer to the circuit shown in Figure 8-44. Assume that on-delay timer TR is set for a delay of 10 seconds. When switch S1 is closed, the coil of timer TR is energized. TR contacts, controlled by coil TR, remain open for a period of 10 seconds before closing. After the contacts have closed and turned on the green pilot lamp, they remain closed until the coil of timer TR is de-energized. When the coil of TR is de-energized, the TR contacts return to their normally open condition immediately.

Off-Delay Timers

The contacts of an off-delay timer change immediately when the timer is energized. They remain in their energized state for some period of time after the timer is de-energized. Refer to the circuit shown in Figure 8-45. Assume that off-delay timer TR is set for a delay of 10 seconds. When switch S1 is closed, the coil of timer TR is energized. TR contacts, controlled by coil TR, close immediately and turn on the amber lamp. When switch S1 is opened, and TR coil

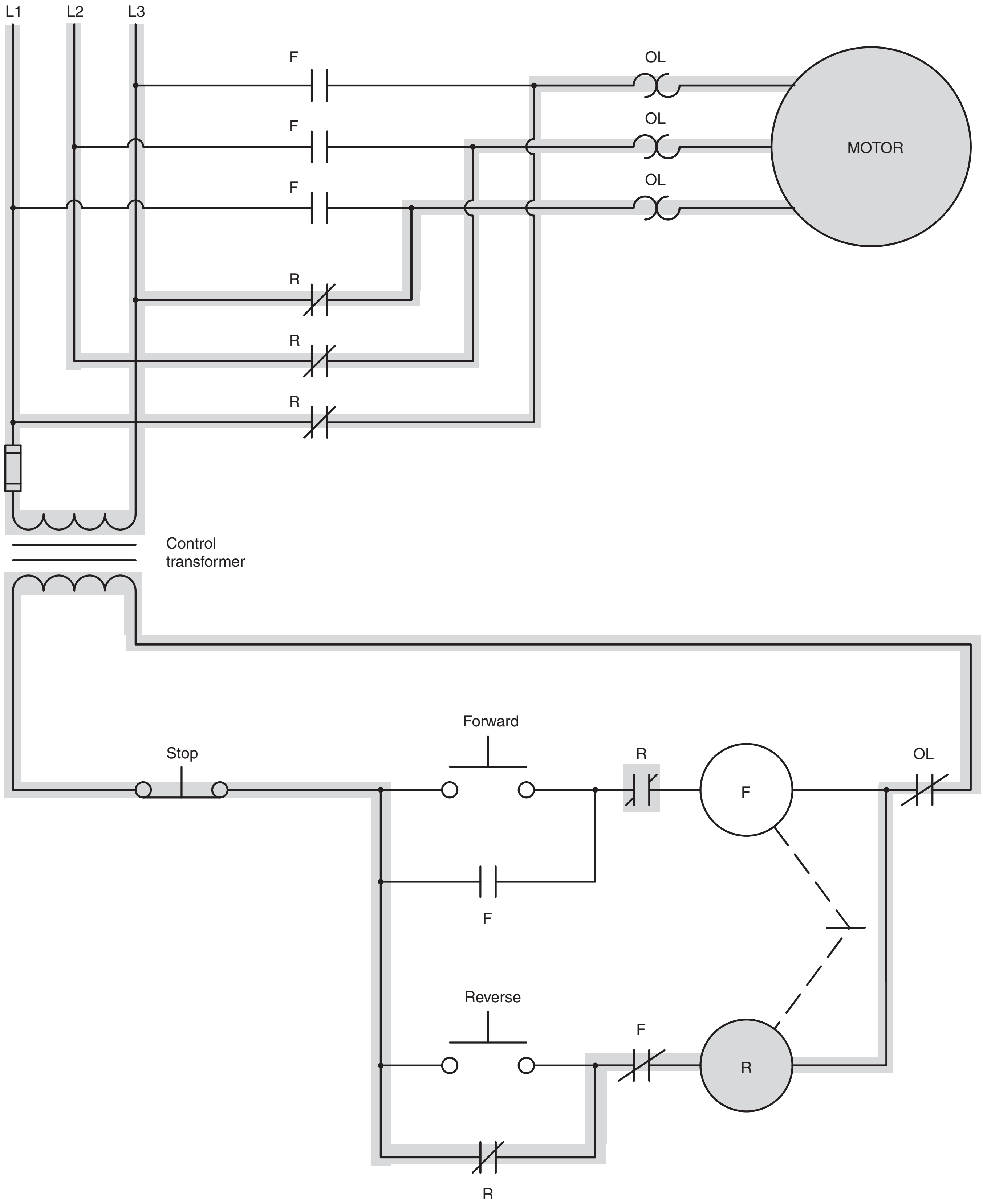


FIGURE 8-40 Motor operating in the reverse direction.

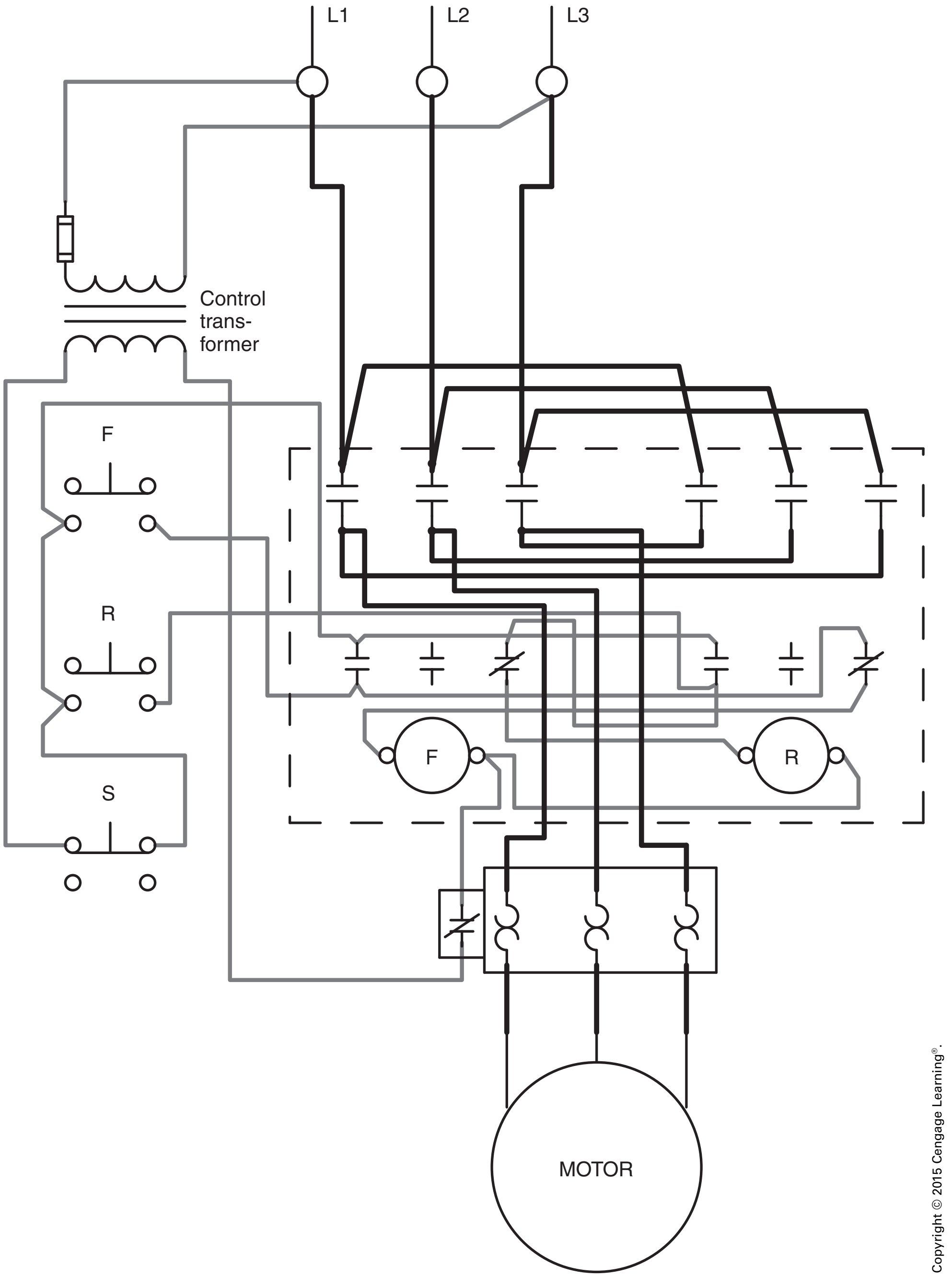


FIGURE 8-41 Wiring diagram for a forward–reverse control circuit with electrical interlock.

is de-energized, TR contact remains closed for 10 seconds before returning to its normally open state.

A Timer Circuit for Two Motors

The circuit shown in Figure 8-46 involves two motors. The circuit functions as follows:

- When the start button is pressed, motor 1 starts running immediately.
- There is a delay of 10 seconds before motor 2 starts running.
- When the stop button is pressed, motor 1 stops immediately, but motor 2 continues to run for 5 seconds before stopping.

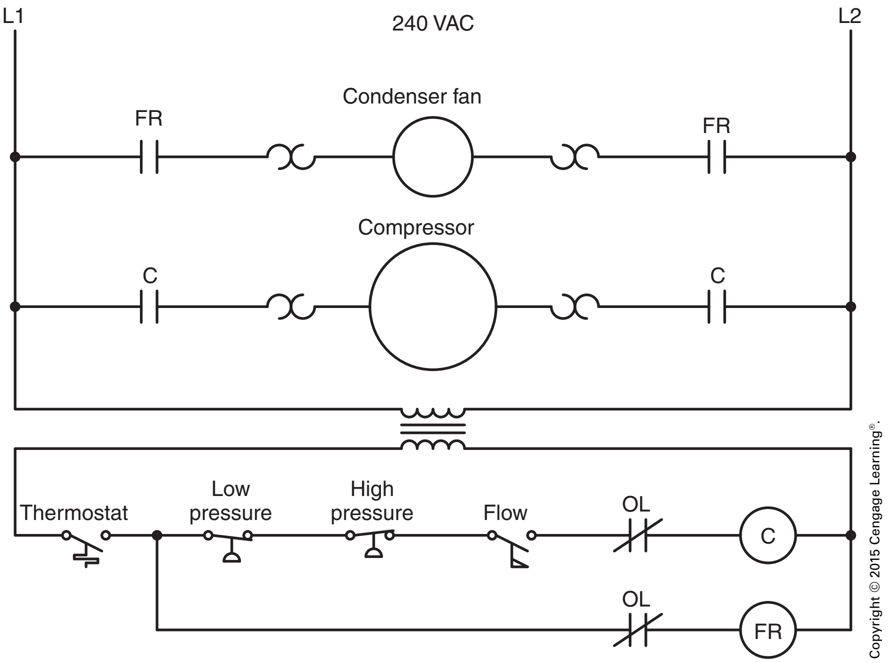


FIGURE 8-42 Basic control circuit for a central air conditioner.

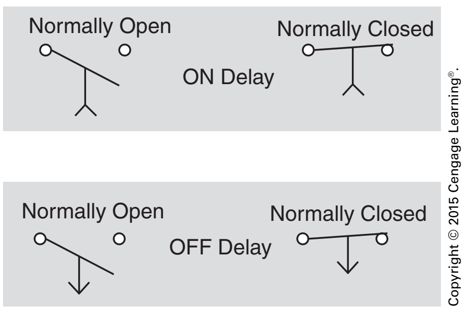


FIGURE 8-43 Contact symbols for timing relays.

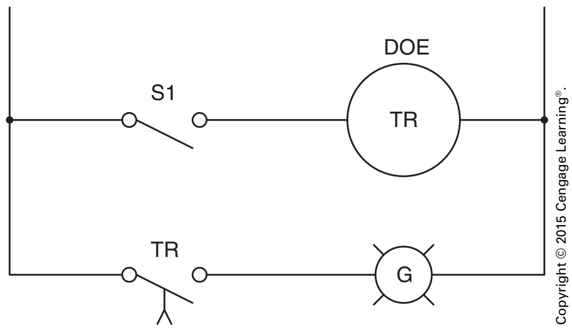


FIGURE 8-44 Basic on-delay timer circuit.

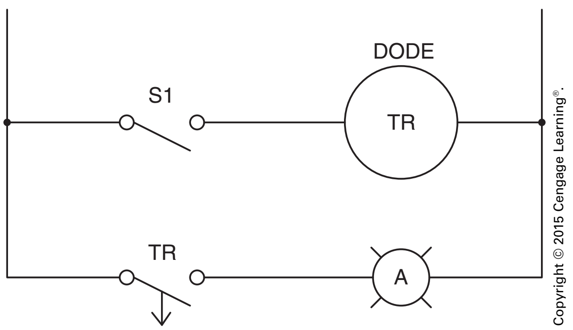


FIGURE 8-45 Basic off-delay timer circuit.

- An emergency stop button will stop both motors immediately without a time delay.
- If the emergency stop button is pressed, the reset button must be pressed before the circuit will operate again.
- An overload on either motor will stop both motors.

To understand the operation of the circuit, assume that the reset button has been pressed and control relay CR is energized, causing both CR contacts to close. When the start button is pressed,

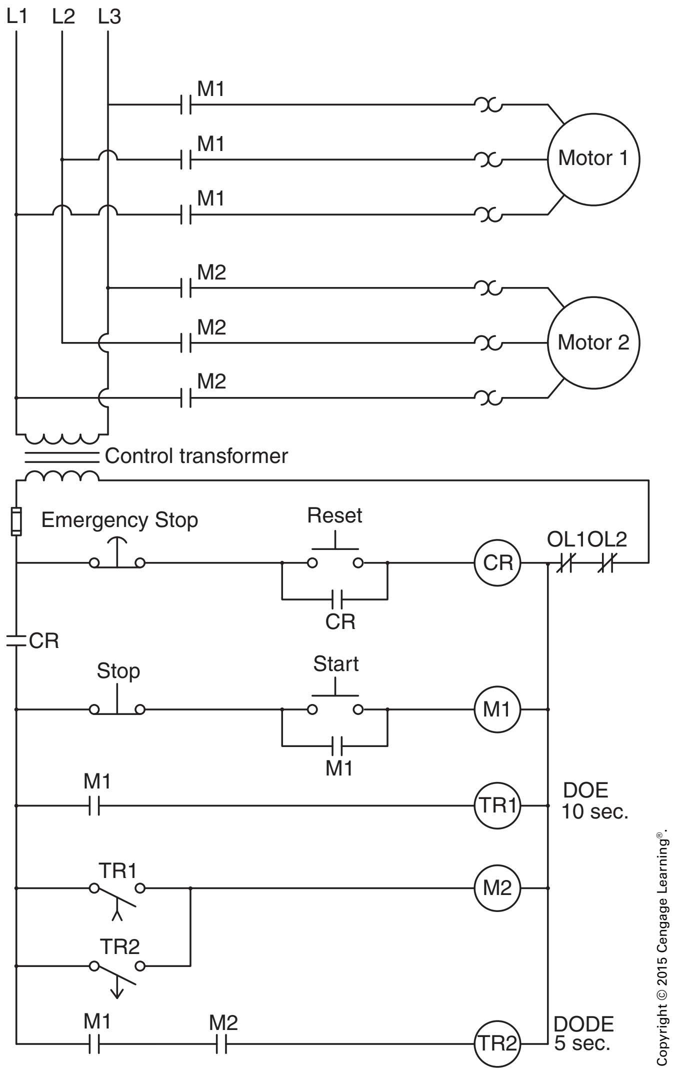


FIGURE 8-46 A timer circuit for two motors.

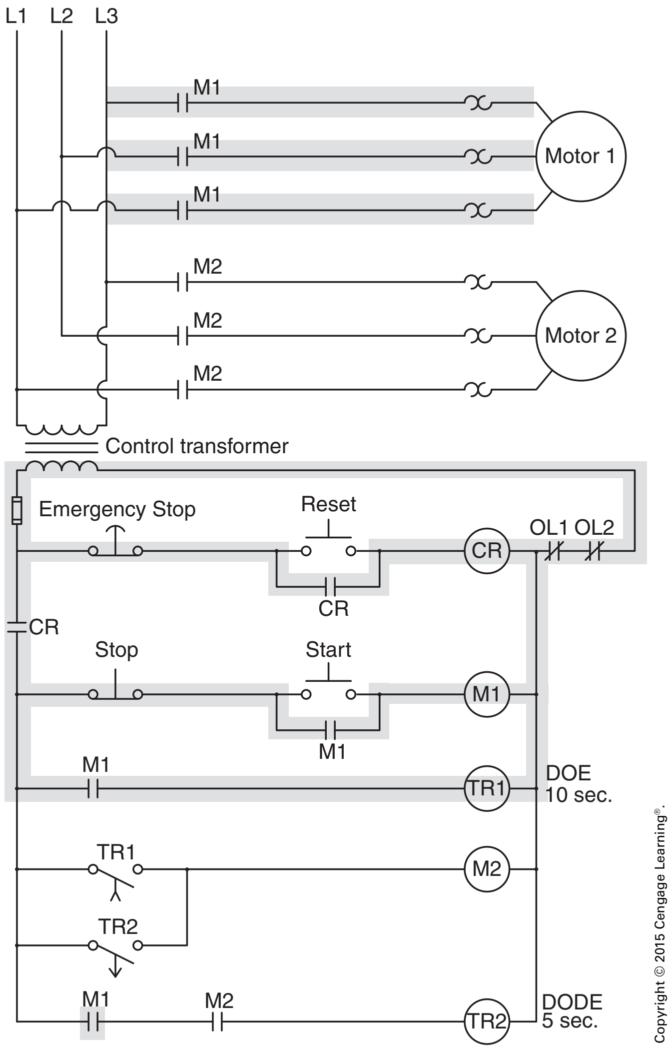


FIGURE 8-47 Motor 1 starts immediately, and timer TR1 begins timing.

power is connected to motor starter coil M1. All M1 contacts change position. The three load contacts connected to motor 1 close and supply power to motor 1. The M1 auxiliary contact in parallel with the start button maintains the circuit when the stop button is released. The M1 auxiliary contact connected in series with timer coil TR1 closes to supply power to the timer. Timer TR1 begins timing. The M1 auxiliary contact connected in series with timer TR2 closes, but a circuit is not completed to coil TR2 because auxiliary contact M2 is open, Figure 8-47.

After a delay of 10 seconds, TR1 contact closes and energizes the coil of M2 starter, causing all M2 contacts to change position. The three load contacts close and supply power to motor 2. The M2 auxiliary contact connected in series with timer coil TR2 closes and supplies power to timer TR2. Because TR2 is an off-delay timer, TR2 contact closes immediately, Figure 8-48. Both motors are now running.

When the stop button is pressed, the circuit to M1 coil is open and all M1 contacts return to their normal position. The three M1 load contacts open and disconnect power to motor 1. The M1 auxiliary contact connected in series with timer coil TR1 opens and de-energizes the timer. Because TR1 is an on-delay timer, TR1 contact opens immediately. The circuit is maintained to motor starter coil M2 by the now closed TR2 contact. The M1 auxiliary contact connected in series with timer TR2 opens

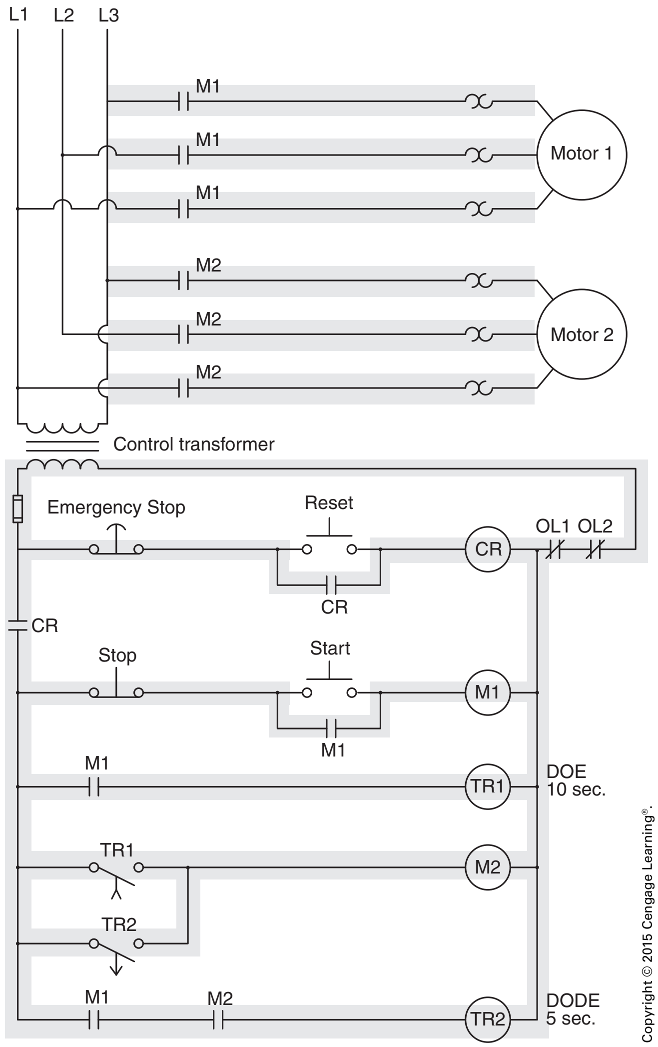


FIGURE 8-48 Both motors are running.

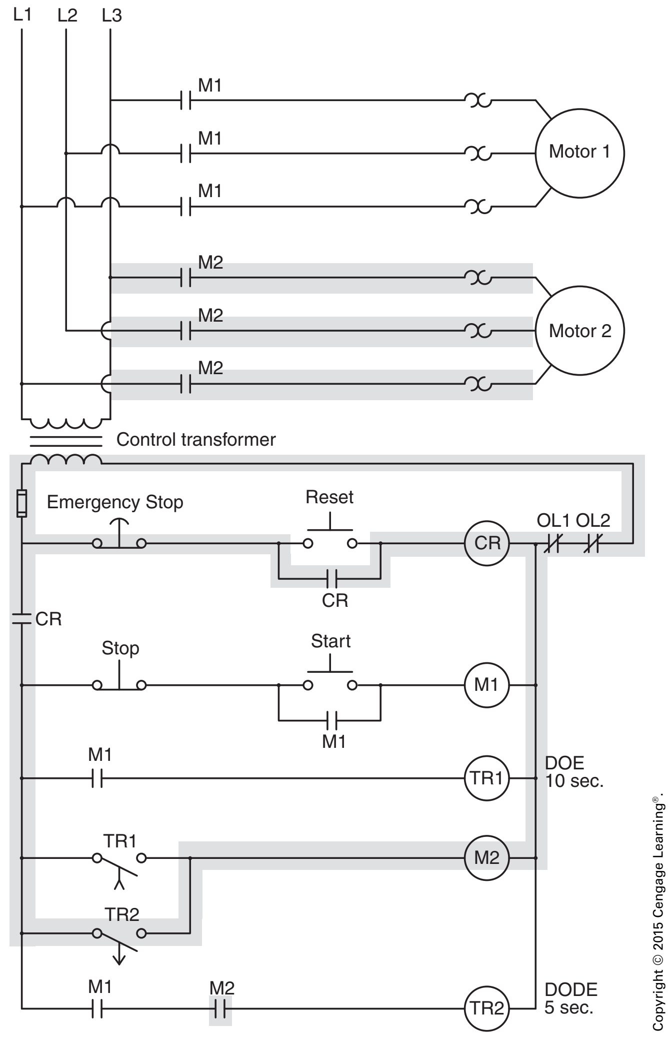


FIGURE 8-49 Motor 1 stops, but motor 2 continues to run for 5 seconds.

and de-energizes the timer. Because TR2 is an off-delay timer, the time delay begins when the timer is de-energized, Figure 8-49.

After a delay of 5 seconds, contact TR2 returns to its normally open state causing starter coil M2 to de-energize and stop motor 2. The M2 auxiliary contact connected in series with timer TR2 opens and the circuit is back to its original de-energized state.

Capacitor Discharge Timers

Time delay relays achieve a time delay in different ways. Some use a capacitive discharge, whereas others employ air. Clock timers are common as well as electronic timers. Capacitive discharge timers are generally used with direct-current control systems that operate at on-line voltage. If a capacitor is connected in parallel with the coil of a relay, Figure 8-50, when the switch is closed, the capacitor will charge to the voltage applied to the coil.

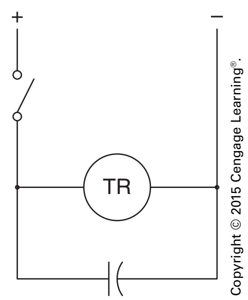


FIGURE 8-50 A capacitor is connected in parallel with a relay coil.

When the switch is opened, the capacitor discharges through the relay coil. The relay contacts remain in their energized position until the capacitor voltage drops below the point that the magnetic field of the coil can resist the spring tension trying to de-energize the relay. The spring tension of the relay can be adjusted so that more or less current is required to de-energize the relay. Capacitors discharge at an exponential rate. If the spring tension is set to the amount of current necessary to resist the spring force to position I_1 in Figure 8-51, then the time delay will be T_1. If the spring tension is readjusted so that the current can resist the spring force to position I_2, the time delay will be T_2. A capacitor discharge timer is shown in Figure 8-52.

Pneumatic Timers

Pneumatic, or air, timers depend on the flow of air through an orifice to a bellows or diaphragm, to achieve a time delay. Figure 8-53 illustrates the operation of a simple bellows timer.

When the relay is energized, rod A pushes against the bellows and causes air to be forced out of the check valve. Contact TR closes when the bellows contracts. Rod A remains against the bellows as long as the relay is energized. When the relay is de-energized, rod A moves away. The spring forces the bellows to expand, but air must flow into the bellows through the air inlet for expansion to be possible. A needle valve regulates the time necessary for the bellows to expand. When the bellows expands, contact TR again opens. Pneumatic timers have good repeat accuracy, and many can be adjusted for seconds or minutes. Some timers can be set to operate as either on delay or off delay. A pneumatic timer is shown in Figure 8-54.

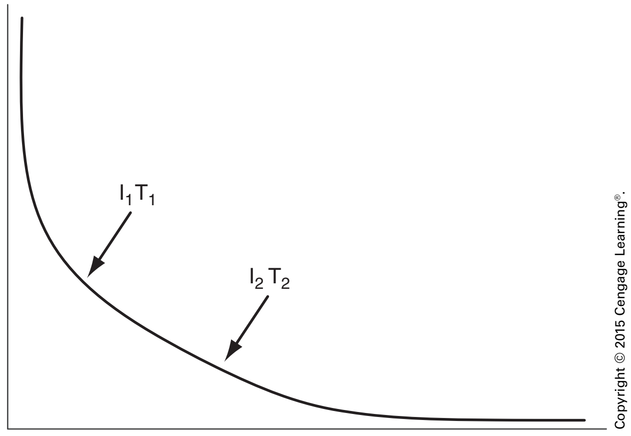


FIGURE 8-51 Capacitors discharge at an exponential rate.

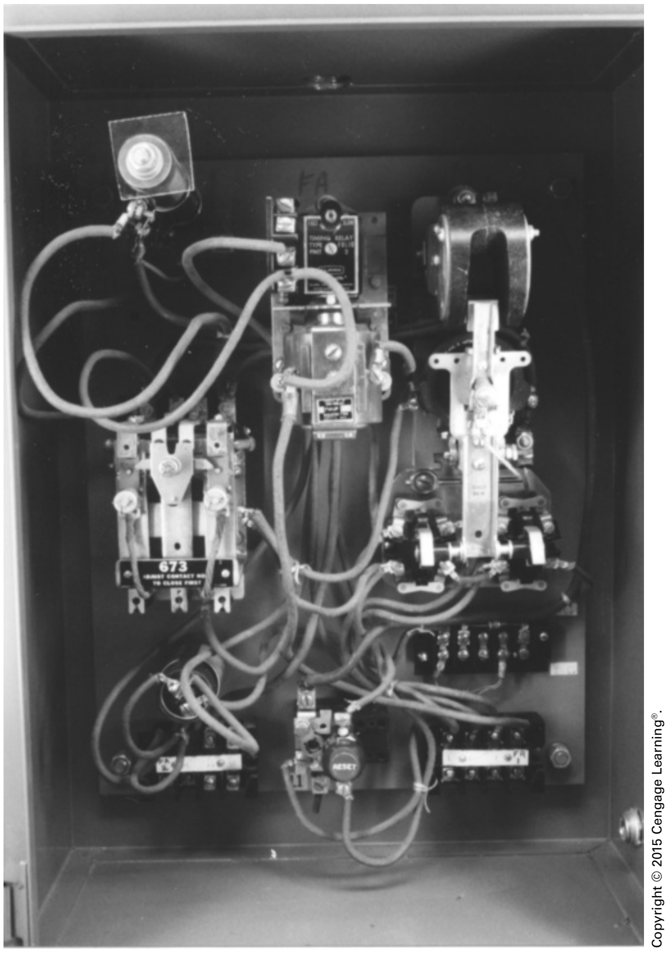


FIGURE 8-52 Capacitor discharge timer.

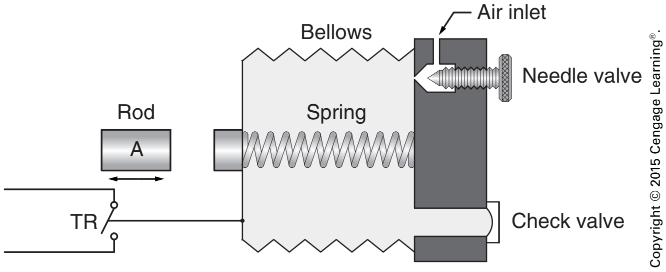


FIGURE 8-53 A simple bellows timer.

FIGURE 8-54 Pneumatic timer.

FIGURE 8-55 Clock timer.

FIGURE 8-56 Electronic on-delay timer.

Clock Timers

Clock timers employ the used of a small synchronous motor similar to those used in electric wall clocks. The time can vary greatly from one timer to another. Some may have a range of 1 second or less, and others may have a range of hours. Some have the ability to provide a wide range of delay timers by changing gear ratios inside the timer. Clock timers are generally very easy to set the time delay and have very good repeat accuracy. A clock timer is shown in Figure 8-55.

Electronic Timers

Electronic timers have become very popular because they have excellent repeat accuracy; most can be set for a wide range of time delay; and they are much less expensive than other types of timers. Many are designed to fit into some type of plug socket, which makes replacing a defective timer fast and simple. An 8-pin on-delay timer is shown in Figure 8-56. Because on-delay timers begin their timing when power is applied, only 8 pins are needed. When power is applied to pins 2 and 7, the time sequence begins. When the timer is de-energized, the time is reset to zero.

Multifunction timers can generally be employed as on delay, off delay, interval, one shot, or repeat, Figure 8-57. These timers generally require an 11-pin socket base. Certain functions, such as off delay and one shot, require that constant power be connected

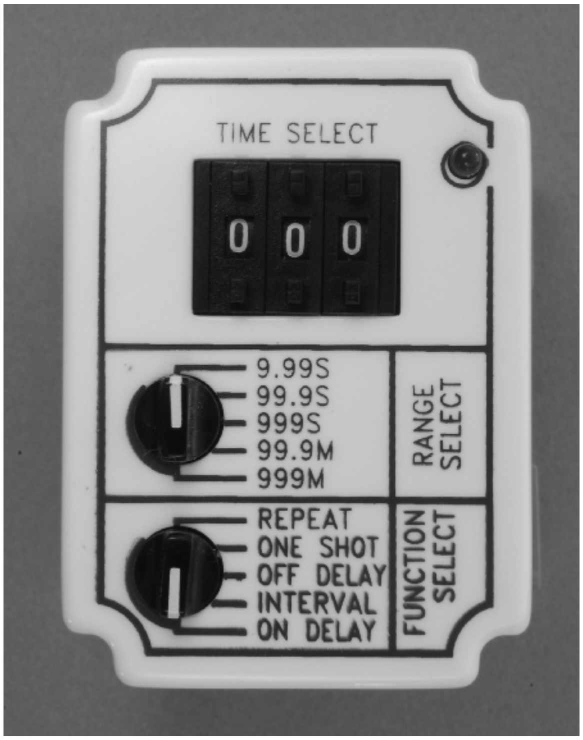


FIGURE 8-57 Electronic multifunction timer.

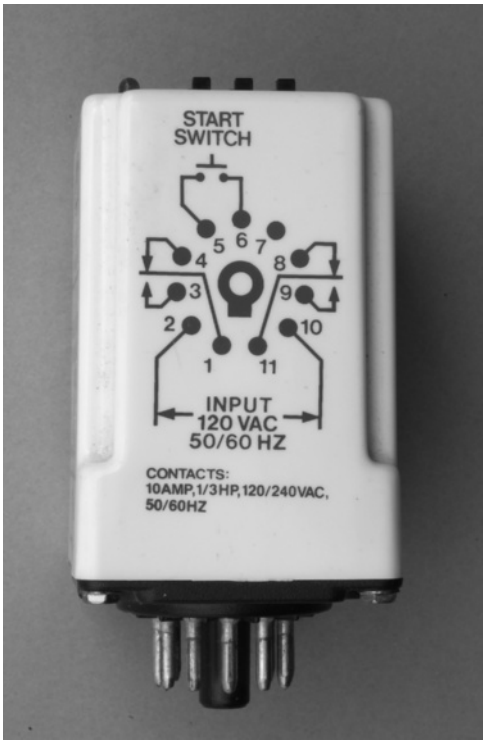


FIGURE 8-58 Pin diagram for a multifunction timer.

to the timer at all times in order for the timing circuit to operate. A separate method of triggering the timer must be used. The pin connection for the timer shown in Figure 8-57 is shown in Figure 8-58.

Note that power is connected to pins 2 and 10. If the timer is to be used as an on-delay or repeat timer, all that is necessary is to apply power to pins 2 and 10. If the timer is to be used as an off-delay or one-shot timer, it must be triggered. To use this timer as an off-delay timer, power must be continuously applied to pins 2 and 10. Activation of the timer will not begin until pins 5 and 6 are shorted together. This has the same effect as energizing the coil of a common off-delay timer. When pins 5 and 6 are shorted together, the timer contacts change position immediately. As long as pins 5 and 6 are shorted together, the contacts will remain in their energized position. When the short is removed, the time sequence will begin, and the contacts will not return to their normal position until the set time has expired.

Other manufacturers may employ different methods of controlling an electronic multifunction timer. The diagram in Figure 8-59 indicates that the timer is started by connecting pin 6 to pin 2. The diagram of another timer shown in Figure 8-60

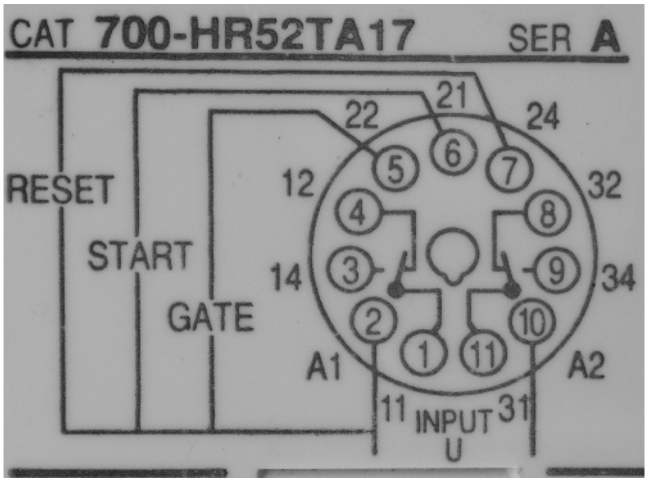


FIGURE 8-59 Operation starts when pin 6 is connected to pin 2.

indicates that the timer is triggered when 120 VAC is applied to pins 5 and 7.

Because different manufacturers employ different methods of controlling a multifunction timer, care must be taken when replacing a defective timer with a new one. If the manufacturers are different, it may require modifying the circuit to accommodate the pin

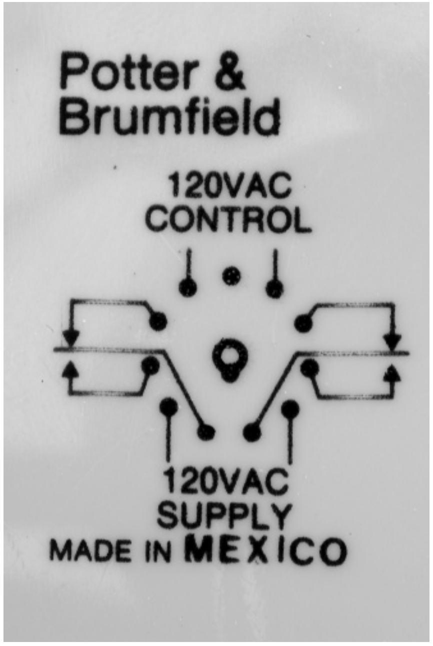


FIGURE 8-60 The timer is triggered by applying 120 VAC to pins 5 and 7.

arrangement of the new timer or finding a timer with the same pin arrangement as the one being replaced.

Interval Timer

The following descriptions of operations are for the timer shown in Figure 8-57 and the pin configuration shown in Figure 8-58. It is assumed that a time delay of 2 seconds is set for each illustration. An interval timer does not depend on triggering the timer by shorting pins 5 and 6. The time sequence starts when power is applied to pins 2 and 10. A schematic diagram of the circuit is shown in Figure 8-61. When switch S1 is closed, the indicator lamp lights immediately for a period of 2 seconds and then turns off. It remains off until switch S1 is opened.

One-Shot Timer

The one-shot timer is very similar to the interval timer. It operates basically the same way except that the trigger is used to active the timer. When switch S1 is closed the indicator lamp will not turn on. When the timer is triggered by shorting pins 5 and 6 together, the indicator lamp turns on for 2 seconds and then turns off. If the trigger circuit is opened, the timer remains off until the timer is triggered again.

Repeat Timer

The repeat timer does not require the use of the trigger. When switch S1 is closed, the indicator lamp remains off for 2 seconds. It then turns on for 2 seconds. It will continue to turn on for 2 seconds and off for 2 seconds until switch S1 is opened.

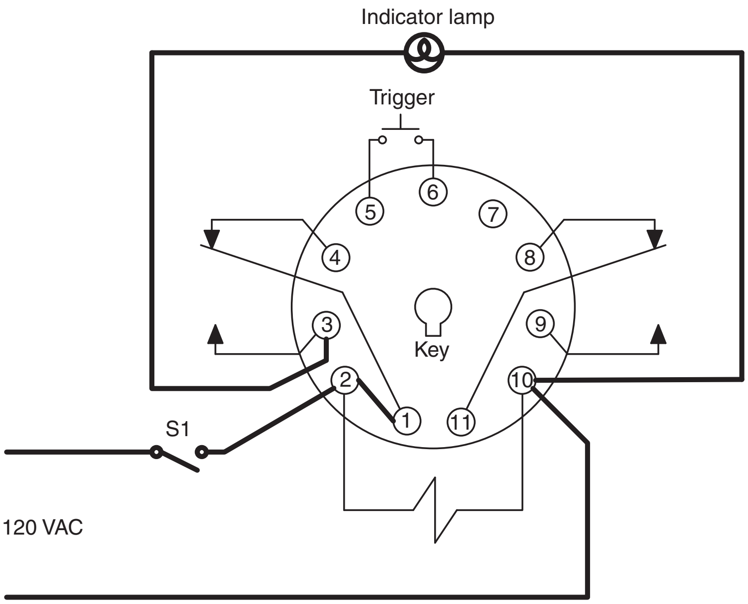


FIGURE 8-61 Schematic of a timer circuit.

REVIEW QUESTIONS

All answers should be written in complete sentences. Calculations should be shown in detail, and *Code* references should be cited when appropriate.

1. What are the two basic types of control circuits? ______________________________
____
2. Describe the differences among relays, contactors, and motor starters. ______________
____
____
3. The most commonly accepted set of schematic symbols are used by what organization?
____
4. When contact and switch symbols are drawn on a schematic, are they drawn in such a manner as to represent their state when the circuit is in operation or turned off? _____
____
5. True or false: A normally open push-button symbol is drawn so that the movable contact is above and touching the stationary contacts. ______________________________
6. True or false: A normally closed push-button symbol is drawn so that the movable contact is below and touching the stationary contacts. ______________________________
7. A limit switch is illustrated by drawing a wedge shape on the movable contact of a switch symbol. What does the wedge represent? ______________________________
8. What are the two types of thermal overload relays? ______________________________
9. Name two characteristics bimetal strip–type overload relays generally possess that solder pot–types do not. ____
____
10. If three single-phase overload relays are to be used to protect a 3-phase motor, how are the normally closed overload contacts arranged? ______________________________
____
11. When overload contacts are connected into a control circuit, are they connected in series with the starter coil or in parallel with the starter coil? ______________________________

12. Explain how a schematic or ladder diagram differs from a wiring diagram in how it shows an electrical circuit. ______________________________

____

____

13. In a start–stop push-button control circuit, what is the function of the normally open auxiliary contact connected in parallel with the start push button? ______________________________

____

14. In a forward–reverse control circuit, what is the function of the normally closed F and R auxiliary contacts? ______________________________

15. Refer to the circuit shown in Figure 8-42. Describe the type of switch used for the following (normally open, normally closed, normally open held closed, or normally closed held open).

Thermostat ______________________________

Low-pressure switch ______________________________

High-pressure switch ______________________________

Flow switch ______________________________

CHAPTER 9

Motors and Controllers

OBJECTIVES

After studying this chapter, the student should be able to

- describe the machine layout in the industrial building.
- describe the various types of motors used in the industrial building.
- explain the operation of the types of motor controllers used.
- describe how the motor branch circuits are installed.

Chapters 3 and 5 of this text detailed the method of distributing power to the various machines in the manufacturing area of the industrial building. Recall that plug-in busway is installed throughout the plant, and bus plugs are installed at selected points. With the use of rubber cord drops to each machine, power is supplied to the motor branch circuit that operates each machine.

THE MACHINES AND THEIR MOTORS

Sheet E-2 of the industrial building plans shows the layout of the 111 machines in the manufacturing area. The various types of machines are identified by a code number, as shown in the following list.

MA	Engine Lathes
MB	Turret Lathes
MC	Vertical Drills
MD	Multispindle Drills
ME	Milling Machines
MF	Shapers
MG	Vertical Boring Mills
MH	Planers
MI	Power Hacksaws
MJ	Band Saws
MK	Surface Grinders
ML	Cylindrical Grinders
MN	Punch Presses
MO	Special Machines

Each of these machines has a 3-phase motor rated at 460 volts. The current required by each motor is based on the horsepower rating of the motor. The current can be determined by the following equation:

$$\text{Amperes} = \frac{\text{Hp} \times 746}{\text{Volts} \times 1.73 \times \text{Eff.} \times \text{PF}}$$

where
- Hp = horsepower
- 1.73 = the square root of 3
- Eff. = the assumed efficiency
- PF = the power factor (estimated)
- 746 = watts per horsepower

By applying this equation to the engine lathes (MA), the current required can be determined.

$$\text{Amperes} = \frac{5 \times 746}{460 \times 1.73 \times 0.82 \times 0.86} = 6.64$$

The efficiency of 82% and the power factor of 86% were taken from Table 9-1. Note that larger motors may have slightly higher efficiencies, whereas smaller motors usually have lower power factors and lower efficiencies. The values used in the equation are the assumed values at full load. When the motor is less than fully loaded, the values are much lower.

When the conductors to a motor are being selected, *430.6(A)* requires that the values given in *NEC Tables 430.247*, *430.248*, *430.249*, and *430.250* (reproduced in this book as Tables 9-1 through 9-4) be used in place of the actual full-load current of the motor, as determined by the equation given previously. Thus, for a 5-horsepower, 460-volt, 3-phase motor (look ahead to Table 10-4), a full-load current of 7.6 amperes is used to determine conductor sizes rather than the value of 6.64 amperes as calculated.

MOTOR TYPES

Several different types of motors having entirely different characteristics or patterns of performance are required for the various machine tools. One of the most commonly used motors is the squirrel-cage type. Refer to Figure 9-1 for a listing of motor control symbols.

SINGLE-SPEED SQUIRREL-CAGE INDUCTION MOTOR

The squirrel-cage type of induction motor does not have a conventional rotor winding. Instead, the laminated steel rotor has copper or aluminum bars that run axially around the periphery of the rotor. These bars are short-circuited by copper or aluminum end rings. When aluminum is used for the assembly, the bars and end rings are usually cast in one piece.

Three-phase squirrel-cage motors have a good starting torque, and their performance characteristics make them an ideal motor for general use. Figure 9-2 is a cutaway view of a 3-phase squirrel-cage motor.

TABLE 9-1

Motor efficiencies and power factors.

Average Efficiencies and Power Factors for Polyphase Squirrel-Cage Induction Motors						
	Efficiencies			Power Factor		
Hp	One-half Load	Three-fourths Load	Full Load	One-half Load	Three-fourths Load	Full Load
¼	60.0	67.0	69.0	45	56	65
½	64.0	68.0	69.0	48	58	65
1	75.0	77.0	76.0	57	69	76
1 ½	75.0	77.0	78.0	64	76	81
2	77.0	80.0	81.0	68	79	84
3	80.0	82.0	81.0	70	80	84
5	80.0	82.0	82.0	76	83	86
7 ½	83.0	85.0	85.0	77	84	87
10	83.0	85.0	85.0	77	86	88
15	84.0	86.0	88.0	81	85	87
20	87.0	88.0	87.0	82	86	87
25	87.0	88.0	87.5	82	86	87
30	87.5	88.5	88.0	83	86.5	87
40	87.5	89.0	89.5	84	87	88
50	87.5	89.0	89.5	84	87	88
60	88.0	89.5	89.0	84	87	88
75	88.5	89.5	89.5	84	87	88
100	89.0	90.0	90.5	84	88	88
125	90.0	90.5	91.0	84	88	89
150	90.0	91.5	92.0	84	88	89
200	90.0	91.5	92.0	85	89	90
250	91.0	92.5	93.0	84	89	90
300	92.0	93.5	94.0	84	89	90

An induction motor is much like a transformer, except that the secondary winding and core are mounted on a shaft set in bearings. This arrangement permits the secondary winding to rotate (hence the name rotor). An induction motor consists of two electrical circuits (the stator and the rotor) linked by a common magnetic circuit. Electric current applied to the stator winding induces a secondary current in the rotor winding. This winding is a closed circuit, either a short-circuit or nearly so. The induced current in the secondary always flows in a direction opposite to that of the applied current. In addition, the induced current lags 90° or one-quarter cycle behind the applied current. Magnetic fields are set up in the stator and rotor in a manner that gives rise to attracting and repelling forces. Because these forces are in the same direction (either clockwise or counterclockwise), a torque is produced and rotation results.

For example, Figure 9-3 shows that the north and south poles of the induction motor stator rotate at synchronous speed. That is, the poles of the stator and rotor are always in the position shown, with respect to each other. Because unlike poles attract and like poles repel, forces are set up that produce rotation. The force acting at the rim of the rotor multiplied by the radius from the center of the rotor is called the torque. Torque can be determined by the following equation:

$$T = \frac{Hp \times 5252}{RPM}$$

where T = torque (in lb.-ft)
Hp = motor horsepower
5252 = constant (33,000/2π)
RPM = rotor speed (in revolutions per minute)

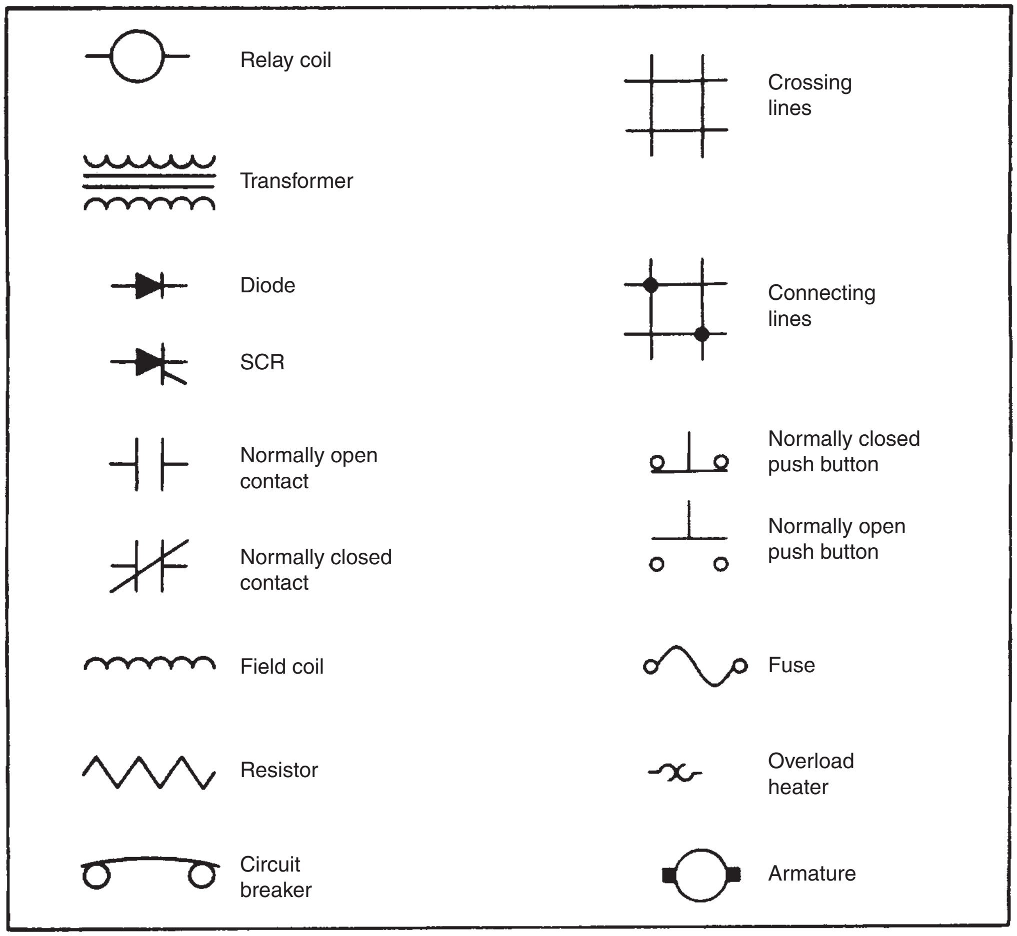


FIGURE 9-1 Electrical symbols.

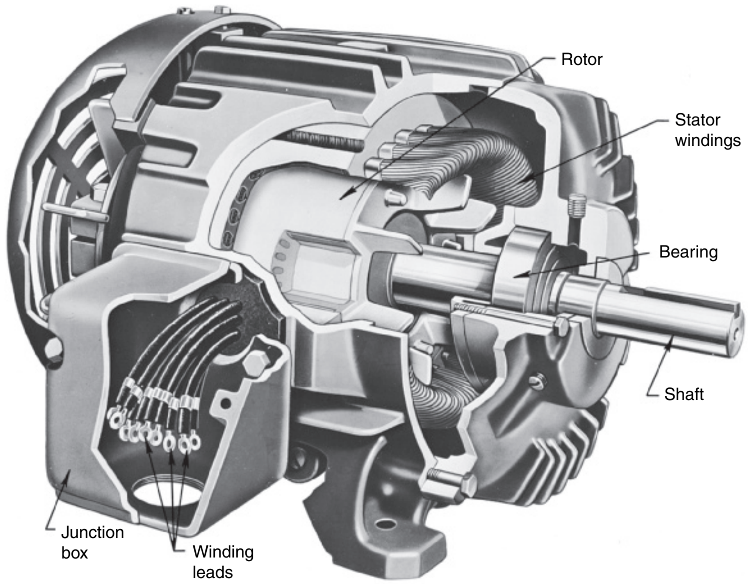


FIGURE 9-2 Cutaway view of 5-horsepower, totally enclosed, fan-cooled standard squirrel-cage motor.

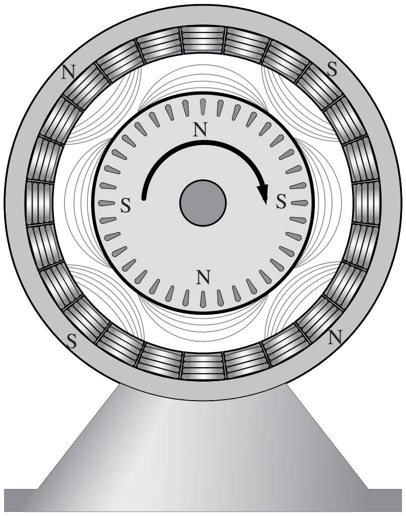


FIGURE 9-3 Diagram of 4-pole induction motor.

Figure 9-3 also shows that the magnetic poles of the rotor are always midway between the magnetic poles of the stator so that the attracting and repelling forces work together. The frequency of the current in this case is 60 hertz (supplied by the power company). Sixty-hertz current is applied to the stator winding, but the frequency in the rotor is very low at operating speed and varies with the slip. The slip is the difference between the synchronous speed of the motor and its actual speed under full load.

The synchronous speed of an AC motor is obtained from the formula given as follows:

$$\text{Synchronous speed} = \frac{120 \times \text{frequency}}{\text{number of poles per phase}} = \text{RPM}$$

where the 120 is used to convert from seconds to minutes and to adjust for pairs of poles and the frequency is in cycles per second.

Thus, for a 4-pole, 60-hertz motor, the synchronous speed is

$$\text{Synchronous speed} = \frac{120 \times 60}{4} = 1800\,\text{RPM}$$

If the load causes the rotor to slip 75 RPM below the value of the synchronous speed, then the actual speed under full load is 1800 minus 75, or 1725 revolutions per minute.

Similarly, the synchronous speed of a 6-pole, 60-hertz motor is

$$\text{Synchronous speed} = \frac{120 \times 60}{6} = 1200\,\text{RPM}$$

Thus, with a full-load slip of 60 RPM, the actual full-load speed of the motor is 1200 minus 60, or 1140 RPM.

Induction Motors in the Industrial Plant

Many of the machines in the industrial building are driven by 3-phase, squirrel-cage, single-speed induction motors, Table 9-2. In addition to the motors listed in Table 9-2, other single-speed squirrel-cage motors are used as listed in Table 9-3.

The smaller sizes of squirrel-cage motors use controllers known as across-the-line starters, Figure 9-4. The controller is a magnetic switch or contactor including overload relays that provide running protection for the motor. A push-button station can provide a means for starting, stopping, reversing, or jogging the motor, Figure 9-5 and Figure 9-6.

TABLE 9-2

Single-speed squirrel-cage induction motors.

CODE NUMBER	NUMBER OF MACHINES	KIND OF MACHINES	NUMBER OF MOTORS	HP OF MOTORS
MA	20	Engine Lathes	20	5
MB	10	Turret Lathes	10	7.5
MC	12	Vertical Drills	12	1
ME	6	Milling Machines	18	10, 1, 1
MF	6	Shapers	6	7.5
MG	5	Boring Mills	15	3, 3, 3
MI	6	Power Hacksaws	6	3
MJ	4	Band Saws	4	5
MK	6	Surface Grinders	6	10
ML	10	Cylindrical Grinders	10	7.5
	5	Special Machines	5	5

TABLE 9-3

List of single-speed squirrel-cage motors.

NUMBER OF MOTORS	DESCRIPTIONS OF MOTORS
6	3 Hp motors driving the six ventilating blowers on the roof
6	12.5 Hp motors (two to a unit) installed in the three liquid chillers used in conjunction with the air-conditioning equipment
10	2 Hp motors for the fan coil units
23	¼ Hp motors used at the twenty-three machines equipped with oil fog precipitation units

Four-Speed Squirrel-Cage Motors

The manufacturing area of the industrial building contains eight multispindle drills (MDs) that are equipped with 4-speed squirrel-cage induction motors. Motors of this type are called consequent-pole motors. The synchronous speed (the speed of the rotating magnetic field) of an induction motor is determined by two factors:

1. The number of stator poles per phase.
2. Frequency of the applied voltage.

The standard frequency supplied by utility companies throughout the United States and Canada is 60 Hz. A chart showing synchronous speeds

Courtesy of Square D

FIGURE 9-4 Across-the-line magnetic motor starter.

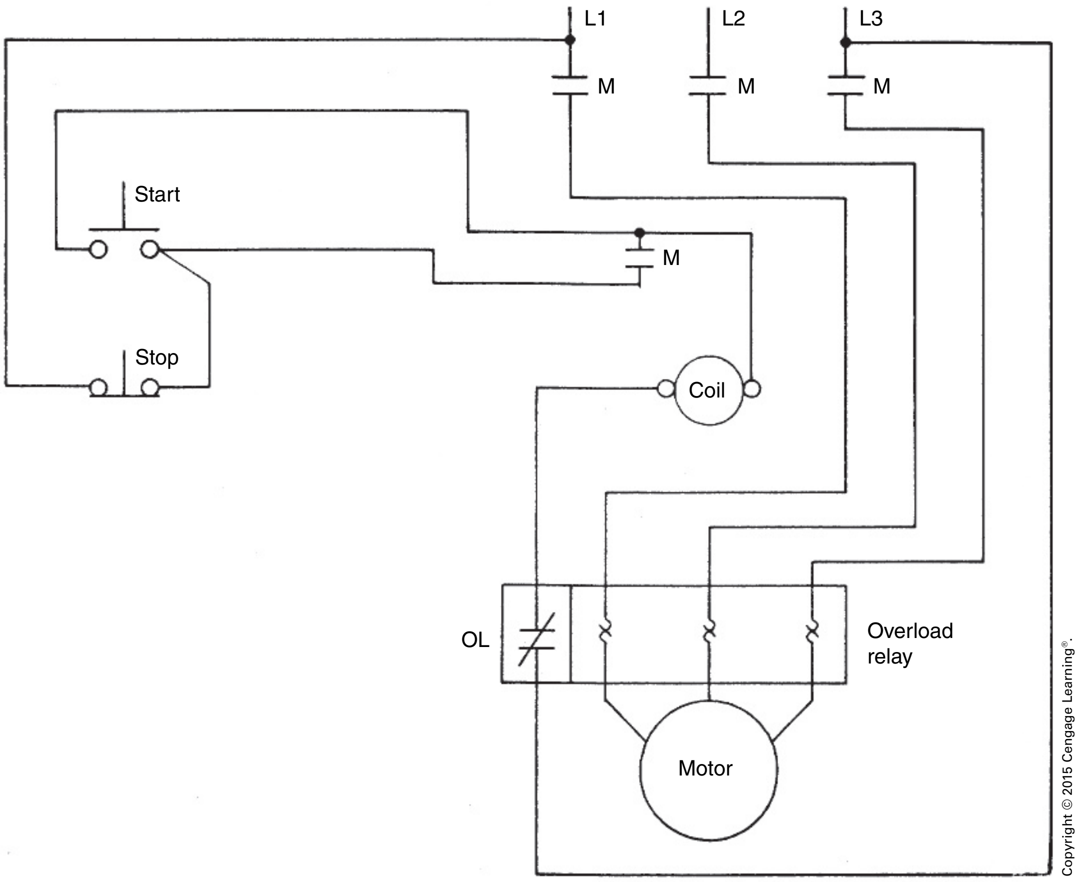


FIGURE 9-5 Wiring diagram of an across-the-line starter.

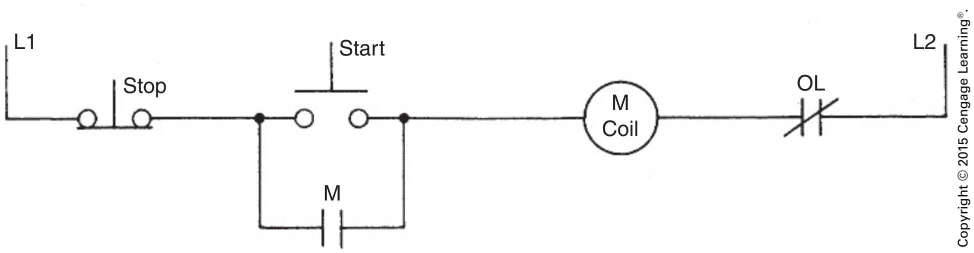


FIGURE 9-6 Schematic diagram of an across-the-line starter.

of 60 Hz motors with different numbers of poles is shown in Table 9-4. A 3-phase, 2-pole motor contains six actual poles. The magnetic field will make one revolution of a 2-pole motor each complete cycle. If the stator of a motor were to be cut and laid out flat, the magnetic field would traverse the entire length in one cycle, Figure 9-7A. If the number of stator poles is doubled to four per phase, Figure 9-7B, the magnetic will traverse the same number of stator poles during one cycle. Because the number of poles has been doubled, the magnetic field will travel only half as far during one complete cycle. Consequent-pole motors have an advantage over some others types of variable-speed alternating-current motors in that they maintain a high torque when speed is reduced.

Consequent-pole motors obtain different speeds by changing the number of stator poles per phase.

TABLE 9-4

Synchronous speeds at 60 Hz.

NUMBER OF POLES PER PHASE	SYNCHRONOUS SPEED IN RPM AT 60 HZ
2	3600
4	1800
6	1200
8	900
10	720
12	600

Figure 9-8 illustrates the method used to change the number of stator poles. In Figure 9-8A, the two windings are connected in series, producing a single path for current flow. Because the current flows in the same direction through both windings, the polarity of the magnetic field is the same for both windings, and they are essentially one pole. If the windings are reconnected in such a manner that the direction of current flow through the two windings is in opposite directions, as shown in Figure 9-8B, the magnetic polarity of the two windings is different and they are essentially two separate poles. In this manner a 4-pole stator winding can be changed to an 8-pole winding.

Consequent-pole motors that produce two speeds contain one reconnectable stator winding. Three-speed consequent-pole motors contain two stator windings. One is reconnectable, and the other is not. Four-speed motors contain two separate stator windings. Each of these windings can be reconnected to produce two separate speeds.

Two-speed stator windings can be connected to form a series delta or parallel wye, Figure 9-9. If the motor is wound in such a way that the series delta

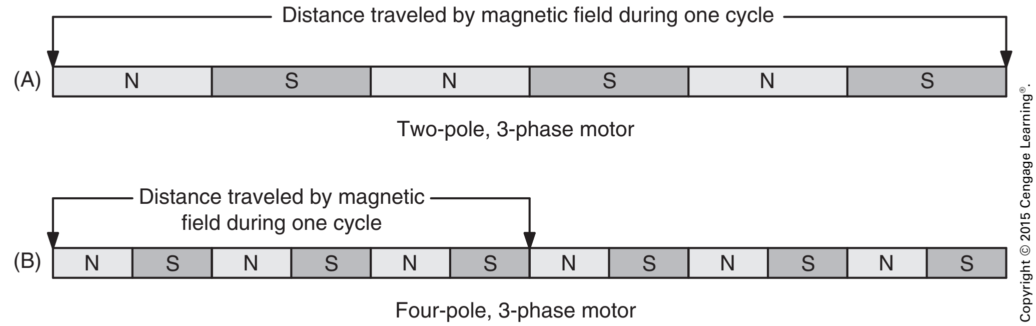


FIGURE 9-7 The magnetic field will travel through the same number of poles during each cycle.

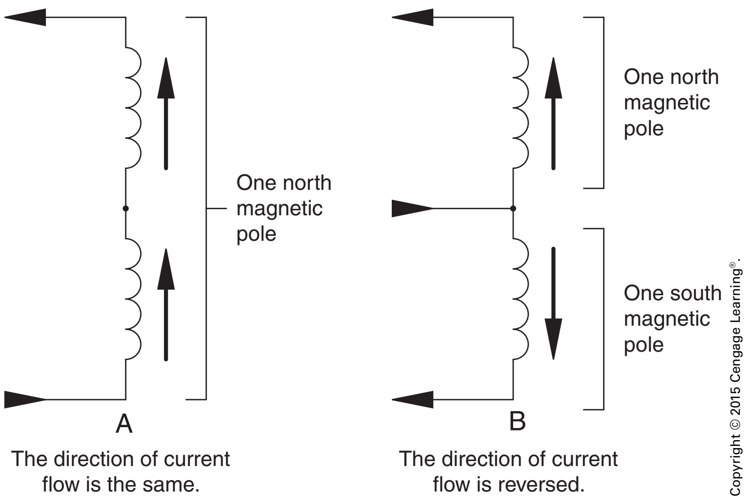


FIGURE 9-8 The number of stator poles can be changed by reversing the current flow through alternate windings.

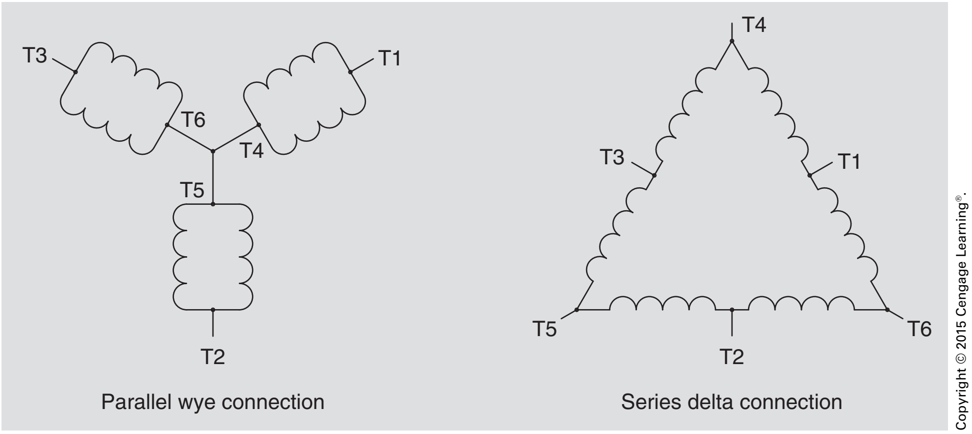


FIGURE 9-9 Two-speed windings can be connected as series delta or parallel wye.

connection gives the high speed and the parallel wye provides the low speed, the horsepower will be the same for either connection. If the winding is such that the series delta provides the low speed and the parallel wye gives the high speed, the torque will be the same for both speeds.

Induction motors cannot operate at the speed of the rotating magnetic field. At no load, a motor will operate to within 95% of the synchronous speed. The speed reduces as load is added to the motor. The speed listed on the nameplate of a motor is the full-load speed. The drill motors in this example have nameplate speeds of 560 RPM, 870 RPM, 1175 RPM, and 1740 RPM. These full-load speeds indicate that the synchronous speeds would be 600 RPM, 900 RPM, 1200 RPM, and 1800 RPM. Each speed is one-half of another. One stator winding contains four poles, to produce a synchronous speed of 1800 RPM. If that winding is changed to an 8-pole winding, the synchronous speed will be 900 RPM. The second stator winding contains six poles, to produce a synchronous speed of 1200 RPM. This stator winding can be reconnected to provide 12 poles that will produce a synchronous speed of 600 RPM.

The motor in this example contains fourteen terminal leads. The four speeds are obtained by connecting certain leads to the power supply and in some cases certain leads together. Table 9-5 lists the terminal connections for each speed. The controller is generally arranged to provide a sequence of speeds such as REVERSE, OFF, LOW, 2nd, 3rd,

TABLE 9-5

Connection diagram for a 4-speed consequent-pole motor.

CONNECTION OF LEADS FOR VARIOUS DESIRED SPEEDS

Speed	L1	L2	L3	Together
R LOW	T2	T1	T3,T7	—
F LOW	T1	T2	T3,T7	—
F 2	T11	T12	T13,T17	—
F 3	T6	T4	T5	T1,T2,T3,T7
F HIGH	T16	T14	T15	T11,T12,T13,T17

Note: All other terminals are left open.

and HIGH. In this example, a manual controller is used to select the direction and speed of the motor, Figure 9-10.

The wiring has been omitted. The motor terminal leads are connected to a terminal strip. The terminal strip makes connection to different sections of the controller. Each section of the controller is labeled to indicate how it is connected to the terminal strip. Controllers can be drum type, cam type, or push button. The schematic diagram of a push-button control for a 4-speed, 3-phase consequent-pole motor is shown in Figure 9-11.

The control permits any speed to be selected by pushing the button that initiates that particular speed. In this circuit, stacked push buttons are used to break the circuit to any other speed before the starter that controls the selected speed

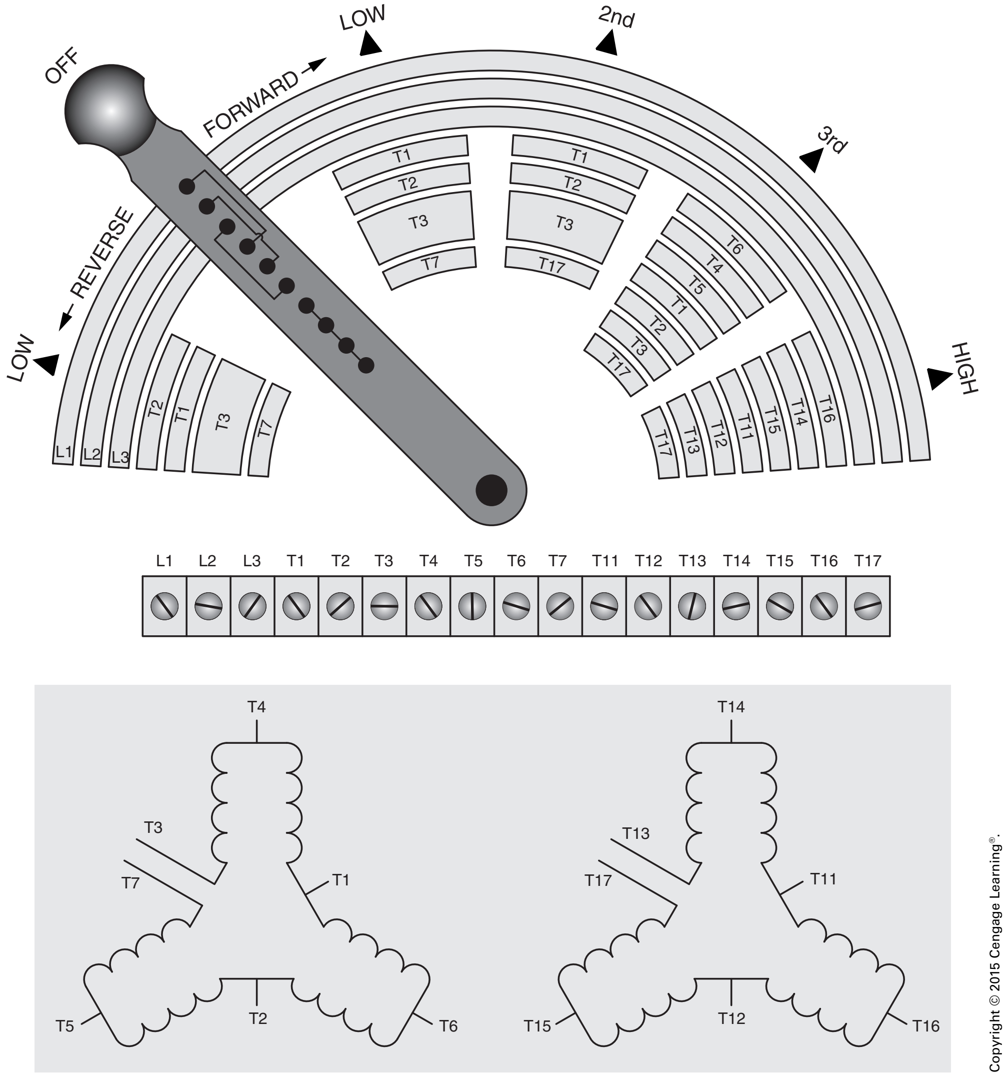


FIGURE 9-10 Manual speed controller for a 4-speed consequent-pole motor.

is energized. Electrical interlocks are also used to ensure that two speeds cannot be energized at the same time. Eleven-pin control relays are used to provide interlock connection because each contains three sets of double-acting contacts. Double-acting contacts can be connected as either normally open or normally closed. The load contact connection is also shown. The circuit assumes that the starters and contactors each contain three load contacts. Note that 3rd speed and high speed require the used of two contactors to supply the necessary number of load contacts. The winding arrangement and connection diagram for this motor is shown in Figure 9-12.

Primary Resistance Starters

The milling machines are equipped with primary resistance starters. For this type of starter or controller, the heavy starting current results in a voltage drop while it passes through the primary resistors; thus, there is a lower voltage value at the motor terminals. The motor accelerates gently with less torque than is the case when line starters are used. When the motor has almost reached its normal speed, a time-delay relay (set for about 5 seconds) closes a second contactor to short out the primary resistors. At this point, the motor receives the full line voltage and accelerates to its normal speed, Figure 9-13.

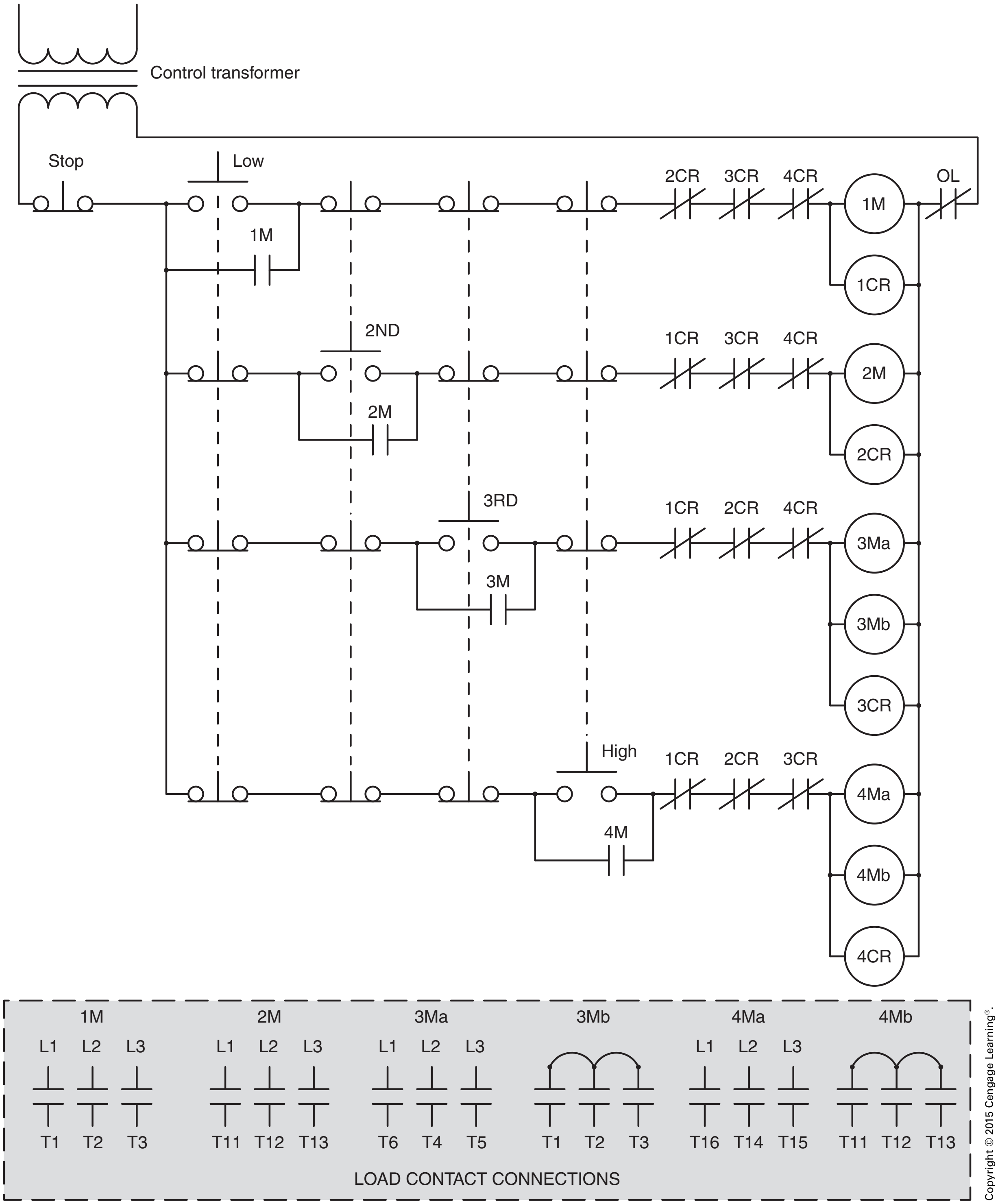
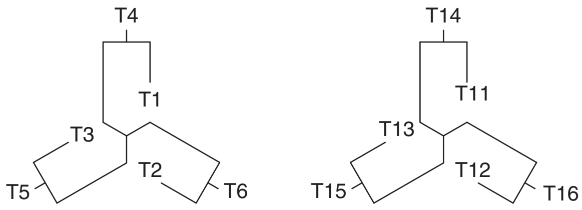


FIGURE 9-11 Push-button control for a 4-speed, 3-phase consequent-pole motor.

Reduced Voltage Starters

The motors used on the surface grinders have another type of controller called a reduced voltage starter, Figure 9-14. This type of controller uses an autotransformer to obtain a reduced voltage. When the starting push button is depressed, a magnetic 5-pole contactor (S) connects the autotransformer to the line. Taps are made from the autotransformer at a value of about 70% of the line voltage at the start portion of the



SPEED	L1	L2	L3	OPEN	TOGETHER
LOW	T1	T2	T3	ALL OTHERS	———
2ND	T11	T12	T13	ALL OTHERS	———
3RD	T6	T4	T5	ALL OTHERS	T1, T2, T3
HIGH	T16	T14	T15	ALL OTHERS	T11, T12, T13

FIGURE 9-12 Winding arrangement and connection diagram for a 4-speed, 3-phase consequent-pole motor.

cycle. Several seconds after the motor begins to rotate, a timing relay opens the first contactor (S) and closes a second 3-pole contactor (R). This action disconnects the autotransformer from the line and connects the motor directly across the line. As a result, the motor is accelerated to its normal speed, Figure 9-15.

The controllers covered in the chapter to this point are used with squirrel-cage motors. There are several other types of controllers used on other motors of various types in the industrial building.

THE WOUND-ROTOR INDUCTION MOTOR

The punch presses (MN) are equipped with wound-rotor induction motors. These motors operate on the same rotating magnetic field principle as a

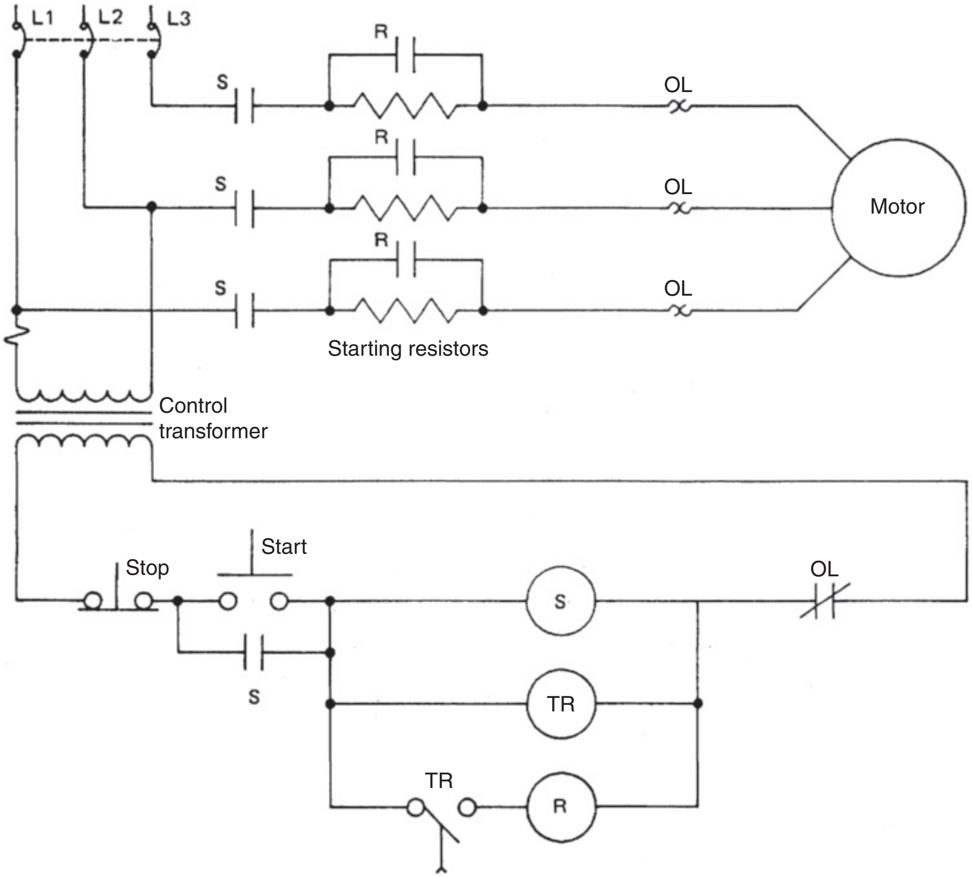


FIGURE 9-13 Typical primary resistance starter.

FIGURE 9-14 Reduced voltage starter.

squirrel-cage induction motor. The difference between the two motors is the construction of the rotor. The rotor of the squirrel-cage induction motor contains bars connected together at each end by shorting rings. The rotor of the wound-rotor induction motor contains a 3-phase winding very similar to the stator winding. The stator winding leads are marked L1, L2, and L3. The rotor winding leads are marked M1, M2, and M3. One end of each rotor winding is connected together with the others to form a wye connection. The other end of the winding is connected to slip rings (collector rings) located on the rotor shaft, Figure 9-16. Low-resistance carbon brushes in contact with the slip rings provide connection to external resistors, Figure 9-17. The ability to control the amount of resistance connected to the rotor circuit causes the wound-rotor induction motor to exhibit several desirable characteristics over other types of 3-phase motors:

1. The amount of starting current can be controlled by controlling the amount of resistance connected to the rotor. Induction motors are very similar to transformers. The stator winding is the primary and the rotor is the secondary. Limiting the amount of rotor (secondary) current limits the stator (primary) current also.
2. The wound-rotor induction motor exhibits the highest amount of starting torque per ampere of starting current of any 3-phase motor. There are three factors that determine the amount of torque developed by an induction motor:
   a. The magnetic field strength of the stator.
   b. The magnetic field strength of the rotor.
   c. The phase angle difference between rotor and stator current.

   The torque reaches maximum when the rotor and stator currents are in phase with each other. Adding resistance to the rotor circuit causes the rotor current to be more in phase with the stator current, thus producing a greater amount of starting torque.
3. The speed of the wound-rotor induction motor can be controlled by the amount of resistance connected in the rotor circuit. Because the amount of resistance in the rotor circuit controls the current in both the rotor and stator windings, it controls the strength of the magnetic fields in the rotor and stator windings. Controlling the magnetic field strength controls the amount of torque produced by the motor. Inserting resistance in the rotor circuit results in a reduction of torque, which causes a greater amount of slip between the speed of the rotor and the speed of the rotating magnetic field. When resistance is decreased, magnetic field strength increases, causing an increase in torque and a corresponding increase in speed. Full motor speed is obtained when all the resistance has been shorted out of the rotor circuit. The rotors of wound-rotor induction motors are shown in Figure 9-18.

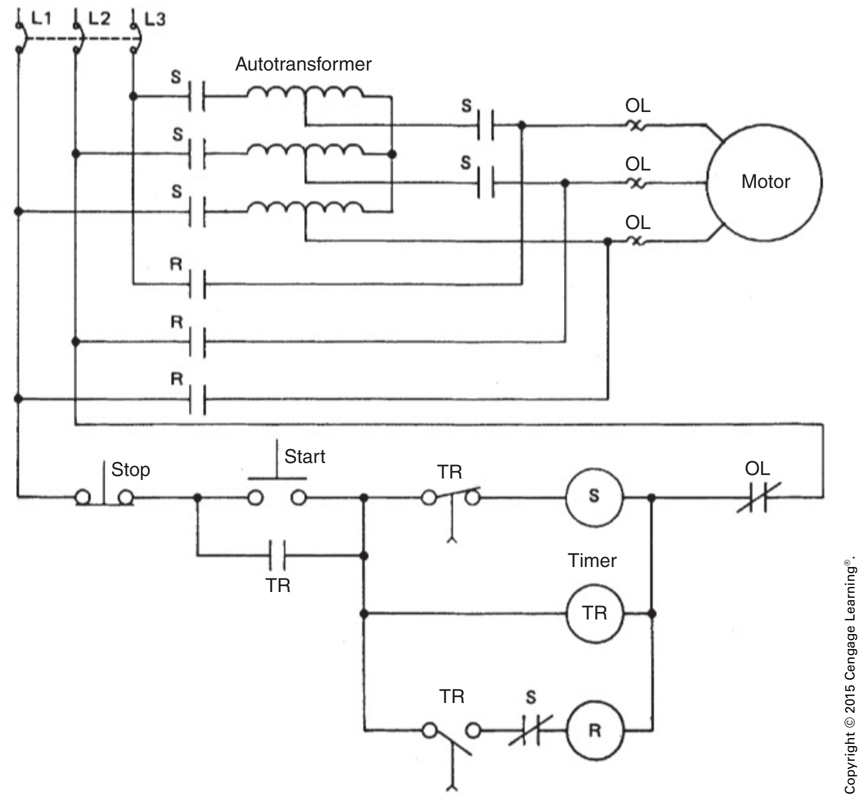


FIGURE 9-15 Schematic of an autotransformer-type reduced voltage starter.

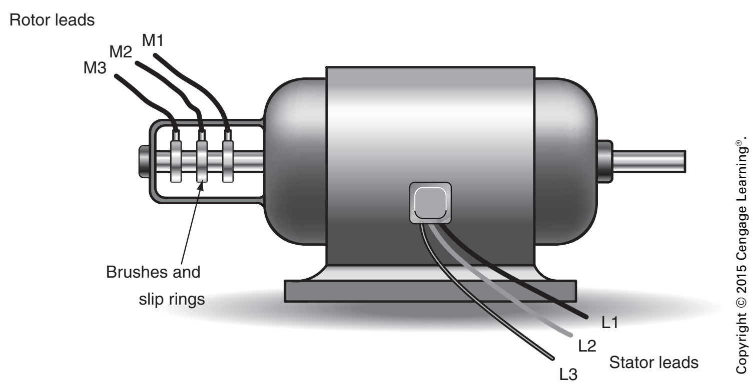


FIGURE 9-16 Wound-rotor induction motor.

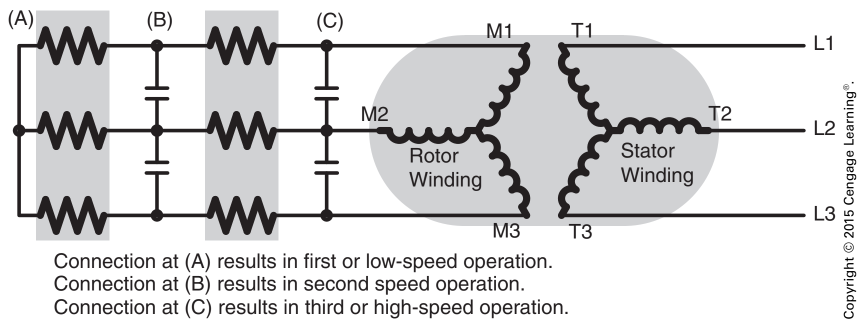


FIGURE 9-17 Wound-rotor motor connections.

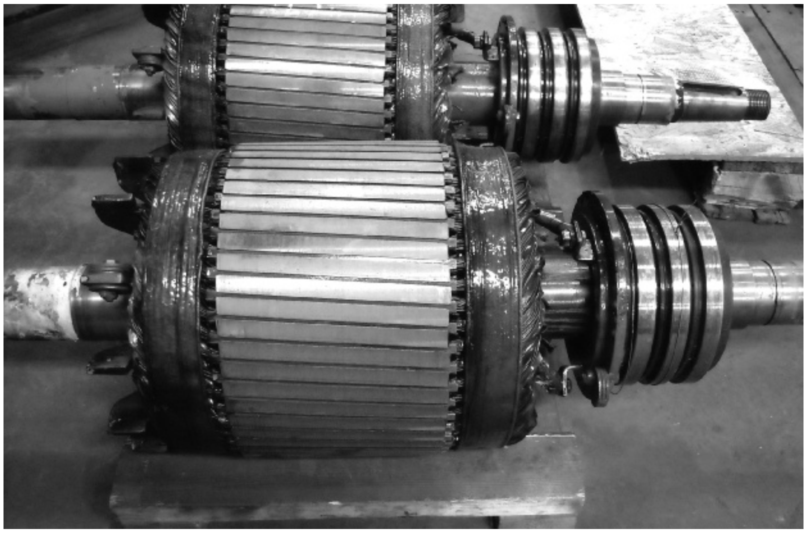


FIGURE 9-18 Rotors of wound-rotor induction motors.

Secondary Resistance Controller

The punch press motors can be operated in any of three speeds. The control circuit is shown in Figure 9-19. Motor speed is controlled by two sets of three resistors each connected in the rotor circuit. Three push buttons permit the motor to be operated in any of the three speeds. The speed can be changed at any time by pressing the appropriate button. However, there is a time delay of 3 seconds between any increases in speed. If the third speed button is pressed, for example, the motor will start in the first or lowest speed. After a 3-second delay, the motor will increase to the second speed. After another 3-second delay, the motor will increase to third or full speed. Motor speed can be decreased by pressing either of the other two push buttons. There is no time delay if the motor speed is decreased.

The wound-rotor induction has a larger than normal shaft diameter because of its ability to develop high torque. It is possible for the motor to develop torque that is 300% above normal running torque. This can create a great amount of stress on the shaft.

The wound-rotor motor is used for extra heavy-duty starting. Typical applications include the use of this type of motor with pumps having an extremely high back pressure, or with machines having a very high static inertia. The secondary resistance controller is used to bring the motor up to speed smoothly. In addition, this controller is used in normal running operations to adjust the torque and speed to any desired values.

DETERMINING DIRECTION OF ROTATION FOR 3-PHASE MOTORS

On many types of machinery, the direction of rotation of the motor is critical. The direction of rotation of any 3-phase motor can be changed by reversing two of its stator leads. This causes the direction of the rotating magnetic field to reverse. When a motor is connected to a machine that will not be damaged when its direction of rotation is reversed, power can be momentarily applied to the motor to observe its direction of rotation. If the rotation is incorrect, any two line leads can be interchanged to reverse the motor's rotation.

When a motor is to be connected to a machine that can be damaged by incorrect rotation, however, the direction of rotation must be determined before the motor is connected to its load. This can be accomplished in two basic ways. One way is to make electrical connection to the motor before it is mechanically connected to the load. The direction of rotation can then be tested by momentarily applying power to the motor before it is coupled to the load.

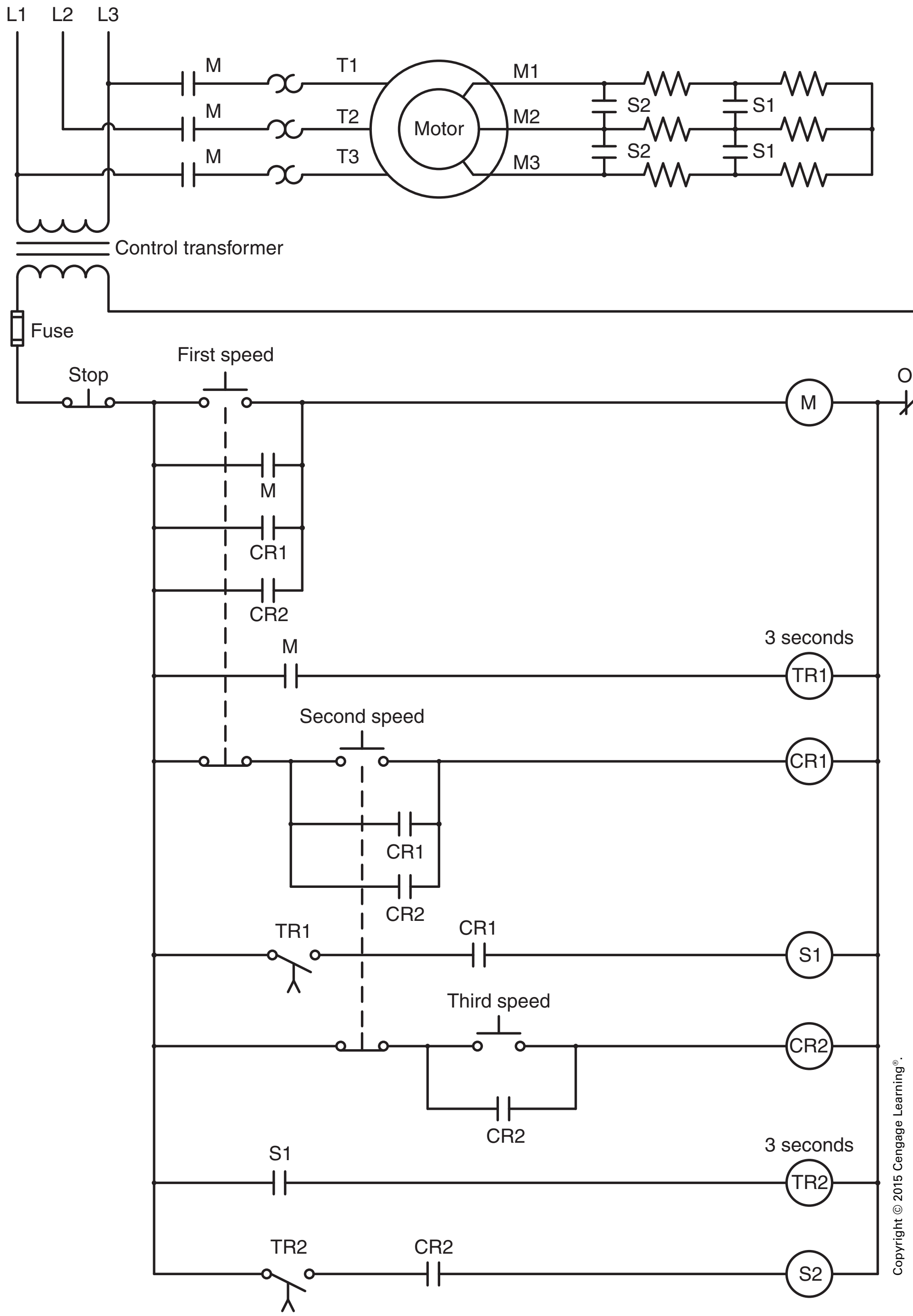


FIGURE 9-19 Automatic starter with three steps of speed control.

There may be occasions when this is not practical or convenient. It is possible to determine the direction of rotation of a motor before power is connected to it with the use of a phase rotation meter, as shown in Figure 9-20. The phase rotation meter is used to compare the phase rotation of two different 3-phase connections. The meter contains six terminal leads. Three of the leads are connected to one side of the meter and labeled "Motor." Each of these three motor leads is labeled A, B, or C. The *line* leads are located on the other side of the meter, and each of these leads is labeled A, B, or C.

FIGURE 9-20 Phase rotation meter.

To determine the direction of rotation of the motor, first zero the meter by following the instructions provided by the manufacturer. Then set the meter selector switch to motor, and connect the three *motor* leads of the meter to the "T" leads of the motor, as shown in Figure 9-21. The phase rotation meter contains a zero-center voltmeter. One side of the voltmeter is labeled "INCORRECT," and the other side is labeled "CORRECT." While observing the zero-center voltmeter, turn the motor shaft in the direction of desired rotation. The zero-center voltmeter will immediately swing in the CORRECT or INCORRECT direction. When the motor shaft stops turning, the needle may swing in the opposite direction. It is the *first* indication of the voltmeter that is to be used.

If the voltmeter needle indicated CORRECT, label the motor "T" leads A, B, or C to correspond with the *motor* leads from the phase rotation meter. If the voltmeter needle indicated INCORRECT, change any two of the *motor* leads from the phase rotation meter and again turn the motor shaft. The voltmeter needle should now indicate CORRECT. The motor "T" leads can now be labeled to correspond with the *motor* leads from the phase rotation meter.

After the motor "T" leads have been labeled A, B, or C to correspond with the leads of the phase rotation meter, the rotation of the line supplying power to the motor must be determined. Set the selector switch on the phase rotation meter to the *line* position. After making certain the power has been turned off, connect the three *line* leads of the phase rotation meter to the motor supply line, Figure 9-22. Turn on the power and observe the zero-center voltmeter. If the meter is pointing in the CORRECT direction, turn off the power and label the line leads A, B, or C to correspond with the *line* leads of the phase rotation meter.

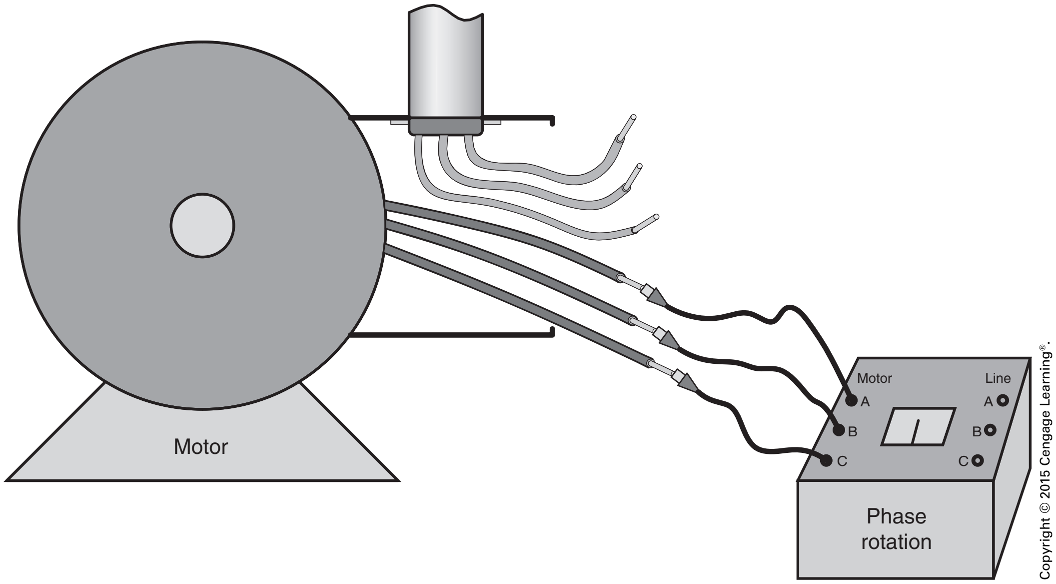


FIGURE 9-21 Connecting the phase rotation meter to the motor.

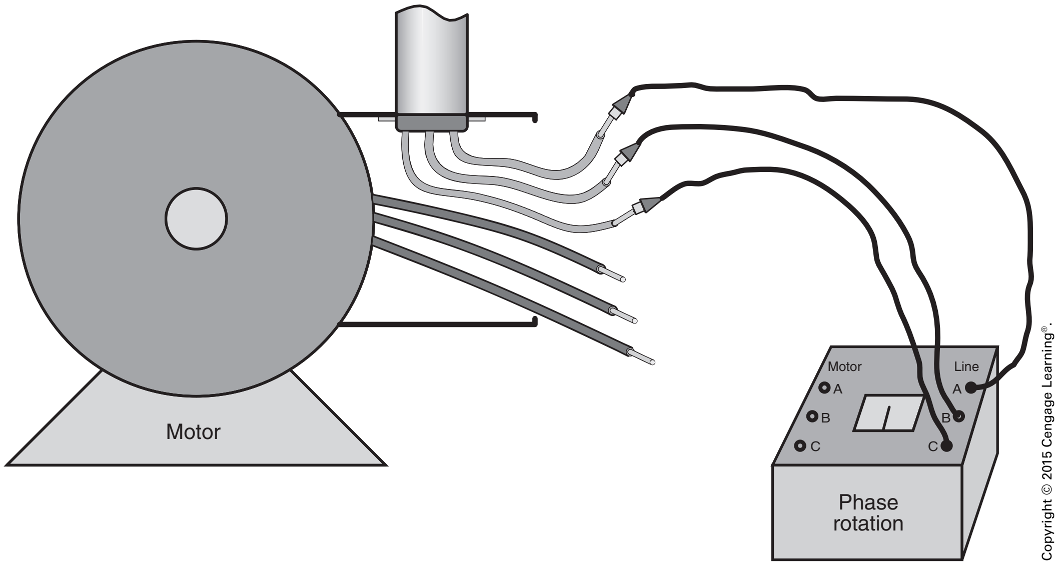


FIGURE 9-22 Connecting the phase rotation meter to the line.

If the voltmeter is pointing in the INCORRECT direction, turn off the power and change any two of the leads from the phase rotation meter. When the power is turned on, the voltmeter should point in the CORRECT direction. Turn off the power and label the line leads A, B, or C to correspond with the leads from the phase rotation meter.

Now that the motor "T" leads and the incoming power leads have been labeled, connect the line lead labeled A to the "T" lead labeled A; the line lead labeled B to the "T" lead labeled B; and the line lead labeled C to the "T" lead labeled C. When power is connected to the motor, it will operate in the proper direction.

Notice that the phase rotation meter can be used to determine the *phase rotation* of two different connections. It cannot determine which of the three phase lines is A, B, or C, or which line lead is L1, L2, or L3. The phase rotation meter can be used to determine the rotation of two separate 3-phase systems. For example, assume all the short-circuit protective devices and switch gear for an existing 3-phase system must be replaced. To minimize downtime, a temporary 3-phase service will be connected to supply power while the existing switch gear is being replaced. It is critical that the phase rotation of the temporary service be the same as the existing service when power is applied. The phase rotation meter can be used to ensure the connection is correct.

The first step is to connect the *line* leads of the phase rotation meter to the existing power, Figure 9-23. If the zero-center voltmeter indicates CORRECT, label the load side of the service A, B, and C to correspond with the leads of the phase rotation meter. If the voltmeter indicates INCORRECT, change two of the meter leads. This should cause the phase rotation meter to indicate CORRECT. Label the load side of the service to correspond with A, B, or C of the phase rotation meter leads.

Before connecting the temporary service to the load side of the circuit, connect the phase rotation meter to the line side of the temporary service, Figure 9-24. Obtain a CORRECT reading on the phase rotation meter by changing two of the meter leads if necessary. After the correct reading has been obtained, label the service leads A, B, and C to correspond with the leads of the phase rotation meter. If the marked temporary service leads are connected to their like-marked load leads, the phase rotation of the temporary service will be the same as the existing service.

CONNECTING DUAL-VOLTAGE 3-PHASE MOTORS

Many of the 3-phase motors used in industry are designed to be operated on two voltages, such as 240 to 480 volts. Motors of this type contain two sets of windings per phase. Most dual-voltage motors bring out nine "T" leads at the terminal box. There is a standard method used to number these leads,

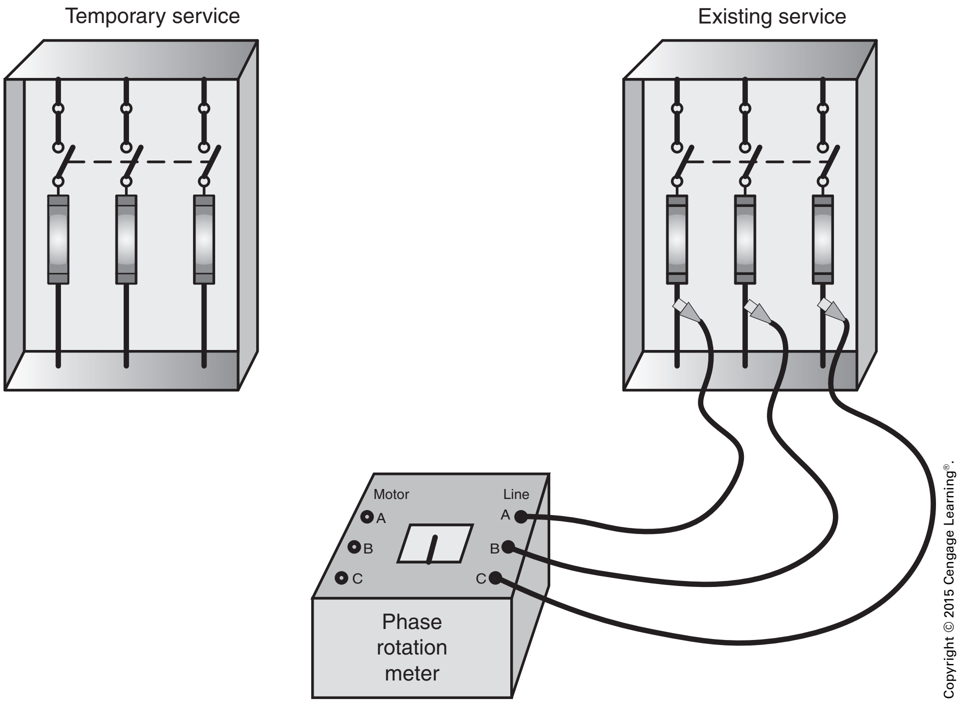


FIGURE 9-23 Testing the phase rotation of the existing service.

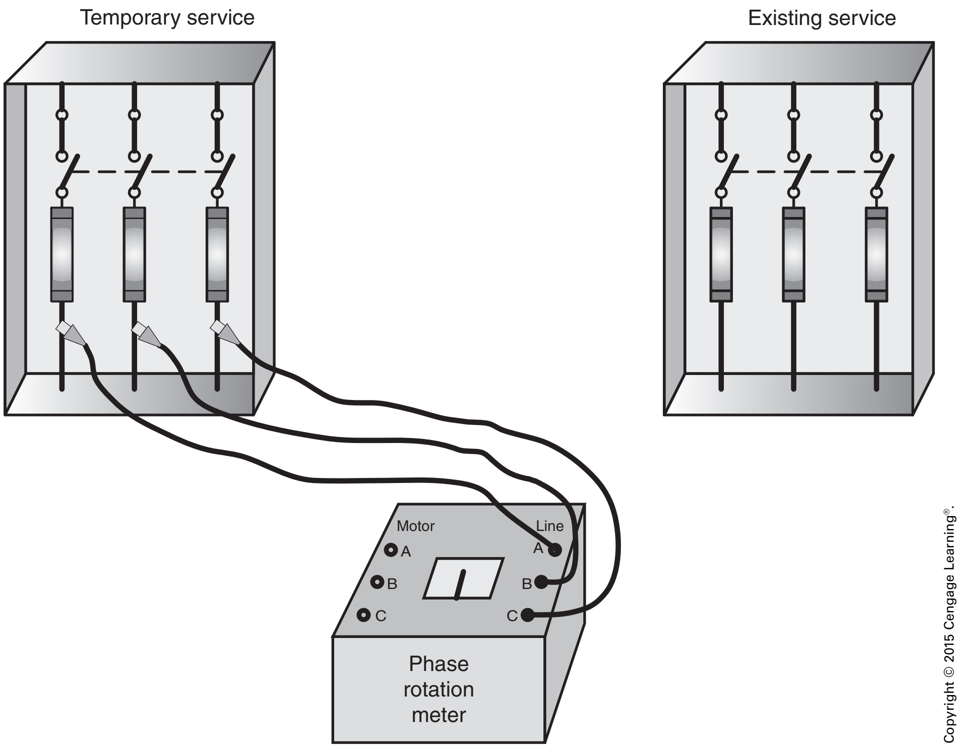


FIGURE 9-24 Testing the phase rotation of the temporary service.

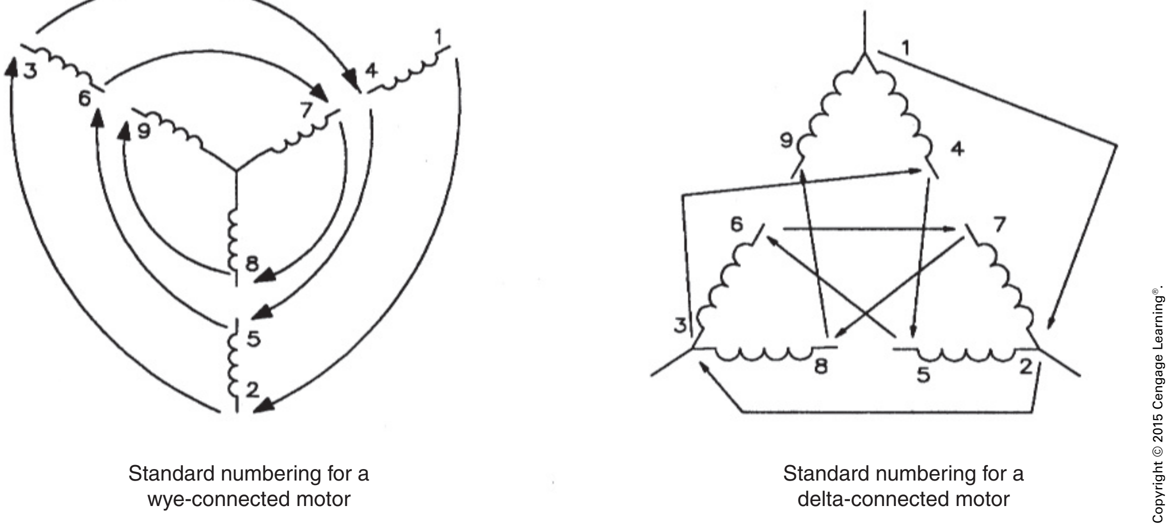


FIGURE 9-25 Standard numbering for a wye-connected motor and a delta-connected motor.

as shown in Figure 9-25. Starting with terminal #1, the leads are numbered in a decreasing spiral as shown. Another method of determining the proper lead numbers is to add three to each terminal. For example, starting with lead #1, add three to one. Three plus one equals four. The phase winding that begins with #1 ends with #4. Now add three to four. Three plus four equals seven. The beginning of the second winding for phase one is seven. This method will work for the windings of all phases. If in doubt, draw a diagram of the phase windings and number them in a spiral.

Three-phase motors can be constructed to operate in either wye or delta. If a motor is to be connected to high voltage, the phase windings will be connected in series. In Figure 9-26, a schematic diagram and terminal connection chart for high voltage are shown for a wye-connected motor. In Figure 9-27, a schematic diagram and terminal connection chart for high voltage are shown for a delta-connected motor.

When a motor is to be connected for low-voltage operation, the phase windings must be connected in parallel. Figure 9-28 shows the basic schematic diagram for a wye-connected motor with parallel phase windings. In actual practice, however, it is not possible to make this exact connection with a nine-lead motor. The schematic shows that terminal #4 connects to the other end of the phase winding that starts with terminal #7. Terminal #5 connects to the other end of winding #8, and terminal #6 connects

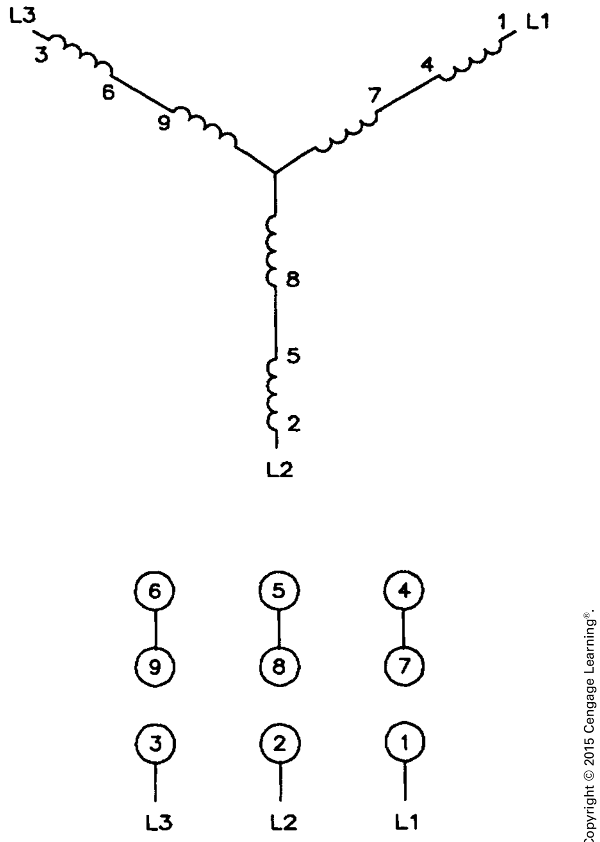


FIGURE 9-26 High-voltage wye connection.

to the other end of winding #9. In actual motor construction, the opposite ends of windings 7, 8, and 9 are connected together inside the motor and are not brought outside the motor case. The problem is

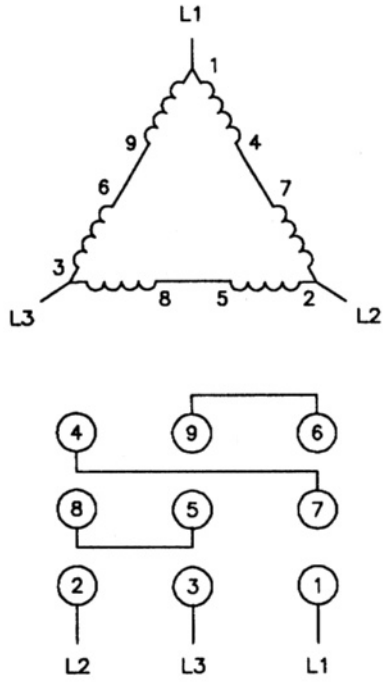


FIGURE 9-27 High-voltage delta connection.

solved, however, by forming a second wye connection by connecting terminals 4, 5, and 6, as shown in Figure 9-29.

The phase winding of a delta-connected motor must also be connected in parallel for use on low voltage. A schematic for this connection is shown in Figure 9-30. A connection diagram and terminal connection chart for this hookup are shown in Figure 9-31.

Some dual-voltage motors contain twelve “T” leads instead of nine. In this instance, the opposite

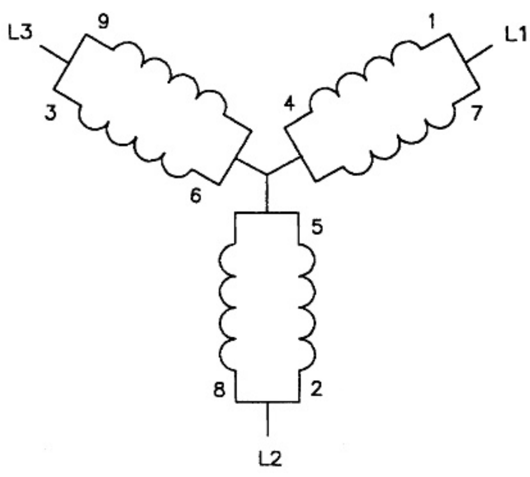


FIGURE 9-28 Stator windings connected in parallel.

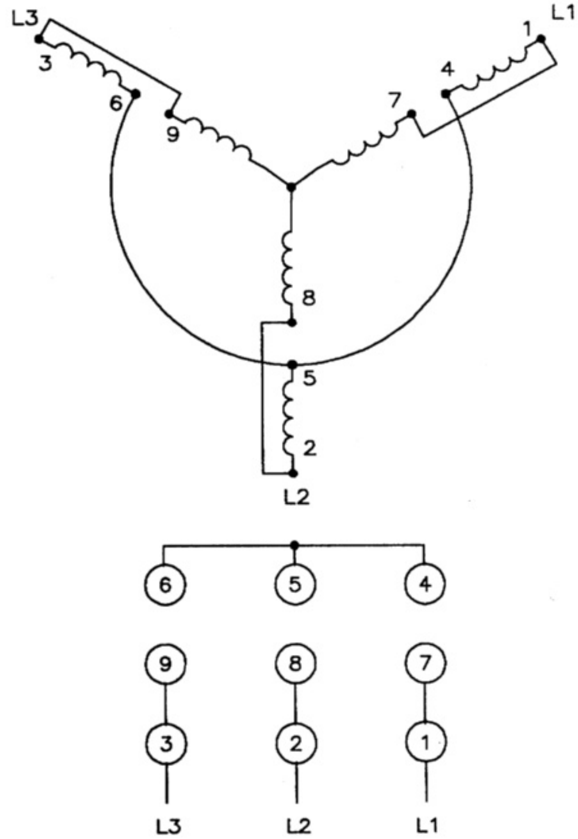


FIGURE 9-29 Low-voltage wye connection.

ends of terminals 7, 8, and 9 are brought out for connection. Figure 9-32 shows the standard numbering for both delta- and wye-connected motors. Twelve leads are brought out if the motor is intended to be used for wye-delta starting. When this is the case, the motor must be designed for normal operation with its windings connected in delta. If the windings are connected in wye during starting, the starting current of the motor is greatly reduced.

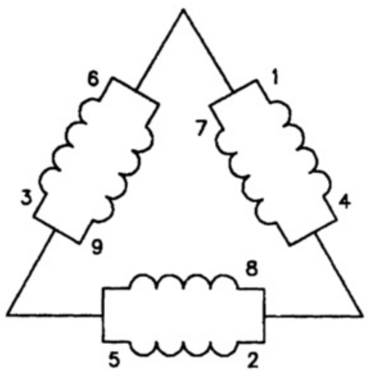


FIGURE 9-30 Parallel delta connection.

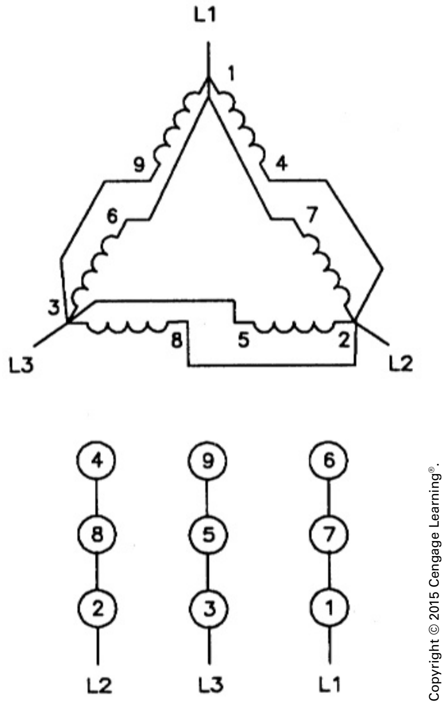


FIGURE 9-31 Low-voltage delta connection.

DUAL-VOLTAGE SINGLE-PHASE MOTORS

Many single-phase motors are designed to be connected to either 120 or 240 volts. Most dual-voltage single-phase motors will be of the split-phase type, which contains both run and starting windings. Figure 9-33 shows the schematic diagram of a split-phase motor designed for dual-voltage operation. This particular motor contains two run windings and two start windings. The lead numbers for single-phase motors are also numbered in a standard manner. One of the run windings has lead numbers of T1 and T2. The other run winding has its leads numbered T3 and T4. This particular motor uses two different sets of start winding leads. One set is labeled T5 and T6, and the other set is labeled T7 and T8.

If the motor is to be connected for high-voltage operation, the run windings and start windings will be connected in series, as shown in Figure 9-34. The start windings are then connected in parallel with the run windings. It should be noted that if the opposite direction of rotation is desired, T5 and T8 will be changed.

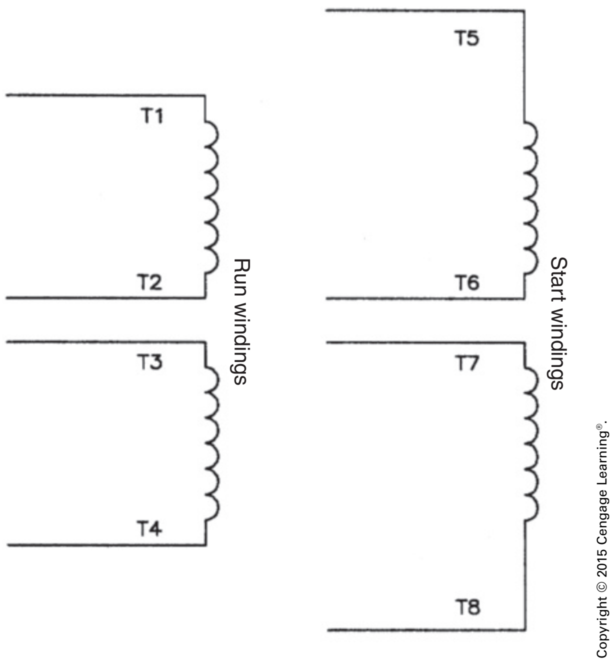


FIGURE 9-33 Single-phase dual-voltage motor.

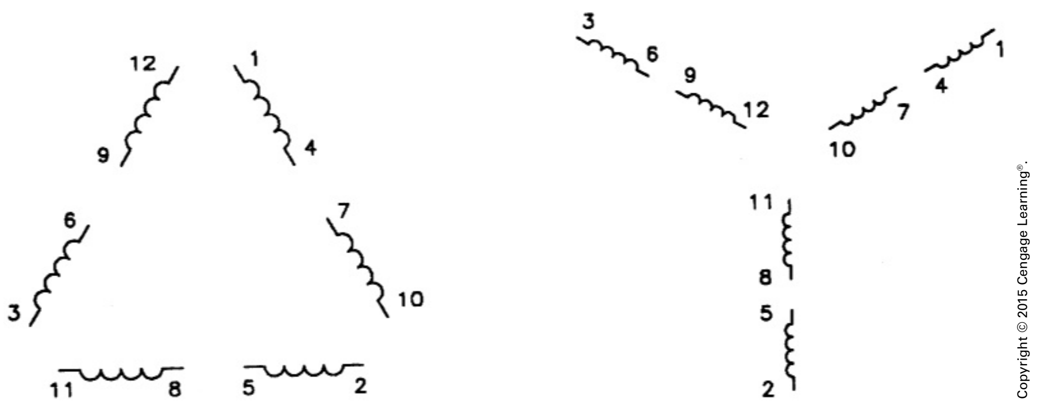


FIGURE 9-32 Twelve-lead motor.

For low-voltage operation, the windings must be connected in parallel, as shown in Figure 9-35. This connection is made by first connecting the run windings in parallel by hooking T1 and T3 together, and T2 and T4 together. The start windings are paralleled by connecting T5 and T7 together, and T6 and T8 together. The start windings are then connected in parallel with the run windings. If the opposite direction of rotation is desired, T5 and T6, and T7 and T8 should be reversed.

Not all dual-voltage single-phase motors contain two sets of start windings. Figure 9-36 shows the schematic diagram of a motor that contains two sets of run windings and only one start winding. In this illustration, the start winding is labeled T5 and T6. It should be noted, however, that some motors identify the start winding by labeling it T5 and T8, as shown in Figure 9-37.

Regardless of which method is used to label the terminal leads of the start winding, the connection will be the same. If the motor is to be connected for high-voltage operation, the run windings will be connected in series, and the start winding will be connected in parallel with one of the run windings, as shown in Figure 9-38. In this type of motor, each winding is rated at 120 volts. If the run windings are connected in series across 240 volts, each winding will have a voltage drop of 120 volts. By connecting the start winding in parallel across only one run winding, it will receive only 120 volts when power is applied to the motor. If the opposite direction of rotation is desired, T5 and T8 should be changed.

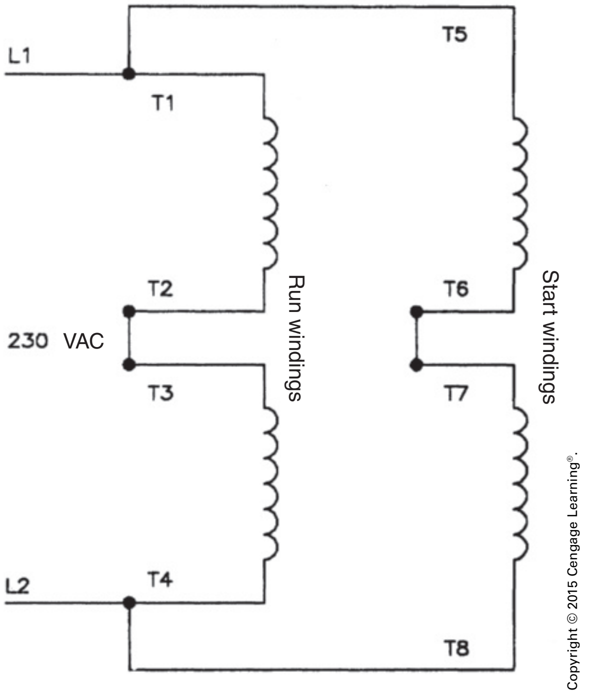


FIGURE 9-34 High-voltage connection for single-phase motor with two run windings and two start windings.

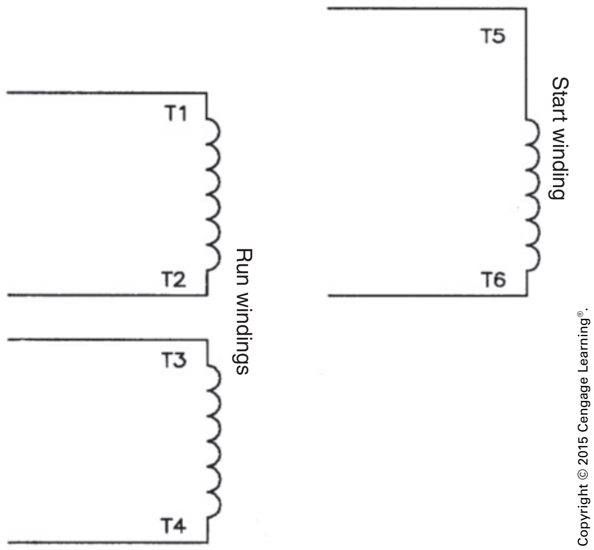


FIGURE 9-36 Dual-voltage motor with one start winding labeled T5 and T6.

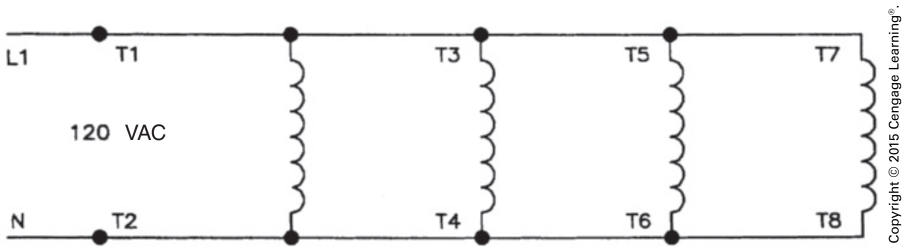


FIGURE 9-35 Low-voltage connection for single-phase motor with two start windings.

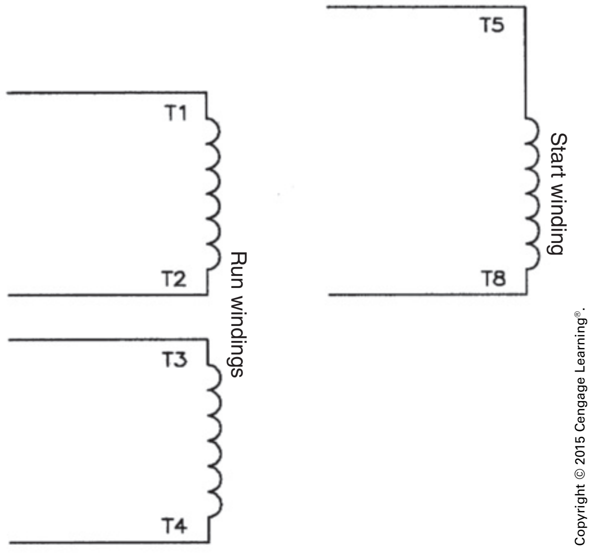


FIGURE 9-37 Dual-voltage motor with one start winding labeled T5 and T8.

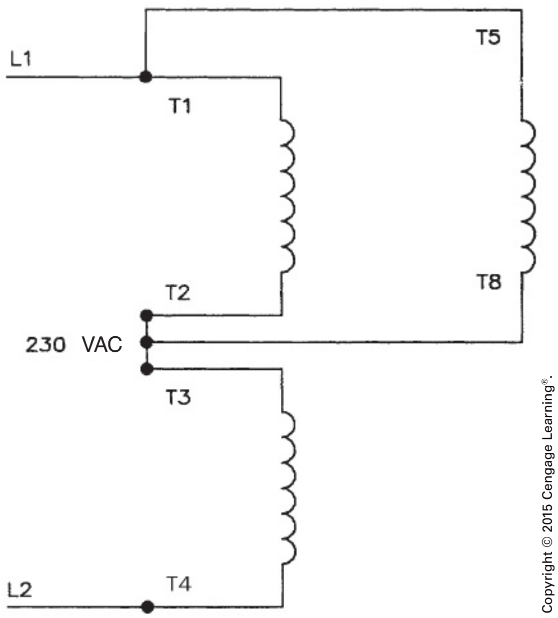


FIGURE 9-38 High-voltage connection with one start winding.

If the motor is to be operated on low voltage, the windings are connected in parallel, as shown in Figure 9-39. Because all windings are connected in parallel, each will receive 120 volts when power is applied to the motor.

DETERMINING DIRECTION OF ROTATION FOR SINGLE-PHASE MOTORS

The direction of rotation of a single-phase motor can generally be determined when the motor is connected. The direction of rotation is determined by facing the back or rear of the motor. Figure 9-40 shows a connection diagram for rotation. If clockwise rotation is desired, T5 should be connected to T1. If counterclockwise rotation is desired, T8 (or T6) should be connected to T1. It should be noted that this connection diagram assumes the motor contains two sets of run and two sets of start windings. The type of motor used will determine the actual connection. For example, Figure 9-38 shows the connection of a motor with two run windings and only one start winding. If this motor were to be connected for clockwise rotation, terminal T5 should be connected to T1 and terminal T8 should be connected to T2 and T3. If counterclockwise rotation were desired, terminal T8 would be connected to T1, and terminal T5 would be connected to T2 and T3.

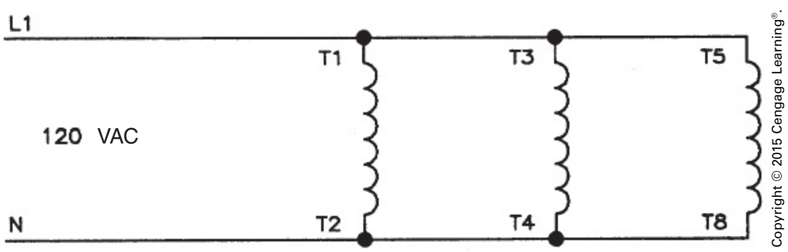


FIGURE 9-39 Low-voltage connection for a single-phase motor with one start winding.

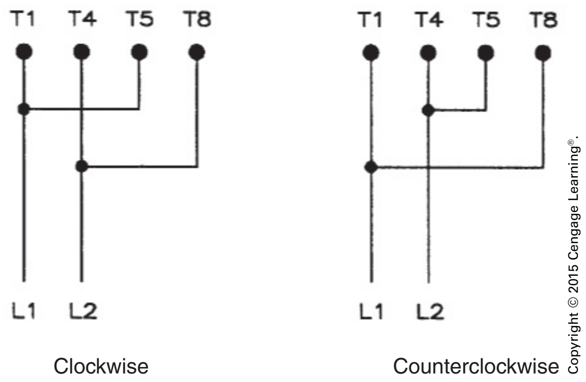


FIGURE 9-40 Determining direction of rotation for single-phase motors.

Direct-Current Motors

Two types of machine tools in the industrial building require DC motors. Five vertical boring mills (MG) require one DC motor each, and three planers (MH) require the same type of motors and controllers.

The motors used are standard compound wound DC motors and are all rated at 25 horsepower. The motors are not operated from regular DC sources, but rather are operated from 480-volt AC lines through electronic controllers that rectify the current (change it from AC to DC).

Direct-current compound motors contain a rotating armature and a stationary field. The field also serves as the frame or housing of the motor. End bells or end brackets support the shaft bearings. The armature has a winding that is connected to a commutator. Brush holders and carbon brushes mounted on the front end bell contact the commutator, which rotates when the motor is running.

A typical DC motor is shown in Figure 9-41.

The compound wound field consists of two separate field windings. The shunt field is wound with relatively small wire and has thousands of turns. The series field is wound with large wire and has only a few turns. The field windings or coils are placed on pole pieces attached to the frame or yoke.

Compound wound motors have an even number of poles, with the smaller motor sizes usually having two or four poles, and the larger motor sizes having a larger number of poles. The field frame of a DC motor is shown in Figure 9-42.

A part of the shunt field and a part of the series field are wound on each pole piece. The windings on each alternate pole piece are made in opposite directions, clockwise and counterclockwise. In this manner, each pole piece is alternately magnetized north and south. The ends of the shunt winding (two ends) and the series field winding (two ends) are brought out to the motor terminal box.

Commutating poles or interpoles are also provided. These very small pole pieces are placed midway between the main pole pieces. The interpoles are wound with a few turns of heavy wire. As with the main pole pieces, the interpoles are also wound in an alternate clockwise and counterclockwise manner. The pole pieces are connected permanently in series with the armature brush holders and are considered to be a part of the armature circuit. Interpoles counteract the distortion of the field magnetism caused by the rotation of the heavily magnetized armature in the field flux. As a result, sparking or arcing at the brushes is reduced.

A DC compound motor can be connected in several ways. When the shunt field spans only the armature, it is known as a *short shunt connection*, Figure 9-43. If, on the other hand, the shunt field spans both the armature and the series field, it is called a *long shunt connection*. When the motor is connected short shunt, the shunt field current is added to the series field current. This generally causes a slight overcompounding of the motor, which permits it to exhibit stronger torque characteristics. When the motor is connected long shunt, it exhibits better speed regulation.

If the motor terminal connections are made so that the series field magnetism aids or strengthens the magnetism produced by the shunt field, then the motor is said to be a cumulative compound motor, Figure 9-44.

If the motor terminal connections are reversed so that the magnetism of the series field opposes or weakens the magnetism of the shunt field, the motor is called a differential compound motor, Figure 9-44.

Although the differential compound motor gives a more constant speed at all loads, the motor is somewhat unstable. For this reason, this type of motor is not used in as many applications as the cumulative compound motor.

The strength of the shunt field is constant. However, because the series field is connected in

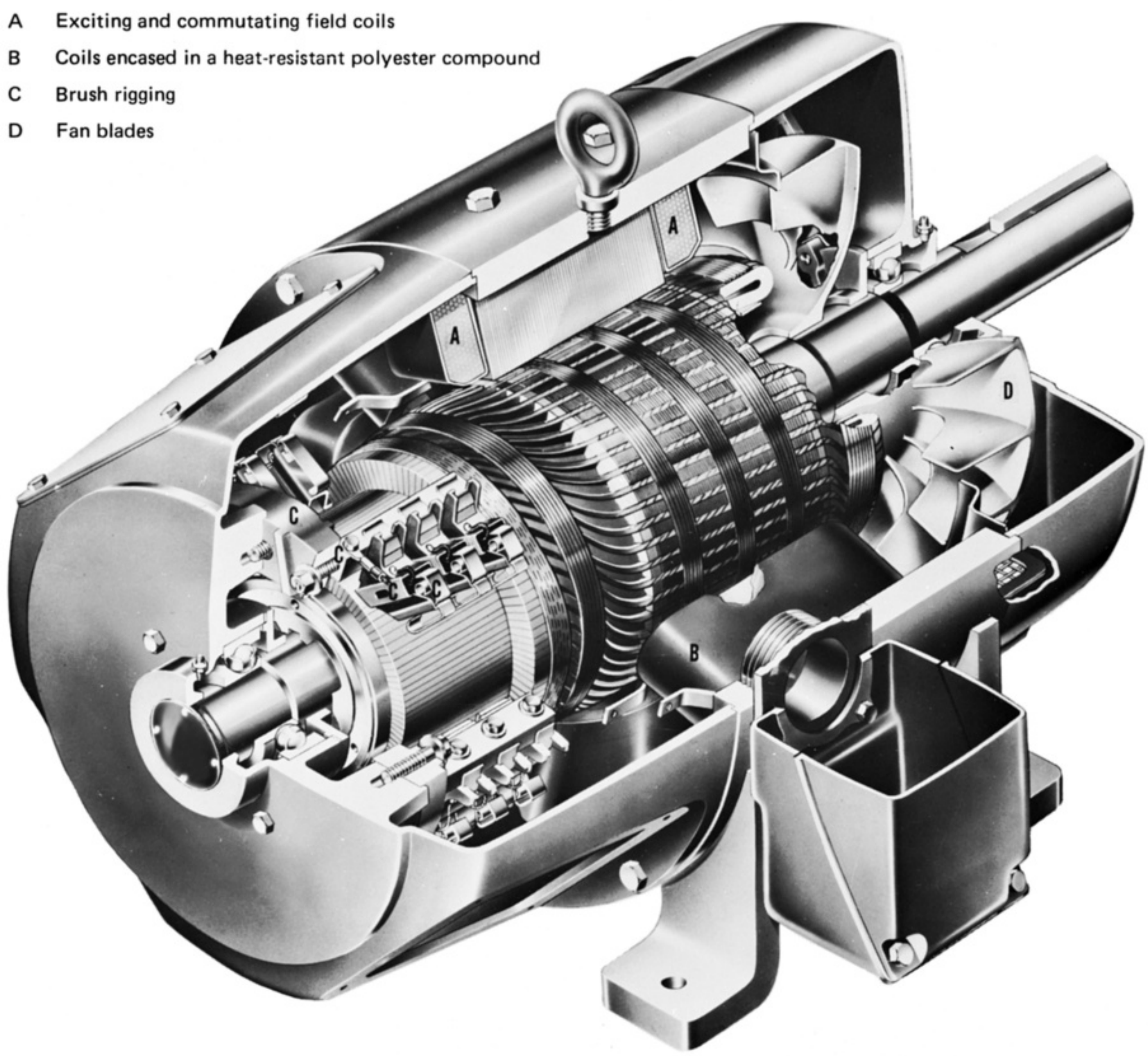


FIGURE 9-41 Cutaway view of DC motor.

series with the armature, the strength of the series field varies with the load on the motor. When the motor is running at idle speed (no output), the series field contributes almost no magnetism to that of the shunt field. When the motor is loaded, the series field increases the magnetism of the shunt field to produce more torque and cause a slight drop in the motor speed.

The armature/commutator also has poles. This component of the motor is a wrought copper cylinder with segments or bars. These segments are insulated from one another and serve as a mounting to which the armature winding is connected. A 2-pole armature has a coil span equal to the diameter of the armature, less a few slots. A 4-pole armature has a coil span equal to one-quarter of the circumference of the armature, less a few slots. A 6-pole armature has a coil span equal to one-sixth of the circumference of the armature, less one or two slots, Figure 9-45. The coil span arrangement depends entirely on the number of poles present. A 4-pole armature cannot be used with a 2-pole field. The two units, the armature and the field, must be wound with the same number of poles.

It was shown that for AC motors, the torque and horsepower are proportional to the square of the voltage applied, and the speed of rotation depends upon the frequency and the number of poles in the motor. However, the performance of a DC motor depends upon entirely different factors. The speed

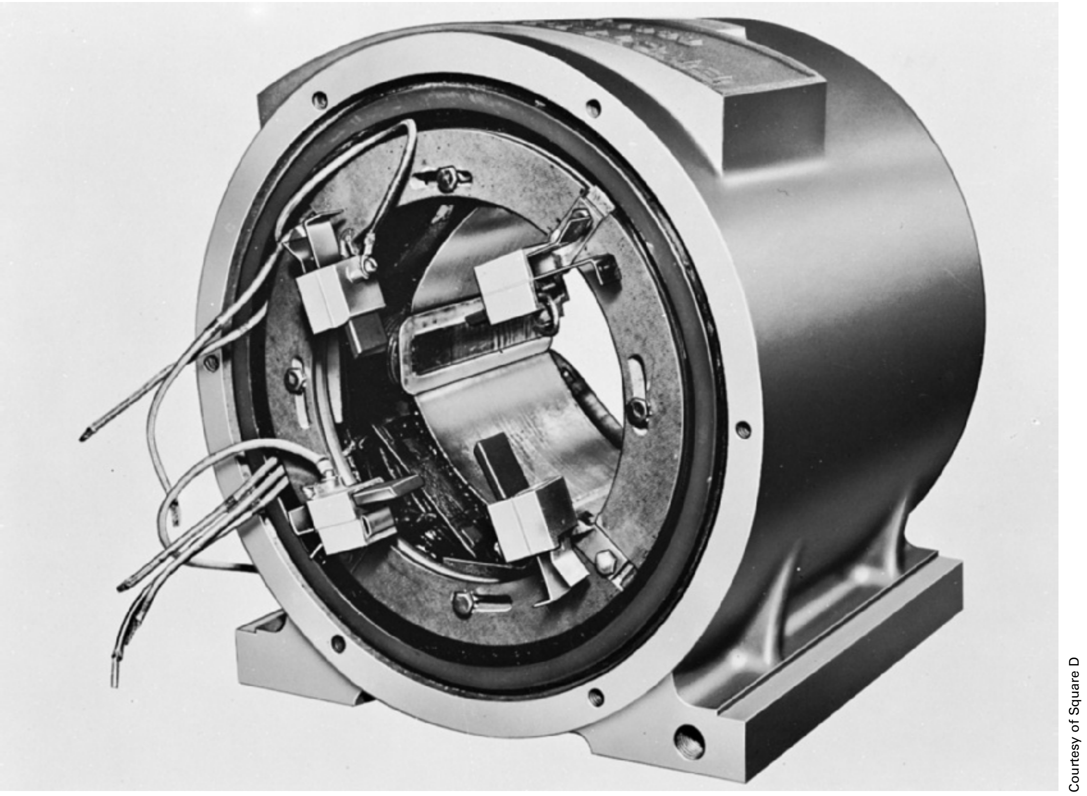


FIGURE 9-42 Field frame of a DC motor.

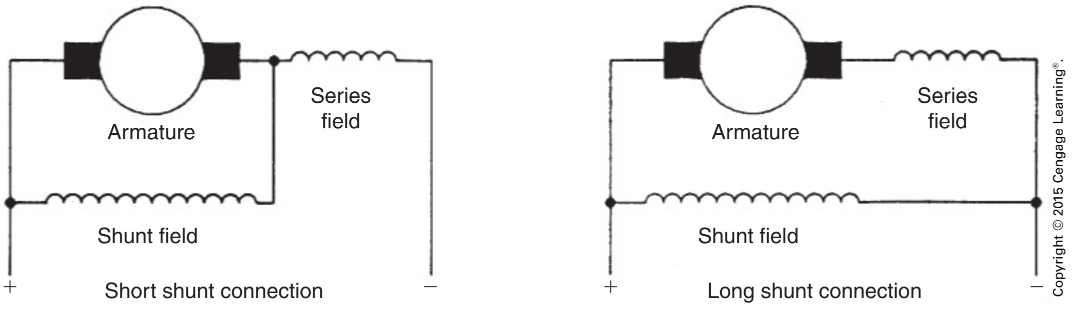


FIGURE 9-43 Direct-current motor connection.

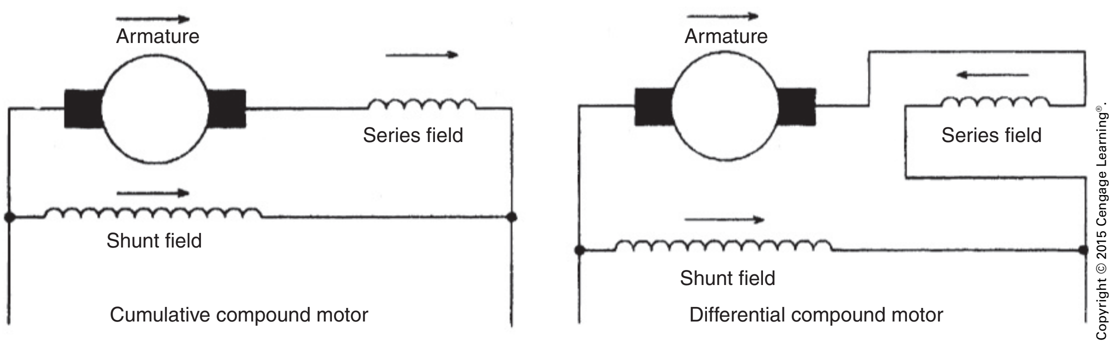
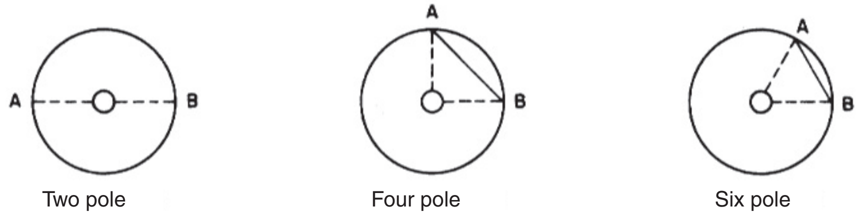


FIGURE 9-44 Connections for cumulative and differential compound connection motors.



The coil span is the line A–B. With a 2-pole motor, coil span is 180. A 4-pole motor has a coil span of 90, and a 6-pole motor has a coil span of 60. In actual practice, coil span is chorded and is slightly less than the full span.

FIGURE 9-45 Relation of armature coil span to number of poles.

of a DC motor increases when the voltage increases and decreases if the field strength is increased or if there is an increase in the number of poles or turns of wire wound on the armature.

For all motors, the horsepower output is

$$\text{Hp} = \frac{2\pi F \times R \times S}{33{,}000} \text{ or } \frac{T \times S}{5250}$$

where F = force, in pounds
R = radius, in feet
S = speed, in RPM
T = torque, in foot-pounds

TERMINAL IDENTIFICATION FOR DIRECT-CURRENT MOTORS

The terminal leads of DC machines are labeled so they can be identified when they are brought outside the motor housing to the terminal box. Figure 9-46 illustrates this standard identification. Terminals A1 and A2 are connected to the armature through the brushes. The ends of the series field are identified with S1 and S2, and the ends of the shunt field are marked F1 and F2. Some DC machines will provide access to another set of windings called the commutating field or interpoles. The ends of this winding will be labeled C1 and C2, or S3 and S4. It is common practice to provide access to the interpole winding on machines designed to be used as motors or generators.

DETERMINING THE DIRECTION OF ROTATION OF A DIRECT-CURRENT MOTOR

The direction of rotation of a DC motor is determined by facing the commutator end of the motor. This is generally the back or rear of the motor. If the windings have been labeled in a standard manner,

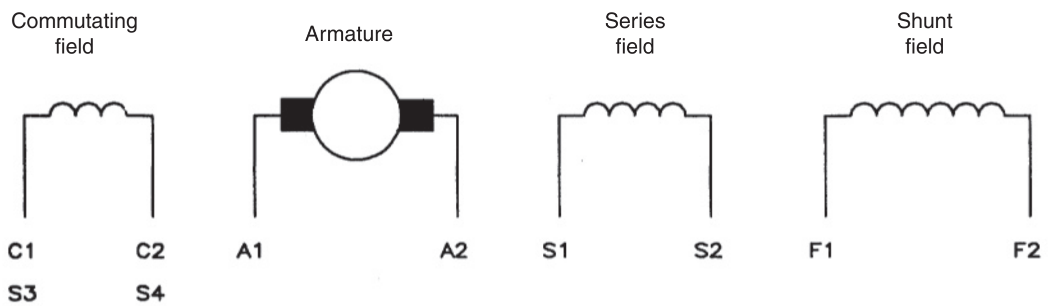


FIGURE 9-46 Lead identification for DC machines.

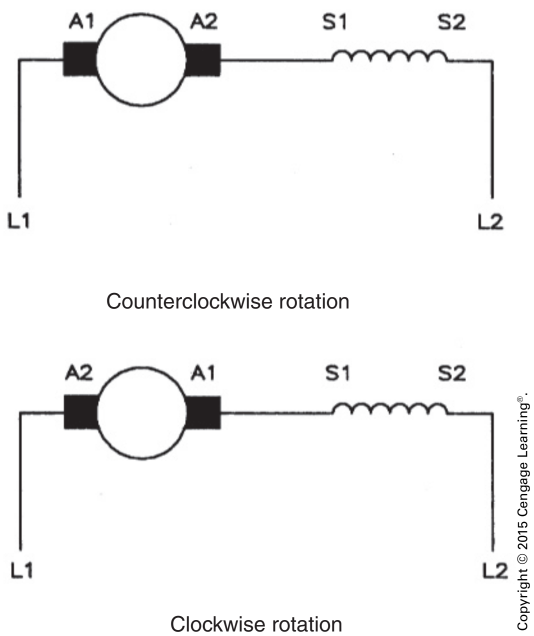


FIGURE 9-47 Series motor.

it is possible to determine the direction of rotation when the motor is connected. Figure 9-47 illustrates the standard connections for a series motor. The standard connections for a shunt motor are illustrated in Figure 9-48, and the standard connections for a compound motor are shown in Figure 9-49.

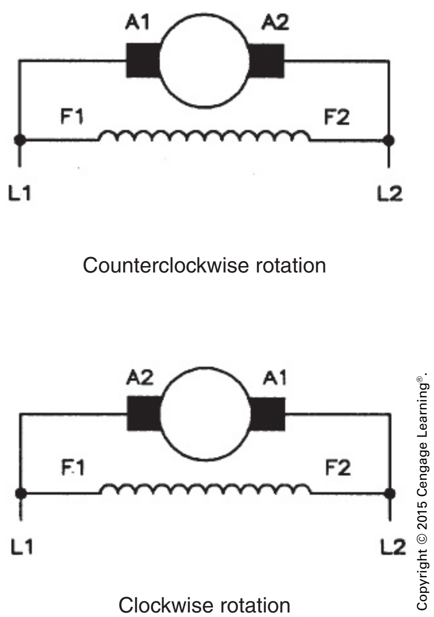


FIGURE 9-48 Shunt motor.

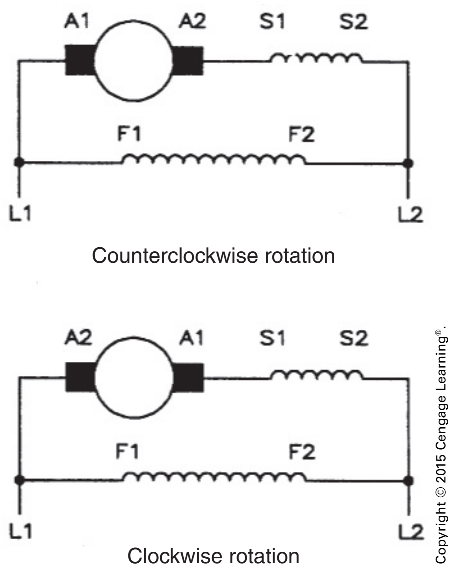


FIGURE 9-49 Compound motor.

The direction of rotation of a DC motor can be reversed by changing the connections of the armature leads or the field leads. It is common practice to change the connection of the armature leads. This is done to prevent changing a cumulative compound motor into a differential compound motor.

DIRECT-CURRENT POWER SUPPLIES

The use of direct-current motors in industry creates a need for a supply of DC power. Because most of industry operates on AC power, the DC power needed is generally produced within the industrial plant. The most common method to convert AC voltage to DC voltage is by the use of solid-state components.

A simple half-wave rectifier is shown in Figure 9-50. The diode is used to convert the AC voltage to DC voltage. The diode operates like an electric check valve; it permits the current to flow through it in only one direction. When the voltage applied to the cathode end of the diode is more negative than the voltage applied to the anode end, the diode becomes *forward biased*. This permits current to flow through the load resistor and then through the diode to complete the circuit. When the voltage applied to the cathode end of the diode becomes more positive than the voltage applied to the anode end, the diode becomes *reverse biased* and turns off. When the diode is reverse biased, no current flows in the circuit. The waveforms in Figure 9-50 illustrate this condition. The negative half of the AC input wave has been cut off to produce the DC output wave. This type of rectifier is called a half-wave because only one-half of the AC waveform is used. The output voltage is pulsating. It turns on and off, but the direction of current flow never reverses. Because the output voltage never reverses direction, it is direct current.

Single-Phase, Full-Wave Rectifiers

Full-wave rectification of single-phase AC can be obtained by using either of two circuits. Figure 9-51 shows these two types of full-wave rectifiers: the two-diode type and the bridge type. The *two-diode* rectifier requires the use of a center-tapped transformer. It is the more efficient of the two because there is a voltage drop across only two diodes instead of four. To understand the operation of this rectifier, assume the voltage applied to the cathode of diode D1 to be negative, and the voltage applied to the cathode of diode D2 to be positive. Because diode D1 has a negative voltage applied to its cathode, it is forward biased and current can flow through it. Diode D2, however, is reverse biased and no current can flow through it. The current must flow from the center tap of the transformer, through the load resistor, and complete the circuit through diode D1 back to the transformer.

During the next half-cycle of AC voltage, a negative voltage is applied to the cathode of diode D2 and a positive voltage is applied to the cathode of diode D1. Diode D2 is now forward biased and diode D1 is reverse biased. Current can flow from the center tap of the transformer, through the load resistor, and then complete the circuit through diode D2 back to the transformer. Notice in this rectifier that current flowed through the load resistor during both half cycles of AC voltage. Because both cycles of AC voltage were changed into DC, it is full-wave rectification.

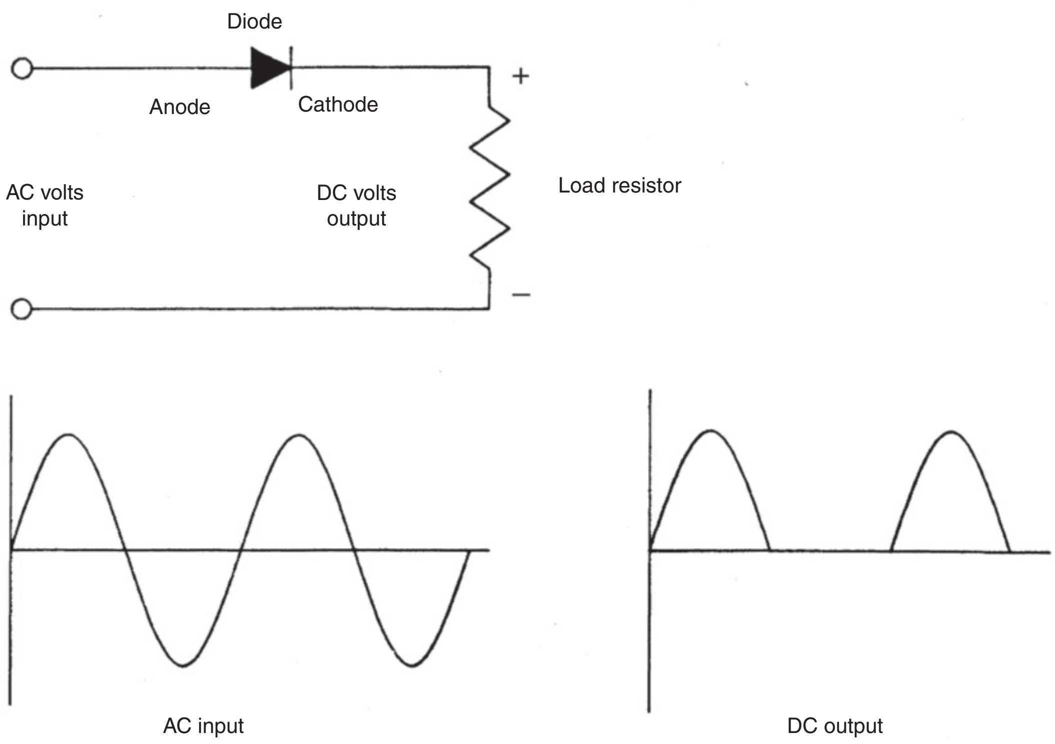


FIGURE 9-50 Half-wave rectifier.