Electrical Distribution Systems

Course No: E02-004
Credit: 2 PDH

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SYSTEM COMPONENTS AND PROTECTION DEVICES

Nuclear facilities rely on dependable electrical distribution systems to provide power to key vital equipment. Knowledge of the basic electrical power distribution system and its components will help the operator understand the importance of electrical power distribution systems.

EO 1.1 **EXPLAIN the following terms as they apply to Electrical Distribution Systems:**
  a. **Single (one-line) diagram**
  b. **Commercial or utility power**
  c. **Diesel power**
  d. **Failure-free power**
  e. **Neutral grounding**
  f. **Voltage class**
  g. **Protective relays**
  h. **Overlapping protective zones**

EO 1.2 **DESCRIBE the protection provided by each of the following:**
  a. **Fuses**
  b. **Protective relays**

Single (One-Line) Diagram

A *single*, or *one-line diagram* of a distribution system is a simple and easy-to-read diagram showing power supplies, loads, and major components in the distribution system (Figure 1).

Commercial or Utility Power

Commercial or *utility power* is electrical power that is provided by commercial generating systems to the facility.

Diesel Power

Diesel power is power generated by a diesel-driven generator. Diesel-driven generators are the most economical and practical source of "standby power."
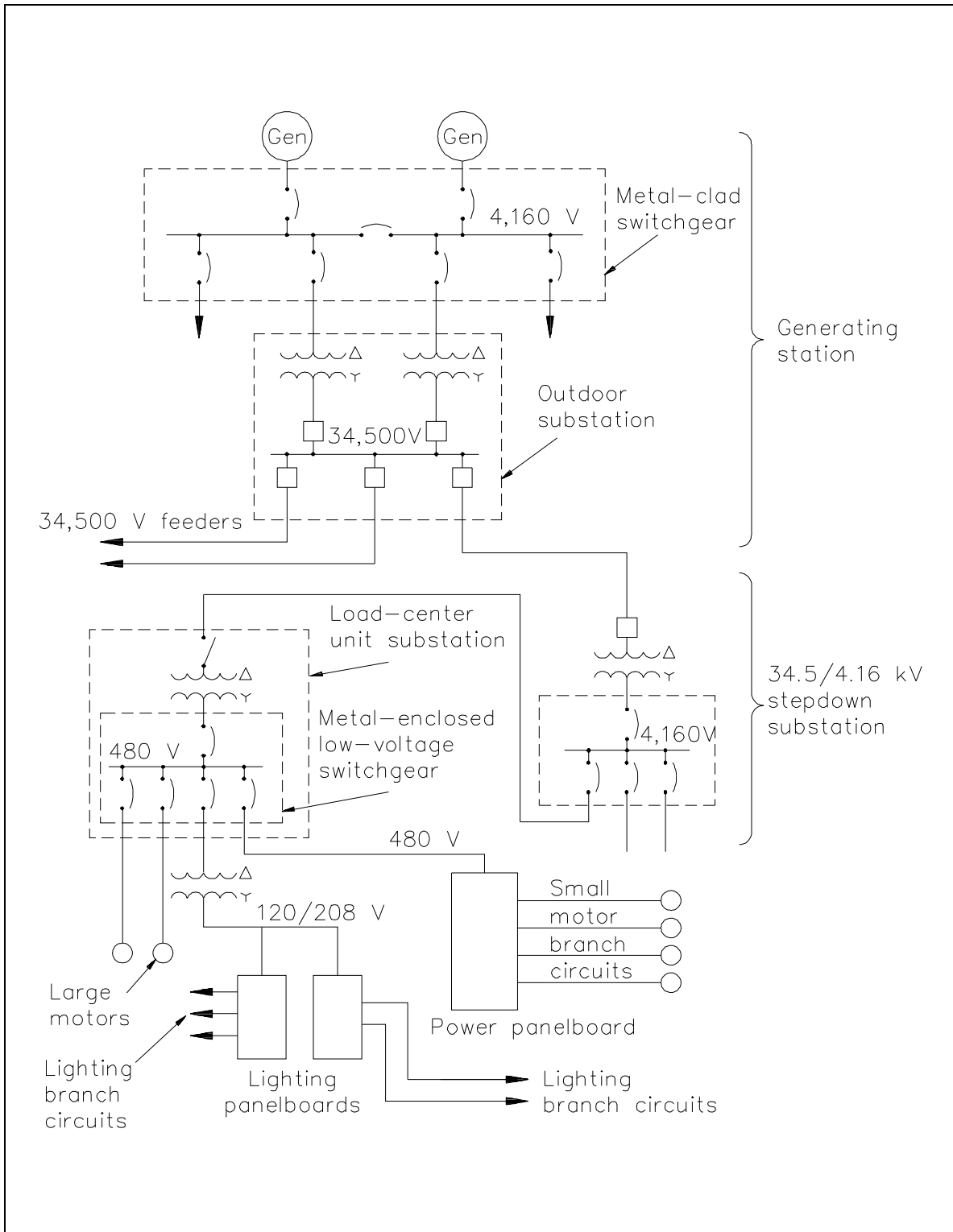
Figure 1   One-Line Distribution Diagram

Failure-Free Power

Failure-free power is accomplished by providing vital equipment with automatic switching between two or more power supplies so that interruption of power is minimized.

Neutral Grounding

Neutral grounding in electrical distribution systems helps prevent accidents to personnel and damage to property caused by: fire in case of lightning; a breakdown between primary and secondary windings of transformers; or accidental contact of high-voltage wires and low- voltage wires. If some point on the circuit is grounded (in this case neutral ground), lightning striking the wires will be conducted into the ground, and breakdown between the primary and secondary windings of a transformer will cause the primary transformer fuses to blow. Another advantage of neutral grounding is that it reduces the amount of insulation required for high-voltage transmission lines.

Voltage Class

Voltage in distribution systems is classified into three groups: high voltage, intermediate voltage, and low voltage. *High voltage* is voltage that is above 15,000 volts, *intermediate voltage* is voltage between 15,000 volts and 600 volts, and *low voltage* is voltage at 600 volts or less.

Protective Relays

Protective relays are designed to cause the prompt removal of any part of a power system that might cause damage or interfere with the effective and continuous operation of the rest of the system. Protective relays are aided in this task by circuit breakers that are capable of disconnecting faulty components or subsystems.

Protective relays can be used for types of protection other than short circuit or overcurrent. The relays can be designed to protect generating equipment and electrical circuits from any undesirable condition, such as undervoltage, underfrequency, or interlocking system lineups.

There are only two operating principles for protective relays: (1) electromagnetic attraction and (2) electromagnetic induction. Electromagnetic attraction relays operate by a plunger being drawn up into a solenoid or an armature that is attracted to the poles of an electromagnet. This type of relay can be actuated by either DC or AC systems. Electromagnetic induction relays operate on the induction motor principle whereby torque is developed by induction in a rotor. This type of relay can be used only in AC circuits.

Overlapping Protective Zones

A separate zone of protection is provided around each system element (Figure 2). Any failure that may occur within a given zone will cause the tripping or opening of all circuit breakers within that zone. For failures that occur within a region where two protective zones overlap, more breakers will be tripped than are necessary to disconnect the faulty component; however, if there were no overlap of protective zones, a fault in a region between the two zones would result in no protective action at all. Therefore, it is desirable for protective zone overlap to ensure the maximum system protection.
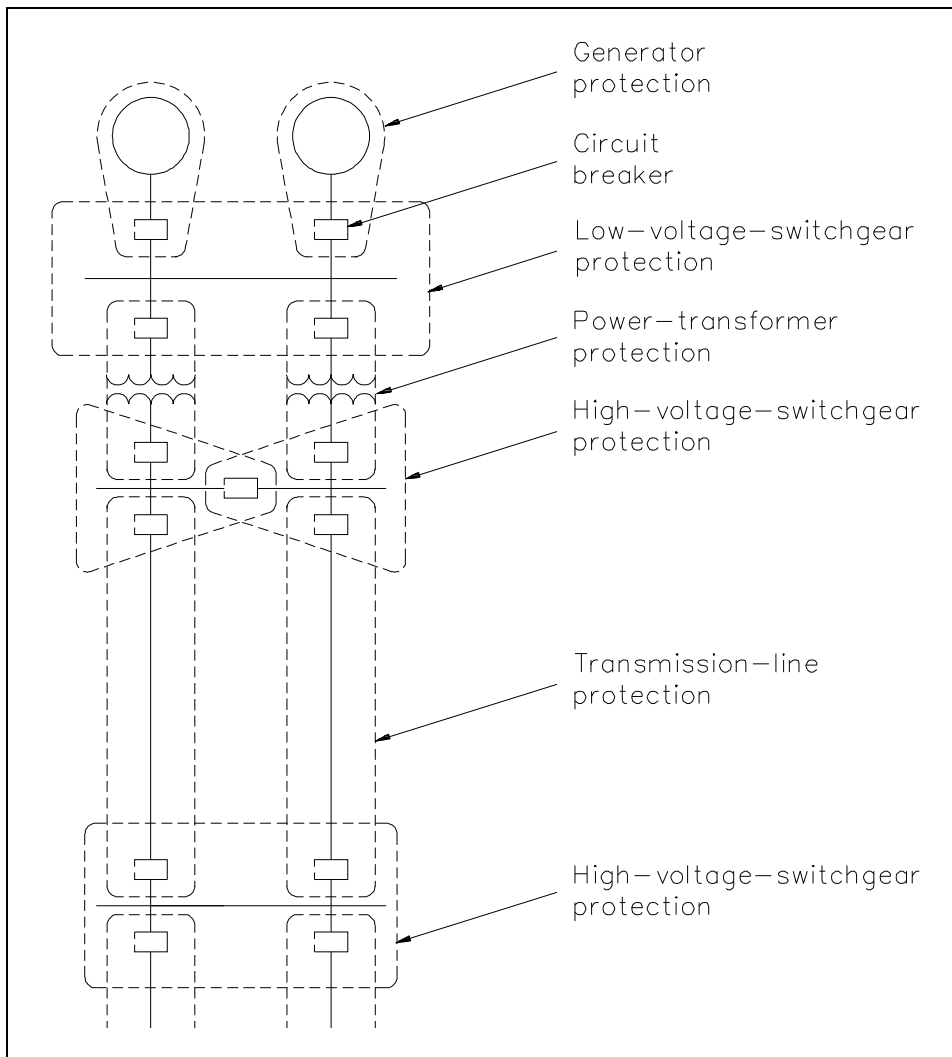

Figure 2   Protective Relaying Zones

Fuses

A fuse is a device that protects a circuit from an overcurrent condition only. It has a fusible link directly heated and destroyed by the current passing through it. A fuse contains a current-carrying element sized so that the heat generated by the flow of normal current through it does not cause it to melt the element; however, when an overcurrent or short-circuit current flows through the fuse, the fusible link will melt and open the circuit. There are several types of fuses in use (Figure 3).
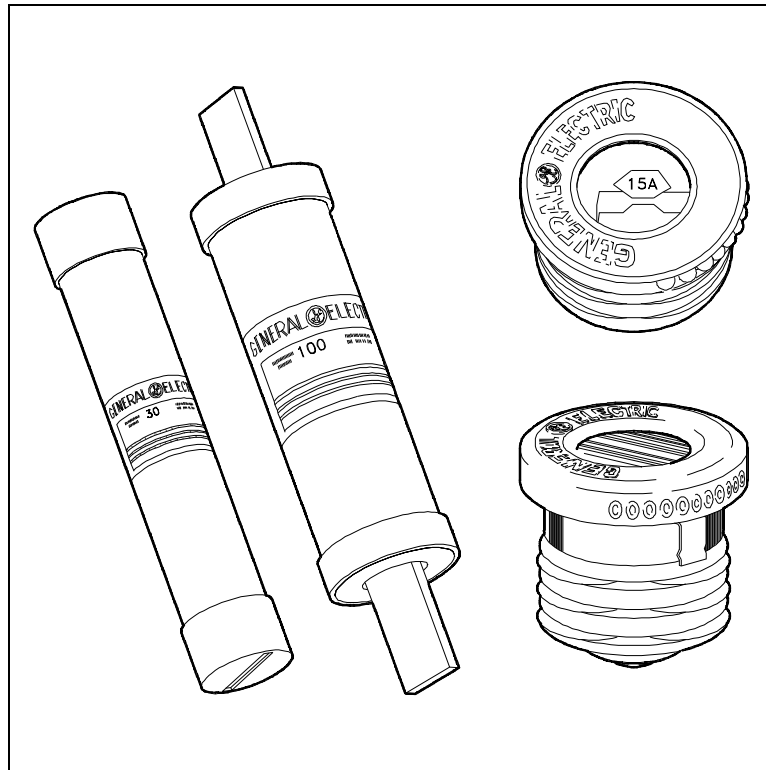

Figure 3   Types of Fuses

The plug fuse is a fuse that consists of a zinc or alloy strip, a fusible element enclosed in porcelain or pyrex housing, and a screw base. This type of fuse is normally used on circuits rated at 125 V or less to ground and has a maximum continuous current-carrying capacity of 30 amps.

The cartridge fuse is constructed with a zinc or alloy fusible element enclosed in a cylindrical fiber tube with the element ends attached to a metallic contact piece at the ends of the tube. This type of fuse is normally used on circuits rated at either 250 volts or 600 volts and has a maximum continuous current-carrying capacity of 600 amps.

<u>Summary</u>

The important information contained in this chapter is summarized below.

System Components and Protection Devices Summary

- Single (one-line) diagram - simple and easy to read diagram showing power supplies, loads, and major components in the distribution system

- Commercial or utility power - electric power supplied to the facility

- Diesel power - economical/practical source of standby power

- Failure-free power - power supplied to vital equipment with automatic switching so that interruption of power is minimized

- Neutral grounding - helps prevent accidents to personnel and damage to property by fire

- Voltage class - high voltage > 15,000 volts, intermediate voltage is 600-15,000 volts, low voltage ≤ 600 volts

- Protective relays - cause prompt removal of any part of a power system that suffers a short circuit

- Overlapping protective zones - created around each element of the power system to prevent element failure from interrupting the whole system operation

- Breakers - disconnect component from the power system

- Fuse - protects component from overcurrent

CIRCUIT BREAKERS

A circuit breaker is a device that is used to completely disconnect a circuit when any abnormal condition exists. The circuit breaker can be designed to actuate under any undesirable condition.

EO 1.3   **STATE the purpose of circuit breakers.**

EO 1.4   **Given a simple schematic of a circuit breaker control circuit, DESCRIBE the operation of that breaker during remote operation and automatic tripping.**

EO 1.5   **LIST the three most widely-used protective features that may be incorporated into a circuit breaker control circuit.**

Introduction

The purpose of a circuit breaker is to break the circuit and stop the current flow when the current exceeds a predetermined value without causing damage to the circuit or the circuit breaker. Circuit breakers are commonly used in place of fuses and sometimes eliminate the need for a switch. A circuit breaker differs from a fuse in that it "trips" to break the circuit and may be reset, while a fuse melts and must be replaced. Air circuit breakers (ACBs) are breakers where the interruption of the breaker contacts takes place in an air environment. Oil circuit breakers (OCBs) use oil to quench the arc when the breaker contacts open.

Low-Voltage Air Circuit Breakers

A low-voltage circuit breaker is one which is suited for circuits rated at 600 volts or lower. One of the most commonly used low-voltage air circuit breakers is the molded case circuit breaker (Figure 4).
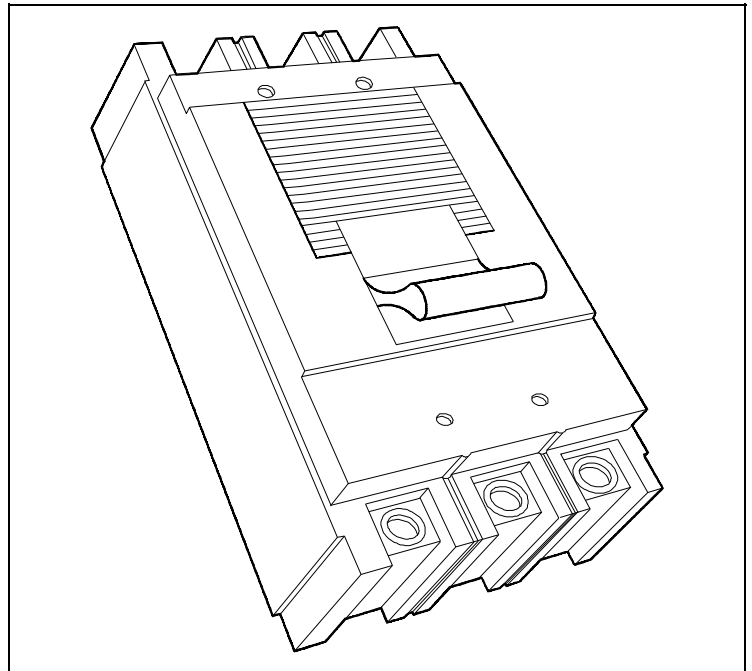
Figure 4   Molded Case Circuit Breaker

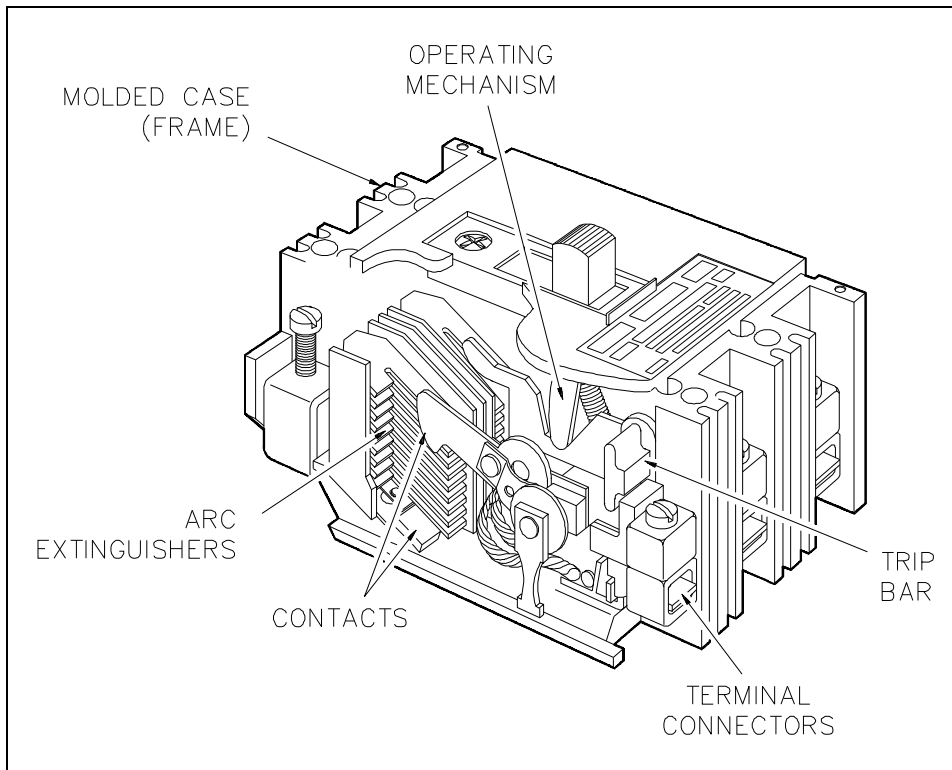A cutaway view of the molded case circuit breaker is shown in Figure 5.

Figure 5 Cutaway View of Molded Case Circuit Breaker

A circuit can be connected or disconnected using a circuit breaker by manually moving the operating handle to the ON or OFF position. All breakers, with the exception of very small ones, have a linkage between the operating handle and contacts that allows a quick make (quick break contact action) regardless of how fast the operating handle is moved. The handle is also designed so that it cannot be held shut on a short circuit or overload condition. If the circuit breaker opens under one of these conditions, the handle will go to the trip-free position. The trip-free position is midway between the ON and OFF positions and cannot be re-shut until the handle is pushed to the OFF position and reset.

A circuit breaker will automatically trip when the current through it exceeds a pre-determined value. In lower current ratings, automatic tripping of the circuit breaker is accomplished by use of thermal tripping devices. Thermal trip elements consist of a bimetallic element that can be calibrated so that the heat from normal current through it does not cause it to deflect. An abnormally high current, which could be caused by a short circuit or overload condition, will cause the element to deflect and trip the linkage that holds the circuit breaker shut. The circuit breaker will then be opened by spring action. This bimetallic element, which is responsive to the heat produced by current flowing through it, has an inverse-time characteristic. If an extremely high current is developed, the circuit breaker will be tripped very rapidly.

For moderate overload currents, it will operate more slowly. Molded case breakers with much larger current ratings also have a magnetic trip element to supplement the thermal trip element. The magnetic unit utilizes the magnetic force that surrounds the conductor to operate the circuit breaker tripping linkage.

When the separable contacts of an air circuit breaker are opened, an arc develops between the two contacts. Different manufacturers use many designs and arrangements of contacts and their surrounding chambers. The most common design places the moving contacts inside of an arc chute. The construction of this arc chute allows the arc formed as the contacts open to draw out into the arc chute. When the arc is drawn into the arc chute, it is divided into small segments and quenched. This action extinguishes the arc rapidly, which minimizes the chance of a fire and also minimizes damage to the breaker contacts.

Molded case circuit breakers come in a wide range of sizes and current ratings. There are six frame sizes available: 100, 225, 400, 600, 800, and 2,000 amps. The size, contact rating, and current interrupting ratings are the same for all circuit breakers of a given frame size. The continuous current rating of a breaker is governed by the trip element rating. The range of voltage available is from 120 to 600 volts, and interrupting capacity ranges as high as 100,000 amps.

Much larger air circuit breakers are used in large commercial and industrial distribution systems. These circuit breakers are available in much higher continuous current and interrupting ratings than the molded case circuit breaker. Breakers of this type have current ratings as high as 4,000 amps, and interrupting ratings as high as 150,000 amps.

Most large air circuit breakers use a closing device, known as a "stored energy mechanism," for fast, positive closing action. Energy is stored by compressing large powerful coil springs that are attached to the contact assembly of a circuit breaker. Once these springs are compressed, the latch may be operated to release the springs, and spring pressure will shut the circuit breaker. Circuit breaker closing springs may be compressed manually or by means of a small electric motor. This type of circuit breaker can be classified as either a manually- or electrically-operated circuit breaker.

When a large air circuit breaker is closed, the operating mechanism is latched. As the circuit breaker is closed, a set of tripping springs, or coils, are compressed, and the circuit breaker may then be tripped by means of a trip latch. The trip latch mechanism may be operated either manually or remotely by means of a solenoid trip coil.

As previously stated, circuit breakers may be operated either manually or electrically. Electrically-operated circuit breakers are used when circuit breakers are to be operated at frequent intervals or when remote operation is required.

When the electrically-operated stored energy circuit breaker is tripped, the spring is recharged by the spring charging motor so that the breaker is ready for the next closing operation. The manually-operated circuit breaker closing springs are normally compressed by a hand crank just prior to operation of the breaker. Figure 6 shows a large air circuit breaker which is classified as a manually-operated stored energy circuit breaker. The closing springs are compressed by pulling downward on the large operating handle on the front of the breaker. Closing this circuit breaker is accomplished manually by depressing the small closing lever. Tripping this circuit breaker is done by means of the tripping lever, located at the bottom front of the breaker.
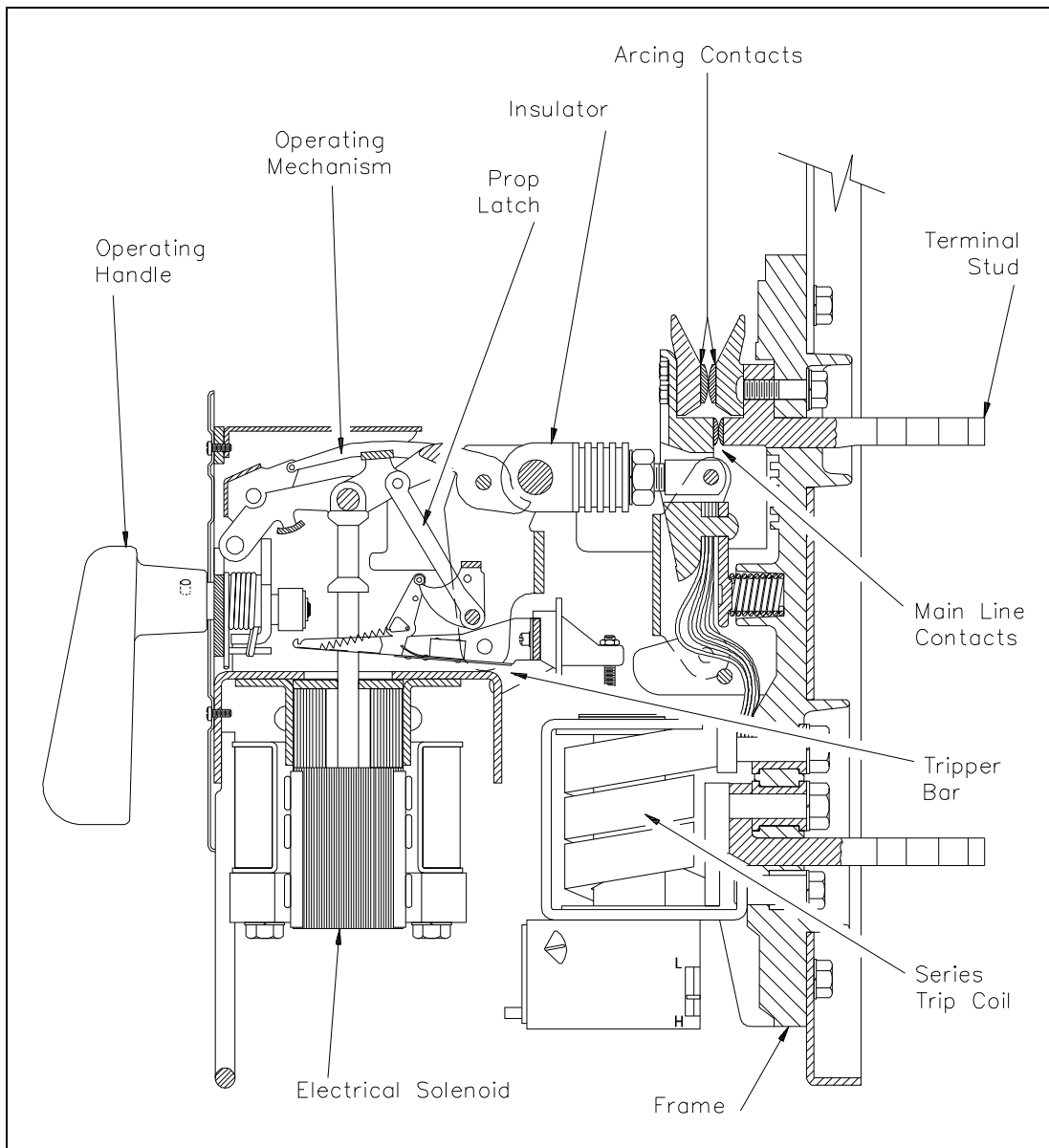
Figure 6 Large Air Circuit Breaker

High-Voltage Circuit Breakers

High-voltage circuit breakers (including breakers rated at intermediate voltage) are used for service on circuits with voltage ratings higher than 600 volts. Standard voltage ratings for these circuit breakers are from 4,160 to 765,000 volts and three-phase interrupting ratings of 50,000 to 50,000,000 kVA.

In the early stages of electrical system development, the major portion of high-voltage circuit breakers were oil circuit breakers. However, magnetic and compressed-air type air circuit breakers have been developed and are in use today.

The magnetic air circuit breaker is rated up to 750,000 kVA at 13,800 volts. This type of circuit breaker interrupts in air between two separable contacts with the aid of magnetic blowout coils. As the current-carrying contacts separate during a fault condition, the arc is drawn out horizontally and transferred to a set of arcing contacts. Simultaneously, the blowout coil provides a magnetic field to draw the arc upward into the arc chutes. The arc, aided by the blowout coil magnetic field and thermal effects, accelerates upward into the arc chute, where it is elongated and divided into many small segments.

The construction of this type of circuit breaker is similar to that of a large air circuit breaker used for low-voltage applications, except that they are all electrically operated.

Compressed-air circuit breakers, or air-blast circuit breakers, depend on a stream of compressed air directed toward the separable contacts of the breaker to interrupt the arc formed when the breaker is opened. Air-blast circuit breakers have recently been developed for use in extra high-voltage applications with standard ratings up to 765,000 volts.

Oil circuit breakers (OCBs) are circuit breakers that have their contacts immersed in oil. Current interruption takes place in oil which cools the arc developed and thereby quenches the arc. The poles of small oil circuit breakers can be placed in one oil tank; however, the large high-voltage circuit breakers have each pole in a separate oil tank. The oil tanks in oil circuit breakers are normally sealed. The electrical connections between the contacts and external circuits are made through porcelain bushings.

Circuit Breaker Control

As we have discussed, circuit breakers may be remotely operated. In order to operate the breakers from a remote location, there must be an electrical control circuit incorporated. Figure 7 shows a simple control circuit for a remotely-operated breaker.

Control power is supplied by an AC source and then rectified to DC. The major components of a simple control circuit are: the rectifier unit, the closing relay, the closing coil, the tripping coil, the auxiliary contacts, and the circuit breaker control switch.

CKT. BKR.

FUSE

CR — CLOSING RELAY
CC — CLOSING COIL
TC — TRIP COIL

"a" contact closes
"a" when breaker closes

"b" contact opens
"b" when breaker closes

CC

"b"   CR   • Close
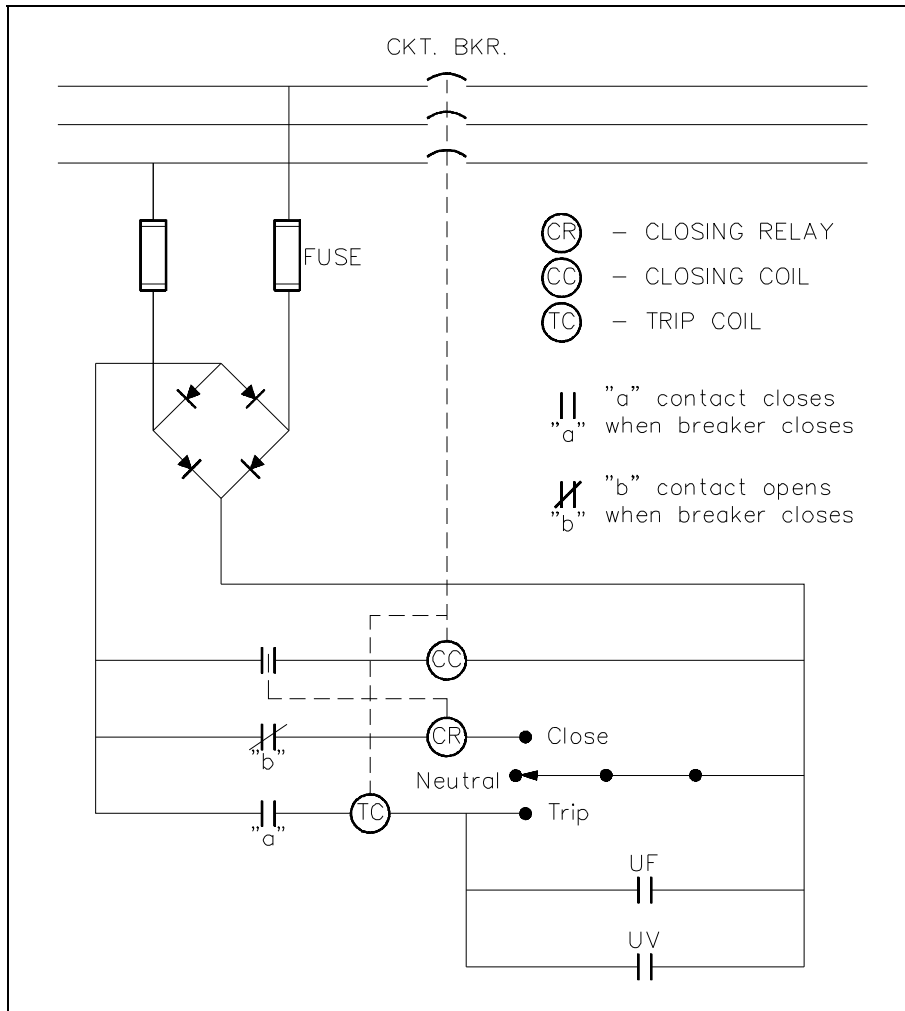
Neutral •

"a"   TC   • Trip

UF

UV

Figure 7   Simple Circuit Breaker Control Circuit -
Breaker Open

To close the remotely-operated circuit breaker, turn the circuit breaker control switch to the close position. This provides a complete path through the closing relay (CR) and energizes the closing relay. The closing relay shuts an auxiliary contact, which energizes the closing coil (CC), which, in turn, shuts the circuit breaker, as shown in Figure 8.   The breaker latches in the closed position.   Once the breaker is shut, the "b" contact associated with the closing relay opens, de-energizing the closing relay and, thereby, the closing coil. When the breaker closes, the "a" contact also closes, which enables the trip circuit for manual or automatic trips of the breaker. The circuit breaker control switch may now be released and will automatically return to the neutral position.

To open the circuit breaker, turn the circuit breaker control switch to the trip position.   This action energizes the trip coil (TC), which acts directly on the circuit breaker to release the latching mechanism that holds the circuit breaker closed.

When the latching mechanism is released, the circuit breaker will open, opening the "a" contact for the tripping coil and de-energizing the tripping coil. Also, when the circuit breaker opens, the "b" contact will close, thereby setting up the circuit breaker to be remotely closed using the closing relay, when desired. The circuit breaker control switch may now be released.
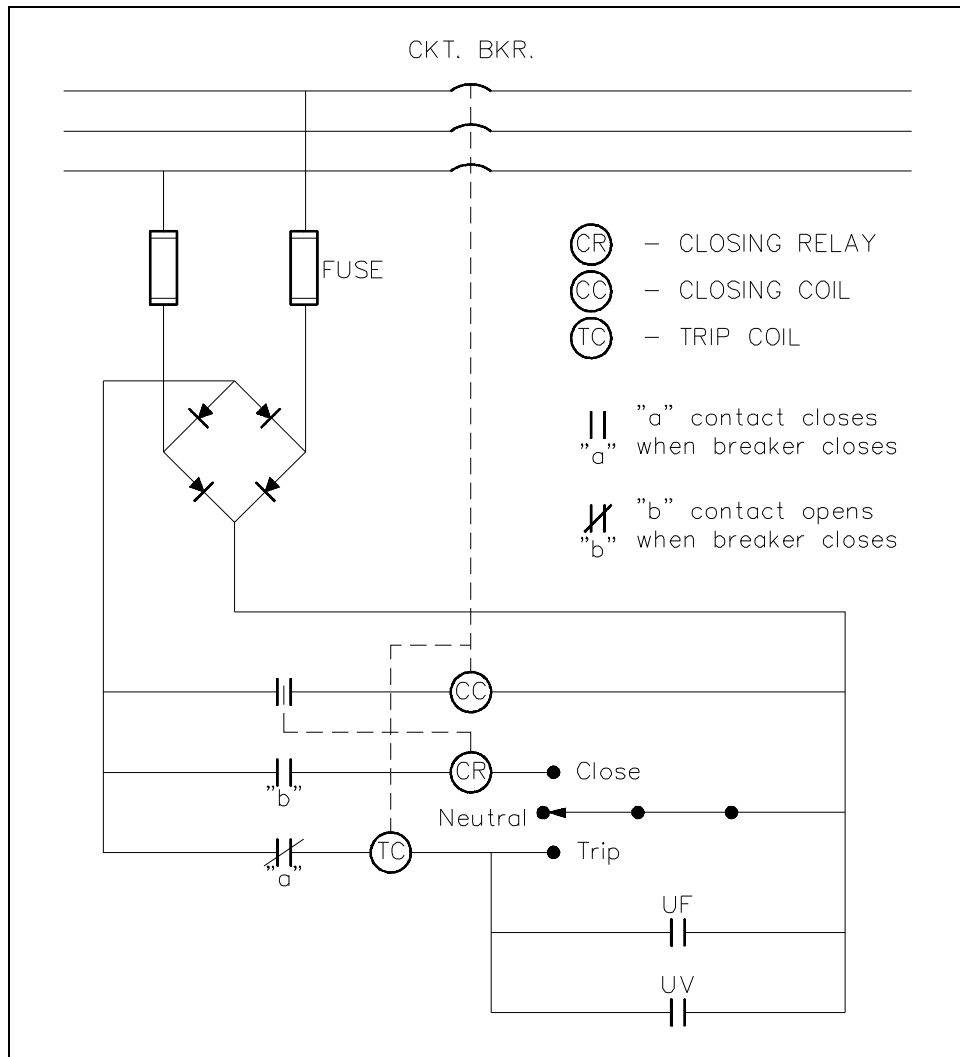

Figure 8 Simple Circuit Breaker Control Circuit
- Breaker Closed

As you can see from Figure 7 or 8, the circuit breaker control circuit can be designed so that any one of a number of protective features may be incorporated. The three most commonly-used automatic trip features for a circuit breaker are overcurrent (as discussed previously), underfrequency, and undervoltage. If any one of the conditions exists while the circuit breaker is closed, it will close its associated contact and energize the tripping coil, which, in turn, will trip the circuit breaker.

<u>Summary</u>

The important information covered in this chapter is summarized below.

Circuit Breaker Summary

- The purpose of a circuit breaker is to provide a means for connecting and disconnecting circuits of relatively high capacities without causing damage to them.

- The three most commonly-used automatic trip features for a circuit breaker are overcurrent, underfrequency, and undervoltage.

MOTOR CONTROLLERS

Motor controllers range from a simple toggle switch to a complex system using solenoids, relays, and timers. The basic functions of a motor controller are to control and protect the operation of a motor.

EO 1.6   **STATE the function of motor controllers.**

EO 1.7   **STATE three protective features (overloads) that may be incorporated into a motor controller.**

EO 1.8   **Given a simplified drawing of a motor controller, DESCRIBE the operation of that motor controller.**

Motor Controllers

Motor controllers range from a simple toggle switch to a complex system using solenoids, relays, and timers. The basic functions of a motor controller are to control and protect the operation of a motor. This includes starting and stopping the motor, and protecting the motor from overcurrent, undervoltage, and overheating conditions that would cause damage to the motor. There are two basic categories of motor controllers: the manual controller and the magnetic controller.

Manual Controllers

A manual controller, illustrated by Figure 9, is a controller whose contact assembly is operated by mechanical linkage from a toggle-type handle or a pushbutton arrangement. The controller is operated by hand.

The manual controller is provided with thermal and direct-acting overload units to protect the motor from overload conditions. The manual controller is basically an "ON-OFF" switch with overload protection.

Manual controllers are normally used on small loads such as machine tools, fans, blowers, pumps, and compressors. These types of controllers are simple, and they provide quiet operation. The contacts are closed simply by moving the handle to the "ON" position or pushing the START button. They will remain closed until the handle is moved to the "OFF" position or the STOP button is pushed. The contacts will also open if the thermal overload trips.

Manual controllers do NOT provide low voltage protection or low voltage release. When power fails, the manual controller contacts remain closed, and the motor will restart when power is restored. This feature is highly desirable for small loads because operator action is not needed to restart the small loads in a facility; however, it is undesirable for larger loads because it could cause a hazard to equipment and personnel.
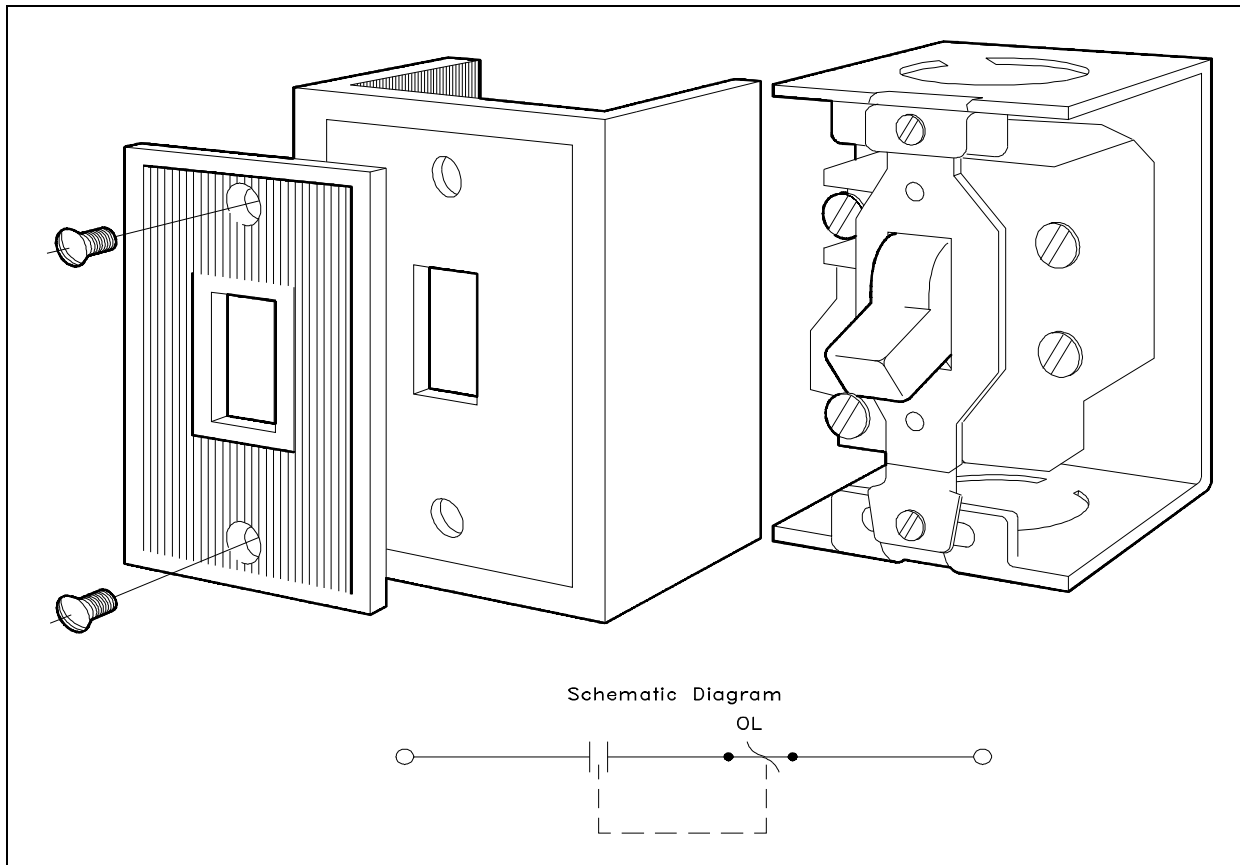
Figure 9   Single Phase Manual Controller

Magnetic Controller

A large percentage of controller applications require that the controller be operated from a remote location or operate automatically in response to control signals. As discussed, manual controllers cannot provide this type of control; therefore, magnetic controllers are necessary.

Basic operations using a magnetic controller, such as the closing of switches or contacts, are performed by magnetic contactors. A magnetic controller is one that will automatically perform all operations in the proper sequence after the closure of a master switch. The master switch (for example, float switch, pressure switch, or thermostat) is frequently operated automatically. But in some cases, such as pushbuttons, drum switches, or knife switches, the master switch is manually operated. Figure 10 shows a typical magnetic controller and its component parts.
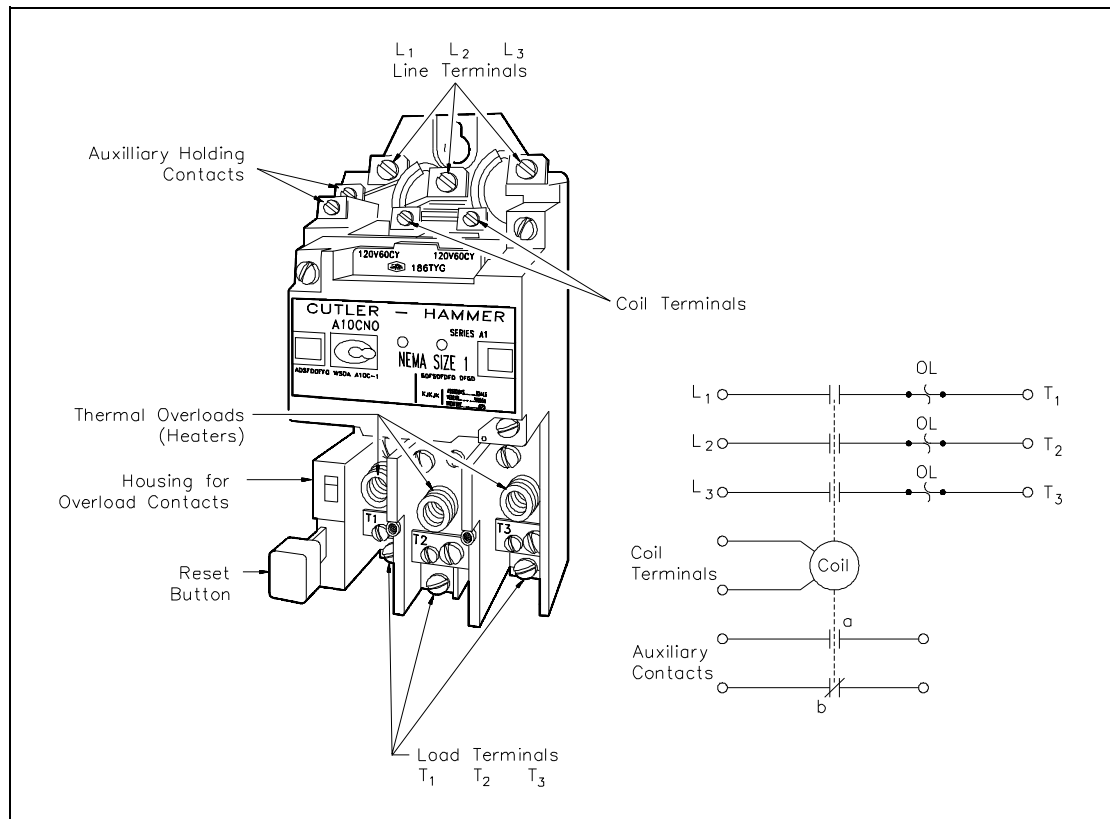
Figure 10   Typical Three-Phase Magnetic Controller

A magnetic contactor (Figure 11) is a device operated by an electromagnet.

The magnetic contactor consists of an electromagnet and a movable iron armature on which movable and stationary contacts are mounted. When there is no current flow through the electromagnetic coil, the armature is held away by a spring. When the coil is energized, the electromagnet attracts the armature and closes the electrical contacts.

Overload devices are incorporated into magnetic controllers. These overload devices protect the motor from overcurrent conditions that would be extremely harmful. There are many types and forms of overload devices. The following types of overload devices are commonly used in motor-control equipment.

• Fuses
• Thermal overloads
• Magnetic overloads

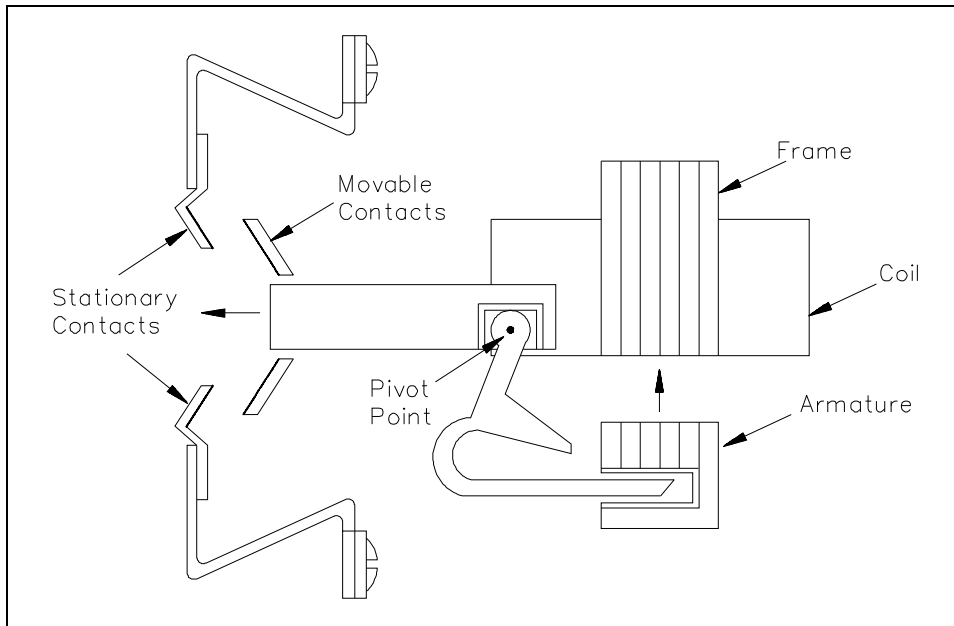The thermal overload device is shown in Figure 10.

Figure 11   Magnetic Contactor Assembly

Motor Controller Types and Operation

Within the two basic categories of motor controllers, there are three major types of AC across-the-line controllers in use today. There are low-voltage protection (LVP), low-voltage release (LVR), and low-voltage release effect (LVRE) controllers.

The main purpose of an LVP controller is to de-energize the motor in a low voltage condition and keep it from re-starting automatically upon return of normal voltage (Figure 12).

Figure 12   LVP Controller

LVP Controller Operation:

1.   Push the START button, which energizes contactor coil M, closing the M and M_a contacts. When the START button is released, the circuit will remain complete, because the M_a contact remains closed, shunting the open start switch.
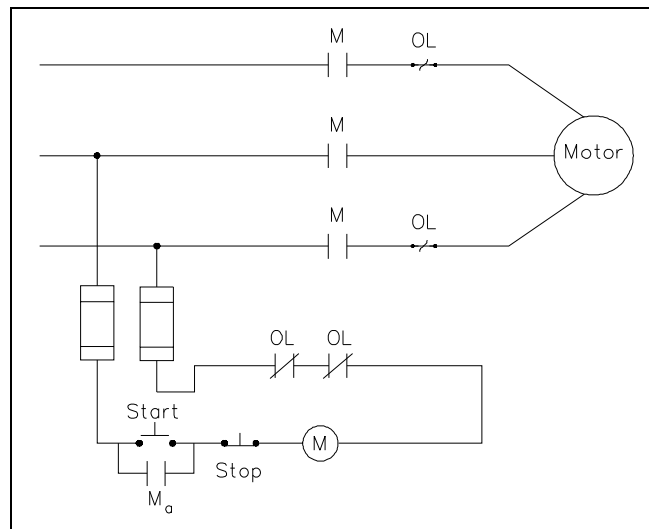
2.   When a low voltage condition occurs, the M coil will drop out at some pre-determined value of voltage, and the M and M_a contacts will open. The START button must then be pushed to restart the motor.

3.   Depressing the STOP button de-energizes the M coil, which then opens the M and M_a contacts.

The purpose of the LVR controller is to de-energize the motor in a low voltage condition and restart the motor when normal voltage is restored. This type of controller (Figure 13) is used primarily on small and/or critical loads (e.g., cooling water pumps required for safety-related equipment).
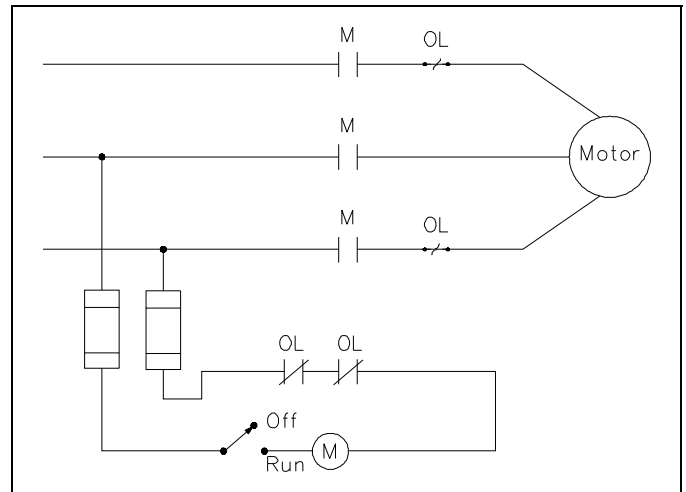
Figure 13   LVR Controller

LVR Controller Operation:

1.   Place the START switch in Run which energizes coil M, closing the M contacts and starting the motor.

2.   When a low voltage condition occurs, the M coil drops out, opening the M contacts and de-energizing the motor. When normal voltage is restored, the M coil is again energized, closing the M contacts and restarting the motor.
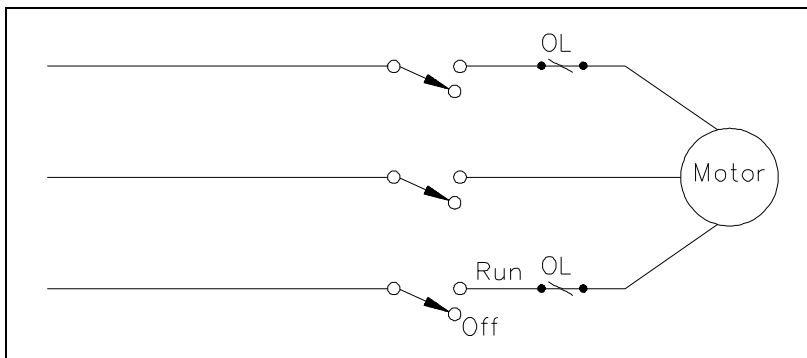
Figure 14   LVRE Controller

The LVRE controller maintains the motor across the line at all times. This type of controller is of the manual variety and is found mostly on small loads that must start automatically upon restoration of voltage (Figure 14). An LVRE controller may or may not contain overloads. If overloads are used, they will be placed in the lines to the load.

The motor controllers that have been discussed are very basic. There are many automatic control functions that can be incorporated into these types of controllers, but they are beyond the scope of this text.

Summary

The important information contained in this chapter is summarized below.

Motor Controllers Summary

• Motor controller - controls and protects the operation of a motor

• Controller's protective features - fuses, thermal overloads, and magnetic overloads

• LVP - de-energizes motor on low voltage and keeps it from automatically restarting

• LVR - de-energizes motor on low voltage and restarts when the voltage is restored to normal

• LVRE - maintains motor across the line at all times

WIRING SCHEMES AND GROUNDING

Nuclear facilities rely on standardized wiring schemes to provide both single-phase and three-phase power distribution systems and protective grounds to insure safe operation.

EO 1.9   **DEFINE the following terms as they apply to wiring schemes used in power distribution systems:**
a.   **Ampacity**
b.   **Bond**
c.   **Conductor**
d.   **Ground**
e.   **Ground voltage**
f.   **Leg**
g.   **Neutral**
h.   **Phase voltage**

EO 1.10   **DESCRIBE the two methods of connecting single-phase loads to a three-phase power source.**

EO 1.11   **DESCRIBE the purpose of the following power distribution schemes.**
a.   **3-wire, single-phase Edison system**
b.   **3-wire, three-phase Delta system**
c.   **4-wire, three-phase Delta system**
d.   **4-wire, three-phase Wye system**

Introduction

Many advisory boards exist to insure the standardization of electrical installations in accordance with accepted designs and safe practices. The Institute of Electrical and Electronics Engineers (IEEE) and the American National Standards Institute (ANSI) are two advisory boards that have published numerous standards. These standards are utilized by the Department of Energy and the nuclear industry.   However, for a day-to-day practical guide for noncritical installations, the recognized guide is the National Electrical Code Handbook (NEC), published by the National Fire Protection Association and endorsed by ANSI. The NEC Handbook is the primary source of much of the material presented in this chapter and may serve as a ready reference for specific questions not covered in this fundamental discussion.

Terminology

To understand wiring schemes used in power distribution systems, you must be familiar with the following terms.

- *Ampacity* - the current in amperes that a conductor can carry continuously under the conditions of use without exceeding its temperature rating.

- *Bond* - the permanent joining of metallic parts or circuits assuring electrical continuity and capacity to safely conduct any current likely to be imposed.

- *Conductor* - any wire, cable, or substance capable of carrying an electrical current.

- *Ground* - a conducting connection, whether intentional or accidental, between a circuit or piece of equipment and the earth, or some body serving as earth; a place of zero electrical potential.

- *Ground voltage* - the voltage between any given conductor and any point at ground potential.

- *Leg* - a current-carrying conductor intended to deliver power to or from a load normally at an electrical potential other than ground.

- *Neutral* - a current-carrying conductor normally tied to ground so that the electrical potential is zero.

- *Phase voltage* - the greatest root mean square (effective) difference of potential between any two legs of the circuit.

Single-Phase Power

The source of single-phase (1ϕ) power in all facilities is by generation from a single-phase generator or by utilization of one phase of a three-phase (3ϕ) power source. Basically, each phase of the 3ϕ distribution system is a single-phase generator electrically spaced 120 degrees from the other two; therefore, a 3ϕ power source is convenient and practical to use as a source of single-phase power.

Single-phase loads can be connected to three-phase systems utilizing two methods. The diagram shown in Figure 15 illustrates these connections.
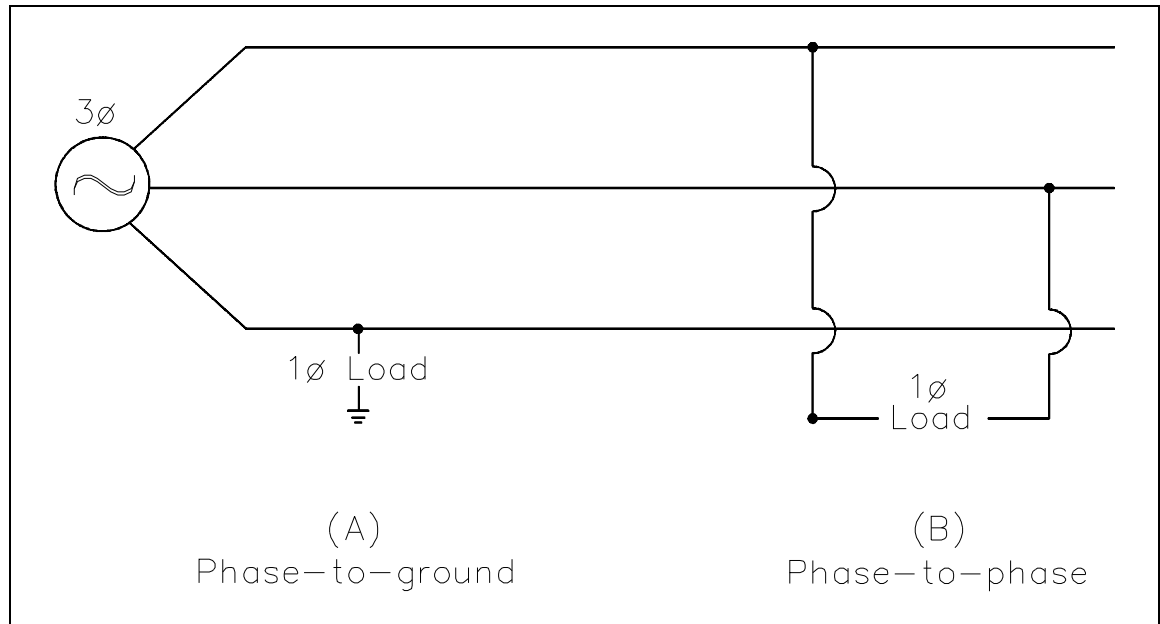
Figure 15   Three-Phase To Single-Phase Connections

The first scheme (Figure 15A) provides for the connection of the load from a phase leg to any ground point and is referred to as a phase-to-ground scheme. The remaining scheme (Figure 15B) connects the single-phase load between any two legs of the three-phase source and is referred to as a phase-to-phase connection. The choice of schemes, phase-to phase or phase-to-ground, allows several voltage options depending on whether the source three-phase system is a delta or wye configuration. This will be discussed in the three-phase segment of this chapter.

The only approved method of wiring single-phase power is the scheme commonly referred to as the 3-wire, single-phase Edison system. The illustration in Figure 16 depicts the use of a center-tapped transformer, with the center tap grounded, providing half voltage (120 V) connections on either side or full voltage (240 V) across both sides.
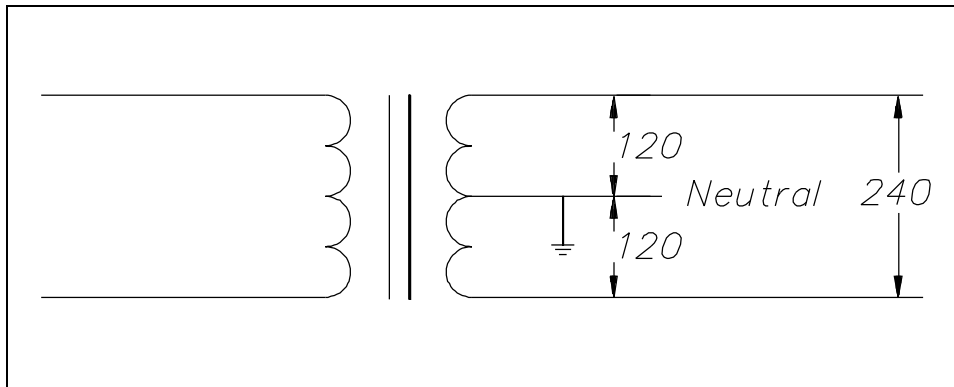
Figure 16   3-Wire Edison Scheme

The physical connections to the transformer secondary involve two insulated conductors and one bare conductor. If the conductor is a current-carrying leg or neutral leg, the conductor will be insulated. The remaining uninsulated conductor will serve as a safety ground and will be bonded to the ground point of the system. In all cases, 3 wires will be presented to the load terminals, and the safety ground will be bonded to each junction box, or device, in the distribution system. In the case of half voltage (120 V) use, the intended path of the current is from the supply leg through the load and back to the source on the neutral leg. No current would be carried on the ground unless a fault occurred in the system, in which case the current would flow safely to ground.

In the full voltage system (240 V), the insulated conductors are connected across the full winding of the transformer, and the uninsulated conductor is again bonded to the grounded center tap. In a balanced system, all currents will flow on the insulated conductors, and the grounded neutral will carry no current, acting only in a ground capacity. In the case of either an unbalanced load or a fault in the system, the bare conductor will carry current, but the potential will remain at zero volts because it is tied to the ground point. As in the case of the half voltage system, the uninsulated conductor will be bonded to each device in the system for safety.

Three-Phase Wiring Schemes

Unlike the single-phase wiring scheme that must make a provision for a neutral leg and separate ground, the three-phase system needs neither a separate neutral nor a ground to operate safely. However, to prevent any unsafe condition, all 3- and 4-wire, three-phase systems can include an effective ground path. As with the previous single-phase discussion, only the secondary side of the transformer and its connected load need to be studied.

3-Wire, Three-Phase Delta System

The simplest three-phase system is the 3-wire Delta configuration, normally used for transmission of power in the intermediate voltage class from approximately 15,000 volts to 600 volts. The diagram in Figure 17 depicts the two methods of connecting the Delta secondary.

The upper diagram depicts the ungrounded Delta, normally confined to protected environments such as fully enclosed ducts or overhead transmission lines that cannot be reached without extraordinary means. Each conductor's ground voltage is equal to the full phase voltage of the system.

The lower diagram shows a ground point affixed to one corner of the Delta, which effectively lowers one phase's voltage reference to ground to zero, but retains a phase-to-phase voltage potential. The corner-grounded phase acts in much the same way as the grounded neutral of the single-phase Edison system, carrying current and maintaining ground potential.

The corner-grounded Delta system has an obvious economy in wiring costs, and the grounded phase can be used to physically protect the other two phases from accidental grounding or lightning strikes in outdoor settings. This system is rarely used for low voltage (under 600 V), however, because of the absence of a safety ground required by many facilities for circuits involving potential worker contact.

Figure 17   3-Wire, Three-Phase Delta Scheme

4-Wire, Three-Phase Delta System

The 4-wire, three-phase Delta system combines the ungrounded Delta discussed above for three-phase loads with the convenience of the Edison system for single-phase loads. As depicted in the example illustration in Figure 18, one side of the Delta has a grounded-neutral conductor connected to a center tap winding on one phase.
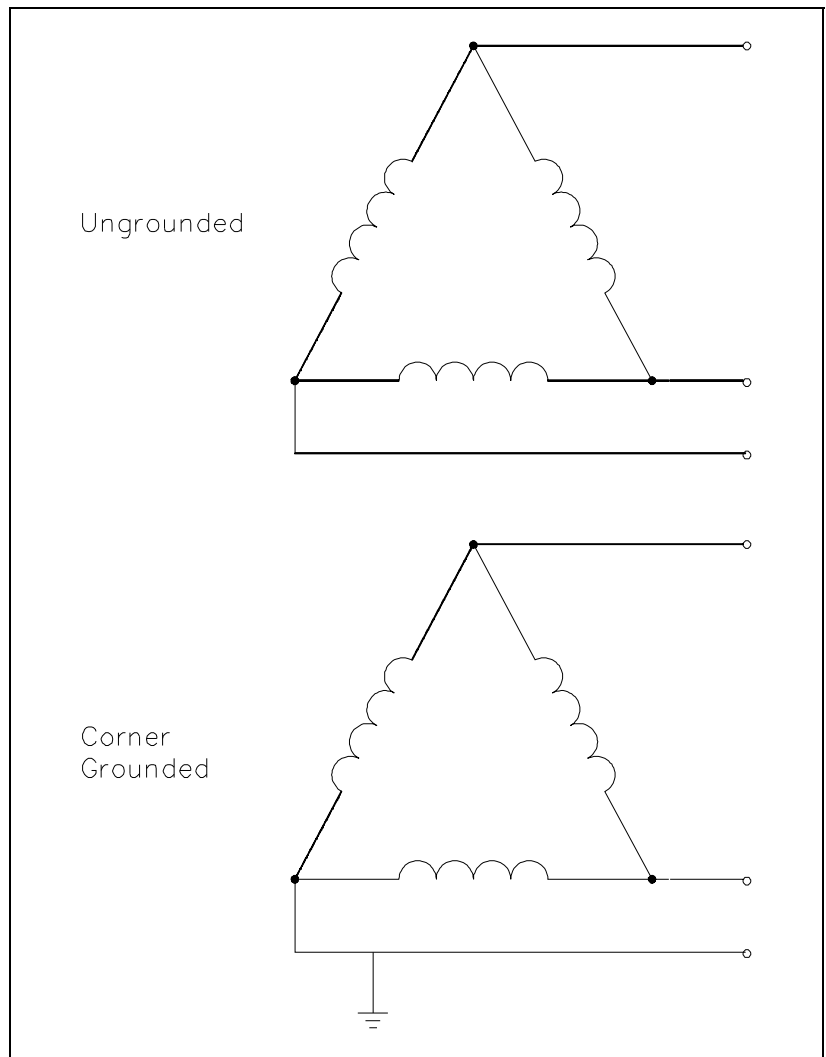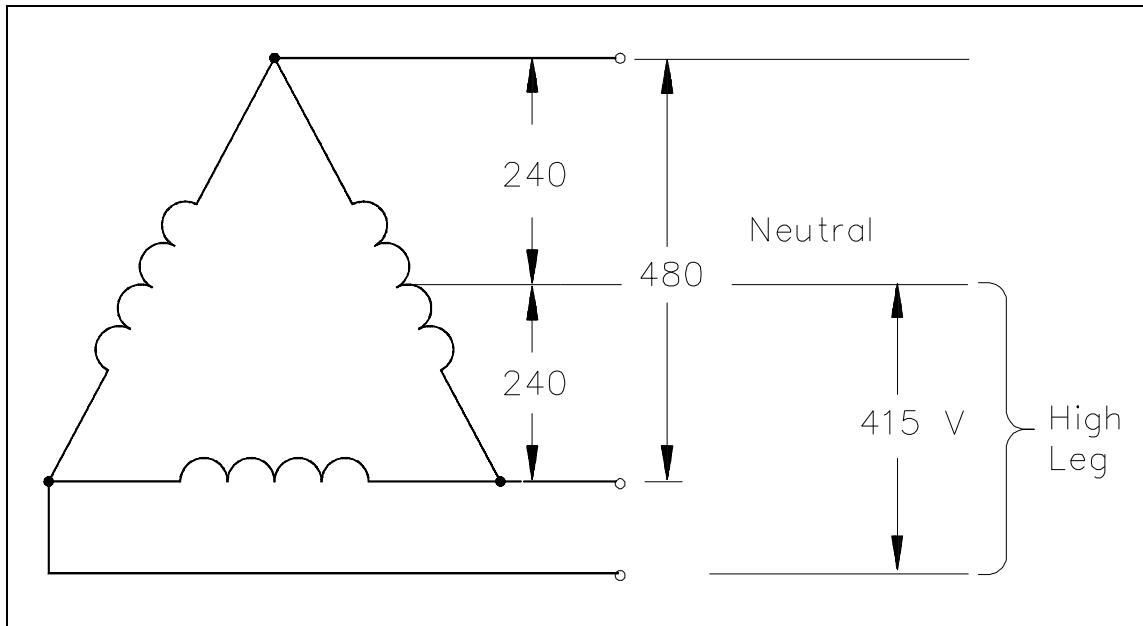
Figure 18   4-Wire Delta System

The single-phase voltage on each side of the half-tap is one-half the voltage available in the normal phase-to-phase relationship. This provides the same half- or full-voltage arrangement seen in the normal Edison scheme with a grounded neutral. Notice also that the legs coming from the corners of the Delta would have a normal ungrounded appearance if it were not for the center tap of one phase. Thus, at any given location in the system, either three-phase power at full voltage or single-phase power with half or full voltage is equally possible. However, there are several strict precautions that must be observed in the operation of this system. First, all loads must be carefully balanced on both the single-phase and three-phase legs. Second, because the voltage between one leg and the grounded neutral is considerably higher than the rest of the single-phase system, a measurement between the neutral and the phase must be taken to identify the "high leg," or "bastard voltage." Last, the "high leg" is never used as a single-phase source because no ground or grounded neutral exists for this circuit.

<u>4-Wire, Three-Phase Wye System</u>

Until now, the voltage, the phase voltage, and the ground voltage of the three-phase systems have been equal, with the one exception of one phase of the corner-grounded Delta. The Wye system has completely different voltage characteristics from the Delta system. In the Wye system, the ground voltage or voltage available from phase to ground is the phase voltage divided by 1.73.

In Figure 19, an example of the Wye system, or center-grounded Wye as it is commonly referred to, extends three current-carrying insulated conductors and an insulated grounded neutral to the loads. Depending on the selection of conductors, one of the following is available: a reduced-voltage single phase between a phase leg and the neutral; a full-voltage single-phase circuit between any two phase legs; or a full-voltage three-phase power. Again, some precautions must be taken when balancing the single-phase loads in the system. The full load ampacity of the neutral must be sized to 1.73 times the highest phase ampacity. This is done to avoid either an over-current condition if a fault is present or the operation of single-phase loads at reduced voltage if the loads become severely unbalanced by accidental interruption.
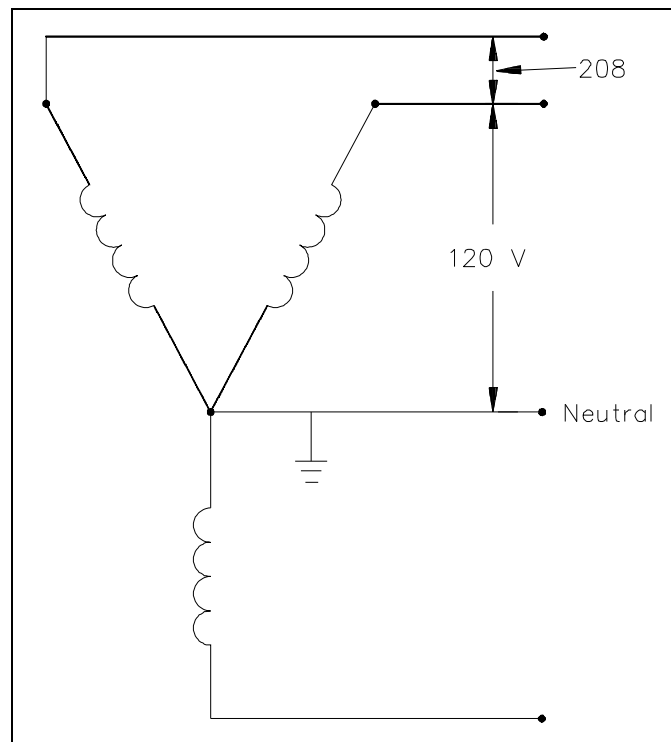

Figure 19   4-Wire, Three-Phase Wye System

As with all other grounded systems, bonds are established between the grounded neutral and all components of the system. This system is recognized as the safest possible multi-purpose distribution system for low voltage and is commonly seen in the 208/120-volt range in many facilities.

<u>Summary</u>

The important information in this chapter is summarized on the following page.

Wiring Schemes And Grounding Summary

Terminology

Ampacity - current-carrying capacity of a conductor in amperes

Bond - permanent joining of metallic parts or circuits assuring electrical continuity

Conductor - any wire, cable, or substance capable of carrying an electrical current

Ground - a conducting connection between a circuit or piece of equipment and the earth, or some body serving as earth

Ground voltage - the voltage between any given conductor and any point at ground potential

Leg - a current-carrying conductor intended to deliver power to or from a load

Neutral - a current-carrying conductor intended to deliver power to or from a load normally at an electrical potential other than ground

Phase voltage - the greatest root mean square (effective) difference of potential between any two legs of the circuit

Two methods to connect single-phase loads to a three-phase system are:
Phase-to-phase
Phase-to-ground

The purposes of the following wiring schemes are:
3-wire, single-phase Edison system - the only approved method of wiring single-phase power

3-wire, three-phase Delta system - normally used for transmission of power in the intermediate voltage class from approximately 15,000 volts to 600 volts

4-wire, three-phase Delta system - combines the ungrounded Delta for three-phase loads with the convenience of the Edison system for single-phase loads

4-wire, three-phase Wye system - the safest possible multi-purpose distribution system for low voltage