THIRD EDITION

Electric Motors and Control Systems

Mc Graw Hill

Frank D. **Petruzella**

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ABOUT THE AUTHOR

Frank D. Petruzella has extensive practical experience in the electrical motor control field, as well as many years of experience teaching and authoring textbooks. Before becoming a full-time educator, he was employed as an apprentice and electrician in areas of electrical installation and maintenance. He holds a Master of Science degree from Niagara University, a Bachelor of Science degree from the State University of New York College–Buffalo, as well as diplomas in Electrical Power and Electronics from the Erie County Technical Institute.

One unique feature with all of his texts is that they are all supported with the latest in related computer simulation software. Working in conjunction with National Instruments for Multisim, CMH Software for Constructor, and The Learning Pit for LogixPro, he has developed program files directly related to circuits explained in the text.

BRIEF CONTENTS

CONTENTS

Chapter 5
Electric Motors 105

Chapter 6
Contactors and Motor Starters 158

Chapter 7
Relays 186

Chapter 8
Motor Control Circuits 211

Chapter 9
Motor Control Electronics 245

Chapter 10
Adjustable-Speed Drives and PLC Installations 275

This book has been written for a course of study that will introduce the reader to a broad range of motor types and control systems. It provides an overview of electric motor operation, selection, installation, control, and maintenance. Every effort has been made to present the most up-to-date information, reflecting the current needs of the industry.

The broad-based approach taken makes this text viable for a variety of motor and control system courses. Content is suitable for colleges, technical institutions, and vocational/technical schools as well as apprenticeship and journeymen training. Electrical apprentices and journeymen will find this book to be invaluable because of National Electrical Code references as well as information on maintenance and troubleshooting techniques. Personnel involved in motor maintenance and repair will find the book to be a useful reference text.

The text is comprehensive! It includes coverage of how motors operate in conjunction with their associated control circuitry. Both older and newer motor technologies are examined. Topics covered range from motor types and controls to installing and maintaining conventional controllers, electronic motor drives, and programmable logic controllers.

Features you will find unique to this motors and controls text include:

Self-Contained Chapters. Each chapter constitutes a complete and independent unit of study. All chapters are divided into parts designed to serve as individual lessons. Instructors can easily pick and choose chapters or parts of chapters that meet their particular curriculum needs.

How Circuits Operate. When understanding the operation of a circuit is called for, a bulleted list is used to summarize its operation. The lists are used in place of paragraphs and are especially helpful for explaining the sequenced steps of a motor control operation.

Integration of Diagrams and Photos. When the operation of a piece of equipment is illustrated by means of a diagram, a photo of the device is included. This feature is designed to increase the level of recognition of devices associated with motor and control systems.

Troubleshooting Scenarios. Troubleshooting is an important element of any motors and controls course. The chapter troubleshooting scenarios are designed to help students with the aid of the instructor to develop a systematic approach to troubleshooting.

Discussion and Critical Thinking Questions. These open-ended questions are designed to give students an opportunity to reflect on the material covered in the chapter. In most cases, they allow for a wide range of responses and provide an opportunity for the student to share more than just facts.

The following content has been added to the chapters listed below:

Chapter 1
- Safety light curtains
- Safety interlock switches
- Emergency stop controls
- Safety laser scanners

Chapter 2
- Comparison of common motor NEMA and IEC symbols
- Riser diagrams
- Dual voltage three-phase motor connections
- IEC three-phase motor connections
- IEC 2-wire and 3-wire control circuits

Chapter 3
- Motor control center three-phase full-voltage starter bucket
- Electrical grounding
- Transformer testing

Chapter 4
- IEC break-make pushbutton control circuit
- Two motor emergency stop control circuit
- Signal light towers
- Alternating pumping operation and control circuit
- Comparison of the features and application of sensors

Chapter 5
- DC brushless motor operation and applications

Chapter 6 - Capacitor switching contactor operation and applications
- DC inverter power contactors

Chapter 7 - Interposing relay operation and applications
- Analog-switching relay operation and applications
- Conveyor motor warning signal control circuit
- Timed and instantaneous relay timer contacts
- One-shot timer solenoid control circuit
- Symmetrical recycle timer flasher circuit

Chapter 8 - Three motor sequential motor starting interlocking circuit.
- Two motor sequential motor stopping interlocking circuit.
- Three-phase motor selector jogging circuit.
- Zero-speed switch operation.
- Antiplugging executed using time-delay relays.

Chapter 9 - Inverter applications and output waveforms.
- Building blocks of an electronic motor control system.
- Three-wire sourcing and sinking sensor connections.

Chapter 10- Analog versus digital signals.
- 4–20 mA control loop.
- PLC processor module troubleshooting.
- PLC input module troubleshooting.
- PLC output module troubleshooting.

Ancillaries

- **Activities Manual for *Electric Motors and Control Systems.*** This manual contains quizzes, practical assignments, and computer-generated simulated circuit analysis assignments.

  Quizzes made up of multiple choice, true/false, and completion-type questions are provided for each part of each chapter. These serve as an excellent review of the material presented.

  Practical assignments are designed to give the student an opportunity to apply the information covered in the text in a hands-on motor installation.

  The Constructor motor control simulation software is included as part of the manual. This special edition of the program contains preconstructed simulated motor control circuits constructed using both NEMA and IEC symbols. The constructor analysis assignments provide students with the opportunity to test the motor control circuits discussed in the text. The constructor simulation engine visually displays power flow to each component and using animation and sound effects; each component will react accordingly once power is supplied.

  The constructor troubleshooting mode includes a Test Probe that provides an indication of power or continuity. The test probe leads are inserted into the circuit to determine common preprogrammed motor faults.

- **Instructor's Resources** are available to instructors who adopt *Electric Motors and Control Systems*. They can be found on the Instructor Library on Connect and include:

  Answers to the textbook review questions and the Activities Manual quizzes and assignments.

  PowerPoint presentations that feature enhanced graphics along with explanatory text.

  Instructional videos for text motor control circuits.

ACKNOWLEDGMENTS

The efforts of many people are needed to develop and improve a text. Among these people are the reviewers and consultants who point out areas of concern, cite areas of strength, and make recommendations for change. In particular, I would like to acknowledge Don Pelster of Nashville Community College. Don has done an impeccable job of performing a technical edit of the text as well as all the additional Instructor resources.

E*lectric Motors and Control Systems,* **3e contains the most up-to-date information on electric motor operation, selection, installation, control, and maintenance. The text provides a balance between concepts and applications to offer students an accessible framework to introduce a broad range of motor types and control systems.**

Electric Motors and Control Systems provides . . .

CHAPTER OBJECTIVES provide an outline of the concepts that will be presented in the chapter. These objectives provide a roadmap to students and instructors on what new material will be presented.

CHAPTER OBJECTIVES

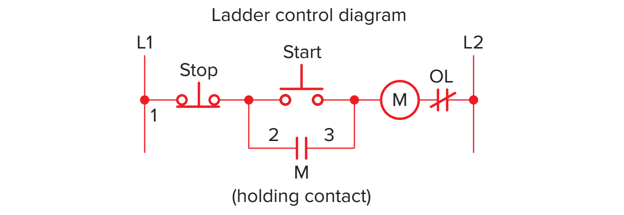
This chapter will help you:

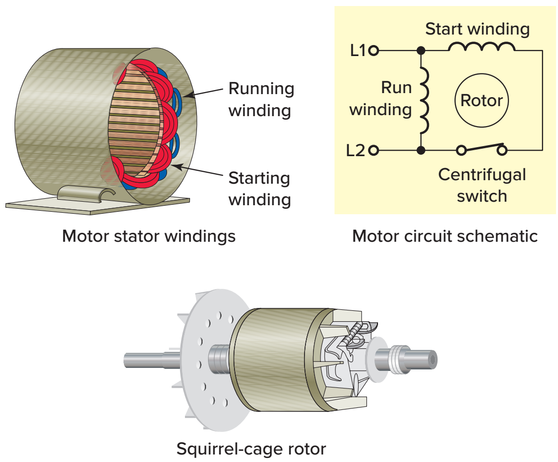
- Recognize symbols frequently used on motor and control diagrams.
- Differentiate between NEMA and IEC motor control symbols.
- Interpret and construct ladder diagrams.
- Interpret wiring, single-line, and block diagrams.
- Explain the terminal connections for different types of motors.
- Interpret connection schemes used for dual-voltage three-phase motors.
- Interpret information found on motor nameplates.
- Explain the terminology used in motor circuits.

CIRCUIT LISTS When a new operation of a circuit is presented, a bulleted list is used to summarize the operation. The lists are used in place of paragraphs to provide a more accessible summary of the necessary steps of a motor control operation.

The operation of the circuit can be summarized as follows:

- Three-wires are run from the start/stop pushbutton station to the starter.
- When the momentary-contact start button is closed, line voltage is applied to the starter coil to energize it.
- The three main M contacts close to apply voltage to the motor.





Motor stator windings

Motor circuit schematic

Squirrel-cage rotor

DIAGRAMS AND PHOTOS When the operation of a piece of equipment is illustrated, a photo of the device is included. The integration of diagrams and photos increases the students' recognition of devices associated with motor and control systems.

an engaging framework in every chapter to help students master concepts and realize success beyond the classroom.

REVIEW QUESTIONS Each chapter is divided into parts designed to represent individual lessons. These parts provide professors and students the flexibility to pick and choose topics that best represent their needs. Review questions follow each part to reinforce the new concepts that have been introduced.

Part 1 Review Questions

1. Does the severity of an electric shock increase or decrease with each of the following changes?
   a. A decrease in the source voltage
   b. An increase in body current flow
   c. An increase in body resistance
   d. A decrease in the length of time of exposure
2. **a.** Calculate the theoretical body current flow (in amperes and milliamperes) of an electric shock victim who comes in contact with a 120 V energy source. Assume a total resistance of 15,000 Ω (skin, body, and ground contacts).
   b. What effect, if any, would this amount of current likely have on the body?
3. Normally a 6 volt lantern battery capable of delivering 2 A of current is considered safe to handle. Why?
4. Why is AC of a 60 Hz frequency considered to be potentially more dangerous than DC of the same voltage and current value?
5. What circuit fault can result in an arc flash?
8. State the piece of electrical safety equipment that should be used to perform each of the following tasks:
   a. A switching operation where there is a risk of injury to the eyes or face from an electric arc.
   b. Using a multimeter to verify the line voltage on a three-phase 480 volt system.
   c. Opening a manually operated high-voltage disconnect switch.
9. Outline the safety procedure to follow when you are connecting shorting probes across de-energized circuits.
10. List three pieces of personal protection equipment required to be worn on most job sites.
11. Explain the way in which safety light curtains operate.
12. **a.** Describe a typical example of point of operation light curtain control.
    b. Describe a typical example of perimeter access light curtain control.
13. What type of safety switch is used to monitor the

TROUBLESHOOTING SCENARIOS These scenarios are designed to help students develop a systematic approach to troubleshooting that is vital in this course.

Troubleshooting Scenarios

1. Heat is the greatest enemy of a motor. Discuss in what way nonadherence to each of the following motor nameplate parameters could cause a motor to overheat: (*a*) voltage rating; (*b*) current rating; (*c*) ambient temperature; (*d*) duty cycle.
2. Two identical control relay coils are incorrectly connected in series instead of parallel across a 230 V source. Discuss how this might affect the operation of the circuit.
3. A two-wire magnetic motor control circuit controlling a furnace fan uses a thermostat to automatically operate the motor on and off. A single-pole switch is to be installed next to the remote thermostat and wired so that, when closed, it will override the automatic control and allow the fan to operate at all times regardless of the thermostat setting. Draw a ladder control diagram of a circuit that will accomplish this.
4. A three-wire magnetic motor control circuit uses a remote start/stop pushbutton station to operate the motor on and off. Assume the start button is pressed but the starter coil does not energize. List the possible causes of the problem.
5. How is the control voltage obtained in most motor control circuits?
6. Assume you have to purchase a motor to replace the one with the specifications shown below. Visit the website of a motor manufacturer and report on the specifications and price of a replacement motor.

Horsepower	10
Voltage	200
Hertz	60
Phase	3
Full-load amperes	33
RPM	1725
Frame size	215T
Service factor	1.15
Rating	40C AMB-CONT
Locked rotor code	J
NEMA design code	B
Insulation class	B
Full-load efficiency	85.5
Power factor	76
Enclosure	OPEN

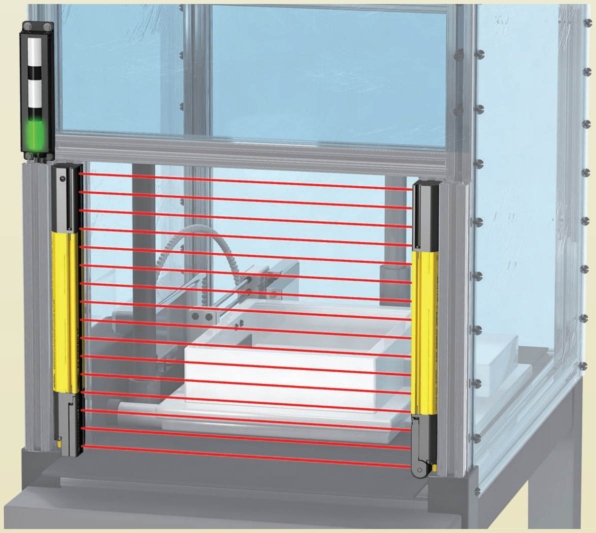
DISCUSSION TOPICS AND CRITICAL THINKING QUESTIONS These open-ended questions are designed to give students an opportunity to review the material covered in the chapter. These questions cover all the parts presented in each chapter and provide an opportunity for the student to show comprehension of the concepts covered.

Discussion Topics and Critical Thinking Questions

1. Why are contacts from control devices not placed in parallel with loads?
2. Record all the nameplate data for a given motor and write a short description of what each item specifies.
3. Search the Internet for electric motor connection diagrams. Record all information given for the connection of the following types of motors:
   a. DC compound motor
   b. AC single-phase dual-voltage induction motor
   c. AC three-phase two-speed induction motor
4. The AC squirrel-cage induction motor is the dominant motor technology in use today. Why?
5. In general, how do NEMA motor standards compare to IEC standards?

CHAPTER ONE

Safety in the Workplace



Banner Engineering

CHAPTER OBJECTIVES

This chapter will help you:

- Identify the electrical factors that determine the severity of an electric shock.
- Describe arc flash hazard recognition and prevention.
- List of general principles of electrical safety including wearing approved protective clothing and using protective equipment.
- Understand the application of different types of electrical machine safety devices.
- Explain the safety aspects of grounding an electrical motor installation.
- Outline the basic steps in a lockout procedure.
- Identify the functions of the different organizations responsible for electrical codes and standards.

Safety is the number one priority in any job. Every year, electrical accidents cause serious injury or death. Many of these casualties are young people just entering the workplace. They are involved in accidents that result from carelessness, from the pressures and distractions of a new job, or from a lack of understanding about electricity. This chapter is designed to develop an awareness of the dangers associated with electrical power and the potential dangers that can exist on the job or at a training facility.

PART 1 PROTECTING AGAINST ELECTRICAL SHOCK

Electrical Shock

The human body conducts electricity. Even low currents may cause severe health effects. Spasms, burns, muscle paralysis, or death can result, depending on the amount of the current flowing through the body, the route it takes, and the duration of exposure.

The main factor for determining the severity of an electric shock is the amount of electric current that passes through the body. This current is dependent upon the voltage and the resistance of the path it follows through the body.

Electrical **resistance** (R) is the opposition to the flow of current in a circuit and is measured in ohms (Ω). The lower the body resistance, the greater the current flow and potential electric shock hazard. Body resistance can be divided into external (skin resistance) and internal (body tissues and blood stream resistance). Dry skin is a good insulator; moisture lowers the resistance of skin, which explains why shock intensity is greater when the hands are wet. Internal resistance is low owing to the salt and moisture content of the blood. There is a wide degree of variation in body resistance. A shock that may be fatal to one person may cause only brief discomfort to another. Typical body resistance values are:

- Dry skin—100,000 to 600,000 Ω
- Wet skin—1,000 Ω
- Internal body (hand to foot)—400 to 600 Ω
- Ear to ear—100 Ω

Thin or wet skin is much less resistant than thick or dry skin. When skin resistance is low, the current may cause little or no skin damage but severely burn internal organs and tissues. Conversely, high skin resistance can produce severe skin burns but prevent the current from entering the body.

Voltage (E) is the pressure that causes the flow of electric current in a circuit and is measured in units called volts (V). The amount of voltage that is dangerous to life varies with each individual because of differences in body resistance and heart conditions. Generally, any voltage *above 30 V* is considered dangerous.

Electric **current** (I) is the rate of flow of electrons in a circuit and is measured in amperes (A) or milliamperes (mA). One milliampere is one-thousandth of an ampere. The amount of current flowing through a person's body depends on the voltage and resistance. Body current can be calculated using the following Ohm's law formula:

$$\textbf{Current} = \frac{\textbf{Voltage}}{\textbf{Resistance}}$$

If you came into direct contact with 120 volts and your body resistance was 100,000 ohms, then the current that would flow would be:

$$I = \frac{120\text{ V}}{100{,}000\ \Omega}$$
$$= 0.0012\text{ A}$$
$$= 1.2\text{ mA } (0.0012 \times 1{,}000)$$

This is just about at the threshold of perception, so it would produce only a tingle.

If you were sweaty and barefoot, then your resistance to ground might be as low as 1,000 ohms. Then the current would be:

$$I = \frac{120\text{ V}}{1{,}000\ \Omega} = 0.12\text{ A} = 120\text{ mA}$$

This is a lethal shock, capable of producing ventricular fibrillation (rapid irregular contractions of the heart) and death!

Voltage is not as reliable an indication of shock intensity because the body's resistance varies so widely that it is impossible to predict how much current will result from a given voltage. The amount of current that passes through the body and the length of time of exposure are perhaps the two most reliable criteria of shock intensity. Once current enters the body, it follows through the circulatory system in preference to the external skin. Figure 1-1 illustrates the relative magnitude and effect of electric current. It doesn't take much current to cause a painful or even fatal shock. A current of 1 mA (1/1000 of an ampere) can be felt. A current of 10 mA will produce a shock of sufficient intensity to prevent voluntary control of muscles, which explains why, in some cases, the victim of electric shock is unable to release grip on the conductor while the current is flowing. A current of 100 mA passing through the body for a second or longer can be fatal. Generally, any current flow *above 0.005 A, or 5 mA,* is considered dangerous.

A 1.5 V flashlight cell can deliver more than enough current to kill a human being, yet it is safe to handle. This is because the resistance of human skin is high enough to limit greatly the flow of electric current. In lower voltage circuits, resistance restricts current flow to very low values. Therefore, there is little danger of an electric shock. Higher voltages, on the other hand, can force enough current though the skin to produce a shock. The danger of harmful shock increases as the voltage increases.

The pathway through the body is another factor influencing the effect of an electric shock. For example, a current from hand to foot, which passes through the heart and part of the central nervous system, is far more dangerous than a shock between two points on the same arm (Figure 1-2).

AC (alternating current) of the common 60 Hz frequency is three to five times more dangerous than DC (direct current) of the same voltage and current value. DC tends to cause a convulsive contraction of the muscles, often forcing the victim away from further current exposure. The effects of AC on the body depend to a great extent on the frequency: low-frequency currents (50–60 Hz) are usually more dangerous than high-frequency currents. AC causes muscle spasm, often "freezing" the hand (the most common part of the body to make contact) to the

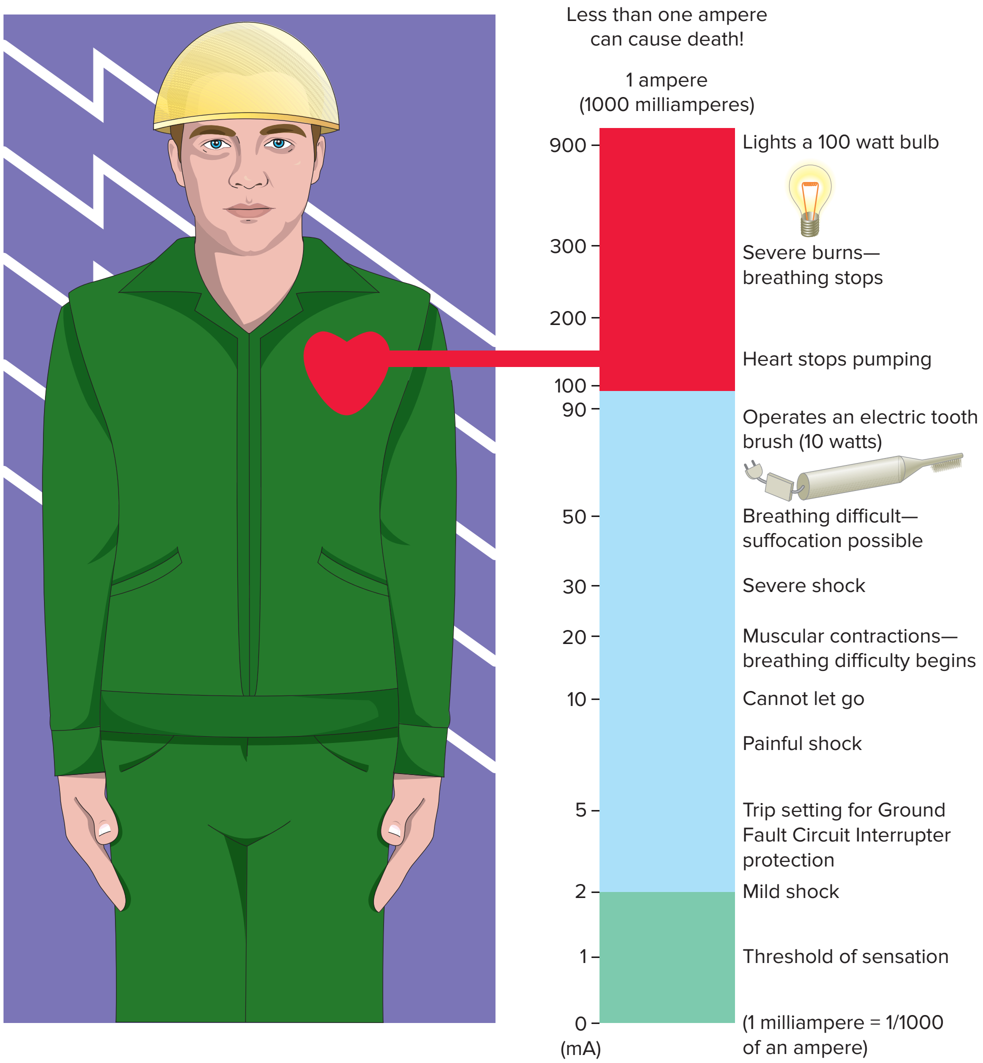


Figure 1-1 **Relative magnitude and effect of electric current on the body.**

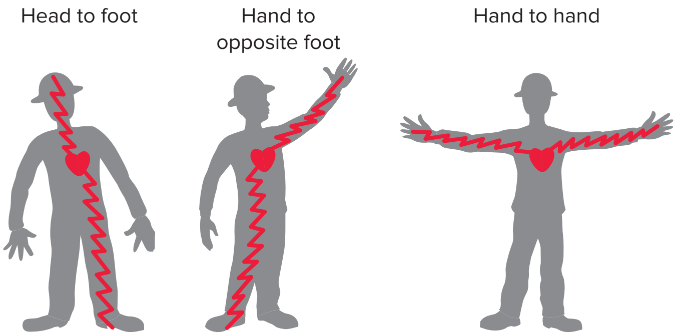


Figure 1-2 **Typical electric current pathways that stop normal pumping of the heart.**

circuit. The fist clenches around the current source, resulting in prolonged exposure with severe burns.

The most common electric-related injury is a burn. The major types of burns:

- **Electrical burns,** which are a result of electric current flowing through the tissues or bones. The burn itself may be only on the skin surface or deeper layers of the skin may be affected.
- **Arc burns,** which are a result of an extremely high temperature caused by an electric arc (as high as 35,000°F) in close proximity to the body. Electric arcs can occur as a result of poor electrical contact or failed insulation.
- **Thermal contact burns,** which are a result of the skin coming in contact with the hot surfaces of overheated components. They can be caused by contact with objects dispersed as a result of the blast associated with an electric arc.

If a person does suffer a severe shock, it is important to free the victim from the current as quickly as can be done safely. Do not touch the person until the electric power is turned off. You cannot help by becoming a second victim. The victim should be attended to immediately by a person trained in CPR (cardiopulmonary resuscitation).

Figure 1-3 Arc flash.
Photo Courtesy of Honeywell, www.honeywell.com

Arc Flash Hazards

An **arc flash** is the ball of fire that explodes from an electrical **short circuit** between one exposed live conductor and another conductor or to ground. The arc flash creates an enormous amount of energy (Figure 1-3) that can damage equipment and cause severe injury or loss of life.

An arc flash can be caused by dropped tools, unintentional contact with electrical systems, or the buildup of conductive dust, dirt, corrosion, and particles.

Electrical short circuits are either bolted faults or arcing faults. A **bolted fault** is current flowing through bolted bus bars or other electric conductors. An **arcing fault** is current flowing through the air. Because air offers opposition to electric current flow, the arc fault current is always lower than the bolted fault current. An **arc blast** is a flash that causes an explosion of air and metal that produces dangerous pressure waves, sound waves, and molten steel.

In order to understand the hazards associated with an arc flash incident, it is important to understand the difference between an arcing short circuit and a bolted short circuit. A bolted short circuit occurs when the normal circuit current bypasses the load through a very low conductive path, resulting in current flow that can be hundreds or thousands of times the normal load current. In this case, assuming all equipment remains intact, the fault energy is contained within the conductors and equipment, and the power of the fault is dissipated throughout the circuit from the source to the short. All equipment needs to have adequate interrupting ratings to safely contain and clear the high fault currents associated with bolted faults.

In contrast, an arcing fault is the flow of current through a higher-resistance medium, typically the air, between phase conductors or between phase conductors and neutral or ground. Arcing fault currents can be extremely high in current magnitude approaching the bolted short-circuit current but are typically between 38 and 89 percent of the bolted fault. The inverse characteristics of typical overcurrent protective devices generally result in substantially longer clearing times for an arcing fault due to the lower fault values.

Eighty percent of electrical workplace accidents are associated with arc flash and involve burns or injuries caused by intense heat or showers of molten metal or debris. In addition to toxic smoke, shrapnel, and shock waves, the creation of an arc flash produces an intense flash of blinding light. This flash is capable of causing immediate vision damage and can increase a worker's risk of future vision impairment.

An arc flash hazard exists when a person interacts with equipment in a way that could cause an electric arc. Such tasks may include testing or troubleshooting, application of temporary protective grounds, or the opening or closing of power circuit breakers as illustrated in Figure 1-4. ***Arcs can produce temperature four times hotter than the surface of the sun.*** To address this hazard, safety standards such as National Fire Protection Association (NFPA) 70E have been developed to minimize arc flash hazards. The NFPA standards require that any panel likely to be serviced by a worker be **surveyed** and **labeled**. Injuries can be avoided with training; with proper work practices; and by using protective face shields, hoods, and clothing that are NFPA-compliant.

Figure 1-4 An arc flash hazard exists when a person interacts with equipment.
Chemco Electrical Contractors Ltd.

Figure 1-5 Typical safety signs.

Personal Protective Equipment

Construction and manufacturing worksites, by nature, are potentially hazardous places. For this reason, safety has become an increasingly large factor in the working environment. The electrical industry, in particular, regards **safety** to be unquestionably the most single important priority because of the hazardous nature of the business. A safe operation depends largely upon all personnel being informed and aware of potential hazards. Safety signs and tags indicate areas or tasks that can pose a hazard to personnel and/or equipment. Signs and tags may provide warnings specific to the hazard, or they may provide safety instructions (Figure 1-5).

To perform a job safely, the proper protective clothing must be used. Appropriate attire should be worn for each particular job site and work activity (Figure 1-6). The following points should be observed:

1. Hard hats, safety shoes, and goggles must be worn in areas where they are specified. In addition, hard hats shall be approved for the purpose of the electrical work being performed. ***Metal hats are not acceptable!***
2. Safety earmuffs or earplugs must be worn in noisy areas.
3. Clothing should fit snugly to avoid the danger of becoming entangled in moving machinery. Avoid wearing synthetic-fiber clothing such as polyester material as these types of materials may melt or ignite when exposed to high temperatures and may increase the severity of a burn. Instead always wear cotton clothing.
4. Remove all metal jewelry when working on energized circuits; gold and silver are excellent conductors of electricity.
5. Confine long hair or keep hair trimmed when working around machinery.

Figure 1-6 Appropriate attire should be worn for each particular job site and work activity.
Photo courtesy of Capital Safety, www.capitalsafety.com

A wide variety of electrical safety equipment is available to prevent injury from exposure to live electric circuits (Figure 1-7). Electrical workers should be familiar with safety standards such as **NFPA-70E** that pertain to the type of protective equipment required, as well as how such equipment shall be cared for. To make sure electrical protective equipment actually performs as designed, it must be inspected for damage before each day's use and immediately following any incident that can reasonably be suspected of having caused damage. All electrical protection equipment must be listed and may include the following:

Rubber Protective Equipment—Rubber gloves are used to prevent the skin from coming into contact with energized circuits. A separate outer leather cover is used to protect the rubber glove from punctures and other damage. Rubber blankets are used to prevent contact with energized conductors or circuit parts when working near exposed energized circuits. All rubber protective equipment must be marked with the appropriate voltage rating and the last inspection date. It is important that the insulating value of both rubber gloves and blankets have a voltage rating that matches that of the circuit or equipment they are to be used with. Insulating gloves must be given an air test daily, along with inspection. Twirl the glove around quickly or roll it down to trap air inside. Squeeze the palm, fingers, and thumb

Figure 1-7 Electrical safety equipment.
Photo courtesy of W.W. Grainger, www.grainger.com

to detect any escaping air. If the glove does not pass this inspection, it must be disposed of.

Protection Apparel—Special protective equipment available for high-voltage applications include high-voltage sleeves, high-voltage boots, nonconductive protective helmets, nonconductive eyewear and face protection, switchboard blankets, and flash suits.

Hot Sticks—Hot sticks are insulated tools designed for the manual operation of high-voltage disconnecting switches, high-voltage fuse removal and insertion, as well as the connection and removal of temporary grounds on high-voltage circuits. A hot stick is made up of two parts, the head, or hood, and the insulating rod. The head can be made of metal or hardened plastic, while the insulating section may be wood, plastic, or other effective insulating materials.

Shorting Probes—Shorting probes are used on de-energized circuits to discharge any charged capacitors or built-up static charges that may be present when power to the circuit is disconnected. Also, when working on or near any high-voltage circuits, shorting probes should be connected and left attached as an extra safety precaution in the event of any accidental application of voltage to the circuit. When installing a shorting probe, first connect the test clip to a good ground contact. Next, hold the shorting probe by the handle and hook the probe end over the part or terminal to be grounded. Never touch any metal part of the shorting probe while grounding circuits or components.

Face Shields—Listed face shields should be worn during all switching operations where there is a possibility of injury to the eyes or face from electrical arcs or flashes, or from flying or falling objects that may result from an electrical explosion.

With proper precautions, there is no reason for you to ever receive a serious electrical shock. Receiving an electrical shock is a clear warning that proper safety measures have not been followed. To maintain a high level of electrical safety while you work, there are a number of precautions you should follow. Your individual job will have its own unique safety requirements. However, the following are given as essential basics.

- Never take a shock on purpose.
- Keep material or equipment at least 10 feet away from high-voltage overhead power lines.
- Do not close any switch unless you are familiar with the circuit that it controls and know the reason for its being open.
- When working on any circuit, take steps to ensure that the controlling switch is not operated in your absence. Switches should be padlocked open, and warning notices should be displayed (**lockout/tagout**).
- Avoid working on "live" circuits as much as possible.
- When installing new machinery, ensure that the framework is efficiently and permanently grounded.
- Always treat circuits as "live" until you have proven them to be "dead." Presumption at this point can kill you. It is a good practice to take a meter reading before starting work on a dead circuit.
- Avoid touching any grounded objects while working on electrical equipment.
- Remember that even with a 120 V control system, you may well have a higher voltage in the panel. Always work so that you are clear of any of the higher voltages. (Even though you are testing a 120 V system, you are most certainly in close proximity to 240 V or 480 V power.)
- Don't reach into energized equipment while it is being operated. This is particularly important in high-voltage circuits.
- Use good electrical practices even in temporary wiring for testing. At times you may need to make alternate connections, but make them secure enough so that they are not in themselves an electrical hazard.
- When working on live equipment containing voltages over approximately 30 V, work with only one hand. Keeping one hand out of the way greatly reduces the possibility of passing a current through the chest.
- Safely discharge capacitors before handling them. Capacitors connected in live motor control circuits can store a lethal charge for a considerable time after the voltage to the circuits has been switched off. Although Article 460 of the National Electrical Code (NEC) requires an automatic **discharge** to under 50 volts within 1 minute, never assume that the discharge is working! Always verify that there is no voltage present.

Confined spaces can be found in almost any workplace. Figure 1-8 illustrates examples of typical confined spaces. In general, a "confined space" is an enclosed or partially enclosed space that:

- Is not primarily designed or intended for human occupancy.
- Has a restricted entrance or exit by way of location, size, or means.
- Can represent a risk for the health and safety of anyone who enters, because of its design, construction, location, or atmosphere; the materials or substances in it; work activities being carried out in it; or the mechanical, process, and safety hazards present.

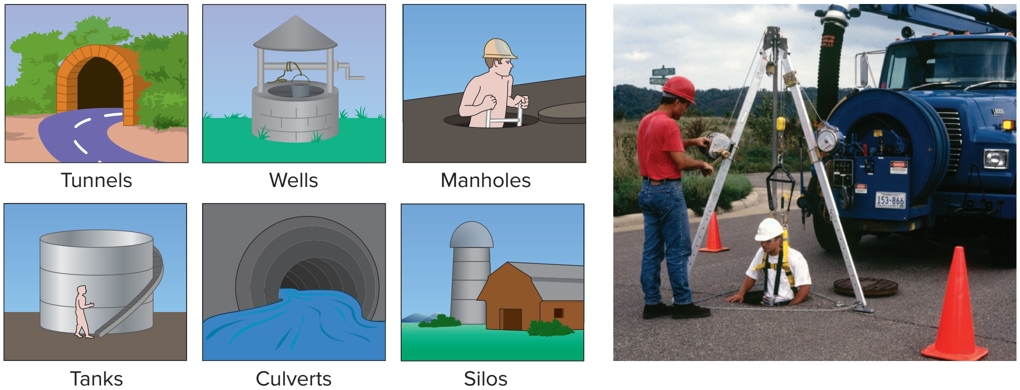


Figure 1-8 **Confined spaces.**
Photo courtesy of Capital Safety, www.capitalsafety.com

All hazards found in a regular workspace can also be found in a confined space. However, they can be even more hazardous in a confined space than in a regular worksite. Hazards in confined spaces can include poor air quality, fire hazard, noise, moving parts of equipment, temperature extremes, poor visibility, and barrier failure resulting in a flood or release of free-flowing solid. A "permit-required confined space" is a confined space that has specific health and safety hazards associated with it. Permit-required confined spaces require assessment of procedures in compliance with Occupational Safety and Health Administration (OSHA) standards prior to entry.

Machine Safety

Safety Light Curtains

Safety light curtains protect personnel from injury and machines from damage. They create a curtain of photoelectric light beams between an **emitter** and a receiver that then sense whenever an object intrudes into this light field. (Figure 1-9).

- When the light curtain is active, the emitter LEDs emit pulses of infrared light in rapid sequence.
- When the light reaches the corresponding phototransistor in the receiver, it produces an electrical signal.
- When an object such as an operator's hand blocks one of the light beams, the phototransistor that normally detects that beam receives no light.
- As a result, the phototransistor does not produce the signal it normally would at that time in the sequence.
- The light-curtain control circuitry senses this and sends a stop signal to the machinery
- They have an advantage over mechanical guards in that they're relatively small and unobtrusive.

Two general categories of safety light curtains are based on the scale of protection they provide.

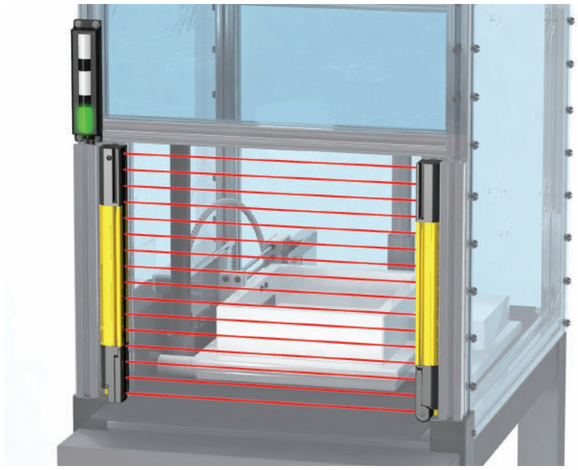


Figure 1-9 **Safety light curtain.**
Banner Engineering

- **Point of Operation Control (POC)** These light curtains are designed to protect on a small scale. Specifically, they help protect hands, fingers and arms that are going to be operating the machinery. These light curtains are generally located very close to the machine, directly where the worker will be interacting with it.
- **Perimeter Access Control (PAC)** These light curtains offer full body protection. They essentially create a fence around machines that don't require up-close usage by workers and are designed to detect people or objects when they intrude into the light barrier.

Safety Interlock switches

Safety interlock switches are a means of safeguarding that monitors the position of a guard or gate. They can be used to shut off power, control personnel access and prevent a machine from starting when the guard is open. Figure 1-10 shows an example of a tongue-operated safety interlock switch. The switching element and tongue actuator are

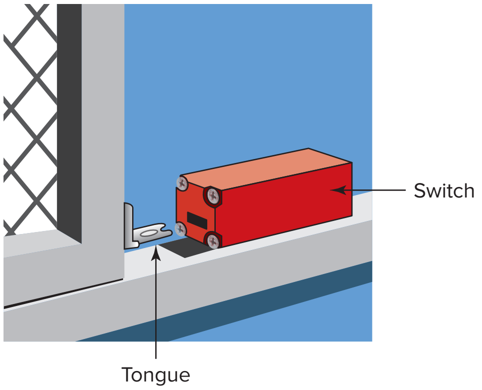


Figure 1-10 **Tongue-operated safety interlock switch.**

combined or separated during actuation. They fit to the leading edge of sliding of machine guards and provide interlock detection of movement.

Emergency Stop Controls

Emergency stop controls provide workers a means of stopping a device during an emergency in order to prevent injury to personnel and material loss. An emergency stop switch (Figure 1-11) must be highly visible in color and shape and must be easy to operate in emergency situations. Requirements for emergency stop buttons include:

- A direct opening mechanism must be installed on a normally closed (NC) contact. A general-purpose push button switch doesn't have a direct opening mechanism on the NC contact. If the contact welds, conduction will be maintained and the device cannot be stopped in a hazardous situation (load). If this occurs, the device may keep operating in the hazardous state. Therefore, use the NC contact of an emergency stop push button switch for safety applications.
- There must be a self-holding function. This function requires that once emergency stop is activated the control process cannot be started again until the actuating stop switch has been reset to the ON position.
- The button must be a mushroom head design or something equally easy to use.
- The button must be red and the background must be yellow.

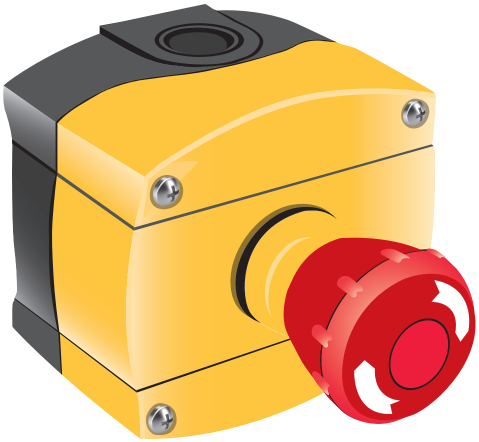


Figure 1-11 **Emergency stop switch.**

Safety Laser Scanners

Safety laser scanners (Figure 1-12) provide a laser safety solution for safeguarding mobile vehicles and stationary applications, such as the interior of robotic work cells that cannot be solved by other safeguarding solutions. Common uses for safety laser scanners include:

- A safety laser scanner can be mounted on an automated guide vehicle or transfer cart (Figure 1-13) to

Figure 1-12 **Safety laser scanner.**
Banner Engineering

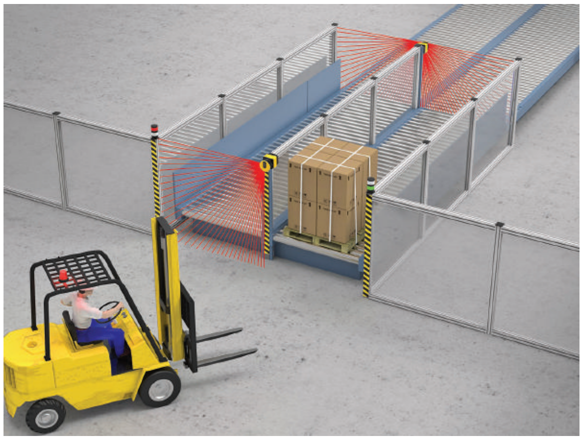


Figure 1-13 **Safety laser scanner mounted on a transfer cart.**
Banner Engineering

eliminate the risk of collisions with objects or people in its path.

- Scanners allow for vertical mounting to detect any undesirable entrances into a hazardous area. This is ideal in locations where it would be too difficult to effectively mount a light curtain.
- Safety scanners prevent hazards from operating when an unintended object or person is in a dangerous area. These safety devices can be unobtrusively mounted to avoid damage or potential impact, while protecting a simple or complex shaped area.

Part 1 Review Questions

1. Does the severity of an electric shock increase or decrease with each of the following changes?
   a. A decrease in the source voltage
   b. An increase in body current flow
   c. An increase in body resistance
   d. A decrease in the length of time of exposure
2. **a.** Calculate the theoretical body current flow (in amperes and milliamperes) of an electric shock victim who comes in contact with a 120 V energy source. Assume a total resistance of 15,000 Ω (skin, body, and ground contacts).
   b. What effect, if any, would this amount of current likely have on the body?
3. Normally a 6 volt lantern battery capable of delivering 2 A of current is considered safe to handle. Why?
4. Why is AC of a 60 Hz frequency considered to be potentially more dangerous than DC of the same voltage and current value?
5. What circuit fault can result in an arc flash?
6. Define each of the following terms associated with an arc flash:
   a. *Bolted fault*
   b. *Arcing fault*
   c. *Arc blast*
7. Explain why an arc flash is so potentially dangerous.
8. State the piece of electrical safety equipment that should be used to perform each of the following tasks:
   a. A switching operation where there is a risk of injury to the eyes or face from an electric arc.
   b. Using a multimeter to verify the line voltage on a three-phase 480 volt system.
   c. Opening a manually operated high-voltage disconnect switch.
9. Outline the safety procedure to follow when you are connecting shorting probes across de-energized circuits.
10. List three pieces of personal protection equipment required to be worn on most job sites.
11. Explain the way in which safety light curtains operate.
12. **a.** Describe a typical example of point of operation light curtain control.
    b. Describe a typical example of perimeter access light curtain control.
13. What type of safety switch is used to monitor the position of a guard or gate?
14. Emergency stop controls are required to have a self-holding function. What does this function require?
15. What type of safety device can be mounted on a transfer cart to eliminate the risk of collisions with objects in its path?

PART 2 GROUNDING—LOCKOUT—CODES

Grounding and Bonding

Proper grounding practices protect people from the hazards of electric shock and ensure the correct operation of overcurrent protection devices. Intentional grounding is required for the safe operation of electrical systems and equipment. Unintentional or accidental grounding is considered a fault in electrical wiring systems or circuits.

"Grounding" is the intentional connection of a current-carrying conductor to the earth. For AC premises wiring systems in buildings and similar structures, this ground connection is made on the premise side of the service equipment and the supply source, such as a utility transformer. The prime reasons for grounding are:

- To limit the voltage surges caused by lightning, utility system operations, or accidental contact with higher-voltage lines.
- To provide a ground reference that stabilizes the voltage under normal operating conditions.
- To facilitate the operation of overcurrent devices such as circuit breakers, fuses, and relays under ground-fault conditions.

"Bonding" is the permanent joining together of metal parts that aren't intended to carry current during normal operation, which creates an electrically conductive path that can safely carry current under ground-fault conditions. The prime reasons for bonding are:

- To establish an effective path for fault current that facilitates the operation of overcurrent protective devices.
- To minimize shock hazard to people by providing a low-impedance path to ground. Bonding limits the touch voltage when non-current-carrying metal parts are inadvertently energized by a ground fault.

The Code requires all metal used in the construction of a wiring system to be bonded to, or connected to, the ground system. The intent is to provide a low-impedance path back to the utility transformer in order to quickly clear faults. Figure 1-14 illustrates the ground-fault current path required to ensure that overcurrent devices operate to open the circuit. The earth is not considered an effective ground-fault current path. The resistance of earth is so high that very little fault current returns to the electrical supply source through the earth. For this reason the main bonding jumper is used to provide the connection between the grounded service conductor and the equipment grounding conductor at the service. Bonding jumpers may be located throughout the electrical system, but a main bonding jumper is located only at the service entrance. Grounding is accomplished by connecting the circuit to a metal underground water pipe, the metal frame of a building, a concrete-encased electrode, or a ground ring.

A grounding system has two distinct parts: system grounding and equipment grounding. **System grounding** is the electrical connection of one of the current carrying conductors of the electrical system to the ground. **Equipment grounding** is the electrical connection of all the metal parts that do not carry current to ground. Conductors that form parts of the grounding system include the following:

Equipment grounding conductor (EGC) is an electrical conductor that provides a low-impedance ground path between electrical equipment and enclosures within the distribution system. Figure 1-15 shows the connection for

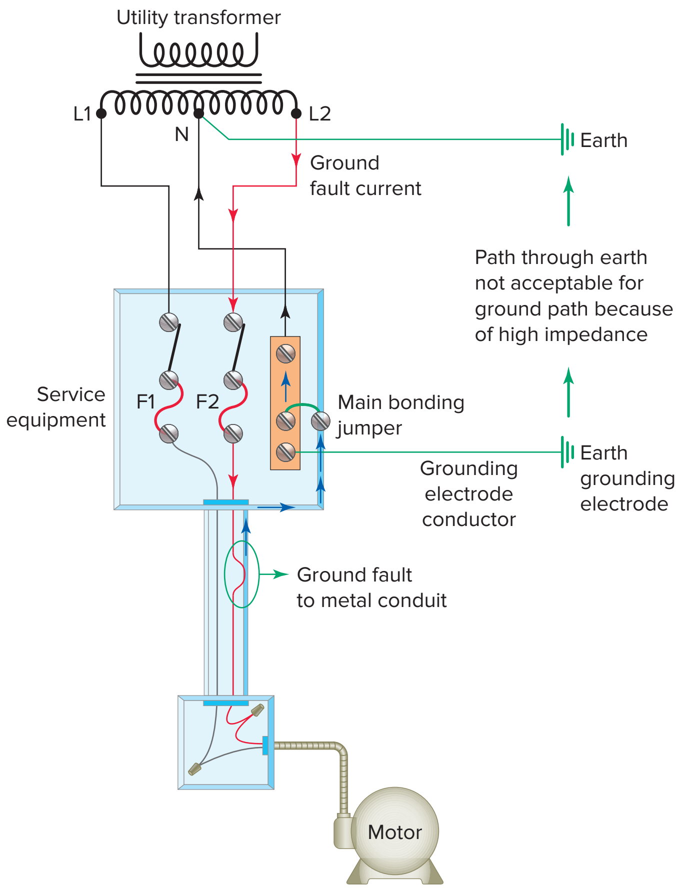


Figure 1-14 Ground-fault current path.

an EGC. Electrical motor windings are normally insulated from all exposed non-current-carrying metal parts of the motor. However, if the insulation system should fail, then the motor frame could become energized at line voltage. Any person contacting a grounded surface and the energized motor frame simultaneously could be

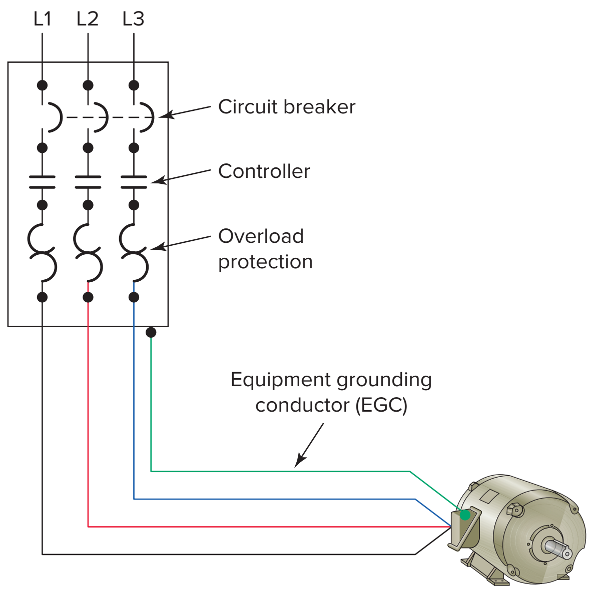


Figure 1-15 Equipment grounding conductor (EGC).

severely injured or killed. Effectively grounding the motor frame forces it to take the same zero potential as the earth, thus preventing this possibility.

Grounded conductor is a conductor that has been intentionally grounded.

Grounding electrode conductor is a conductor used to connect the equipment grounding conductor or the grounded conductor (at the service entrance or at the separately derived system) to the grounding electrode(s). A **separately derived system** is a system that supplies electrical power derived (taken) from a source other than a service, such as the secondary of a distribution transformer.

A **ground fault** is defined as an unintentional, electrically conducting connection between an ungrounded conductor of an electric circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth. The **ground-fault circuit interrupter (GFCI)** is a device that can sense small ground-fault currents. The GFCI is fast acting; the unit will shut off the current or interrupt the circuit within 1/40 second after its sensor detects a leakage as small as 5 milliamperes (mA). Most circuits are protected against overcurrent by 15 ampere or larger fuses or circuit breakers. This protection is adequate against short circuits. Overloads implies protection for a motor. Leakage currents to ground may be much less than 15 amperes and still be hazardous.

Figure 1-16 shows the simplified circuit of a GFCI receptacle. The device compares the amount of current in the ungrounded (hot) conductor with the amount of current in the grounded (neutral) conductor. Under normal operating conditions, the two will be **equal** in value. If the current in the neutral conductor becomes less than the current in the hot conductor, a ground-fault condition exists. The amount of current that is missing is returned to the source by the ground-fault path. Whenever the ground-fault current exceeds approximately *5 mA,* the device automatically opens the circuit to the receptacle.

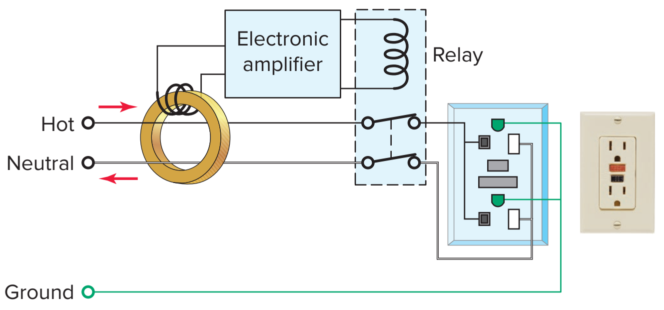


Figure 1-16 **GFCI receptacle.**
Steve Wisbauer/Stockbyte/Getty Images

GFCIs can be used successfully to reduce electrical hazards on construction sites. The ground-fault protection rules and regulations of OSHA have been determined necessary and appropriate for employee safety and health. According to OSHA, it is the employer's responsibility to provide either (1) ground-fault circuit interrupters on construction sites for receptacle outlets in use and not part of the permanent wiring of the building or structure or (2) a scheduled and recorded assured equipment-grounding conductor program on construction sites, covering all cord sets, receptacles that are not part of the permanent wiring of the building or structure, and equipment connected by cord and plug that are available for use or used by employees.

Lockout and Tagout

Electrical "lockout" is the process of removing the source of electrical power and installing a lock, which prevents the power from being turned ON. Electrical "tagout" is the process of placing a danger tag on the source of electrical power, which indicates that the equipment may not be operated until the danger tag is removed (Figure 1-17). This procedure is necessary for the safety of personnel in that it ensures that no one will inadvertently energize the equipment while it is being worked on. Electrical lockout and tagout is used when servicing electrical equipment that does not require power to be on to perform the service as in the case of motor alignment or replacement of a motor or motor control component.

Lockout means achieving a zero state of energy while equipment is being serviced. Just pressing a stop button to shut down machinery won't provide you with security. Someone else working in the area can simply reset it. Even a separate automated control could be activated to override the manual controls. It's essential that all interlocking or dependent systems also be deactivated. These could

Figure 1-17 **Lockout/tagout devices.**
Photo courtesy of Panduit Corp, www.panduit.com

feed into the system being isolated, either mechanically or electrically. It's important to test the start button before resuming any work in order to verify that all possible energy sources have been isolated.

The "danger tag" has the same importance and purpose as a lock and is used alone only when a lock does not fit the disconnect means. Danger tags are required to be securely attached at the disconnect device with space provided for the worker's name, craft, and procedure that is taking place.

The following are the basic steps in a lockout procedure:

- **Prepare for machinery shutdown:** Document all lockout procedures in a plant safety manual. This manual should be available to all employees and outside contractors working on the premises. Management should have policies and procedures for safe lockout and should also educate and train everyone involved in locking out electrical or mechanical equipment. Identify the location of all switches, power sources, controls, interlocks, and other devices that need to be locked out in order to isolate the system.
- **Machinery or equipment shutdown:** Stop all running equipment by using the controls at or near the machine.
- **Machinery or equipment isolation:** Disconnect the switch (do not operate if the switch is still under load). Stand clear of the box and face away while operating the switch with the left hand (if the switch is on the right side of the box).
- **Lockout and tagout application:** Lock the disconnect switch in the OFF position. If the switch box is the breaker type, make sure the locking bar goes right through the switch itself and not just the box cover. Some switch boxes contain fuses, and these should be removed as part of the lockout process. If this is the case, use a fuse puller to remove them. Use a tamper-proof lock with one key, which is kept by the individual who owns the lock. Combination locks, locks with master keys, and locks with duplicate keys are not recommended.

  Tag the lock with the signature of the individual performing the repair and the date and time of the repair. There may be several locks and tags on the disconnect switch if more than one person is working on the machinery. The machine operator's (and/or the maintenance operator's) lock and tag will be present as well as the supervisor's.
- **Release of stored energy:** All sources of energy that have the potential to unexpectedly start up, energize, or release must be identified and locked, blocked, or released.

  Capacitors retain their charge for a considerable period of time after having been disconnected from the power source. Always assume there is a voltage present when working with circuits having high capacitance, even when the circuit has been disconnected from its power source.

Figure 1-18 Testing for the presence of voltage.
Photo courtesy of Fluke, www.fluke.com. Reproduced with Permission.

- **Verification of isolation:** Use a voltage test to determine that voltage is present at the line side of the switch or breaker. When all phases of outlet are dead with the line side live, you can verify the isolation. Ensure that your voltmeter is working properly by performing the "live-dead-live" check before each use: First check your voltmeter on a known live voltage source of the same voltage range as the circuit you will be working on. Next check for the presence of voltage on the equipment you have locked out (Figure 1-18). Finally, to ensure that your voltmeter did not malfunction, check it again on the known live source.
- **Lockout/tagout removal:** Remove tags and locks when the work is completed. Each individual must remove his or her own lock and tag. If there is more than one lock present, the person in charge of the work is the last to remove his or her lock. Before reconnecting the power, check that all guards are in place and that all tools, blocks, and braces used in the repair are removed. Make sure that all employees stand clear of the machinery.

Electrical Codes and Standards

Occupational Safety and Health Administration (OSHA) In 1970, Congress created a regulatory agency known as the Occupational Safety and Health Administration

(OSHA). The purpose of OSHA is to assure safe and healthful working conditions for working men and women by authorizing enforcement of standards developed under the Act, by encouraging and assisting state governments to improve and expand their own occupational safety and health programs, and by providing for research, information, education, and training in the field of occupational health and safety.

OSHA inspectors check on companies to make sure they are following prescribed safety regulations. OSHA also inspects and approves safety products. OSHA's electrical standards are designed to protect employees exposed to dangers such as electric shock, electrocution, fires, and explosions.

National Electrical Code (NEC) The National Electrical Code (NEC) comprises a set of rules that, when properly applied, are intended to provide a safe installation of electrical wiring and equipment. This widely adopted minimum electrical safety standard has as its primary purpose "the practical safeguarding of persons and property from hazards arising from the use of electricity." Standards contained in the NEC are enforced by being incorporated into the different city and community ordinances that deal with electrical installations in residences, industrial plants, and commercial buildings. The NEC is the most widely adopted code in the world and many jurisdictions adopt it in its entirety without exception or local amendments or supplements.

An "Article" of the Code covers a specific subject. For example, Article 430 of the NEC covers motors and all associated branch circuits, overcurrent protection, overload, and so on. The installation of motor-control centers is covered in Article 409, and air-conditioning equipment is covered in Article 440. Each Code rule is called a "Code Section." A Code Section may be broken down into subsections. For example, the rule that requires a motor disconnecting means be mounted within sight of the motor and driven machinery is contained in Section 430.102 (B). "In sight" is defined by the Code as visible and not more than 50 feet in distance (Article 100—definitions).

Article 430 on motors is the longest article in the Code. One of the reasons for this is that the characteristics of a motor load are quite different from heating or incandescent lighting loads and so the method of protecting branch circuit conductors against excessive current is slightly different. Non-motor branch circuits are protected against overcurrent, whereas motor branch circuits are protected against overload conditions as well as groundfaults and short circuits. The single-line diagram of Figure 1-19 illustrates some of the motor terminology used throughout the Code and by motor control equipment manufacturers.

The use of electrical equipment in hazardous locations increases the risk of fire or explosion. Hazardous locations can contain gas, dust (e.g., grain, metal, wood, or coal), or flying fibers (textiles or wood products). A substantial part of the NEC is devoted to the discussion of hazardous locations, because electrical equipment can become a source of ignition in these volatile areas. Articles 500 through 504 and 510 through 517 provide classification and installation standards for the use of electrical equipment in these locations. Explosion-proof apparatus, dust-ignition-proof equipment, and purged and pressurized equipment are examples of protection techniques that can be used in certain hazardous (classified) locations. Figure 1-20 shows a motor start/stop station designed to meet hazardous location requirements.

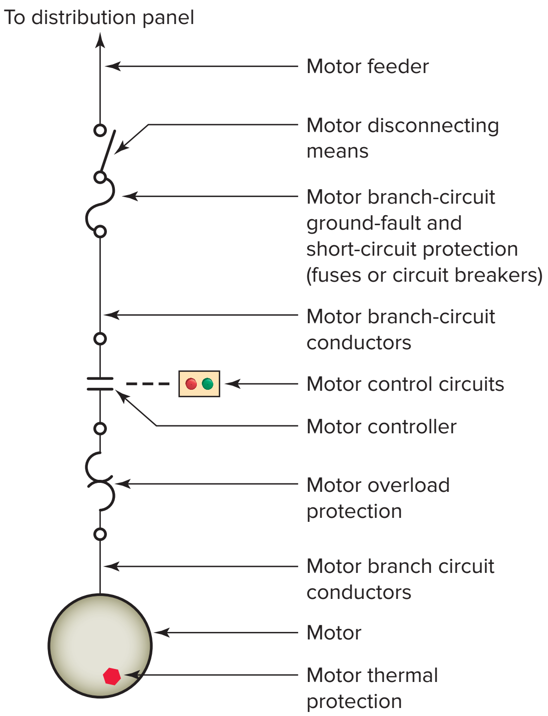


Figure 1-19 **Motor terminology.**

Figure 1-20 **Pushbutton station designed for hazardous locations.**

Photo courtesy of Rockwell Automation, www.rockwellautomation.com

National Fire Protection Association (NFPA) The National Fire Protection Association (NFPA) develops codes governing construction practices in the building and electrical trades. It is the world's largest and most influential fire safety organization. NFPA has published almost 300 codes and standards, including the National Electrical Code, with the mission of preventing the loss of life and property. Fire prevention is a very important part of any safety program. Figure 1-21 illustrates some of the common types of fire extinguishers and their applications. Icons found on the fire extinguisher indicate the types of fire the unit is intended to be used on.

It is important to know where your fire extinguishers are located and how to use them. In case of an electrical fire, the following procedures should be followed:

1. Trigger the nearest fire alarm to alert all personnel in the workplace as well as the fire department.
2. If possible, disconnect the electric power source.
3. Use a carbon dioxide or dry-powder fire extinguisher to put out the fire. ***Under no circumstances use water***, as the stream of water may conduct electricity through your body and give you a severe shock.
4. Ensure that all persons leave the danger area in an orderly fashion.
5. Do not reenter the premises unless advised to do so.

There are four classes of fires, categorized according to the kind of material that is burning (see Figure 1-21):

- **Class A** fires are those fueled by materials that, when they burn, leave a residue in the form of ash, such as paper, wood, cloth, rubber, and certain plastics.
- **Class B** fires involve flammable liquids and gases, such as gasoline, paint thinner, kitchen grease, propane, and acetylene.
- **Class C** fires involve energized electrical wiring or equipment such as motors and panel boxes.
- **Class D** fires involve combustible metals such as magnesium, titanium, zirconium, sodium, and potassium.

Figure 1-21 Types of fire extinguishers and their applications.

Nationally Recognized Testing Laboratory (NRTL) Article 100 of the NEC defines the terms "labeled" and "listed," which are both related with product evaluation. Labeled or listed indicates the piece of electrical equipment or material has been tested and evaluated for the purpose for which it is intended to be used. Products that are big enough to carry a label are usually labeled. The smaller products are usually listed. Any modification of a piece of electrical equipment in the field may void the label or listing.

In accordance with OSHA Safety Standards, a Nationally Recognized Testing Laboratory (NRTL) must test electrical products for conformity to national codes and standards before they can be listed or labeled. The biggest and best-known testing laboratory is the Underwriters' Laboratories, identified with the **UL logo** shown in Figure 1-22. The purpose of the Underwriters' Laboratories is to establish, maintain, and operate laboratories for the investigation of materials, devices, products, equipment, construction, methods, and systems with regard to hazards affecting life and property.

National Electrical Manufacturers Association (NEMA) The National Electrical Manufacturers Association (NEMA) is a group that defines and recommends safety standards for electrical equipment. Standards established by NEMA assist users in proper selection of industrial control equipment. As an example, NEMA standards provide practical information concerning the rating, testing, performance, and manufacture of motor control devices such as enclosures, contactors, and starters.

International Electrotechnical Commission (IEC) The International Electrotechnical Commission (IEC) is a Europe-based organization made up of national committees from more than 60 countries. There are basically two major mechanical and electrical standards for motors: NEMA in North America and IEC in most of the rest of the world. Dimensionally, IEC standards are expressed in metric units. Though NEMA and IEC standards use different units of measurements and terms, they are essentially analogous in ratings and, for most common applications, are largely interchangeable. NEMA standards tend to be more conservative—allowing more room for "design interpretation," as has been U.S. practice. Conversely, IEC standards tend to be more specific, more categorized—some say more precise—and designed with less over

Figure 1-22 Underwriters' Laboratories logo.
Source: Logo of Underwriters' Laboratories.

current tolerance. As an example, a NEMA-rated motor starter will typically be larger than its IEC counterpart.

Institute of Electrical and Electronics Engineers (IEEE) The Institute of Electrical and Electronics Engineers (IEEE) is a technical professional association whose primary goal is to foster and establish technical developments and advancements in electrical and electronic standards. IEEE is a leading authority in technical areas. Through its technical publishing, conferences, and consensus-based standards activities, the IEEE produces more than 30 percent of the world's published literature in electrical and electronic engineering. For example, IEEE Standard 142 provides all the information you need for a good grounding design.

Part 2 Review Questions

1. Explain how grounding the frame of a motor can prevent someone from receiving an electric shock.
2. Compare the terms *grounding* and *bonding*.
3. What is the minimum amount of leakage ground current required to trip a ground-fault circuit interrupter?
4. List the seven steps involved in a lockout/tagout procedure.
5. A disconnect switch is to be pulled open as part of a lockout procedure. Explain the safe way to proceed.
6. What is the prime objective of the National Electrical Code?
7. How are the standards contained in the NEC enforced?
8. Explain the difference between a Code Article and a Section.
9. What do the icons found on most fire extinguishers indicate?
10. What does a UL-labeled or -listed electrical device signify?
11. List three motor control devices that are rated by NEMA.
12. Compare NEMA and IEC motor standards.

Troubleshooting Scenarios

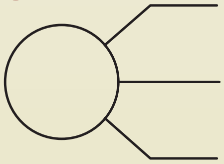
1. The voltage between the frame of a three-phase 208 V motor and a grounded metal pipe is found to be 120 V. What does this indicate? Why?
2. A ground-fault circuit interrupter does not provide overload protection. Why?
3. A listed piece of electrical equipment is not installed according to the manufacturer's instructions. Discuss why this will void the listing.
4. A hot stick is to be used to open a manually operated high-voltage disconnect switch. Why is it important to make certain that no loads are connected to the circuit when the switch is opened?
5. An employee is contemplating using his lockout lock to secure his personal tool crib. Why is this not acceptable?

Discussion Topics and Critical Thinking Questions

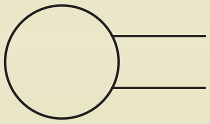
1. Worker A makes contact with a live wire and receives a mild shock. Worker B makes contact with the same live wire and receives a fatal shock. Discuss some of the reasons why this might occur.
2. The victim of death by electrocution is found with his fist still clenched firmly around the live conductor he made contact with. What does this indicate?
3. Why can birds safely rest on high-voltage power lines without getting shocked?
4. You have been assigned the task of explaining the company lockout procedure to new employees. Outline what you would consider the most effective way of doing this.
5. Visit the website of one of the groups involved with electrical codes and standards. Report on the service it provides.

CHAPTER TWO

Understanding Electrical Drawings



Three-phase motor



Single-phase motor

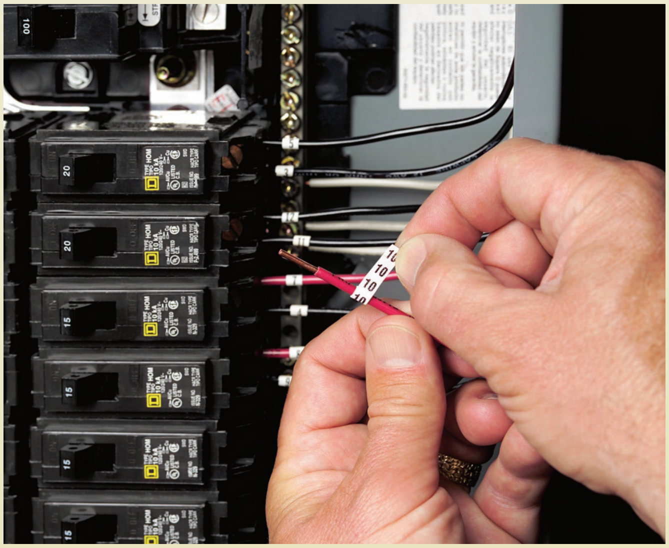


Photo courtesy of Ideal Industries, www.idealindustries.com

CHAPTER OBJECTIVES

This chapter will help you:

- Recognize symbols frequently used on motor and control diagrams.
- Differentiate between NEMA and IEC motor control symbols.
- Interpret and construct ladder diagrams.
- Interpret wiring, single-line, and block diagrams.
- Explain the terminal connections for different types of motors.
- Interpret connection schemes used for dual-voltage three-phase motors.
- Interpret information found on motor nameplates.
- Explain the terminology used in motor circuits.
- Understand the operation of manual and magnetic motor starters.
- Follow IEC type 2-wire and 3-wire circuit schematics.

Different types of electrical drawings are used in working with motors and their control circuits. In order to facilitate making and reading electrical drawings, certain standard symbols are used. To read electrical motor drawings, it is necessary to know both the meaning of the symbols and how the equipment operates. This chapter will help you understand the use of symbols in electrical drawings. The chapter also explains motor terminology and illustrates it with practical applications.

PART 1 SYMBOLS—ABBREVIATIONS—LADDER DIAGRAMS

Motor Symbols

A motor **control circuit** can be defined as a means of supplying power to and removing power from a motor. The symbols used to represent the different components of a motor control system can be considered a type of technical shorthand. The use of these symbols tends to make circuit diagrams less complicated and easier to read and understand.

In motor control systems, symbols and related lines show how the parts of a circuit are connected to one another. Unfortunately, not all electrical and electronic symbols are standardized. You will find slightly different symbols used by different manufacturers. Also, symbols sometimes look nothing like the real thing, so you have to learn what the symbols mean. Figure 2-1 shows some of the typical NEMA symbols used in motor circuit diagrams.

There are two standards for electric motor control symbols: NEMA and IEC. Figure 2-2 shows a comparison of common motor NEMA and IEC symbols.

Abbreviations for Motor Terms

An abbreviation is the shortened form of a word or phase. Uppercase letters are used for most abbreviations. The following is a list of some of the abbreviations commonly used in motor circuit diagrams.

AC	alternating current
ARM	armature
AUTO	automatic
BKR	breaker
COM	common
CR	control relay
CT	current transformer
DC	direct current
DB	dynamic braking
FLD	field
FWD	forward
GND	ground
HP	horsepower
L1, L2, L3	power line connections
LS	limit switch
MAN	manual
MTR	motor
M	motor starter
NEG	negative
NC	normally closed
NO	normally open
OL	overload relay
PH	phase
PL	pilot light
POS	positive
PWR	power
PRI	primary
PB	push button
REC	rectifier
REV	reverse
RH	rheostat
SSW	safety switch
SEC	secondary
1PH	single-phase
SOL	solenoid
SW	switch
T1, T2, T3	motor terminal connections
3PH	three-phase
TD	time delay
TRANS	transformer

Motor Ladder Diagrams

Motor control drawings provide information on circuit operation, device and equipment location, and wiring instructions. Symbols used to represent switches consist of node points (places where circuit devices attach to each other), contact bars, and the specific symbol that identifies that particular type of switch, as illustrated in Figure 2-3. Although a control device may have more than one set of contacts, only the contacts used in the circuit are represented on control drawings.

A variety of control diagrams and drawings are used to install, maintain, and troubleshoot motor control systems. These include ladder diagrams, wiring diagrams, line diagrams, and block diagrams. A “ladder diagram” (considered by some as a form of a schematic diagram) focuses on the electrical operation of a circuit, not the physical location of a device. For example, two stop push buttons may be physically at opposite ends of a long conveyor, but electrically side by side in the ladder diagram.

Ladder diagrams, such as the one shown in Figure 2-4, are drawn with two vertical lines and any number of horizontal lines.

- The vertical lines (called **rails**) connect to the power source and are identified as line 1 (L1) and line 2 (L2).
- The horizontal lines (called **rungs**) are connected across L1 and L2 and contain the control circuitry.
- Ladder diagrams are designed to be *read* like a book, starting at the top left and reading from left to right and top to bottom.

Because ladder diagrams are easier to read, they are often used in tracing through the operation of a circuit. Most programmable logic controllers (PLCs) use the ladder-diagramming concept as the basis for their programming language.

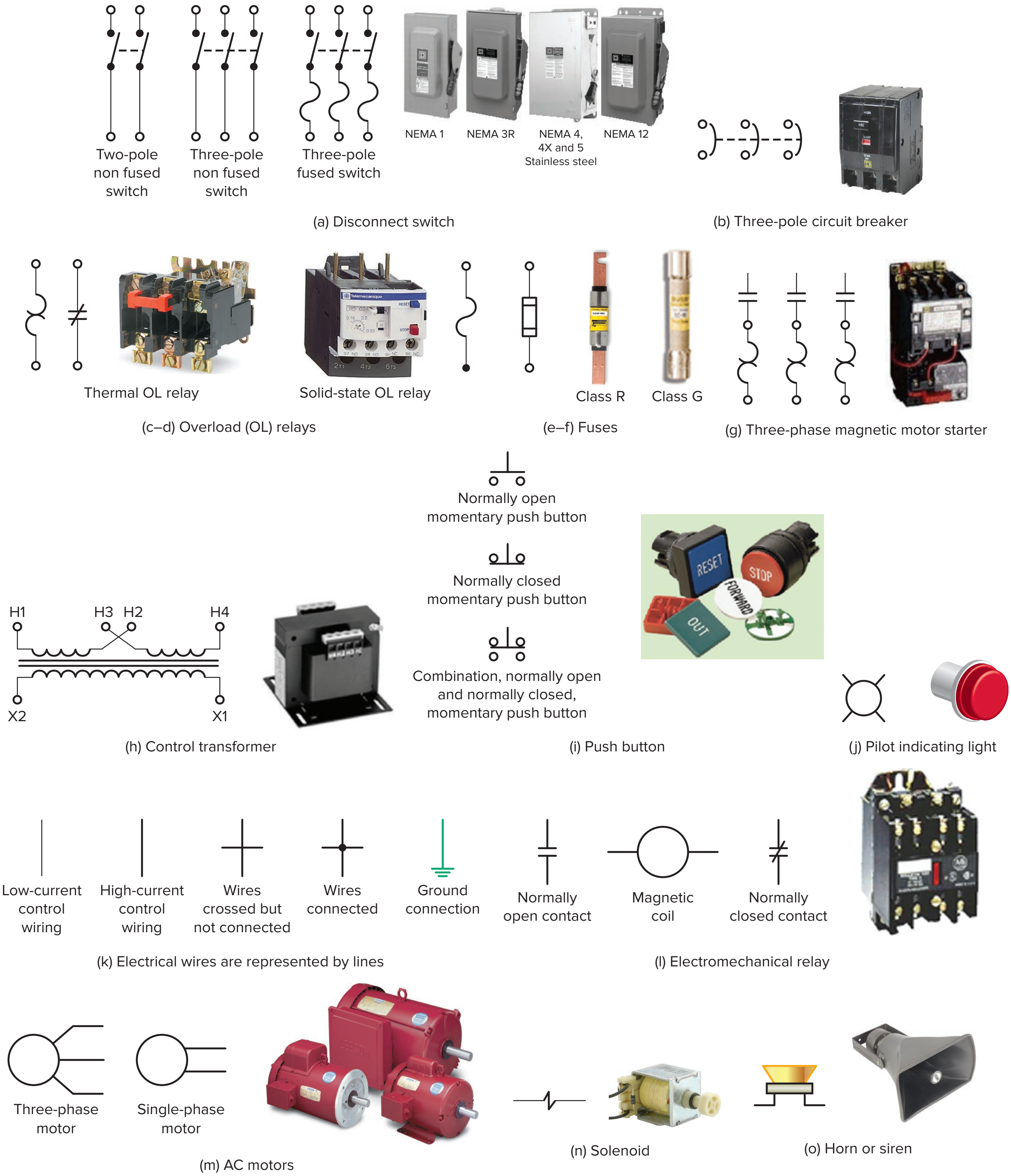


Figure 2-1 **Motor control symbols.**

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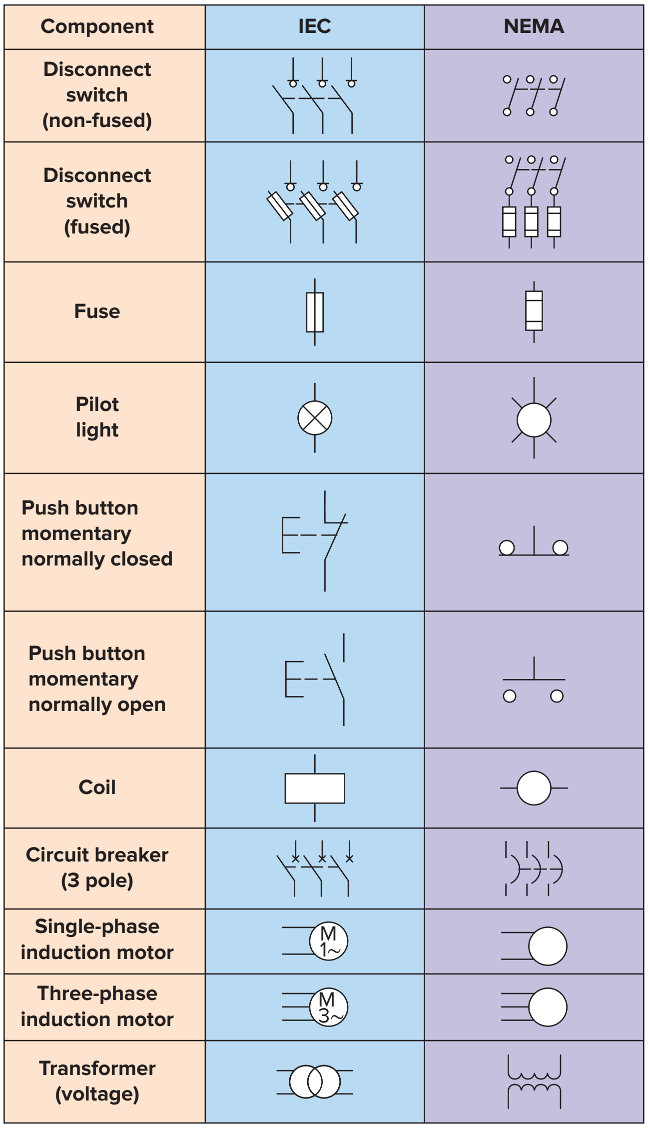


Figure 2-2 **Comparison of common motor NEMA and IEC symbols.**

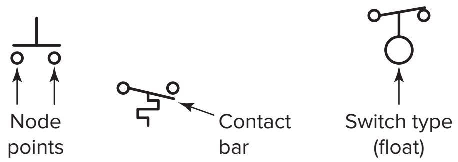


Figure 2-3 **Switch symbol component parts.**

Some motor ladder diagrams illustrate only the single-phase control circuit connected to L1 and L2, and not the three-phase power circuit supplying the motor. Figure 2-5 shows both the power circuit and control circuit wiring.

- On diagrams that include power and control circuit wiring, you may see both heavy and light conductor lines. The **heavy** lines are used for the **higher-current** power circuit and the **lighter** lines for the **lower-current** control circuit.

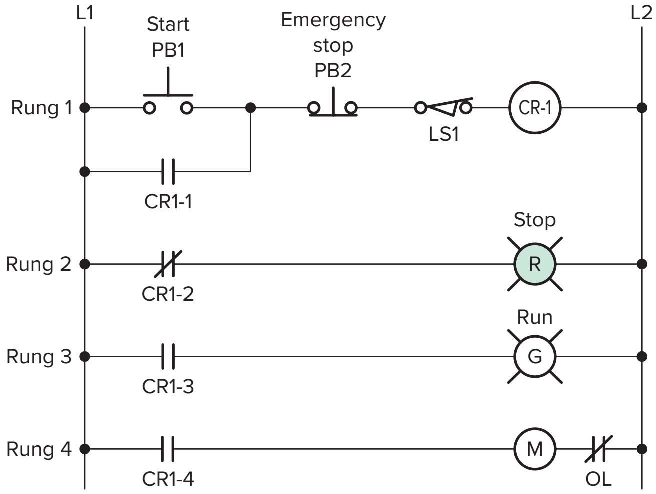


Figure 2-4 **Typical ladder diagram.**

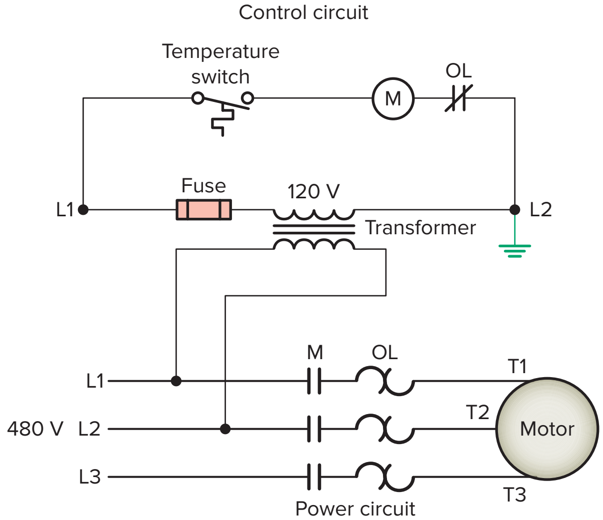


Figure 2-5 **Motor power and control circuit wiring.**

- Conductors that cross each other but make **no electrical contact** are represented by intersecting lines with **no dot.**
- Conductors that **make contact** are represented by a **dot** at the junction.
- In most instances, the control voltage is obtained directly from the power circuit or from a **step-down control transformer** connected to the power circuit. Using a transformer allows a lower voltage (120 V AC) for the control circuit while supplying the three-phase motor power circuit with a higher voltage (480 V AC) for more efficient motor operation.

A ladder diagram gives the necessary information for easily following the sequence of operation of the circuit. It is a great aid in troubleshooting as it shows, in a simple way,

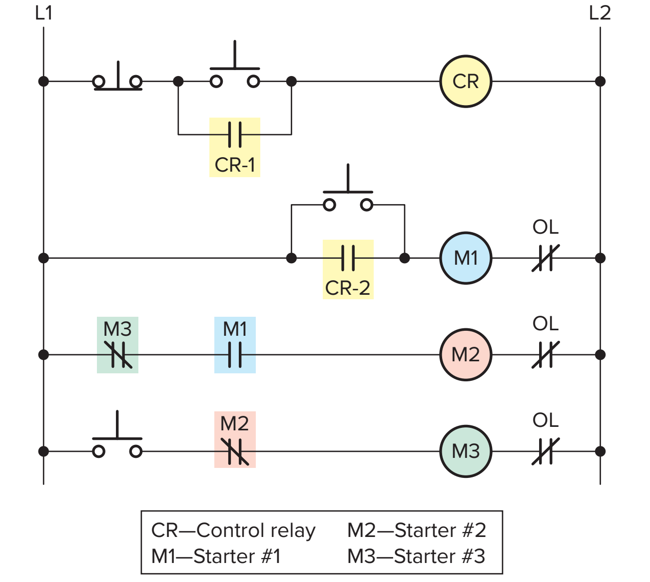


Figure 2-6 **Identification of coils and associated contacts.**

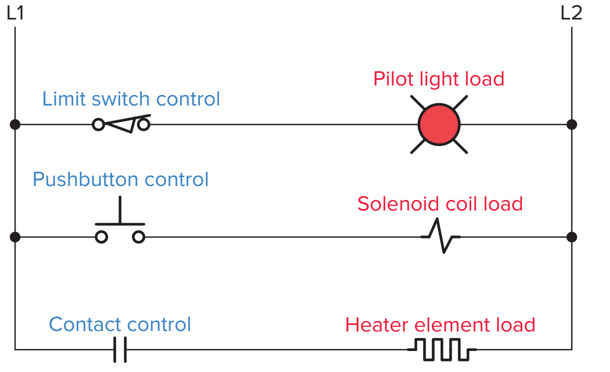


Figure 2-7 **Load and control devices.**

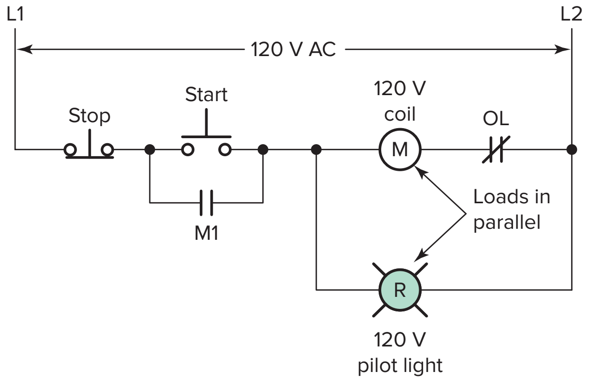


Figure 2-8 **Loads are placed on the right and contacts on the left.**

the effect that opening or closing various contacts has on other devices in the circuit. All switches and relay contacts are classified as normally open (NO) or normally closed (NC). The positions drawn on diagrams are the electrical characteristics of each device as would be found when it is purchased and not connected in any circuit. This is sometimes referred to as the "off-the-shelf" or **de-energized** state. It is important to understand this because it may also represent the de-energized position in a circuit. The de-energized position refers to the component position when the circuit is de-energized, or no power is present on the circuit. This point of reference is often used as the starting point in the analysis of the operation of the circuit.

A common method used to identify the relay coil and the contacts operated by it is to place a letter or letters in the circle that represents the coil (Figure 2-6). Each contact that is operated by this coil will have the coil letter or letters written next to the symbol for the contact. Sometimes, when there are several contacts operated by one coil, a number is added to the letter to indicate the contact number ‘‘separated by dash" or other text to be consistent. Although there are standard meanings of these letters, most diagrams provide a key list to show what the letters mean; generally they are taken from the name of the device.

A **load** is a circuit component that has resistance and consumes electric power supplied from L1 to L2, as illustrated in Figure 2-7. Control coils, solenoids, horns, and pilot lights are examples of loads. At least one load device must be included in each rung of the ladder diagram. Without a load device, the control devices would be switching an open circuit to a short circuit between L1 and L2. **Contacts** from control devices such as switches, push buttons, and relays are considered to have little or no resistance in the closed state. Connection of contacts in parallel with a load also can result in a short circuit when the contact closes. The circuit current will take the path of least resistance through the closed contact, shorting out the energized load.

Normally loads are placed on the right side of the ladder diagram next to L2 and contacts on the left side next to L1. One exception to this rule is the placement of the normally closed contacts controlled by the motor overload protection device. These contacts are drawn on the right side of the motor starter coil as shown in Figure 2-8. When two or more loads are required to be energized simultaneously, they must be connected in parallel. This will ensure that the full line voltage from L1 and L2 will appear across each load. If the loads are connected in series, neither will receive the entire line voltage necessary for proper operation. Recall that in a **series** connection of loads, the applied voltage is divided between each of the loads. In a **parallel** connection of loads, the voltage across each load is the same and is equal in value to the applied voltage.

Control devices such as switches, push buttons, limit switches, and pressure switches operate loads. Devices that start a load are usually connected in parallel, while devices

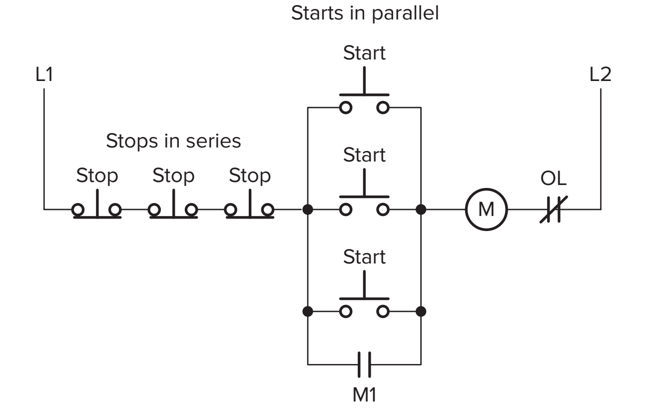


Figure 2-9 **Stop devices connect in series and start devices connect in parallel.**

that stop a load are connected in series. For example, multiple start push buttons controlling the same motor starter coil would be connected in parallel, while multiple stop push buttons would be connected in series (Figure 2-9). All control devices are identified with the appropriate nomenclature for the device (e.g., stop, start). Similarly, all loads are required to have abbreviations to indicate the type of load (e.g., M for starter coil). Often an additional numerical suffix is used to differentiate multiple devices of the same type. For example, a control circuit with two motor starters might identify the coils as M1 (contacts 1-M1, 2-M1, etc.) and M2 (contacts 1-M2, 2-M2, etc.), as illustrated in Figure 2-10.

As the complexity of a control circuit increases, its ladder diagram increases in size, making it more difficult to read and locate which contacts are controlled by which coil. "Rung numbering" is used to assist in reading and

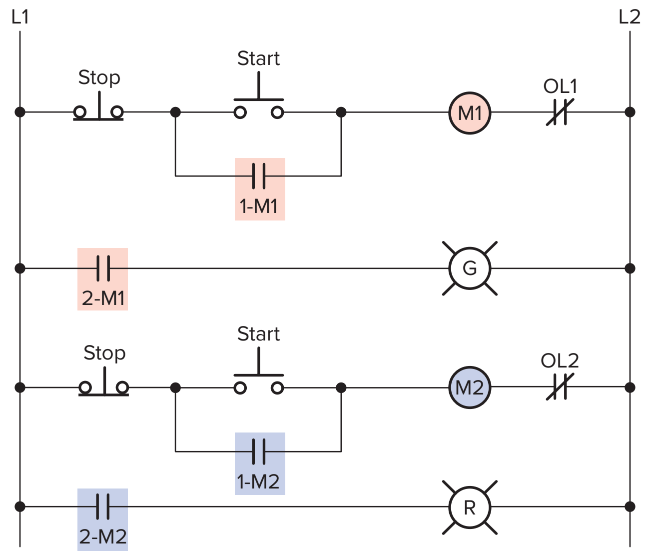


Figure 2-10 **Differentiating between multiple devices of the same type.**

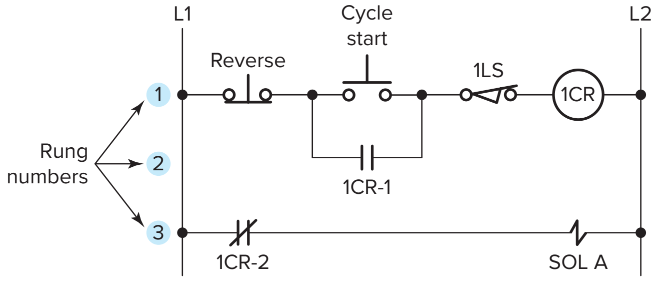


Figure 2-11 **Ladder diagram with rung numbers detailed.**

understanding larger ladder diagrams. Each rung of the ladder diagram is marked (rung 1, 2, 3, etc.), starting with the top rung and reading down. A rung can be defined as a complete path from L1 to L2 that contains a load. Figure 2-11 illustrates the marking of each rung in a line diagram with three separate rungs:

- The path for **rung 1** is completed through the reverse push button, cycle start push button, limit switch 1LS, and coil 1CR.
- The path for **rung 2** is completed through the reverse push button, relay contact 1CR-1, limit switch 1LS, and coil 1CR. Note that rung 1 and rung 2 are identified as two separate rungs even though they control the same load. The reason for this is that either the cycle start push button or the 1CR-1 relay contact completes the path from L1 to L2.
- The path for **rung 3** is completed through relay contact 1CR-2 and solenoid SOL A.

"Numerical cross-referencing" is used in conjunction with the rung numbering to locate auxiliary contacts controlled by coils in the control circuit. At times auxiliary contacts are not in close proximity on the ladder diagram to the coil controlling their operation. To locate these contacts, rung numbers are listed to the right of L2 in parentheses on the rung of the coil controlling their operation. In the example shown in Figure 2-12:

- The contacts of coil 1CR appear at two different locations in the line diagram.

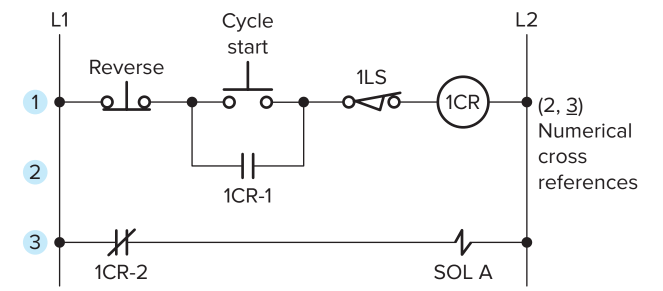
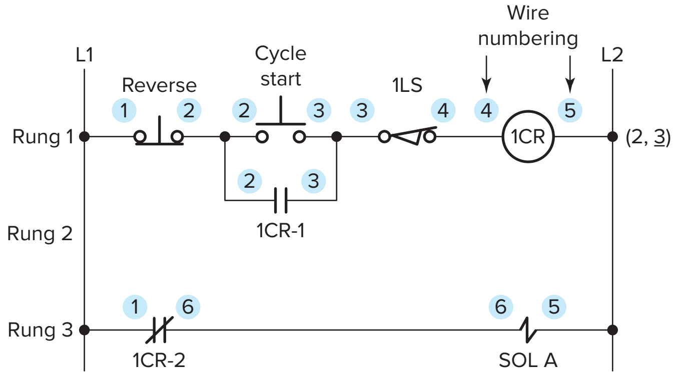


Figure 2-12 **Numerical cross-reference system.**



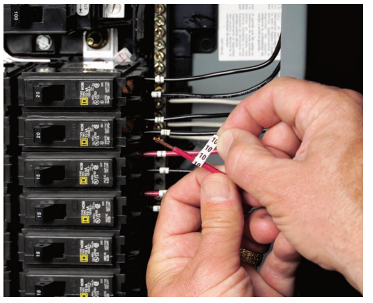


Figure 2-13 **Wire numbering.**
Photo courtesy of Ideal Industries, www.idealindustries.com

- The numbers in parentheses to the right of the line diagram identify the line location and type of contacts controlled by the coil.
- Numbers appearing in the parentheses for normally open contacts have no special markings.
- Numbers used for normally closed contacts are identified by underlining or overscoring the number to distinguish them from normally open contacts.
- In this circuit, control relay coil 1CR controls two sets of contacts: 1CR-1 and 1CR-2. This is shown by the numerical code 2, 3.

Some type of "wire identification" is required to correctly connect the control circuit conductors to their components in the circuit. The method used for wire identification varies for each manufacturer. Figure 2-13 illustrates one method where each common point in the circuit is assigned a reference number:

- Numbering starts with all wires that are connected to the L1 side of the power supply identified with the number 1.
- Continuing at the top left of the diagram with rung 1, a new number is designated sequentially for each wire that crosses a component.
- Wires that are electrically common are marked with the same numbers.
- Once the first wire directly connected to L2 has been designated (in this case 5), all other wires directly connected to L2 will be marked with the same number.
- The number of components in the first line of the ladder diagram determines the wire number for conductors directly connected to L2.

Figure 2-14 illustrates an alternative method of assigning wire numbers. With this method all wires directly connected to L1 are designated 1 while all those connected to L2 are designated 2. After all the wires with 1 and 2 are marked, the remaining numbers are assigned in a sequential order starting at the top left of the diagram. This method has as its advantage the fact that all wires directly connected to L2 are always designated as 2. Ladder diagrams may also contain a series of descriptions located to the right of L2, which are used to document the function of the circuit controlled by the output device.

A broken line normally indicates a **mechanical** connection. Do not make the mistake of reading a broken

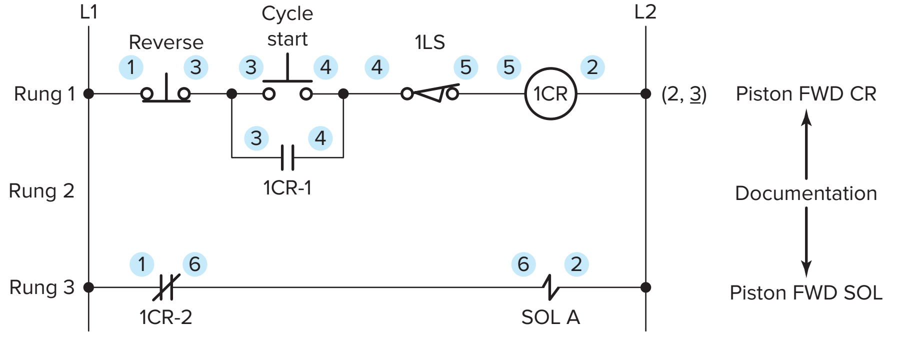


Figure 2-14 **Alternative wiring identification with documentation.**

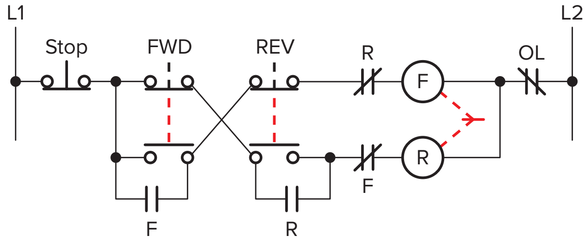


Figure 2-15 **Representing mechanical functions.**

line as a part of the electrical circuit. In Figure 2-15, the vertical broken lines on the forward and reverse push buttons indicate that their normally closed and normally open contacts are mechanically connected. Thus, pressing the button will open the one set of contacts and close the other. The broken line between the F and R coils indicates that the two are mechanically **interlocked.** Therefore, coils F and R cannot close contacts simultaneously because of the mechanical interlocking action of the device.

When a control transformer is required to have one of its secondary lines grounded, the ground connection must be made so that an accidental ground in the control circuit will not start the motor or make the stop button or control inoperative. Figure 2-16a illustrates the secondary of a control transformer properly grounded to the L2 side of the circuit. When the circuit is operational, the entire circuit to the left of coil M is the ungrounded circuit (it is the "hot" leg). A fault path to ground in the ungrounded circuit will create a short-circuit condition causing the control transformer fuse to open.

Figure 2-16b shows the same circuit improperly grounded at L1. In this case, a short to ground to the left of coil M would *energize* the coil, starting the motor unexpectedly. The fuse would not operate to open the circuit and pressing the stop button would not de-energize the M coil. Equipment damage and personnel injuries would be very likely. Clearly, output devices (loads) must be directly connected to the **grounded side** of the circuit.

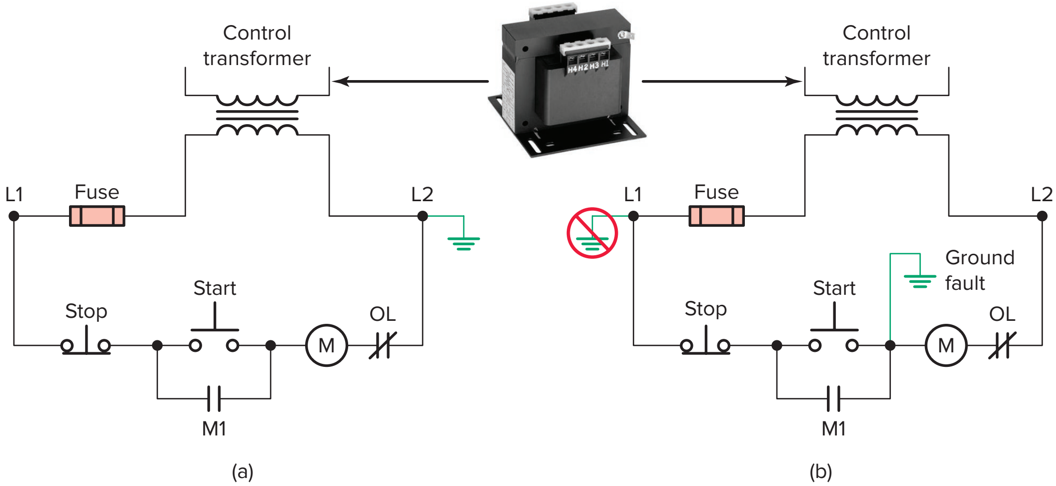


Figure 2-16 **Control transformer ground connection: (*a*) control transformer properly grounded to the L2 side of the circuit; (*b*) control transformer improperly grounded at the L1 side of the circuit.**
Photo courtesy of Rockwell Automation, www.rockwellautomation.com

Part 1 Review Questions

1. Define the term *motor control circuit*.
2. Why are symbols used to represent components on electrical diagrams?
3. An electrical circuit contains three pilot lights. What acceptable symbol could be used to designate each light?
4. Describe the basic structure of an electrical ladder diagram schematic.
5. Lines are used to represent electrical wires on diagrams.
   - **a.** How are wires that carry high current differentiated from those that carry low current?
   - **b.** How are wires that cross but do not electrically connect differentiated from those that connect electrically?

6. The contacts of a pushbutton switch open when the button is pressed. What type of push button would this be classified as? Why?
7. A relay coil labeled TR contains three contacts. What acceptable coding could be used to identify each of the contacts?
8. A rung on a ladder diagram requires that two loads, each rated for the full line voltage, be energized when a switch is closed. What connection of loads must be used? Why?
9. One requirement for a particular motor application is that six pressure switches be closed before the motor is allowed to operate. What connections of switches should be used?
10. The wire identification labels on several wires of an electrical panel are examined and found to have the same number. What does this mean?
11. A broken line representing a mechanical function on an electrical diagram is mistaken for a conductor and wired as such. What two types of problems could this result in?
12. Compare the shape of the symbol used to represent an electromagnetic coil on a NEMA and IEC motor schematic.

PART 2 WIRING—SINGLE LINE—BLOCK DIAGRAMS

Wiring Diagrams

Wiring diagrams are used to show the **point-to-point** wiring between components of an electric system and sometimes their physical relation to each other. They may include wire identification numbers assigned to conductors in the ladder diagram and/or color coding. Coils, contacts, motors, and the like are shown in the actual position that would be found on an installation. These diagrams are helpful in wiring up systems, because connections can be made exactly as they are shown on the diagram. A wiring diagram gives the necessary information for actually wiring up a device or group of devices or for physically tracing wires in troubleshooting. However, it is difficult to determine circuit operation from this type of drawing.

Wiring diagrams are provided for most electrical devices. Figure 2-17 illustrates a typical wiring diagram provided for a motor starter. The diagram shows, as closely as possible, the actual location of all of the component parts of the device. The open terminals (marked by an open circle) and arrows represent connections made by the user. Note that bold black lines denote the power circuit, and thinner red lines are used to show the control circuit.

The routing of wires in cables and conduits, as illustrated in Figure 2-18, is an important part of a wiring diagram. A **conduit** layout diagram indicates the start and the finish of the electrical conduits and shows the approximate path taken by any conduit in progressing from one point to another. Integrated with a drawing of this nature is the conduit and cable schedule, which tabulates each conduit as to number, size, function, and service and also includes the number and size of wires to be run in the conduit.

Wiring diagrams show the details of actual connections. Rarely do they attempt to show complete details of panel board or equipment wiring. The wiring diagram of Figure 2-18, reduced to a simpler form, is shown in Figure 2-19 with the internal connections of the magnetic starter omitted. Wires encased in conduit C1 are part of the power circuit and sized for the current requirement of the motor. Wires encased in conduit C2 are part of the lower-voltage control circuit and sized to the current requirements of the control transformer.

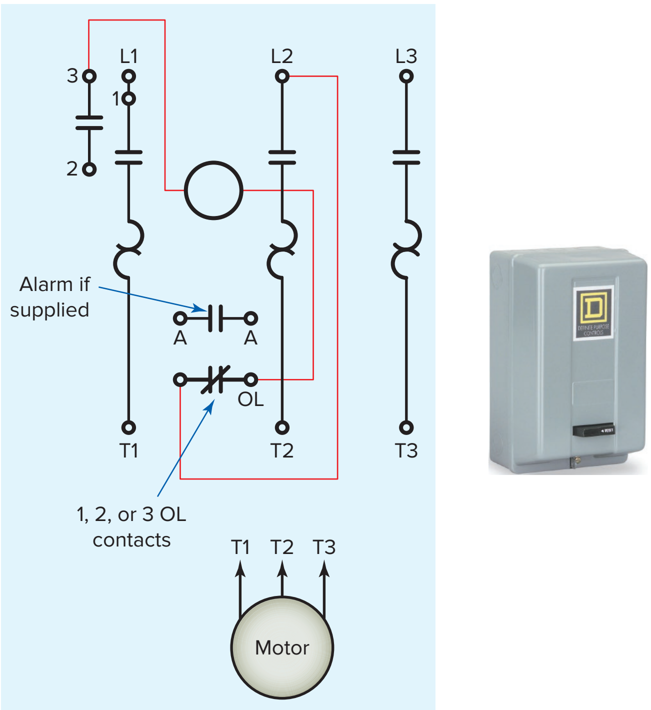


Figure 2-17 **Typical motor starter wiring diagram.**

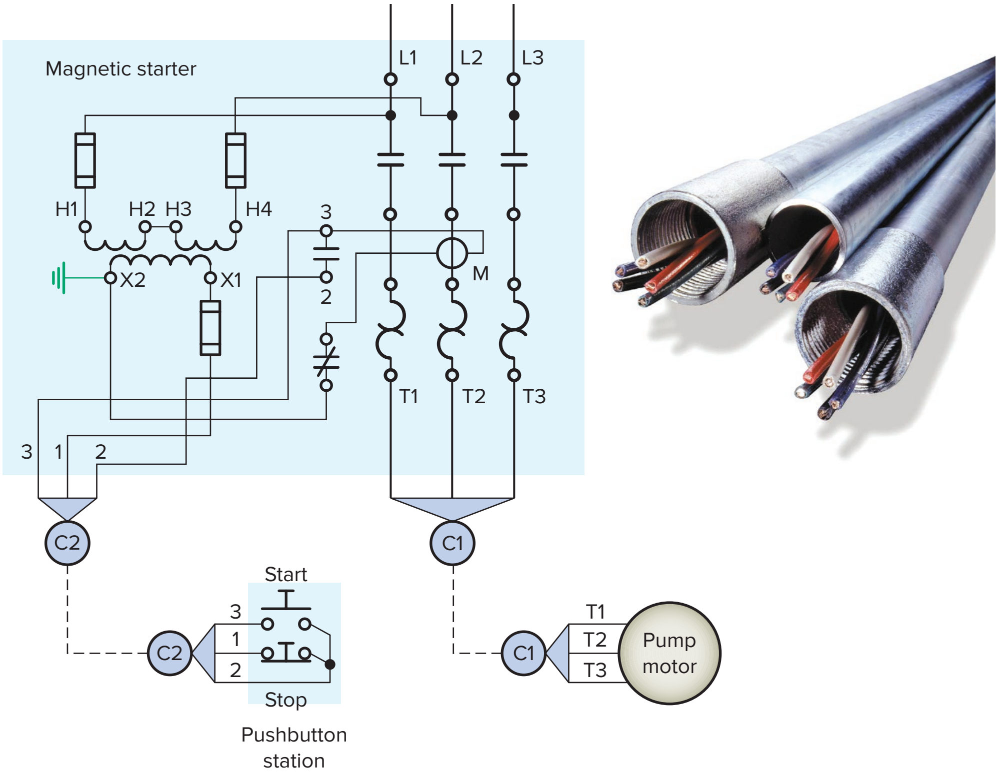


Figure 2-18 **Routing of wires in cables and conduits.**
Photo courtesy of JMC Steel Group

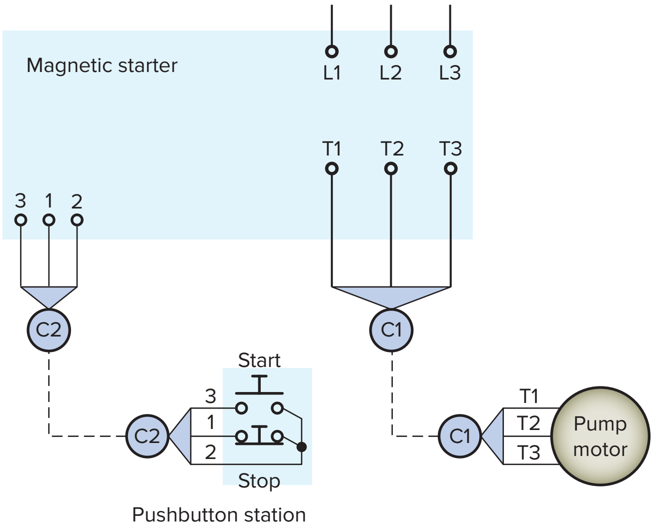


Figure 2-19 **Wiring with the internal connections of the magnetic starter omitted.**

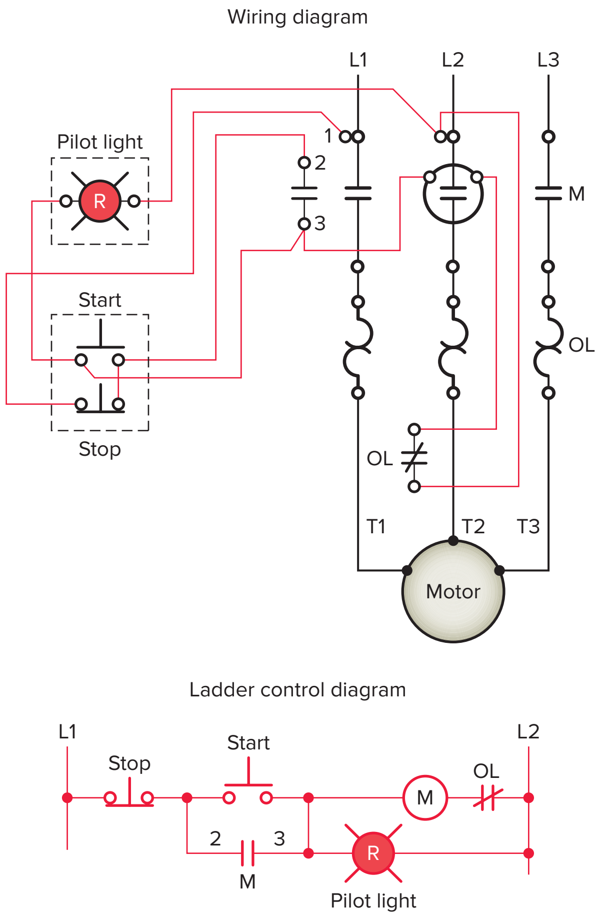


Figure 2-20 **Combination wiring and ladder diagram.**

Wiring diagrams are often used in conjunction with ladder diagrams to simplify understanding of the control process. An example of this is illustrated in Figure 2-20. The wiring diagram shows both the power and control circuits. A separate ladder diagram of the control circuit is included to give a clearer understanding of its operation. By following

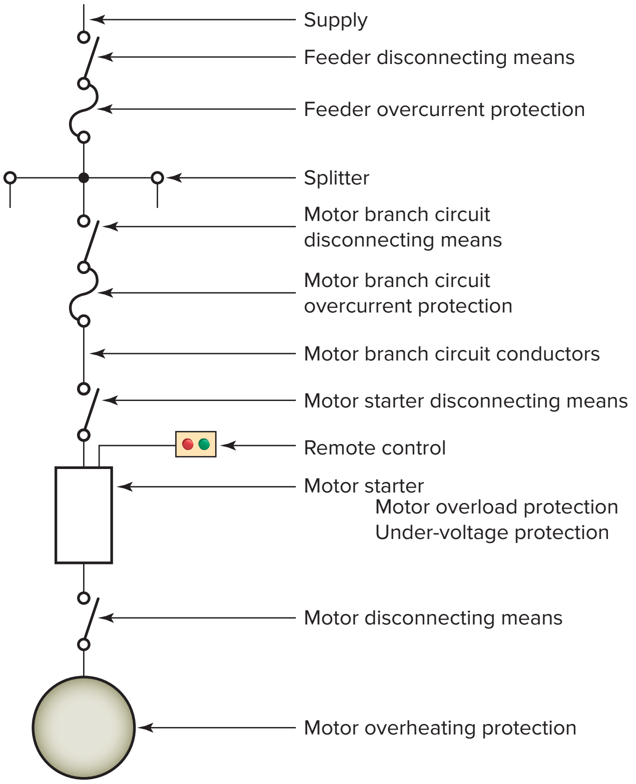


Figure 2-21 **Single-line diagram of a motor installation.**

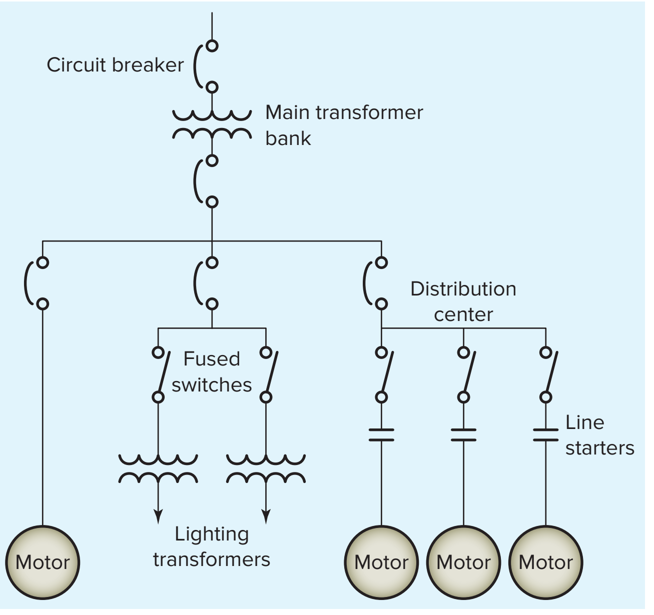


Figure 2-22 **Single-line diagram of a power distribution system.**

the ladder diagram, it can be seen that the pilot light is wired so that it will be on whenever the starter is energized. The power circuit has been omitted for clarity, since it can be traced readily on the wiring diagram (heavy black lines).

Single-Line Diagrams

A **single-line** (also called a one-line) diagram uses symbols along with a single line to show all major components of an electric circuit. Some motor control equipment manufacturers use a single-line drawing, like the one shown in Figure 2-21, as a road map in the study of motor control installations. The installation is reduced to the simplest possible form, yet it still shows the essential requirements and equipment in the circuit.

Power systems are extremely complicated electrical networks that may be geographically spread over very large areas. For the most part, they are also three-phase networks—each power circuit consists of three conductors and all devices such as generators, transformers, breakers, and disconnects installed in all three phases. These systems can be so complex that a complete conventional diagram showing all the connections is impractical. When this is the case, use of a single-line diagram is a concise way of communicating the basic arrangement of the power system's component. Figure 2-22 shows a single-line diagram of a small power distribution system. These types of diagrams are also called "power riser" diagrams.

Block Diagrams

A block diagram represents the major functional parts of complex electrical/electronic systems by **blocks** rather than symbols. Individual components and wires are not shown. Instead, each block represents electrical circuits that perform specific functions in the system. The functions the circuits perform are written in each block. Arrows connecting the blocks indicate the general direction of current paths.

Figure 2-23 shows a block diagram of a variable-frequency AC motor drive. A **variable-frequency drive** controls the speed of an AC motor by varying the frequency supplied to the motor. The drive also regulates the output voltage in proportion to the output frequency to provide a relatively constant ratio (volts per hertz; V/Hz) of voltage

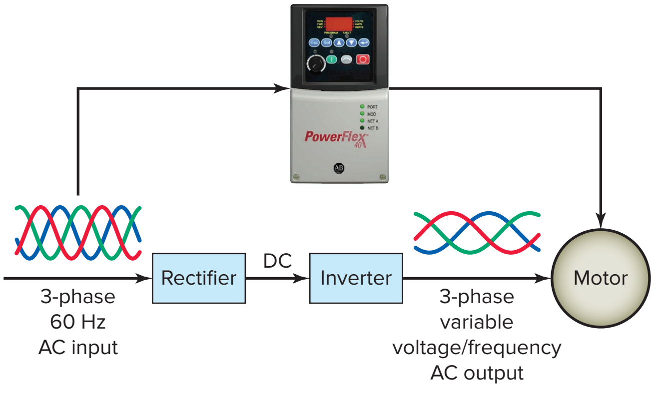


Figure 2-23 **Block diagram of a variable-frequency AC drive.**
Photo courtesy of Rockwell Automation, www.rockwellautomation.com

to frequency, as required by the characteristics of the AC motor to produce adequate torque. The function of each block is summarized as follows:

- 60 Hz three-phase power is supplied to the rectifier block.
- The **rectifier block** is a circuit that converts or rectifies its three-phase AC voltage into a DC voltage.
- The **inverter block** is a circuit that inverts, or converts, its DC input voltage back into an AC voltage. The inverter is made up of electronic switches, which switch the DC voltage on and off to produce a controllable AC power output at the desired frequency and voltage.

Riser Diagrams

A **riser diagram** is similar to line and block diagrams in that it shows the relationship of components within a circuit and the single line connections between them. The main difference is that a riser diagram shows the circuit as an **elevation** and is more physical than electrical oriented. Riser diagrams are often part of construction installation drawings. Figure 2-24 shows an example of a **power riser diagram** that shows at a glance how electrical power is distributed throughout the floors of a building.

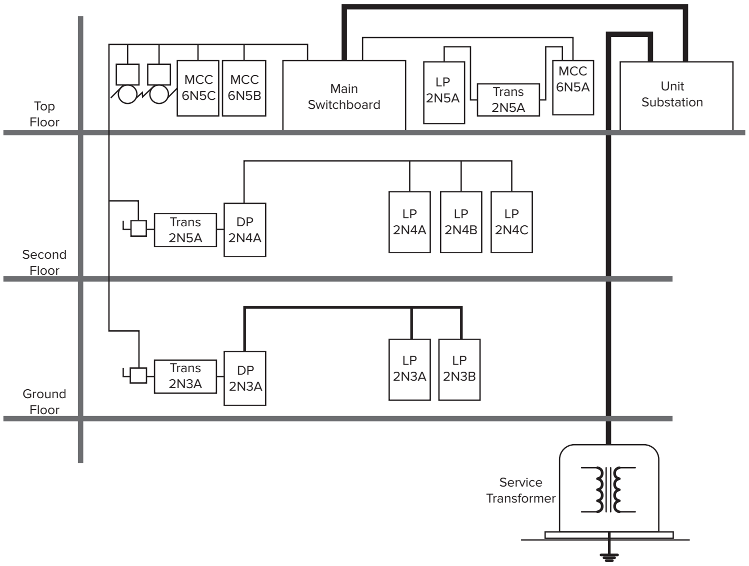


Figure 2-24 Electrical power riser diagram.

Part 2 Review Questions

1. What is the main purpose of a wiring diagram?
2. In addition to numbers, what other method can be used to identify wires on a wiring diagram?
3. What role can a wiring diagram play in the troubleshooting of a motor control circuit?
4. List the pieces of information most likely to be found in the conduit and cable schedule for a motor installation.
5. Explain the purpose of using a motor wiring diagram in conjunction with a ladder diagram of the control circuit.
6. What is the main purpose of a single-line diagram?
7. What is the main purpose of a block diagram?
8. Explain the function of the rectifier and inverter blocks of a variable-frequency AC drive.
9. In what way do electrical risers diagrams differ from line and block diagram types?

PART 3 MOTOR TERMINAL CONNECTIONS

Motor Classification

Electric motors have been an important element of our industrial and commercial economy for over a century. Most of the industrial machines in use today are driven by electric motors. Industries would cease to function without properly designed, installed, and maintained motor control systems. In general, motors are classified according to the type of power used (AC or DC) and the motor's principle of operation. The "family tree" of motor types is illustrated in Figure 2-25.

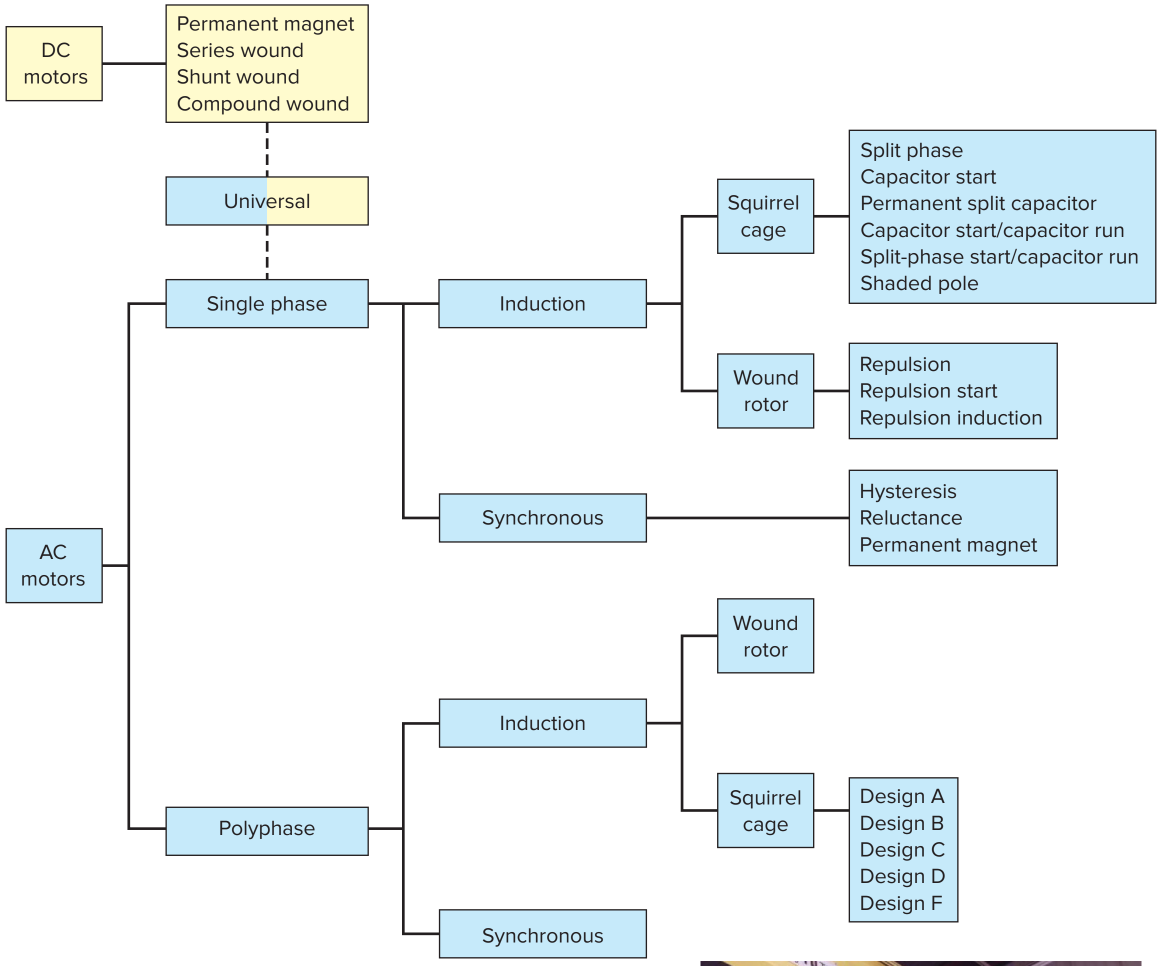


Figure 2-25 Family tree of motor types.

In the United States the Institute of Electrical and Electronics Engineers (IEEE) establishes the standards for motor testing and test methodologies, while the National Electrical Manufacturers Association (NEMA) prepares the standards for motor performance and classifications. Additionally, motors shall be installed in accordance with Article 430 of the National Electrical Code (NEC).

DC Motor Connections

Industrial applications use DC motor because the speed–torque relationship can be easily varied. DC motor applications include cranes (Figure 2-26), conveyors, elevators, and material-handling processes.

- DC motors feature a speed, which can be controlled smoothly down to zero, immediately followed by acceleration in the opposite direction.
- In emergency situations, DC motors can supply over **five times rated torque** without stalling.

Figure 2-26 DC motor used on cranes.
Photo courtesy of Wilcox Door Service Inc., www.wilcoxdoor.com

Figure 2-27 **Parts of a DC compound motor.**
Photo courtesy of Siemens, www.siemens.com

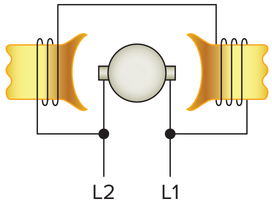
- **Dynamic braking** (DC motor-generated energy is fed to a resistor grid) or **regenerative braking** (DC motor-generated energy is fed back into the DC motor supply) can be obtained with DC motors on applications requiring quick stops, thus eliminating the need for, or reducing the size of, a mechanical brake.

Figure 2-27 shows the symbols used to identify the basic parts of a direct current (DC) compound motor. The rotating part of the motor is referred to as the armature; the stationary part of the motor is referred to as the stator, which contains the series field winding and the shunt field winding. In DC machines **A1 and A2** always indicate the armature leads, **S1 and S2** indicate the series field leads, and **Fl and F2** indicate the shunt field leads.

It is the kind of field excitation provided by the field that distinguishes one type of DC motor from another; the construction of the armature has nothing to do with the motor classification. There are three general types of DC motors, classified according to the method of field excitation as follows:

- A shunt DC motor (Figure 2-28) uses a comparatively high resistance shunt field winding, made up of many turns of fine wire, connected in parallel (shunt) with the armature.
- A series DC motor (Figure 2-29) uses a very low resistance series field winding, made up of very few turns of heavy wire, connected in series with the armature.
- A compound DC motor (Figure 2-30) uses a combination of a shunt field (many turns of fine wire) in parallel with the armature, and series field (few turns of heavy wire) in series with the armature.

All connections shown in Figures 2-28, 2-29, and 2-30 are for counterclockwise and clockwise rotation facing the end opposite the drive (commutator end). One purpose of applying markings to the terminals of motors according to a standard is to aid in making connections when a predictable rotation direction is required. This may be the case when improper rotation could result in unsafe operation or damage. Terminal markings are normally used to tag only



Counterclockwise		Clockwise	
Line 1 F1-A1	Line 2 F2-A2	Line 1 F1-A2	Line 2 F2-A1

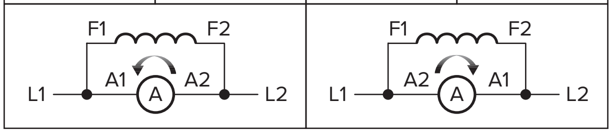
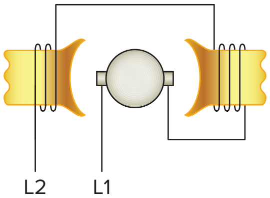


Figure 2-28 **Standard DC shunt motor connections for counterclockwise and clockwise rotation.**



Counterclockwise			Clockwise		
Line 1 A1	Tie A2-S1	Line 2 S2	Line 1 A2	Tie A1-S1	Line 2 S2

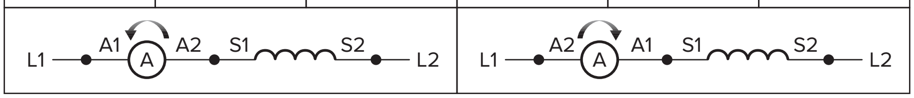
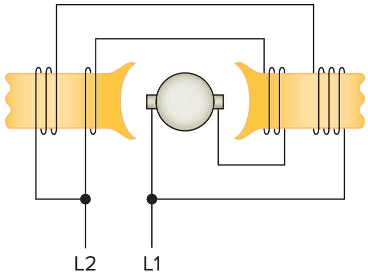


Figure 2-29 **Standard DC series motor connections for counterclockwise and clockwise rotation.**



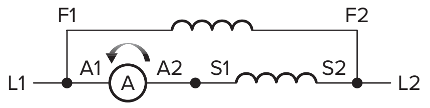
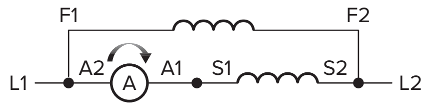
Counterclockwise			Clockwise		
Line 1 F1-A1	Tie A2-S1	Line 2 F2-S2	Line 1 F1-A2	Tie A1-S1	Line 2 S2-F2
					

Figure 2-30 **Standard DC compound (cumulative) motor connections for counterclockwise and clockwise rotation. For differential compound connection, reverse S1 and S2.**

those terminals to which connections must be made from outside circuits.

The direction of rotation of a DC motor depends on the direction of the magnetic field and the direction of current flow in the armature. If **either** the direction of the field or the direction of current flow through the armature is reversed, the rotation of the motor will reverse. However, if **both** of these factors are reversed at the same time, the motor will continue rotating in the same direction.

AC Motor Connections

The **AC induction motor** is the dominant motor technology in use today, representing more than 90 percent of installed motor capacity. Induction motors are available in single-phase (1ϕ) and three-phase (3ϕ) configurations, in sizes ranging from fractions of a horsepower to tens of thousands of horsepower. They may run at fixed speeds—most commonly 900, 1200, 1800, or 3600 rpm—or be equipped with an adjustable-speed drive.

The most commonly used AC motors by far have a **squirrel-cage** configuration (Figure 2-31), so named because of the aluminum or copper squirrel cage imbedded within the iron laminates of the rotor. There is no physical electrical connection to the squirrel cage. Current in the rotor is induced by the rotating magnetic field of the stator. **Wound-rotor** models, in which coils of wire in the rotor windings, are also available. These are expensive but offer greater control of the motor's performance characteristics, so they are most often used for special torque and acceleration applications and for adjustable-speed applications.

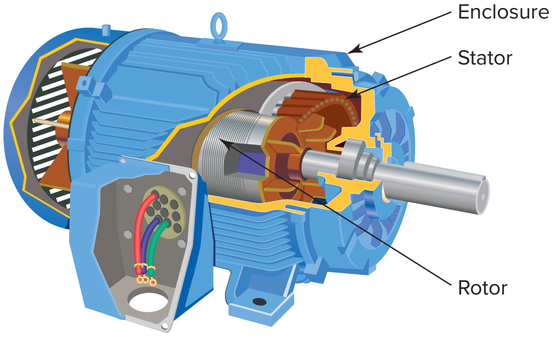


Figure 2-31 **Three-phase squirrel-cage AC induction motor.**
Photo courtesy of Siemens, www.siemens.com

Single-Phase Motor Connections The majority of single-phase AC induction motors are constructed in fractional horsepower sizes for 120 to 240 V, 60 Hz power sources. Although there are several types of single-phase motors, they are basically identical except for the means of starting. The "split-phase motor" is most widely used for medium starting applications (Figure 2-32). The operation of the split-phase motor is summarized as follows:

- The motor has a start and a main winding, which are both energized when the motor is started.
- The start-winding produces a phase difference to start the motor and is switched out by a centrifugal switch as running speed is approached. When the

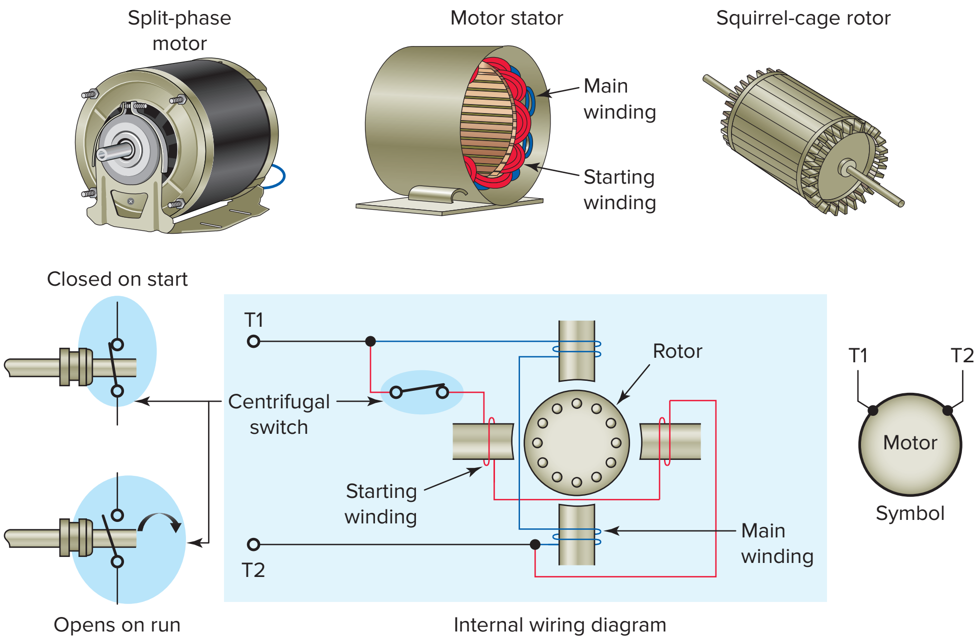


Figure 2-32 **AC split-phase induction motor.**

motor reaches about 75 percent of its rated full load speed, the starting winding is disconnected from the circuit.

- Split-phase motor sizes range up to about ½ horsepower. Popular applications include fans, blowers, home appliances such as washers and dryers, and tools such as small saws or drill presses where the load is applied after the motor has obtained its operating speed.
- The motor can be reversed by reversing the leads to the start-winding or main winding, but not to both. Generally, the industry standard is to reverse the start winding leads

In a **dual-voltage** split-phase motor (Figure 2-33), the running winding is split into two sections and can be connected to operate from a **120 V or 240 V** source. The two run windings are connected in series when operated from a 240 V source, and in parallel for 120 V operation. The start winding is connected across the supply lines for low voltage and at one line to the midpoint of the run windings for high voltage. This ensures that all windings receive the 120 V they are designed to operate at. To reverse the direction of rotation of a dual-voltage split-phase motor, interchange the two start winding leads. Dual-voltage motors are connected for the desired voltage by following the connection diagram on the nameplate.

The nominal dual-voltage split-phase motor rating is 120/240 V. With any type of dual-voltage motor, the **higher** voltage is preferred when a choice between voltages is available. The motor uses the same amount of power and produces the same amount of horsepower when operating from a 120 V or 240 V supply. However, as the voltage is doubled from 120 V to 240 V, the current is cut in half. Operating the motor at this reduced current level allows you to use smaller circuit conductors and reduces line power losses.

Many single-phase motors use a capacitor in series with one of the stator windings to optimize the phase difference between the start and run windings for starting. The result is a higher starting **torque** than a split-phase motor can produce. There are three types of capacitor motors: **capacitor start,** in which the capacitor phase is in the circuit only during starting; **permanent-split capacitor,** in which the capacitor phase is in the circuit for both starting and running; and **two-value capacitor,** in which there are different values of capacitance for starting and running. The permanent-split capacitor motor, illustrated in Figure 2-34, uses a capacitor permanently connected in series with one of the stator windings. This design is lower in cost than the capacitor-start motors that incorporate capacitor switching systems. Installations include compressors, pumps, machine tools, air conditioners, conveyors, blowers, fans, and other hard-to-start applications.

Three-Phase Motor Connections The three-phase AC induction motor is the most common motor used in commercial and industrial applications. Single-phase larger horsepower motors are not normally used because they are

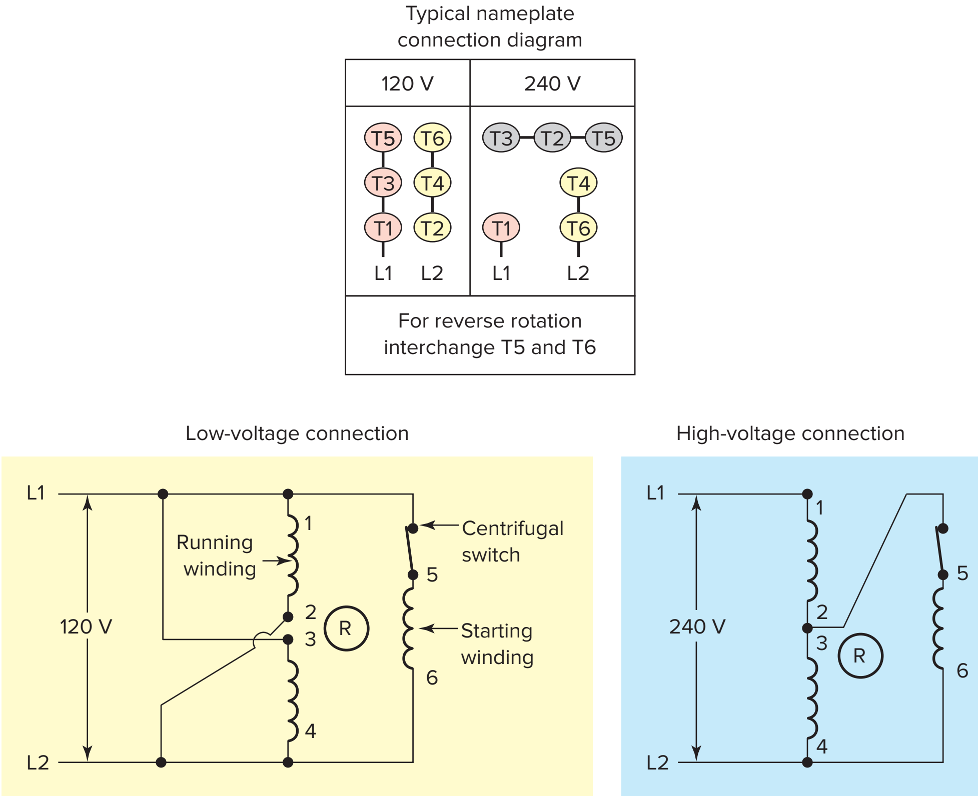


Figure 2-33 **Dual-voltage split-phase motor stator connections.**

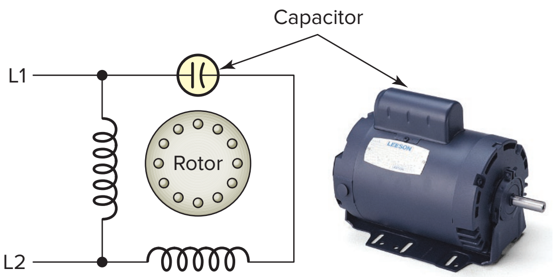


Figure 2-34 **Permanent-split capacitor motor.**
Photo courtesy of Leeson, www.leeson.com

inefficient compared to three-phase motors. In addition, single-phase motors are not self-starting on their running windings, as are three-phase motors.

Large horsepower AC motors are usually three-phase. All three-phase motors are constructed internally with a number of individually wound coils. Regardless of how many individual coils there are, the individual coils will always be wired together (series or parallel) to produce three distinct windings, which are referred to as phase A, phase B, and phase C. All three-phase motors are wired so that the phases are connected in either **wye (Y)** or **delta (Δ)** configuration, as illustrated in Figure 2-35.

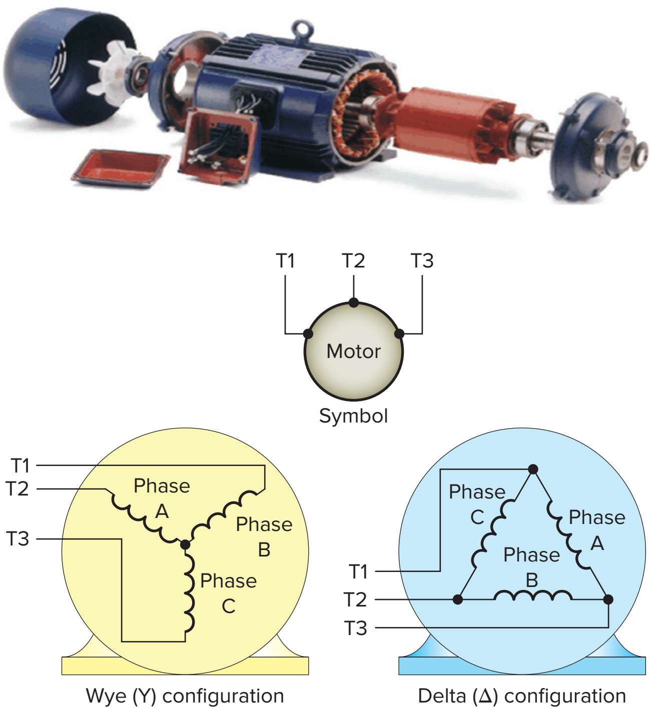


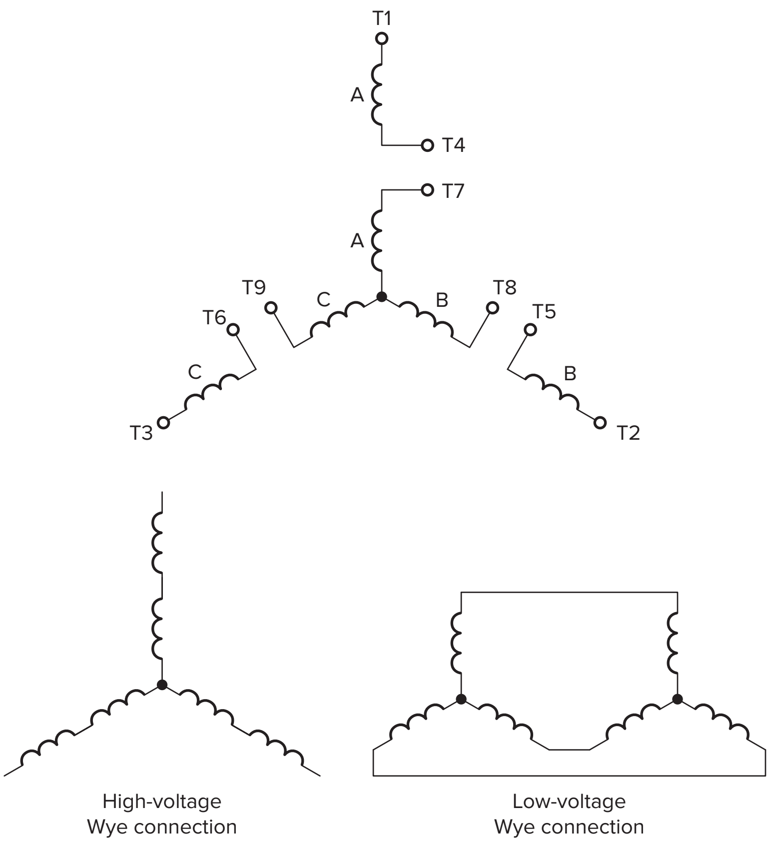
Figure 2-35 **Three-phase wye and delta motor connections.**
Photo courtesy of Leeson, www.leeson.com

Dual-Voltage Motor Connections Manufacturers deploy various external connection schemes to produce three-phase induction motors for multiple voltages and/or starting methods. The following apply to common three-phase motor connections.

- **Three-lead** single voltage connections are the most common and simple. Supply line leads L1, L2, L3 are directly connected to motor leads T1, T2, T3. If there's any doubt about the connection, it's a good idea to run the machine unloaded to determine the direction of rotation.
- **Six-lead** dual voltage connections are numbered 1 through 6. The winding can be connected wye or delta. On machines rated for two voltages, the wye connection is for the high voltage; the delta connection is for the low voltage. The voltage ratio is 1.73, for example, 220 volts low voltage and 380 volts high voltage.
- **Nine-lead** dual voltage connections are numbered 1 through 9. The motor is typically rated for two voltages and could be designed with either a wye connection or a delta connection. The two connections have a 2-to-1 voltage difference. The nine-lead wye connected motor is the most common type of three-phase motor used in commercial and industrial installations.
- **Twelve-lead** dual voltage connections are numbered 1 through 12. The motor is typically rated for standardized voltages of 230/460 volts that requires 12 leads to accommodate.

It is common practice to manufacture three-phase motors that can be connected to operate at different voltage levels. The most common multiple-voltage rating for three-phase motors is 208/230/460 V. Always check the motor specifications or nameplate for the proper voltage rating and wiring diagram for method of connection to the voltage source.

Figure 2-36 illustrates the typical terminal identification and connection table for a nine-lead dual-voltage wye-connected three-phase motor. One end of each phase is internally permanently connected to the other phases. Each phase coil (A, B, C) is divided into two equal parts and connected in either series for high-voltage operation or parallel for low-voltage operation. According to NEMA nomenclature, these leads are marked T1 through T9. High-voltage and low-voltage connections are given in the accompanying connection table and motor terminal board. The same principle of series (high-voltage) and parallel (low-voltage) coil connections is applied for dual-voltage wye–delta connected



Connection table

Voltage	L1	L2	L3	Tie together
Low	1-7	2-8	3-9	4-5-6
High	1	2	3	4-7, 5-8, 6-9

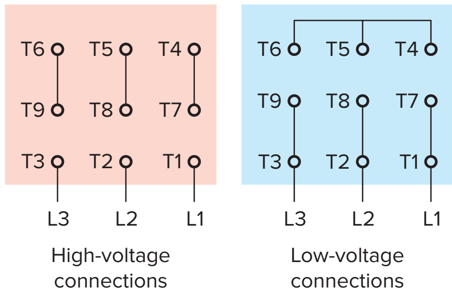


Figure 2-36 **Dual-voltage wye connections.**

three-phase motors. In all cases refer to the wiring diagram supplied with the motor to ensure proper connection for the desired voltage level.

Figure 2-37 illustrates the IEC nomenclature for an equivalent IEC nine-lead dual-voltage wye connected three-phase motor. For the **high-voltage** connection:

- Nine leads are brought out of the motor.
- These leads are labeled U1, U2, U5 – V1, V2, V5 – W1, W2, W5.
- They are externally connected for either of the two voltages.
- To connect the wye configuration for high voltage, connect L1 to U1, L2 to V1, L3 to W1, and tie U2 to U5, V2 to V5, and W2 to W5.
- The internally connected ***Y points***, which otherwise would have been U6, V6, and W6, are not brought out.
- This connects the two individual parts of the phase coils A, B, and C in **series,** with each coil receiving 50 percent of the line-to-neutral point voltage.

In a similar fashion, for the **low-voltage** wye configuration:

- Connect L1 to U1 and U5, L2 to V1 and V5, L3 to W1 and W5 and tie U2, V2, and W2 together.
- This connects the two individual parts of the phase coils in **parallel** with each coil receiving 100 percent of the line-to-neutral point voltage.

Multispeed Motor Connections Some three-phase motors, referred to as **multispeed motors,** are designed to provide two separate speed ranges. The speed of an induction motor depends on the number of poles built into the motor and the frequency of the electrical power supply. Changing the number of poles provides specific speeds that correspond to the number of poles selected. The more poles per phase, the slower the operating rpm of the motor.

$$\text{RPM} = 120 \times \frac{\text{Frequency}}{\text{Number of poles}}$$

Two-speed motors with single windings can be reconnected, using a controller, to obtain different speeds. The controller circuitry serves to change the connections of the stator windings. These motors are wound for one speed, but when the winding is reconnected, the number of magnetic poles within the stator is doubled and the motor speed is reduced to one-half the original speed. This type of reconnection should not be confused

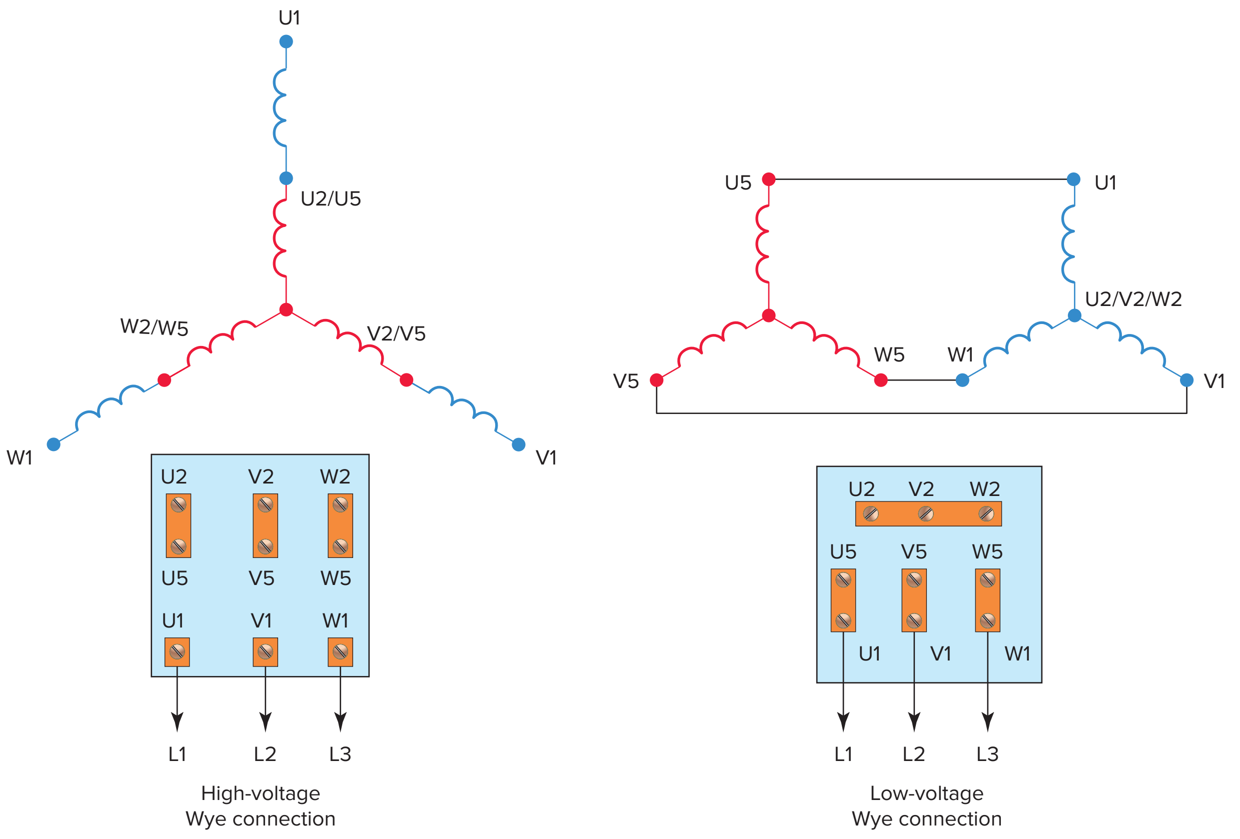
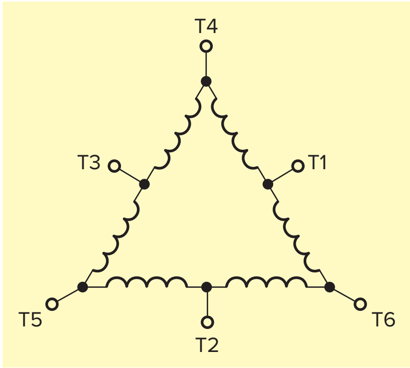


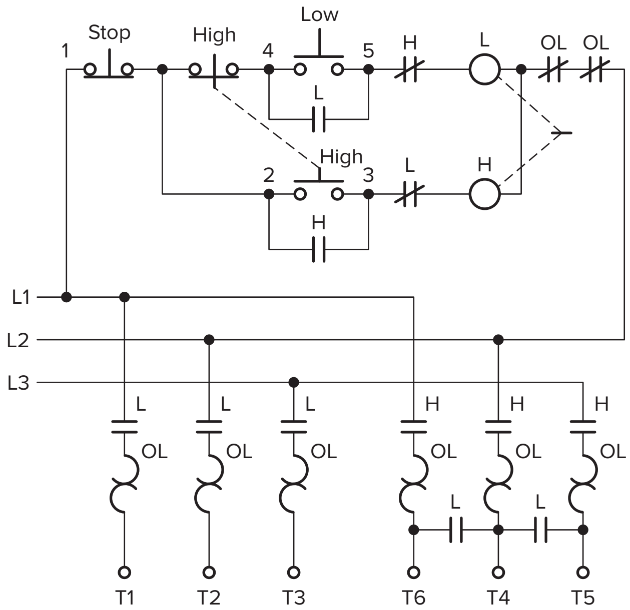
Figure 2-37 IEC nomenclature for an equivalent IEC nine-lead dual-voltage wye connected three-phase motor.



Motor windings

Speed	Line wires	Tie together	Winding connection
Low	T1-T2-T3	T4-T5-T6	2-parallel Y
High	T4-T5-T6	–––––––	Series Δ

Connection table



Typical controller wiring diagram

Figure 2-38 **Constant-horsepower two-speed, three-phase motor and controller.**

with the reconnection of dual-voltage three-phase motors. In the case of multispeed motors, the reconnection results in a motor with a different number of magnetic poles. Three types of single-winding two-speed motors are available: **constant horsepower, constant torque,** and **variable torque.** Figure 2-38 shows the connections for a constant-horsepower two-speed, three-phase motor and controller.

To reverse the direction of rotation of any three-phase wye- or delta-connected motor, simply **reverse or interchange** any two of the three main power leads to the motor. Standard practice is to interchange L1 and L3 as illustrated in Figure 2-39. When you are connecting a motor, the direction of rotation is usually not known until the motor is started. In this case, the motor may be temporarily connected to determine the direction of rotation before making permanent connections.

In certain applications, unintentional reversal of motor rotation can result in serious damage. When this is the case, phase failure and phase reversal relays are used to protect motors, machines, and personnel from the hazards

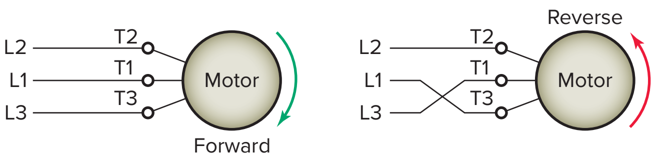


Figure 2-39 **Reversing the direction of rotation of a three-phase motor.**

of open-phase or reversed phase conditions. The schematic diagram of Figure 2-40 shows a typical application for a **reverse-phase relay.** The operation of this circuit can be summarized as follows:

- The relay is designed to continuously **monitor phase rotation** of the three-phase lines.
- A solid-state sensing circuit within the relay controls an electromechanical relay coil, the **normally open (NO) contact,** that **closes** when power with correct phase rotation is applied.
- The relay coil **will not energize** if the applied phases are reversed and will **de-energize** if phase rotation is reversed while the motor is running.

The speed of an AC induction motor depends on two factors: the number of motor poles and the frequency of the applied power. In variable-frequency motor drives, variable speed of an induction motor is achieved by varying the frequency of the voltage applied to the motor. The lower the frequency, the slower the operating rpm of the motor.

Standard induction motors can be detrimentally affected when operated by variable-frequency drives. **"Inverter duty"** and **"vector duty"** describe a class of motors that are capable of operation from a variable-frequency drive. Low temperature rise in this class of motor is accomplished with better insulation systems, additional active material (iron and copper), and/or external fans for better cooling at low-speed operation.

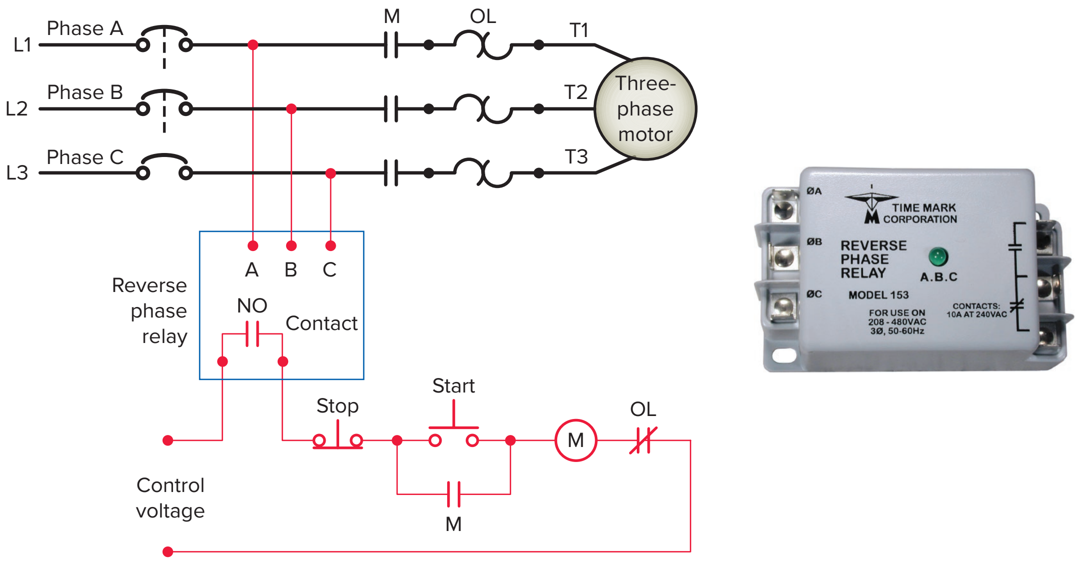


Figure 2-40 **Reverse-phase relay circuit.**
Time Mark Corporation, 2014.

Part 3 Review Questions

1. In what two general ways are motors classified?
2. List three major organizations involved with motor standards and installation requirements in the United States.
3. What two DC motor operating features make them useful for industrial applications?
4. What part of a DC motor is identified by each of the following lead designations?
   a. A1 and A2
   b. S1 and S2
   c. F1 and F2
5. List the three general types of DC motors.
6. What two factors determine the direction of rotation of a DC motor?
7. In what phase configurations are AC induction motors available?
8. What terms are used to identify the rotating and stationary parts of an AC induction motor?
9. Describe the construction of and external electrical connection to the squirrel-cage rotor used in AC induction motors.
10. Outline the starting sequence of a split-phase motor.
11. Assume the direction of rotation of a split-phase motor needs to be reversed. How is this done?
12. A dual-voltage split-phase motor is to be connected for the lower voltage. What connection of the two run windings would be used?
13. You have the option of operating a dual-voltage motor at either the high- or low-voltage level. What are the advantages of operating it at the high-voltage level?
14. What is the main advantage of the capacitor motor over the standard split-phase type?
15. How are the three distinct windings of a three-phase motor identified?
16. Large horsepower AC motors are usually three-phase. Why?
17. What two basic configurations are used for the connection of all three-phase motors?
18. According to NEMA nomenclature, how are the leads of a nine-lead dual-voltage three-phase motor labeled?
19. State the relationship between the speed of a three-phase induction motor and the number of poles per phase.
20. Assume the direction of rotation of a three-phase motor needs to be reversed. How is this done?
21. State the relationship between the speed of a three-phase induction motor and the frequency of the power source.

22. Why should inverter-duty AC induction motors be used in conjunction with variable-frequency motor drives?
23. According to NEMA nomenclature the output leads of a three-phase motor are identified as T1, T2, T3. What is the equivalent IEC nomenclature?
24. For a dual-voltage nine-lead three-phase motor each phase coil (A, B, C) is divided into two equal parts. What electrical connection of the phase coils is used for high-voltage operation and low-voltage operation?
25. For six-lead dual-voltage three-phase motors what three-phase configuration is used for the low- and high-voltage connections?

PART 4 MOTOR NAMEPLATE AND TERMINOLOGY

The motor nameplate (Figure 2-41) contains important information about the connection and use of the motor. An important part of making motors interchangeable is ensuring that nameplate information is common among manufacturers.

NEC Required Nameplate Information

Motor Manufacture This will include the name and logo of the manufacturer along with catalog numbers, parts numbers, and model numbers used to identify a motor. Each manufacturer uses a unique coding system.

Voltage Rating Voltage rating is abbreviated **V** on the nameplate of a motor. It indicates the voltage at which the motor is designed to operate. The voltage of a motor is usually determined by the supply to which it is being attached. NEMA requires that the motor be able to carry its rated horsepower at nameplate voltage ±10 percent although not necessarily at the rated temperature rise. Thus, a motor with a rated nameplate voltage of 460 V should be expected to operate successfully between 414 V and 506 V.

The voltage may be a single rating such as 115 V or, for dual-voltage motors, a dual rating such as 115 V/230 V. Most 115/230 V motors are shipped from the factory connected for 230 V. A motor connected for 115 V that has 230 V applied will burn up immediately. A motor connected for 230 V that has 115 V applied will be a slow-running motor that overheats and trips out.

NEMA standard motor voltages are:

Single-phase motors—115, 230, 115/230, 277, 460, and 230/460 V

Three-phase motors up to 125 hp—208, 230, 460, 230/460, 575, 2,300, and 4,000 V

Three-phase motors above 125 Hp—460, 575, 2,300, and 4,000 V

When dealing with motors, it is important to distinguish between **nominal** system and **nameplate** voltages. Examples of the differences between the two are as follows:

Nominal system voltage	Nameplate voltage
120 V	115 V
220 V	208 V
240 V	230 V
480 V	460 V
600 V	575 V
2,400 V	2,300 V
4,160 V	4,000 V
6,900 V	6,600 V

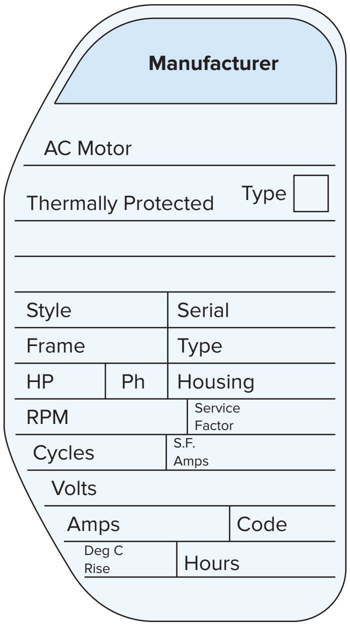


Figure 2-41 Typical motor nameplate.

Current Rating The nameplate current rating of a motor is abbreviated **A or AMPS.** The nameplate current rating is the full-load current (also known as FLA) at rated load, rated voltage, and rated frequency. Motors that are not fully loaded draw less than the rated nameplate current. Similarly, motors that are overloaded draw more than the rated nameplate current.

Motors that have dual voltage ratings also have dual current ratings. A dual-voltage motor operated at the higher voltage rating will have the lower current rating. For example, a ½ hp motor rated 115/230 V and 7.4/3.7 A will have a rated current of 3.7 A when operating from a 230 V supply.

Line Frequency The line frequency rating of a motor is abbreviated on the nameplate as **CY or CYC (cycle), or Hz (hertz).** A cycle is one complete wave of alternating voltage or current. Hertz is the unit of frequency and equals the number of cycles per second. In the United States, 60 cycles/second (Hz) is the standard, while in other countries 50 Hz (cycles) is more common.

Phase Rating The phase rating of a motor is abbreviated on the nameplate as **PH.** The phase rating is listed as direct current (DC), single-phase alternating current (1ϕ AC), or three-phase alternating current (3ϕ AC).

Motor Speed The rated speed of a motor is indicated on the nameplate in revolutions per minute **(rpm).** This rated motor speed is not the exact operating speed, but the approximate speed at which a motor rotates when delivering rated horsepower to a load.

The number of poles in the motor and the frequency of the supply voltage determine the speed of an AC motor. The speed of a DC motor is determined by the amount of supply voltage and/or the amount of field current.

Ambient Temperature The ambient temperature rating of a motor is abbreviated **AMD or DEG** on the nameplate of a motor. Ambient temperature is the temperature of the air surrounding the motor. In general, maximum ambient temperature for motors is **40°C or 104°F** unless the motor is specifically designed for a different temperature and indicates so on its nameplate.

Motors operating at or near rated full load will have reduced life if operated at ambient temperatures above their ratings. If the ambient temperature is over 104°F, a higher-horsepower motor or a special motor designed for operation at higher ambient temperatures must be used.

Temperature Rise A motor's permissible temperature rise is abbreviated **Deg.C/Rise** on the nameplate of the motor. This indicates the amount the motor winding temperature will increase above the ambient temperature because of the heat from the current drawn by the motor at full load. It can also be thought of as the amount by which a motor operating under rated conditions is hotter than its surrounding temperature.

Thermal imagers (also known as infrared cameras or infrared imagers) capture images of infrared energy or temperature. Thermal images of electric motors (Figure 2-42) reveal their temperature operating conditions as reflected by their surface temperature. While the infrared camera cannot see the inside of the motor, the exterior surface temperature is an indicator of the internal temperature. As the motor gets hotter inside, it also gets hotter outside. Such condition monitoring is one way to avert many unexpected motor malfunctions in systems.

Insulation Class Motor insulation prevents windings from shorting to each other or to the frame of the motor. The type of insulation used in a motor depends on the operating temperature the motor will experience. As the heat in a motor increases beyond the temperature rating of the insulation, the life of the insulation and of the motor is shortened.

Standard NEMA insulation classes are given by **alphabetic classifications** according to their maximum temperature rating. A replacement motor must have the same

Figure 2-42 **Motor thermal imaging inspection.**
Photo courtesy of Fluke, www.fluke.com. Reproduced with Permission.

insulation class or a higher temperature rating than the motor it is replacing. The four major NEMA classifications of motor insulation are as follows:

NEMA classification	Maximum operating temperatures
A	221°F (105°C)
B	266°F (130°C)
F	311°F (155°C)
H	356°F (180°C)

Duty Cycle The duty cycle is listed on the motor nameplate as DUTY, DUTY CYCLE, or TIME RATING. Motors are classified according to the length of time they are expected to operate under full load as either continuous duty or intermittent duty. Continuous duty cycle–rated motors are identified as **CONT** on the nameplate, while intermittent-duty cycle motors are identified as **INTER** on the nameplate.

Continuous-duty motors are rated to operate continuously without any damage or reduction in the life of the motor. General-purpose motors will normally be rated for continuous duty. Intermittent-duty motors are rated to operate continuously only for short time periods and then must be allowed to stop and cool before restarting.

Horsepower Rating The horsepower rating of the motor is abbreviated on the nameplate as **HP.** Motors below 1 horsepower are referred to as fractional-horsepower motors and motors 1 horsepower and above are called integral-horsepower motors. The HP rating is a measure of the full load output power the shaft of the motor can produce without reducing the motor's operating life. NEMA has established standard motor horsepower ratings from 1 hp to 450 hp.

Some small fractional-horsepower motors are rated in watts (1 hp = 746 W). Motors rated by the International Electrotechnical Commission (IEC) are rated in kilowatts (kW). When an application calls for a horsepower falling between two sizes, the larger size is chosen to provide the appropriate power to operate the load.

Code Letter An alphabetic letter is used to indicate the National Electric Code Design Code letter for the motor. When AC motors are started with full voltage applied, they draw a starting or "locked-rotor" line current substantially greater than their full-load running current rating. The value of this high current is used to determine circuit breaker and fuse sizes in accordance with NEC requirements. In addition, the starting current can be important on some installations where high starting currents can cause a voltage dip that might affect other equipment.

Motors are furnished with a code letter on the nameplate that designates the locked-rotor rating of the motor in kilovolt-amperes (kVA) per nameplate horsepower. Code letters from A to V are listed in Article 430 of the National Electrical Code. As an example, an M rating allows for 10.0 to 11.19 kVA per horsepower.

Code	kVA/hp	Code	kVA/hp
A	0–3.14	L	9.0–9.99
B	3.15–3.54	M	10.0–11.19
C	3.55–3.99	N	11.2–12.49
D	4.0–4.49	P	12.5–13.99
E	4.5–4.99	R	14.0–15.99
F	5.0–5.59	S	16.0–17.99
G	5.6–6.29	T	18.0–19.99
H	6.3–7.09	U	20.0–22.39
J	7.1–7.99	V	22.4 & Up
K	8.0–8.99		

Code Letters

Design Letter The design letter is an indication of the shape of the motor's torque–speed curve. The most common design letters are A, B, C, D, and E.

Design B is the standard industrial-duty motor, which has reasonable starting torque with moderate starting current and good overall performance for most industrial applications.

Optional Nameplate Information

Service Factor Service factor (abbreviated **SF** on the nameplate) is a multiplier that is applied to the motor's normal horsepower rating to indicate an increase in power output (or overload capacity) that the motor is capable of providing under certain conditions. For example, a 10 hp motor with a service factor of 1.25 safely develops 125 percent of rated power, or 12.5 hp. Generally, electric motor service factors indicate that a motor can:

- Handle a known overload that is occasional.
- Provide a factor of safety where the environment or service condition is not well defined, especially for general-purpose electric motors.
- Operate at a cooler-than-normal temperature at rated load, thus lengthening insulation life.

Common values of service factor are 1.0, 1.15, and 1.25. When the nameplate does not list a service factor, a service factor of 1.00 is assumed. In some cases, the

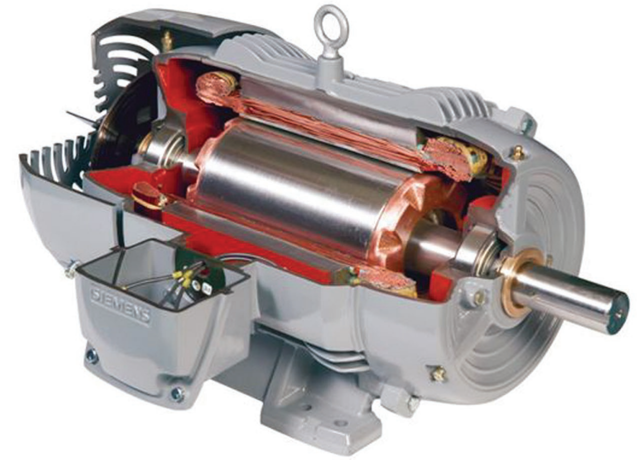
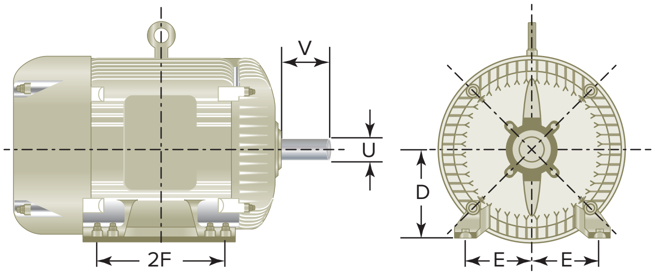


Figure 2-43 **Totally enclosed motor.**
Photo courtesy of Siemens, www.siemens.com



Frame Size	U	D	E	2F	V Min.
42	3/8″	2-5/8″	1-1/4″	1-11/16″	1-1/8″

Figure 2-44 **Typical NEMA frame size dimensions.**

running current at service factor loading is also indicated on the nameplate as service factor amperes (SFA).

Motor Enclosure The selection of a motor enclosure depends on the ambient temperature and surrounding conditions. The two general classifications of motor enclosures are open and totally enclosed. An **open** motor has ventilating openings, which permit passage of external air over and around the motor windings. A **totally enclosed** motor is constructed to prevent the free exchange of air between the inside and outside of the frame, but not sufficiently enclosed to be termed airtight (Figure 2-43).

Frame Size Refers to a set of **physical dimensions** of motors as established by NEMA and IEC. Frame sizes include physical size, construction, dimensions, and certain other physical characteristics of a motor. When you are changing a motor, selecting the same frame size regardless of manufacturer ensures the mounting mechanism and hole positions will match.

Dimensionally, NEMA standards are expressed in English units (Figure 2-44) and IEC standards are expressed in metric units. NEMA and IEC standards both use letter codes to indicate specific mechanical dimensions, plus number codes for general frame size.

Efficiency Efficiency is included on the nameplate of many motors. The efficiency of a motor is a measure of the effectiveness with which the motor converts electrical energy into mechanical energy. Motor efficiency varies from the nameplate value depending on the percentage of the rated load applied to the motor. Most motors operate near their maximum efficiency at rated load.

Energy-efficient motors, also called premium or high-efficiency motors, are 2 to 8 percent more efficient than standard motors. Motors qualify as "energy efficient" if they meet or exceed the efficiency levels listed in the NEMA's MG1 publication. Energy-efficient motors owe their higher performance to key design improvements and more accurate manufacturing tolerances.

Power Factor The letters **P.F.** when marked on the nameplate of motors stand for power factor. The power factor rating of a motor represents the motor's power factor at rated load and voltage. Motors are inductive loads and have power factors less than 1.0, usually between 0.5 and 0.95, depending on their rated size. A motor with a low power factor will draw more current for the same horsepower than a motor with a high power factor. The power factor of induction motors varies with load and drops significantly when the motor is operated at below 75 percent of full load.

Thermal Protection Thermal protection, when marked on the motor nameplate, indicates that the motor was designed and manufactured with its own **built-in** thermal protection device. There are several types of protective devices that can be built into the motor and used to sense excessive (overload) temperature rise and/or current flow. These devices disconnect the motor from its power source if they sense the overload to prevent damage to the insulation of the motor windings.

The primary types of thermal overload protectors include automatic and manual reset devices that sense either current or temperature. With **automatic-reset** devices, after the motor cools, this electrical circuit–interrupting device automatically restores power to the motor. With **manual reset** devices, the electrical circuit–interrupting device has an external button located on the motor enclosure that must be manually pressed to restore power to the motor. Manual reset protection should be provided where automatic restart of the motor after it cools down could cause personal injury should the motor start unexpectedly. Some low-cost motors have no internal thermal protection