Basics of Control Components

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Introduction

Welcome to another course in the STEP series, **S**iemens **T**echnical **E**ducation **P**rogram, designed to prepare our distributors to sell Siemens Energy & Automation products more effectively. This course covers **Basics of Control Components** and related products.

Upon completion of Basics of Control Components you will be able to:

- State the purpose and general principles of control components and circuits
- State the difference between manual and automatic control operation
- Identify various symbols which represent control components
- Read a basic line diagram
- Describe the construction and operating principles of manual starters
- Describe the construction and operating principles of magnetic contactors and magnetic motor starters
- Identify various manual starters and magnetic motor starters, and describe their operation in a control circuit
- Explain the need for motor overload protection
- State the need for reduced-voltage motor starting
- Describe typical motor starting methods

- Describe the construction and operating principles of lighting and heating contactors
- Describe the operating principles of control relays

This knowledge will help you better understand customer applications. In addition, you will be better able to describe products to customers and determine important differences between products. You should complete **Basics of Electricity** before attempting **Basics of Control Components**. An understanding of many of the concepts covered in **Basics of Electricity** is required for **Basics of Control Components**.

If you are an employee of a Siemens Energy & Automation authorized distributor, fill out the final exam tear-out card and mail in the card. We will mail you a certificate of completion if you score a passing grade. Good luck with your efforts.

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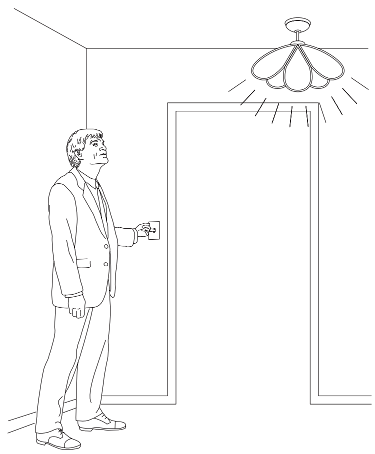
Control Circuits

Control

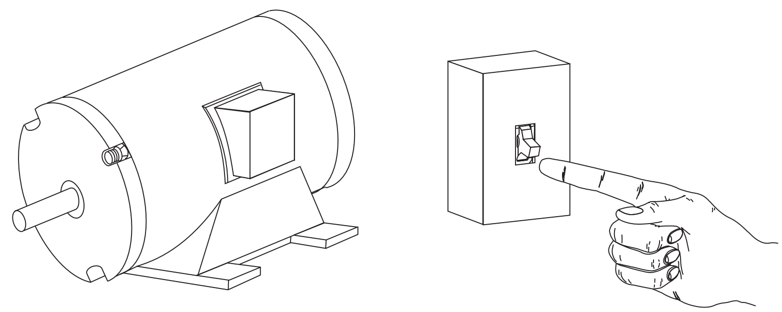
Control, as applied to control circuits, is a broad term that means anything from a simple toggle switch to a complex system of components (which may include relays, contactors, timers, switches, and indicating lights). Every electrical circuit for light or power has control elements. One example of a simple control circuit is a light switch that is used to turn lights on and off.



Of course, there are many other devices and equipment systems in industrial applications. Motor control, for example, can be used to start and stop a motor and to protect the motor, associated machinery, and personnel. In addition, motor controllers might also be used for reversing, changing speed, jogging, sequencing, and pilot-light indication. Control circuits can be complex, accomplishing high degrees of automatic, precise machine operation.

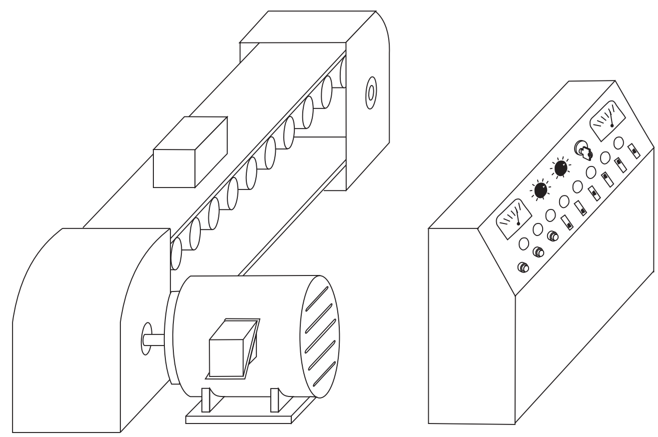
Manual Control

Control is considered to be **manually** operated when someone must initiate an action in order for the circuit to operate. For example, someone might have to flip the switch of a manual starter to start and stop a motor.



Automatic Operation

While manual operation of machines is still common practice, many machines are started and stopped **automatically**. Frequently there is a combination of manual and automatic control. A process may have to be started manually, but may be stopped automatically.



Control Elements

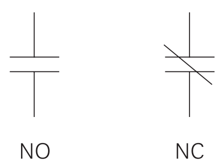
The elements of a control circuit include all of the equipment and devices concerned with the circuit function: enclosures, conductors, relays, contactors, pilot devices, and overcurrent-protection devices. The selection of control equipment for a specific application requires a thorough understanding of controller operating characteristics and wiring layout. The proper control devices must be selected and integrated into the overall circuit design.

Electrical Symbols

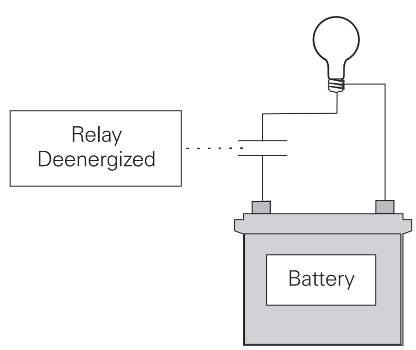
Language has been developed in order to transfer ideas and information. In order to understand the ideas and information being communicated, an understanding of the language is necessary. The language of controls consists of a commonly used set of symbols which represent control components.

Contact Symbols

Contact symbols are used to indicate an open or closed path of current flow. Contacts are shown as normally open (NO) or normally closed (NC). Contacts shown by this symbol require another device to actuate them.

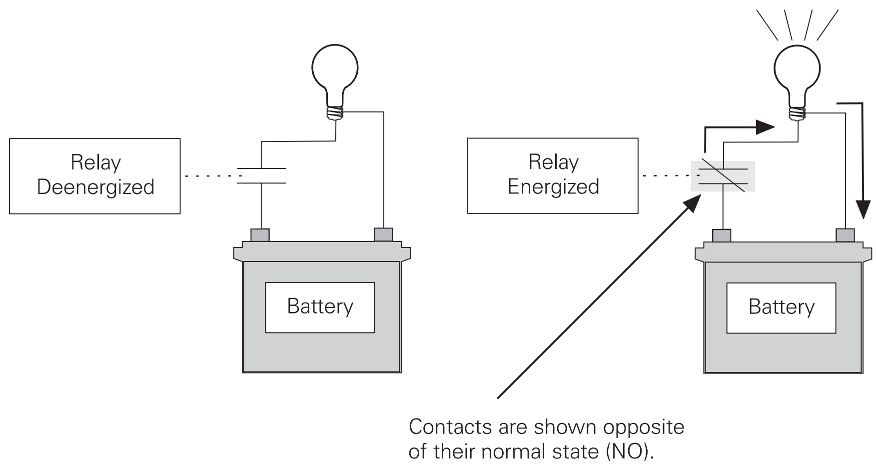


The standard method of showing a contact is to indicate the circuit condition produced when the actuating device is in the de-energized state. For example, in the following illustration a relay is used as the actuating device. The contacts are shown as normally open, meaning the contacts are open when the relay is de-energized. A complete path of current does not exist and the light is off.



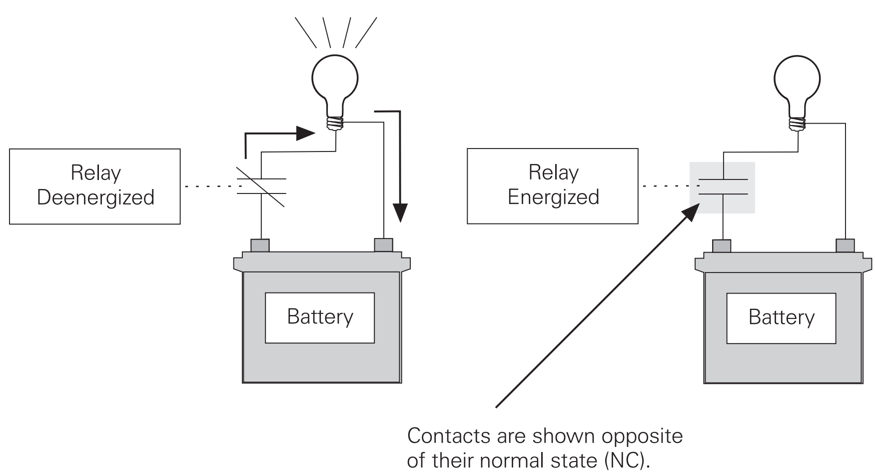
Normally Open Contact Example

In a control diagram or schematic, symbols are usually <u>not</u> shown in the energized or operated state. However, for the purposes of explanation in this text, a contact or device shown in a state opposite of its normal state will be highlighted. For example, in the following illustration the circuit is first shown in the de-energized state. The contacts are shown in their normally open (NO) state. When the relay is energized, the contacts close, completing the path of current and illuminating the light. The contacts have been highlighted to indicate they are now closed. *(This is not a legitimate symbol. It is used here for illustrative purposes only.)*



Normally Closed Contact Example

In the following illustration the contacts are shown as normally closed (NC), meaning the contacts are closed when the relay is de-energized. A complete path of current exists and the light is on. When the relay is energized, the contacts open turning the light off.

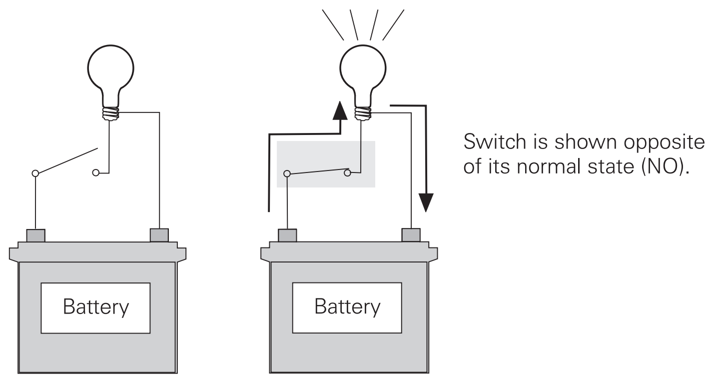


Switch Symbols

Switch symbols are also used to indicate an open or closed path of current flow. Variations of this symbol are used to represent limit switches, foot switches, pressure switches, level switches, temperature-actuated switches, flow switches, and selector switches. Like contacts, switches require another device or action to change their state. In the case of a manual switch, someone must manually change the position of the switch.

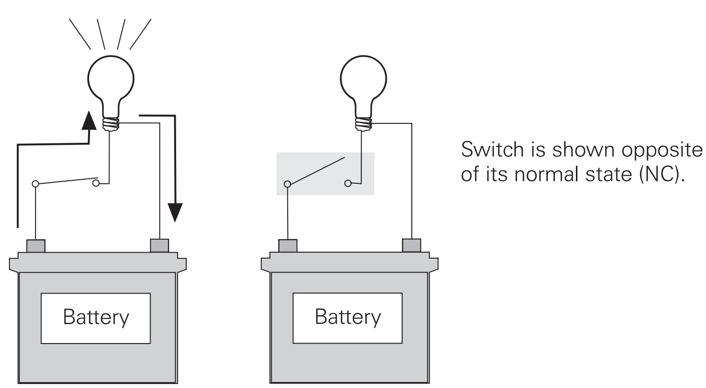
Normally Open Switch Example

In the following illustration a battery is connected to one side of a normally open switch and a light to the other. Current is prevented from flowing to the light when the switch is open. When someone closes the switch, the path of current flow is completed and the light illuminates.



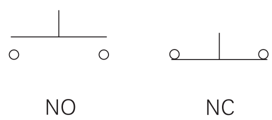
Normally Closed Switch Example

In the following illustration a battery is connected to one side of a normally closed switch and a light to the other. Current is flowing to the light when the switch is closed. When someone opens the switch, the path of current flow is interrupted and the light turns off.



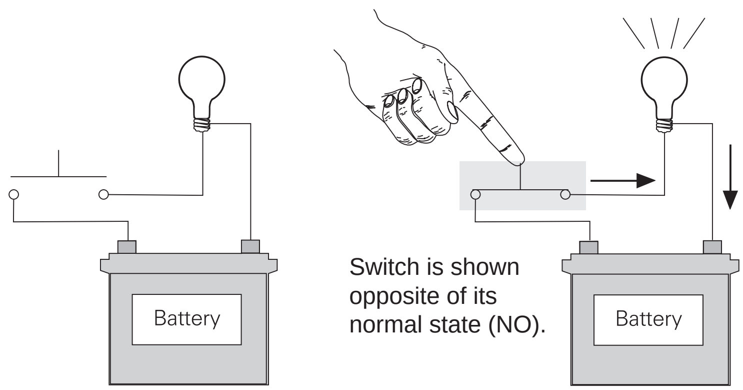
Pushbutton Symbols

There are two basic types of **pushbuttons**: *momentary* and *maintained*. A normally open momentary pushbutton closes as long as the button is held down. A normally closed momentary pushbutton opens as long as the button is held down. A maintained pushbutton latches in place when the button is pressed.



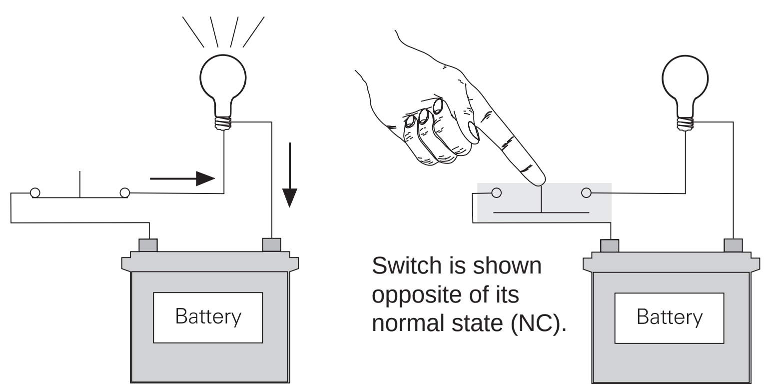
Normally Open Pushbutton Example

In the following illustration, a battery is connected to one side of a normally open pushbutton, and a light is connected to the other side. When the pushbutton is depressed a complete path of current flow exists through the pushbutton, and the light is illuminated.



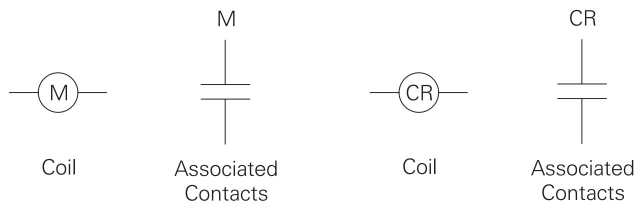
Normally Closed Pushbutton Example

In the following example, current will flow to the light as long as the pushbutton is not depressed. When the pushbutton is depressed, current flow is interrupted and the light turns off.



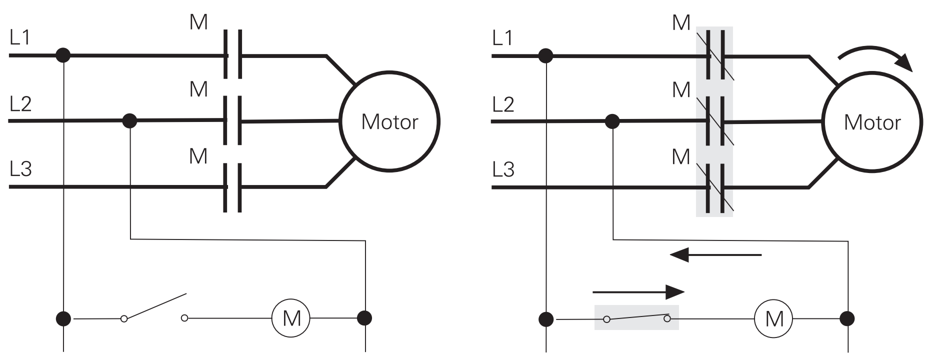
Coil Symbols

Coils are used in electromagnetic starters, contactors, and relays. The purpose of contactors and relays is to open and close associated contacts. Letters are used to designate the coil; for example, “M” frequently indicates a motor starter and “CR” indicates a control relay. The associated contacts have the same identifying letter. Contactors and relays use an electromagnetic action (which will be described later) to open and close these contacts. The associated contacts can be either normally open or normally closed.



Coil Example Using Normally Open Contacts

In the following example, the “M” contacts in series with the motor are controlled by the “M” contactor coil. When someone closes the switch, a complete path of current flow exists through the switch and “M” contactor coil. The “M” contactor coil actuates the “M” contacts which provide power to the motor.



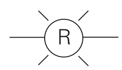
Overload Relay Symbols

Overload relays are used to protect motors from overheating resulting from an overload on the driven machinery, low line voltage, or an open phase in a three-phase system. When excessive current is drawn for a predetermined amount of time, the relay opens and the motor is disconnected from its source of power.

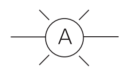
Thermal Overload

Indicator Light Symbols

An **indicator light** (sometimes referred to as a **pilot light**) is a small electric light used to indicate a specific condition of a circuit. For example, a red light might be used to indicate a motor is running. The letter in the center of the indicator light symbol indicates the color of the light.



Red Indicator Light

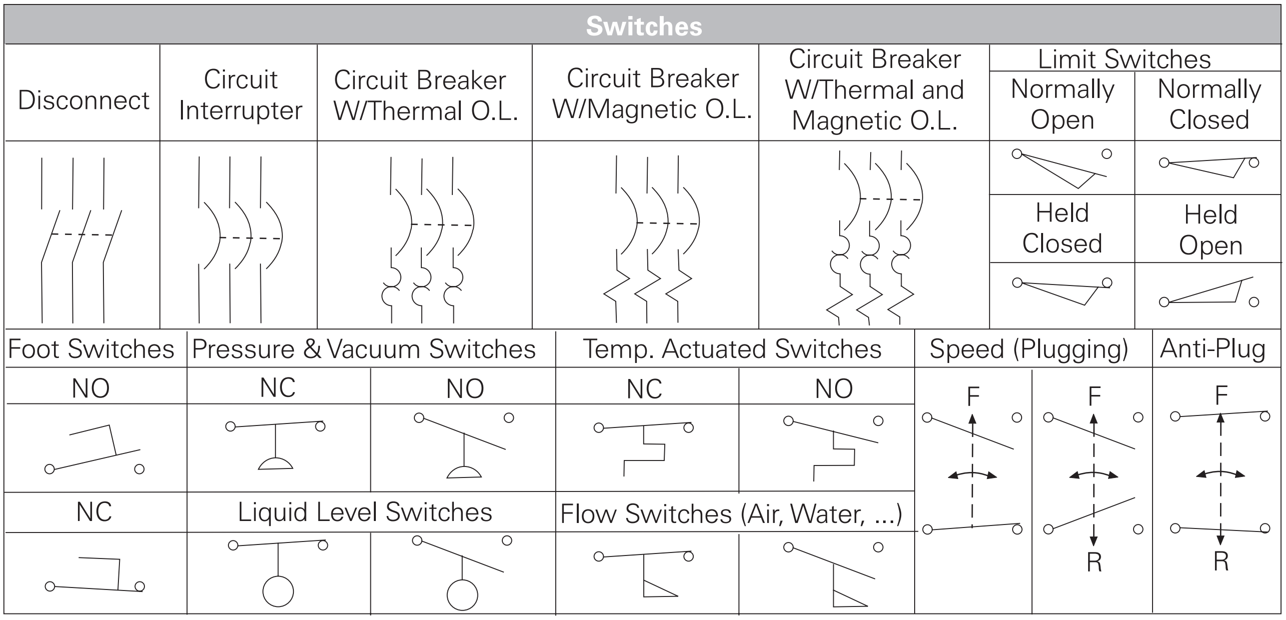


Amber Indicator Light

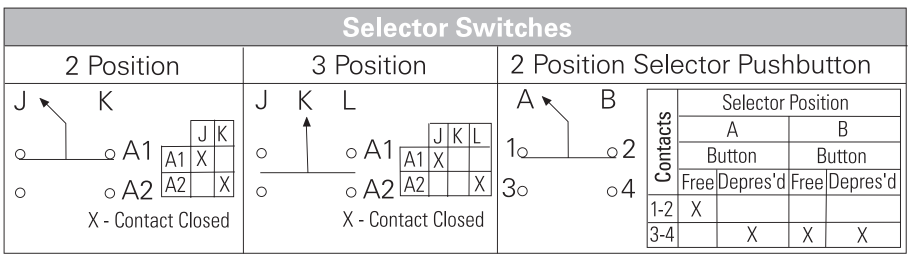
Other Symbols

In addition to the symbols discussed here, there are many other symbols used in control circuits. The following chart shows many of the commonly used symbols.

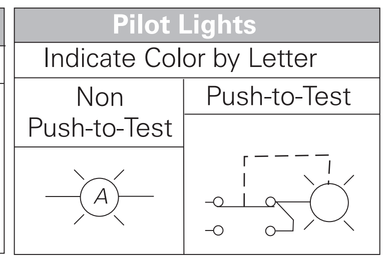
Switches



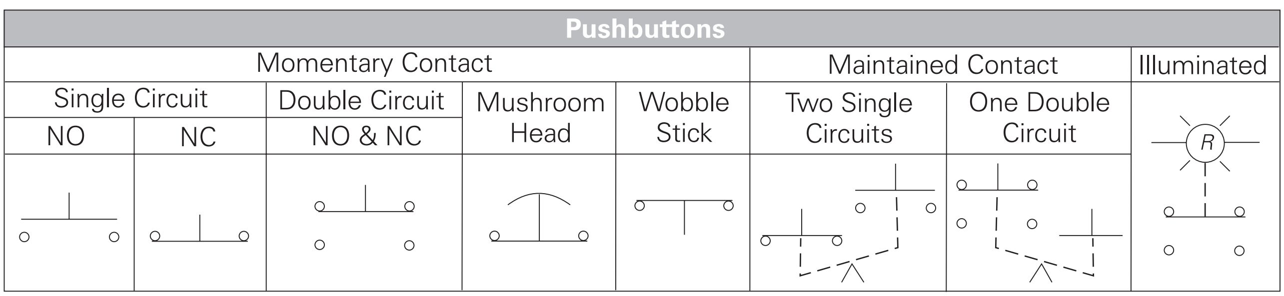
Selector Switches



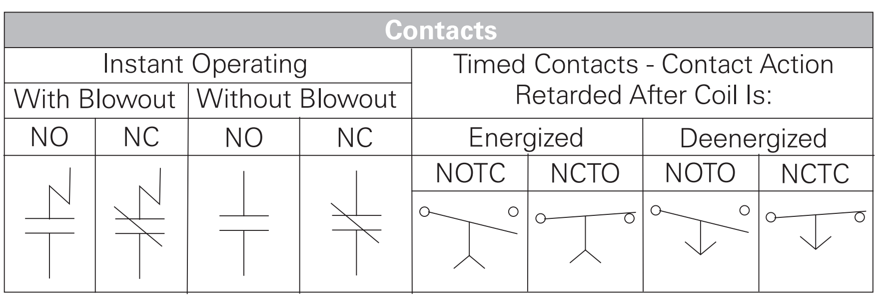
Pilot Lights



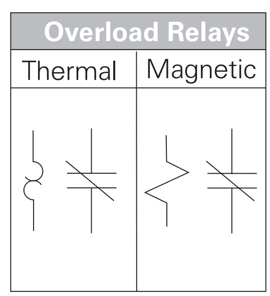
Pushbuttons



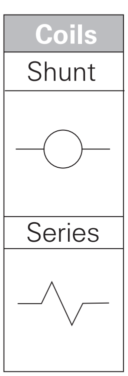
Contacts



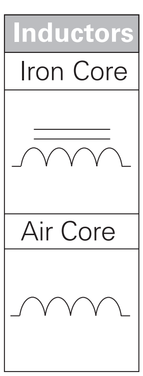
Overload Relays



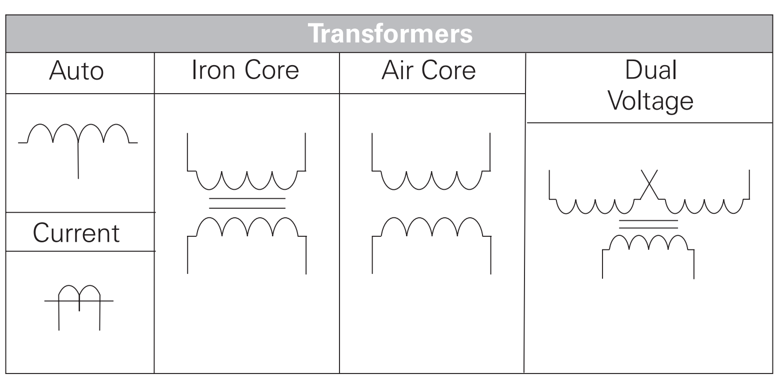
Coils

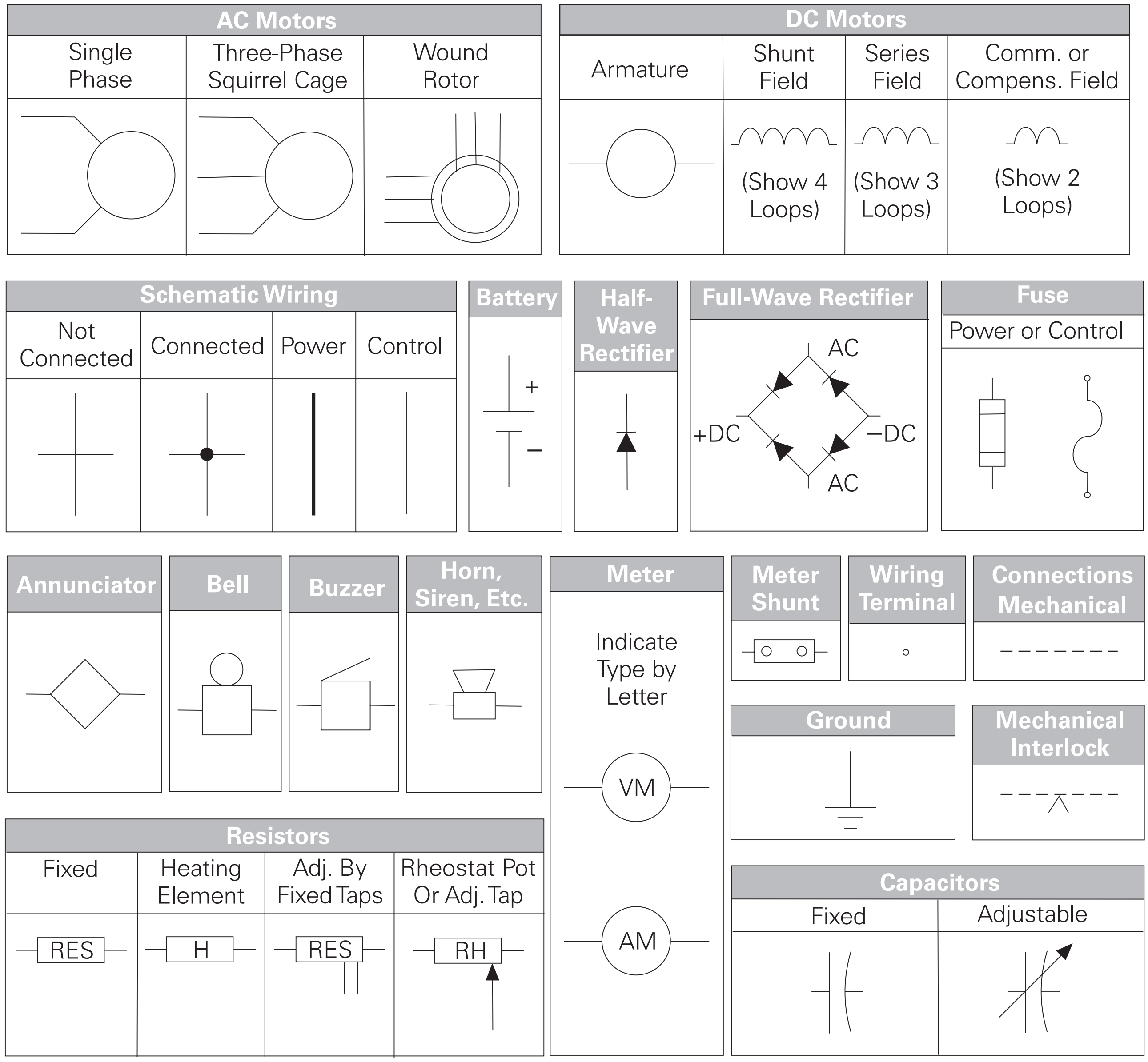


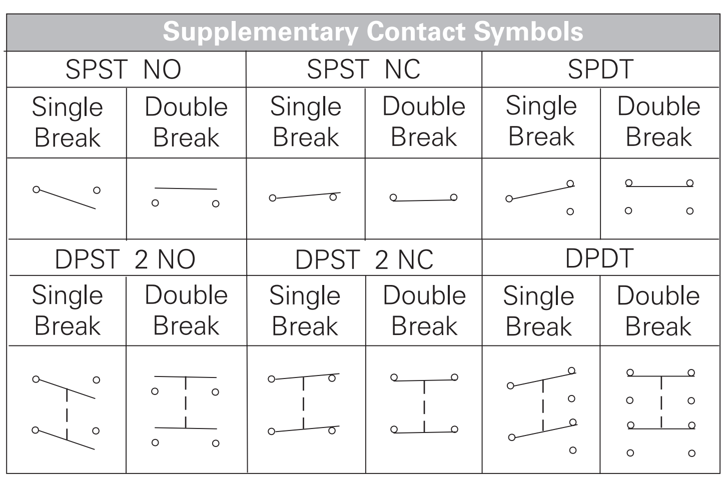
Inductors



Transformers







Terms

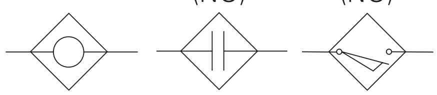
SPST	Single-Pole Single-Throw
SPDT	Single-Pole Double-Throw
DPST	Double-Pole Single-Throw
DPDT	Double-Pole Double-Throw
NO	Normally Open
NC	Normally Closed

Symbols For Static Switching Control Devices

Static switching control is a method of switching electrical circuits without the use of contacts. Primarily by solid-state devices. Use the symbols shown in the table on the previous page except enclosed in a diamond.

Examples:

Input "Coil" | Output (NO) | Limit Switch (NO)



Control and Power Connections - 600 Volts or Less - Across-the-Line Starters (From NEMA Standard ICS 2-321A.60)

		1 Phase	2 Phase 4 Wire	3 Phase
Line Markings		L1,L2	L1,L3-Phase 1 L2,L4-Phase 2	L1,L2,L3
Ground When Used		L1 is always Ungrounded	——	L2
Motor Running Overcurrent Units In	1 Element	L1	——	——
	2 Element	——	L1,L4	——
	3 Element	——	——	L1,L2,L3
Control Circuit Connected To		L1,L2	L1,L3	L1,L2
For Reversing Interchange Lines		——	L1,L3	L1,L3

Abbreviations

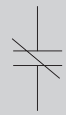
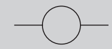
Abbreviations are frequently used in control circuits. The following list identifies a few commonly used abbreviations.

AC	**Alternating Current**
ALM	**Alarm**
AM	**Ammeter**
ARM	**Armature**
AU	**Automatic**
BAT	**Battery**
BR	**Brake Relay**
CAP	**Capacitor**
CB	**Circuit Breaker**
CKT	**Circuit**
CONT	**Control**
CR	**Control Relay**
CT	**Current Transformer**
D	**Down**
DC	**Direct Current**
DISC	**Disconnect Switch**
DP	**Double-Pole**
DPDT	**Double-Pole, Double-Throw**
DPST	**Double-Pole, Single-Throw**
DT	**Double Throw**
F	**Forward**
FREQ	**Frequency**
FTS	**Foot Switch**
FU	**Fuse**
GEN	**Generator**
GRD	**Ground**
HOA	**Hand/Off/Auto Selector Switch**
IC	**Integrated Circuit**
INTLK	**Interlock**
IOL	**Instanstaneous Overload**
JB	**Junction Box**
LS	**Limit Switch**
LT	**Lamp**
M	**Motor Starter**
MSP	**Motor Starter Protector**
MTR	**Motor**
MN	**Manual**
NEG	**Negative**
NEUT	**Neutral**
NC	**Normally Closed**
NO	**Normally Open**
OHM	**Ohmmeter**
OL	**Overload**
PB	**Pushbutton**
PH	**Phase**
POS	**Positive**
PRI	**Primary**
PS	**Pressure Switch**
R	**Reverse**
REC	**Rectifier**
RES	**Resistor**
RH	**Rheostat**
S	**Switch**
SEC	**Secondary**
SOL	**Solenoid**
SP	**Single-Pole**
SPDT	**Single-Pole, Double Throw**
SPST	**Single-Pole, Single Throw**
SS	**Selector Switch**
SSW	**Safety Switch**
T	**Transformer**
TB	**Terminal Board**
TD	**Time Delay**
THS	**Thermostat Switch**
TR	**Time Delay Relay**
U	**Up**
UV	**Under Voltage**
VFD	**Variable Frequency Drive**
XFR	**Transformer**

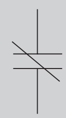
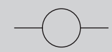
Review 1

1. A control is _____________ operated when someone must initiate an action for the circuit to operate.

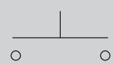
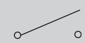
2. Which of the following symbols represents a normally open contact?

   a.    b.    c. 

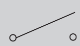
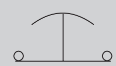
3. Which of the following symbols represents a normally closed contact?

   a.    b.    c. 

4. Which of the following symbols indicates a normally open pushbutton?

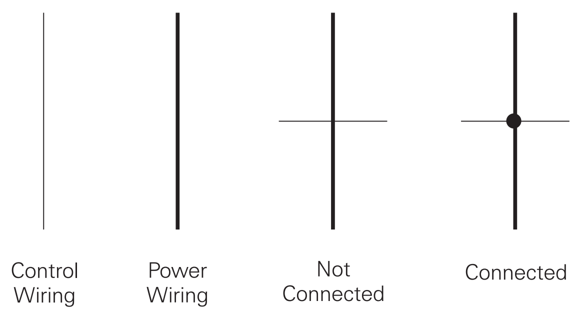
   a.    b.    c. 

5. Which of the following symbols indicates a mushroom head pushbutton?

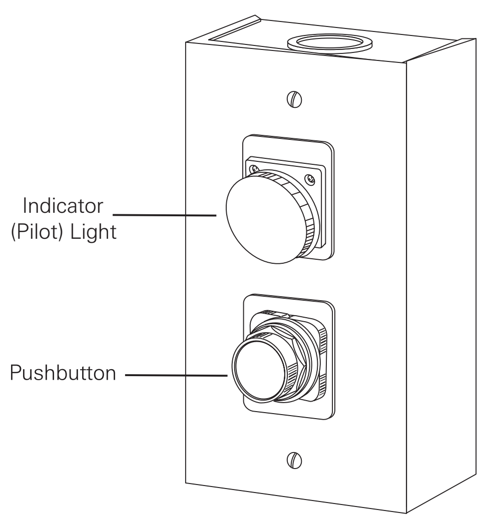
   a.    b.    c. 

Line Diagrams

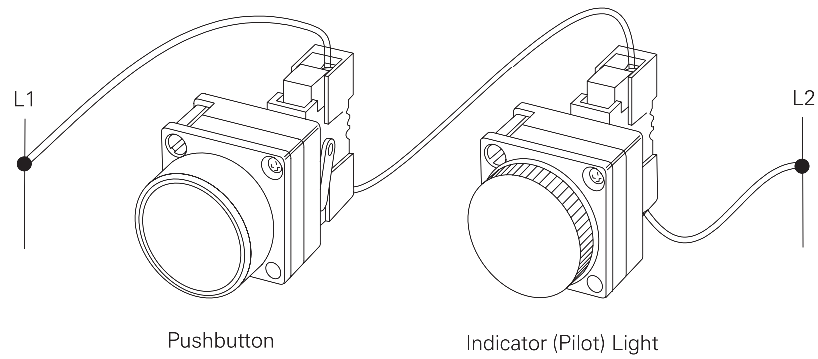
The method of expressing the language of control symbols is a **line diagram**, also referred to as a ladder diagram. Line diagrams are made up of two circuits, the control circuit and the power circuit. Electrical wires in a line diagram are represented by lines. Control-circuit wiring is represented by a lighter-weight line, and power-circuit wiring is represented by a heavier-weight line. A small dot or node at the intersection of two or more wires indicates an electrical connection.



Line diagrams show the functional relationship of components and devices in an electrical circuit, not the physical relationship. For example, the following illustration shows the physical relationship of an indicator light and a pushbutton.

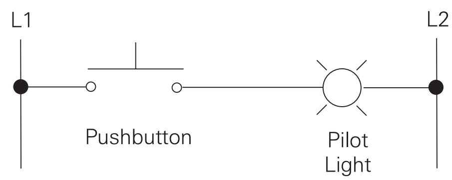


The functional relationship can be shown pictorially with the following illustration.



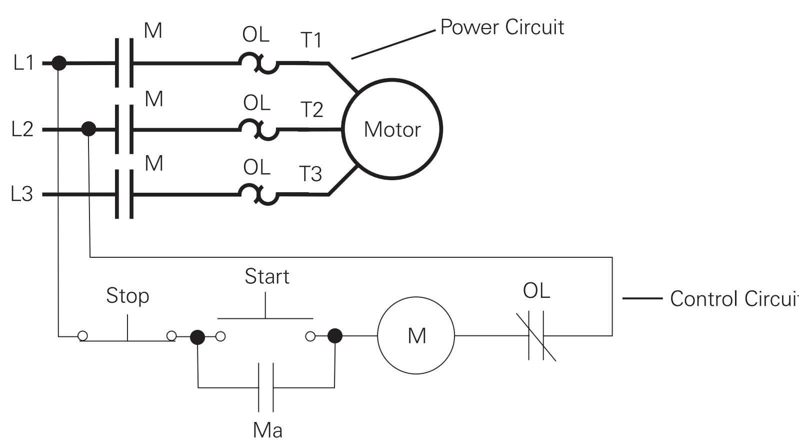
Reading a Line Diagram

This functional relationship is shown symbolically with a line diagram. Line diagrams are read from left to right. Depressing the pushbutton would allow current to flow from L1 through the pushbutton, illuminating the indicator light, to L2. Releasing the pushbutton stops current flow turning the indicator light off.



Power Circuit and Control Circuit

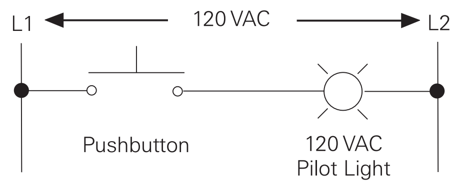
The **power circuit** (indicated by the heavier-weight line) is what actually distributes power from the source to the connected load (motor). The **control circuit** (indicated by the lighter-weight line) is used to “control” the distribution of power.



Connecting Loads and Control Devices

Control circuits are made up of control loads and control devices. **Control loads** are electrical devices that use electrical power; for example, indicator lights, relays, and contactors. **Control devices** (such as pushbuttons and switches) are used to activate the control load.

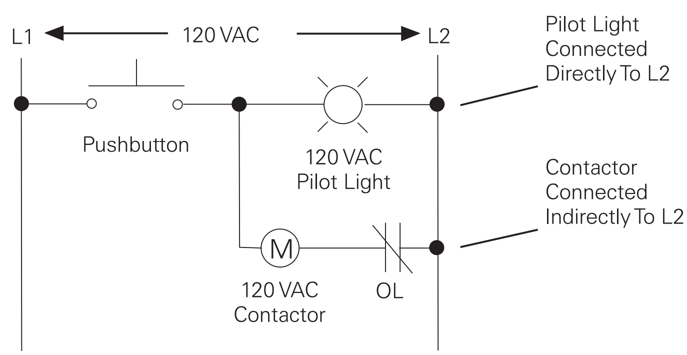
The following illustration shows the proper connection of an indicator light (load) with a pushbutton (control device). The power lines are drawn vertically and marked L1 and L2. In this example, the voltage potential between L1 and L2 is 120 VAC. The indicator light selected must be rated for 120 VAC. When the pushbutton is depressed, the full 120 volt potential is applied to the indicator light.



Connecting the Load to L2

Only one control load should be placed in any one circuit line between L1 and L2. One side of the control load is connected to L2 either directly or through overload relay contacts.

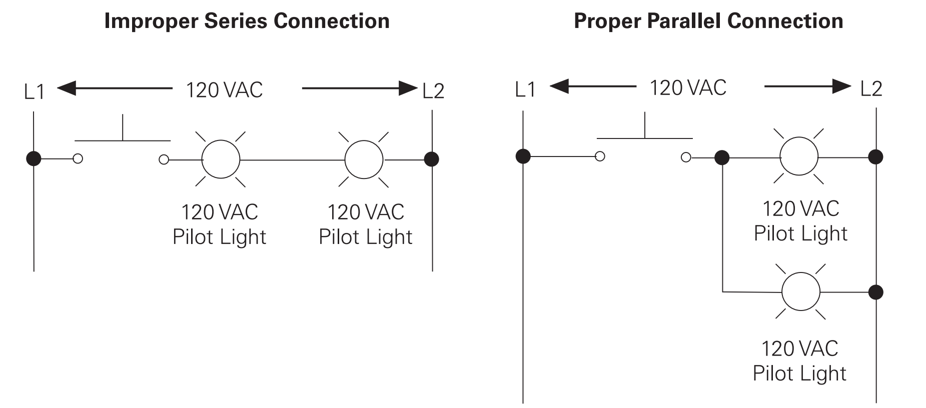
In the following example, an indicator light is directly connected to L2 on one circuit line. A contactor coil is indirectly connected through a set of overload contacts (OL) to L2 on a second, parallel circuit line. Depressing the pushbutton would apply 120 VAC to the indicator light and to the "M" contactor.



Control loads are generally not connected in series. The following illustration shows why.

In the first instance, the control loads are improperly connected in series. When the pushbutton is depressed, the voltage across L1 and L2 is divided across both loads with neither load receiving the full 120 volts necessary for proper operation. If one load fails in this configuration, the entire circuit is rendered useless.

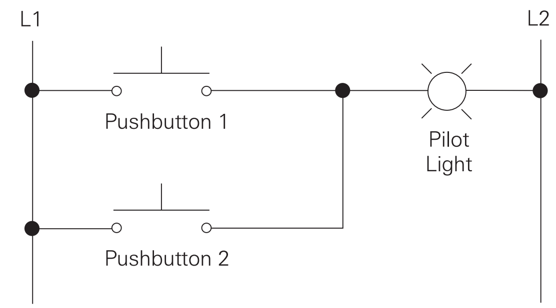
In the second instance, the loads are properly connected in parallel. In this circuit, there is only one load for each line between L1 and L2. The full 120 volts will appear across each load when the pushbutton is depressed. If one load fails in this configuration, the other load will continue to operate normally.



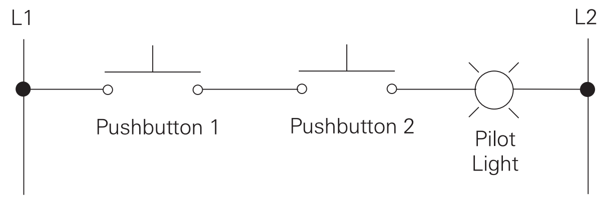
Connecting Control Devices

Control devices are connected between L1 and the load. The control device can be connected in series or parallel, depending on the desired operation of the circuit.

In the following illustration, the pushbuttons are connected in parallel. Depressing either pushbutton will allow current to flow from L1, through the depressed pushbutton, through the indicator light, to L2.

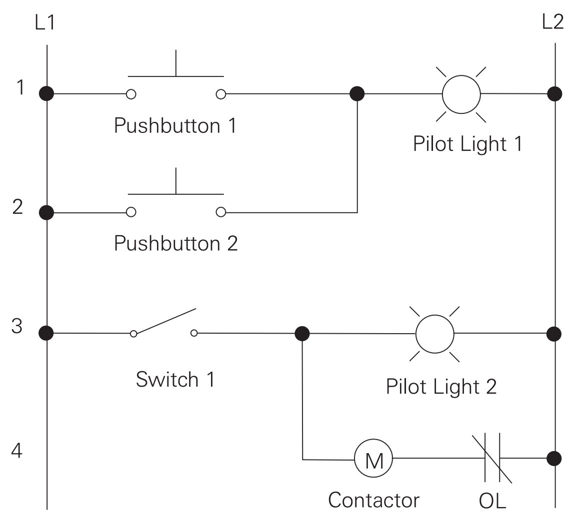


In this second illustration, two pushbuttons are connected in series. Both pushbuttons must be depressed in order to allow current to flow from L1 through the load to L2.



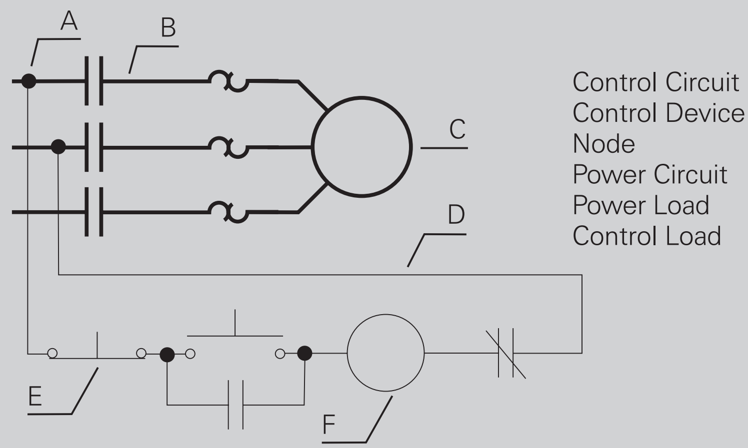
Line Numbering

Numbering each line makes it easier to understand more complex line diagrams. In the illustration below, line 1 connects pushbutton 1 to indicator light 1; line 2 connects pushbutton 2 to indicator light 1; and line 3 connects switch 1 to indicator light 2 and to the “M” contactor on line 4.



1. Line diagrams are read from ____________ to ____________ , or L1 to L2.

2. Match the items on the line diagram with the associated list.



A ____________

B ____________

C ____________

D ____________

E ____________

F ____________

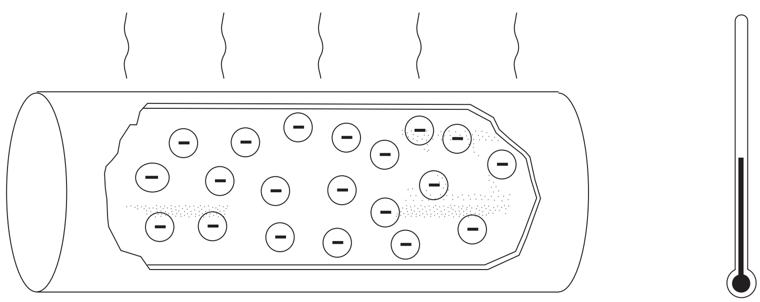
Overload Protection

Before discussing specific control components, it is necessary to review what an overload is, and what steps can be taken to limit the damage an overload can cause.

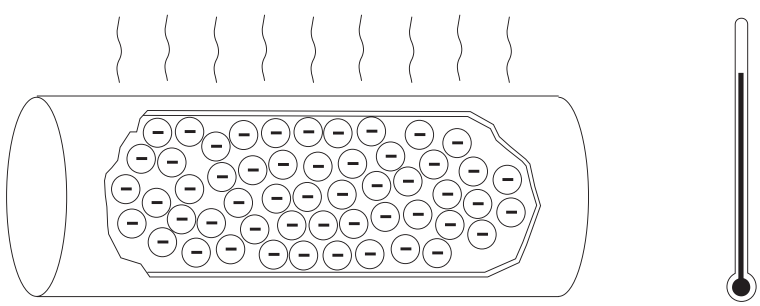
Current and Temperature

Current flow in a conductor always generates heat due to resistance; the greater the current flow, the hotter the conductor. Excess heat is damaging to electrical components. For that reason, conductors have a rated continuous current carrying capacity or **ampacity**.

Overcurrent protection devices are used to protect conductors from excessive current flow. Overload relays are designed to protect the conductors (windings) in a motor. These protective devices are designed to keep the flow of current in a circuit at a safe level to prevent the conductors from overheating.



Normal Current Flow

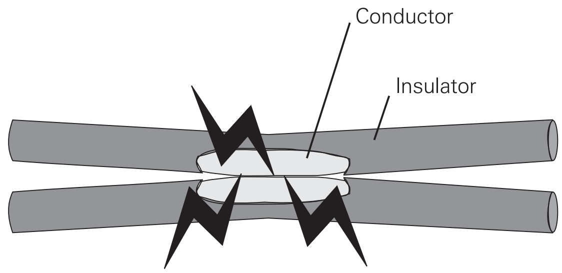


Excessive Current Flow

Excessive current is referred to as **overcurrent**. An overcurrent may result from a short circuit, overload, or ground fault.

Short Circuits

When two bare conductors touch, a short circuit is created, and resistance drops to almost zero. Short-circuit current can be thousands of times higher than normal operating current.



Ohm's Law demonstrates the relationship of current, voltage, and resistance. For example, a 240 volt motor with 24 ohms of resistance would normally draw 10 amps of current.

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

where **I** represents **Current**,
E represents **Voltage**, and
R represents **Resistance**

$$I = \frac{240}{24}$$

$$I = 10 \text{ amps}$$

As noted above, resistance drops in the event of a short circuit. If resistance drops to 24 milliohms, current will be 10,000 amps.

$$I = \frac{240}{0.024}$$

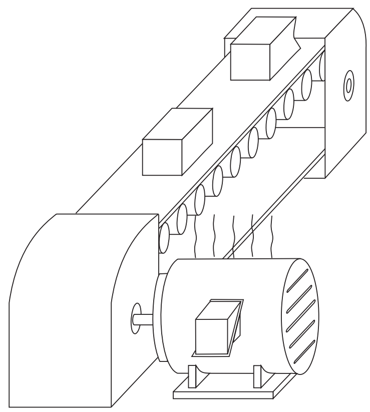
$$I = 10{,}000 \text{ amps}$$

The heat generated by this current will cause extensive damage to connected equipment and conductors. This dangerous current must be interrupted immediately when a short circuit occurs.

Overload Conditions

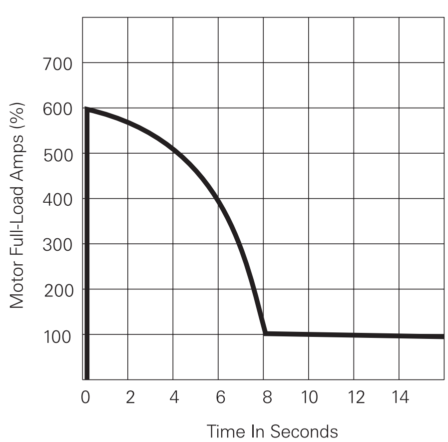
An overload occurs when too many devices are operated on a single circuit, or a piece of electrical equipment is made to work harder than it is designed for. For example, a motor rated for 10 amperes may draw 20, 30, or more amperes in an overload condition.

In the illustration below, a package has become jammed on a conveyor causing the motor to work harder and draw more current. Because the motor is drawing more current, it heats up and will be damaged within a short time if the problem is not corrected or the circuit is not shut down by the overload relay.



Temporary Overload Due to Starting Current

Electric motors are rated according to the amount of current they will draw at full load. When most motors start, they draw current in excess of the motor's full-load current rating. Motors are designed to tolerate this overload current for a short period of time. Many motors require 6 times (600%) the full-load current rating to start. High-efficiency motors may require up to 12 times (1200%) starting current. As the motor accelerates to operating speed, the current drops off quickly. The time it takes for a motor to accelerate to operating speed depends on the operating characteristics of the motor and the driven load. For example, a particular motor might require 600% of full-load current and take 8 seconds to reach operating speed.



Overload Protection

Fuses and circuit breakers are designed to protect circuit conductors in the event of a short circuit or overload condition. If a short circuit or overload condition occurs, these devices will open the path for current flow before damage to conductors occurs.

When fuses or circuit breakers are used in a circuit providing power to a motor, the protective devices and the circuit conductors must be sized to allow for the high starting current of the motor. Because of this, overload protection for the motor must be provided by a separate device known as an overload relay. In the next section, you will learn about overload relays.