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# Introduction

Welcome to another course in the STEP 2000 series, **Siemens Technical Education Program**, 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 Siemens and Furnas 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 difference between normally open and normally pilot devices
- 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**. In addition, you may want to complete the STEP 2000 course **Sensors** after completing **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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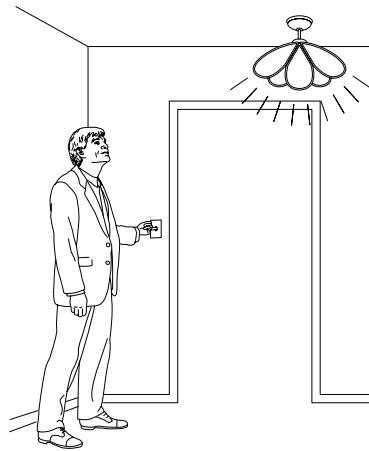
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# Control Circuits

The National Electrical Code® (NEC®) defines a controller as a *device or group of devices that serves to govern, in some predetermined manner, the electrical power delivered to the apparatus to which it is connected* (Article 100-definitions).

## 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 used to turn lights on and off.

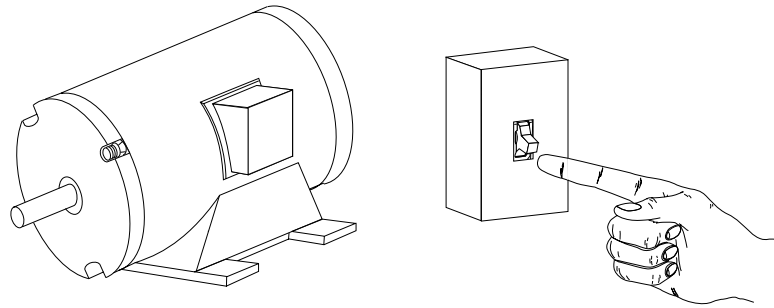


Of course there are many other devices and equipment systems in industrial applications. Motor control, for example, can be used to start and stop a motor and protect the motor, associated machinery, and personnel. In addition, motor controllers might also be used for reversing, changing speed, jogging,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

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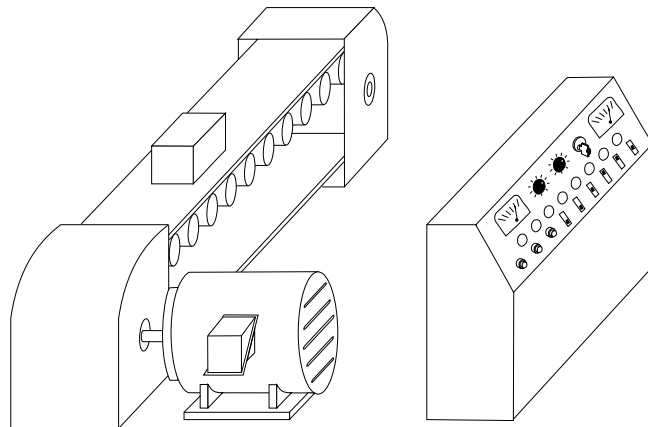
## Manual Control

Control is considered to be manually operated when someone must initiate an action 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

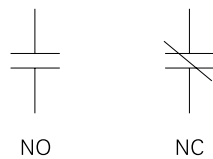
The elements of a control circuit include all of the equipment and devices concerned with the circuit function. This includes enclosures, conductors, relays, contactors, pilot devices, and overcurrent-protection devices. The selection of control equipment for a specific application requires a thorough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

# Electrical Symbols

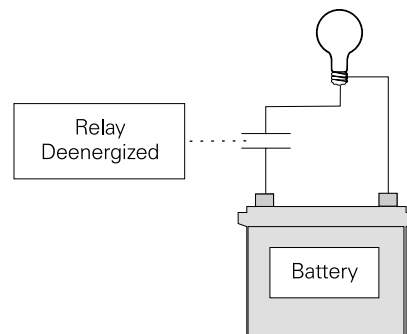
Language has been developed in order to transfer ideas and information. In order to understand the ideas and information being communicated, an understanding of the language is necessary. The language of controls consists of a commonly used set of symbols which represents control components.

## 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.

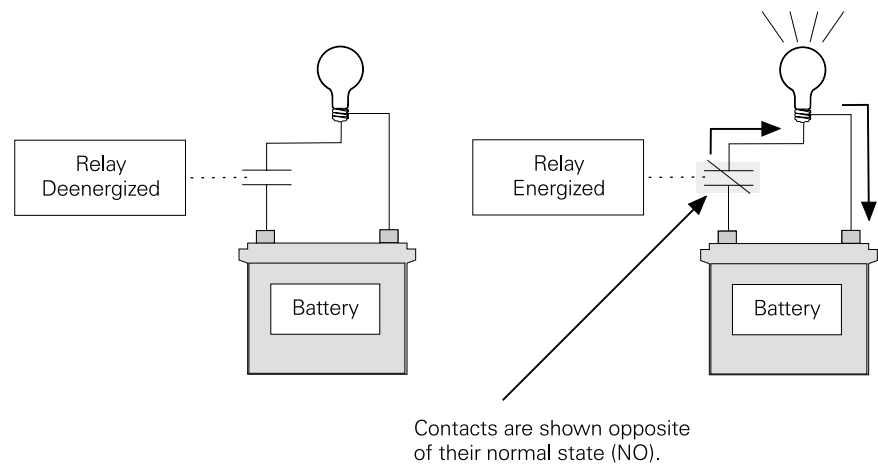


The standard method of showing a contact is by indicating the circuit condition it produces when the actuating device is in the deenergized or nonoperated state. For example, in the following illustration a relay is used as the actuating device. The contacts are shown as normally open, meaning the contacts are open when the relay is deenergized. A complete path of current does not exist and the light is off.



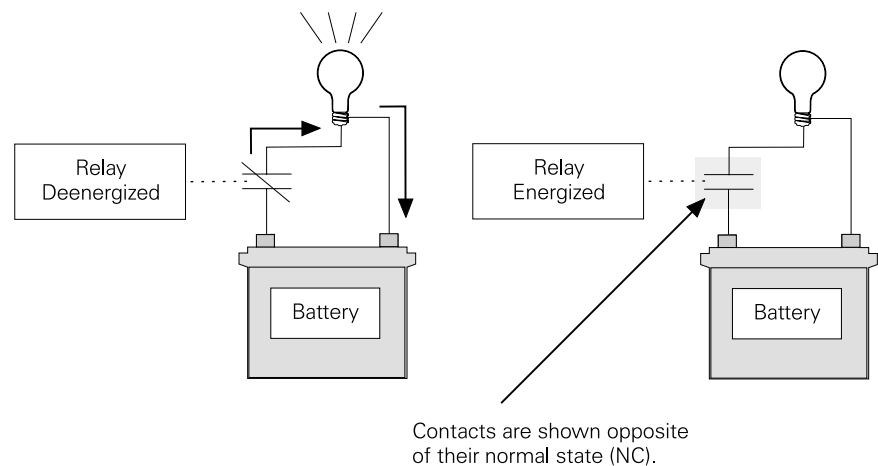
## Normally Open Contact Example

In a control diagram or schematic, symbols are usually not shown in the energized or operated state. 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 deenergized 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.



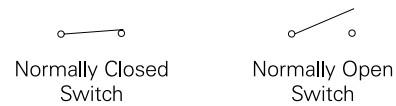
## Normally Closed Contact Example

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



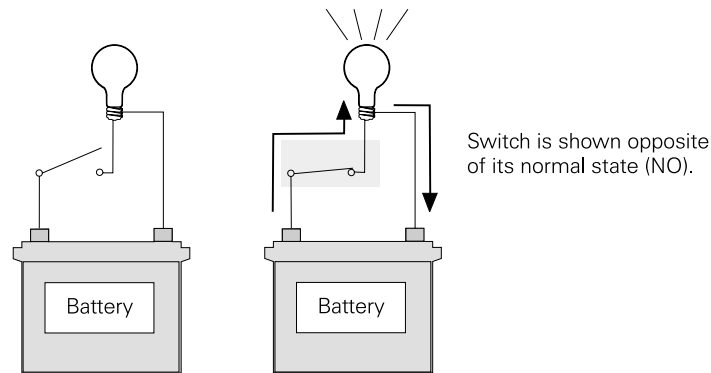
## Switch Symbols

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. Switches, like contacts, 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.



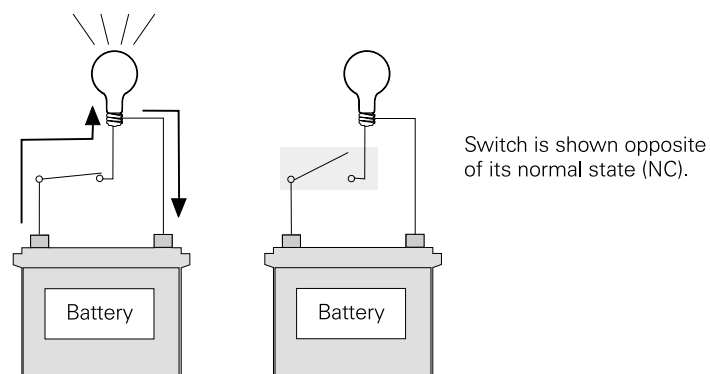
### Normally Open Switch Example

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

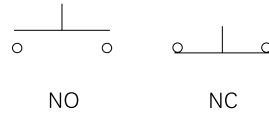
In the following illustration a battery is connected to one side of a normally closed switch and a light to the other. Current is flowing to the light when the switch is closed. When someone opens the switch, the path of current flow is interrupted and the light turns off.





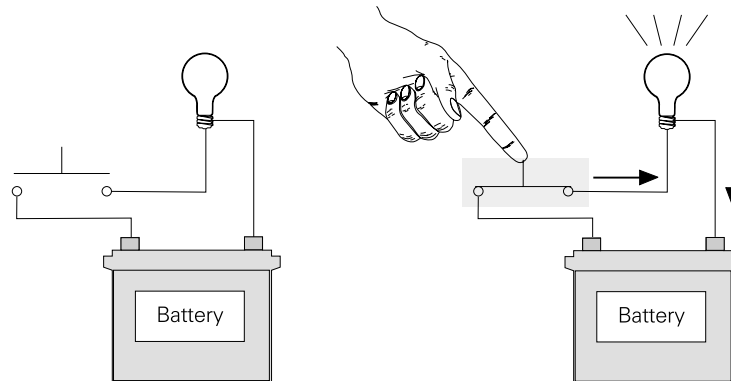
## Pushbutton Symbols

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.



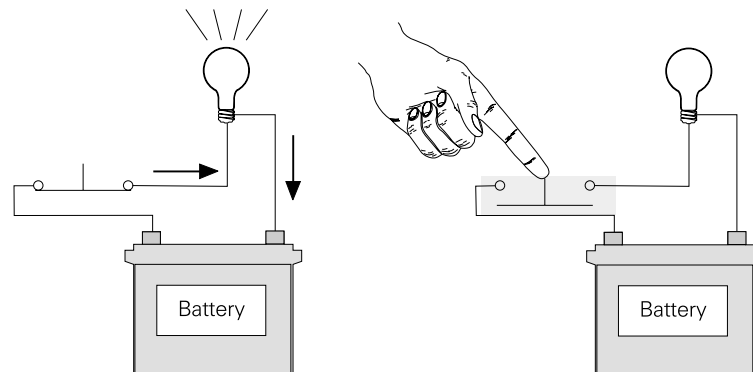
## Normally Open Pushbutton Example

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.



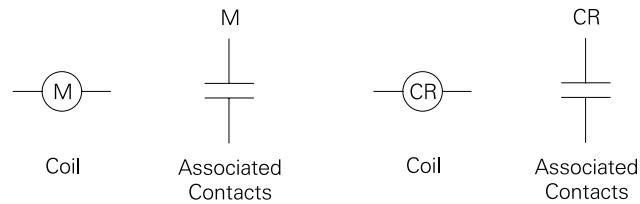
## Normally Closed Pushbutton Example

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.



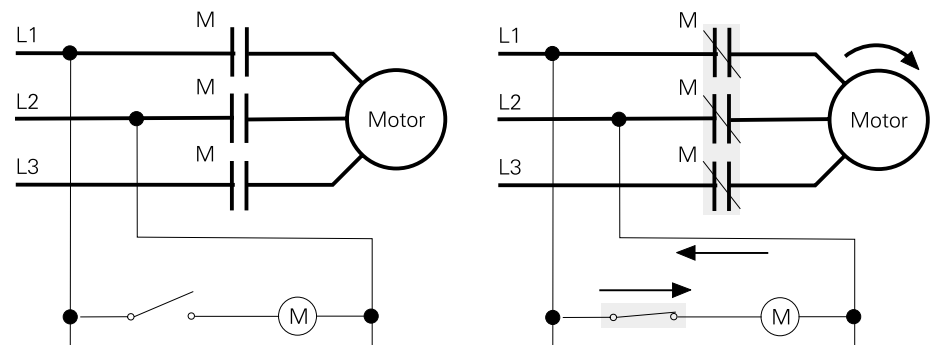
## Coil Symbols

Coils are used in electromagnetic starters, contactors, and relays. The purpose of contactors and relays is to open and close associated contacts. A letter is 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.



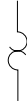
## Coil Example Using Normally Open Contacts

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

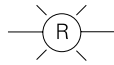
Overload relays are used to protect motors from overheating due to an overload on the driven machinery, low-line voltage, or an open phase in a three-phase system. When excessive current is drawn for a predetermined amount of time, the relay opens and the motor is disconnected from its source of power.



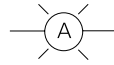
Thermal  
Overload

## Pilot Light Symbols

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 pilot light symbol indicates the color of the light.



Red  
Pilot Light



Amber  
Pilot 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						
Disconnect	Circuit Interrupter	Circuit Breaker W/Thermal O.L.	Circuit Breaker W/Magnetic O.L.	Circuit Breaker W/Thermal and Magnetic O.L.	Limit Switches	
					Normally Open	Normally Closed
					Held Closed	Held Open
Foot Switches	Pressure & Vacuum Switches		Temp. Actuated Switches		Speed (Plugging)	Anti-Plug
NO	NC	NO	NC	NO		
NC	Liquid Level Switches		Flow Switches (Air, Water, ...)			

Selector Switches				Pilot Lights	
2 Position		3 Position		2 Position Selector Pushbutton	
Indicate Color by Letter					
Non Push-to-Test		Push-to-Test			

Pushbuttons						
Momentary Contact				Maintained Contact		Illuminate
Single Circuit		Double Circuit		Mushroom Head	Wobble Stick	Two Single Circuits
NO	NC	NO & NC				One Double Circuit

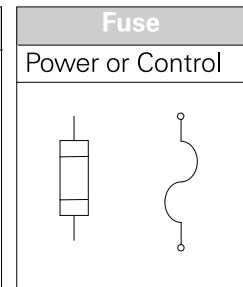
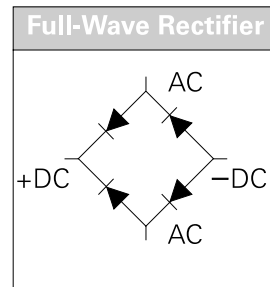
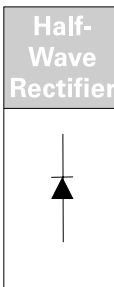
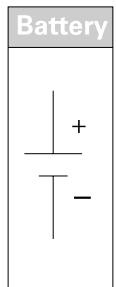
Contacts				Overload Relays			
Instant Operating		Timed Contacts - Contact Action Retarded After Coil Is:				Thermal	Magnetic
With Blowout	Without Blowout	Energized		Deenergized			
NO	NC	NO	NC	NOTC	NCTO	NOTO	NCTC

Coils		Inductors		Transformers			
Shunt	Series	Iron Core	Air Core	Auto	Iron Core	Air Core	Dual Voltage

AC Motors		
Single Phase	Three-Phase Squirrel Cage	Wound Rotor

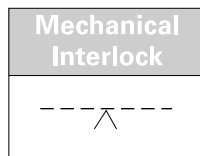
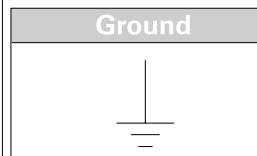
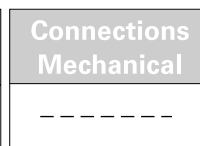
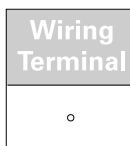
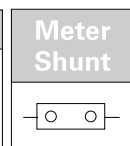
DC Motors			
Armature	Shunt Field	Series Field	Comm. or Compens. Field
	(Show 4 Loops)	(Show 3 Loops)	(Show 2 Loops)

Schematic Wiring			
Not Connected	Connected	Power	Control



Annunciator	Bell	Buzzer	Horn, Siren, Etc.

Meter
Indicate Type by Letter



Resistors			
Fixed	Heating Element	Adj. By Fixed Taps	Rheostat Pot Or Adj. Tap

Capacitors	
Fixed	Adjustable

Supplementary Contact Symbols					
SPST NO		SPST NC		SPDT	
Single Break	Double Break	Single Break	Double Break	Single Break	Double Break
DPST 2 NO		DPST 2 NC		DPDT	
Single Break	Double Break	Single Break	Double Break	Single Break	Double Break

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	
<p>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.</p> <p>Examples:</p> <p>Input "Coil"      Output (NO)      Limit Switch (NO)</p>	

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 — 2 Element — 3 Element —	— L1,L4 —	— — L1,L2,L3
Control Circuit Connected To	L1,L2	L1,L3	L1,L2
For Reversing Interchange Lines	—	L1,L3	L1,L3

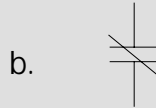
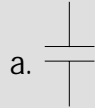
## Abbreviations

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

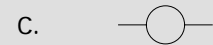
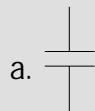
AC	Alternating Current	MTR	Motor
ALM	Alarm	MN	Manual
AM	Ammeter	NEG	Negative
ARM	Armature	NEUT	Neutral
AU	Automatic	NC	Normally Closed
BAT	Battery	NO	Normally Open
BR	Brake Relay	OHM	Ohmmeter
CAP	Capacitor	OL	Overload
CB	Circuit Breaker	PB	Pushbutton
CKT	Circuit	PH	Phase
CONT	Control	POS	Positive
CR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

## Review 1

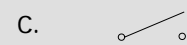
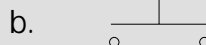
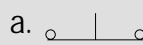
1. A control is \_\_\_\_\_ operated when someone must initiate an action for the circuit to operate.
2. Which of the following symbols represents a normally open contact?



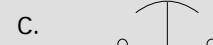
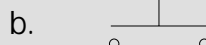
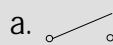
3. Which of the following symbols represents a normally closed contact?



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

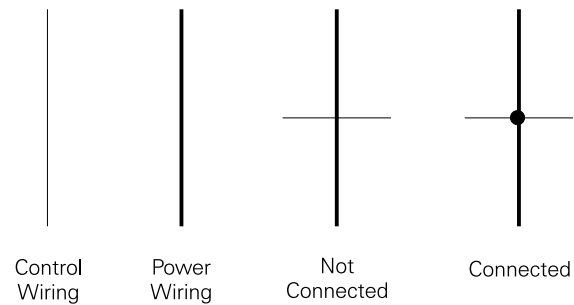


5. Which of the following symbols indicates a mushroom head pushbutton?

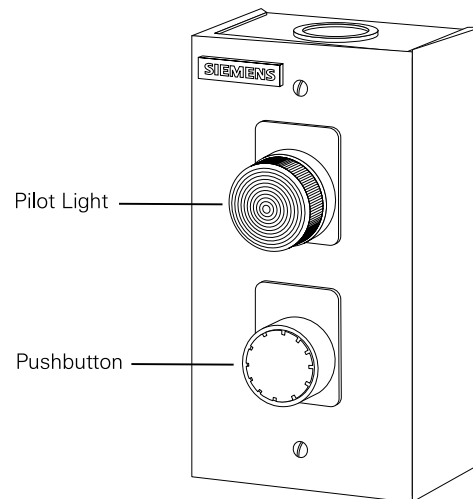


# Line Diagrams

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.

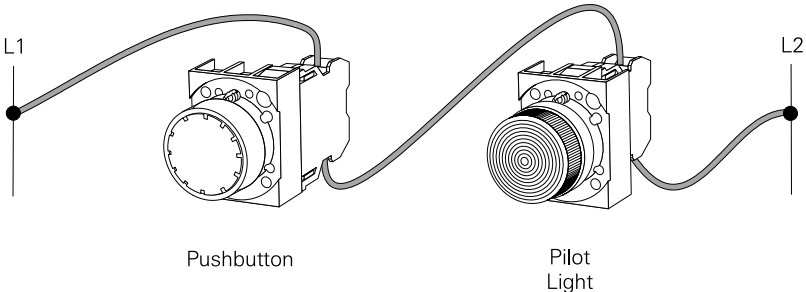


Line diagrams show the functional relationship of components and devices in an electrical circuit, not the physical relationship. For example, the following illustration shows the physical relationship of a pilot light and a pushbutton.



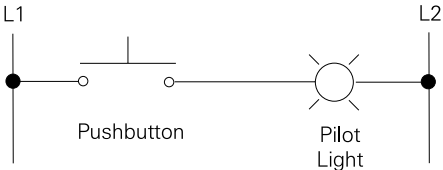


The functional relationship can be shown pictorially with the following illustration.



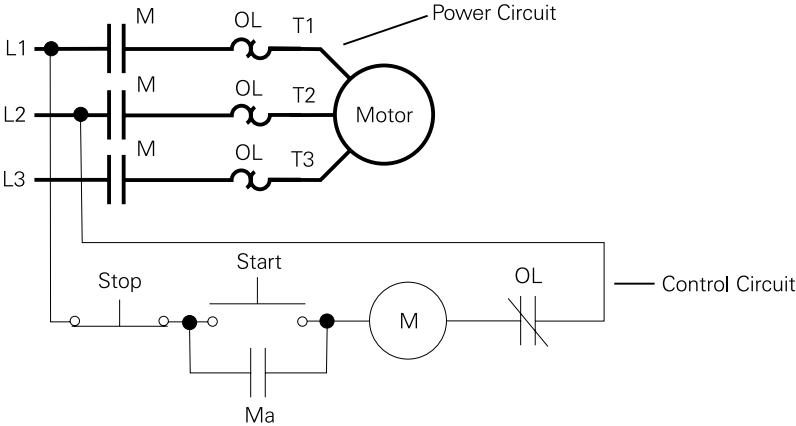
**Reading a Line Diagram**

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 pilot light, to L2. Releasing the pushbutton stops current flow turning the pilot light off.



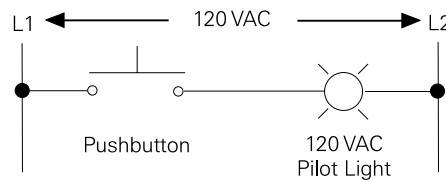
**Power Circuit and Control Circuit**

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.



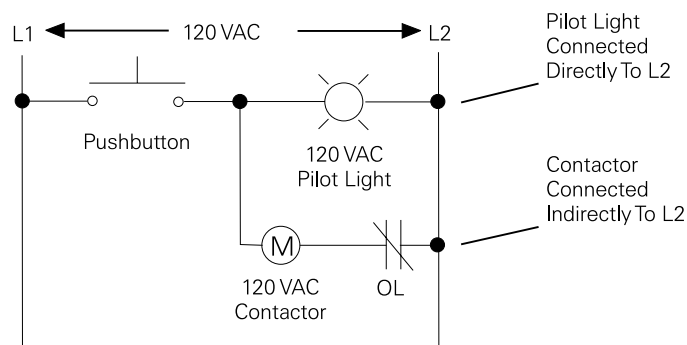
## Connecting Loads and Control Devices

Control circuits are made up of control loads and control devices. The control load is an electrical device that uses electrical power. Pilot lights, relays, and contactors are examples of control loads. Control devices are used to activate the control load. Pushbuttons and switches are examples of control devices. The following illustration shows the proper connection of a pilot 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 pilot light selected must be rated for 120 VAC. When the pushbutton is depressed, the full 120 volt potential is applied to the pilot light.



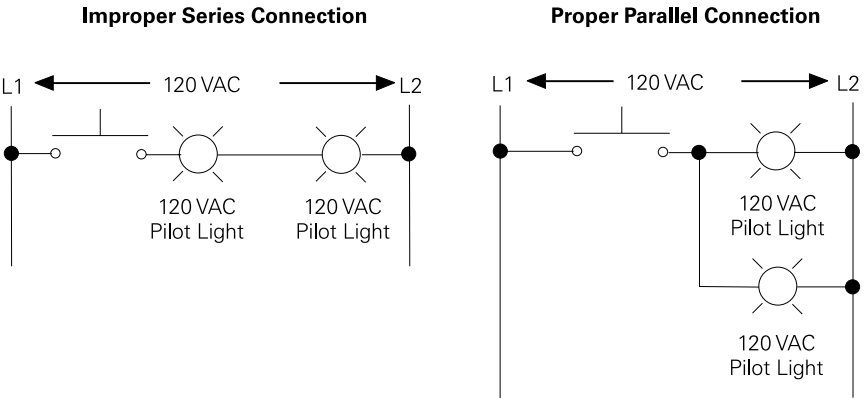
## Connecting the Load to L2

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, in some instances, through overload relay contacts. In the following example a pilot 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 circuit line. This is a parallel connection. Depressing the pushbutton would apply 120 VAC to the pilot light and the "M" contactor.



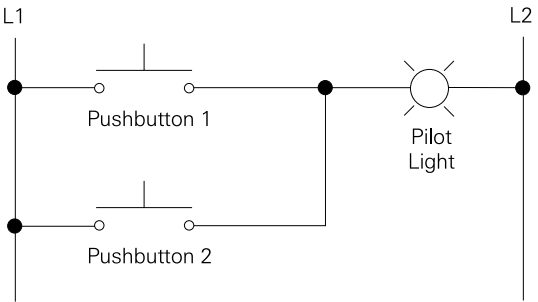
Control loads are generally not connected in series. The following illustration shows two ways to connect a control load. In one instance the control loads are improperly connected in series. When the pushbutton is depressed, the voltage across L1 and L2 is divided across both loads, the result being that neither load will receive the full 120 volts necessary for proper operation. If one load fails in this configuration, the entire circuit is rendered useless.

In the other 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.

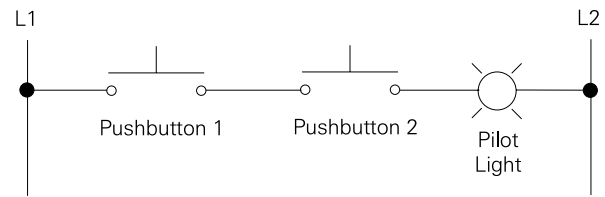


**Connecting Control Devices**

Control devices are connected between L1 and the load. The control device can be connected in series or parallel, depending on the desired results. 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 pilot light, to L2.

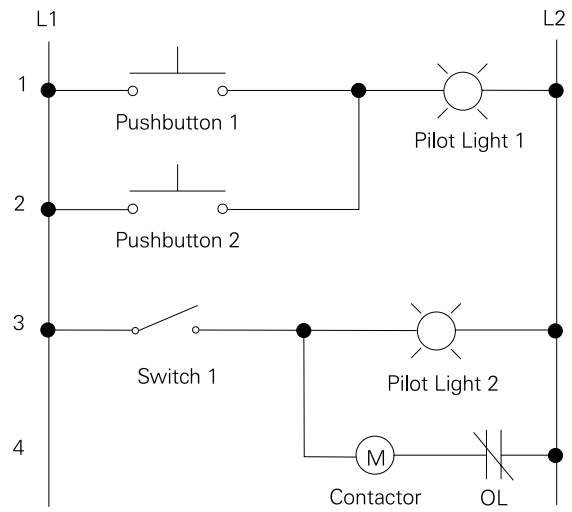


In the following illustration, two pushbuttons are connected in series. Both pushbuttons must be depressed in order to allow current to flow from L1 through the load to L2.



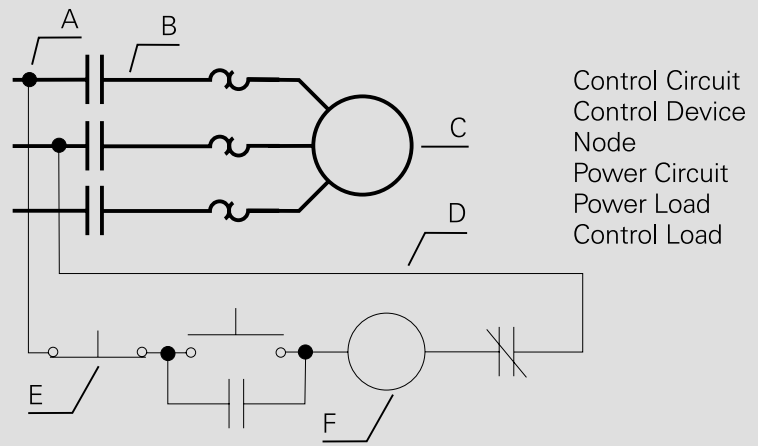
## Line Numbering

Numbering each line makes it easier to understand more complex line diagrams. In the following illustration, line 1 connects pushbutton 1 to pilot light 1. Line 2 connects pushbutton 2 to pilot light 1. Line 3 connects switch 1 to pilot light 2 and the "M" contactor on line 4.



## Review 2

- Line diagrams are read from \_\_\_\_\_ to \_\_\_\_\_, or L1 to L2.
- Match the items on the line diagram with the associated list.



A \_\_\_\_\_

B \_\_\_\_\_

C \_\_\_\_\_

D \_\_\_\_\_

E \_\_\_\_\_

F \_\_\_\_\_