Skillplex

Wiring Fundamentals

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Chapter 1: Course Overview

1.1 Course Goal

This course is intended for high school students enrolled in CTE pathway programs to learn the fundamentals of wiring motor contactors, relay circuits, and using a PLC to interface with discrete field devices.

This course is structured to provide students hands-on experience wiring and troubleshooting industrial control circuits. The student will explore different methods of controlling a motor contactor using an operator push button station, control relay, and PLC.

Skillplex is not an expert in safety systems or equipment and does not represent itself as an authority on safety practices in either educational or workplace environments.

1.2 Course Objectives

Upon successful completion of this course, the student will be able to perform the following:

- Use a multimeter to verify the correct voltages are present at power distribution terminal banks.
- Use a multimeter to diagnose open and short circuits.
- Use a relay logic ladder diagram to wire a motor contactor.
- Control a motor contactor using 2-wire and 3-wire motor control circuits.
- Use a control relay to change the operation of a motor control circuit.
- Covert a relay logic ladder diagram to a PLC program.
- Establish communications with a PLC using a programming laptop.
- Use RSLogix500 to create a ladder logic program.
- Download a ladder logic program to a PLC and monitor its operation.
- Detect, diagnose, and repair electrical faults in a PLC system.

Chapter 3: Relay Circuits

3.1 Chapter Objectives

After completing this chapter, you will be able to:

- Interpret basic ladder logic diagrams and symbols.
- Explain the difference between NO and NC contact types.
- Wire relay circuits using ladder diagrams.
- Use a multimeter to analyze the operation of relay circuits.

3.2 Push Buttons and Contact Types

Electrical switches like the ones you use to turn the lights on and off inside your home are a simple mechanism which allow an electric circuit to close or open. When the switch is **open**, there is no continuity and current cannot flow through the circuit. When the switch is **closed**, there is continuity and current is allowed to flow through the circuit.

In industrial control circuits**, hand switches** are often used by operators to turn different devices (such as control relays and motor starters) on and off. A common type of hand switch is a **push button**, which is operated by pressing down on a button to activate a set of contacts to close or open a circuit.

A **contact** is a switching mechanism used with push buttons and other discrete devices used for on/off control. A contact can be one of two types: **normally open (NO)** or **normally closed (NC)**. Here the word "normally" refers to the contact's "normal" at-rest state when it is not being activated by an operator. The diagram symbols for a push button with each style of contacts is shown below in figure 3.4a.

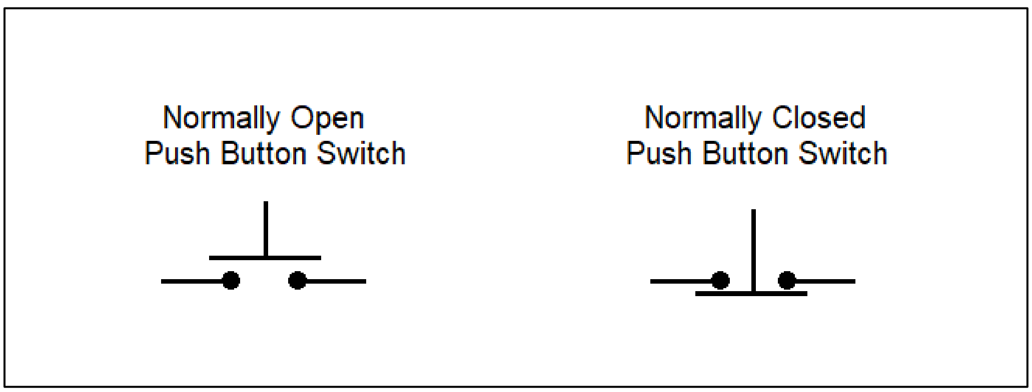

Figure 3.2a

If a push button has a set of NO contacts, this means that when the button is not being pressed by an operator, the contacts will be in an open state and current will not be allowed to flow to the load device(s). When the operator presses the push button, the NO contacts will close, allowing current to flow to the load device(s). When the operator releases the push button, a spring returns the contacts to their normal (open) position

If a push button has a set of NC contacts, this means that when the button is not being pressed by an operator, the contacts will be in a closed state and current will be allowed to flow. When the push button is pressed, the NC contacts will open, and current will not be allowed to flow. When the operator releases the push button, a spring returns the contacts to their normal (closed) position

Since these types of push buttons return back to their normal positions by a spring and only have their contacts switched to their activated state while the operator is holding down the button, they are considered **momentary push buttons**.

Let's examine how these types of push button contacts affect the operation of an electric circuit. Figure 3.2b shows a type of electrical drawing called a **ladder diagram**. It has two vertical "power rails" on the left and right sides which represent the positive and negative poles of a DC power supply. In between the vertical rails, you can see two horizontal "rungs" which each have a push button on the left side to control turning on or off a pilot light on the right side. Rung 001 has a normally open push button and rung 002 has a normally closed push button. The name "ladder diagram" is fitting since the drawing resembles a ladder with its rails and rungs.

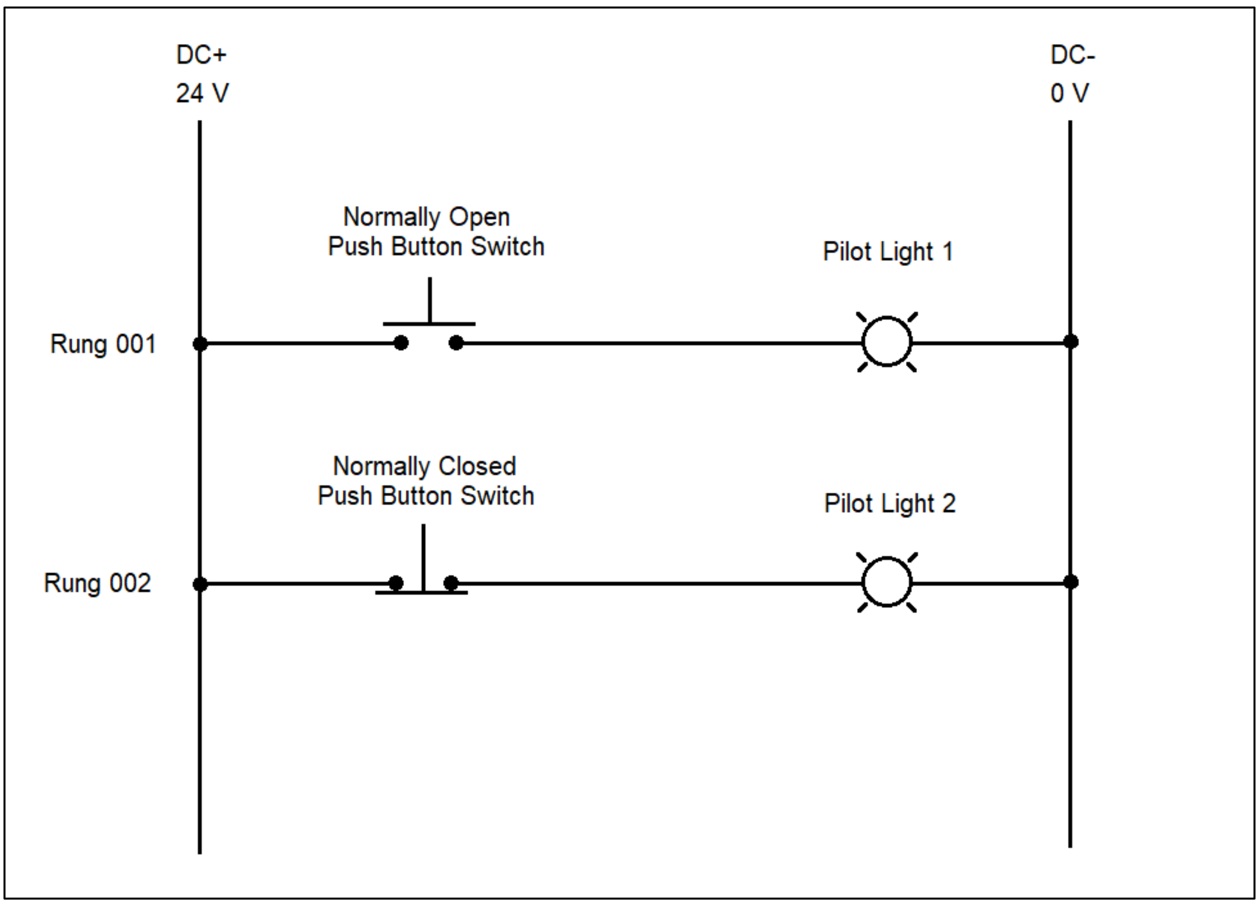

Figure 3.2b

When an operator presses the NO push button its contacts will close, allowing current to flow from the DC+ rail, through the push button contacts, through Pilot Light 1, and returning at the DC- rail to complete the circuit. When the operator releases the NO push button, the contacts open and the light turns off.

On the second rung, the NC push button is already closed before the operator presses it, so as long as the push button is not pressed, current will flow from left to right turning on Pilot Light 2. When an operator presses the NC push button, the contacts will open and the light turns off. When the operator releases the NC push button, the contacts close and light turns back on.

A **three-position selector switch** is another common type of hand switch which allows an operator to select between three different switch positions: **Hand**, **Off**, and **Auto**. These positions are associated with how the circuit or system being controlled will operate. The switch has two sets of normally open contacts: one NO contact closes when the switch is in the Hand position, one NO contact closes in the Auto position, and both contacts are left open when the switch is in the Off position. The contacts that close in the Hand and Auto positions are used to allow a machine or control system to be operated manually by an operator (Hand), or to be automatically controlled (Auto) using relay circuits or a programmable logic controller. In figure 3.2c you can see the ladder diagram symbol for this type of switch.

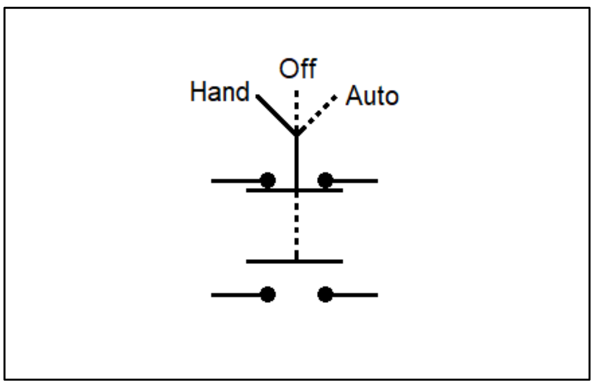

Figure 3.2c

In figures 3.2d, 3.2e, and 3.2f, you can see a ladder diagram of a three-position selector switch controlling two different pilot lights. The green light will turn on when the switch is in the Hand position, the red light will turn on when the switch is in the Auto position, and both lights will remain off when the switch is in the Off position.

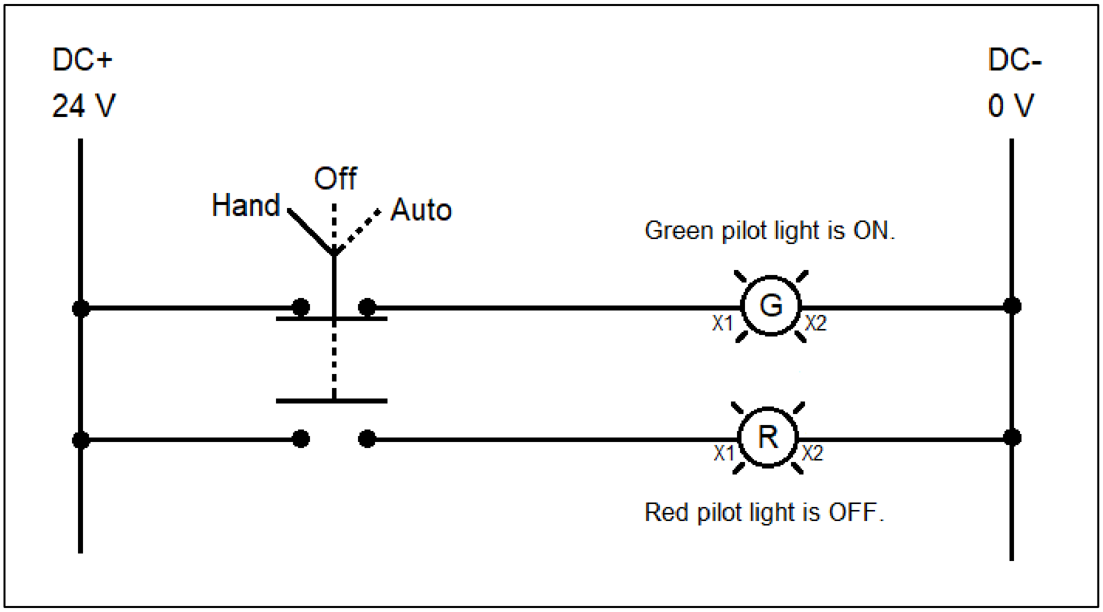

Figure 3.2d

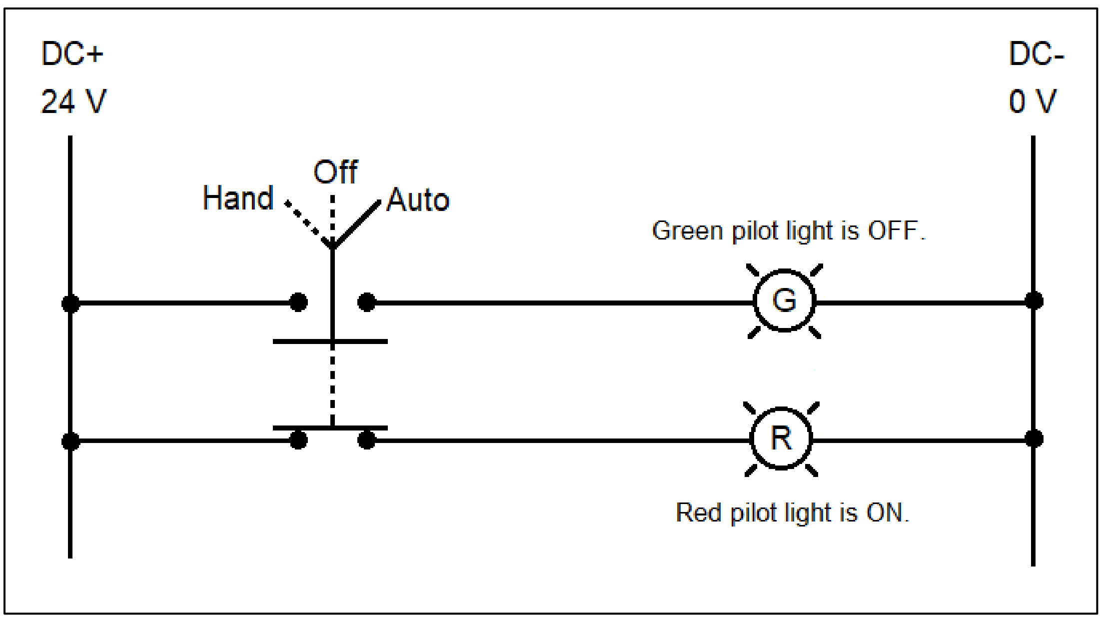

Figure 3.2e

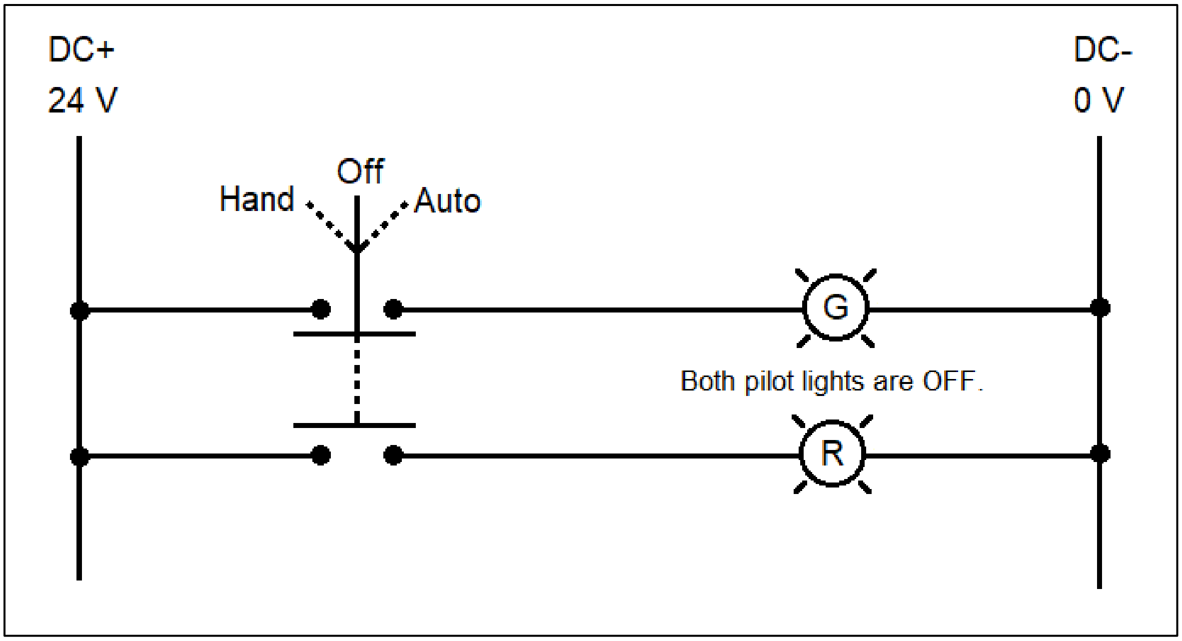

Figure 3.2f

The main difference between how a selector switch operates compared to a pushbutton, is that a selector switch allows the selected contact state to be **maintained** without having to hold the switch in that position. The selector switch will actually “click” into one of the three positions and remain in that position until adjusted by the operator. The pushbuttons we have discussed in this chapter, on the other hand, only allow for **momentary** contact closure, and must be held down by an operator to keep the contacts in their activated state.

3.3 Electromagnetic Relays

A relay is a discrete control device that is used to switch power on and off to other circuits connected to it. The word **discrete** means "individual" or "distinct" and indicates that the device only has two possible states: on or off. An electromagnetic relay is made up of an electromagnetic coil and one or more sets of contacts which can be used to turn different load circuits on or off.

An **electromagnetic coil** is an electrically-operated magnet in which a copper wire is wound around an iron core; when energized with the proper voltage, the coil generates a magnetic field which attracts or "pulls in" an iron armature that is mechanically linked to a set of contacts that switch open or closed depending on the contact type (NO or NC). Relays can have a single NO contact, a single NC contact, one NO and one NC contact, or two NO and two NC contacts.

The electrical schematic symbol for a single-pole, single-throw (SPST) relay with a normally open contact is shown below in figure 3.3a. The **pole** or **common** of the relay contact is the side of the contact set that performs the switching action. The term **throw** refers to how many contacts there are for the pole to connect to (only one in this case). The effect of the coil's magnetic field which causes the relay contacts to actuate (operate) is represented by a dashed line.

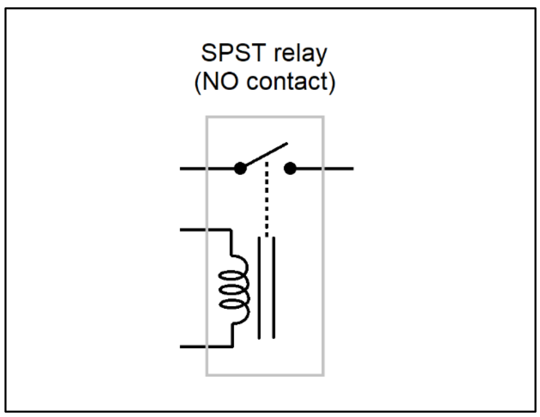

Figure 3.3a

The electrical schematic symbol for an SPST relay with a normally closed contact is shown below.

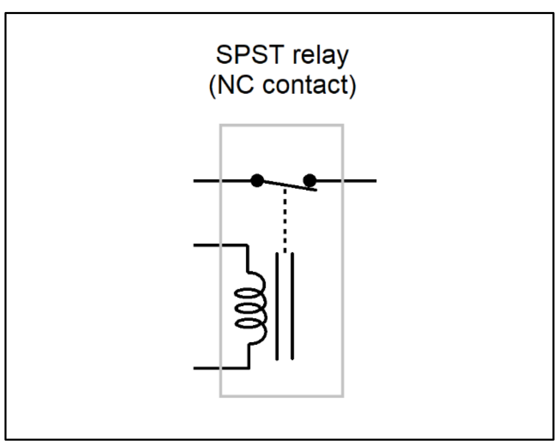

Figure 3.3b

A single-pole, double-throw (SPDT) relay has one normally open and one normally closed contact. The electrical schematic symbol for a SPDT relay is shown below in figure 3.3c

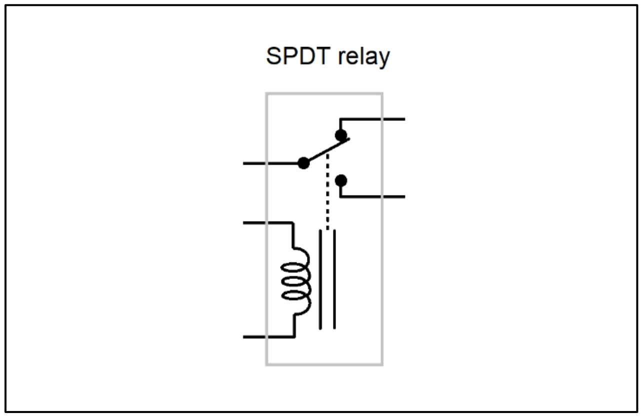

Figure 3.3c

The double-pole, double throw (DPDT) relay is shown below in figure 3.3d and is one of the most common type used in industry. The DPDT relay has two pairs of normally open and normally closed contacts. This style of relay can be used for a wide variety of applications and since it has the most options of contact styles it is quite flexible in terms of how it can be used to control the operation of devices.

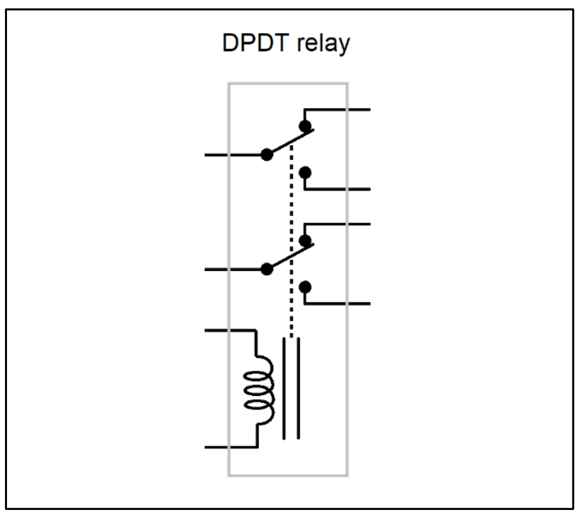

Figure 3.3d

A relay circuit actually consists of two circuits: the **control circuit** and the **load circuit**. The control circuit is the circuit which energizes the coil, causing the relay contacts to switch states between open and closed. The load circuit is the circuit that energizes a load device once the relay contacts become closed.

In figure 3.3e below, you can see the control circuit has a toggle switch that is used to energize the relay coil. When the switch is closed, the coil's magnetic field will pull the NO contact closed, completing the load circuit and turning on the indicator lamp, which is the load device in the load circuit. When the switch is opened, the relay coil will de-energize, causing the NO contact to return to the open position, turning off the load device.

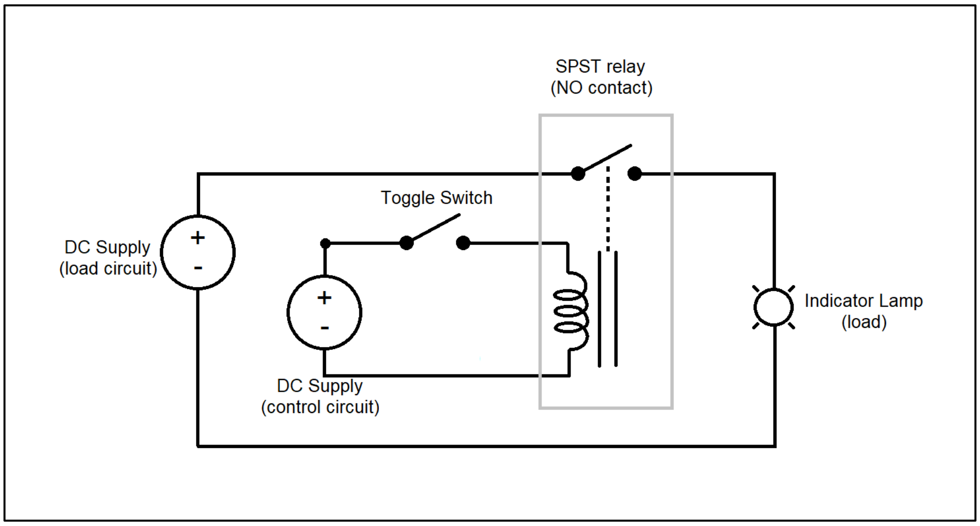

Figure 3.3e

Notice that there are two power supplies in the example above. It is sometimes necessary to use two separate power supplies if the relay coil and the load device(s) are not rated for the same voltage. When a relay is used to power loads that have a different voltage rating than the relay coil, we call it an **interposing relay**. For example, if the relay coil is rated to operate using 24 VDC and the load device is rated to operate using 12 VDC, we would need one 24 VDC power supply for the control circuit and one 12 VDC power supply for the load circuit.

However, if the relay coil and the load device(s) are compatible with the same voltage (such as 24 VDC), we could have used a single DC power supply to energize both the control circuit and the load circuit, as shown below in figure 3.3f.

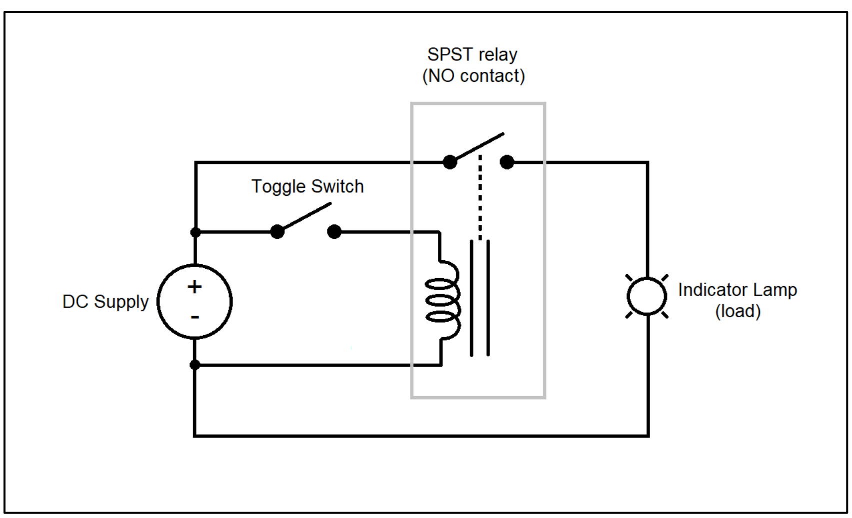

Figure 3.3f

In figure 3.3g below, you can see the internal parts of an electromagnetic relay. An electromagnetic coil is positioned below an iron armature. The armature is resting on a pivot point (like a seesaw) and is held in its normal position by a spring. While the relay coil is **de-energized** (does not have voltage applied to it), the tension from the spring keeps the armature tilted up and away from the coil. There are two contacts positioned above and below the end of the armature. The upper contact is normally closed, since the armature is already touching it while the coil is de-energized. The lower contact is normally open, since the armature is not touching it while the coil is de-energized.

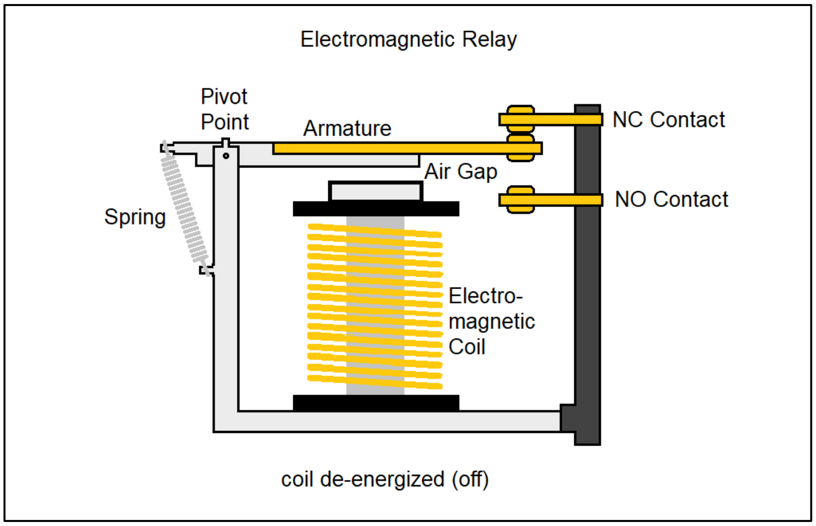

Figure 3.3g

In figure 3.3h below, the same relay is shown with the coil **energized** (has voltage applied to it). When current flows through the coil, it causes a magnetic field to be generated which attracts the iron armature towards the coil. This pulls the armature down, causing the normally closed contact to open, and causing the normally open contact to close. The magnetic field is now overcoming the force of tension from the spring. When the coil becomes de-energized again, the spring will return the armature back to its normal position, tilted up and away from the coil.

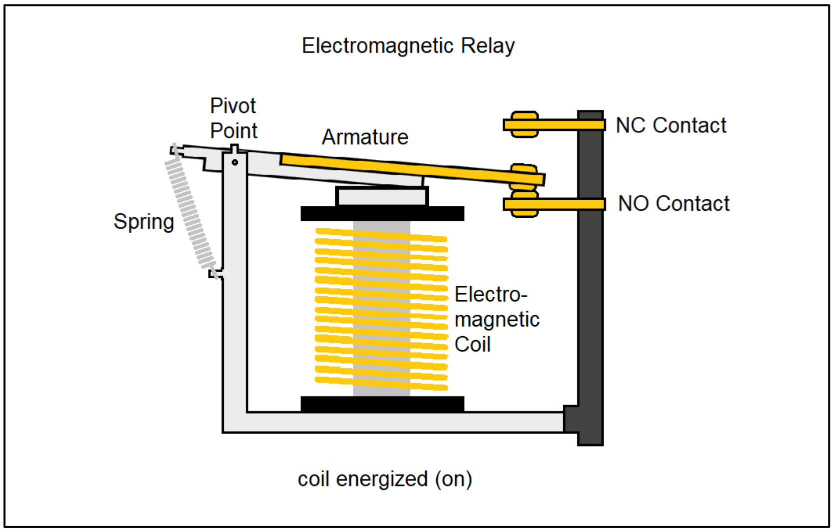

Figure 3.3h

The internal components of the relay are housed inside of a (usually clear) plastic case which protects the relay mechanism and allows for visual inspection of the relay's condition. This clear plastic case causes the physical appearance of the relay to resemble an ice cube, and in the manufacturing industry this style of relay is referred to as an **ice cube relay**. Wiring connections for the relay contacts, armature, and coil are fed through the relay's plastic casing to external pins or terminals (figures 3.3i and 3.3g). The external pins allow the "ice cube" to be plugged into a terminal base, which connects each pin to screw-style wiring terminals.

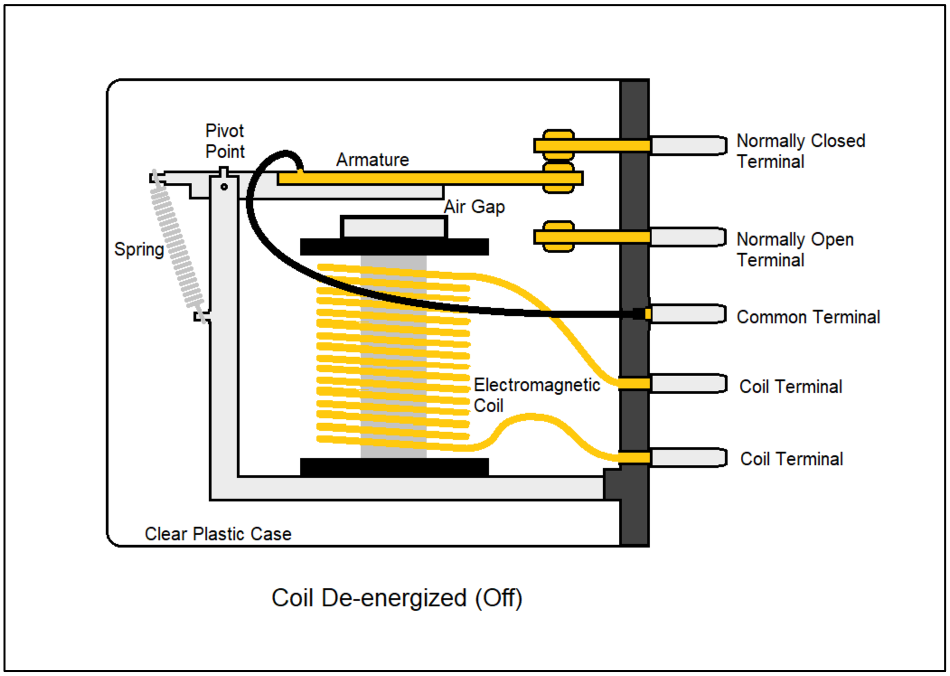

Figure 3.3i

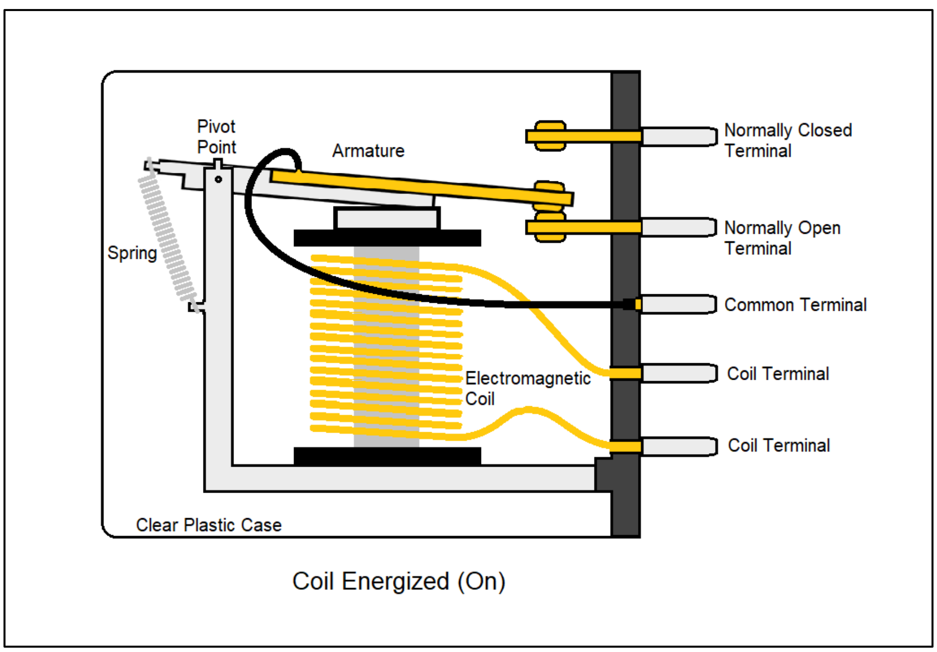

Figure 3.3g

Electromagnetic relays consist of two parts: the **relay** or “ice cube” and the **terminal base** which the relay is plugged into. The relay terminal base brings the connections from the external pins or blades of the relay to the wiring terminals at the top and bottom of the terminal base. The wiring terminals are used to wire the control circuit and load circuits to the relay. In figure 3.3h below, you can see the **pinout diagram** for a DPDT relay and its terminal base. A pinout diagram shows which internal component of a device each pin or wiring terminal is connected to.

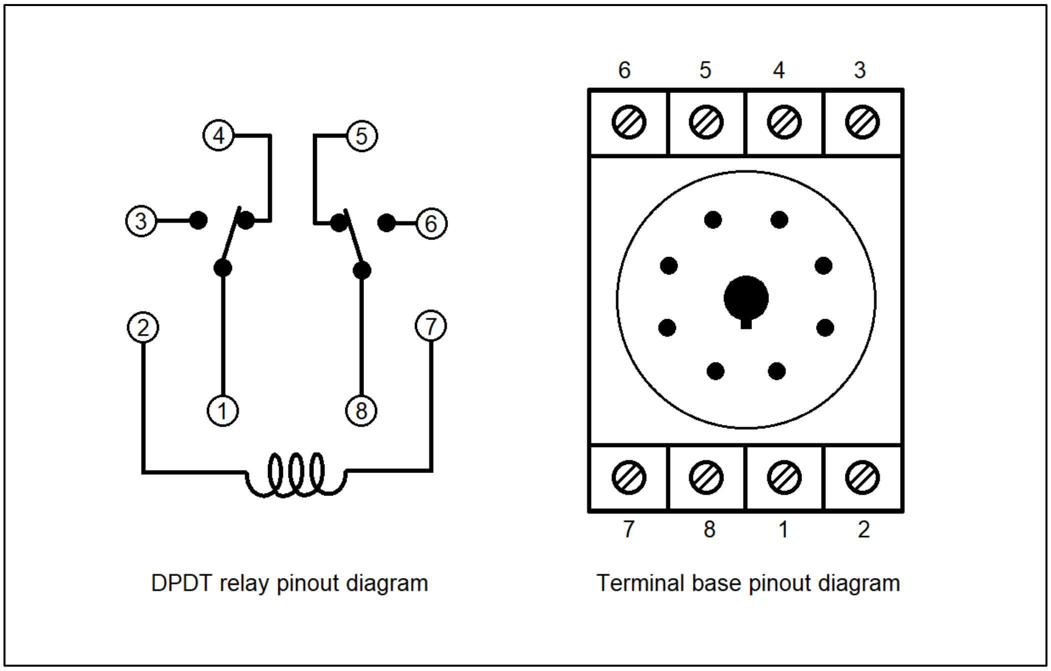

Figure 3.3h

You can see in the relay pinout diagram in figure 3.3h that the relay coil is connected to pins 2 and 7. The poles (also called “commons” or abbreviated to COM) of the relay are connected to pins 1 and 8. The poles are what you connect the voltage you will be using in the load circuits (e.g. +24 VDC). The normally closed contacts are connected to pins 4 and 5, and the normally open contacts are connected to pins 3 and 6. On the terminal base pinout on the right side of the picture above, you can see that once the relay is plugged into the base, the pins labeled on the relay pinout will correspond to the wiring terminals labeled on the terminal base pinout. For example, if you were going to wire power to the relay coil, you would connect +V and -V to terminals 2 and 7 on the terminal base.

Two other types of relay pinout diagrams for the same DPDT relay are shown below in figure 3.3i. While these two diagrams may look different from figure 3.3h, they represent the same type of relay using different symbols.

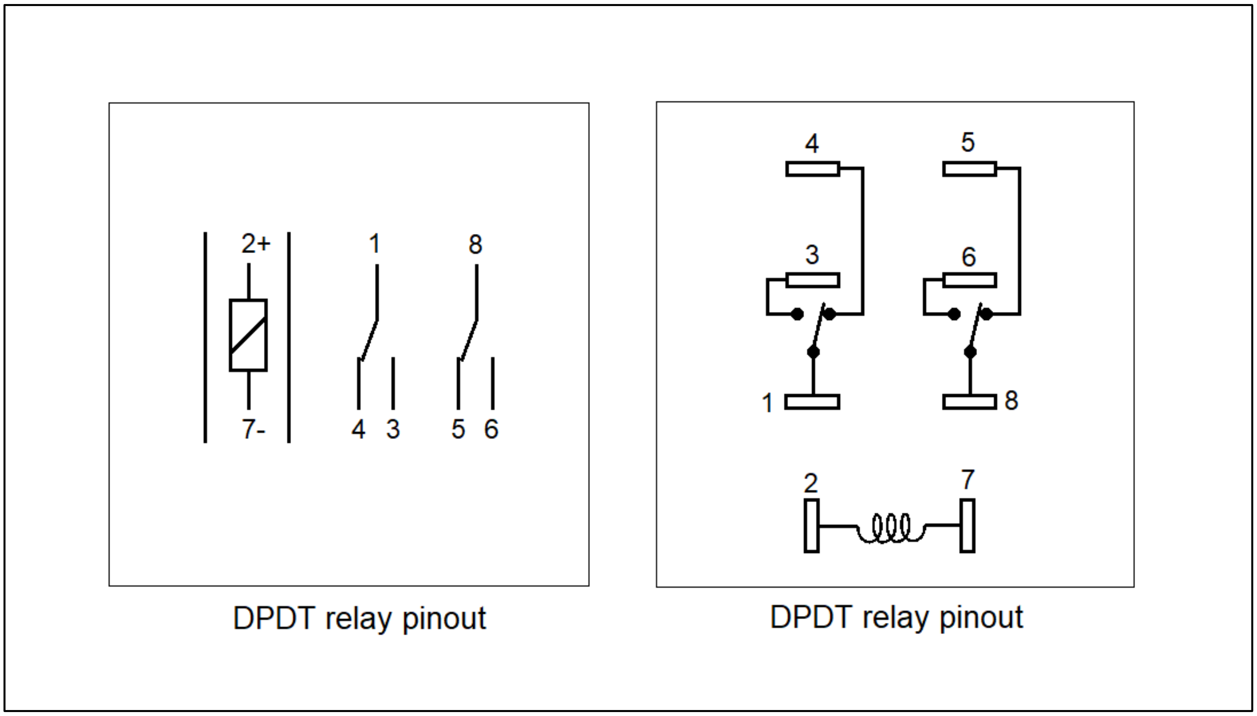

Figure 3.3i

On the left diagram, the coil is represented by a rectangle with a diagonal line through it. You can see that pins 2 and 7 for the coil have **polarity markings** (+ and -) indicating that the coil will only work if current flows across it from pin 2 to pin 7. The left diagram's contacts are represented by simple lines. The diagram on the right, by contrast, does not have polarity markings for the coil, meaning it does not matter which direction current flows across it, it will work either way. Pinout diagrams for control relays will vary based on the manufacturer, however all of them will share the same concept of depicting a relay coil which actuates one or more sets of NO or NC contacts.

The ladder logic diagram symbols for NO and NC relay contacts are different from those used to represent NO and NC push buttons. NO relay contacts are represented by two vertical lines with a space in between (showing there is no continuity across the contacts in their normal state). NC relay contacts are represented by a two vertical lines with a diagonal line through them (showing there is continuity across the contacts in their normal state). The relay coil symbol is an empty circle. These symbols are shown below in figure 3.3j.

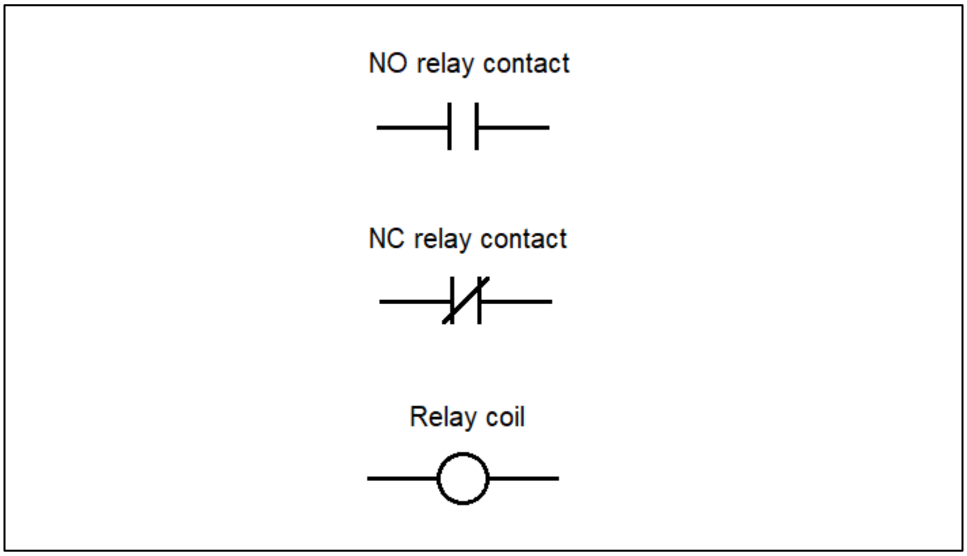

Figure 3.3j

Ladder diagrams do not show the connections between the coil and contacts of a relay the way an electrical schematic does (such as figures 3.3e or 3.3f). Instead, ladder diagrams show the corresponding coil and contacts of the same relay using **labels**. You will either see the relay contacts have the exact same name as the coil (i.e. coil labeled CR2 and all contacts also labeled CR2), or you will see the relay contacts labeled with the name of the coil along with a unique number to separate it from the other contacts in the same relay (i.e. coil labeled CR2 and contacts labeled CR2-1, CR2-2, CR2-3, CR2-4).

The ladder diagram in figure 3.3k shows a relay circuit that controls two pilot lights using one SPDT relay. On rung 001, a NO push button is used to control the relay coil labeled CR1. On rung 002, the NO relay contact labeled CR1-1 controls a green pilot light. On rung 003, the NC relay contact labeled CR1-2 controls a red pilot light. When the push button is not pressed, the red light is on and the green light is off, and when the push button is pressed the red light turns off and the green light turns on.

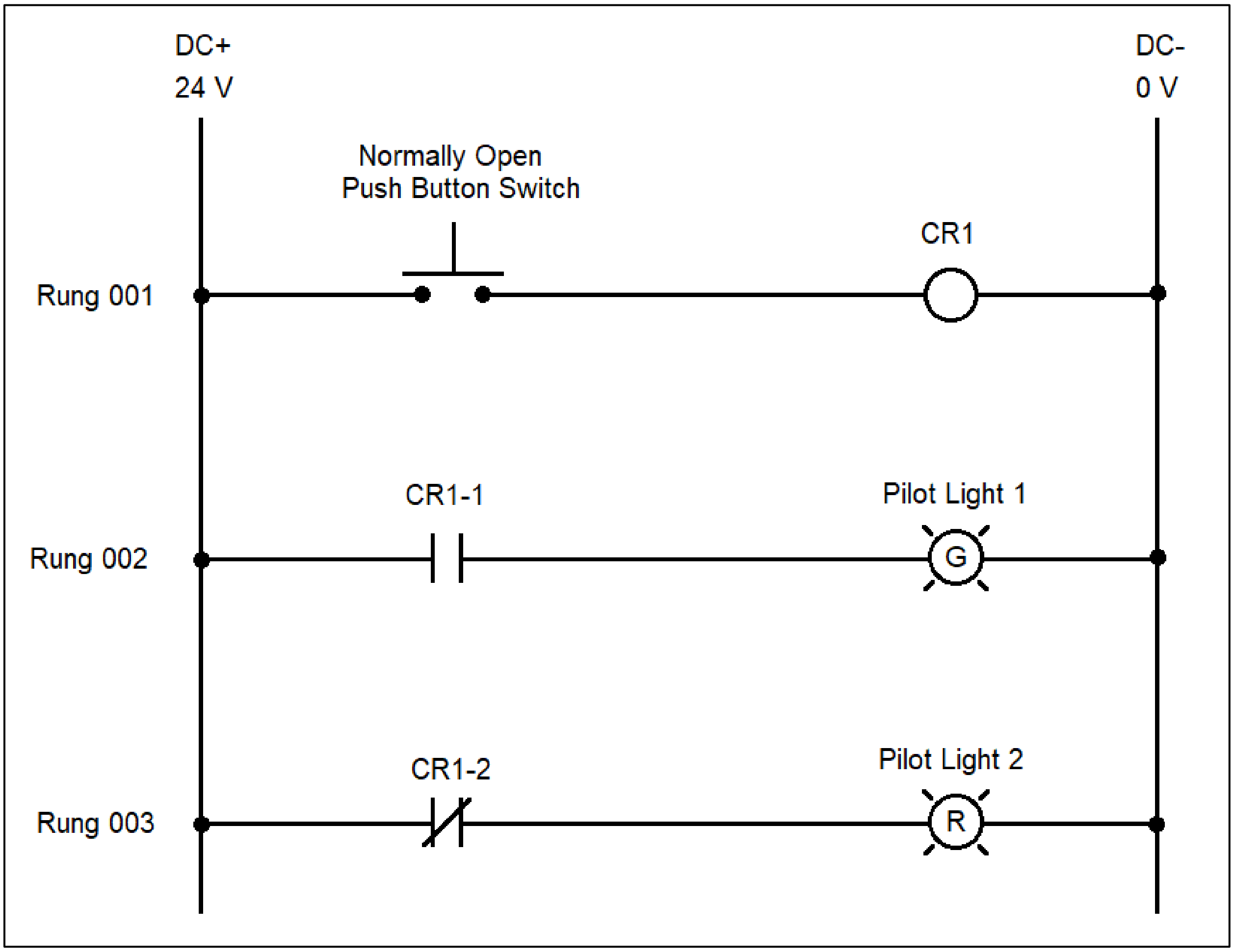

Figure 3.3k

An equivalent electrical schematic of the ladder logic diagram on the previous page is shown below in figure 3.3l. Here you can clearly see the connections between the relay coil and relay contacts of the SPDT relay, so it is not necessary to use labels to associate them with one another.

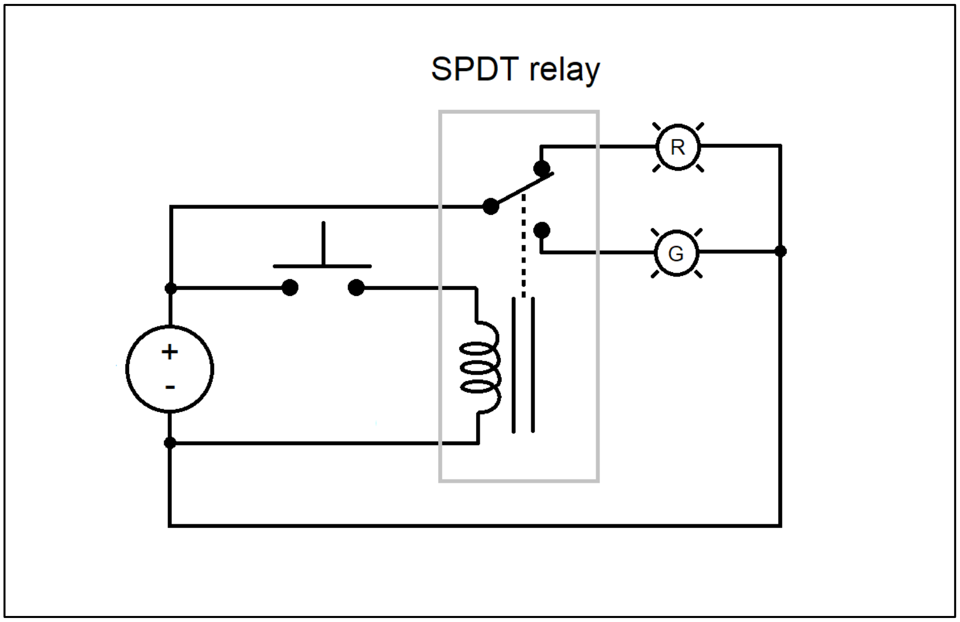

Figure 3.3l