Electrical Tech Note — 350B

Biosystems & Agricultural Engineering Department
Michigan State University

Electric Motor Circuit Requirements

An electrical motor converts electrical power into mechanical power. Electric motors have some characteristics that are different than most other electrical devices and the motor circuit must be capable of dealing with these differences. In general an electric motor circuit only supplies one motor and all circuit components are sized to that one motor. This *Tech Note* will help understanding of unique issues of dealing with a motor control circuits.

Electrical wires and other circuit components have a finite resistance and when they carry current heat is produced. Different sizes of wires and electrical components such as switches and receptacles have a maximum safe current rating that must not be exceeded. This is also true with motors and control circuits.

Electrical circuits are required to originate at a circuit breaker or set of fuses that are sized to open the circuit and shut off power when current exceeds a safe level. The main purpose is to prevent a fire due to the heat produced by an excessive circuit current. This excessive current can be the result of a circuit overload or the result of a short-circuit or a ground-fault. Circuit breakers and fuses are designed to provide protection from excessive overloads as well as short-circuits and ground-faults.

Electric motors typically create unique conditions that make them difficult for a circuit breaker or a set of fuses to provide both *overload protection* as well as *short-circuit and ground-fault protection*. Motors draw a very high current when they are started and a much lower current during normal operation. Starting time can range from a fraction of a second to several seconds. This is illustrated in the time-current graph of *Figure 350.1.* Because of these extreme conditions fuses or circuit breaker provide although usually overcurrent devices cannot provide both short-circuit and ground-fault protection as well as motor overload protection. Running over-current protection is usually provided by a device added to the motor over-load sensors inside the motor controller.

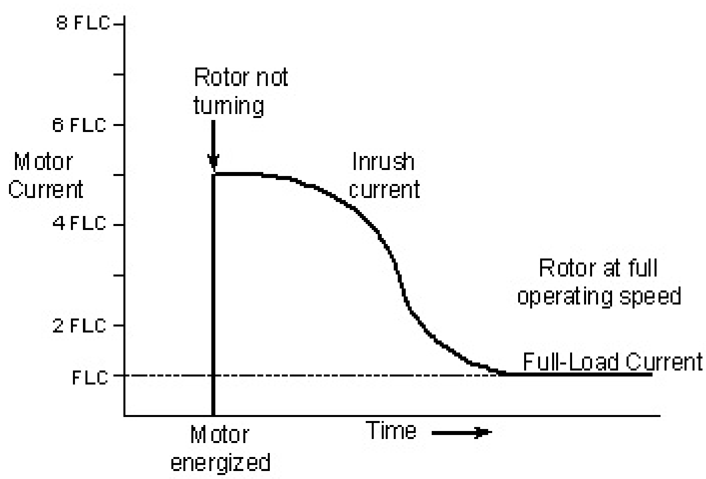


Figure 350.1 *The instant an electric motor is energized and the rotor is not turning an inrush current occurs that reaches from 5 to 8 times higher than full-load running current.*

An electric motor responds to the power demand of the load and attempts to provide the power required. If the load power required exceeds the motor's design capability for too long it will sustain internal damage due to excessive heat resulting in premature failure. An electric motor will attempt to provide the power required. Motor current draw will increase above the rated full-load current if the power delivered by the motor exceeds the motor full-load power rating. Internal winding heat will become excessive.

The wire used to make the windings inside the motor always have some resistance. Some heat is produced as the current flows through these windings. Heat produced is proportional to the square of the current. Even a small increase in winding current above the maximum design rating can result in a large amount of excess heat. The insulation on the winding wire is thin and delicate. Motor insulation on the winding wires has a maximum temperature limit. If an electric motor is placed in a hot or very warm environment excess heating will occur in the windings.

The electrical circuit that supplies a motor must provide protection to prevent motor overload in addition to providing circuit overcurrent protection. What makes this circuit and motor protection difficult is the large inrush current when it starts as illustrated in *Figure 350.1.* The overcurrent protection for the circuit must be capable of allowing the inrush current to pass and still provide proper safety at the much lower full-load current level. In order to accomplish this task the general rule is that a *circuit is only permitted to supply one motor*.

Electrical circuits must be provided protection for major overcurrent events such as short circuits and ground faults. These conditions are usually the result of component failure or external damage to the circuit or equipment. Circuits must also be protected from overloads where the current exceeds the rating of the wires or components. In the case of an electric motor circuit the *short-circuit and ground-fault protection* is located at the origination of the circuit in the form of a circuit breaker or set of fuses. The *overload protection* is located at the motor or at the motor controller. The overload protection must be selected for each motor. Motor nameplates are required to provide information necessary to properly select these overcurrent devices. Motor nameplates are discussed in detail in *Tech Note 103.* A typical motor circuit is illustrated in *Figure 350.2* showing the common location of these overcurrent devices.

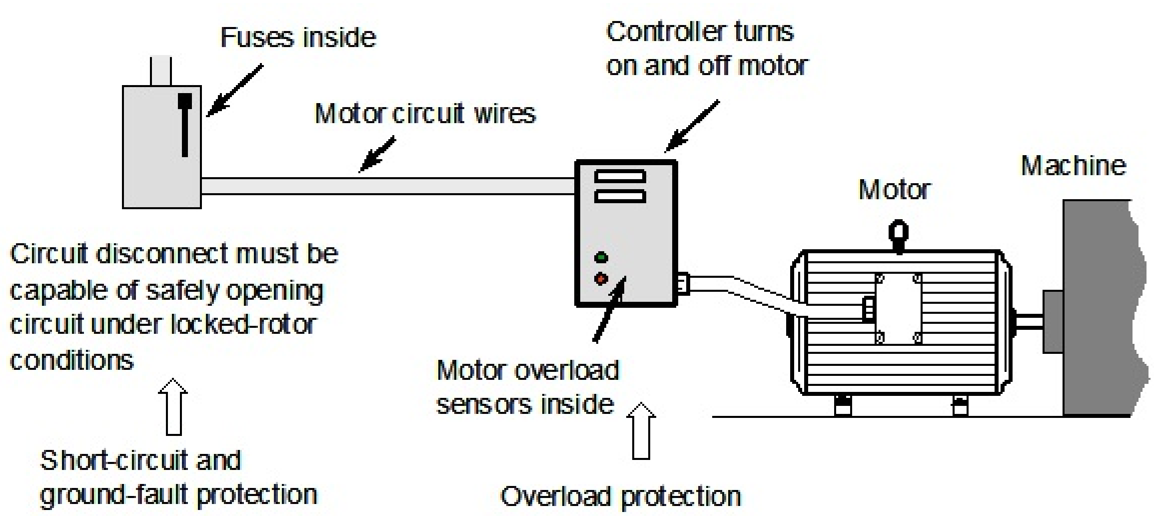


Figure 350.2 *A motor circuit has a disconnect that provides short-circuit and ground-fault protection at the disconnect. The controller is the device that turns the motor on and off and provides the motor running overload protection.*

The motor circuit originates at a circuit breaker or a switch containing a set of fuses. The circuit breaker or fuse rating must be set high enough to handle the motor inrush current and with a rating low enough to disconnect power if there is a ground-fault or short-circuit. These rules are required by the *National Electrical Code*.

A circuit disconnect is required to be within sight of the motor, the controller, and the device or machinery powered by the motor. The electrical code requires the disconnect be in sight from the controller, the motor, and the equipment supplied power by the motor. A disconnect within sight also requires the disconnect distance not exceed 50 feet from the motor and controller. Any device that opens the circuit to disconnect power to the motor must be capable of safely disconnecting this locked-rotor current. Motor switches and controllers are specially designed to safely handle these extreme conditions.

There must also be some type of overload protection specifically selected for the motor that will detect excessive overload current to the motor. The motor rated full-load current is printed on the motor nameplate. The overload sensing device must be capable of automatically activating the controller to disconnect power to the motor when these safe limits are exceeded. The overload sensing device must be slow enough at responding to a short overload condition such as allowing the starting inrush current to pass and sensitive enough to detect a longer duration overload that may damage the motor.

The motor is turned on and off with a switch or controller that is capable of safe operation under the most extreme conditions. Motor switches and controllers have a nameplate that provide maximum horsepower ratings at various circuit voltages. Some switches are operated manually and most controllers are operated with a magnetic solenoid. *Figure 350.3* is a general diagram of a motor controller showing required components. This diagram shows how a **3-wire** control diagram with manual stop/start push buttons.

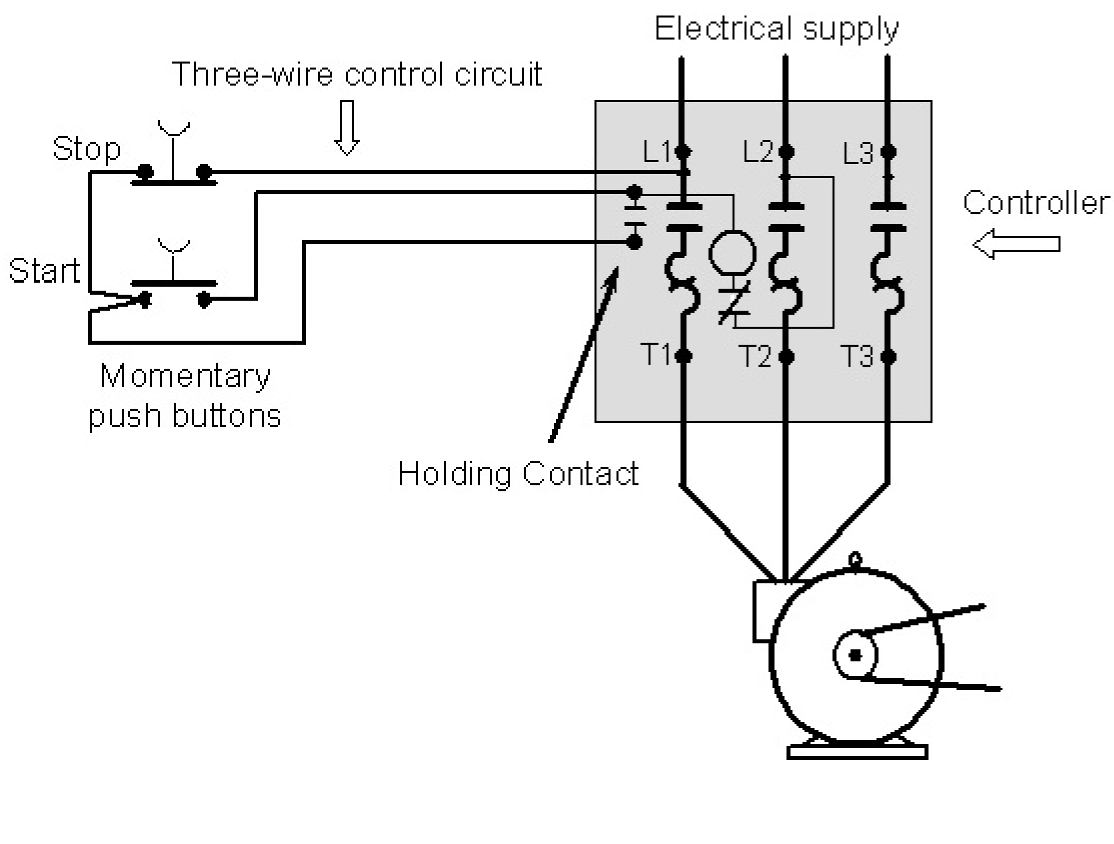


Figure 350.3 *The main contacts and the holding contact close when the solenoid is energized. The solenoid is energized with an external device.*

Control Circuit: The dashed lines in *Figure 350.4* is the external control circuit that is installed to operate the motor supplied by the controller. The control circuit of *Figure 350.4* is a manual switch that when closed completes a circuit that supplies power from a supply circuit wire "L1" to the solenoid. The solenoid circuit is completed through the overload contact ending at supply circuit wire "L2." The controller shown in *Figure 350.4* has three supply conductors and is controlling a 3-phase motor. Typical voltages between 3-phase supply conductors are 208 volts, 240 volts, and 480 volts. Solenoid coils are interchangeable and must be selected for the proper supply voltage.

The overload switch in the control circuit of *Figure 350.4* is closed as shown in the diagram. There are typically three motor current sensors one for each of the three supply conductors. If any one of the current sensors detects an overload that potentially can damage the motor windings the solenoid switch opens and breaks the control circuit and shuts off the motor.

Two-Wire Control Circuit: The control circuit indicated by the dashed lines of *Figure 350.4* is a two-wire control circuit. Power from supply conductor "L1" is connected to a control device such as a manual switch, a thermostat, a pressure switch, a liquid level float switch a proximity switch, or any other sensing device operated switch. When the sensing switch closes the solenoid is energized and the motor operates. Two wires are needed to connect the external control the sensor switch to the motor controller. Two-wire control *Figure 350.7*, page 7.

Three-Wire Control Circuit: A three-wire control circuit operated by two momentary push buttons is shown in *Figure 350.3.* One push button starts the motor and the other stops the motor. The stop push button switch is closed unless pressed to open. The start push button is open unless pressed to close. This type of control device requires three wires to connect to the motor controller. A *holding contact* in the motor controller keeps the control circuit operating when the start push button is released. This same concept is used when one sensor switch turns on a motor and another sensor switch turns off the motor.

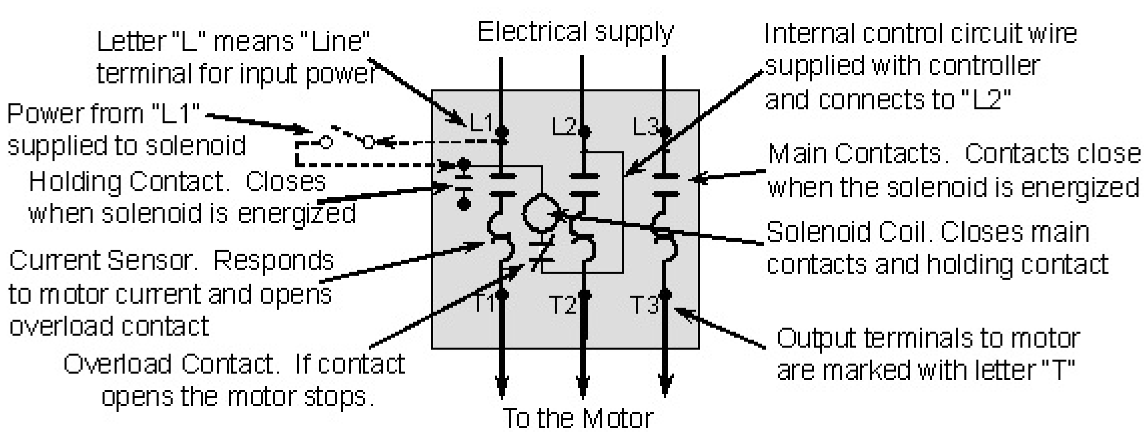
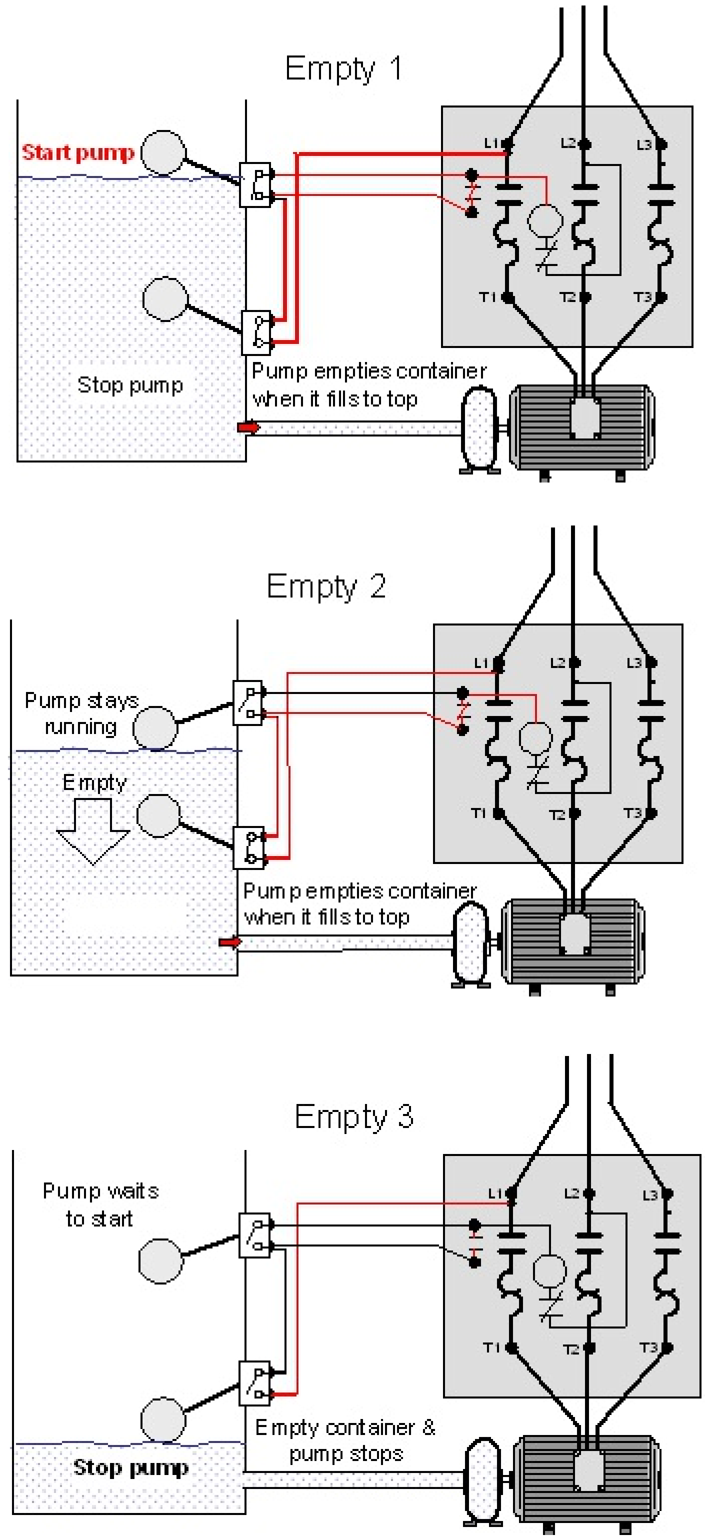


Figure 350.4 *Closing the switch in the control circuit (dashed line) activates the controller to turn on the motor. Opening the switch turns off the motor. Various sensor switches can also control the motor as a 2-wire control circuit.*

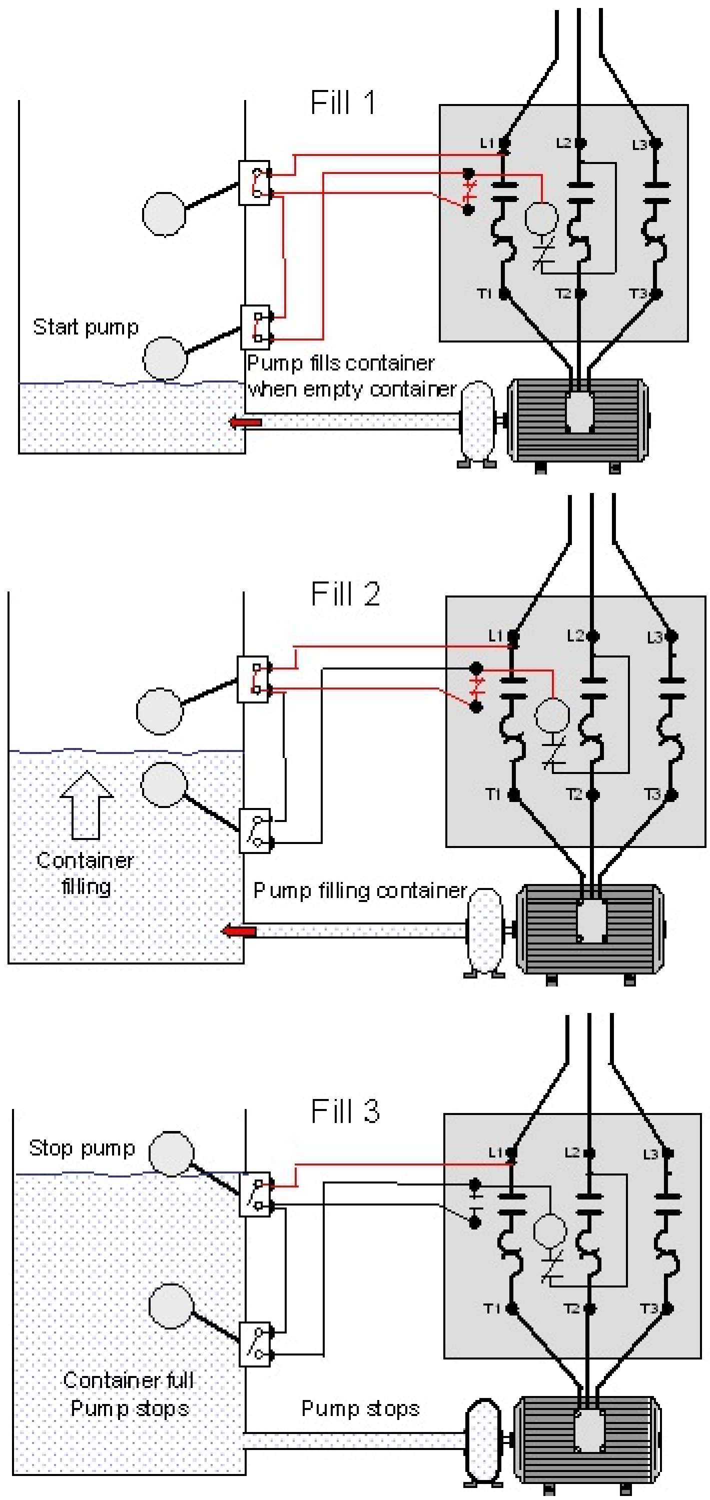
This example of a 3-wire control circuit is a container that is controlled automatically to fill the container with liquid starting when the container is empty and automatically shutting off when the container is filled. Some type of sensor is needed at the bottom of the container that will turn on the re-fill pump. Another sensor is needed at the top to shut off the pump when the container is full. *Figure 350.5* is a series of three stages of the refill process. Power from the motor controller must be connected to the **Stop** float switch.

Figure 350.5 Empty container.

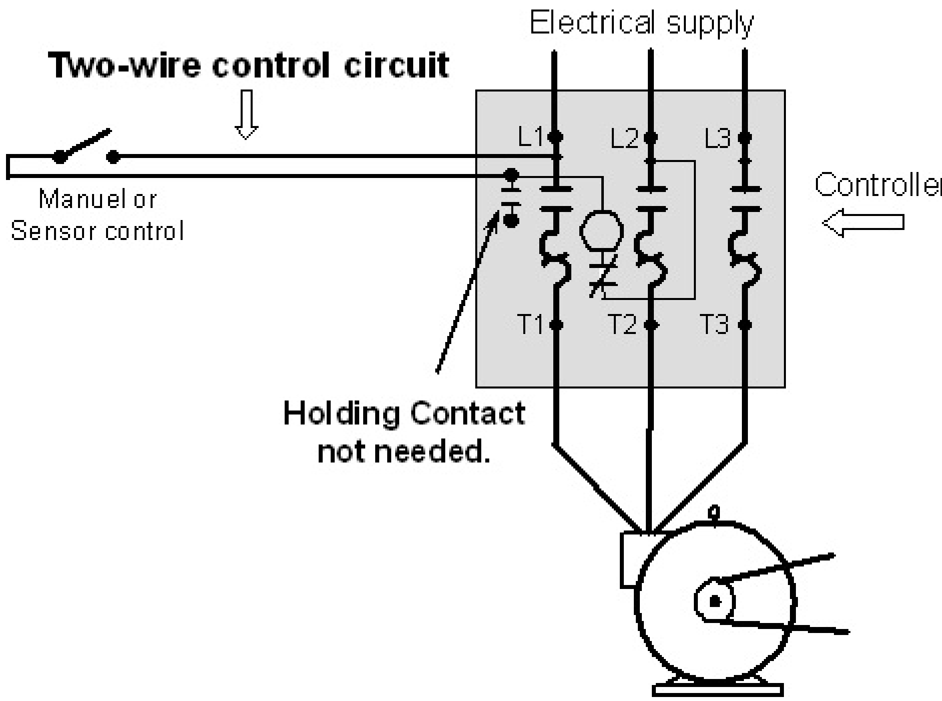


Sometimes a container fills with a fluid and automatically emptied by a pump. For this example a float switch is at the top to turn off the pump when container is filled. At the bottom of the container is another float switch to start the pump when the container is empty. The wiring is slightly different than the previous example. Power from the motor controller must first run to the shut-off float switch. The sequence to empty the container is shown in *Figure 350.6.* Both examples require a 3-wire control circuit similar to that of a start-stop push button control as shown in *Figure 530.3.*

Figure 350.6 Fill container.



2-Wire Control: A two-wire control circuit to operate an electric motor uses any type of two contact switch device either manual or sensor operated. The holding contact in the motor controller is not needed for a two-wire control circuit.



Conclusion: Electric motors have unique operating characteristics that require special consideration when wiring the circuit. Rules for circuit wiring are provided in detail in the *National Electrical Code*. Small motors can be controlled with a switch but large motors require a device called a controller. A disconnect located within sight of the controller and the motor is required that de-energize all circuit conductors if necessary.

The controller can be of the magnetic type where an electrical control circuit operates the controller. Under normal conditions the only current flow in this control circuit is the current required to operate the solenoid that operates the main contacts in the controller. As illustrated in this *Tech Note* the control circuit can receive it's electrical supply by using two of the main motor circuit conductors. In the case of smaller motors it is not necessary to install fuses to protect the control circuit conductors. For larger motors it is required to provide fuses in this control circuit. This *Tech Note* shows control circuits that operate at the same voltage as the motor itself. In many cases a transformer is installed to lower the voltage for the control circuit. This requires changes in the control circuit wires inside the controller. Sometimes the control circuit receives it's source of supply separate from the motor circuit. These cases are common and are to be installed only by experienced electricians.