Introduction to Circuit and Motor Protection Components—Fuses, Breakers, and Overloads

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Here's a valuable handbook that you can use right now. This particular reference is taken from one of the video programs in our training series— ***Electrical & Motor Controls Video Training Series.***

In it, you'll get an overview of all the protective type switches that protect electrical circuits and the machinery controlled by them. There's also lots of graphics to help explain the topics.

Best yet, we've included the chapter summary and review questions. Here you can look over the key points as well as see how much you learned by answering the review questions. And, yes, the answers are also included.

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INTRODUCTION TO MOTOR CONTROL OPERATIONS & PROTECTION

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This program gives everyone the practical motor control knowledge they need as well as explains the different causes of motor failures and the ways to prevent them.

Whether you're using AC or DC motors, this program will give everyone in your plant the skills to protect your equipment. This program, combined with *Sizing the Protection of Motors & Control Circuits*, provides the best reference for safe motor operation in your plant.

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A Must-Have for All Your Motors

- ✔ Learn to prevent the seven most common causes of heat-related motor failure
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- ✔ Class 10, 20, 30 heaters—which one offers the right protection for your motor application
- ✔ Learn why and when troubleshooting 2-wire control can be dangerous
- ✔ When a starter is wired incorrectly anything can happen—make sure it's done right the first time
- ✔ Implement proper arc suppression to protect against shorts and fire hazards
- ✔ Make sense out of NEMA standards
- ✔ Fuses, breakers, and overloads look simple, but they each offer a different type of protection—make sure everyone understands their function and uses them properly
- ✔ Learn how spending a few extra dollars can add invaluable backup motor protection

CONTENTS:

Tape 1

- Understanding, application, installation & wiring of contactors, and manual & magnetic motor starters
- Types of motor starters: full-voltage, combination, reversing, two-speed & reduced-voltage
- Arc suppression & protection in contactors & starters
- Motor & circuit protection: fuses (single & double element), circuit breakers (magnetic & thermal), & overloads (eutectic, bimetal & solid-state)

Tape 2

- Understanding motor protection curves, overload conditions & proper sizing of heater elements
- Use of double-element fuses as motor backup protection
- Controlling motor operations & plugging
- Understanding electrical & wiring control diagrams
- 2-wire & 3-wire control: application & uses
- Low-voltage release & low-voltage protection
- Causes of motor failure: symptoms & prevention

TECH TIPS

Did you know that thermal overloads can be affected by ambient temperature?

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In this handbook you will be exposed to all protective type switches which protect electrical circuits and the machinery controlled by them. These switches include fuses, circuit breakers, and motor overload heaters.

1—CIRCUIT PROTECTION

The distribution of electrical power in a plant can be very complicated. In addition, the circuits that are receiving power are subject to destructive overcurrents and short circuits. To protect these circuits and power systems from blackouts, prolonged downtime, and fire hazards, fuses and circuit breakers are widely used. Let's first define what an overcurrent is.

An overcurrent is the result of an overload current, a short-circuit, or a ground-fault current. An overload current is an excessive current, relative to the normal operating current, that is confined to the normal conductive path provided by conductors, other components, and loads, such as motors, that form part of the power distribution system (see Figure 1). A short-circuit or a ground-fault current is an excessive current that flows outside the normal conducting path (see Figure 2).

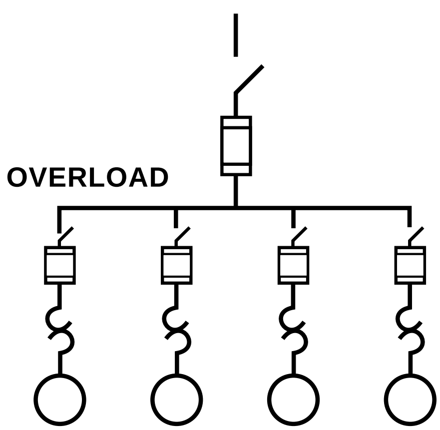

Figure 1

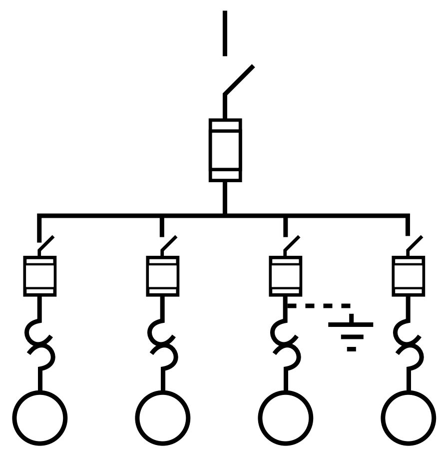

Figure 2

While overloads are most often at no more than 6 to 10 times the normal current levels, short-circuit currents can be hundreds of times that of the normal operating current. This high current, if not stopped in a few thousands of a second, can cause severe insulation damage. In addition, overloads can cause melting of metal and conductors, vaporization of metal, ionization of gases, and arcing, all of which can result in a fire.

Fuses—Single Element & Dual Element

Fuses are used to protect a circuit in which a short-circuit fault can occur. This protection is supplied by the design built into the fuse, which quickly disconnects the power provided to a system. Fuses are represented by the symbol shown in Figure 3.

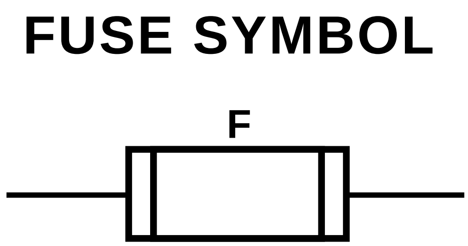

Figure 3

Inductive loads, such as squirrel-cage motors, will pull between 6 to 10 times the amount of full-load, normal current when they are first started. For example, a 200-volt, 10-horsepower motor will pull 193.2 amps for a short duration before it reaches its full-load amperage current (see Figure 4). In this case, it pulls 6 times its full-load current. When this circuit is protected with fuses against short circuits and ground faults (see Figure 5), the fuse must be able to allow this overcurrent situation to occur without breaking or disconnecting power to the motor circuit.

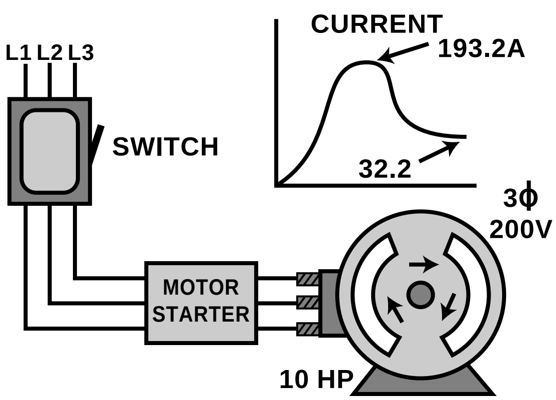

Figure 4

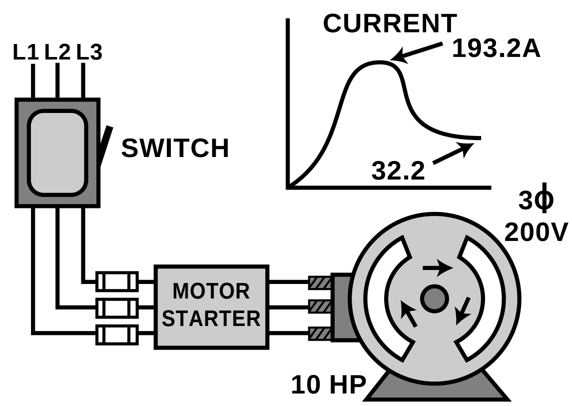

Figure 5

Single element and *dual element* fuses are used in different applications. A single element fuse, also called a *non time-delay* fuse, is made of one conducting element that has one or more links enclosed in a tube, or cartridge, surrounded by arc-quenching filler material.

Under normal operation, the fuse conducts current simply by acting as a conductor (see Figure 6). If an overload occurs and persists for a short interval, the temperature created by the overcurrent will reach a level that melts the link forming a gap and breaking the circuit.

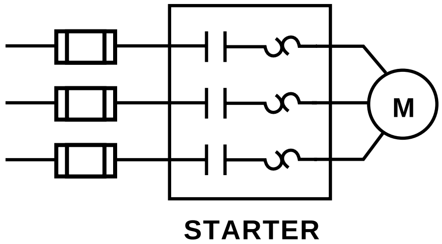

Figure 6

While overload currents are normally 6 to 10 times the normal current, short-circuit currents are much higher than the normal current (see Figure 7).

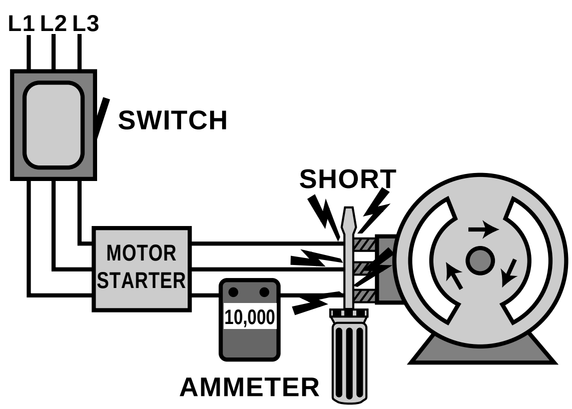

Figure 7

Single-element fuses can be subjected to short-circuit currents of 50,000 amps or higher. The response to these currents must be extremely fast to avoid serious damage and run the risk of fire. In fact, if a large ground fault occurs, the response of a fuse must be within a matter of a few milliseconds.

A single element fuse, when exposed to short circuit conditions, will melt its links simultaneously. A short-circuit current is cut off in less than 1/2 cycle, or about 8.3 thousands of a second. This is long before the short-circuit current can reach its full value.

Single element fuses are an excellent source of short-circuit protection (see Figure 8). However, temporary and harmless overloads like those created by motors can cause nuisance openings unless the fuses are oversized. These overloads will occur when a fuse is sized to protect a motor circuit and it trips during the inrush current generated when the motor is started (see Figure 8).

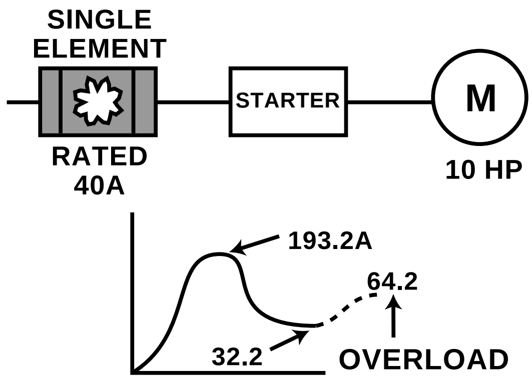

Figure 8

However, if a fuse is allowed to withstand the inrush current, it will not provide adequate protection when a motor is running at full load current. For example, if a 10-horsepower motor circuit is fused to the maximum inrush current of 193.2 amps, the motor runs the risk of being burned out if an overcurrent exists at, for instance, double its full load current for a period of time (see curve in Figure 8). The single element fuse must be sized higher than the full load current of a motor in a circuit to allow the motor to start. The proper sizing of non time-delay fuse is specified according to the National Electric Code.

Dual-element time delay fuses are used to protect conductors and circuits from both short circuits and ground faults. Dual-element fuses not only protect against short circuits, but also protect motors from overcurrents caused by stalling, overloads, worn bearings, improper voltage, single phasing, and other possible causes.

The dual-element time-delay fuse has two overload and short-circuit elements built in. If a fuse experiences a short-circuit overcurrent, the fuse will separate the links the same way a single element fuse does. If the fuse experiences an overload condition for 10 seconds, at about 5 times the value of the rated fuse, the overload element will snap out of the connector, disengaging the fuse from the circuit.

This fuse allows motor protection from overloading. For example, if a dual element fuse rated at 40 amps is protecting a circuit of a 10-horsepower motor, we could sustain the overload inrush current of 193 amps for a little over 10 seconds before the fuse would open (see Figure 9).

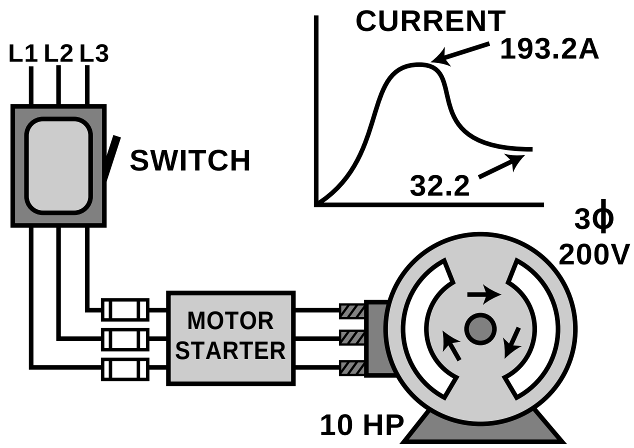

Figure 9

In normal motor control circuit applications, a dual-element time-delay fuse serves as an invaluable motor-running backup protection to the motor starter overloads (see Figure 10). A dual-element time-delay fuse can be particularly helpful if a phase is lost. In addition, if the magnetic starter's overload contacts fail to open and the power contacts remain closed because a severe overload has melted the contacts, the backup protection provided by a dual-element fuse will save the motor and circuit.

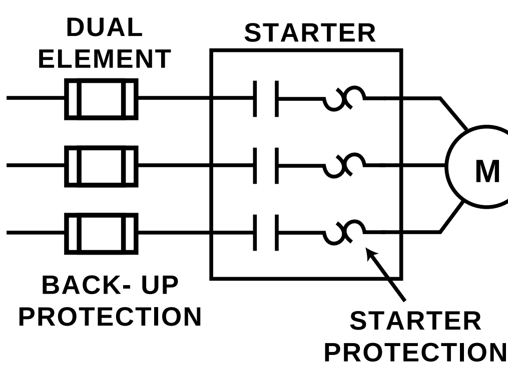

Figure 10

During troubleshooting, if a fuse is found to be open, it is a good idea to cut it in half and determine if the cause of the opening was a short circuit or an overload. This will help determine the source of a problem.

Fuse Curves

In the National Electric Code, non time-delay and dual-element time-delay fuses are rated under normal conditions in the range of 300 and 175 percent of the full load current of motors. This gives, for example, a non time-delay fuse only three times its rating to allow for the surge of current created by starting a motor (see Figure 11). A motor may pull at least six times the full load current when it is first started. Fuses, however, do not open instantly when current is just above the fuse rating.

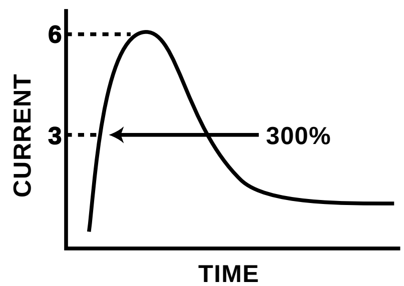

Figure 11

The graph in Figure 12 represents single-element and dual-element time-delay fuses, rated at 100 amps. It takes 10 seconds (see Figure 13) for the time-delay fuse to open at a current of 500 amps. However, it only takes 2 tenths of a second for the non time-delay fuse to open at a current of 500 amps (see Figure 14).

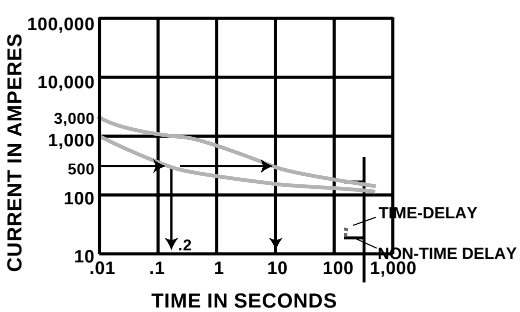

Figure 12

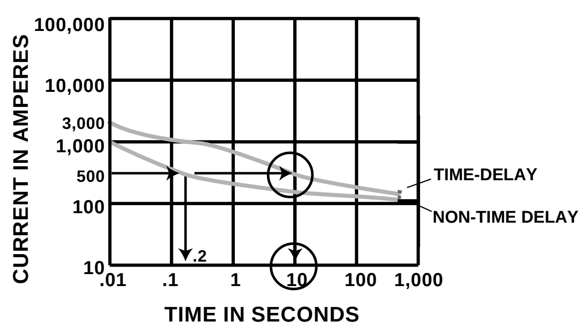

Figure 13

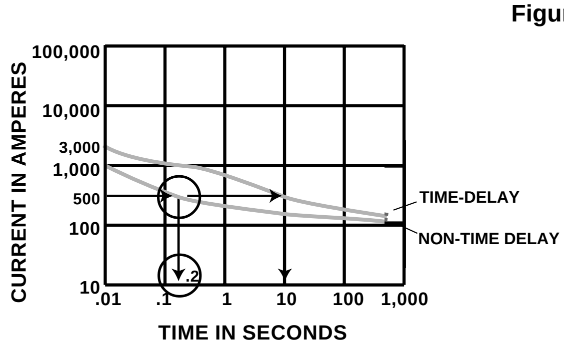

Figure 14

A non time-delay fuse can be used to protect a circuit if the motor inrush current can be sustained by a fuse during the inrush time. If the motor current passes this limit, the fuse will open. If this is the case, a slightly larger fuse, up to 4 times the full load current according to code, can be used to protect the circuit. Otherwise, it is best to select a dual-element time-delay fuse that will provide adequate time for the inrush current.

Other Advantages of Dual Elements in Motor Control Circuits

To illustrate the advantages of dual elements, let's use as an example with both single-element and double-element fuses for a 10-horsepower, 200-volt motor (see Figure 15). This motor has a full-load amperage rating of 32.2 amps. According to rule 430-52 of the National Electric Code, we could select a single-element, non time-delay fuse of 90 amps to protect the circuit.

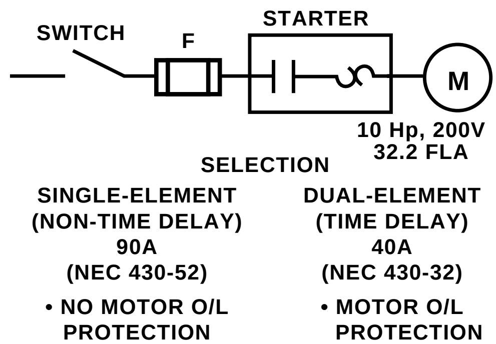

Figure 15

The fuse curve shown in Figure16 for this non time-delay fuse should be enough to let the motor start for a short duration. Remember that fuses, according to the curves, will let motors start if the motor start-current curve does not trip the fuse. For instance, this 90-amp fuse does not provide protection for the motor that is under overload as shown by the dotted line of the motor curve in Figure 16. Therefore, it would require overload protection at the starter.

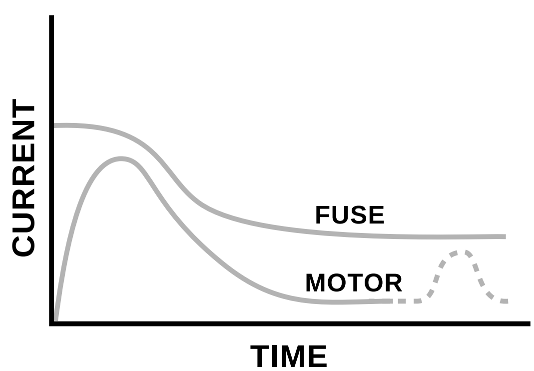

Figure 16

According to article 430-32 of the NEC, if we want to use a dual-element time-delay fuse to protect the motor from overloads and the circuit from short circuits, we would select a 40-amp fuse. This fuse will protect the circuit against short circuits and overload conditions and allow the motor to start when it pulls the starting inrush current. In fact, if motor overload relays are used in a motor control circuit, the dual-element fuses will serve as motor backup protection just in case the overload relays are the wrong size or fail to operate. The graph in Figure 17 shows the motor damage curve and the protection curve provided by the motor overload heaters. The dual-element curve is shown as backup protection. In addition, the disconnect switch used in the dual-element circuit has a smaller current-carrying capacity than the dual-element circuit in the 90-amp circuit, therefore reducing space and money (see Figure 18). A disconnect switch rating must be equal to or larger than the amperage rating of the fuse protecting the circuit.

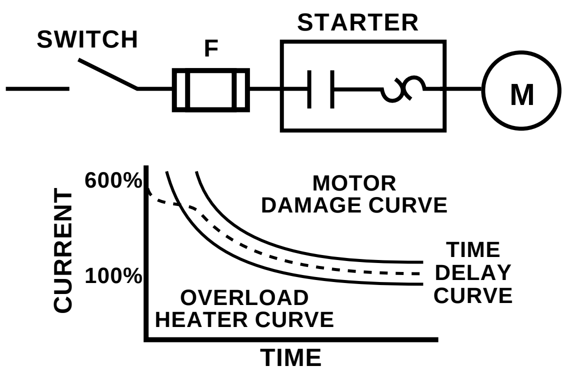

Figure 17

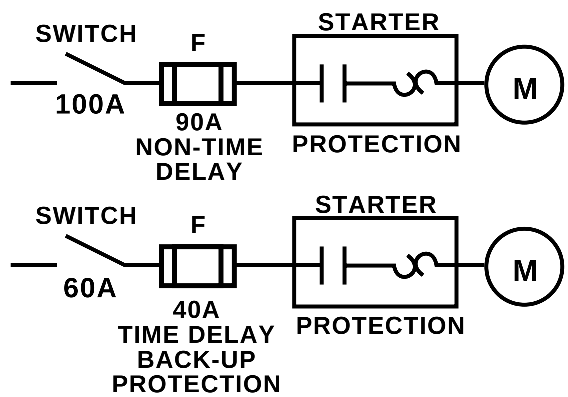

Figure 18

Fuse Types

There are several different types of fuses available, depending on the base the fuse mounts to, the socket or adapter that is used, and the interrupting current ratings. The two categories of fuse sizes include fuses that are 600 volts or less and fuses that are 600 volts or more.

There are also classes of fuses, such as H, K, R, G, J, L, and T, which are rated for specific voltages and currents, depending on the application. Classes of fuses are placed in their corresponding holders. For example, class R rejection clips, or holders, will accept only class R type fuses.

Circuit Breakers

As defined by NEMA, a circuit breaker is a device that opens and closes a circuit by nonautomatic means if used as a disconnect. In other words, a circuit breaker opens the circuit automatically because of predetermined overcurrents created by an overload or a short circuit. A circuit breaker trips a mechanism inside which disconnects the circuit from the overcurrent condition (see Figure 19).

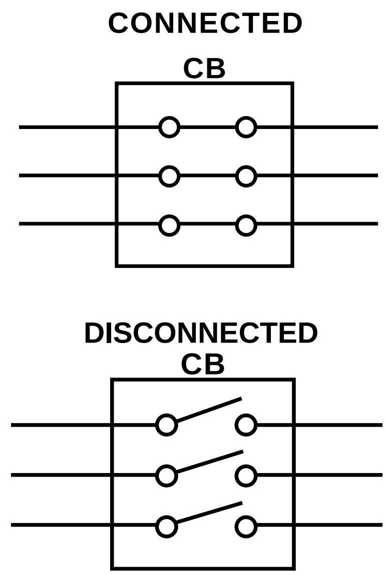

Figure 19

The basic part of a circuit breaker, a circuit interrupter, is shown in Figure 20 for a three-pole circuit. This section of the breaker, which is nonautomatic, is followed by the representation of the automatic breaker section.

Circuit breakers use two types of tripping elements: a bimetal, or thermal tripping element, or a magnetic tripping element. Circuit breakers occasionally use both types of tripping elements. These devices can trip instantly in what is called inverse time (see Figure 21).

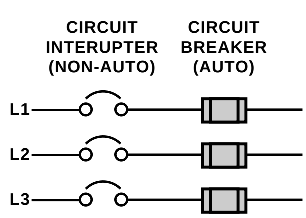

Figure 20

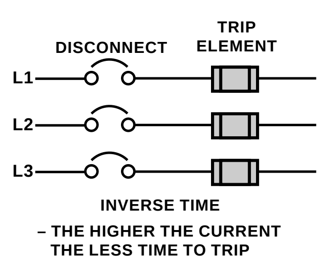

Figure 21

Inverse time means that the time it takes the breaker to trip is inversely proportional to the amount of current. The higher the amount of current, the less time needed for the circuit breaker to trip. For instance, a 20-amp breaker may take several minutes to trip a current of 25 amps (see Figure 22). However, if the same 20-amp breaker is subjected to a 50-amp current, it will trip in a fraction of a second.

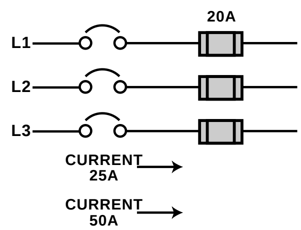

Figure 22

A bimetal breaker responds in an inverse time manner. As the current passes, it bends the bimetal breaker and makes the circuit trip (see Figure 23). A magnetic breaker has an electromagnet element which responds to a high current generated by a short circuit. The activation in a magnetic breaker is instantaneous (see Figure 24).

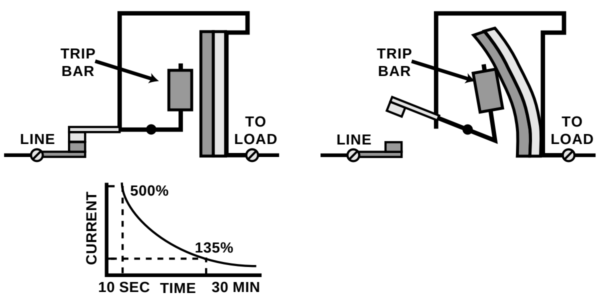

Figure 23

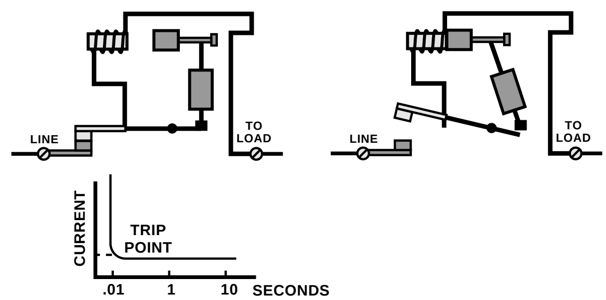

Figure 24

Therefore, the most desirable circuit breaker has both bimetal and magnetic mechanisms: an element that responds to time delay and an element that responds instantaneously (see Figure 25).

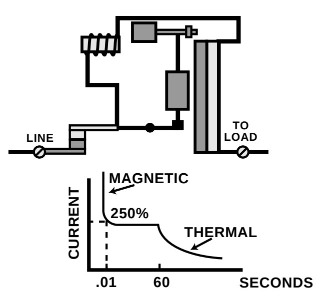

Figure 25

The symbols shown in Figure 26 represent a thermal-magnetic circuit breaker. Notice that one side represents the bimetal or thermal mechanism and the other side represents the magnetic component.

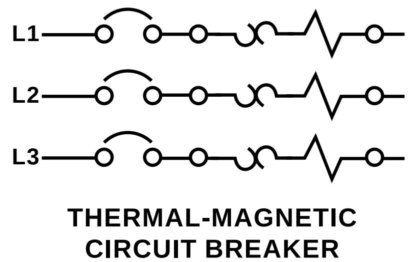

Figure 26

2—MOTOR PROTECTION

Motors are required to have protection against overload situations when the motor draws excessive current for a certain period of time (see Figure 27). For instance, excessive current occurs when a motor is overloaded by a jamming condition in the line that stops motor rotation.
A motor can also overheat if it is started and stopped too frequently. When overloading occurs in a motor, the motor will overheat, resulting in a deterioration of its insulation and causing damage to the motor.

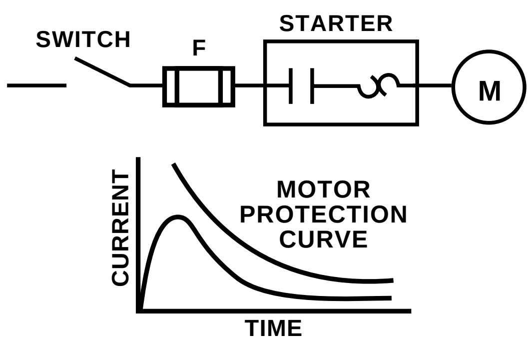

Figure 27

Overloads

To meet the protection requirements of a motor, overload relays provide a time delay to allow for temporary overcurrent during start up, tripping capability of a motor circuit once a dangerous level of overcurrent has been detected for a period of time, and the means for resetting the circuit.

Overload relays are represented by an S and by the symbol shown in Figure 28. The overloads illustrated in Figure 29 are available for single pole–single phase, double pole–single phase, and three pole–three phase motor circuits. There are two main types of overload relays: mechanical state, operated by a heater element, and solid-state.

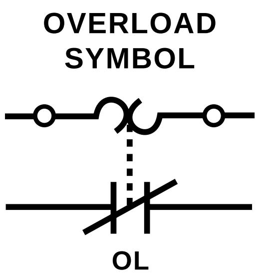

Figure 28

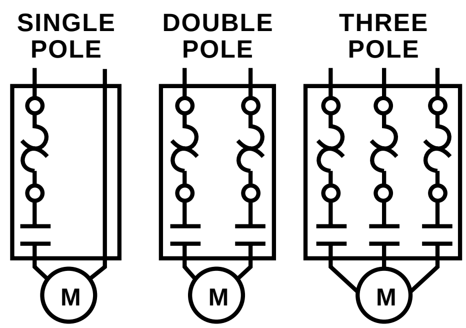

Figure 29

Overload Components and Operation

The assembly of a mechanical overload relay is formed by the heater coil, also called an overload heater, and the contact mechanism (see Figure 30). Although there are different types of heaters made by different manufacturers, all of them work by the same principle of measuring the heat generated by flowing current (see Figure 31). There are two design types that are commonly used: the eutectic melting alloy and the bimetal overload relays.

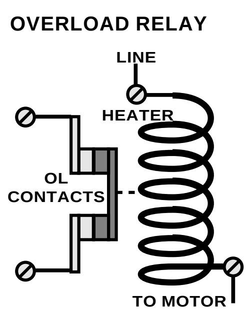

Figure 30

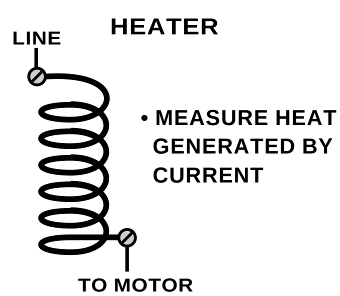

Figure 31

The eutectic melting alloy overload uses a heater element surrounding a solder-like mechanism that holds the pin of a rachet wheel element (see Figure 32). Eutectic means low-melting temperature solder.

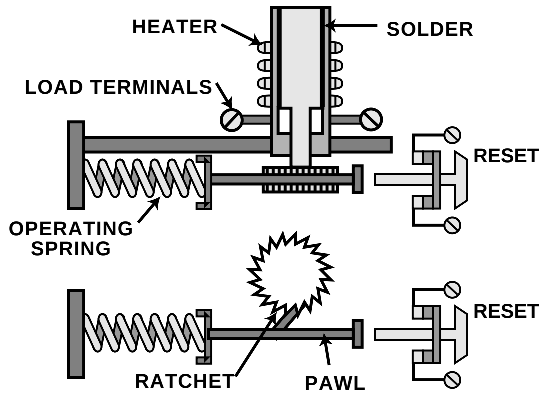

Figure 32

When excessive current passes through a heater, the solder will melt and will transform into a liquid state very quickly without going through a plastic stage (see Figure 33). This will cause the rachet wheel to release the pawl it is holding. Once the pawl is released with pressure of the loaded spring, the normally closed contacts will open (see Figure 34). When the solder-like melting alloy has cooled down to a solid state, the overload relay contacts can be reset to the normal state. If you try to reset the overload relay contacts while the alloy is still liquid, the contacts will open because the rachet will not be able to hold the pawl mechanism.

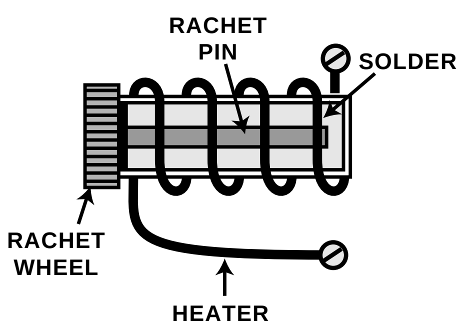

Figure 33

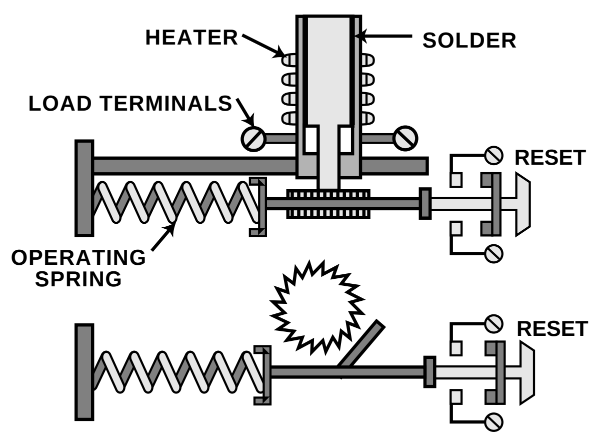

Figure 34

The bimetal overload relay operates similarly to the eutectic melting alloy, except that the bimetal overload relay uses a bimetal strip made of two bonded metals that expand with heat (see Figure 35). This heat is the result of overload current created by the heater element and then transferred to the bimetal element. When an overload condition is detected, the bimetal element will bend and open the normally closed overload contacts (see Figure 36). After cooling off from the heat created by the current, the bimetal may return to its original position automatically or manually, depending on the assembly. The automatic resetting feature of these overloads is restricted according to Article 430-43 of the National Electric Code because of the potential for injury and equipment damage due to an automatic restart of a motor (see Figure 37).

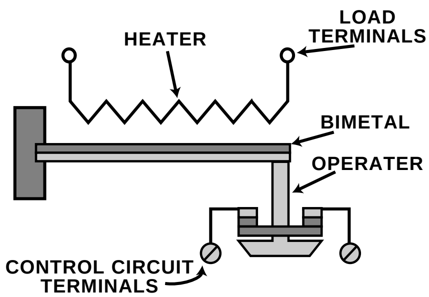

Figure 35

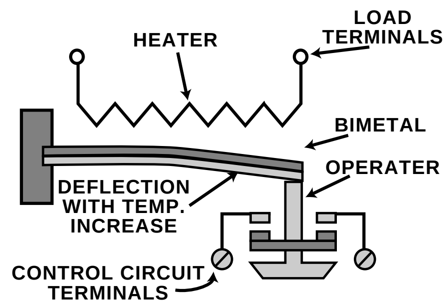

Figure 36

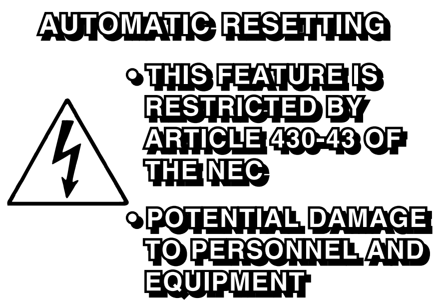

Figure 37

The bimetal overload relays will disconnect the motor from the circuit as soon as the heater coils detect enough current to disengage the normally closed contacts (see Figure 38). Therefore, it is important for the heater elements to be properly sized.

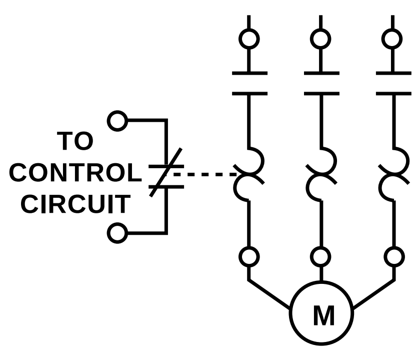

Figure 38

The solid-state overload relay in a motor circuit is represented by the symbol shown in Figure 39. This overload relay provides the same action as the heaters. The overload relay detects overcurrents by sensing the AC current magnetically from the motor leads passing through its current loops. This overload assembly provides an automatic reset, producing the additional circuitry necessary to provide for the manual reset. One advantage that this overload assembly provides is that it is unaffected by ambient temperature as heater coils are, thus eliminating the problem of tripping during hot weather.

ELECTRONIC OVERLOAD RELAY

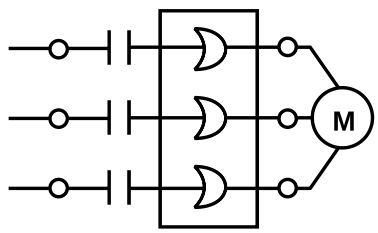

Figure 39

Sizing Proper Heater Coils

The National Electric Code specifies the amount of protection that must be provided to a motor. For example, a three-phase, AC induction motor with a service factor of 1.15 would require three overloads selected to trip at no more than 125% of a motor's full load current rating.

The selection of the appropriate size of heater components is important. The standard tripping curves of heater elements are specified at an ambient temperature of 40°C to correspond with the temperature at which most motors are specified for ambient conditions. At a temperature of 40°C, Underwriters Laboratory requires that an overload relay trip in 4 hours of operation at 100% the trip current, in 8 minutes at 200%, and in 30 seconds at 600% (see Figure 40).

"A" Underwriter's Requirements
"B" Melting Alloy With 'H' Heaters (Standard Trip)
"C" Bimetal With 'E' Heaters (Standard Trip)

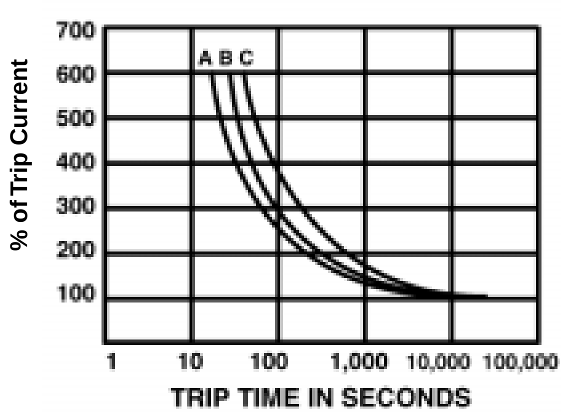

Figure 40

NEMA rates heater elements by the amount of time it takes to melt the alloy when the motor is drawing 6 times the full load current. These heaters are grouped into three categories: class 10, class 20, and class 30. Class 10 heaters will melt the alloy in 10 seconds, the class 20 heaters will melt the alloy in 20 seconds, and the class 30 heaters will melt the alloys in 30 seconds (see Figure 41). Class 10 heaters should be used in applications to protect hermetic motors like compressors in air conditioning systems, submersible pumps, and other motors with short locked-rotor times. Class 20 heaters are the most common since they can be used in many types of applications. Class 30 heaters should only be used in motor applications with high inertia loads, such as driving grinding wheels and fly wheels.

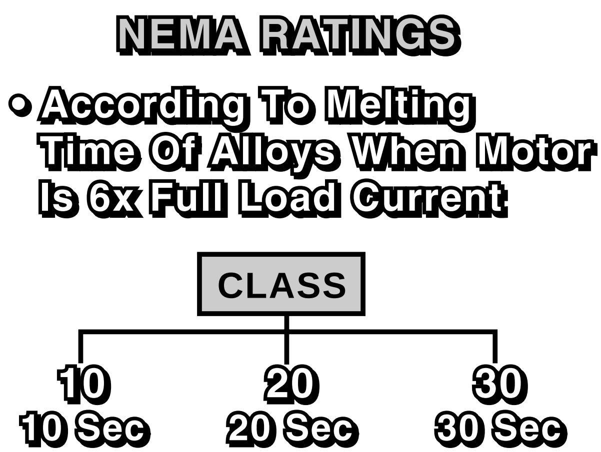

Figure 41

Manufacturers provide tables to use as a reference in choosing the proper heater for a motor pulling the indicated amount of current. When choosing a heater, it is important to make sure that the one you are referencing in the table has the appropriate amount of current. The current of a heater can be calculated at 125% of the full load current, or without the 125% required by the code.

Effects of Ambient Temperature

Thermal overloads are sensitive to heat, including ambient temperature. For example, if the total heat required by the overload relay to trip the motor is as shown on the left side of Figure 42, and the ambient temperature creates part of the heat, the rest of the heat is left for overcurrents due to an overload. If the motor draws the full load current for a long period of time, the overload relay will trip. If the ambient heat is as shown in the middle of Figure 42, the overload can be tripped at less overcurrent. Conversely, if the ambient heat is high (see Figure 42 right side) the amount of heat necessary by the heater will be as much as indicated at the top right of the table, requiring more current than necessary to protect the motor. Excessive current can result in the motor burning out due to overheating.

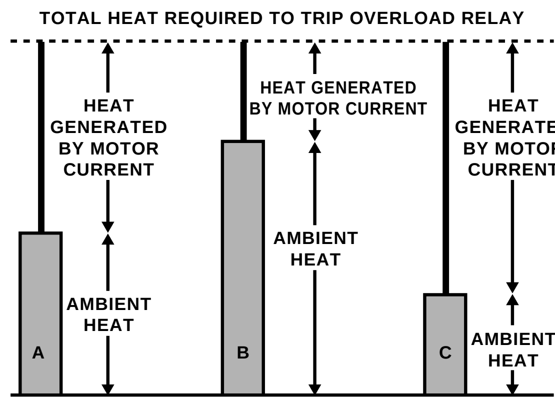

Figure 42

Bimetal overloads may provide a compensating bimetal strip that is added to the assembly (see Figure 43). This compensating strip allows the relay to adjust for changes in ambient temperature at the location of the overload assembly which is usually close to the motor starter (see Figure 44).

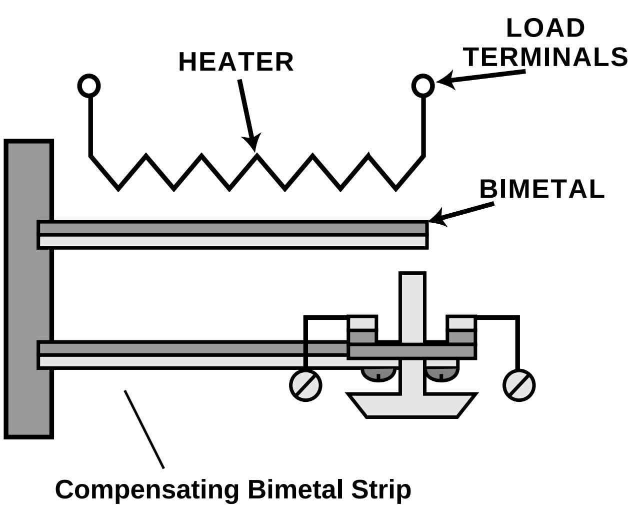

Figure 43

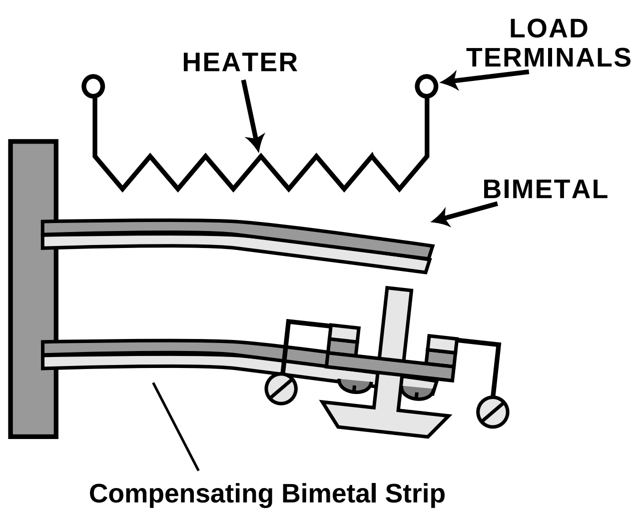

Figure 44

The curve shown in Figure 45 indicates the relationship between ambient temperature and the trip current. For example, at 40°C, a trip current of 10 amps will trip the heater, while at 60°C, the same heater will trip at 8 amps. At 20°C, the heater will trip at about 11.5 amps. A compensating overload relay will make the curve essentially flat across the different temperatures. Therefore, if you have an application in which the motor is in a constant ambient and the overload is in a varying ambient, you should use a compensating overload relay.

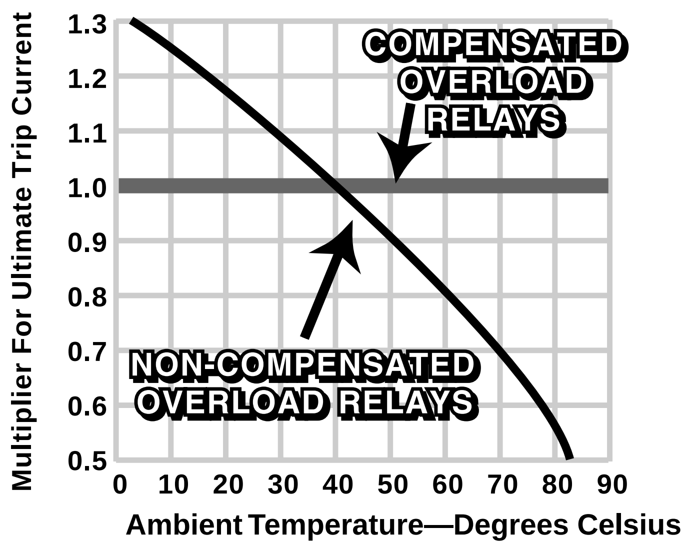

Figure 45

3—SUMMARY

- Starters use overload relays to provide protection to a motor.
- An overcurrent is the result of an overload current, a short-circuit, or a ground-fault current.
- Fuses are used to protect a circuit from short-circuit faults.
- A single-element fuse is also known as a non time-delay fuse.
- Dual-element time-delay fuses can also protect conductors and circuits from short-circuit and ground faults.
- When used as a disconnect device, a circuit breaker can open and close a circuit nonautomatically.
- Circuit breakers use two types of tripping elements—bimetal and magnetic.
- The activation of a magnetic circuit breaker is instantaneous.
- Overload relays are used to protect a motor.
- The eutectic melting alloy overload uses a heater element surrounding a solder-like mechanism that holds the pin of a ratchet wheel element.
- A solid-state overload relay is unaffected by ambient temperature.
- Heater elements are rated by NEMA according to the amount of time it will take to melt the alloy when the motor is drawing six times its full load current.
- Heaters are grouped into three categories—class 10, 20, and 30.
- A compensating bimetal strip should be used in the relay when the ambient temperatures of the motor and the overload are different.

4—REVIEW QUESTIONS

1. True/False. Starters use overload relays to provide protection to a motor.

2. True/False. An overcurrent is a result of an overload current, a short-circuit, or ground-fault current.

3. Fuses are used to protect _______________.

   a. a motor from overloads

   b. a circuit from short-circuit faults

   c. the entire branch circuit

   d. the main switchboard

4. A _______________ fuse is also known as a non time-delay fuse.

   a. single-element

   b. dual-element

   c. two-way

   d. full-load amperage

5. True/False. Dual-element time-delay fuses can also be used to protect conductors and circuits from short-circuit and ground faults.

6. When used as a disconnect device, a _______________ can open and close a circuit nonautomatically.

   a. solenoid

   b. circuit breaker

   c. current-carrying capacity switch

   d. thermal overload

7. Circuit breakers use two types of tripping elements:

   a. bimetal

   b. class R rejection clips

   c. magnetic

   d. static

8. True/False. The activation in a magnetic breaker is instantaneous.

9. Overload relays are used to protect a _______________.

   a. motor

   b. circuit

   c. branch circuit

   d. complete busway

10. True/False. The eutectic melting alloy overload uses a heater element surrounding a solder-like mechanism that holds the pin of a ratchet wheel element.

11. A _______________ is unaffected by ambient temperature.

   a. heater coil overload relay

   b. solid-state overload relay

   c. closed-end overload relay

   d. cadmium-oxide overload relay

5—ANSWERS

1. True
2. True
3. b. a circuit from short-circuit faults
4. a. single-element
5. True
6. b. circuit breaker
7. a. bimetal   c. magnetic
8. True
9. a. motor
10. True
11. b. solid-state overload relay