Voltage Unbalance & Single-Phasing

For Summary of Suggestions to Protect Three-Phase Motors Against Single-Phasing see the end of this section, page 137.

Historically, the causes of motor failure can be attributed to:

Overloads	30%
Contaminants	19%
Single-phasing	14%
Bearing failure	13%
Old age	10%
Rotor failure	5%
Miscellaneous	9%
	100%

From the above data, it can be seen that 44% of motor failure problems are related to HEAT.

Allowing a motor to reach and operate at a temperature 10°C above its maximum temperature rating will reduce the motor's expected life by 50%. Operating at 10°C above this, the motor's life will be reduced again by 50%. This reduction of the expected life of the motor repeats itself for every 10°C. This is sometimes referred to as the "half life" rule.

Although there is no industry standard that defines the life of an electric motor, it is generally considered to be 20 years.

The term, temperature "rise", means that the heat produced in the motor windings (copper losses), friction of the bearings, rotor and stator losses (core losses), will continue to increase until the heat dissipation equals the heat being generated. For example, a continuous duty, 40°C rise motor will stabilize its temperature at 40°C above ambient (surrounding) temperature.

Standard motors are designed so the temperature rise produced within the motor, when delivering its rated horsepower, and added to the industry standard 40°C ambient temperature rating, will not exceed the safe winding insulation temperature limit.

The term, "Service Factor" for an electric motor, is defined as: "a multiplier which, when applied to the rated horsepower, indicates a permissible horsepower loading which may be carried under the conditions specified for the Service Factor of the motor."

"Conditions" include such things as operating the motor at rated voltage and rated frequency.

Example: A 10Hp motor with a 1.0 SF can produce 10Hp of work without exceeding its temperature rise requirements. A 10Hp motor with a 1.15 SF can produce 11.5Hp of work without exceeding its temperature rise requirements.

Overloads, with the resulting overcurrents, if allowed to continue, will cause heat build-up within the motor. The outcome will be the eventual early failure of the motor's insulation. As stated previously for all practical purposes, insulation life is cut in half for every 10°C increase over the motor's rated temperature.

Voltage Unbalance

When the voltage between all three phases is equal (balanced), current values will be the same in each phase winding.

The NEMA standard for electric motors and generators recommends that the maximum voltage unbalance be limited to 1%.

When the voltages between the three phases (AB, BC, CA) are not equal (unbalanced), the current increases dramatically in the motor windings, and if allowed to continue, the motor will be damaged.

It is possible, to a limited extent, to operate a motor when the voltage between phases is unbalanced. To do this, the load must be reduced.

Voltage Unbalance in Percent	Derate Motor to These Percentages of the Motor's Rating*
1%	98%
2%	95%
3%	88%
4%	82%
5%	75%

*This is a general "rule of thumb", for specific motors consult the motor manufacturer.

Some Causes of Unbalanced Voltage Conditions

- Unequal single-phase loads. This is why many consulting engineers specify that loading of panelboards be balanced to ± 10% between all three phases.
- Open delta connections.
- Transformer connections open - causing a single-phase condition.
- Tap settings on transformer(s) not proper.
- Transformer impedances (Z) of single-phase transformers connected into a "bank" not the same.
- Power factor correction capacitors not the same, .or off the line.

Insulation Life

The effect of voltage unbalance on the insulation life of a typical T-frame motor having Class B insulation, running in a 40°C ambient, loaded to 100%, is as follows:

	Insulation Life	
Voltage Unbalance	Service Factor 1.0	Service Factor 1.15
0%	1.00	2.27
1%	0.90	2.10
2%	0.64	1.58
3%	—	0.98
4%	—	0.51

Note that motors with a service factor of 1.0 do not have as much heat withstand capability as do motors having a service factor of 1.15.

Older, larger U-frame motors, because of their ability to dissipate heat, could withstand overload conditions for longer periods of time than the newer, smaller T-frame motors.

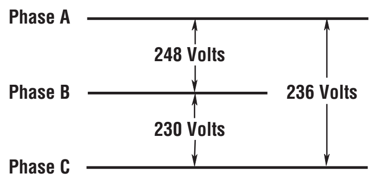
Insulation Classes

The following shows the maximum operating temperatures for different classes of insulation.

Class A Insulation	105°C
Class B Insulation	130°C
Class F Insulation	155°C
Class H Insulation	180°C

Voltage Unbalance & Single-Phasing

How to Calculate Voltage Unbalance and The Expected Rise in Heat



Step 1: Add together the three voltage readings:

248 + 236 + 230 = 714V

Step 2: Find the “average” voltage.

714 = 238V/3

Step 3: Subtract the “average” voltage from one of the voltages that will indicate the greatest voltage difference. In this example:

248 – 238 = 10V

Step 4: 100 x greatest voltage difference average voltage = 100 x 10 = 4.2 percent voltage unbalance 238

Step 5: Find the expected temperature rise in the phase winding with the highest current by taking 2 x (percent voltage unbalance)2

In the above example:

2 x (4.2)2 = 35.28 percent temperature rise.

Therefore, for a motor rated with a 60°C rise, the unbalanced voltage condition in the above example will result in a temperature rise in the phase winding with the highest current of:

60°C x 135.28% = 81.17°C

The National Electrical Code®

The National Electrical Code®, in Table 430.37, requires three over-load protective devices, one in each phase, for the protection of all three-phase motors.

Prior to the 1971 National Electrical Code® , three-phase motors were considered to be protected from overload (overcurrent) by two overload protective devices. These devices could be in the form of properly sized time-delay, dual-element fuses, or overload heaters and relays (melting alloy type, bi-metallic type, magnetic type, and solid-state type.)

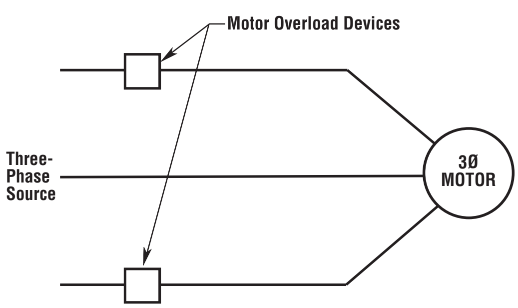


Diagram showing two overload devices protecting a three-phase motor. This was acceptable by the National Electrical Code® prior to 1971.

Two motor overload protective devices provide adequate protection against balanced voltage overload conditions where the voltage between phases is equal. When a balanced voltage over-load persists, the protective devices usually open simultaneously. In some cases, one device opens, and shortly thereafter, the second device opens. In either case, three-phase motors are protected against balanced voltage overload conditions.

Three-phase motors protected by two overload protective devices are not assured protection against the effect of single-phasing. For example, when the electrical system is WYE/DELTA or DELTA/WYE connected, all three phases on the secondary side of the transformer bank will continue to carry current when a single-phasing caused by an open phase on the primary side of the transformer bank occurs. As will be seen later, single-phasing can be considered to be the **worst case** of unbalanced voltage possible.

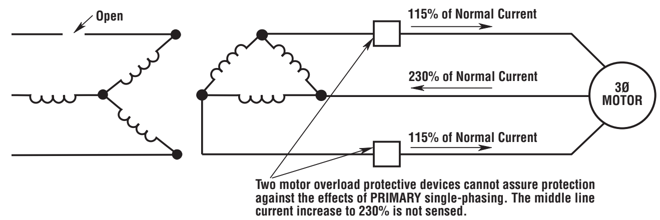
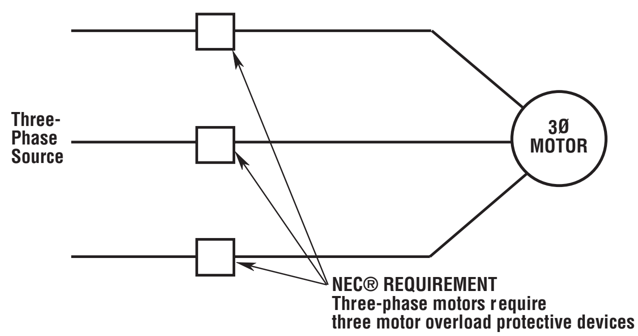


Diagram of a WYE/DELTA transformation with one primary phase open. The motor is protected by two overload devices. Note that one phase to the motor is carrying two times that of the other two phases. Without an overload device in the phase that is carrying two times the current in the other two phases, the motor will burn out.

The National Electrical Code®, Section 430.36 requires that when fuses are used for motor overload protection, a fuse shall be inserted in each phase. Where thermal overload devices, heaters, etc. are used for motor overload protection, Table 430.37 requires one be inserted in each phase. With these requirements, the number of single-phasing motor burnouts are greatly reduced, and are no longer a serious hazard to motor installations. The following figure shows three overload protective devices protecting the three-phase motor.



Since 1971, The National Electrical Code® has required three overload protective devices for the protection of three-phase motors, one in each phase.

Motor Branch Circuit, Short Circuit and Ground Fault Protection

When sized according to NEC® 430.52, a 3-pole common trip circuit breaker or MCP can not protect against single-phasing damage.

It should be emphasized, the causes of single-phasing cannot be eliminated. However, motors can be protected from the damaging effects of single-phasing through the use of proper overcurrent protection.

Dual-element, time-delay fuses can be sized at or close to the motor’s nameplate full-load amp rating without opening on normal motor start-up. This would require sizing the fuses at 100-125% of the motors full-load current rating. Since all motors are not necessarily fully loaded, it is recommended that the actual current draw of the motor be used instead of the nameplate rating. This is possible for motor’s that have a fixed load, but not recommended where the motor load varies.*

Voltage Unbalance & Single-Phasing

Thus, when single-phasing occurs, Fusetron FRS-R and FRN-R and Low-Peak LPS-RK_SP and LPN-RK_SP dual-element, time-delay fuses will sense the overcurrent situation and respond accordingly to take the motor off the line.

For motor branch-circuit protection only, the following sizing guidelines † per 430.52 of the National Electrical Code® are allowed.

	Normal	Maximum
• Dual-element, time-delay fuses	175%	225%
• Non-time-delay fuses and all Class CC fuses	300%	400%
• Inverse-time circuit breaker	250%	400% for motors 100 amps or less. 300% for motors more than 100 amps.
• Instantaneous only trip** circuit breakers	800%††	1300%†††

(sometimes referred to as MCPs. These are motor circuit protectors, not motor protectors.)

†See NEC® 430.52 for specifics and exceptions.

††1100% for other than design B energy efficient motors.

†††1700% for design B motors.

*When sizing to the actual running current of the motor is not practical, an economic analysis can determine if the addition of one of the electronic "black boxes" is financially justified. These electronic "black boxes" can sense voltage and current unbalance, phase reversal, single-phasing, etc.

**Instantaneous only trip breakers are permitted to have time-delay. This could result in more damaging let-through current during short circuits.

Note: When sized according to table 430.52, none of these overcurrent devices can provide single-phasing protection.

Single-Phasing

The term single-phasing, means one of the phases is open. A secondary single-phasing condition subjects an electric motor to the worst possible case of voltage unbalance.

If a three-phase motor is running when the "single-phase" condition occurs, it will attempt to deliver its full horsepower …enough to drive the load. The motor will continue to try to drive the load…until the motor burns out…or until the properly sized overload elements and/or properly sized dual-element, time-delay fuses take the motor off the line.

For lightly loaded three-phase motors, say 70% of normal full-load amps, the phase current will increase by the square root of three ($\sqrt{3}$) under secondary single-phase conditions. This will result in a current draw of approximately 20% more than the nameplate full load current. If the overloads are sized at 125% of the motor nameplate, circulating currents can still damage the motor. That is why it is recommended that motor overload protection be based upon the actual running current of the motor under its given loading, rather than the nameplate current rating.

Single-Phasing Causes Are Numerous

One fact is sure: Nothing can prevent or eliminate all types of single-phasing.

There are numerous causes of both primary and secondary single-phasing. A device must sense and respond to the resulting increase in current when the single-phasing condition occurs…and do this in the proper length of time to save the motor from damage.

The term "single-phasing" is the term used when one phase of a three-phase system opens. This can occur on either the primary side or secondary side of a distribution transformer. Three-phase motors, when not individually protected by three time-delay, dual-element fuses, or three overload devices, are subject to damaging overcurrents caused by primary single-phasing or secondary single-phasing.

Single-Phasing on Transformer Secondary – Typical Causes

1. Damaged motor starter contact–one pole open. The number of contact kits sold each year confirms the fact that worn motor starter contacts are the most common cause of single-phasing. Wear and tear of the starter contacts can cause contacts to burn open, or develop very high contact resistance, resulting in single-phasing. This is most likely to occur on automatically started equipment such as air conditioners, compressors, fans, etc.
2. Burned open overload relay (heater) from a line-to-ground fault on a 3 or 4 wire grounded system. This is more likely to occur on smaller size motor starters that are protected by non-current- limiting overcurrent protective devices.
3. Damaged switch or circuit breaker on the main, feeder, or motor branch circuit.
4. Open fuse or open pole in circuit breaker on main, feeder, or motor branch circuit.
5. Open cable or bus on secondary of transformer terminals.
6. Open cable caused by overheated lug on secondary side connection to service.
7. Open connection in wiring such as in motor junction box (caused by vibration) or any pull box. Poor connections, particularly when aluminum conductors are not properly spliced to copper conductors, or when aluminum conductors are inserted into terminals and lugs suitable for use with copper conductors or copper-clad conductors only.
8. Open winding in motor.
9. Open winding in one phase of transformer.
10. ANY open circuit in ANY phase ANYWHERE between the secondary of the transformer and the motor.

Hazards of Secondary Single-Phasing For A Three-Phase Motor

When one phase of a secondary opens, the current to a motor in the two remaining phases theoretically increases to 1.73 (173%) times the normal current draw of the motor. The increase can be as much as 2 times (200%) because of power factor changes. Where the motor has a high inertia load, the current can approach locked rotor values under single-phased conditions. Three properly sized time-delay, dual-element fuses, and/or three properly sized overload devices will sense and respond to this overcurrent.

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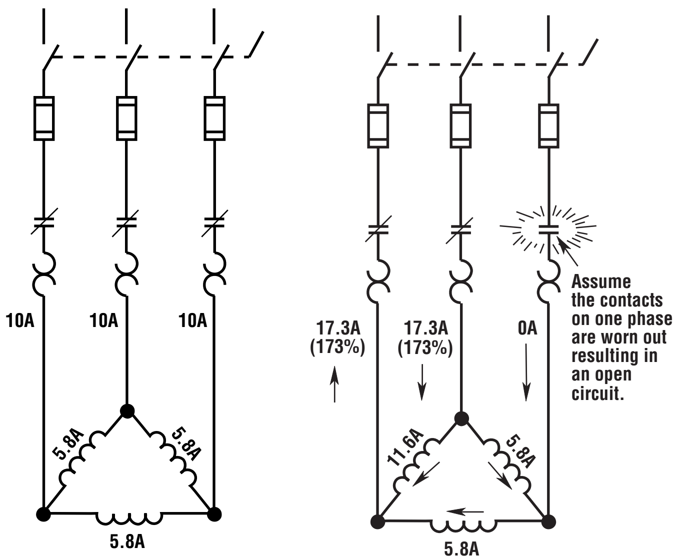
Voltage Unbalance & Single-Phasing

Single-Phasing On Secondary

Delta-Connected Motor, FLA = 10 Amps

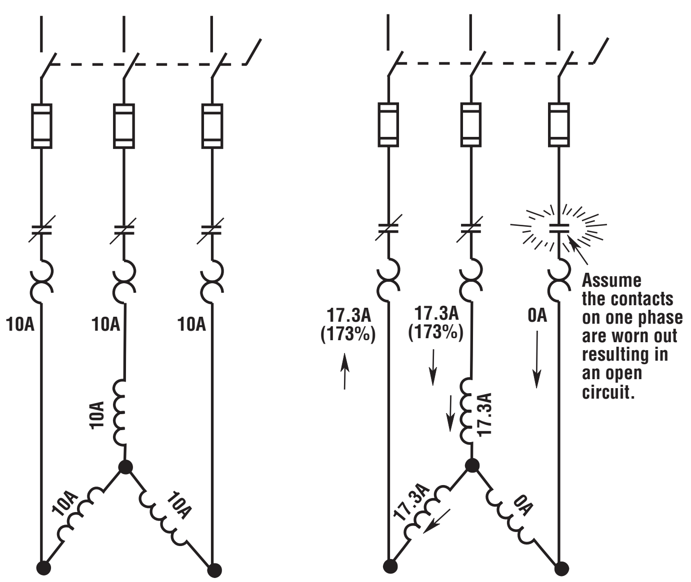
Normal Condition **Single-Phasing Condition**



(Delta-Connected Motor) Diagram showing the increase in current in the two remaining phases after a single-phasing occurs on the secondary of a transformer.

Wye-Connected Motor, FLA = 10 Amps

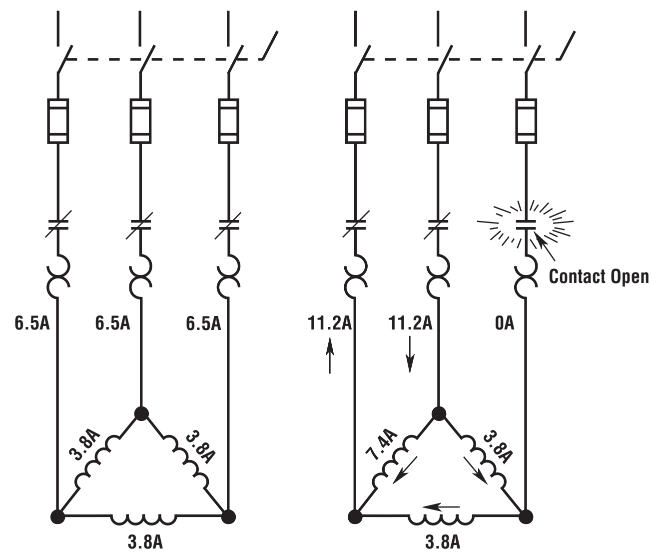
Normal Condition **Single-Phasing Condition**



(WYE-Connected Motor) Diagram showing the increase in current in the two remaining phases after a single-phasing occurs on the secondary of a transformer.

Single-Phasing On Secondary

Normal Condition **Single-Phasing Condition**



Delta-connected three-phase motor loaded to only 65% of its rated horsepower. Normal FLA = 10 amps. Overload (overcurrent) protection should be based upon the motor's actual current draw for the underloaded situation for optimum protection. If load varies, overload protection is difficult to achieve. Temperature sensors, phase failure relays and current differential relays should be installed.

When a motor is single-phased, the current in the remaining two phases increases to 173% of normal current. Normally the overload relays will safely clear the motor from the power supply. However, should the overload relays or controller fail to do so, Low-Peak or Fusetron time-delay, dual-element fuses, properly sized to provide back-up overload protection, will clear the motor from its power supply.

If the overload relays were sized at 12 amps, based upon the motor nameplate FLA of 10 amps, they would not "see" the single-phasing. However, if they were sized at 8 amps (6.5A x 1.25 = 8.13 amps), they would "see" the single-phasing condition.

Single-Phasing on Transformer Primary – Typical Causes

1. Primary wire broken by:
   a. Storm – wind
   b. Ice – sleet – hail
   c. Lightning
   d. Vehicle or airplane striking pole or high-line
   e. Falling trees or tree limbs
   f. Construction mishaps
2. Primary wire burned off from short circuit created by birds or animals.
3. Defective contacts on primary breaker or switch – failure to make up on all poles.
4. Failure of 3-shot automatic recloser to make up on all 3 poles.
5. Open pole on 3-phase automatic voltage tap changer.
6. Open winding in one phase of transformer.
7. Primary fuse open.

Hazards of Primary Single-Phasing For A Three-Phase Motor

Probably the most damaging single-phase condition is when one phase of the primary side of WYE/DELTA or DELTA/WYE transformer is open. Usually these causes are not within the control of the user who purchases electrical power. When primary single-phasing occurs, unbalanced voltages appear on the motor circuit, causing excessive unbalanced currents. This was covered earlier in this bulletin.

When primary single-phasing occurs, the motor current in one secondary phase increases to 230% of normal current. Normally, the overload relays will protect the motor. However, if for some reason the overload relays or controller fail to function, the Low-Peak and Fusetron time-delay, dual-element fuses properly sized to provide backup overload protection will clear the motor from the power supply.

Effect of Single-Phasing on Three-Phase Motors

The effects of single-phasing on three-phase motors varies with service conditions and motor thermal capacities. When single-phased, the motor temperature rise may not vary directly with the motor current. When single-phased, the motor temperature may increase at a rate greater than the increase in current. In some cases, protective devices which sense only current may not provide complete single-phasing protection. However, PRACTICAL experience has demonstrated that motor running overload devices properly sized and maintained can greatly reduce the problems of single-phasing for the majority of motor installations. In some instances, additional protective means may be necessary when a higher degree of single-phasing protection is required. Generally, smaller horsepower rated motors have more thermal capacity than larger horsepower rated motors and are more likely to be protected by conventional motor running overload devices.

Case Study

During the first week of January, 2005, an extended primary single phasing situation of over two hours occurred at the Cooper Bussmann facility in St. Louis, Missouri. While the utility would not divulge the root cause of the single-phasing incident, Cooper Bussmann was running over 100 motors in their St. Louis facility. Since the motors were adequately protected with a motor overload protective device or element in *each* phase (such as a starter with three heater elements/ overload relay) and with three properly sized Fusetron or Low-Peak fuses for backup motor overload protection, all motors survived the single-phasing incident. Not a single motor replacement nor repair was needed and the facility was quickly returned to service after replacing fuses and resetting overload relays.

Summary of Suggestions to Protect Three-Phase Motors Against Single-Phasing

1. Per NEC® 430.37, three-phase motors must have an overload protective device in each phase. Use motor overload protection such as overload relays/heater elements in each phase of the motor. Prior to 1971, only two overload protective devices were required and motors were much more susceptible to motor burnout.
2. For fully loaded motors, size the heater elements or set the overload protection properly per the motor nameplate FLA.
3. If the motor is oversized for the application or not fully loaded, then determine the full load current via a clamp on amp meter and size the heaters or set the overload protection per the motor running current.
4. Electronic motor overload protective devices typically have provisions to signal the controller to open if the phase currents/voltages are significantly unbalanced.
5. Install phase voltage monitor devices that detect loss of phase or significant imbalances and signal the controller to open.
6. Periodically test overload protective devices using proper testing equipment and procedures to ensure the overload heaters/overload relays are properly calibrated.

With one or more of the above criteria, three-phase motors can be practically protected against overloads including single-phasing. Then the motor circuit branch circuit, short circuit, ground fault protection required per NEC® 430.52 can be achieved by many different types of current-limiting fuses including LPJ_SP, LP-CC, TCF, LPN-R, LPS-R, FRN-R, FRS-R, JJS, JJN, SC and others. Many personnel size these fuses for short circuit protection only. However, some engineers and maintenance personnel want another level of protection and utilize the fuse types and sizing in (7) below.

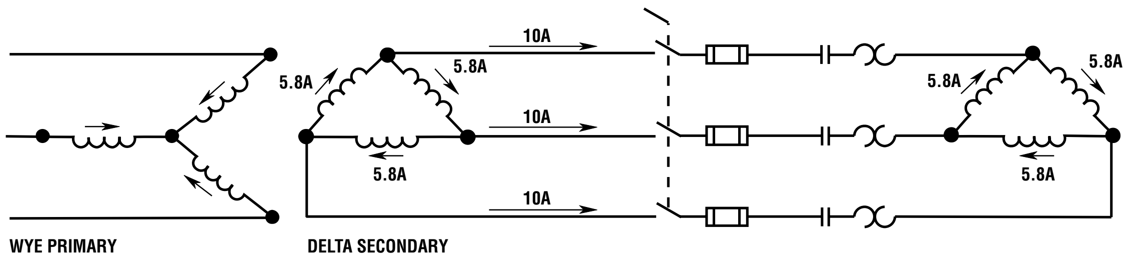
7. In addition to the motor overload protection in the circuit, use three Fusetron dual-element, time-delay fuses (FRS-R/FRN-R) sized for backup motor overload protection. Low-Peak dual-element, time-delay fuses (LPS-RK/LPN-RK) can also be used, but in some cases, must be sized slightly greater than the FRS-R and FRN-R fuses. These fuses, sized properly, serve two purposes: (1) provide motor branch circuit, short circuit and ground fault protection (NEC 430.52) and (2) provide motor running back-up overload protection. For further details, refer to the Motor Circuit Protection section or contact Cooper Bussmann Application Engineering.

Voltage Unbalance & Single-Phasing

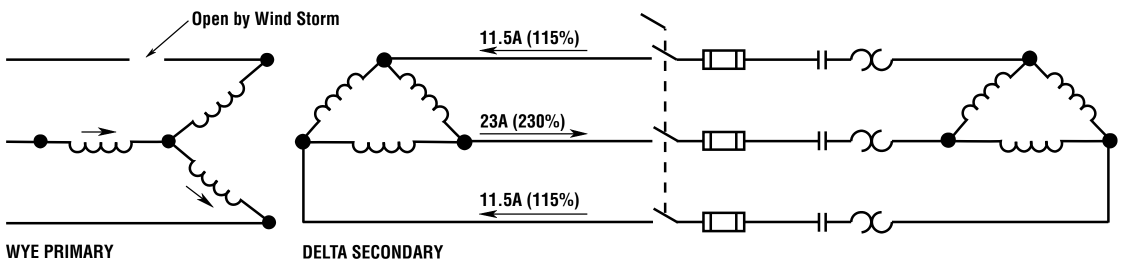
Single-Phasing On Primary

Delta-Connected Motor; FLA = 10 Amps

Normal Condition



Single-Phasing Condition

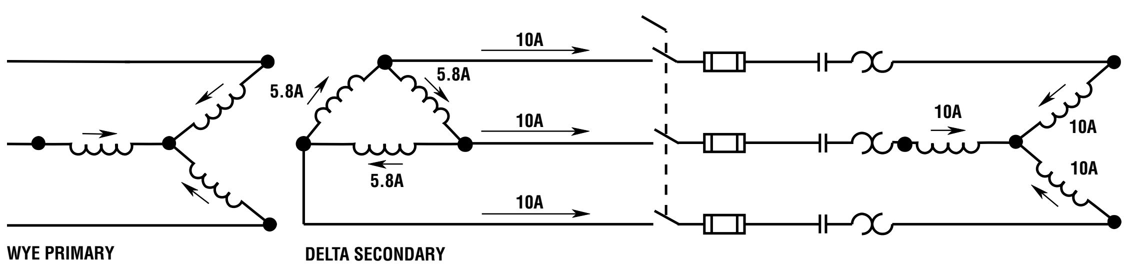


(Delta-Connected Motor) Diagram showing how the phase currents to a three-phase motor increase when a single-phasing occurs on the primary. For older installations where the motor is protected by two overload devices, the phase winding having the 230% current will burn up. However, properly sized overload relays or Low-Peak or Fusetron dual-element, time-delay fuses will clear the motor from the power supply.

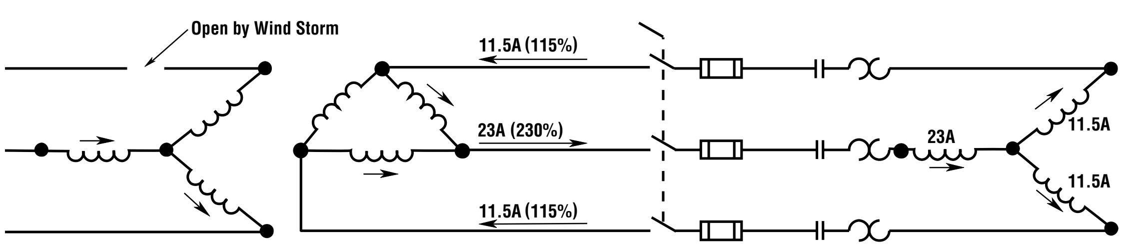
Single-Phasing On Primary

WYE-Connected Motor; FLA = 10 Amps

Normal Condition



Single-Phasing Condition



(WYE-Connected Motor) Diagram showing how the phase currents to a three-phase motor increase when a single-phasing occurs on the primary. For older installations where the motor is protected by two overload devices, the phase winding having the 230% current will burn up. However, properly sized over-load relays or Low-Peak or Fusetron dual-element, time-delay fuses, will clear the motor from the power supply.

Basic Explanation

Overload Protection

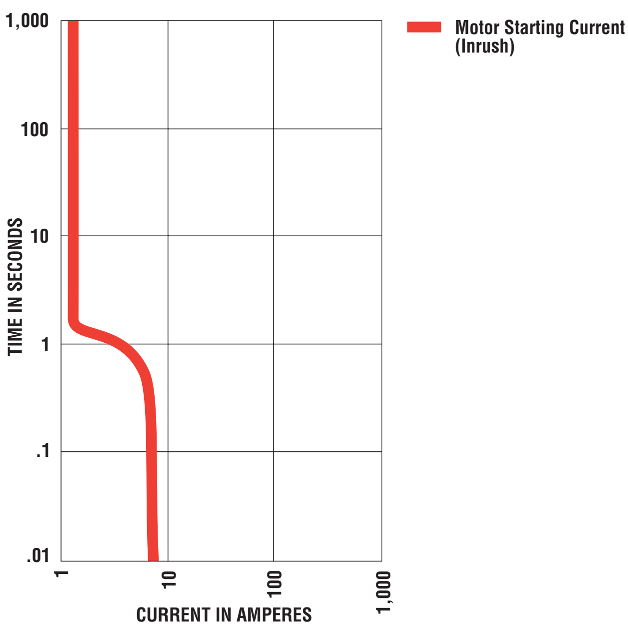
Overcurrents

An overcurrent exists when the normal load current for a circuit is exceeded. It can be in the form of an overload or short circuit. When applied to motor circuits an overload is any current, flowing within the normal circuit path, that is higher than the motor's normal Full Load Amps (FLA). A short-circuit is an overcurrent which greatly exceeds the normal full load current of the circuit. Also, as its name infers, a short-circuit leaves the normal current carrying path of the circuit and takes a "short cut" around the load and back to the power source. Motors can be damaged by both types of currents.

Single-phasing, overworking and locked rotor conditions are just a few of the situations that can be protected against with the careful choice of protective devices. If left unprotected, motors will continue to operate even under abnormal conditions. The excessive current causes the motor to overheat, which in turn causes the motor winding insulation to deteriorate and ultimately fail. Good motor overload protection can greatly extend the useful life of a motor. Because of a motor's characteristics, many common overcurrent devices actually offer limited or no protection.

Motor Starting Currents

When an AC motor is energized, a high inrush current occurs. Typically, during the initial half cycle, the inrush current is often higher than 20 times the normal full load current. After the first half-cycle the motor begins to rotate and the starting current subsides to 4 to 8 times the normal current for several seconds. As a motor reaches running speed, the current subsides to its normal running level. Typical motor starting characteristics are shown in Curve 1.

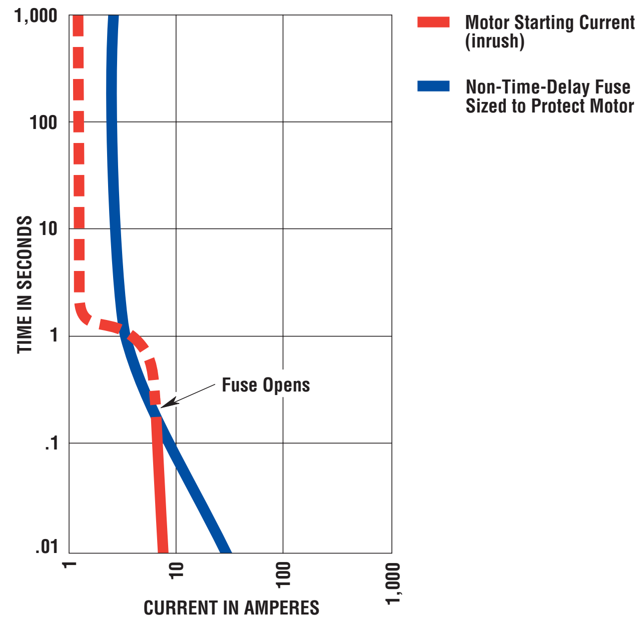


Curve 1

Because of this inrush, motors require special overload protective devices that can withstand the temporary overloads associated with starting currents and yet protect the motor from sustained overloads. There are four major types. Each offers varying degrees of protection.

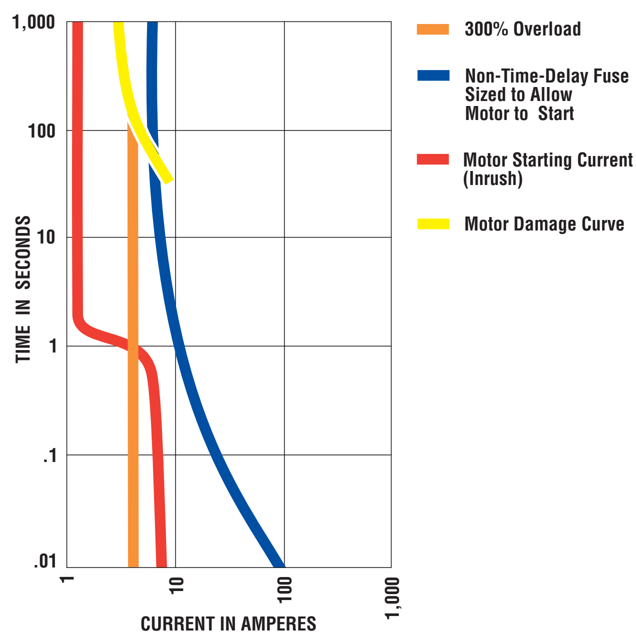
Fast Acting Fuses

To offer overload protection, a protective device, depending on its application and the motor's Service Factor (SF), should be sized at 115% or less of motor FLA for 1.0 SF or 125% or less of motor FLA for 1.15 or greater SF However, as shown in Curve 2, when fast-acting, non-time-delay fuses are sized to the recommended level the motors inrush will cause nuisance openings.



Curve 2

A fast-acting, non-time-delay fuse sized at 300% will allow the motor to start but sacrifices the overload protection of the motor. As shown by Curve 3 below, a sustained overload will damage the motor before the fuse can open.

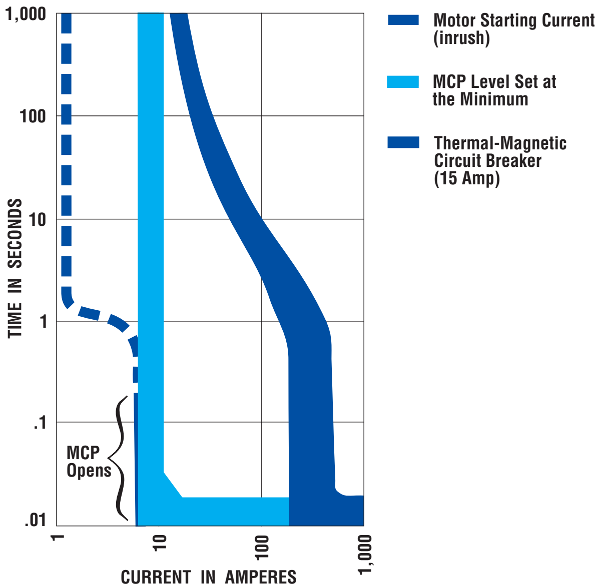


Curve 3

MCPs and Thermal Magnetic Breakers

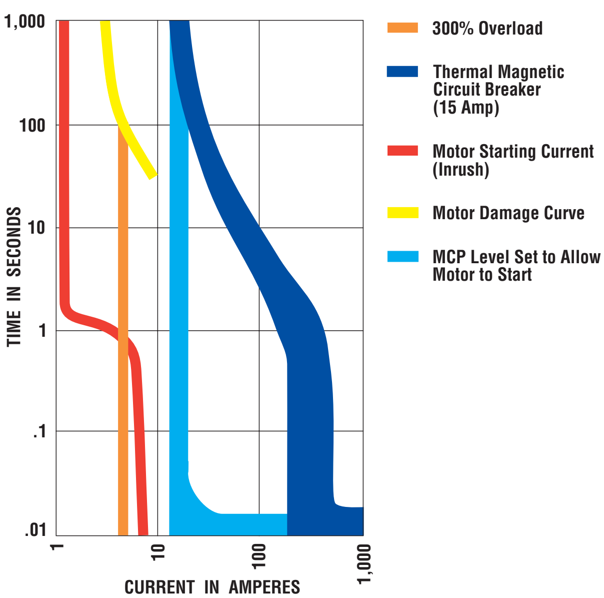
Magnetic only breakers (MCPs) and thermal magnetic breakers are also unsatisfactory for the protection of motors. Once again to properly safeguard motors from overloads, these devices should be sized at 115% or less of motor FLA for 1.0 SF or 125% or less of motor FLA for 1.15 or greater SF When sized this close to the FLA the inrush causes these breakers to open needlessly.

Curve 4 shows an MCP opening from motor inrush and an unaffected 15 amp thermal magnetic circuit breaker (the minimum standard size).



Curve 4

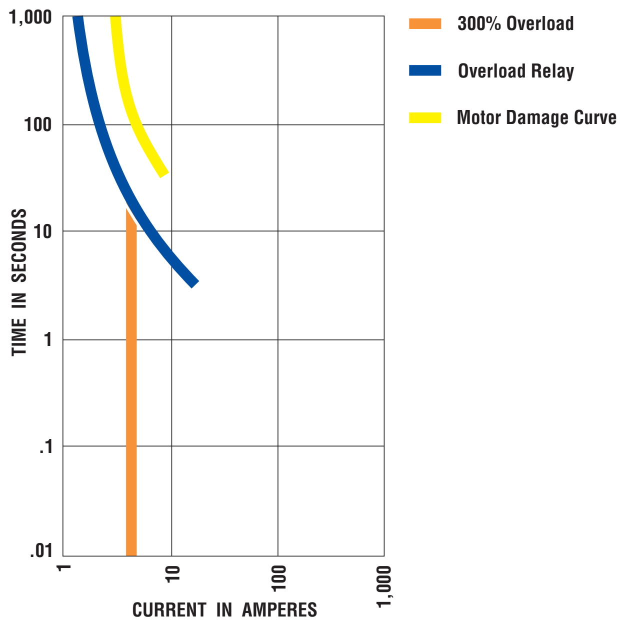
To allow the motor to start, the MCP must be sized at about 700-800% of the FLA and the thermal magnetic breaker must be sized at about 250% of FLA Curve 5 clearly shows that breakers sized to these levels are unable to protect motors against over-loads.



Curve 5

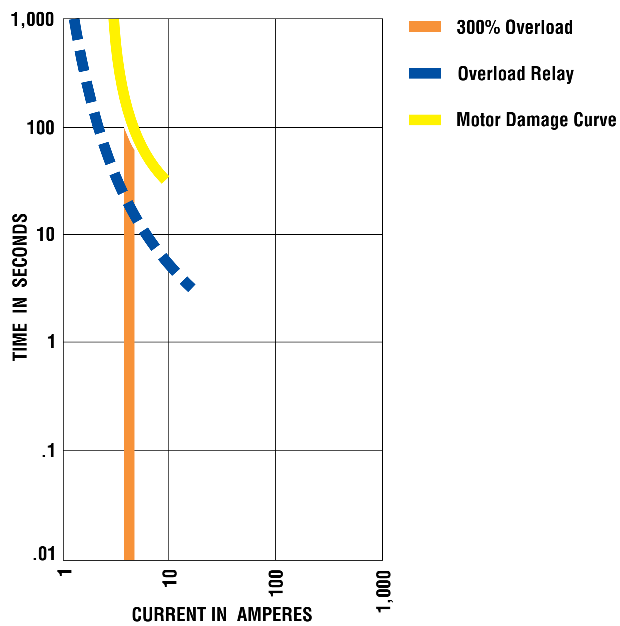
Overload Relays

Overload relays, or heaters, installed in motor starters are usually the melting alloy or bi-metallic type. When properly sized and maintained, the relay can offer good overload protection. When operating properly, overload relays allow the motor to start, but when a sustained overload occurs the overload relays cause the contacts to open (Curve 6).



Curve 6

However, if the overload relays are oversized or if the contacts fail to open for any reason (i.e., welded contacts), the motor is left unprotected. Also, overload relays cannot offer any protection for short circuits, and in fact must be protected by fuses or circuit breakers under short circuit conditions Curve 7.

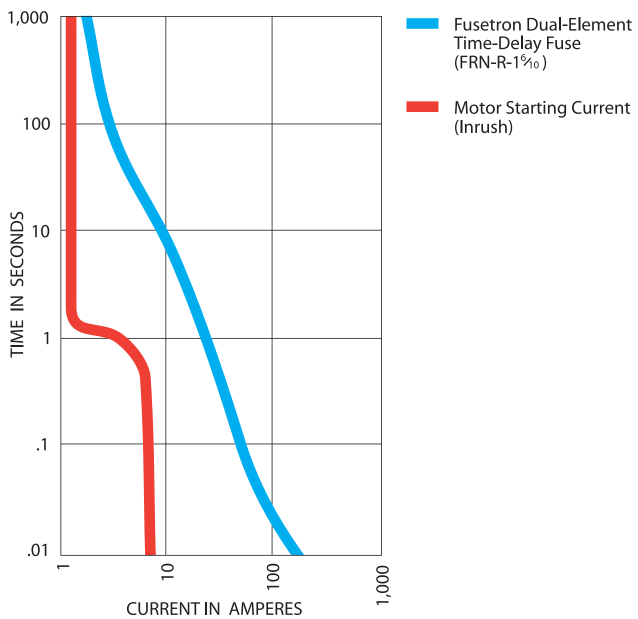


Curve 7

Basic Explanation

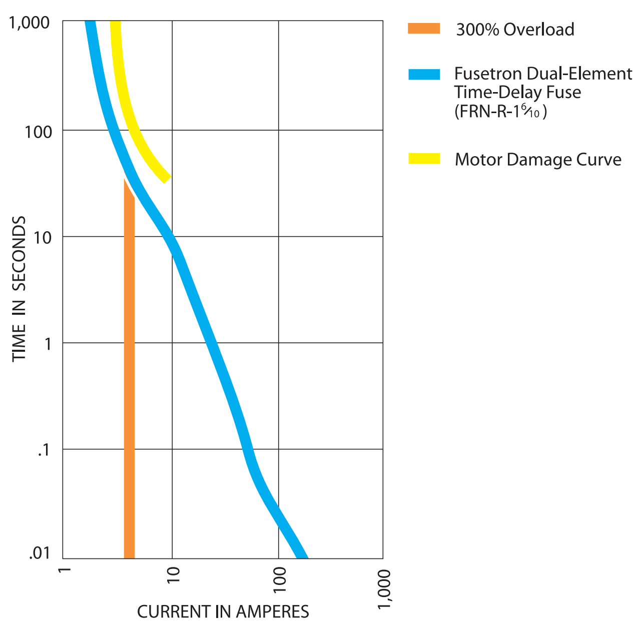
Dual-Element Fuses

The dual-element fuse is unaffected by the motor inrush current (Curve 8), but opens before a sustained overload can reach the motor damage curve (Curve 9).



Curve 8

The NEC® allows dual-element fuses to be used by themselves for both overload and short circuit protection, (see NEC® sections 430.36, 430.37, 430.55, 430.57, & 430.90). Curve 9 shows that the dual-element fuse offers excellent overload protection of motors.



Curve 9

Motor Overload Protection

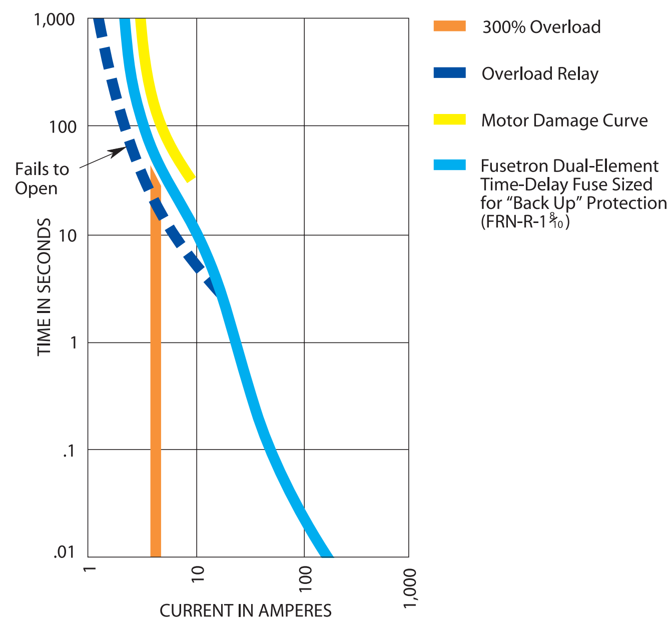
Given a motor with 1.15 service factor or greater, size the FRN-R or FRS-R fuse at 125% of the motor full load current or the next smaller available fuse size. With a motor having a service factor of less than 1.15, size these same fuses at 115% of the motor's FLA or the next smaller size.

Motor Backup Overload Protection

By using the following "backup" method of fusing, it is possible to have two levels of overload protection. Begin by sizing the over-load relays according to the manufacturers directions. Then, size the fuse at 125%-130% or the next larger size. With this combination you have the convenience of being able to quickly reset the overload relay after solving a minor problem, while the fuses remain unopened. However, if the overload relays are sized too large, if the contacts fail to open for any reason or the heaters lose calibration, the fuses will open before the motor damage curve is reached.

Typically LPN-RK_SP, and LPS-RK_SP or FRN-R, and FRS-R fuses have sufficient delay and thermal capacity to be sized for motor backup overload protection.

Curve 10 below shows the backup protection available with this method.



Curve 10

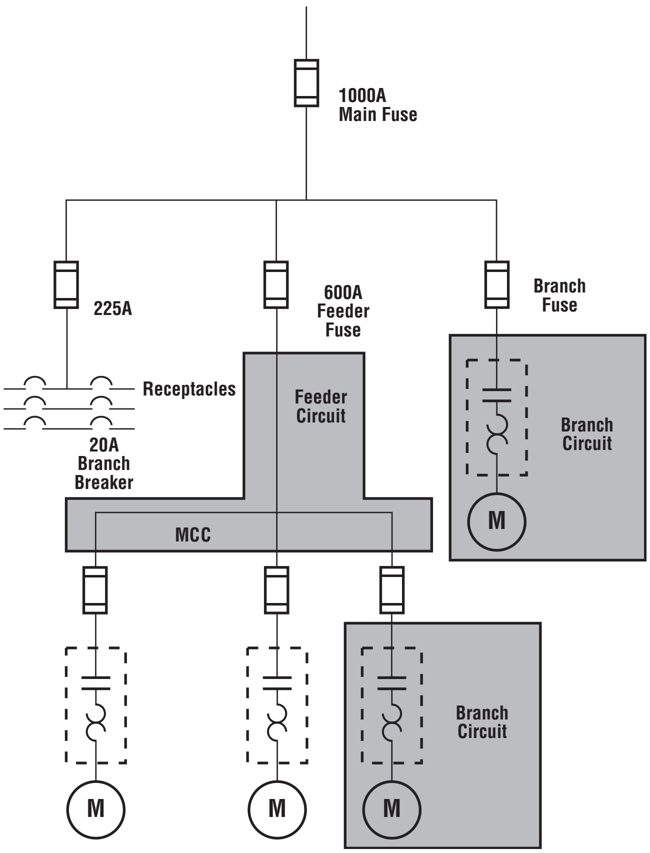
NEC® 430.52 Explanation

Motor Circuit Protection

Motor circuit protection describes the short-circuit protection of conductors supplying power to the motor, the motor controller, and motor control circuits/conductors.

430.52 provides the maximum sizes or settings for overcurrent devices protecting the motor branch circuit. A branch circuit is defined in Article 100 as "The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s)."

NEC® Motor Circuit Protection Requirements



Note that the branch circuit extends from the last branch circuit overcurrent device to the load.

Table 430.52 lists the maximum sizes for Non-Time-Delay Fuses, Dual Element (Time-Delay) Fuses, Instantaneous Trip Circuit Breakers, and Inverse Time Circuit Breakers. Sizing is based on full load amp values shown in Table 430.247 through 430.250, not motor nameplate values.

For example, the maximum time-delay fuse for a 10HP, 460 volt, 3 phase motor with a nameplate FLA of 13 amps would be based on 175% of 14 amps, not 175% of 13 amps.

Table 430.52. Maximum Rating or Setting of Motor Branch Circuit, Short-Circuit and Ground Fault Protective Devices

	Percent of Full-Load Current			
Type of Motor	Non-Time-Delay Fuse**	Dual-Element (Time-Delay) Fuse**	Instantaneous Trip Breaker	Inverse Time Breaker*
Single-phase motors	300	175	800	250
AC polyphase motors other than wound-rotor				
Squirrel Cage:				
Other than Design E	300	175	800	250
Design E	300	175	1100	250
Synchronous†	300	175	800	250
Wound Rotor	150	150	800	150
Direct-current (constant voltage)	150	150	250	150

For certain exceptions to the values specified, see 430.52 through 430.54.

* The values given in the last column also cover the ratings of non-adjustable inverse time types of circuit breakers that may be modified as in 430.52.

** The values in the Non-Time-Delay Fuse Column apply to Time-Delay Class CC fuses.

† Synchronous motors of the low-torque, low-speed type (usually 450 rpm or lower), such as are used to drive reciprocating compressors, pumps, etc., that start unloaded, do not require a fuse rating or circuit-breaker setting in excess of 200 percent of full-load current.

Standard sizes for fuses and fixed trip circuit breakers, per 240.6, are 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000 5000, and 6000 amps. Additional standard fuse sizes are 1, 3, 6, 10, and 601 amps.

The exceptions in 430.52 allow the user to increase the size of the overcurrent device if the motor is not able to start. All Class CC fuses can be increased to 400%, along with non-time-delay fuses not exceeding 600 amps. Time-delay (dual-element) fuses can be increased to 225%. All Class L fuses can be increased to 300%. Inverse time (thermal-magnetic) circuit breakers can be increased to 400% (100 amp and less) or 300% (larger than 100 amps). Instant trip circuit breakers may be adjusted to 1300% for other than Design B motors and 1700% for energy efficient Design B motors.

430.52(C)(2) reminds the user that the maximum device ratings which are shown in a manufacturer's overload relay table must not be exceeded even if higher values are allowed by other parts of 430.52.

430.52(C)(3) details the requirements that instant-trip CBs can only be used if part of a listed combination motor controller.

Disconnecting Means for Motor Circuits

Notes:

1. "In Sight From" means that the motor must be visible and not more than 50 feet distant. (Definitions in Article 100.)
2. "Controller" includes any switch or device normally used to start or stop a motor by making and breaking the motor circuit current (430.81).
3. A disconnecting means must be located in sight of the controller (430.102). For exceptions see 430.102.
4. A switch can serve both as a controller and disconnecting means if properly rated in accordance with 430.111 and 430.83.

Switches for Motor Circuits

The Code requirements for switches used as controllers and disconnect switches are as follows (430.81, 430.83, 430.109, 430.110, 430.111):

For 0 to 300 volt stationary motors:

- **2Hp or Less** – Use horsepower rated switch, or general use switch having amp rating at least twice the amp rating of the motor, or general use AC (only) snap switch having amp rating at least 125% of motor current rating.
- **Greater than 2Hp to 100Hp** – Switch must have horsepower rating.
- **Larger than 100Hp** – Disconnect purposes–switch must have an amp rating at least 115% of the motor full load current from Tables 430.247 through 430.250.
- Controller purposes–switch must have horsepower rating.

For 301 to 600 Volt Stationary Motors:

- **Less than 100Hp** – Switch must have horsepower rating.
- **Larger than 100Hp** – Disconnect purposes–switch must have an amp rating at least 115% of the motor full load current from Tables 430.247 through 430.250.
- Controller purposes–switch must have horsepower rating.

For Portable Motors:

- An attachment plug and receptacle may serve as disconnect on all sizes.
- 1/3 Hp or Less – An attachment plug and receptacle may serve as controller.
- Larger than 1/3 Hp – Controller must meet requirements as outlined for stationary motors (shown above).

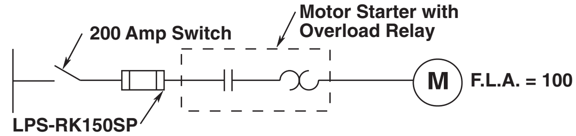
Size of Hp Rated Switches (Switch Size Savings)

Low-Peak and Fusetron dual-element fuses rather than non-time-delay fuses are recommended for motor branch circuit protection because normally dual-element fuses permit the use of a smaller switch size, give better protection, reduce cost, and require less space.

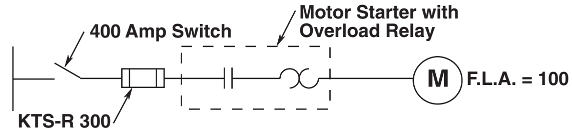
For motors, oversized switches must be used with non-time-delay fuses because this type of fuse has very little time-lag. Non-time-delay fuses are generally sized at 300% of the motor rating to hold normal motor starting current. Consequently, the switch also has be be oversized to accommodate these fuses.

The dual-element fuse can be sized close to the motor full-load amps and a smaller switch used, as shown in the following illustrations.

WHEN USING DUAL-ELEMENT, TIME-DELAY FUSES



WHEN USING NON-TIME-DELAY FUSES



Branch circuit (short-circuit) protection can be provided for the given motor by either a 150 amp dual-element, time-delay fuse or a 300 amp non-time-delay fuse. The dual-element fuse selection above provides these advantages: (1) Backup overload protection, (2) smaller switch size, resulting in lower cost, (3) smaller fuse amp case size, resulting in lower cost, (4) short-circuit protection that is comparable or better than non-time-delay (fast-acting) fuse.

Most switches are listed with two Hp ratings. The Standard horsepower rating is based on the largest non-time-delay (non-dual-element) fuse rating (1) which can be used in the switch, and (2) which will normally permit the motor to start. The Maximum horsepower rating is based on the largest rated time-delay Low-Peak or Fusetron dual-element fuse (1) which can be used in the switch, and (2) which will normally permit the motor to start. Thus when Low-Peak or Fusetron dual-element fuses are used, smaller size switches can be used (430.57 Exception).

Conductors For Motor Branch and Feeder Circuits Motor Branch Circuit Conductors

The ampacity of branch circuit conductors supplying a single motor must be at least 125% of the motor full-load current rating [430.22(A)].

Exceptions: For conductors supplying motors used for short-time, intermittent, periodic, or varying duty refer to 430.22(B).

Any motor application must be considered continuous duty unless the nature of the apparatus it drives is such that the motor will not operate continuously with load under any conditions of use.

Feeder Circuits For Motors

Feeder Conductor Ampacity

The ampacity of a conductor supplying two or more motors must be at least equal to the sum of (1) 125% of the largest motor (if there are two or more motors of the largest size, one of them is considered to be the largest), and (2) the total of the full-load amp ratings for all other motors and other loads.

Where different voltages exist, the current determined per the above shall be multiplied by the ratio of output to input voltage.

Feeder Fuse Size

On normal installations, size Fusetron dual-element fuses or Low-Peak dual-element fuses equal to the combined amp rating of (1) 150% to 175% F.L.A. of the largest AC motor (if there are two or more motors of the same size, one of them is considered to be the largest), and (2) the sum of all the F.L.A. for all other motors.

This dual-element fuse size should provide feeder protection without unnecessary fuse openings on heavy motor startings.

Where conditions are severe, as where a high percentage of motors connected must be started at one time, a larger size may be necessary. In that event, use the maximum size permitted by the Code as follows.

Group Switching

Motors Served by a Single Disconnecting Means (Group Switching)

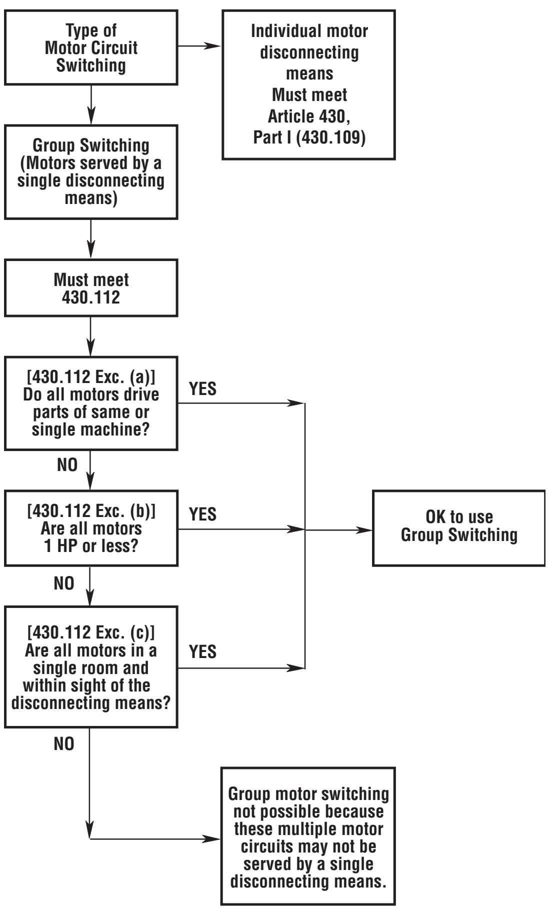
430.112 covers the requirements for serving two or more motors with the same disconnecting means. Each motor must be provided with an individual disconnecting means unless:

(a) all motors drive parts of a single machine

or (b) all motors are 1Hp or less as permitted by 430.53(A)

or (c) all motors are in a single room and within sight (visible and not more than 50 feet) of the disconnecting means.

Group Switching



OPM-NG

CH Series

TCFH & TCF Fuse

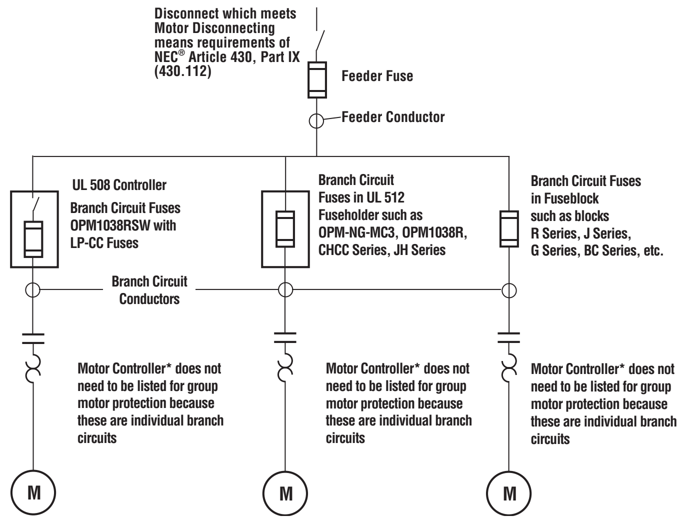
OPM1038

JT Series

OPM1038SW

Group Switching Application

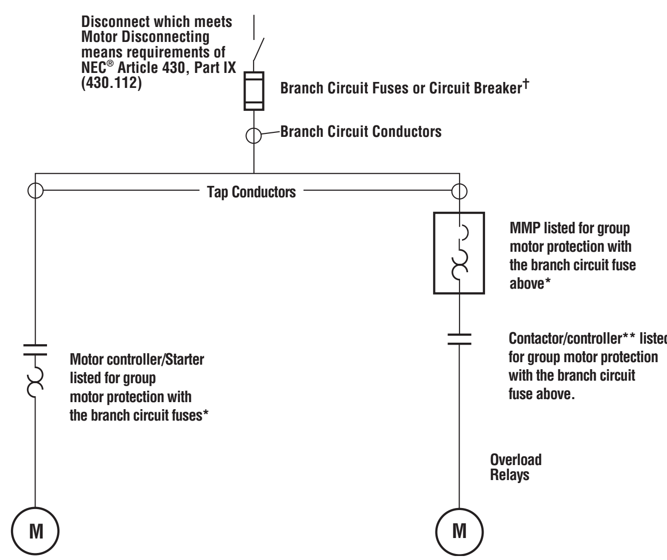
Preferred Method: Can achieve excellent protection and lower cost.



* Must be within sight of the branch circuit disconnecting means.

Group Switching with Group Motor Protection Application§

Group Switching with Group Motor Protection Application♦



* Must be within sight of the branch circuit disconnecting means.

§ Must meet both group motor protection (430.53) and group switching requirements (430.112). Often limited in application. See prior page.

**Often used in addition to MMP for automatic/remote control.

† Unless all motors are 1 horsepower or less, or unless the smallest motor is protected according to 430.52, circuit breakers are required by 430.53(C) to be listed for this purpose. There are no circuit breakers listed for group motor installations except for HVAC equipment. Fuses are not required to be listed for this purpose (current-limiting fuses have maximum short-circuit current let-through I_p and I^2t umbrella limits that circuit breakers do not have).