Application Techniques

Allen-Bradley

North American Standards, Configurations, and Ratings: Introduction to Motor Circuit Design

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Introduction to North American Standards

Introduction

OEMs or panel builders, especially those who serve global markets, are challenged to meet the requirements of local codes and standards. This can be a daunting task when you consider differences in power systems, voltages, and frequencies. Although electrical codes may focus on the installation of equipment in a facility and are relied upon by the contractor, they also affect all areas of the industrial machine from specification to design to building to operation.

There are several standards that address this issue, but the main ones are the National Electrical Code® (*NEC*®), NFPA 79: Electrical Standard for Industrial Machinery (NFPA 79), and UL 508A: Industrial Control Panels (UL 508A). All have similar design requirements for motor circuits.

In the US, the *NEC* exists to guide electricians in the proper installation of electrical equipment and defines the specific requirements for circuit protection. The primary focus of the *NEC* is fire prevention.

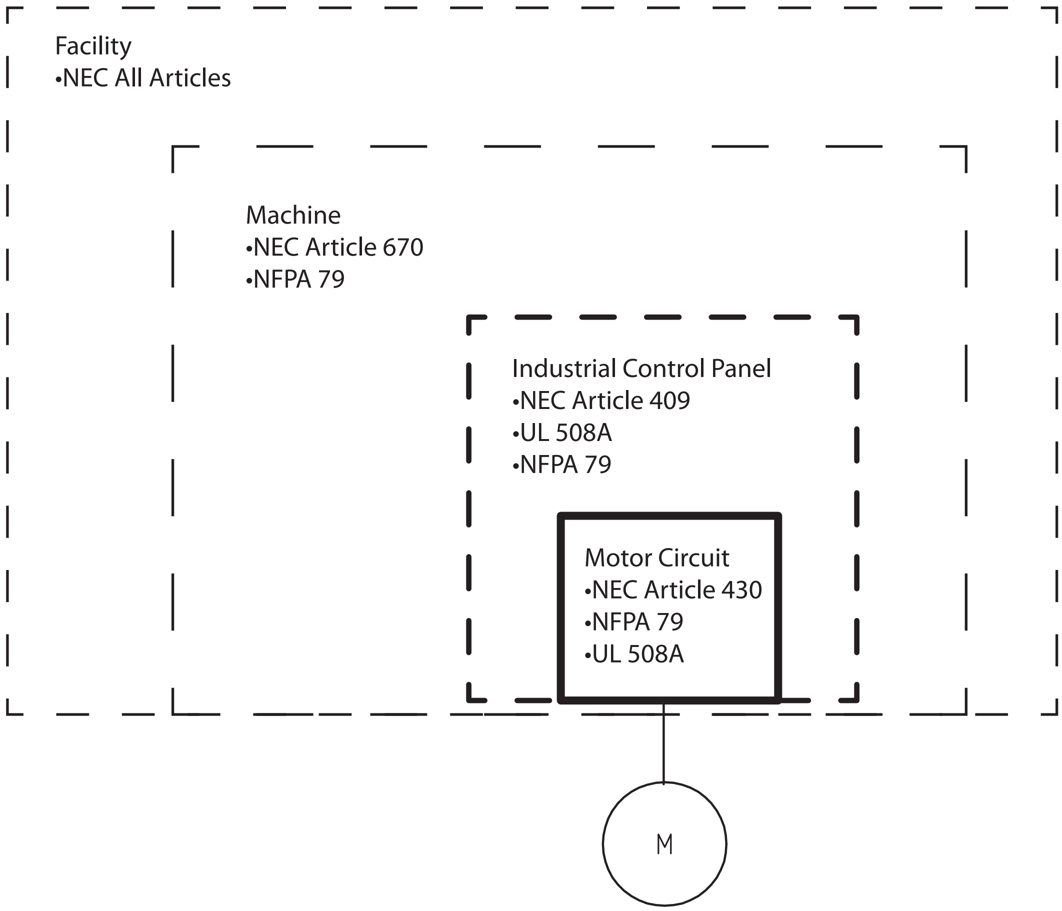
NFPA 79 is the electrical standard for industrial machinery and is closely harmonized with IEC 60204-1. It is intended to be used by specifiers, end users, panel builders, system integrators, contractors, and other qualified persons.

UL 508A is the design standard for safety for Industrial Control panels intended for construction of Listed panels built by panel builders. It is meant to apply to general use panels of less than 600V, and requires compliance with *NEC* installation standards.

Designing equipment that complies with these standards will help to ensure that equipment is designed, properly installed, and used in a safe manner.

This application guide is intended to provide an overview of North American motor circuit design, based on methods outlined in the *NEC*. Examples provided are intended to illustrate typical applications and do not cover every exception.

Figure 1 - Scope of North American Standards



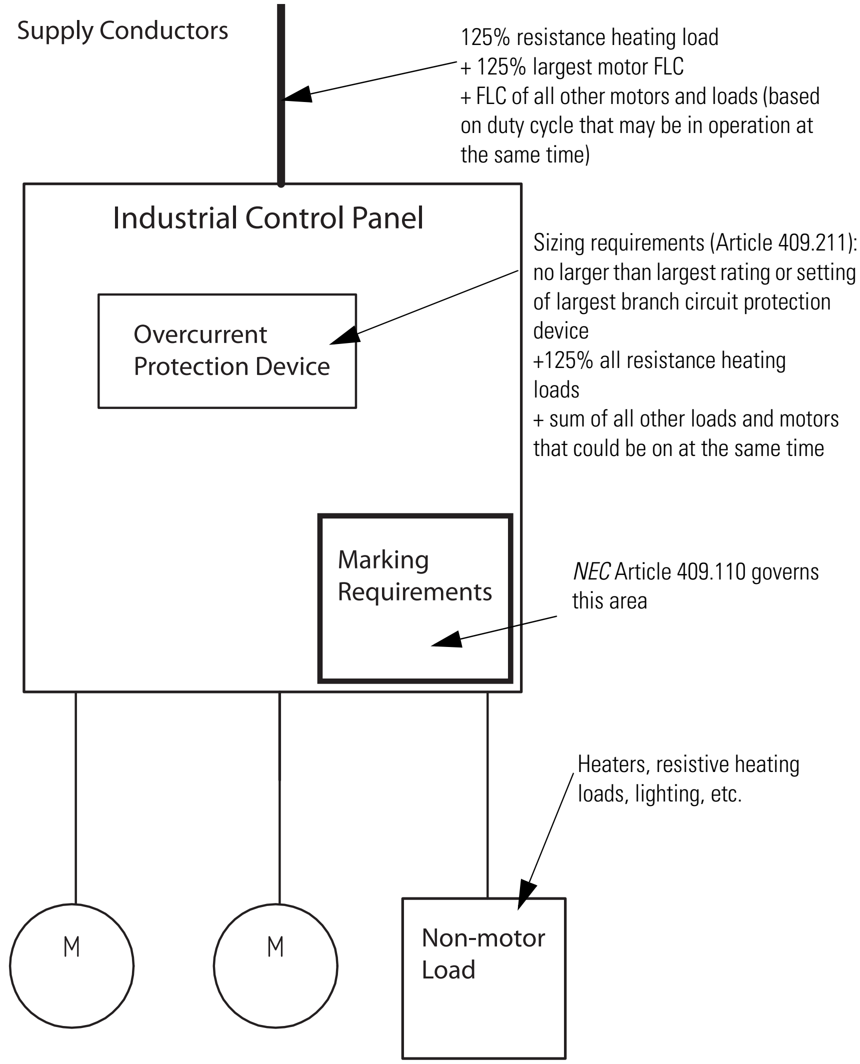
Industrial Control Panels

Industrial control panels discussed here fall within the same scope and definition as defined in the *NEC* and UL508A standard of safety for Industrial Control Panels. These are intended for general use and for operating at voltages no greater than 600 volts.

NEC Article 409 defines the installation and construction requirements of industrial control panels. An industrial control panel can consist of only power components, only control circuit components, or a combination of the two. The requirement to provide an overcurrent protection either ahead or within the panel, as well as a disconnecting means is defined in this section.

The enclosure type requires that the enclosure rated meet environmental conditions. Construction requirements also include the size of the supply conductors, and wiring spacing.

Figure 2 - Industrial Control Panel Supply Conductor and Marking Requirements



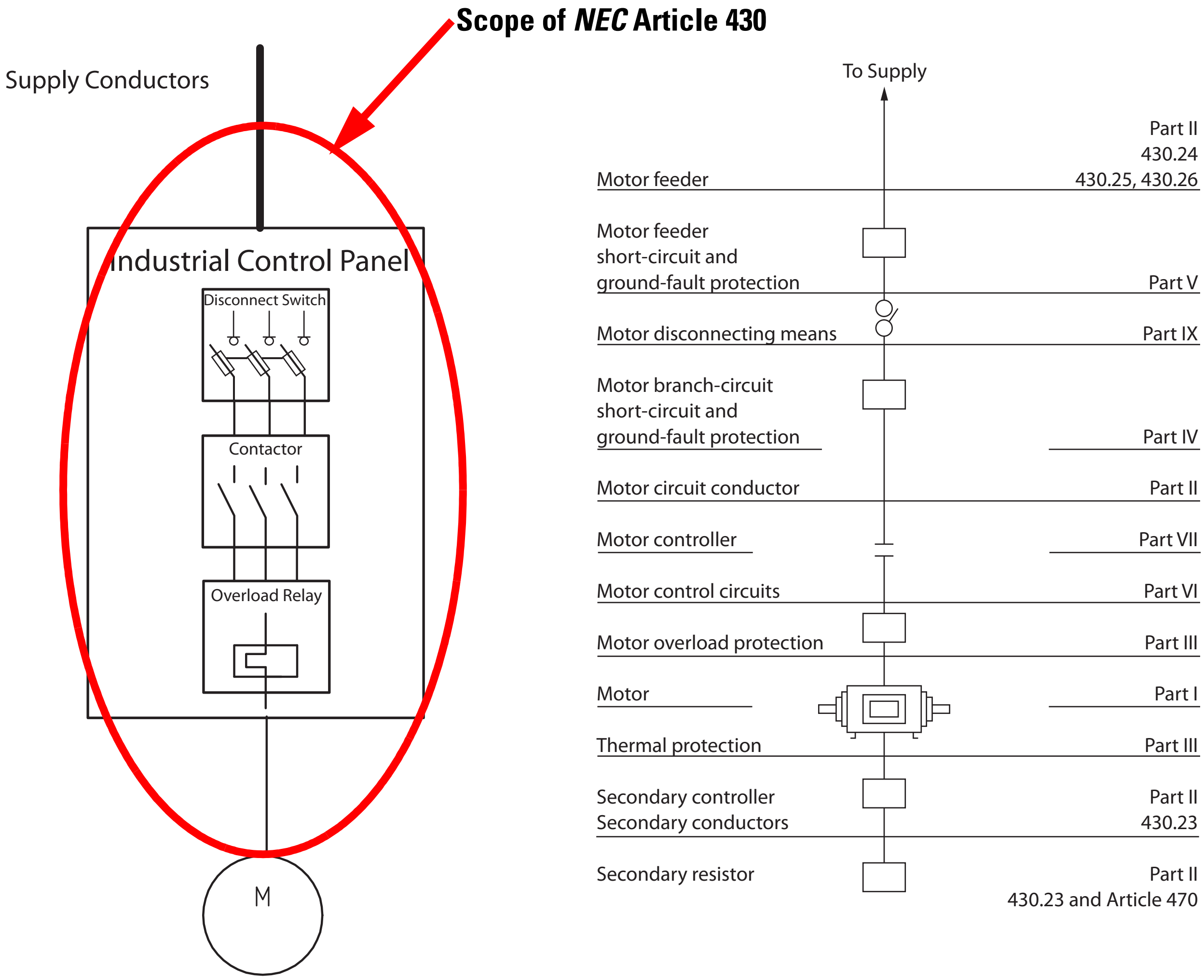
Motors

Within the *NEC*, Article 430 addresses motors, motor circuits, and controllers.

NEC Article 430 is divided into ten parts, shown in Figure 3. When sizing circuit components, it is important to address each part in order. Doing so will help to minimize errors and standards compliance issues.

We will discuss the aspects of *NEC* Article 430 in greater details in later chapters.

Figure 3 - *NEC* Article 430 Contents



Motors

Introduction

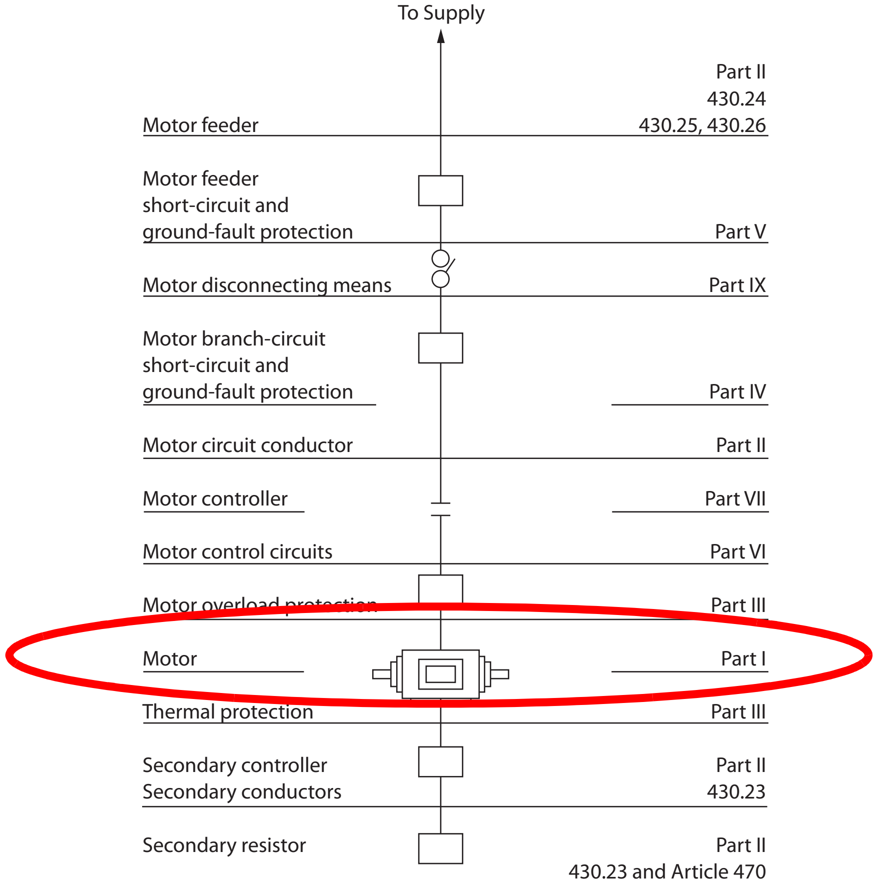
In this section, we will discuss motors, motor nameplate information, and how the motor determines the rest of the panel design configuration. *NEC* Article 430 provides the most complete information about the requirements of motor control circuits.

This section of Article 430 includes definitions, terminology, and the required marking for motors. Important information can be found on the motor nameplate including but not limited to full load and locked rotor current, service factor and inverter duty rated. Proper sizing of overload protection in Part III requires the rating or setting of the overload according to full load current and service factor located on the motor nameplate.   The design letter on the nameplate indicates the motor's speed vs torque characteristics. This design letter can indicate specific design differences including the motor's locked rotor current and breakdown torque. We can assume motors are rated for continuous duty; however, intermittent or interval duty is addressed in the standard.

Selection Process

When designing to *NEC* standards, the first component we look at is the motor. It must have sufficient horsepower, voltage, etc. to safely power the machinery with which it is intended to work. Motor characteristics determine everything in the panel design, from wire size to disconnecting means. *NEC* Article 430 provides an outline of the steps required to size the components of a motor circuit, as shown in Figure 4.

Figure 4 - *NEC* Article 430 Contents

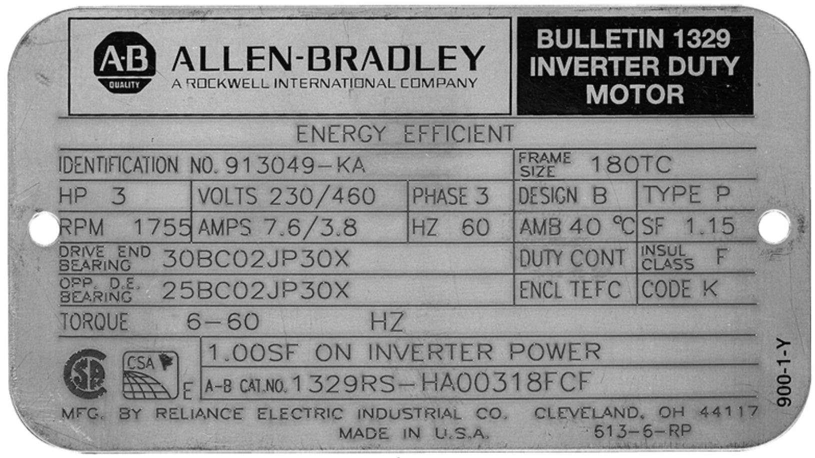


Section 430.6 references table values that must be used in motor full load current (FLC) calculations, rather than the motor nameplate data. The motor nameplate contains useful application information and is a required element on the motor.

Motor Nameplate

The information on a motor nameplate can be arranged in categories. By definition, an induction motor converts electrical energy to useful mechanical energy. The following information provides a brief definition and some application considerations regarding motor data on the nameplate.

Figure 5 - Typical motor nameplate



A nameplate contains the data for a typical AC motor; this one is a 3 Hp, 1,755 rpm, 180T frame unit.

Electrical input

Voltage. The voltage at which the motor is designed to operate is an important parameter. Standard voltage for motors built to NEMA MG 1 (1987) are defined in MG 1-10.30. One common misapplication is of motors marked (rated) at one voltage but applied on a different voltage network using the + 10% voltage tolerance for "successful" operation. Nameplate-defined parameters for the motor such as power factor, efficiency, torque, and current are at rated voltage and frequency. Application at other than nameplate voltage will likely produce different performance.

It is common for manufacturers to mark a wide variety of voltages on one motor nameplate. A common example is a motor wound for 230 and 460V (230/460V) but operable on 208V. This 208-230/460V motor will have degraded performance at 208V. Another common misconception is to request a motor rated at network voltage; for example, at 480V. The NEMA standard is 460V. The voltage rating assumes that there is voltage drop from the network to the motor terminals. Thus, the 460V motor is appropriate on a 480V network.

Frequency. Input frequency is usually 50 or 60 Hz. When more than one frequency is marked, other parameters that will differ at different input frequencies must be defined on the nameplate. The increasing use of adjustable frequency drives (AFDs) is also making it necessary to mark a frequency range, especially for hazardous-duty listed applications.

Phase. This represents the number of AC power lines supplying the motor. Single and three-phase are typical.

Current. Rated load current (FLC) in amperes (A) is at nameplate horsepower (Hp) with nameplate voltage and frequency. When using current measurement to determine motor load, it is important that correction be made for the operating power factor. Unbalanced phases, under voltage conditions, or both, cause current to deviate from nameplate FLC. Review both motor and drive for a matched system regarding current on AFD applications.

Code. A letter code defines the locked-rotor kVA on a per-Hp basis. Codes are defined in MG 1-10.37.2 by a series of letters from **A** to **V.** Generally, the farther the code letter from **A,** the higher the inrush current per Hp. A replacement motor with a "higher" code may require different upstream electrical equipment, such as motor starters.

Type. NEMA MG 1 requires manufacturer's type, but there is no industry standard regarding what this is. Some manufacturers use "Type" to define the motor as single or polyphase, single or multi-speed, or even by type of construction. Type is of little use in defining a motor for replacement purposes unless you also note the specific motor manufacturer.

Power factor. Also given on the nameplate as "P.F." or "PF," power factor is the ratio of the active power (W) to the apparent power (VA) expressed as a percentage. It is numerically equal to the cosine of the angle of lag of the input current with respect to its voltage, multiplied by 100. For an induction motor, power factor also varies with load. The nameplate provides the power factor for the motor at full load.

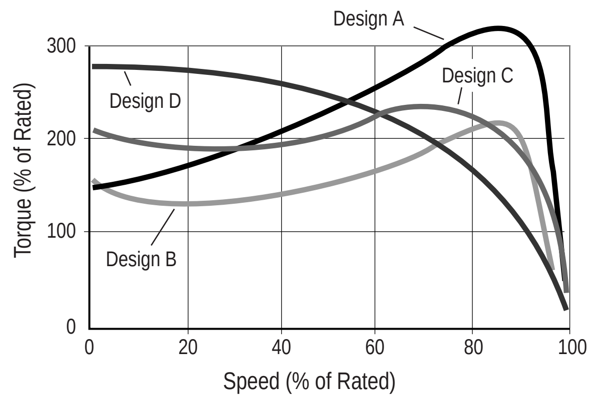
Active power is the power that does work; apparent power has a reactive component. This reactive component is undesirable — the utility company must supply it, but it does no work.

A power factor close to unity (100%) is most desirable. Because there are trade-offs when designing an induction motor for improved efficiency or other performance parameters, power factor sometimes suffers. It can be improved by adding capacitors.

Capacitor correction. The nameplate may list the maximum power-factor correcting capacitor size. Nameplate notation would be similar to "MAX CORR KVAR" followed by a number. The number would indicate capacitor value in kilovars. A value greater than the one suggested may result in higher voltages than desired and could cause damage to the motor or other components.

Design. NEMA MG 1 (1987), Section MG 1-1.16, defines "design", which defines the torque and current characteristics of the motor. Letters are assigned the defined categories. Most motors are Design B,. although the standard also defines Designs A, C, and D. Common headings on nameplates include "Des," "NEMA Design," and "Design."

Figure 6 - Design A, B, C, D for AC Motors



Dimensions

NEMA has standard frame sizes and dimensions designating the height of the shaft, the distance between mounting bolt holes and various other measurements. Integral AC motor NEMA sizes run from 143T-445T, and the center of the shaft height in inches can be figured by taking the first two digits of the frame number and dividing it by 4.

Fractional horsepower motors, for which NEMA spells out dimensions, use 42, 48, and 56 frames. The shaft height in inches can be established by dividing the frame number by 16.

Table 1 - Design A, B, C, D - For AC Motors

Nema Design	Starting Torque	Starting Current	Breakdown Torque	Full Load Slip	Typical Applications
A	Normal	High	High	Low	Mach. Tools, Fans
B	Normal	Normal	Normal	Normal	Same as Design “A”
C	High	Normal	Low	Normal	Loaded compressor Loaded conveyor
D	Very High	Low	-	High	Punch Press

Some motors may not conform to any torque-current characteristics defined in MG 1. The motor manufacturer may assign them a letter that is not a defined industry standard. It is important to check the design letter when replacing a motor in an existing application.

Another note on Design B: Design B constrains the motor designer to limit inrush current to established standards. This insures that the user’s motor-starting devices are suitable. A Design A motor has torque characteristics similar to those of the Design B motor, but there is no limit on starting inrush current. This may cause starter sizing problems. You should be aware of this and work with the motor manufacturer to insure successful operation of your motor systems.

Performance

NEMA Nom. Efficiency. Efficiency is defined as output power divided by input power expressed as a percentage:

(Output/Input) x 100

NEMA nominal efficiency on a nameplate represents an average efficiency of a large population of like motors.

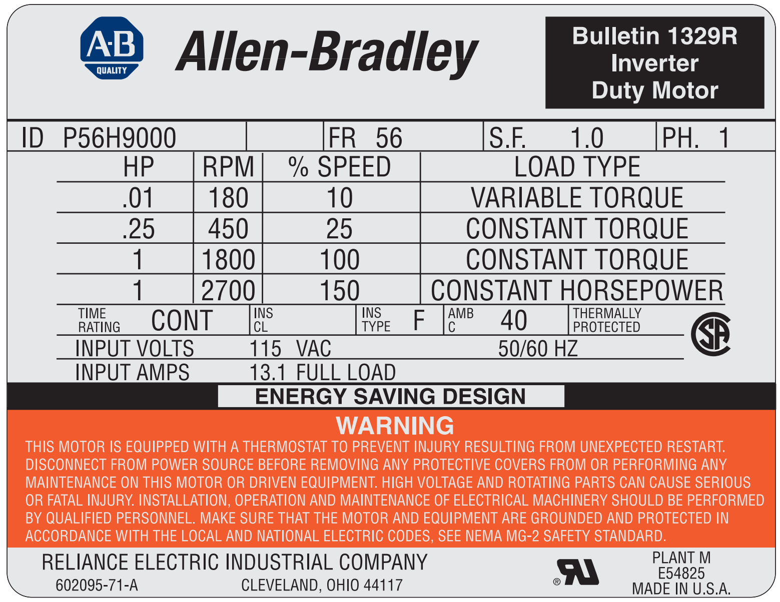
The actual efficiency of the motor is guaranteed by the manufacturer to be within a tolerance band of this nominal efficiency. The band varies depending on the manufacturer. However, NEMA has established the maximum variation allowed. The maximum allowed by NEMA standards represents an additional 20% of motor losses from all sources, such as friction and windage losses, iron losses, and stray load losses. Therefore, you should pay attention to guaranteed minimum efficiencies when evaluating motor performance.

Service factor. The service factor (S.F.) is required on a nameplate only if it is higher than 1.0. Industry standard service factor includes 1.15 for open-type motors and 1.0 for totally-enclosed-type motors. However, service factors of 1.25, 1.4, and higher exist.

It is not considered good design practice to use the rating afforded by S.F. continuously; operating characteristics such as efficiency, power factor, and temperature rise will be affected adversely.

Duty. This block on the nameplate defines the length of time during which the motor can carry its nameplate rating safely. Most often, this is continuous ("Cont"). Some applications have only intermittent use and do not need motor full load continuously. Examples are crane, hoist, and valve actuator applications. The duty on such motors is usually expressed in minutes.

Figure 7 - Nameplate special markings



You can't tell just from a motor's nameplate if it is suitable for explosion-proof or dust ignition-proof service. It takes a separate but nearby tag that says it is UL-listed for hazardous locations and goes into more specifics. The motor that these tags represent is capable of adjustable-speed service

Other special markings may be displayed, such as those of agencies wishing to establish an efficiency certification. You should understand if any special third-party certifications are required and where you can find the proof.

A growing area of nameplate marking relates to capabilities of a motor when used on an adjustable speed drive. Many standard motors are applied to ASDs using general rules of thumb, without the motor manufacturer even knowing of the application. However, given the proper information about the ASD and application, a motor manufacturer can design a motor, or properly apply an existing design, and stamp the approved parameters on the nameplate. This stamping is always required on UL-listed explosion-proof motors.

Reliability

Insulation class. Often abbreviated "INSUL CLASS" on nameplates, it is an industry standard classification of the thermal tolerance of the motor winding. Insulation class is a letter designation such as "A," "B," or "F," depending on the winding's ability to survive a given operating temperature for a given life. Insulations of a letter deeper into the alphabet perform better. For example, class F insulation has a longer nominal life at a given operating temperature than class A, or for a given life it can survive higher temperatures.

Operating temperature is a result of ambient conditions plus the energy lost in the form of heat (causing the temperature rise) as the motor converts electrical to mechanical energy.

Maximum ambient temperature. The nameplate lists the maximum ambient temperature at which the motor can operate and still be within the tolerance of the insulation class at the maximum temperature rise. It is often called "AMB" on the nameplate and is usually given in C.

Altitude. This indicates the maximum height above sea level at which the motor will remain within its design temperature rise, meeting all other nameplate data. If the motor operates below this altitude, it will run cooler. At higher altitudes, the motor would tend to run hotter because the thinner air cannot remove the heat so effectively, and the motor may have to be derated. Not every nameplate has an altitude rating.

Construction

Enclosure. This designation, often shown as "ENCL" on a nameplate, classifies the motor as to its degree of protection from its environment, and its method of cooling. In MG 1, NEMA describes many variations. The most common are Open Drip-Proof (ODP) and Totally Enclosed Fan Cooled (TEFC).

ODP. An open drip-proof motor allows a free exchange of air from outside the motor to circulate around the winding while being unaffected by drops of liquid or particles that strike or enter the enclosure at any angle from 0…15° downward from the vertical.

TEFC. A totally enclosed fan cooled motor prevents free exchange of air between inside and outside the motor enclosure. It has a fan blowing air over the outside of the enclosure to aid in cooling.

A TEFC motor is not considered air or water-tight; it allows outside air containing moisture and other contaminants to enter, but usually not enough to interfere with normal operation. If contamination is a problem in a given application, most manufacturers can provide additional protection such as mill & chemical duty features, special insulations and internal coating, or space heaters for motors subject to extended shutdown periods and wide temperature swings that could make the motor "breathe" contaminants.

Bearings. Though NEMA does not require it, many manufacturers supply nameplate data on bearings, because they are the only true maintenance components in an AC motor. Such information is usually given for both the drive-end bearing and the bearing opposite the drive end.

Nameplate designations vary from one manufacturer to another. For rolling-element bearings, the most common is the "AFBMA Number." That is the number that identifies the bearing by standards of the Anti-Friction Bearing Manufacturers Association. It provides much information about the bearings and lets you buy bearings from a local distributor.

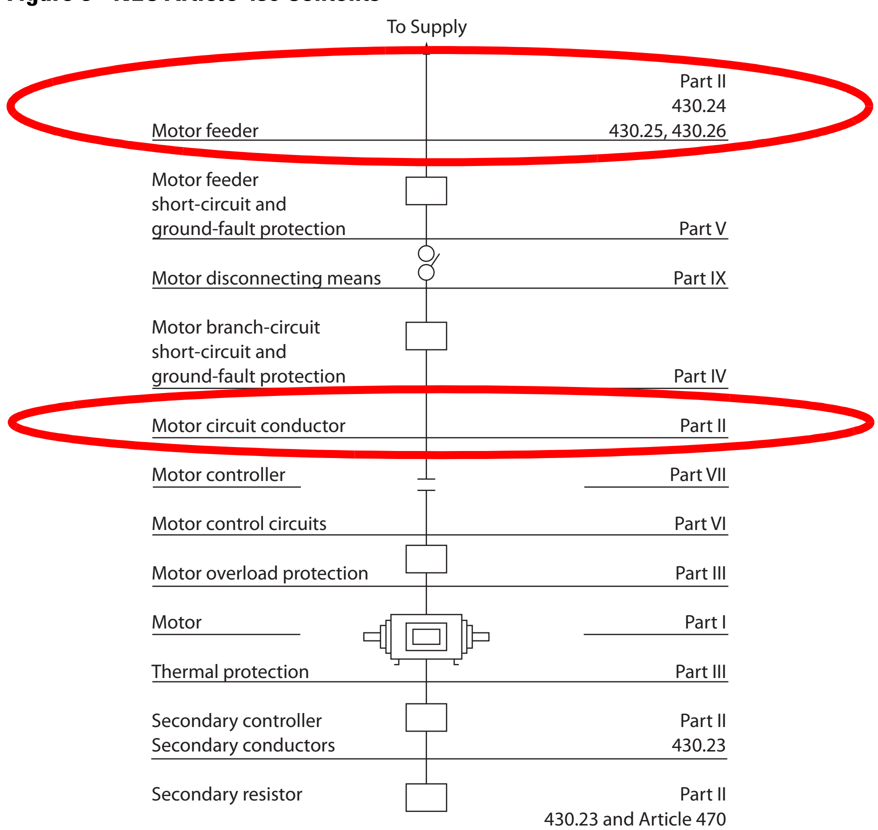
Some manufacturers use a simplified designation simply indicating the bearing size and type -for example, 6309 for a size 309 ball bearing. This brief information can leave questions like: Is the bearing sealed, shielded, or open? Still, some manufacturers may use special bearings and elect to display their own bearing part numbers on the nameplate. Many special bearings are applied in motors for reasons such as high speed, high temperature, high thrust, or low noise. It pays to understand your motors' bearing requirements.

Motor Circuit Conductors

Once the motor information has been determined, the next step is to select the appropriate motor circuit conductor. The conductor needs to be able to carry the motor current without overheating.

NEC provides minimum sizing requirements for conductors, including those used in a motor circuit. Minimum sizing requirements protect against the sizing of conductors beyond their ampacity and protects against overheating of conductors and even the prevention of fire. The amount of current that a conductor can carry continuously under specific conditions is defined as ampacity. The number of conductors grouped together can affect ampacity values. Temperature must also be factored into a conductor's load carrying capabilities. Correction tables are provided to address ambient temperature.

Figure 8 - *NEC* Article 430 Contents



Wire Size

North American wire sizes differ from those used by many other regions. In North America, wire is measured using the American Wire Gauge (AWG) system, which measures the diameter of the conductor (the bare wire) with the insulation removed.

In Europe, wire sizes are expressed in cross sectional area in mm^2 and also as the number of strands of wires of a diameter expressed in mm. For example, 7/0.2 means 7 strands of wire each 0.2 mm diameter. This example has a cross sectional area of 0.22 mm^2. Table 2 compares AWG and metric wire sizes.

Table 2 - Wire Size Comparison

AWG Number	Wire Diameter			AWG Number	Wire Diameter		
	in	mm	mm^2		in	mm	mm^2
6/0 = 000000	0.580	14.73	170.30	18	0.0403	1.02	0.823
5/0 = 00000	0.517	13.12	135.10	19	0.0359	0.912	0.653
4/0 = 0000	0.460	11.7	107	20	0.0320	0.812	0.518
3/0 = 000	0.410	10.4	85.0	21	0.0285	0.723	0.410
2/0 = 00	0.365	9.26	67.4	22	0.0253	0.644	0.326
1/0 = 0	0.325	8.25	53.5	23	0.0226	0.573	0.258
1	0.289	7.35	42.4	24	0.0201	0.511	0.205
2	0.258	6.54	33.6	25	0.0179	0.455	0.162
3	0.229	5.83	26.7	26	0.0159	0.405	0.129
4	0.204	5.19	21.1	27	0.0142	0.361	0.102
5	0.182	4.62	16.8	28	0.0126	0.321	0.0810
6	0.162	4.11	13.3	29	0.0113	0.286	0.0642
7	0.144	3.66	10.5	30	0.0100	0.255	0.0509
8	0.128	3.26	8.36	31	0.00893	0.227	0.0404
9	0.114	2.91	6.63	32	0.00795	0.202	0.0320
10	0.102	2.59	5.26	33	0.00708	0.180	0.0254
11	0.0907	2.30	4.17	34	0.00631	0.160	0.0201
12	0.0808	2.05	3.31	35	0.00562	0.143	0.0160
13	0.0720	1.83	2.62	36	0.00500	0.127	0.0127
14	0.0641	1.63	2.08	37	0.00445	0.113	0.0100
15	0.0571	1.45	1.65	38	0.00397	0.101	0.00797
16	0.0508	1.29	1.31	39	0.00353	0.0897	0.00632
17	0.0453	1.15	1.04	40	0.00314	0.0799	0.00501

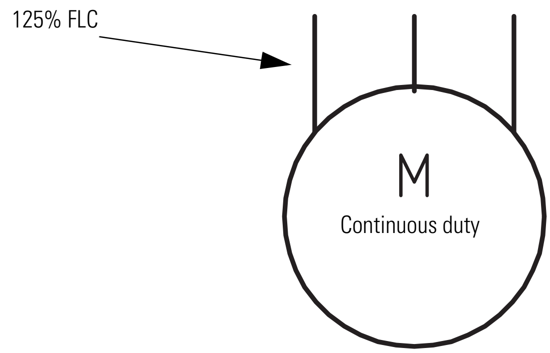
Single Motor Conductor Sizing

In general, Section 430.22 specifies that the conductors used to supply a single motor in continuous duty must be sized at a minimum of 125% motor FLC. Continuous duty is defined as a motor that is in operation for longer than 3 hours.

The provision for a conductor with an ampacity of at least 125% of the motor full-load current rating is not a conductor derating; rather, it is based on the need to provide for a sustained running current that is greater than the rated full-load current and for protection of the conductors by the motor overload protective device set above the motor full-load current rating.

The conductor requirements apply to motor circuits 600V or less, and for continuous duty. The ampacity of branch circuit conductors is calculated from motor FLC in Tables 430.247…430.250, rather than the motor nameplate.

Figure 9 - Single motor conductor sizing



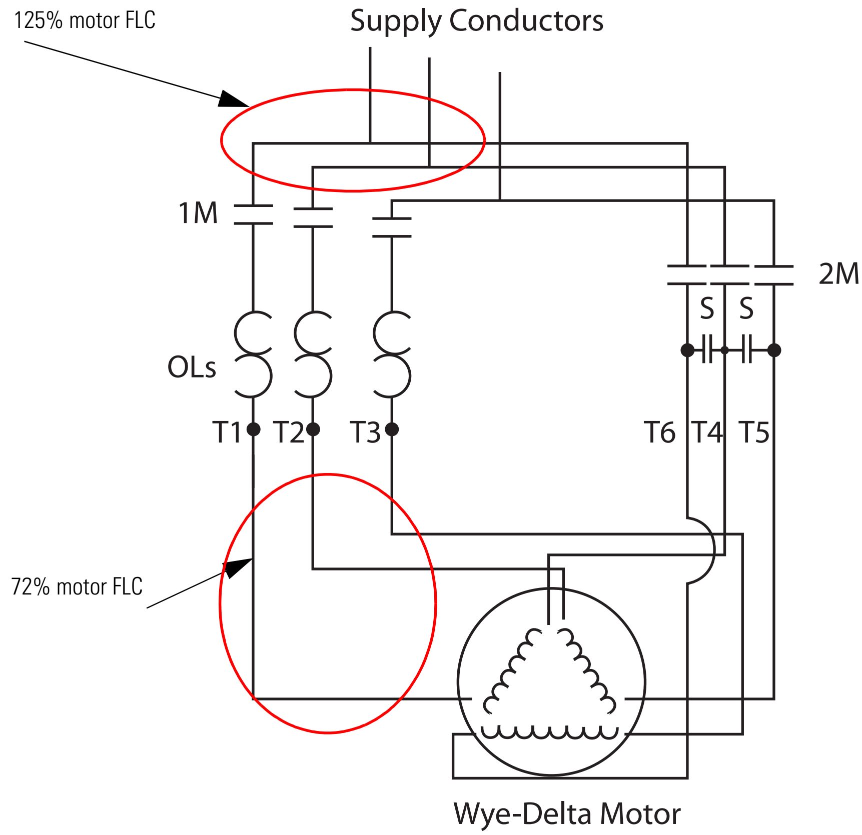
Determining Conductor Size

1. Determine the horsepower of the motor.
2. Locate the appropriate table, and determine the motor FLC.
3. Multiply the motor FLC by 1.25. This value is the ampacity required of motor conductors.
4. Use appropriate tables and correction factors from Section 310.15(B)to determine the correct wire gauge.

Wye-Delta Configurations

The conductor sizing requirements are basically the same as for standard branch circuits. The conductor must be sized for 125% motor FLC. The main difference in this application is that the Wye-Delta motor runs at 58% of the standard motor FLC. This is addressed in *NEC* Section 430.22.

Figure 10 - Conductor sizing for Wye-Delta motors



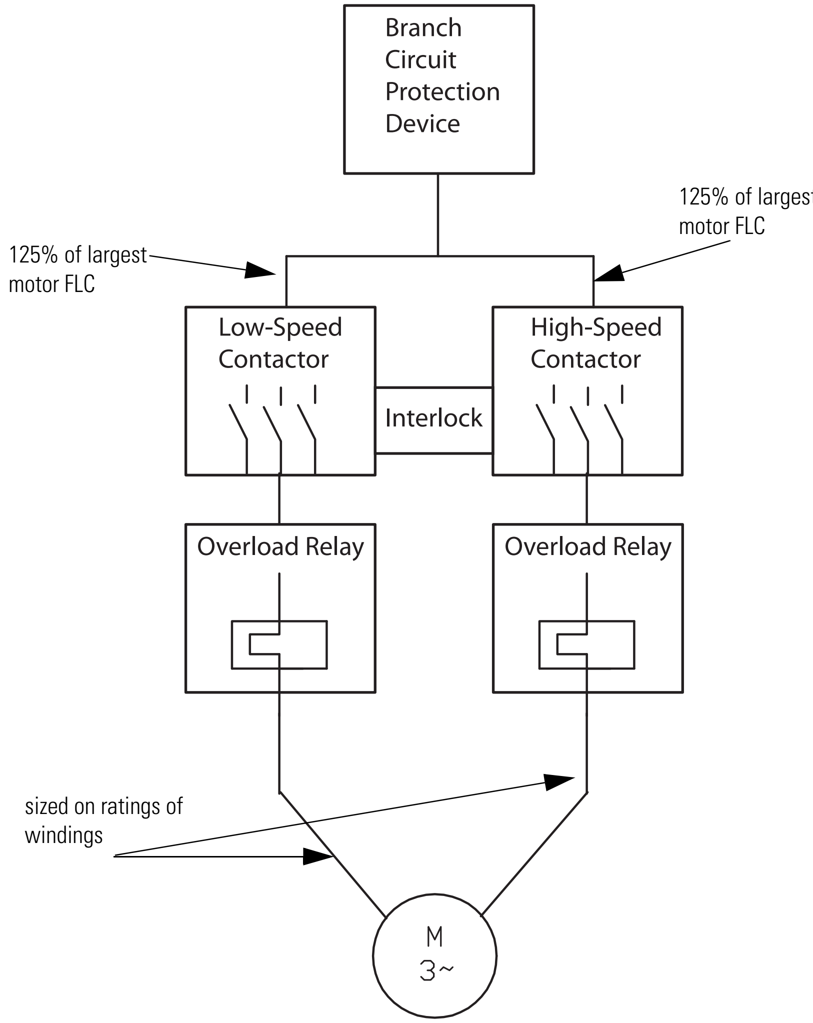
Taking that into account, the conductor sizing calculation is as follows:

- 58 x 1.25 = 72% motor FLC
- Use appropriate tables and correction factors from Section 310.15(B)to determine the correct wire gauge.

Multi-speed motors

In applications where motors are designed to operate at different speeds (e.g., low and high), conductors need to be sized to the highest FLC marked on the motor. Conductors between the controller and the motor should be sized to the nameplate ratings of the windings, per Section 430.22(B).

Figure 11 - Conductor sizing for multi-speed motors



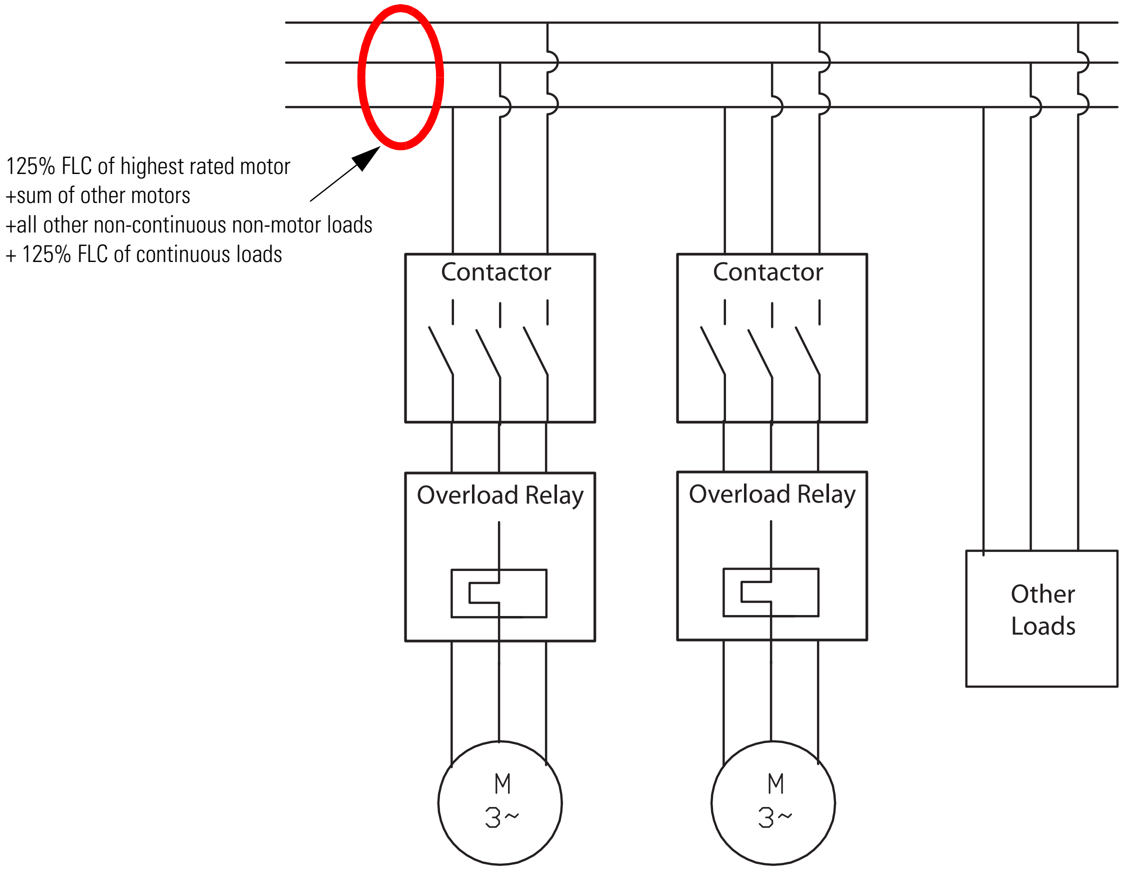
To determine the conductor sizing for multi-speed motors:

1. Determine the highest FLC motor from the motor nameplate
2. Multiply that value by 1.25. This is the ampacity value you will use to select the conductor.
3. Use appropriate tables and correction factors from Section 310.15(B)to determine the correct wire gauge.

Feeder Conductor Sizing

Section 430.24 states that motor feeder conductors supplying multiple loads shall have a rating not less than the sum of the highest breaker rating of any of its branches and the full-load currents of all other motors served by the feeder.

Figure 12 - Feeder conductor sizing



To determine the feeder conductor sizing:

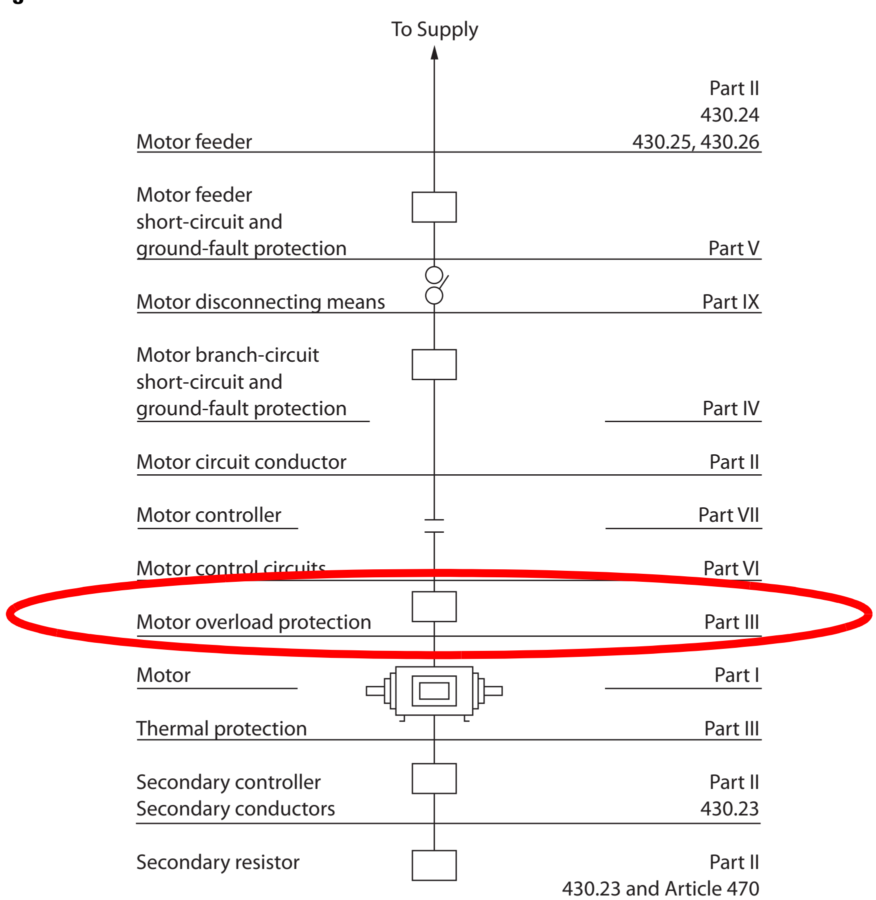
1. Determine FLC of highest speed motor
2. Multiply that value by 1.25.
3. Add the sum of the FLC of all other motor loads
4. Add the sum of all other non-continuous non-motor loads
5. Add in 125% FLC of all continuous non-motor loads
6. Use appropriate tables and correction factors from Section 310.15(B)to determine the correct wire gauge, based on the sum of steps 1…5.

Motor Overload Protection

Introduction

Part III of Article 430 is the requirement for overload protection for motors, conductors, and control devices in a motor circuit. Overloads should provide a degree a protection from excessive heating during the starting or running of a motor. Abnormal operating conditions for extended amounts of time can lead to damage or even fire. These conditions can be a result of excessive mechanical loads, a single phase condition, motor stalling, or locked rotor conditions. Overload protection must respond to any of these conditions before the motor could overheat or be damaged. In addition, the *NEC* clarifies that overload relays are not capable of opening short circuits or ground faults, so they must be used in conjunction with a branch circuit protection device.

Figure 13 - *NEC* Article 430 Contents



Types of overload protection

NEC Section 430.32 permits several types of overload protection, depending on the application. These include the following:

- Thermal protector integral to the motor
- Separate overload device
- Overload device located in the motor controller

Basic Sizing Requirements

The basic requirements for overload device sizing are laid out in *NEC* Section 430.31. they do not apply to motor circuits rated over 600V nominal, or in situations where power loss would cause a hazard.

In general, overload protection is required for motors over 1 Hp that run continuously (defined as > 3 hours). If there is a different duty cycle, you must use the multipliers outlined in Table 430.22 (E). Selection and sizing of elements is affected by motor FLC, service factor, and operating temperature. Overloads must be sized or set so that they will allow the motor to start and carry the load.

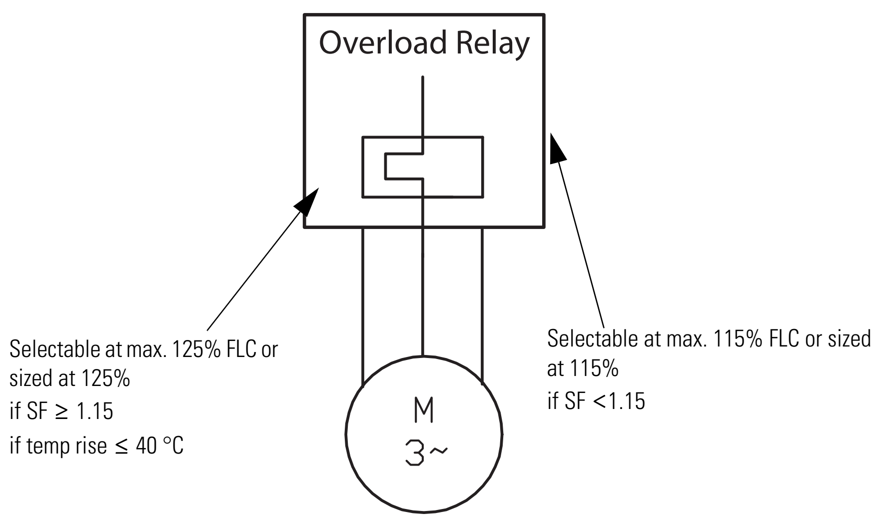
Typical overload devices are designed to be set at motor FLC. It is important to read the manufacturer's instructions for the device, as default trip settings may differ.

NEC Section 430.32 has the following max. ratings:

- 125% motor nameplate FLC for motors where the service factor is ≥ 1.15
- 125% motor nameplate FLC for motors where the temperature rise is ≤ 40 °C
- 115% motor nameplate FLC for all other motors

The above values are the maximum values allowed.

Figure 14 - Basic overload sizing (max. ratings)



Chapter 5

Short-Circuit and Ground Fault Protection of Motor Branch Circuit

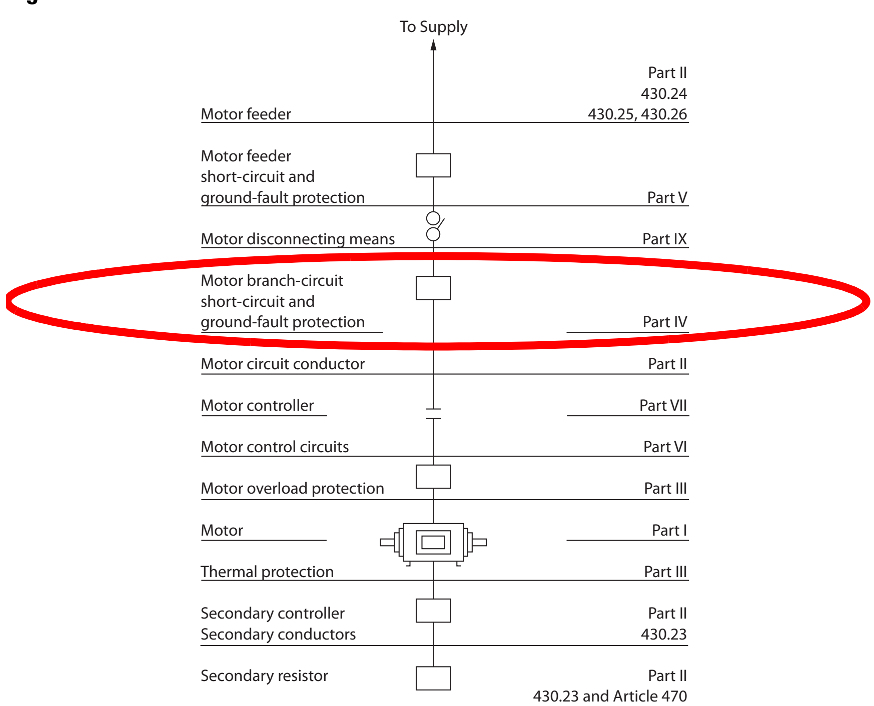
Introduction

In this section, we will discuss Part IV of *NEC* Article 430, which addresses short-circuit and ground fault protection of a motor branch circuit.

Part IV sets the minimum requirements for protection of conductors, motor control apparatus, and motors from overcurrent conditions due to short circuits and ground faults. The use of self-protected combination motor controllers and other types of motor branch circuit protection are described under individual motor circuits. The requirements (rating of setting) of the branch circuit protection device for both individual motor circuits and multi-motor circuits are contained in this section. Table 430.52 lists the maximum permissible rating or setting of fuses and circuit breakers according to motor types. While this table provides maximum values, the branch circuit protection should be sized as low as possible for maximum protection yet should still be allowed to carry the starting current of the motor.

Part IV also allows for the protection of multiple motors or a motor and other load types using a single short circuit/ground fault protection device. This practice is also known as a group motor installation.

Figure 15 - *NEC* Article 430 Contents



UL 508A and *NEC* both use a set of standard sizes for both fuses and fixed trip circuit breakers, shown in Table 3.

Table 3 - Standard ampere ratings for fuses and fixed-trip circuit breakers

Standard Ampere Ratings [A]			
15	80	300	1600
20	90	350	2000
25	100	400	2500
30	110	450	3000
35	125	500	4000
40	150	600	5000
45	175	700	6000
50	200	800	—
60	225	1000	
70	250	1200	
Additional standard ratings for fuses [A]			
1	6	10	601
3	—		

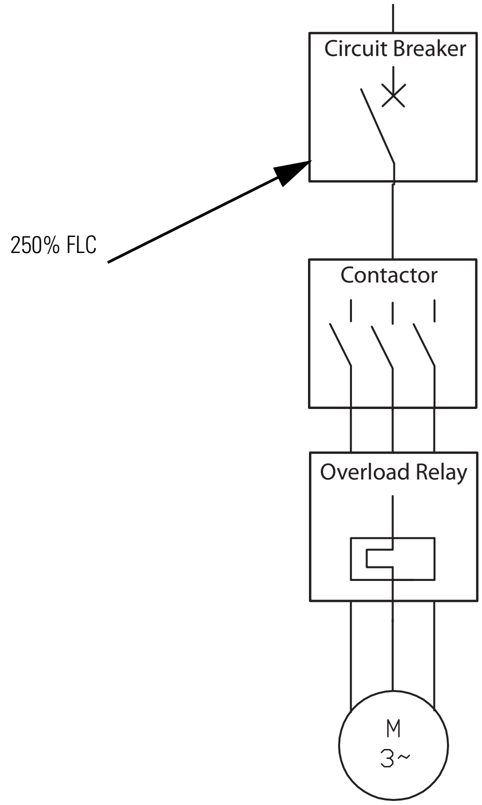
Single Motor Applications

NEC Section 430.52 sets the minimum requirements for protection of conductors, motor control apparatus, and motors from overcurrent conditions due to short circuits and ground faults. The use of a self-protected combination motor controller and other type of motor branch circuit protection are described under individual motor circuits. The requirements (rating of setting) of the branch circuit protection device for both individual motor circuits and multi-motor circuits are contained in this section. Table 430.52 lists the maximum permissible rating or setting of fuses and circuit breakers according to motor types. While this table provides maximum values, the branch circuit protection should be sized for optimal protection yet still allow for the starting current of the motor.

Motors using Circuit Breakers

Figure 16 illustrates one example of sizing an inverse time circuit breaker used for motor branch short-circuit and ground fault protection.

Figure 16 - Standard short-circuit protection

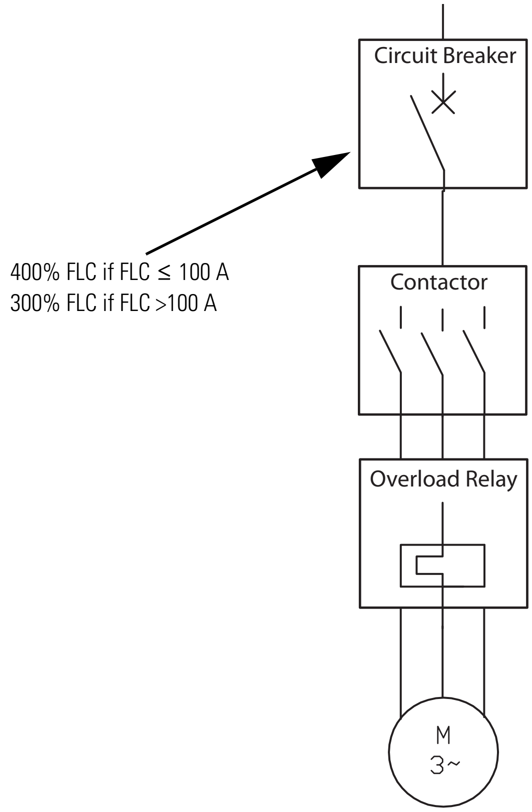


To correctly size an inverse time circuit breaker, complete the following:

1. Using Tables 430.247…430.250, determine the motor FLC
2. From Table 430.52, find the correct max. setting value for standard short-circuit protection
3. Multiply the motor FLC by the value in Table 430.52
4. Round up to the nearest standard rating

NEC Section 430.52(c)(1) addresses some exceptions to the standard method. When there are applications where the rating determined is not sufficient for the starting FLC of the motor. This exception allows the breaker to be sized up to 400% FLC for loads less than 100 A.

Figure 17 - Exception to short-circuit protection sizing



To correctly size an inverse time circuit breaker with this method, complete the following:

1. Using Tables 430.247…430.250, determine the motor FLC
2. From Section 430.52(c)(1), find the correct max. setting value for max. short-circuit protection
3. Multiply the motor FLC by the value from Section 430.52(c)(1)
4. Round **down** to the nearest standard rating

Fuses

Protective devices are generally rated according to Table 430.52. Fuses are sized according to the same general principles as circuit breakers, with the addition of some smaller standard sizes.

Multi-Motor Applications

Several motors or motor loads on the same branch circuit

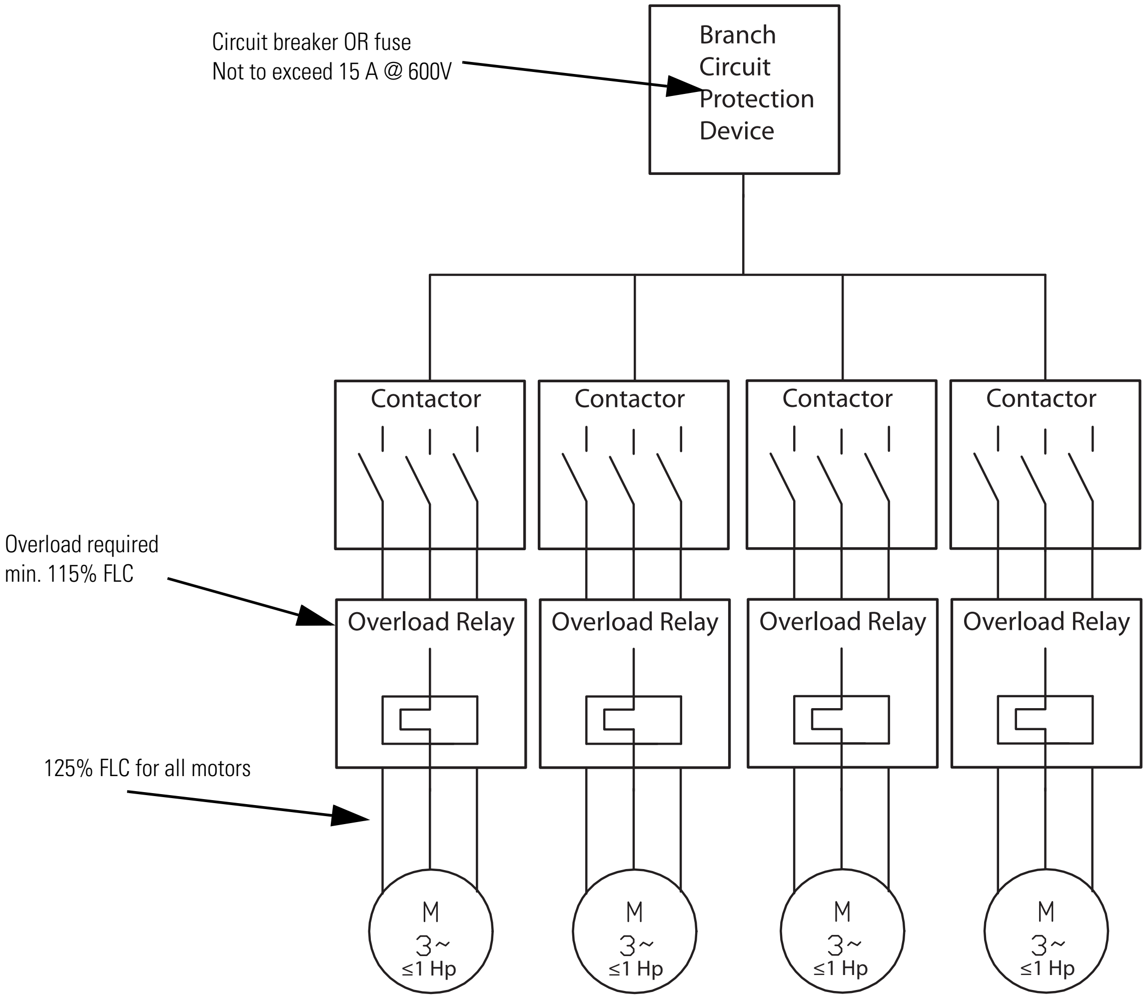
Part lV also allows for the protection of multiple motors or a motor and other load types using a single short circuit/ground fault protection device. This type of construction leads to space savings and cost reduction as an alternative to installing a circuit protection device ahead of each motor. Restrictions on the conductor sizing and length must be followed and are detailed in both National and Canadian Electrical codes as well as the UL508A standard. The addition to the 2011 edition of the *NEC* clarifies that the branch circuit protection used must be either an inverse time circuit breaker or branch circuit fuse.

Motors and motors with other load with a single branch circuit protection device fall under 3 categories

- Installations where all motors are less than 1 Hp in size
- Installations where the smallest motor is protected in the group is according as allowed in a single motor installation (see Table 430.52)
- All other installations fall within “other group installations”

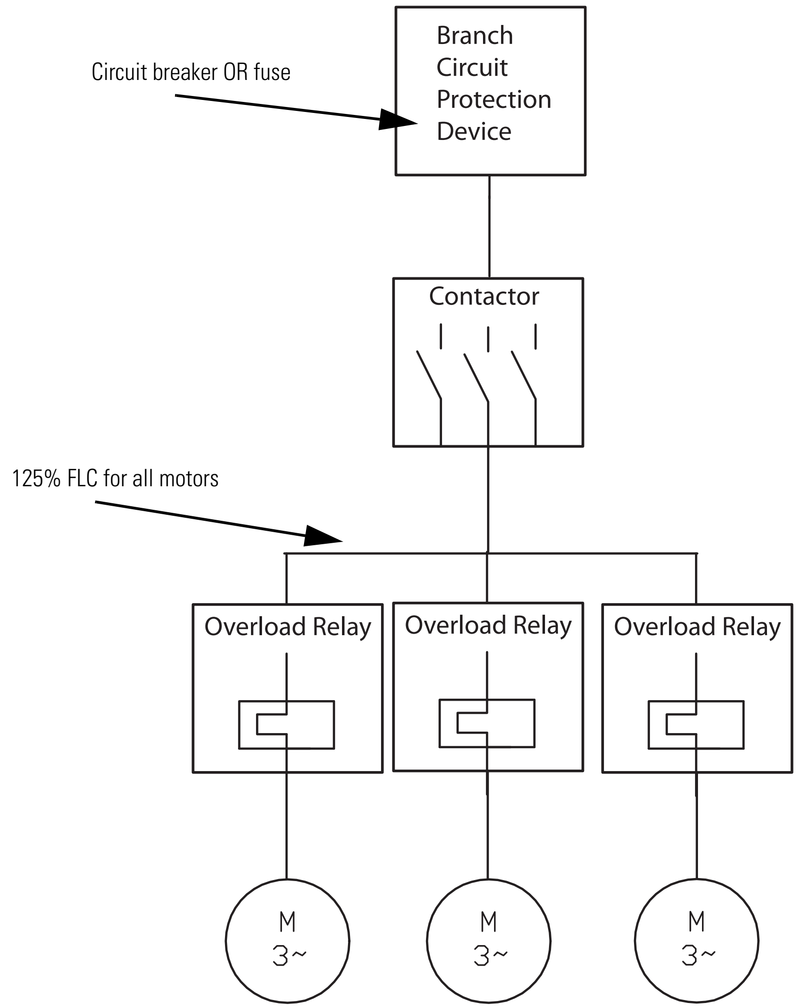
This practice commonly referred to as “group motor installation” often requires the use of motor controllers or motor overloads to be listed as "listed for group installations”. Specific rules for the sizing of conductors to the motor must be followed. These may be better known as tap conductor rules.

Figure 18 - Multiple motors on the same branch circuit (≤ 1 Hp each)



In the application shown in Figure 18, the configuration is allowed because all motors are ≤ 1 Hp and the Branch Circuit Protection Device is a fuse or circuit breaker. Type E Self-Protected devices are not permissible. FLC of each motor much be <6 A, and all other individual branch circuit requirements (e.g. overload) must be met.

Figure 19 - Multiple motors on a single controller



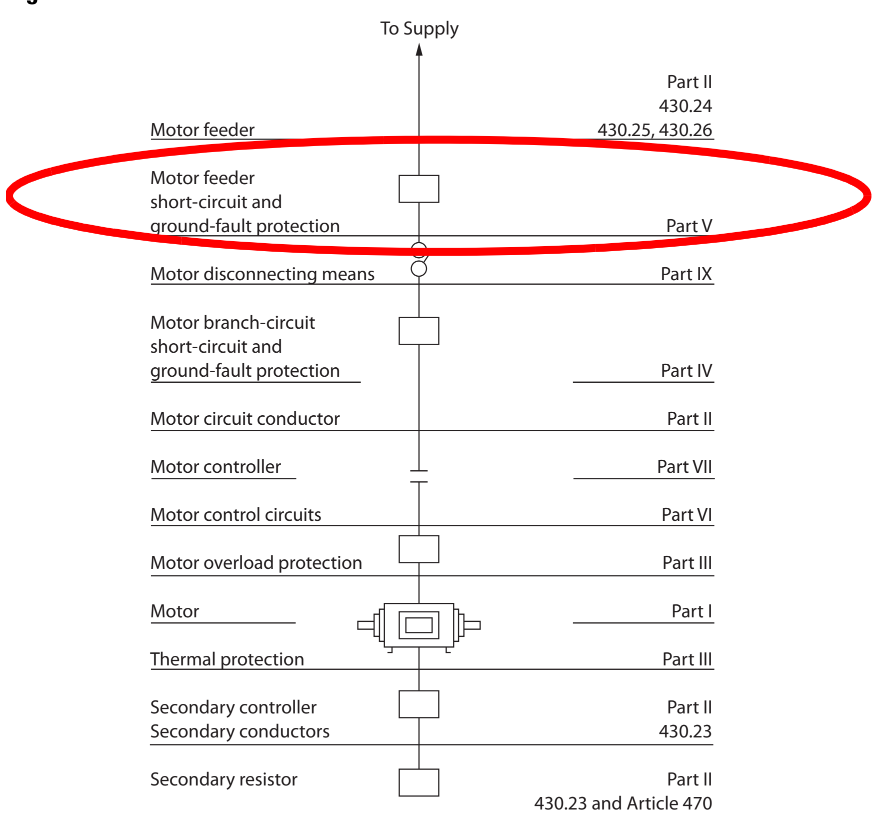
Short-Circuit Protection of Motor Feeder

Introduction

In this section, we will discuss Part V of *NEC* Article 430, which addresses short-circuit and ground fault protection of a motor feeder circuit. A typical industrial control panel is a feeder circuit as defined by the *NEC*, where a feeder is composed of the wires between the service entrance of the panel or line side of the circuit breaker or disconnect switch and the line side of the final branch circuit protective device.

In many industrial control applications, motor control is involved. In that case, you must then follow *NEC* Article 430, which states that breakers for feeders having mixed loads, e.g., heating (lighting and heat appliances) and motors, should have ratings suitable for carrying the heating loads, plus the capacity required by the motor loads. For motor loads, Article 430 states that breakers for motor feeders shall have a rating not greater than the sum of the highest breaker rating of any of its branches and the full-load currents of all other motors served by the feeder.

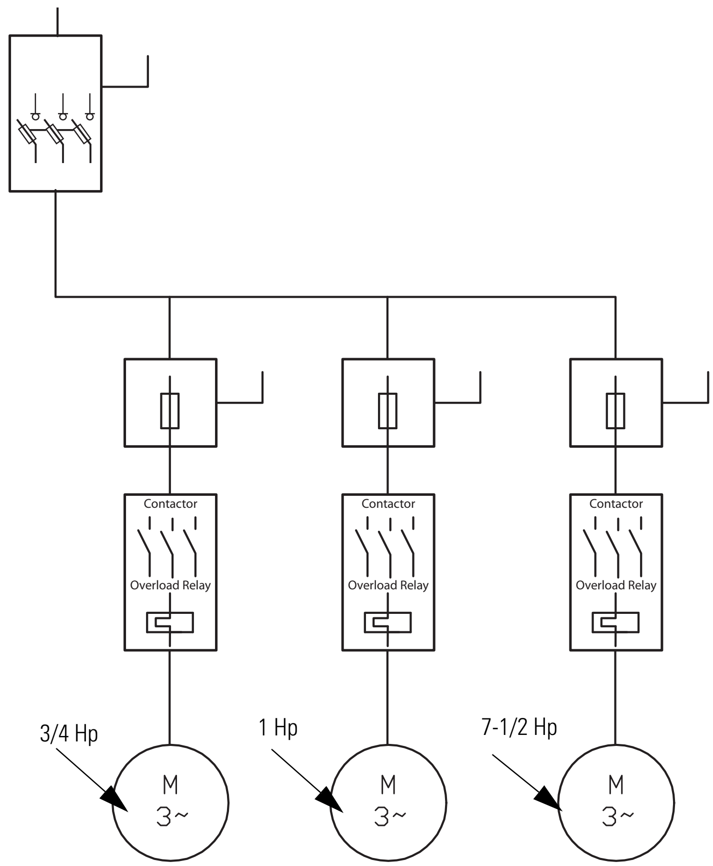
Figure 20 - *NEC* Article 430 Contents



Sizing the Motor Feeder Protective Device (Maximum)

In this method, we are calculating the maximum size of the protective device, based on *NEC* Section 430.62, which requires that the rating of the protective device be no greater than the sum of the largest motor protective device and the sum of all other full-load currents of the other motors of the group . This example assumes a motor voltage of 230V AC.

Figure 21 - Sizing the motor feeder protective device (max.)



The rating of the motor feeder short-circuit / ground fault protective device is determined by the adding the rating of the largest branch circuit protective device to the full load currents of all of the other motors supplied by that feeder (we assume the Branch Circuit Protection Device in the branch is the same type as in the feeder).

Using Table 430.250, the motor FLC is as follows:

- Motor 1 = 3.2 A
- Motor 2 = 4.2 A
- Motor 3 = 22 A - requires 50 A inverse time circuit breaker; sized for max. allowable under Section 430.52

Adding the values together gives us the following:

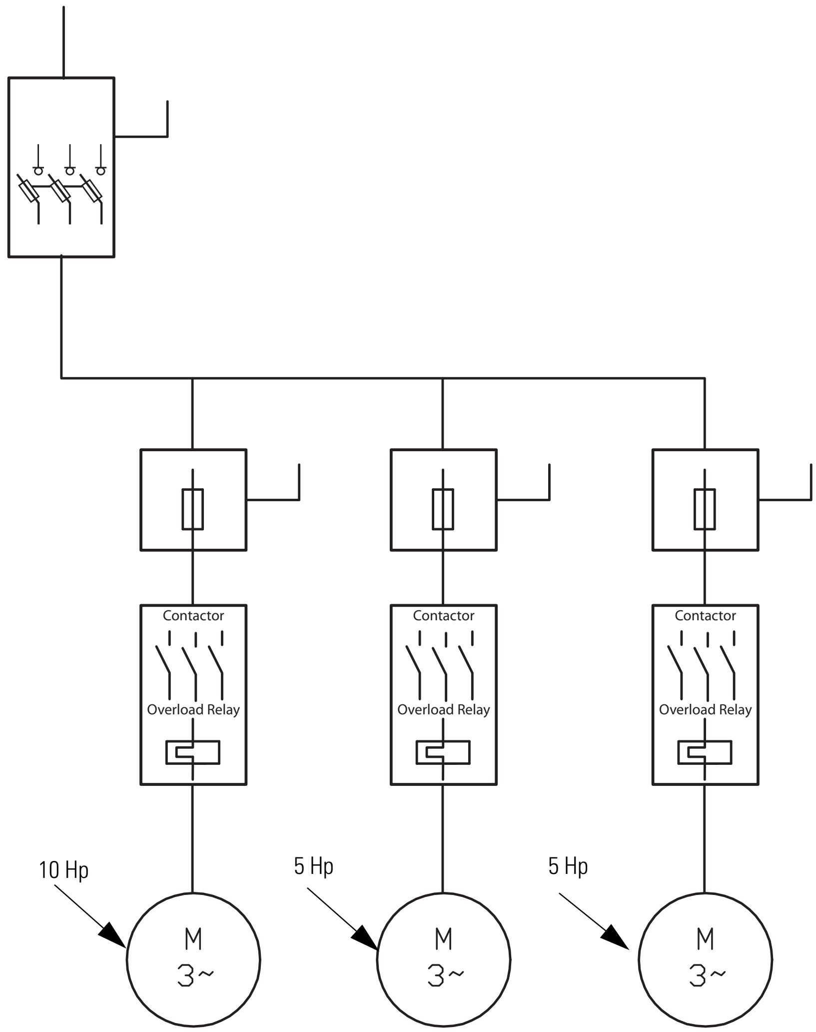
- 3.2 + 4.2 + 50 A = 57.4 A

To follow the requirements of Section 430.62, we need to round **down** to the nearest standard size, which is 50 A.

Sizing the Motor Feeder Protective Device (Minimum)

These calculations assume that the circuit breaker or disconnect switch selected has a voltage rating equal or greater than the application and that the interrupting rating is equal or greater to the available short circuit current. The panel contains a main feeder breaker supply with three motor branch circuits.

Figure 22 - Sizing the motor feeder protective device (min.)



To correctly determine rating of the breaker, we first need to determine the total ampacity of the system.

In our application, the feeder is supplying a 3-motor system at a voltage of 480V. Ampacity is determined from *NEC* Article 430, Table 430.250.

- Motor 1 is 10 Hp. Ampacity is 14 A.
- Motor 2 is 5 Hp. Ampacity is 7.6 A.
- Motor 3 is 5 Hp. Ampacity is 7.6 A.

To calculate the total system FLC, we calculate the sum of the motor loads and multiply that value by 125%. In this scenario, the current calculation is:

- Motor 1 = 14 A

- Motor 2 = 7.6 A
- Motor 3 = 7.6 A
- Total = 29.2 A
- 29.2 A x 125% = 36.5 A

Since the total load comes to 36.5 A and there is not a commercially available breaker available for 36.5 A, the *NEC* allows the next largest standard-sized breaker to be used. Therefore, a 40 A molded case circuit breaker could be selected to protect this control panel. Note that each individual motor branch still also requires protection.

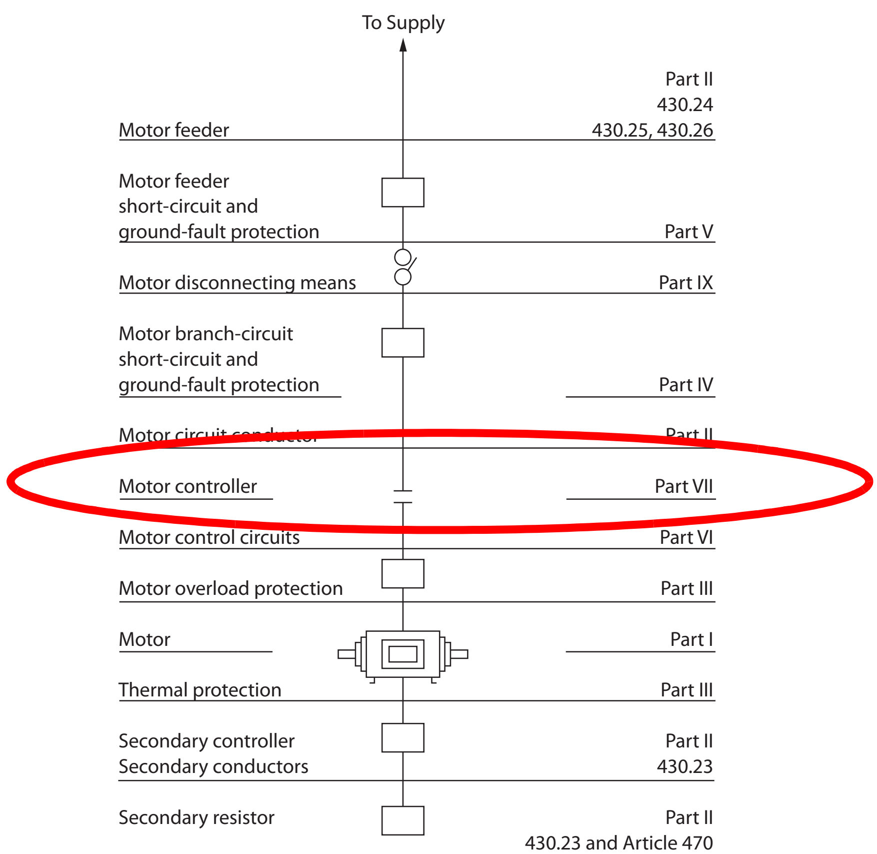
Motor Controller

Introduction

Part VII of *NEC* Article 430, beginning with Section 430.81, is intended to ensure that equipment is provided with controllers that are able to safely operate the circuit. Motor controllers are devices designed to repeatedly establish and interrupt the electrical circuit to a motor. North American applications may list the motor controller by NEMA sizes or maximum horsepower and voltage. They are evaluated to the UL508 and CSA C22.2 # 14 standard for industrial equipment.

Some manual motor controllers meet North American requirements for a Type “E” motor controller. Type E motor controllers are suitable for use as the branch circuit protection device in a motor circuit where traditionally an inverse time circuit breaker or branch fuse was used. Some motor controllers may meet additional approvals, including disconnecting means at the motor, or as suitable to be used in group motor installations.

Figure 23 - *NEC* Article 430 Contents

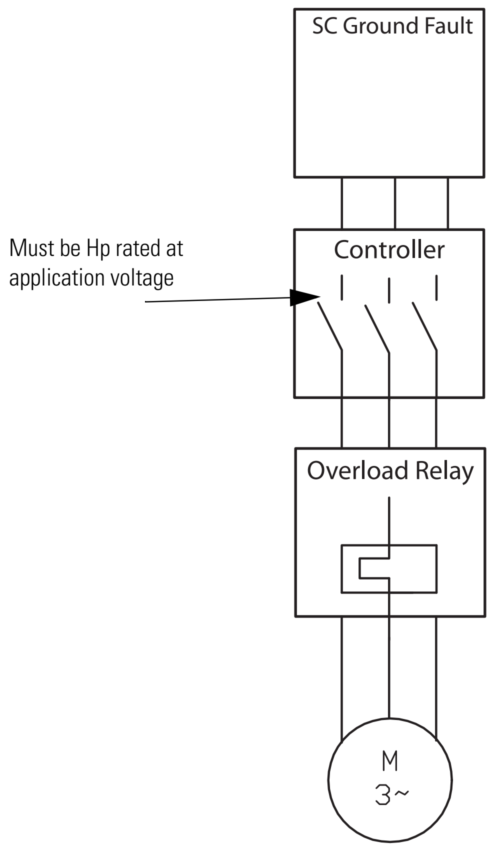


Controller Requirements

Each motor is required to have its own controller, except under certain conditions. This controller can be a contactor/starter, circuit breaker, etc. that performs the following functions:

- Must start, stop, and interrupt motor current
- Have adequate ratings for the application, per Section 430.83(A), unless it falls under an allowable exception
- Generally not required to open all conductors to the motor

Figure 24 - Basic Motor Controller



Motor controllers must be horsepower-rated for application voltage, unless an inverse time circuit breaker or molded case switch is used as the controller.

Typical motor controllers may include:

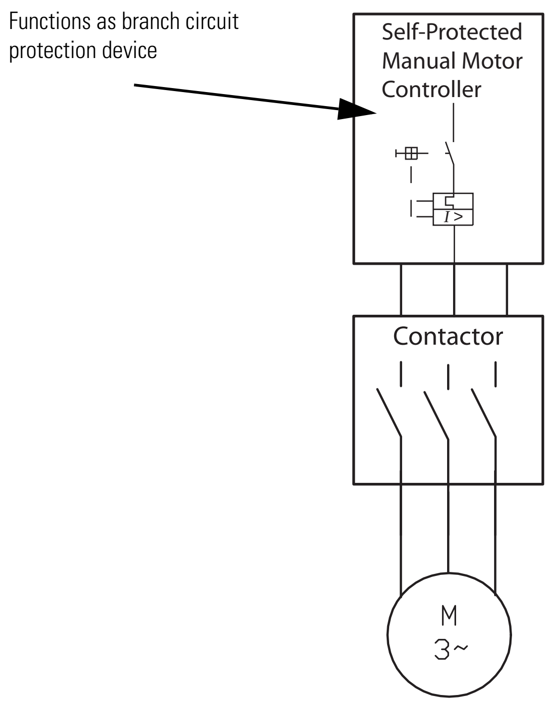
- Starters
- Contactors
- Motor protection circuit breakers
- Solid-state relays
- Solid-state motor controllers
- Variable speed drives

Type E motor controllers meet the requirements for branch circuit protection when used in a motor circuit, as shown in Figure 25. When combined with a

magnetic contactor, as shown below, the two devices make up a combination motor controller. Combination motor controllers provide:

- Disconnecting means
- Branch circuit protection
- Motor controller
- Motor overload

Figure 25 - Motor Controller as Branch Circuit Protective Device

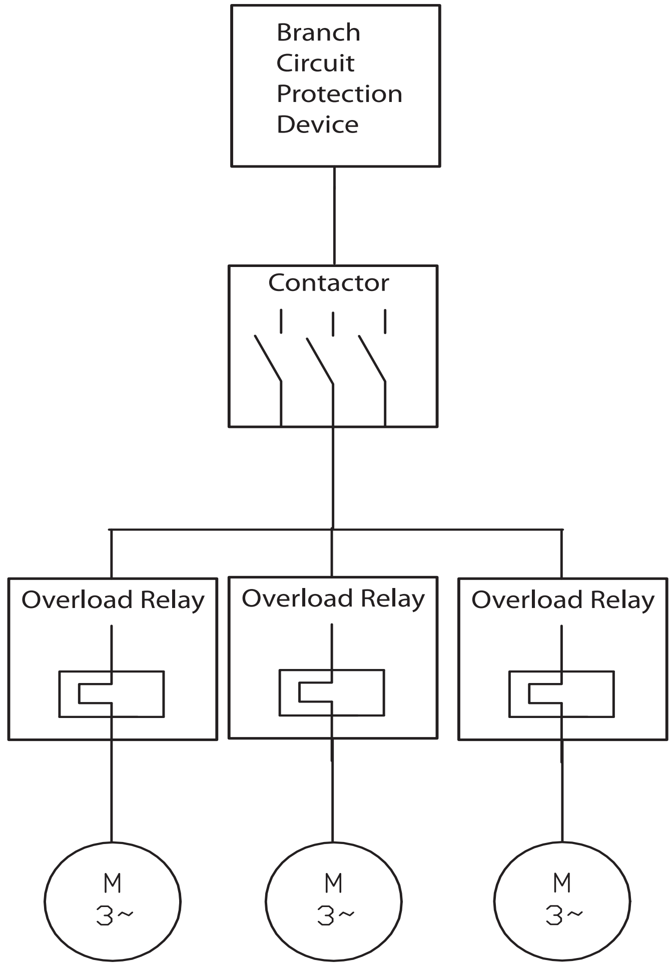


Single Controller with Multiple Motors

Section 430.87 outlines situations in which you can use a single controller for multiple motors. These are:

- If all motors control components of a single piece of machinery, they may be controlled by a single motor controller
- If all motors are ≤ 1/8 Hp, 1 controller is allowable
- If the overcurrent device is sized to comply with 450.53(A)

Figure 26 - Single controller with multiple motors



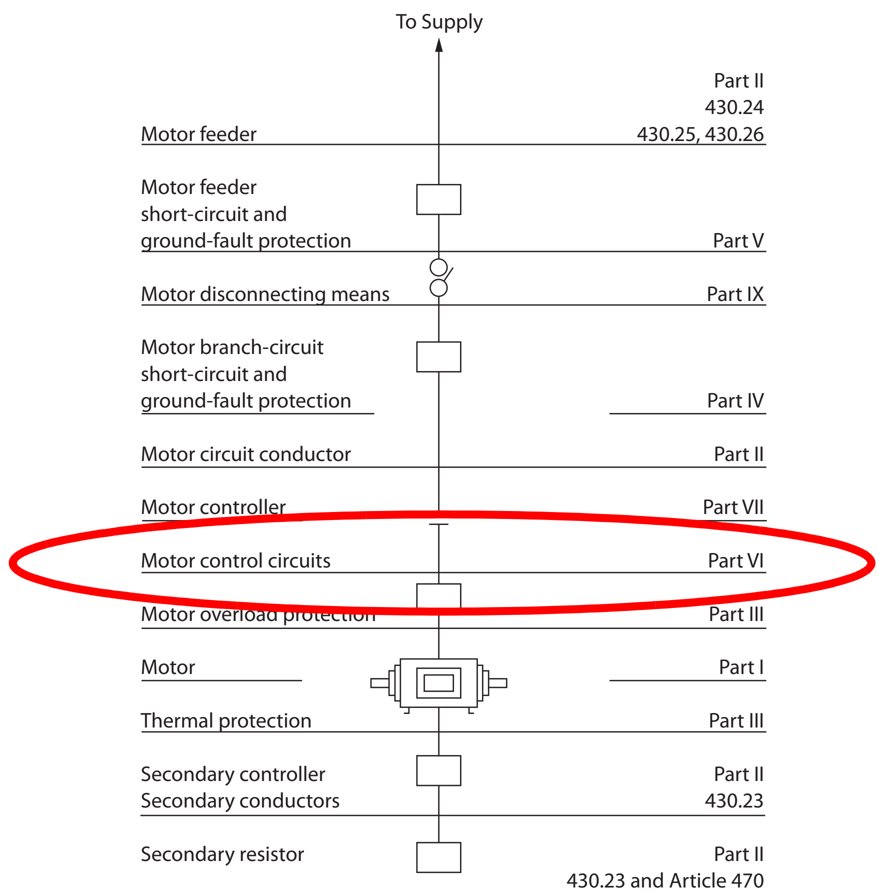
Motor Control Circuits

Introduction

In this section, we will discuss Part VI of *NEC* Article 430, which addresses the motor control circuit. The control circuit uses control devices to determine when loads are energized or de-energized by controlling current flow. Control circuits usually carry lower voltages than power circuits.

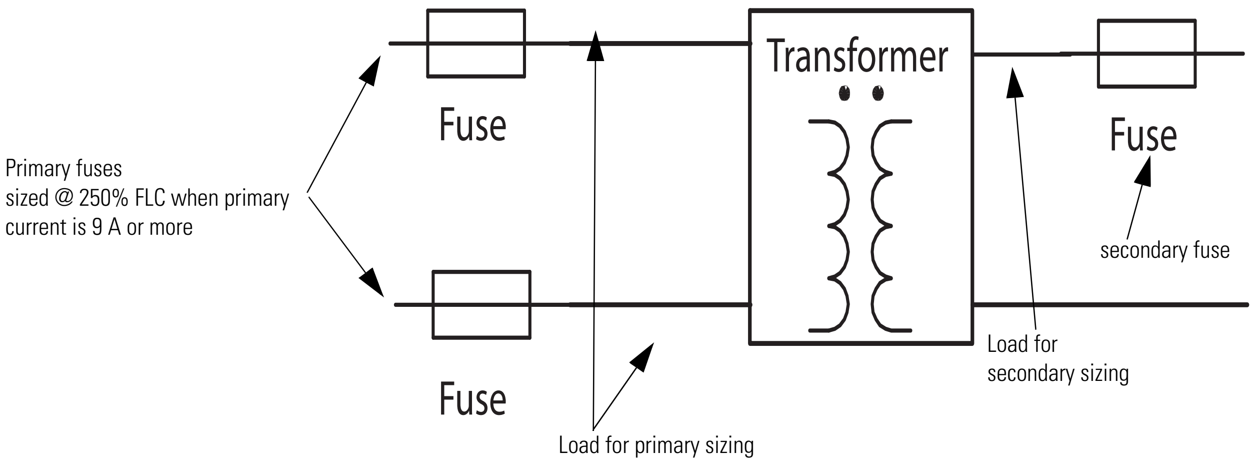
Control circuits are further broken into two sub-categories; Class 1 control circuits, up to 600V and Class 2 energy-limited control circuits, up to 30V.

Figure 27 - *NEC* Article 430 Contents



Transformer with two primary fuses and one secondary fuse

Figure 28 - Transformer with primary and secondary fusing



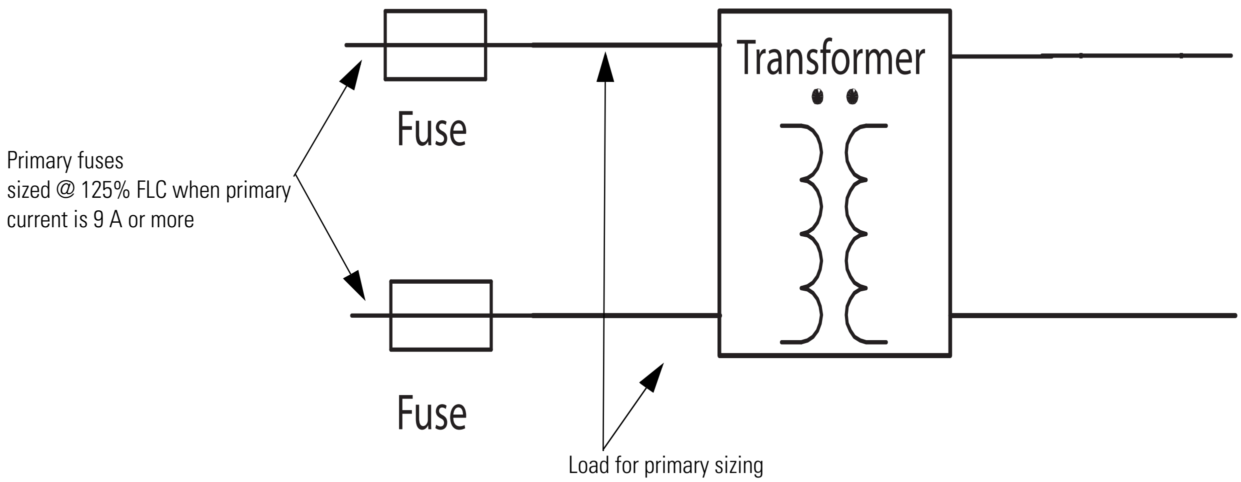
The conductors between the fuse and the transformer on the primary side and between the transformer and the fuse on the secondary side have different sizing requirements, outlined in Table 4.

Table 4 - Fuse requirements for primary and secondary windings

Primary Winding		Secondary Winding	
Rated Amperes [A]	**Overcurrent, % of rated FLC**	**Rated Amperes [A]**	**Overcurrent, % of rated FLC**
9 or more	250	9 or more	125
2…8.99	250	less than 9	167
less than 2	500	—	—

Transformer with two primary fuses

Figure 29 - Transformer with only primary fusing



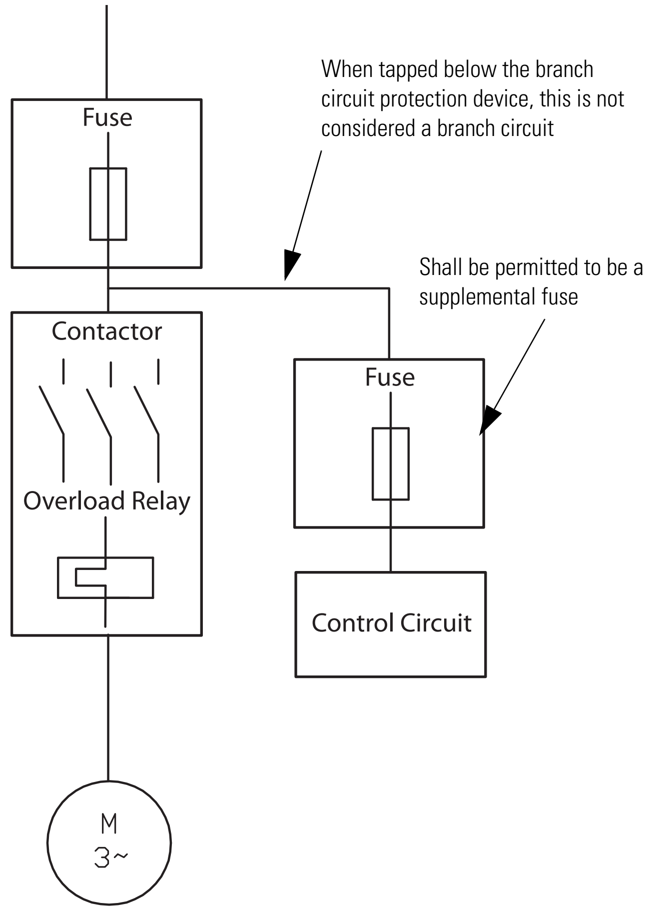
The conductor sizing requirements for fuses in these applications is shown in Table 5.

Table 5 - Fuse requirements for transformers with only primary fusing

Primary Winding	
Rated Amperes [A]	**Overcurrent, % of rated FLC**
9 or more	125
2…8.99	167
less than 2	500

Basic Motor Control Circuits

Section 430.72 states that motor control circuits tapped from the load side of a motor branch-circuit short-circuit and ground-fault protective device and functioning to control the motor connected to that branch circuit shall be protected against overcurrent in accordance with 430.72. A control circuit in this configuration is not considered a branch circuit, and so you can use either a supplementary fuse or branch circuit protective device(s).

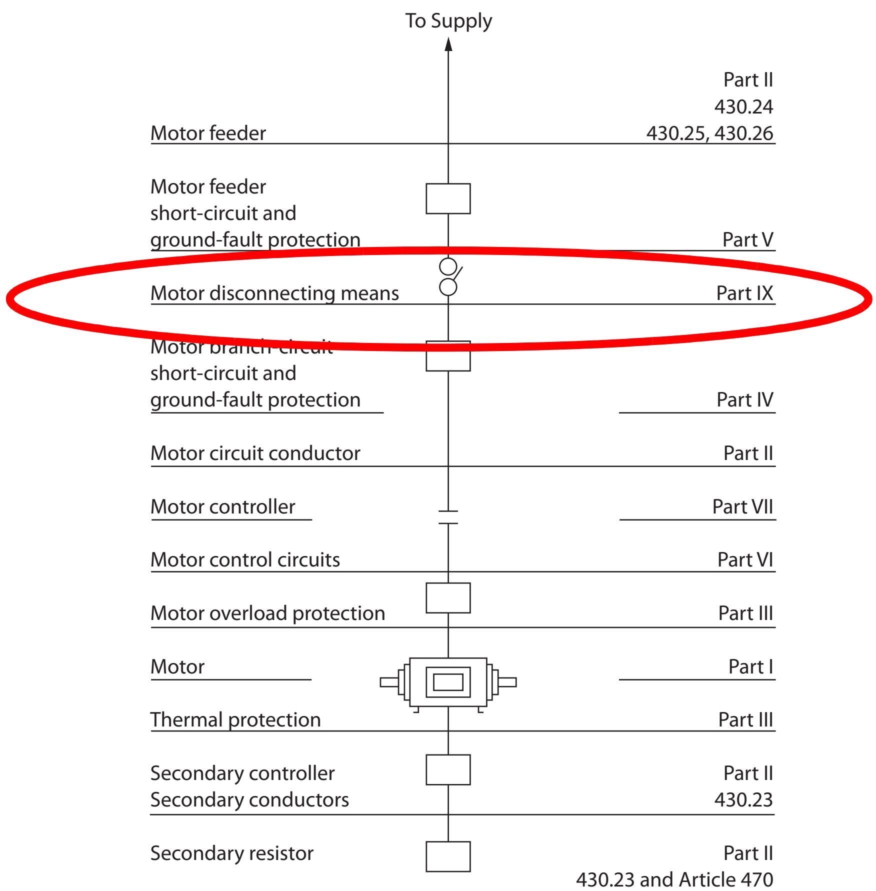


Motor Disconnecting Means

Introduction

This section will address common applications and exceptions when selecting and sizing a motor disconcerting means.

Figure 30 - *NEC* Article 430 Contents



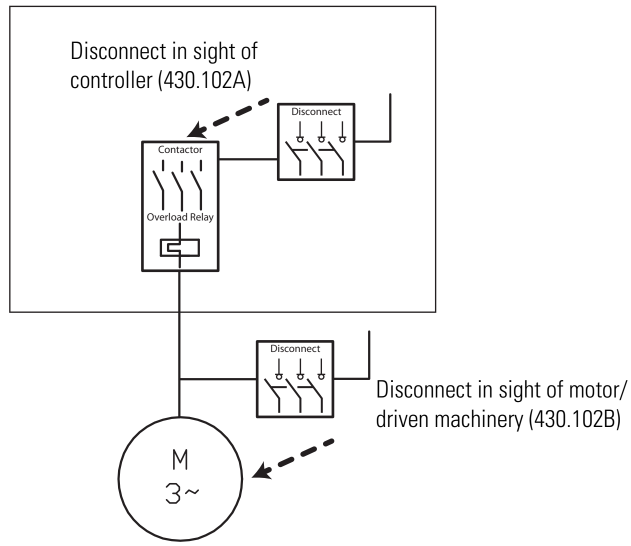
General Considerations

To gain a better understanding of the requirements for motor disconnecting means, refer to *NEC* Article 430, Part IX, which is "intended to require disconnecting means capable of disconnecting motors and controllers from the circuit."

According to Section 430.102, a disconnecting means needs to be provided for each controller in the circuit and be located within sight of the controller. Additionally, a disconnecting means needs to be provided for each motor, and be located within sight of both the motor and driven machinery, as shown in

Figure 31. Note that in this scenario, the driven machinery does not need to be located within sight of the motor.

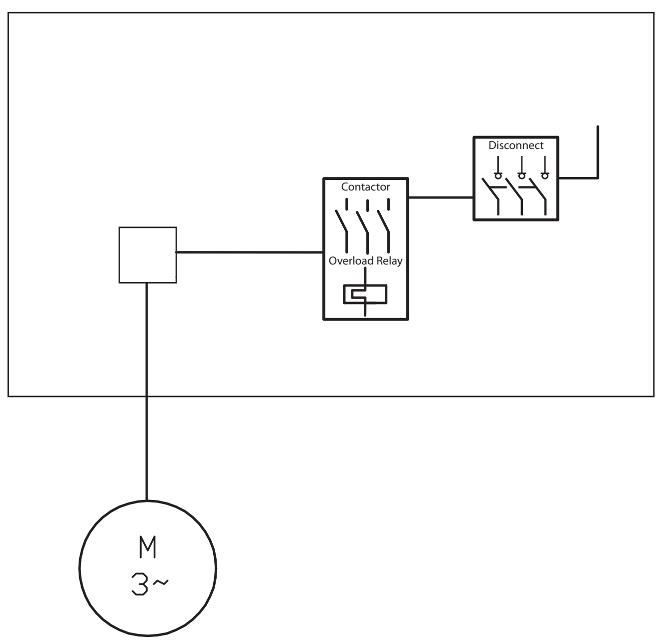
Figure 31 - Motor Disconnecting Means



One Disconnect for Both Controller and Motor

According to Section 430.102(B)2, an installation is allowed to use a single disconnect for both the motor and controller as long as the disconnect is within sight of both the motor and the driven machinery location. Article 100 defines "in sight" as both visible and within 50 feet of the motor.

Figure 32 - Motor within Sight of Disconnect



Adjustable-Speed Drive Systems

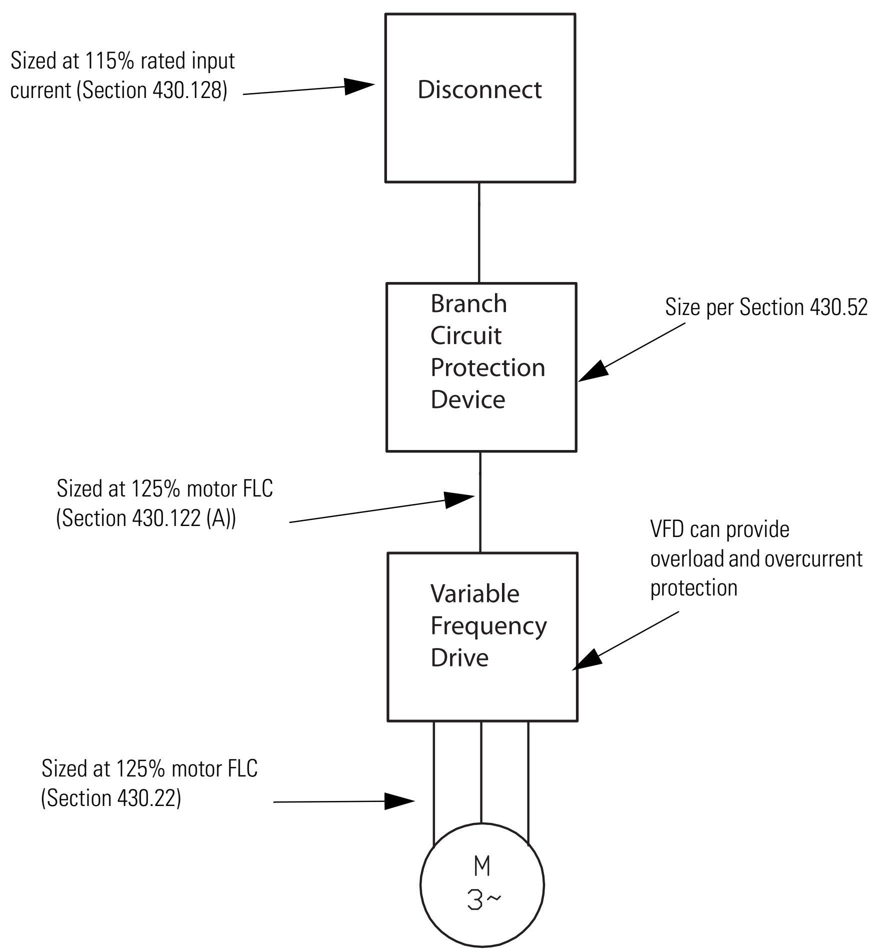
Introduction

When using variable speed drives in motor circuit applications, you must follow the requirements set out in Parts I ...IX, unless the specific requirements for Part X modify them.

Drive Requirements

Figure 33 illustrates some of the basic requirements for a variable-frequency drive (VFD).

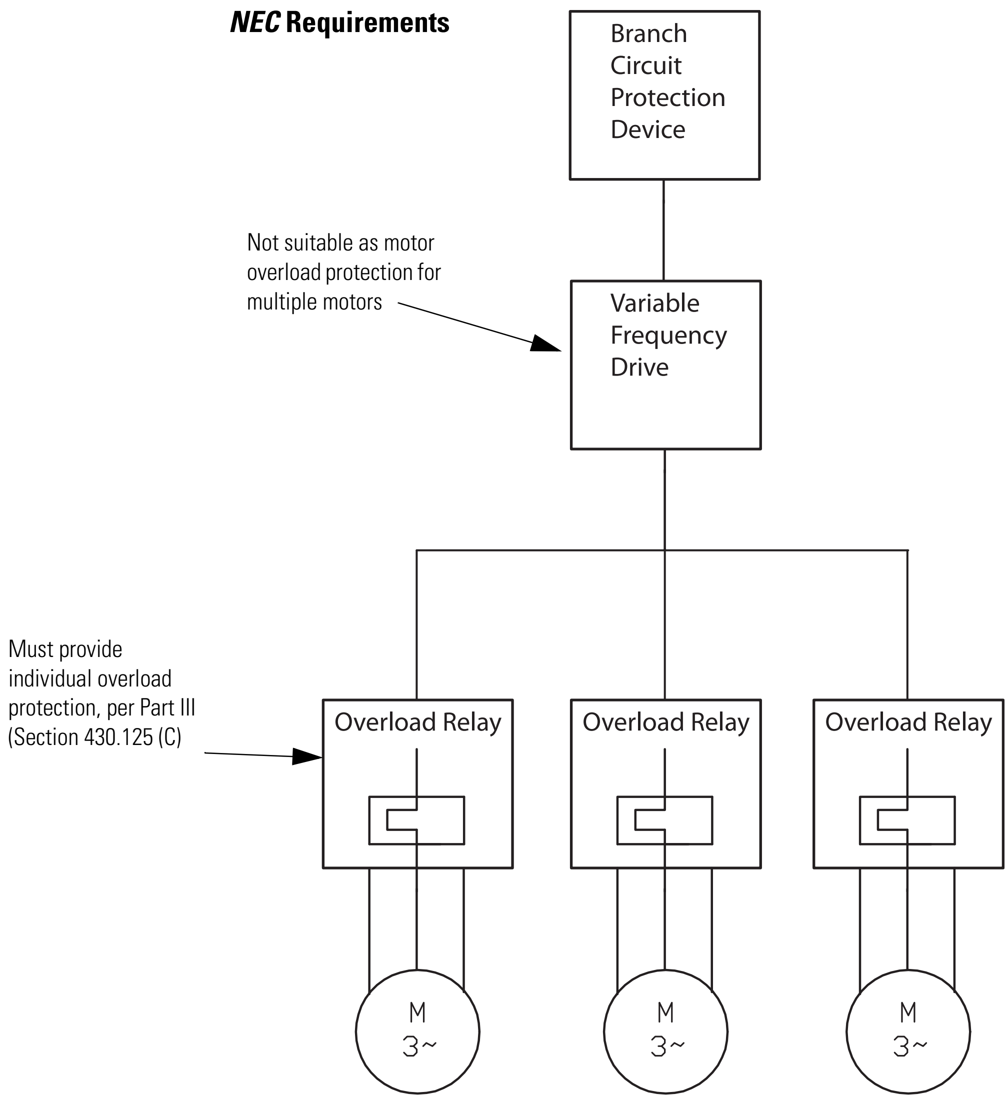
Figure 33 - Variable-Frequency Drive Requirements



Multiple motor applications

Multiple motor drive applications require that each motor be separately protected by either a circuit breaker or a fuse. Type E Self-Protected devices are not allowed.

Figure 34 - Multiple motor drive applications



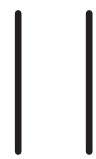
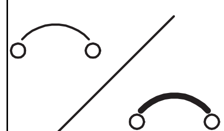
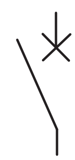
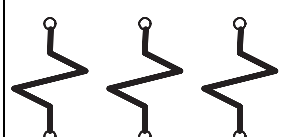
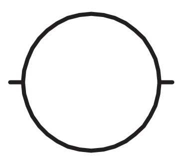
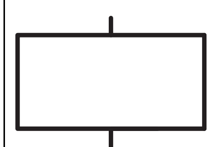
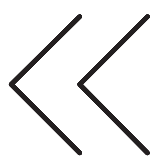
Appendix A

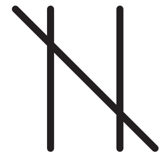
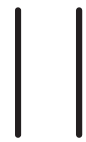
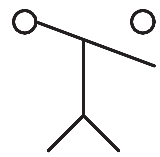
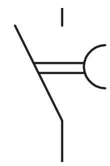
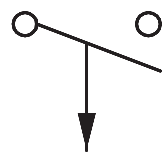
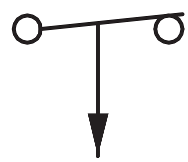
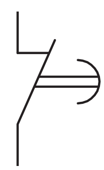
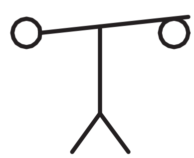
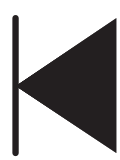
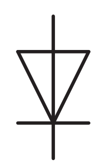
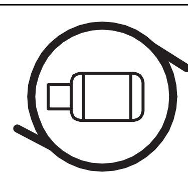
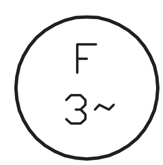
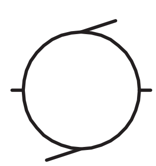
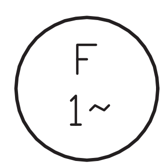
Symbology

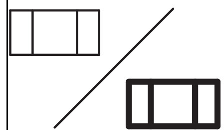
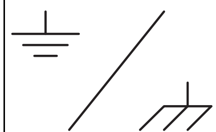
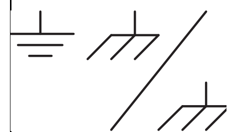
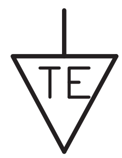
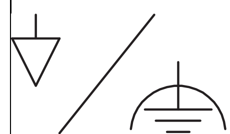
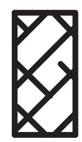
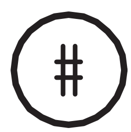
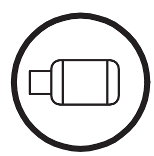
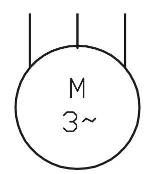
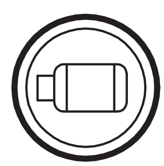
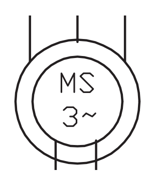
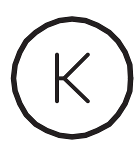
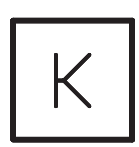
IEC and NEMA Comparison

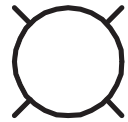
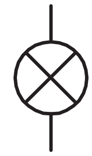
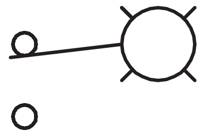
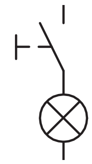
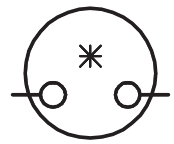
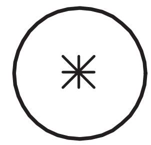
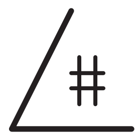
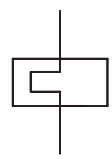
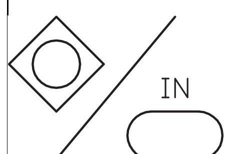
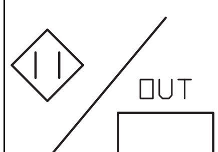
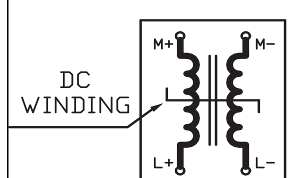
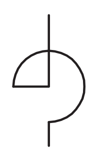
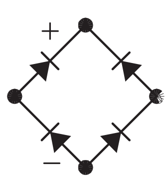
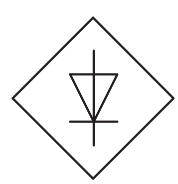
When comparing IEC and NEMA/UL wiring diagrams, it is important to note that there are differences in the symbols used to denote components of an electrical schematic. Whether it is a complex control system or a simple across-the-line motor starter, the need to recognise and understand these symbols is more important than ever. It is possible that products from all parts of the world are being used in any one facility.

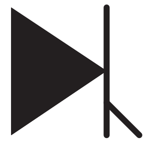
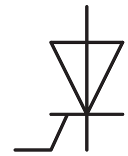
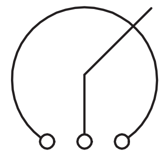
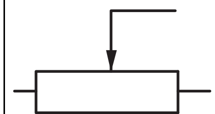
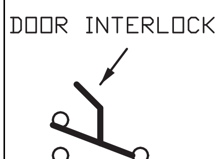
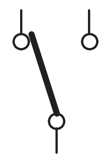
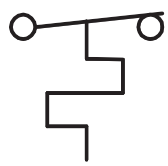
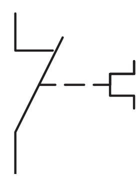
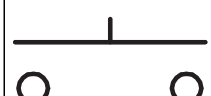
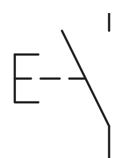
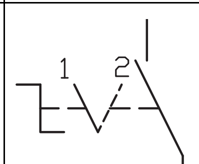
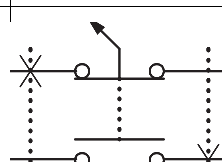
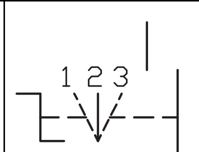
The following tables provide a side-by-side comparison of IEC and NEMA/UL symbology.

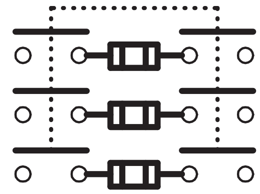
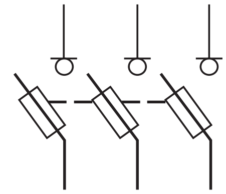
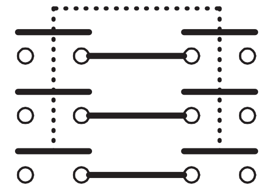
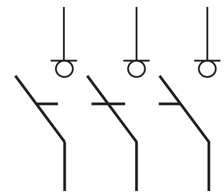
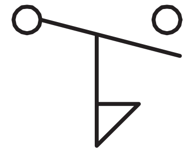
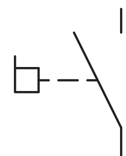
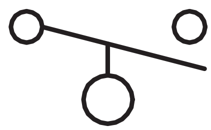
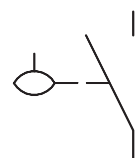
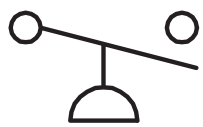
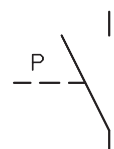
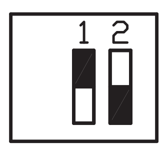
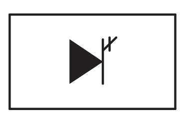
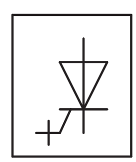
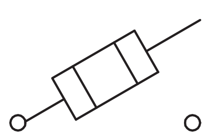
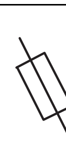
Description	NEMA/UL	IEC
Capacitor		
Circuit Breaker, control/power		
Coil, blowout		
Coil, operating		
Connector, separable or jacks engaged		

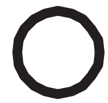
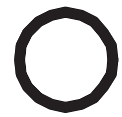
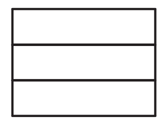
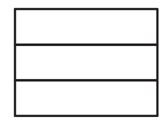
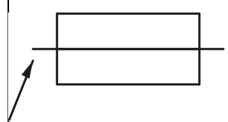
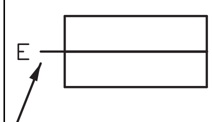
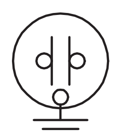
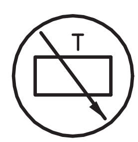
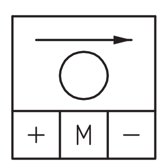
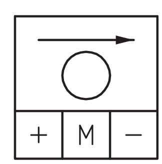
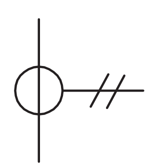
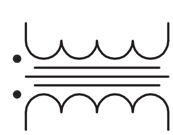
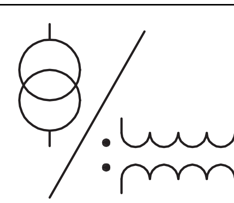
Description	NEMA/UL	IEC
Contact, N.C. (break)		
Contact, N.O. (make)		
Contact, time delay — normally open with time delay closing		
Contact, time delay — normally open with time delay opening		
Contact, time delay — normally closed with time delay closing		
Contact, time delay — normally closed with time delay opening		
Diode, semiconductor		
Fan — 3-phase induction motor		
Fan — 1-phase induction motor		

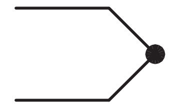
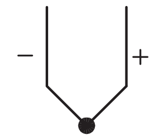
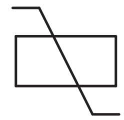
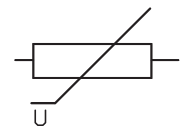
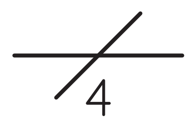
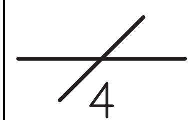
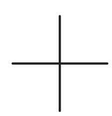
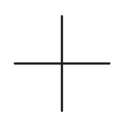
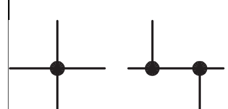
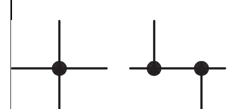
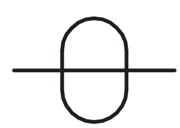
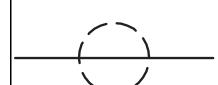
Description	NEMA/UL	IEC
Fuse, control/power		
PE Ground — chassis or frame ground		
Ground, signal		
Heat sink		
IEEE Number for protective device		
Induction machine		
Induction machine — synchronous		
Key interlock on isolation switch or breaker		
Key interlock on MV door		

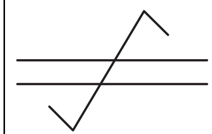
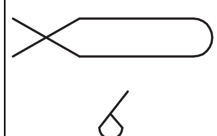
Description	NEMA/UL	IEC
Light, indicating — pilot, signalling, or switchboard		
Light, indicating — push-to-test		
Meter — "*" indicates meter's function		
Note number indicator		
Overload relay, thermal		
PLC input		
PLC output		
Reactor, saturable core		
Rectifier, full wave bridge		

Description	NEMA/UL	IEC
Rectifier, silicon controlled		
Resistor, adjustable, (potentiometer)		
Resistor, general		
Switch, single throw		
Switch, toggle (maintained position) — transfer, single pole, 2 position		
Switch, temperature actuated —opening on rising temperature		
Switch, push button — momentary, circuit closing (make)		
Switch, selector (multi-position) — with contact closed indicator. "X" indicates contacts close		
Switch, selector (multi-position) — with push button type contact mechanism. "X" indicates contacts close		

Description	NEMA/UL	IEC
Switch, disconnect (fused)		
Switch, disconnect (non-fused)		
Switch, flow — actuated, closes on increase in flow		
Switch, liquid level — actuated (float), closes on rising level		
Switch, pressure or vacuum operated — closes on rising pressure		
Switch — shading indicated switch closed		
Symmetrical gate-commutated thyristor and gate driver board		
Surge suppressor		
Switch, fused		

Description	NEMA/UL	IEC
Terminal		
Terminal blocks		
Terminal block barrier		
Terminal block end barrier		
Receptacle		
Thermistor		
Hall effect current sensor		
Transformer, current		
Transformer, with magnetic core		

Description	NEMA/UL	IEC
Thermocouple		
Varistor		
Winding		
Cable, multiconductor		
Conductor, or conductive path		
Conductor, associated or future		
Conductor, crossing of paths or conductors not connected		
Conductor, junction of connected paths — conductors or wires		
Conductor, shielded — single or multiconductor		

Description	NEMA/UL	IEC
Conductors, twisted		
Wiring, logic		
Wiring, temporary		
Copper bus bar		
Mechanically connected		
Wire gauge marker		

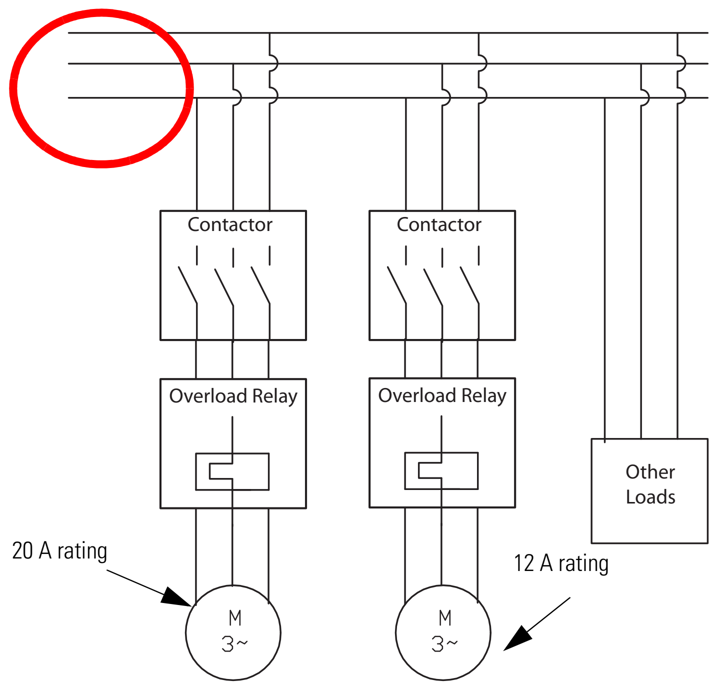
Motor Power Circuit Calculation Examples

Introduction

The examples on the following pages are intended to help you apply the techniques discussed in this application guide when designing and specifying components for motor power circuits. The schematic used in these exercises is based on *NEC* Section 430.

Example 1 — Feeder Conductor Sizing

Given the configuration in the following illustration, what size conductor (copper wire) is most appropriate? Assume an operating temperature of 75 °C.



Step 1: Determine total current load

The requirements for feeder conductor sizing state that the conductors must be capable of carrying 125% FLC of the largest motor, in addition to the FLC of all other loads.

For this scenario, our calculation would look like this:

- (20 A x 1.25) + 12 A

Using these values, we get a total current of **37 A**.

Step 2: Determine appropriate wire size

Next use *NEC* Article 310, Table 310.15(B)(16), to determine the ampacity of the conductor.

Figure 35 - *NEC* Article 310, Table 310.15(B)(16)

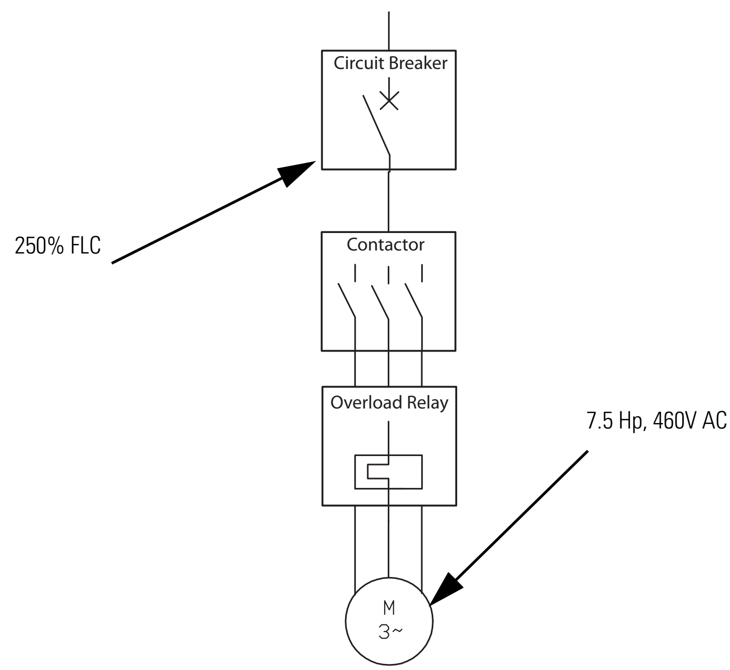
Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

	Temperature Rating of Conductor [See Table 310.104(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			Size AWG or kcmil
18**	—	—	14	—	—	—	—
16**	—	—	18	—	—	—	—
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
[illegible]	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8

Because our calculated value of 37 A falls between two values on the table, we must choose the next largest ampacity, which in this case if 50. Following the row across, we can see that this results in a wire size of **8 AWG**.

Example 2 — Standard Short-Circuit Protection

Given a 7.5 Hp 3-phase motor operating at 460V AC, what is the correct size circuit breaker?



Step 1: Determine the motor FLC

Using Table 430.250, determine the motor FLC. Remember that we are sizing a 7.5 Hp motor at 460V AC.

	Induction-Type Squirrel Cage and Wound Rotor (Amperes)						
Horsepower	**115 Volts**	**200 Volts**	**208 Volts**	**230 Volts**	**460 Volts**	**575 Volts**	**2300 Volts**
½	4.4	2.5	2.4	2.2	1.1	0.9	—
¾	6.4	3.7	3.5	3.2	1.6	1.3	—
1	8.4	4.8	4.6	4.2	2.1	1.7	—
1½	12.0	6.9	6.6	6.0	3.0	2.4	—
2	13.6	7.8	7.5	6.8	3.4	2.7	—
3	—	11.0	10.6	9.6	4.8	3.9	—
5	—	17.5	16.7	15.2	7.6	6.1	—
7½	—	25.3	24.2	22	11	9	—

As shown in the table above, the correct FLC for this motor is **11 A**.

Step 2: Find the correct breaker size

From Table 430.52, find the correct circuit breaker setting for standard short-circuit protection

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

	Percentage of Full-Load Current			
Type of Motor	**Nontime Delay Fuse[1]**	**Dual Element (Time-Delay) Fuse[1]**	**Instantaneous Trip Breaker**	**Inverse Time Breaker[2]**
Single-phase motors	300	175	800	250
AC polyphase motors other than wound-rotor	300	175	800	250
Squirrel cage — other than Design B energy-efficient	300	175	800	250
Design B energy-efficient	300	175	1100	250
Synchronous[3]	300	175	800	250
Wound rotor	150	150	800	150
Direct current (constant voltage)	150	150	250	150

As shown above, the standard setting for any standard 3-phase motor is 250% FLC. We then multiply the motor FLC by 250%

- 11 A x 2.5 = 27.5 A

Step 3: Determine final circuit breaker size

Using the list of standard ampere ratings for fuses and circuit breakers, determine the correct circuit breaker size.

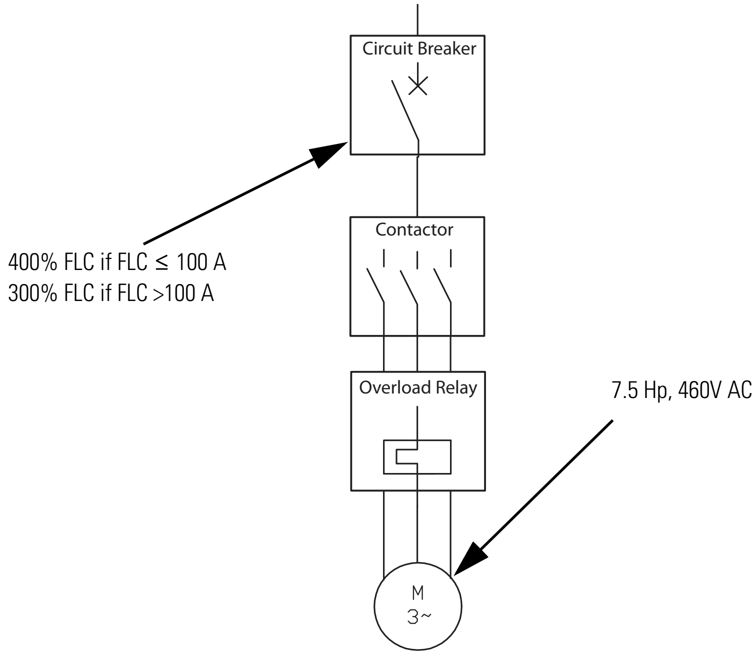
Table 6 - Standard ampere ratings for fuses and fixed-trip circuit breakers

Standard Ampere Ratings [A]			
15	80	300	1600
20	90	350	2000
25	100	400	2500
30	110	450	3000
35	125	500	4000
40	150	600	5000
45	175	700	6000
50	200	800	—
60	225	1000	
70	250	1200	
Additional standard ratings for fuses [A]			
1	6	10	601
3	—		

Per the table above, 27.5 falls between two values, so we round up to the next size, giving us a final solution of a **30 A breaker**.

Example 3 — Exception for Short-Circuit Protection

Given a 7.5 Hp 3-phase motor operating at 460V AC, what is the correct MAXIMUM size circuit breaker?



Step 1: Determine the motor FLC

Using Table 430.250, determine the motor FLC. Remember that we are sizing a 7.5 Hp motor at 460V AC.

	Induction-Type Squirrel Cage and Wound Rotor (Amperes)						
Horsepower	115 Volts	200 Volts	208 Volts	230 Volts	460 Volts	575 Volts	2300 Volts
½	4.4	2.5	2.4	2.2	1.1	0.9	—
¾	6.4	3.7	3.5	3.2	1.6	1.3	—
1	8.4	4.8	4.6	4.2	2.1	1.7	—
1½	12.0	6.9	6.6	6.0	3.0	2.4	—
2	13.6	7.8	7.5	6.8	3.4	2.7	—
3	—	11.0	10.6	9.6	4.8	3.9	—
5	—	17.5	16.7	15.2	7.6	6.1	—
7½	—	25.3	24.2	22	11	9	—

As shown in the table above, the correct FLC for this motor is **11 A**.

Step 2: Find the max. current setting

From the exceptions listed in Section 430.52 (c)(1), find the correct circuit breaker setting for standard short-circuit protection. With an FLC of 11 A, this application falls under the **400% FLC** exception. We then multiply the motor FLC by 400%

- 11 A x 4 = 44 A

Step 3: Determine final circuit breaker size

Using the list of standard ampere ratings for fuses and circuit breakers, determine the correct circuit breaker size.

Table 7 - Standard ampere ratings for fuses and fixed-trip circuit breakers

Standard Ampere Ratings [A]			
15	80	300	1600
20	90	350	2000
25	100	400	2500
30	110	450	3000
35	125	500	4000
40	150	600	5000
45	175	700	6000
50	200	800	—
60	225	1000	
70	250	1200	
Additional standard ratings for fuses [A]			
1	6	10	601
3	—		

Per the table above, 44 falls between two values. Because 44 is the maximum value allowed, we are not allowed to round up. In this case we round DOWN to **40 A**.

The following terms and abbreviations are used throughout this manual. For definitions of terms not listed here, refer to the Allen-Bradley Industrial Automation Glossary, publication AG-7.1.

AC contactor An alternating current (AC) contactor establishes or interrupts an AC power circuit

Altitude The atmospheric altitude (height above sea level) at which the motor will be operating; NEMA standards call for an altitude not exceeding 1,000 meters (3,300 feet). As the altitude increases above 1,000 meters (3,300 feet) and the air density decreases, the air's ability to cool the motor decreases. For higher altitudes, higher grades of insulation or motor derating are required. DC motors require special brushes for operation at high altitudes.

Ambient temperature The temperature of the surrounding cooling medium, such as gas or liquid, which comes into contact with the heated parts of the motor. The cooling medium is usually the air surrounding the motor. The standard NEMA rating for ambient temperature is not to exceed 40 °C.

American National Standards Institute (ANSI) American National Standards Institute. An organization that develops and publishes voluntary industry standards in the United States.

American wire gauge (AWG) A standard system used for designating the size of electrical conductors. Gauge numbers have an inverse relationship to size; larger numbers have a smaller cross-sectional area. However, a single-strand conductor has a larger cross-sectional area than a multi-strand conductor of the same gauge, so that they have the same current-carrying specification.

Approved Use of this term indicated that the device has been found acceptable by the authority having jurisdiction.

Architecture Specific configuration of hardware and software elements in a system.

Authority Having Jurisdiction The entity that has authority to enforce the requirements of a code or standard, or to approve equipment, materials, installations, or procedures.

Branch circuit The conductors and components following the last overcurrent protective device protecting a load (as defined in UL 508A, December 28, 2007).

Branch circuit protection Overcurrent protection with an ampere rating selected to protect the branch circuit. For a motor branch circuit, the overcurrent protection is required for overcurrents due to short circuits and faults to ground only (as defined in UL 508A, December 28, 2007).

Branch circuit protective device A fuse or circuit breaker that has been evaluated to a safety standard for providing overcurrent protection (as defined in UL 508A, December 28, 2007).

Circuit Breaker A device designed to open and close a circuit by non-automatic means, and to open the circuit automatically on a pre-determined overcurrent, without damage to itself when properly applied within its rating.

Class 1 circuit A control circuit on the load side of overcurrent protective device where the voltage does not exceed 600 volts, and where the power available is not limited, or control circuit on the load side of power limiting supply, such as a transformer (as defined in UL 508A, December 28, 2007).

Class 1 wiring Conductors of a Class 1 Circuit (as defined in UL 508A, December 28, 2007).

Class 2 circuit A control circuit supplied from a source having limited voltage (30 Vrms or less) and current capacity, such as from the secondary of a Class 2 transformer, and rated for use with Class 2 remote-control or signaling circuits (as defined in UL 508A, December 28, 2007).

Coil 1.) The electrical conductors wound into the core slot of a motor, electrically insulated from the iron core. A group of coils are connected into circuits, or windings, that carry independent current. These coils carry and produce a magnetic field when a current passes through them. 2.) A ladder diagram symbol that represents an output instruction.

Combination motor controller One or more devices assembled to provide disconnecting means, branch circuit protection, motor control, and motor overload protection for a single motor circuit (as defined in UL 508A, December 28, 2007).

Compensation Adjustment or alteration of a control system to improve performance. A compensator may be an electrical, mechanical, hydraulic, or pneumatic device

Conductor A material, such as copper or aluminum, that offers low resistance or opposition to the flow of electric current.

Conduit box The metal container usually on the side of the motor where the stator (winding) leads are attached to leads going to the power supply

Control circuit A circuit that carries the electric signals directing the performance of a controller, and which does not carry the main power circuit. A control circuit is, in most cases, limited to 15 amperes (as defined in UL 508A, December 28, 2007).

Control circuit transformer A transformer whose secondary supplies power to control circuit devices only (excluding loads) (as defined in UL 508A, December 28, 2007).

Controller A device or group of devices that serves to govern, in some predetermined manner, the electric power delivered to the apparatus to which it is connected (as defined in UL 508A, December 28, 2007).

DC contactor A contactor specifically designed to establish or interrupt a direct-current (DC) power circuit.

DC motor A motor using either generated or rectified DC power. A DC motor is often used when variable-speed operation is required.

Disconnecting means A device that disconnects all ungrounded conductors of a circuit from their electrical supply (as defined in UL 508A, December 28, 2007).

Frame 1.) The supporting structure for the stator parts of an AC motor. In a DC motor, the frame usually forms a part of the magnetic coil. The frame also determines mounting dimensions. 2.) The unit exchanged at the data link layer of a communication network.

Frame size Refers to a set of physical dimensions of motors as established by NEMA. These dimensions include critical mounting dimensions. NEMA 48 and 56 frame motors are considered fractional horsepower sizes even though they can exceed one horsepower. NEMA 143T to 449T is considered integral horsepower AC motors and 5000 series and above are called large motors. (For definition of letters following frame number, see "Suffixes to NEMA frames" on page 74.

Feeder circuit The conductors and circuitry on the supply side of the branch circuit overcurrent protective device (as defined in UL 508A, December 28, 2007).

Field installed equipment Devices to be installed after an industrial control panel is built/ labeled (as defined in UL 508A, December 28, 2007).

Field wiring terminal A terminal provided in an industrial control panel to terminate field wiring (as defined in UL 508A, December 28, 2007).

Fuse, branch circuit type A fuse of Class CC, G, H, J, K, L, R, and T. These fuses are able to provide branch circuit protection (as defined in UL 508A, December 28, 2007).

Fuse, semiconductor type A fuse designed for the protection of semiconductor devices. These fuses are able to provide branch circuit protection of motor circuits containing power conversion equipment as in 31.1.3 (as defined in UL 508A, December 28, 2007).

Fuse, supplementary type Miscellaneous type and miniature type fuses. These fuses are able to provide supplementary protection only (as defined in UL 508A, December 28, 2007).

Frequency The rate at which alternating current makes a complete cycle of reversals. It is expressed in cycles per second. In the U.S., 60 cycles (Hz) is the standard while in other countries 50 Hz (cycles) is common. The frequency of the AC current will affect the speed of a motor

Full-load current (FLC); Full-load Amperage (FLA) The current flowing through the line when the motor is operating at full-load torque and full-load speed with rated frequency and voltage applied to the motor terminals.

Full load torque The torque necessary to produce the rated horsepower at full-load speed.

General-purpose motor A general-purpose motor is any motor having a NEMA "B" design, listed and offered in standard ratings, with standard operating characteristics and mechanical construction for use under usual service conditions without restriction to a particular application or type of application (NEMA).

General-use rating A rating, expressed in volts and amperes, assigned to a device that is intended to control:

a) A load with a continuous or inrush ampere rating not exceeding the ampere rating of the device;
b) When AC rated, a load that has a power factor of 0.75 to 0.80 (inductive); and
c) When DC rated, a load that is resistive (noninductive) (as defined in UL 508A, December 28, 2007).

Hardware 1) Any mechanical, electrical, and electronic components and assemblies. 2) All the physical components of a control system – including the controller, peripherals, and interconnecting wiring – as opposed to the software components that control its operation. Compare with software (programming).

Horsepower (Hp) 1) Unit of power representing the amount of work done per unit of time. One horsepower (Hp) is equivalent to lifting 33,000 pounds to a height of one foot in one minute. It is also equal to 746 watts. 2) The horsepower of a motor is expressed as a function of torque and speed, where torque is measured in units of ft-lbs and speed is measured in units of RPM.
Calculated as (torque x speed) / 5252.

Induction motor AC motor that has no electrical connection to the rotor. The current that is supplied to the primary winding on the stator produces a rotating magnetic field in the stator. This rotating magnetic field induces current in the rotor windings. The induced current in the rotor windings creates a magnetic field in the rotor. The interaction of the stator's magnetic field and the rotor's magnetic field causes motion. It runs very close to synchronous speed.

In sight from Where a standard specifies that equipment shall be "in sight from", "within sight", etc., the specified equipment must be visible and not more than 15 m (50 ft.) from the other equipment.

Instantaneous trip circuit breaker A circuit breaker in which no delay is introduced into the tripping action of the circuit breaker. These circuit breakers are able to provide motor branch circuit protection when evaluated as a part of a combination motor controller as in 31.1.1 (as defined in UL 508A, December 28, 2007).

Insulation 1.) Material that tends to resist the flow of electric current and reduce heat loss. 2.) In a motor, insulation allows high voltage in the system for current flow and for motor torque production.

International Electrotechnical Commission (IEC) Global organization that prepares and publishes international standards for all electrical, electronic and related technologies. These standards serve as a basis for national standardization and as references when drafting international tenders and contracts. The IEC promotes international cooperation on all questions of electrotechnical standardization and related matters, such as the assessment of conformity to standards, in the fields of electricity, electronics and related technologies.

Interrupting Rating The highest current, at rated voltage, that a device is intended to interrupt under standard test conditions.

Inverse-time circuit breaker A circuit breaker in which a delay is introduced into the tripping action of the circuit breaker. The delay decreases as the magnitude of the current increases. These circuit breakers are able to provide branch circuit protection (as defined in UL 508A, December 28, 2007).

Inverter 1.) An inverter is an AC adjustable-frequency drive. 2.) Particular section of an AC drive that uses the DC voltage from a previous circuit stage (intermediate dc circuit) to produce a pulse-width-modulated, stepped AC current, or voltage waveform that has characteristics similar to the desired sine-wave frequency. 3.) Circuit whose output signal is the inverse of its input (a positive-going pulse is inverted to a negative-going pulse, and vice versa). 4.) Electronic device that converts fixed frequency and fixed voltages to variable frequency and voltage. Enables the user to electrically adjust the speed of an AC motor.

Isolated secondary circuit A circuit derived from an isolating source (such as a transformer, optical isolator, limiting impedance, or electro-mechanical relay) and having no direct connection back to the primary circuit (other than through the grounding means). A secondary circuit that has a direct connection back to the primary circuit is evaluated as part of the primary circuit (as defined in UL 508A, December 28, 2007).

Listed Equipment, materials, or services included in a list that is acceptable to the acceptable to the authority having jurisdiction.

Load 1) Burden imposed on a motor by the driven machine. It is often stated as the torque required to overcome the resistance of the machine it drives. Sometimes synonymous with “required power.” 2) Share of work that is demanded of a machine or system. It is the external force applied to a machine or system, or the sum of the external forces and the weight of the structure moved by the machine or system. 3) Amount of power or current needed to start or maintain motion in a power-driven machine or apparatus. 4) External mechanical resistance against which a machine acts. 5) Machine characteristics that are to be moved from one place to another. 6) Function of mass, moment of inertia, static and dynamic forces supported by the robot. It is expressed as the force and torque at the mechanical interface which can be exerted along the various axes of motion under specified conditions of velocity and acceleration.

Locked-rotor current Amount of current drawn at the instant a motor is energized. It is the steady-state current taken from a line with a rotor that is at standstill with rated voltage and frequency. In most cases, it is much higher than the current required for running a motor. It is also known as starting current.

Low-voltage limited energy circuit A control circuit involving a peak open-circuit potential of not more than 42.4 volts (DC or peak) supplied by a primary battery or by an isolated secondary circuit, and where the current capacity is limited by an overcurrent device, such as a fuse, or by the inherent capacity of the secondary transformer or power supply,

or a combination of a secondary winding and an impedance. A circuit derived from a line-voltage circuit by connecting a resistance in series with the supply circuit to limit the voltage and current is not identified as a low-voltage limited energy circuit (as defined in UL 508A, December 28, 2007).

Motor A device that takes electrical energy and converts it into mechanical energy to turn a shaft.

Motor overload Electrical overload, a situation where an electrical machine or system is subjected to a greater load than that for which it was designed

Motor rating A motor's operational capabilities. They are specifications or performance limits that are measured at defined temperatures.

Nameplate The plate on the outside of the motor describing the motor horsepower, voltage, speed efficiency, design, enclosure, etc.

National Electrical Code® (*NEC®*) A set of regulations governing the construction and installation of electrical wiring and apparatus, established by the National Fire Protection Association and suitable for mandatory application by governing bodies exercising legal jurisdiction. It is widely used by state and local authorities within the United States.

National Electrical Manufacturers Association (NEMA) A non-profit organization organized and supported by manufacturers of electric equipment and supplies. NEMA has set standards for: horsepower ratings, speeds, frame sizes and dimensions, standard voltages and frequencies with allowable variations, service factors, torque, starting current & KVA, enclosures.

Original Equipment Manufacturer (OEM) The maker of a piece of equipment. An example would be a machine tool manufacturer who buys programmable controller components, sensors, and actuators - then integrates them with his machine tool to produce the complete system for sale to the end user.

Overcurrent protection A device designed to open a circuit when the current through it exceeds a predetermined value. The ampere rating of the device is selected for a circuit to terminate a condition where the current exceeds the rating of conductors and equipment due to overloads, short circuits and faults to ground (as defined in UL 508A, December 28, 2007).

Overload An electrical load that exceeds the available electrical power.

Overload protection Protection required for motor circuits that will operate to prohibit excessive heating due to running overloads and failure to start (as defined in UL 508A, December 28, 2007).

Phase 1.) Indicates the space relationships of windings and changing values of the recurring cycles of AC voltages and currents. Due to the positioning (or the phase relationship) of the windings, the various voltages and currents will not be similar in all aspects at any given instant. Each winding will lead or lag another in

position. Each voltage will lead or lag another voltage in time. Each current will lead or lag another current in time. The most common power supplies are either single- or three-phase (with 120 electrical degrees between the three-phases). 2.) The separation in electrical degrees between any specified transitions of any two channels in an encoder.

Power The work done per unit of time. Measured in horsepower or watts: 1 Hp= 33,000 ft-lb/min. = 746 W.

Power factor The ratio of the active power (W) to the apparent power (VA) expressed as a percentage. It is numerically equal to the cosine of the angle of lag of the input current with respect to its voltage, multiplied by 100.

Power transformer A transformer whose secondary winding supplies power to loads or a combination of loads and control circuit devices operating at the secondary voltage (as defined in UL 508A, December 28, 2007).

Qualified person A person who has the skills and knowledge related to the construction and operation of electrical equipment and installations and has received safety training to recognize and avoid the hazards involved.

Rated horsepower The maximum or allowable power output of a motor or other prime mover under normal, continuous operating conditions.

Receptacle A contact device installed at the outlet for the connection of an attachment plug. A single receptacle is a single contact device with no other contact device on the same yoke. A multiple receptacle is two or more contact devices on the same yoke.

Safe working procedure A method of working that reduces risk.

Self-protected combination motor controller A self-protected combination motor controller that is operable only by manual means. A combination motor controller that contains coordinated overload and short circuit protection, and also provides disconnecting means and remotely operable motor controller. Coordinated protection is able to be inherent or obtained by correct selection of components or accessory parts in accordance with the manufacturer's instructions
(as defined in UL 508A, December 28, 2007).

Service Factor (SF) 1) When used on a motor nameplate, a number which indicates how much above the nameplate rating a motor can be loaded without causing serious degradation (e.g., a 1.15 SF can produce 15% greater torque than the 1.0 SF rating of the same motor).

2)When used in applying motors or gearmotors, a figure of merit, which is used to "adjust", measured loads in an attempt to compensate for conditions which are difficult to measure or define. Typically, measured loads are multiplied by service factors (experience factors) and the result in an "equivalent required torque" rating of a motor or gearmotor.

Shall Indicates a mandatory requirement in regulatory standards.

Short-circuit current An overcurrent resulting from a short circuit due to a fault or an incorrect connection.

Short-circuit current rating (SCCR) The prospective symmetrical fault current at a nominal voltage to which an apparatus or system is able to be connected without sustaining damage exceeding the defined acceptance criteria (as defined in UL 508A, December 28, 2007).

Suffixes to NEMA frames Letter suffixes sometimes follow the NEMA frame size designations. Some of these suffixes, according to NEMA standards, have the following meanings:

Fractional Horsepower Motors

C	Face mounting
G	Gasoline pump motor
H	Indicates a frame having a larger “F” dimension
J	Jet pump motor
Y	Special mounting dimensions *(see manufacturer)*
Z	All mounting dimensions are standard except the shaft extension

Integral Horsepower Motors

A	DC motor or generator
C	Face mounting on drive end
D	Flange mounting on drive end
P	Vertical hollow and solid shaft motors with P-Base flange
HP	Vertical solid shaft motors with P-Base flange (normal thrust)
JM	Close-coupled pump motor with C-Face mounting and special shaft extensions
JP	Close-coupled pump motor with C-Face mounting and special long shaft extension
LP	Vertical solid shaft motors with P-Base flange (medium thrust)
S	Standard short shaft for direct connection
T	Standardized shaft -“T” frame
V	Vertical mounting
Y	Special mounting dimensions
Z	All mounting dimensions standard except shaft extension

Supplementary protection A device intended to provide additional protection subsequent to branch circuit protection. They have not been evaluated for providing branch circuit protection (as defined in UL 508A, December 28, 2007).

Supplementary protector A manually resettable device designed to open the circuit automatically on a predetermined value of time versus current or voltage within an appliance or other electrical equipment. It is also able to be provided with manual means for opening or closing the circuit. These devices are able to provide supplementary protection only (as defined in UL 508A, December 28, 2007).

Tap conductor A conductor (other than a service conductor) that has overcurrent protection ahead of its point of supply that exceeds the value permitted for similar conductors.

UL (Underwriter's Laboratory) An independent testing organization, which examines and tests devices, systems and materials with particular reference to life, fire and casualty hazards. It develops standards for motors and controls used in hazardous locations through cooperation with manufacturers. UL has standards and tests for explosion-proof and dust ignition-proof motors, which must be met and passed before application of the UL label.

Voltage, nominal A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class.

Watt The amount of power required to maintain a current of one ampere at a pressure of one volt. Most motors are rated in kW equal to 1,000 watts. One horsepower is equal to 746 watts.

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