Electrical, Computer & Energy Engineering
UNIVERSITY OF COLORADO BOULDER

ECEN 5053-003 Homework Assignment

Course Name: Embedding Sensors and Actuators
Corresponding Module: C2M2
Week Number: 6
Module Name: AC Motor Control
Student Name: Rushi James Macwan

Homework is worth 100 points.

Part 1: Each question is worth 5 points.

A. You need to specify an AC induction motor for a machine which requires a minimum of 210 in-lbs of locked rotor torque from the motor. Otherwise, the machine won't start. You find a motor on a web site that specifies 231 in-lb of locked rotor torque. According to IEC 60034-1, what is the lowest locked rotor torque (in-lbs) that your motor will supply? Will it be enough to start the motor?

Sol. **Lowest LRT – 196.35 in-lbs. and it will NOT BE ENOUGH to start the motor**

According to IEC 60034-1 document referenced with this solution, it is specified that the Locked Rotor Torque for an IEC 60034-1 motor would vary between -15% to +25% of the torque value that is specified. Thus, the minimum Locked Rotor Torque value will be -15% of the specified value which is (231 x 0.85 = 196.35 in-lbs.). Thus, ***the lowest Locked Rotor Torque (196.35 in-lbs.)*** is lower than the required value of 210 in-lbs. (since 196.35 in-lbs. < 210 in-lbs.) and therefore, ***it will NOT BE ENOUGH to start the motor*** given that the motor supplies the lowest Locked Rotor Torque.

Courtesy: Reference Links: [1]

B. You purchase a motor in France designed to run at 415 Volts, 50 Hz. It has 50 kW output power, and it runs at 2978 RPM. You ship it to the United States and run it at 460 Volts, 60 Hz. What will be the new torque in N-m?

Sol. **132.6963 Nm**

Based on the referenced document for this problem, the rule of thumb to follow for a 50Hz mains frequency is that the speed in revolutions per minute (r/min. or rpm) is 6000 divided by the number of poles based on the below given equation:

Speed

The speed of an ac motor depends on the mains frequency and the number of poles of the stator winding.

$$n = \frac{2.f.60}{P} \text{ r/min.}$$

where
n = speed
f = frequency
P = number of poles.

Therefore, for the data provided in the problem,

RPM = n = 2 x 50 x 60 / P = 6000 / P (where P is the number of poles)

Therefore, 2978 = 6000 / P leads to P = 6000 / 2978 = **2-pole motor**

Now, for a 2-pole motor, the formula to find RPM for a 60 Hz Mains supply is:

RPM = 2 x f x 60 / P = 2 x 60 x 60 / 2 = 60 x 60 = **3600 RPM**

Furthermore, to calculate the rated torque, we can use the formula as under:

M = 30,000 x P / (PI x n)

Where, P = Output Power (kW) and n = RPM

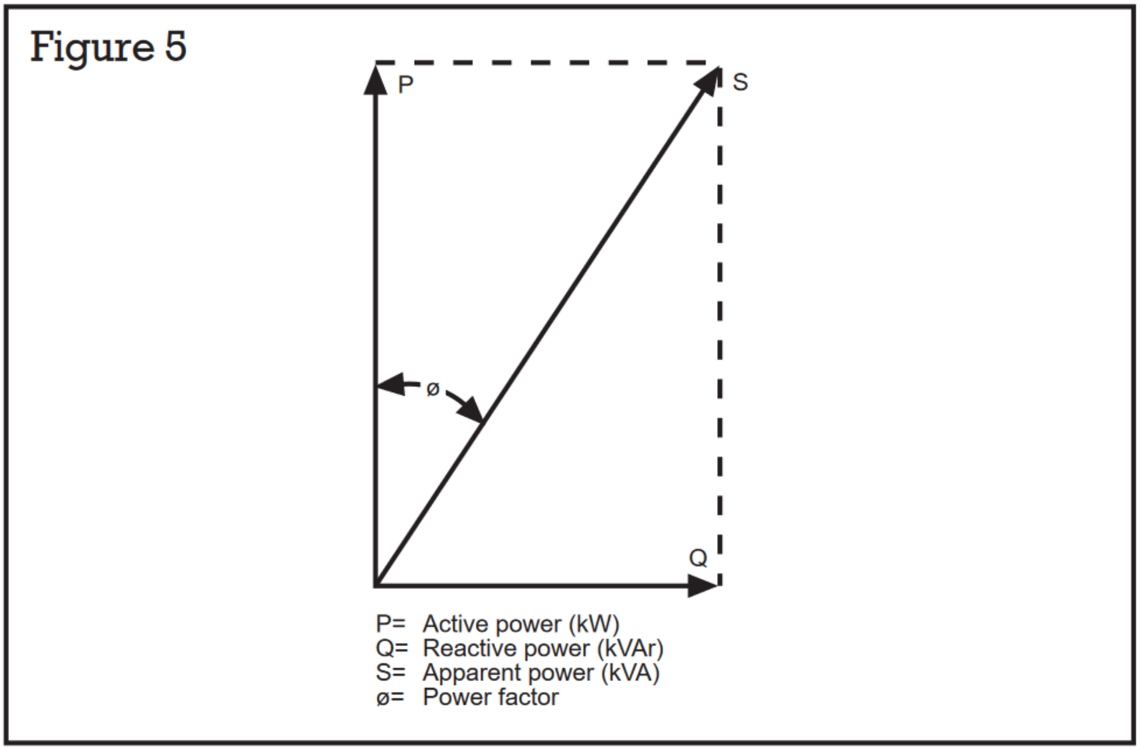
Thus, M = 30,000 x 50 / (3.14 x 3600)
= **132.6963 Nm**

Courtesy: Reference Links: [1]

C. What is the power factor of an AC motor when the active power is 4kW and the reactive power is 3kwW? (Type a 2-decimal number)

Sol. **P.F. = 0.8**

The power factor for an AC motor can be calculated by using the below given formula based on the diagram provided in the referenced document:



Power Factor = cos (Ø)

Now, tan (Ø) = Q / P = Reactive Power / Active Power = 3 / 4 = 0.75

Therefore, Ø = 36.86 degrees (approx.)

Thus, P.F. = cos (Ø) = cos (36.86) = **0.8**

Courtesy: Reference link: [1] [2]

D. An AC motor is operating at 40°C ambient temperature conditions, and it has a temperature rating on its nameplate of Class F. What is the maximum rated internal temperature (°C) of the motor for 20,000 hours of operation? (Type an integer).

Sol. **155°C**

Based on the reference provided for this problem, a Class F motor will have a maximum rated internal temperature (°C) of **155°C** for successful operation for 20,000 hours of working time.

Courtesy: Reference link: [1] [2]

E. NEMA (National Electrical Manufacturers' Association) has established AC motor standards primarily associated with motors used in North America.

Answer the following questions about information that NEM requires to be put on nameplates of motors.

E.1 What is the rated voltage?

Sol.

The rated voltage is the voltage at which the motor is designed to operate and yield optimal performance. 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.

E.2 What is Full Load Amps (FLA)?

Sol.

When the full-load torque and horsepower is reached, the corresponding amperage is known as the full-load amperage (FLA). This value is determined by laboratory tests; the value is usually rounded up slightly and recorded as the nameplate value. Rounding up allows for manufacturing variations that can occur and some normal voltage variations that might increase the full-load amps of the motor. The nameplate FLA is used to select the correct wire size, motor starter, and overload protection devices necessary to serve and protect the motor.

E.3 What is the Full Load RPM?

Sol.

The rated full load speed, or rpm (revolutions per minute) of a motor is the speed at which the motor will operate under full torque conditions when applied voltage and frequency are held constant at the rated values.

E.4 What is the Time Rating?

Sol.

Time rating or duty specifies the length of time the motor can operate at its rated load safely and indicates whether the motor is rated for continuous duty. This is shown as "CONT" on the nameplate.

Standard motors are rated for continuous duty (24/7) at their rated load and maximum ambient temperature. Specialized motors can be designed for “short-time” requirements where intermittent duty is all that is needed.

E.5 What is the Service Factor?

Sol.

Motor Service Factor (SF) is the percentage of overloading the motor can handle for short periods when operating normally within the correct voltage tolerances. This is practical as it gives you some 'fudge' in estimating horsepower needs and actual running horsepower requirements. It also allows for cooler winding temperatures at rated load, protects against intermittent heat rises, and helps to offset low or unbalanced line voltages.

NEMA defines service factor as a multiplier, when applied to the rated horsepower, indicates a permissible horsepower loading, which may be carried under the conditions specified for the service factor at rated voltage and frequency.

This service factor can be used for the following:

1. To accommodate inaccuracy in predicting intermittent system horsepower needs.
2. To lengthen insulation life by lowering the winding temperature at rated load.
3. To handle intermittent or occasional overloads.
4. To allow occasionally for ambient above 40°C.
5. To compensate for low or unbalanced supply voltages.

NEMA does add some cautions, however, when discussing the service factor:

1. Operation at service factor load for extended periods will usually reduce the motor speed, life and efficiency.
2. Motors may not provide adequate starting and pull-out torques, and incorrect starter/overload sizing is possible. This in turn affects the overall life span of the motor.
3. Do not rely on the service factor capability to carry the load on a continuous basis.
4. The service factor was established for operation at rated voltage, frequency, ambient and sea level conditions.

The service factor is required to appear on the nameplate only if it is higher than 1.0.

Courtesy: Reference link: [1]

F. In an AC variable speed controller what can happen if you don't keep the ratio of voltage to frequency constant throughout the speed range.

Sol.

AC motors are designed for a magnetic field (flux) of constant strength. The magnetic field strength is proportional to the ratio of voltage (V) to frequency (Hz), or V/Hz. But a VFD controls the motor speed by varying the frequency of the applied voltage, according to the synchronous speed equation:

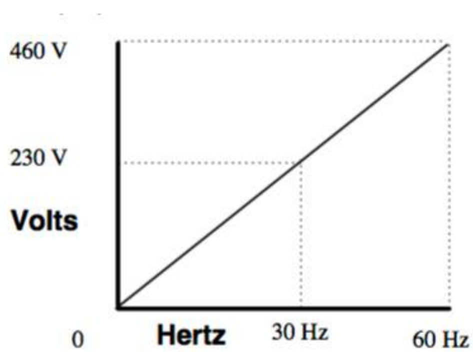
N = 120*f / P

Where:

N = motor speed (RPM)

f = input voltage frequency

P = number of motor poles

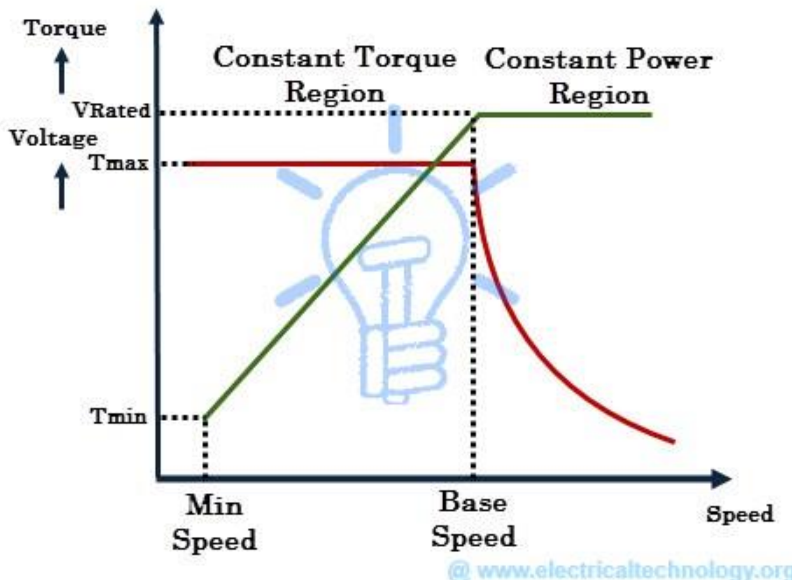


V/Hz control maintains a constant ratio between voltage (V) and frequency (Hz).

Varying the voltage frequency affects both the motor speed and the strength of the magnetic field. When the frequency is lowered (for slower motor speed), the magnetic field increases, and excessive heat is generated. When the frequency is increased (for higher motor speed), the magnetic field decreases, and lower torque is produced. In order to keep the magnetic flux constant, the V/Hz ratio must remain constant. This keeps torque production stable, regardless of frequency.

We know that the **speed of an induction motor is proportional to the frequency** of the supply (**N = 120f/p**) and by varying the frequency we can obtain the variable speed. But, when the frequency is decreased, the torque increases and thereby motor draw a heavy current. This in turn increases the flux in the motor. Also the magnetic field may reach to the saturation level, if the voltage of the supply is not reduced.

Therefore, both the voltage and frequency have to be changed in a constant ratio in order to maintain the flux within the working range. Since the torque is proportional to the magnetic flux, the torque remains constant throughout the operating range of v/f.



The above figure shows the torque and speed variation of an induction motor for voltage and frequency control. In the figure, voltage and frequency are changed at a constant ratio up to the base speed. Thus the flux and thereby torque remain almost constant up to the base speed. This region is called as a constant torque region.

Since the supply voltage can be changed up to the rated value only and hence the speed at rated voltage is the base speed. If the frequency increased, beyond the base speed, the magnetic flux in the motor decreases and thereby torque begins falling off. This is called flux weakening or constant power region.

Thus, if the Voltage to frequency ratio is not kept constant throughout the speed range then when the frequency is decreased, heavy torque is produced which drives heavy current and leads to excessive heat that is generated which can have harmful effects on the motor. Conversely, when the frequency is increased, lower torque is produced which can be insufficient for the assigned load and can result into improper

operation of the motor. Therefore, V/Hz should be maintained constant for constant torque throughout the operating range of V/Hz.

Courtesy: Reference link: [1] [2]

G. Why is a TENV motor enclosure not suitable for an explosive gas environment?

Sol.

Based on NEMA (National Electrical Manufacturers Association) definition, TENV states that the motor housing is fully enclosed and is not ventilated with a fan. The motor is being cooled unassisted (natural convection cooling). Basically, the motor cools by releasing heat into the air and/or conducted through the mounting surface. Again, there are no fans nor are liquid cooling techniques used. TENV motors are not considered airtight, therefore you would not use them in wet environments, but you could use them in slightly damp and definitely dirty environments.

Based on the above data, the TENV motors which are not considered air-tight cools by releasing heat into the outside air and/or by conducting through the mounting surface. Now, since the problem involves a case where there is an explosive gas environment, this TENV motor enclosure is not suitable. **The reason is again that it would release heat into the outside air since it's not airtight and since it does not have a cooling fan. This emitted heat interacts with the explosive gas environment present outside and it can easily result into an explosion or a fatal accident.** Thus, TENV motor enclosure is unsuitable for hazardous or explosive environments.

Courtesy: Reference link: [1] [2]

H. Suppose you need to buy a motor for a piece of automated boring equipment located 2 kilometers below the earth's surface in a hot dusty coal mine. It will be used 5000 hours per year. Coal dust is known to be explosive. You need an intrinsically safe motor. The equipment produces a great amount of heat, so that the motor ambient temperature is up to 135° C. According to the North American ratings, what explosion proof rating of motor should you purchase?

Sol. **Enclosure type: 9, Class II, Group F, T code: T4, Class F insulation**

Based on the attached referenced documents, according to NEMA, the following explosion proof ratings of motor will be implied for the case as mentioned in the problem:

1. Enclosure Type 9 is best suitable for this type of use of motor. It is suitable for hazardous usage as defined in NFPA-70.

2. Hazardous area classification: **Class II** (Combustible Dusts) – **Group F** (for Coal Dust) – Provides auto-ignition temperature of 610° C.
3. For surface temperature rating: T code: **T4** (max surface temperature 135° C)
4. **Class F insulation** suitable for a 20000 hours of life safe operation. This would mean for up to 4 years since the use is 5000 hours / year. This is so because for both of them the temperature is such that it is more than the given ambient temperature here in this problem which is 135 ° C.

Courtesy: Reference link: [0] [1] [2] [3] [4] [5]

I. Suppose you are in charge of specifying an AC motor to run a pump in a pharmaceutical plant that makes antibiotic drugs. The plant is subject to FDA (Food and Drug Administration) rules that require strict cleanliness standards in manufacturing. The motor is run continuously. Temperatures in the plant are held between 18°C and 22°C. Humidity is controlled between 20% and 30%. What type of motor should you specify?

Sol.

The washdown motor can be used for this problem since it is best suitable for industrial usage and can be specially used for the food-processing industry and therefore there remains no problem with the presence of humidity.

Secondly, it withstands direct wash of equipment which means it is directly in contact with liquids which means it is safe for 20-30% humidity levels. It also gives off minimum particles in a clean room and therefore allows cleanliness.

As for the temperature conditions, the Class A insulation class motor would be fine since the ambient temperature lies in between 18°C and 22°C inside the plant which is way lesser than 40°C. Thus, the motor with Class A insulation would be safe to use.

Courtesy: Reference link: [1]

J. Suppose you are in charge of specifying an AC motor to run a pump in a factory making stainless steel. As part of normal operation, the plant uses corrosive chemicals to create the special alloys of steel. Temperatures near the pump soar to 100°C because it is located right next to a blast furnace where the internal temperatures are 1000°C. What type of motor should you specify?

Sol.

For this problem, a severe-duty motor would be required since it is resistant to corrosive chemicals that are required to create the special alloys of steel.

Since, the temperature goes up to 100 C near the pump, the Class F insulation would be suitable.

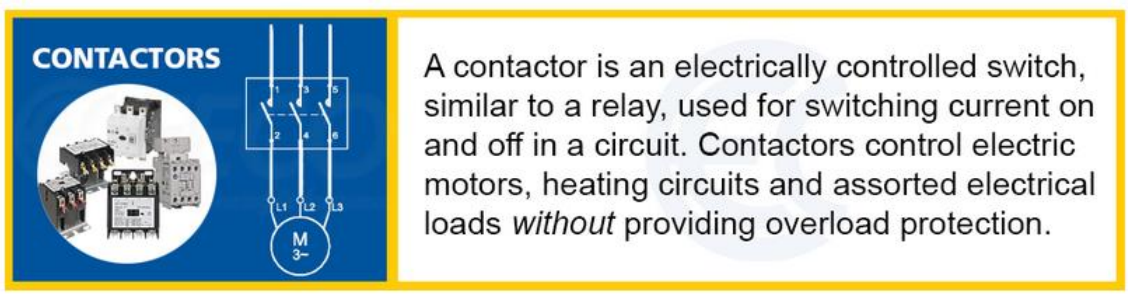
Since, the pump is next to a blast furnace, the hazardous locations will come into picture. Thus, according to NFPA-70, Class II, Group F – for carbon presence in manufacturing of steel will be the correct description for the motor.

An example of motor is: IEEE 841-2001 motor as given in the document here.

Courtesy: Reference link: [1] [2]

K. What would happen to other equipment on the power line if your motor circuit did not include an AC motor contactor?

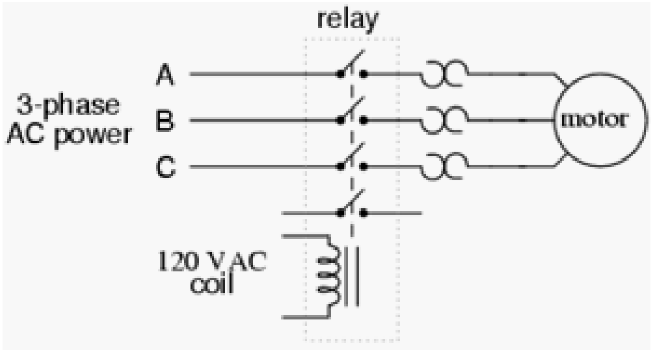
Sol.



A contactor is basically an overgrown relay which applies voltage to a contactor coil to close the contacts and to supply and interrupt power to the circuit. A motor starter is simply a contactor plus an overload relay and is rated by motor HP or amperage. ***Without an overload relay, it's just a contactor and it employs overload relays to protect the motor from load surges by shutting it down to prevent overheating.***

Moreover, NEMA standards require that contacts be able to interrupt currents up to 10 times full-load current.

Furthermore, the overload relay must be used in conjunction with a contactor. The overload relay has no power contacts and cannot disconnect the motor by itself. The control circuit contact must be wired in series with the coil of the contactor so that the contactor will de-energize when an overload occurs.



Thus, to summarize based on the diagram above, when a relay is used to switch a large amount of electrical power through its contacts, it is designated by a special name: **contactor**. Contactors typically have multiple contacts, and those contacts are usually (but not always) normally-open, so that power to the load is shut off when the coil is de-energized. One contactor may have several auxiliary contacts, either normally-open or normally-closed, if required. The three "opposed-question-mark" shaped devices in series with each phase going to the motor are called overload heaters. Each "heater" element is a low-resistance strip of metal intended to heat up as the motor draws current. ***If the temperature of any of these heater elements reaches a critical point (equivalent to a moderate overloading of the motor), a normally-closed switch contact (not shown in the diagram) will spring open. This normally-closed contact is usually connected in series with the relay coil, so that when it opens the relay will automatically de-energize, thereby shutting off power to the motor.***

Thus, contacts provide overcurrent protection and thereby prevents motor overheating which prevents any fatal accidents leading to blast/explosion with the motor working. **Thus, without an AC motor contactor, all other equipment on the power-line will also drive overcurrent when the motor drives overcurrent and there remains a fair chance of blowing up the other equipment on the power-line while the motor overheats and it also leads to fatal outcomes.**

Courtesy: Reference link: [1] [2] [3] [4] [5] [6]

L. These questions below are about overload relays.

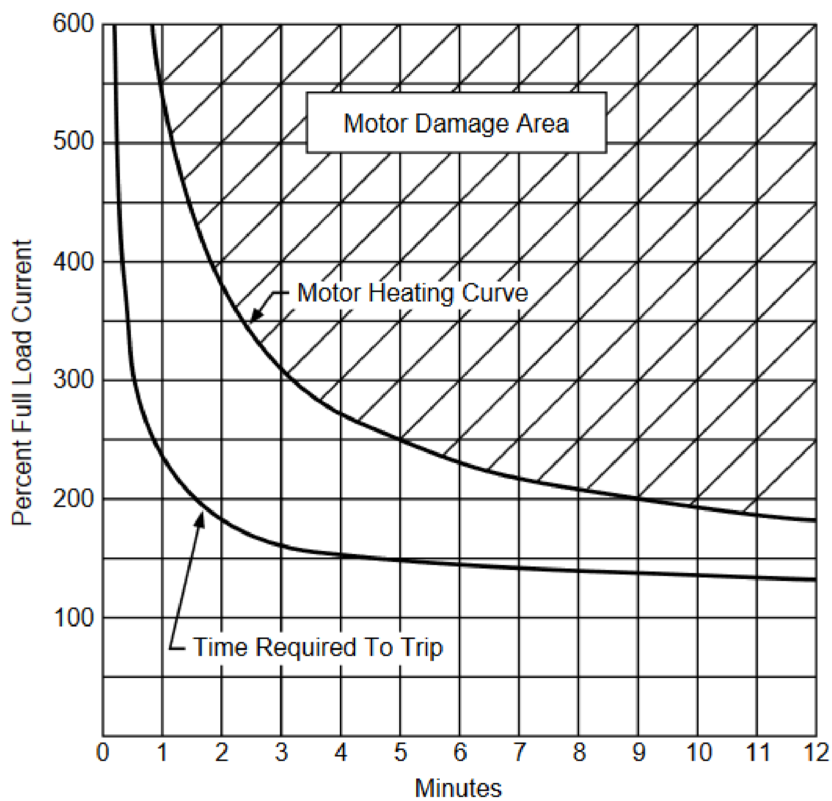
L.1. How does the current to trip an overload relay or circuit breaker compare to the current that can damage a motor?

Sol.

In spite of being relatively simple and inexpensive, thermal overload relays are very effective in providing motor running overcurrent protection. This is possible because the most vulnerable part of most motors is the winding insulation and this insulation is very susceptible to damage by excessively high temperature.

Being a thermal model of a motor, the thermal overload relay will produce a shorter trip time at a higher current similar to the way a motor will reach its temperature limit in a shorter time at a higher current. Similarly, in a high ambient temperature, a thermal overload relay will trip at a lower current or vice versa allowing the motor to be used to its maximum capacity in its particular ambient temperature (if the motor and overload are in the same ambient). Once tripped, the thermal overload relay will not re-set until it has cooled, automatically allowing the motor to cool before it can be re-started.

The overload relay must be used in conjunction with a contactor. The overload relay has no power contacts and cannot disconnect the motor by itself. The control circuit contact must be wired in series with the coil of the contactor so that the contactor will de-energize when an overload occurs. Square D manufactures three types of overload relays, the melting alloy, bimetallic, and solid state. In some types, the bimetallic is available in both non-compensated and ambient temperature-compensated versions. In both melting alloy and bimetallic, single element and three element overloads are available.

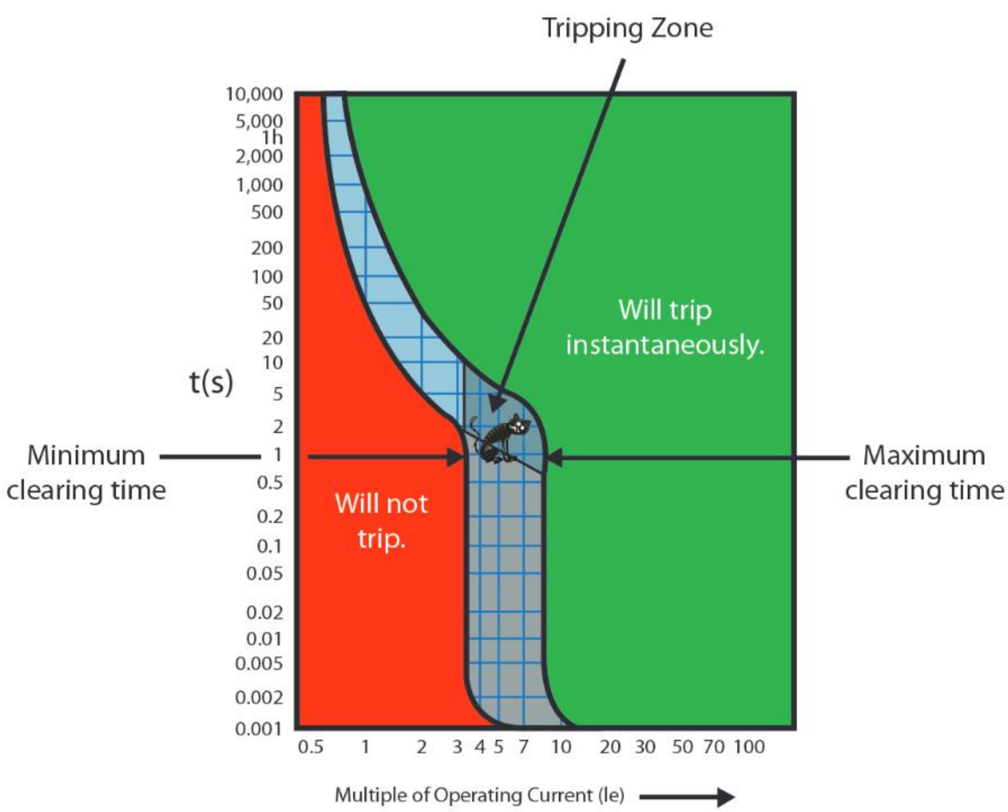


Graph shows motor heating curve and overload relay trip curve.
Overload relay will always trip at a safe value.

Based on the referenced document, it can be seen from the data provided in this graph that Melting alloy and bimetallic overload relays are designed to approximate the heat actually generated in the motor. As the motor temperature increases, so does the temperature of the thermal unit. The motor and relay heating curves (left) show this relationship. From this graph we can see that no matter how high the current drawn, the overload relay will provide protection yet will not trip unnecessarily.

Furthermore, from the data provided in the second referenced document, it can be seen that the overload protection setting for motors is 125% of their full load current according to NEC but the above graph explains the stability and safety of the motor even for worse conditions of Percent Full Load Current.

In addition to the above mentioned details, ***from the graph it can be summarized that the time in minutes to trip is enough for the corresponding percent full load current supplied to the motor to be tripped before the motor overheats. Thus, the graph shows less tripping time for higher value of percent full load current and is so because at higher current, overheating takes place faster and the motor is easily damaged. To save the motor from such incidents, as the percent full load current increases, the tripping time delay reduces.***

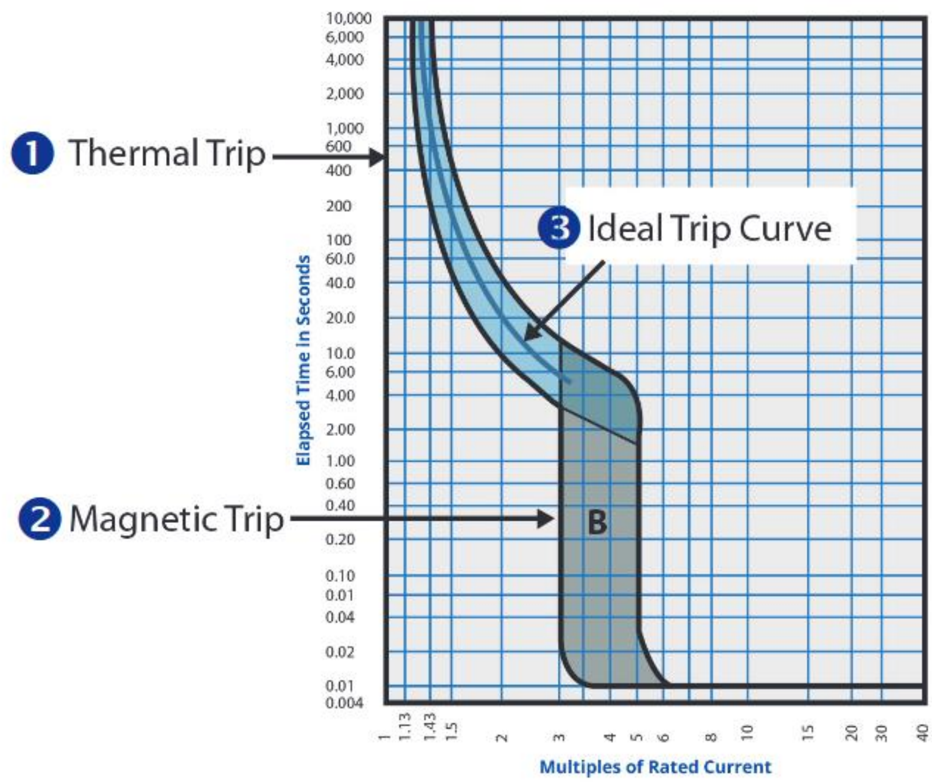


For more insights, the third referenced documents explains the tripping curve as under:

Figure 5 (below) shows a B Trip Curve overlaid onto the chart.

The three major components of the Trip Curve are:

1. Thermal Trip Curve. This is the trip curve for the bi-metallic strip, which is designed for slower overcurrents to allow for in rush/startup, as described above.
2. Magnetic Trip Curve. This is the trip curve for the coil or solenoid. It is designed to react quickly to large overcurrents, such as a short circuit condition.
3. The Ideal Trip Curve. This curve shows what the desired trip curve for the bi-metallic strip is. Because of the organic nature of the bi-metallic strip, and changing ambient conditions, it is difficult to precisely predict the exact tripping point.



Courtesy: Reference link: [1] [2] [3]

L.2. How does the current to trip an overload relay or circuit breaker compare to the starting in the motor?

Sol.

Based on the referenced document, to protect the motor branch circuit against short circuits, overload relay protection must be coordinated with protection provided by the SCPD (short circuit protective device). The SCPD may be a fused switch or a circuit breaker. Figure 2 shows the critical point (Ic) in this coordination. **At current values greater than Ic, the SCPD reacts quicker than the overload relay. At current values less than Ic, the overload relay reacts quicker.** Thus, the relation of the overload relay current, SCPD current, the motor starting current and the motor damage current shows that before the motor reaches the motor damage current value, the overload relay current boundary or the SCPD current boundary is met and therefore one of them trips the current which eventually protects the motor from any harmful hazards.

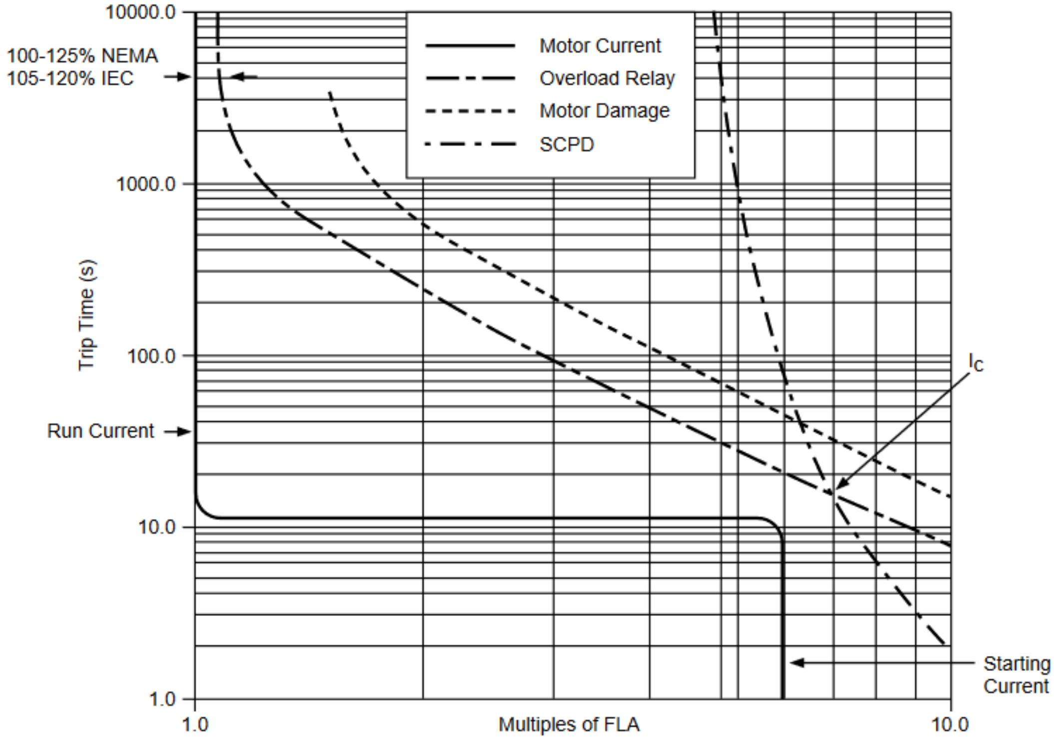


Figure 2 Typical Coordination Curves

Courtesy: Reference link: [1]

L.3. What is the difference between these two thermal overload relays: melting alloy and non-compensated bimetallic?

Sol.

Melting Alloy

In melting alloy thermal overload relays, the motor current passes through a small heater winding. Under overload conditions, the heat causes a special solder to melt allowing a ratchet wheel to spin free thus opening the control circuit contacts. When this occurs, the relay is said to “trip”. To obtain appropriate tripping current for motors of different sizes, or different full load currents, a range of thermal units (heaters) is available. The heater coil and solder pot are combined in a one piece, nontamperable unit. Melting alloy thermal overload relays must be reset by a deliberate hand operation after they trip. A reset button is usually mounted on the cover of enclosed starters. Thermal units are rated in amperes and are selected on the basis of motor full load current, not horsepower.

Non-Compensated Bimetallic

Bimetallic thermal overload relays employ a U-shape bimetal strip associated with a current carrying heater coil. When an overload occurs, the heat will cause the bi-metal to deflect and operate a control circuit contact. Different heaters give different trip points. In addition, most relays are adjustable over a range of 85% to 115% of the nominal heater rating. Bimetallic overload relays are used where the controller is remote or difficult to reach. Three wire control is recommended when automatic restarting of a motor could be hazardous to personnel.

To summarize, the melting alloy are hand reset only with relatively tight trip current ranges and low cost. Bimetallic are selectable hand or auto reset, adjustable 85-115% trip current, available with a standard alarm contact, and available in an optional ambient compensated version.

Courtesy: Reference Links: [1] [2] [3]

L.4. What is the fundamental difference between a motor logic solid state overload relay and a thermal overload relay?

Sol.

Motor Logic Solid State Overload Relay

Motor Logic Solid State overload relays use an electronic method of detection, which responds directly to the motor current. When tripped the overload relay may be reset either manually or remotely using the Remote Reset Module. The Solid State overload relay provides overload protection only for three phase motors rated up to 600 volts AC.

The Solid State overload relay provides protection for phase loss and phase unbalance. In addition, this overload relay is ambient insensitive. The Solid State overload relay is available as a separate trip Class 10 or 20 and as a selectable trip Class 10/20 device. The Motor Logic solid state overload relay must be selected based on the FLA of the motor it is to protect. Applications involving a motor with an FLA less than 1.5 amps can be addressed by passing multiple looped turns of the motor leads through the current transformer windows.

Thermal Overload Relay

Being a thermal model of a motor, the thermal overload relay will produce a shorter trip time at a higher current similar to the way a motor will reach its temperature limit in a shorter time at a higher current. Similarly, in a high ambient temperature, a thermal overload relay will trip at a lower current or vice versa allowing the motor to be used to its maximum capacity in its particular ambient temperature (if the motor and overload are in the same ambient). Once tripped, the thermal overload relay will not reset until it has cooled, automatically allowing the motor to cool before it can be re-started.

Melting alloy and bimetallic overload relays are designed to approximate the heat actually generated in the motor. As the motor temperature increases, so does the temperature of the thermal unit. The motor and relay heating curves (left) show this relationship. From this graph we can see that no matter how high the current drawn, the overload relay will provide protection yet will not trip unnecessarily.

Basic Difference

To summarize based on the referenced documents, **the motor logic solid-state overload relay is designed to protect low 3-phase motors at 50/60 Hz where reliability, low-power dissipation and ease of maintenance is required. The motor logic solid-state overload relay instead of relying on heat produced unlike the thermal overload relay, it will depends on the measurement of the magnetic field which is free from the disturbance of the ambient temperature. The solid-state overload relay will provide an electric measure of the magnetic field of the prevailing current and the response is sent to the digital electronic unit that trips the motor current before it meets an accident.**

Courtesy: Reference Links: [1] [2] [3]

M. What type of environmental protection do you get from an AC motor rated IP64?

Sol.

Based on the reference document for this problem, an AC motor rated IP64 would possess the following environmental protection:

1. For exposure to solids – it will be protected from total dust ingress. In short, it will be dust tight and can stand for as many as 2-8 hours with this protection.
2. For exposure to Liquids – It will be protected against water splashed / sprayed from all directions. Duration of up to 5 minutes shall have no harmful effects.

Courtesy: Reference link: [1] [2]

N. If the ratio of voltage to frequency is held constant throughout the speed range of an AC variable motor speed system, why does the motor power increase linearly with speed?

Sol.

Based on the referenced documents and the solution to Problem F, for an AC motor, varying the voltage frequency affects both the motor speed and the strength of the magnetic field. When the frequency is lowered (for slower motor speed), the magnetic field increases, and excessive heat is generated. When the frequency is increased (for higher motor speed), the magnetic field decreases, and lower torque is produced. In order to keep the magnetic flux constant, the V/Hz ratio must remain constant. This keeps torque production stable, regardless of frequency.

Thus, ***when the voltage to frequency ratio is held constant, the rated torque for a motor remains constant*** which is linearly proportional to the motor output power and is inversely proportional to the motor speed (RPM).

To calculate the rated torque of a motor the following formula can be used:

$$M = \frac{30{,}000 \times P}{\pi \times n} \text{Nm}$$

Where P = output, kW
n = motor speed, r/min.

Thus, based on the screenshot provided in this solution from the referenced document, ***it is clear that if the motor rated torque remains constant which means that M remains constant in the above equation then the ratio of output power (kW) to the motor speed (RPM) must again remain constant. This means that the output power (kW) must vary linearly with the change in the motor speed (RPM). Hence, if the V/Hz ratio is kept constant, it results into constant torque which results into constant Power/Speed ratio which is why the motor power increases and varies linearly with speed of the motor.***

Courtesy: Reference link: [1] [2] [3]

O. Suppose a 3-phase AC motor is rated at 60 Hz 575V, 7.4 A, 7.5 hp, 3501 RPM, and 12 lb-ft torque. It is wired into a Star/Delta (a.k.a. Wye-Delta) starting system. With the Star and Main contactors energized, and the Delta contacts open, at what voltage, current, and torque (lb-ft) will the motor operate?

Sol. **2.467 A, 4 lb.-ft. and 331.97 V**

Based on the reference provided in the assignments page on Canvas, in this problem, the Delta contacts are open and the Star and Main contactors are energized. In this case, the current through the winding would be 1 / 3 of the total in-line current. Thus, the current through the motor current would be ((1/3) x 7.4 A = **2.467 A**).

Moreover, with the above conditions, the torque generated would be one-third of the rated torque value and therefore it will be ((1/3) x 12 lb.-ft. = **4 lb.-ft.**).

Based on the class slides and the referenced document, the voltage would be actually (1 / (root 3)) times of the rated voltage and therefore the voltage through the motor would be: (575 V / (root 3)) = **331.97 V**.

Courtesy: Class slide – C2M2V7

Part 2: The question is worth 25 points, with each sub-question worth 6.25 points.

P. You need to select a 3-phase 460V, 60 Hz AC motor and the associated motor starter, thermal overload relay, circuit breaker and motor contactor for a pump in a propane refinery.

The pump runs 5000 hours per year. The impeller of the pump runs at 3450 RPM, and its impeller must apply 1.5 lb-ft of rated torque. The pump runs in only one direction. The pump operates such that:
"hot gases generated during an internal explosion are cooled below the gas ignition temperature as they escape"

P.1. Select a suitable motor from the web site www.baldor.com. Show the part number and screen shots of the various motor specs that will allow you to select the other components needed.

Sol.

Calculating for 1 HP, the 460V, 60 Hz AC motor as shown below works well for the proposed problem. A Class F insulation is normally suited for severe-applications and since nothing has been said about the temperature in this problem, it is assumed that a Class F insulation will be suitable for 20000 hours of operation life.

The motor details can be accessed by clicking here.

ECP83580T-4

1HP, 3450RPM, 3PH, 60HZ, 143, T, 0516M, TEFC, F1

Product Information Packet PDF

List Price	1,043.00 USD
Multiplier Symbol	SD
Ship Weight	60 LB
UPC	781568295632

The specs can be accessed by clicking the same link as above.

Output	1.000 hp	**Lifting Lugs**	Standard Lifting Lugs
Phase	3	**Locked Bearing Indicator**	Locked Bearing
Synchronous Speed	3,600 rpm	**Max Speed**	5,400 rpm
Frequency	60.00 Hz	**Motor Lead Exit**	KO Box
Voltage	460 V	**Motor Lead Quantity/Wire Size**	3 @ 18 AWG @ 0 AWG
Frame Material	Iron	**Motor Lead Termination**	Flying Leads
Frame	143T	**Motor Standards**	NEMA
XP Class and Group	Class I, Group A,B,C & D	**Motor Type**	0516M
XP Division	Division II	**Number of Poles**	2
Brand	Baldor-Reliance	**Overall Length**	12.88 in
Agency Approvals	CSA CSA EEV UR	**Power Factor**	82
Ambient Temperature	40 °C	**Product Family**	Chem Process S/P 32-8 IEEE 841

Auxillary Box	No Auxillary Box	**Pulley End Bearing Type**	Ball
Auxillary Box Lead Termination	None	**Pulley Face Code**	Standard
Base Indicator	Rigid	**Pulley Shaft Indicator**	Standard
Bearing Grease Type	POLYREX EM (-20F +300F)	**Rodent Screen**	None
Blower	None	**Service Factor**	1.25
Constant Torque Speed Range	6	**Shaft Diameter**	0.875 in
Current	1.4 A	**Shaft Extension Location**	Pulley End
Design Code	B	**Shaft Ground Indicator**	No Shaft Grounding
Drip Cover	No Drip Cover	**Shaft Rotation**	Reversible
Duty Rating	CONT	**Shaft Slinger Indicator**	Shaft Slinger
Efficiency @ 100% Load	84.0%	**Speed**	3,450 rpm
Electrically Isolated Bearing	Not Electrically Isolated	**Speed Code**	Single Speed
Feedback Device	No feedback	**Starting Method**	Direct on line
Front Face Code	Standard	**Thermal Device - Bearing**	NONE (OLD)
		Thermal Device - Winding	None

Front Shaft Indicator	None
Heater Indicator	No heater
High Voltage Full Load Amps	1.4 A
Insulation Class	F
Inverter Code	Inverter duty
KVA Code	L

Vibration Sensor Indicator	No Vibration Sensor
Winding Thermal 1	None
Winding Thermal 2	None
XP Temp Code	T4

Courtesy: Links: [1] [2] [3] [4] – Links will take to the motor specs and data from where it has been selected.

P.2. Select a suitable Square D brand motor starter from the web site www.schneider-electric.us Show the part number and screen shots of the various motor specs that will allow you to select the other components needed.

Sol.

The selected starter can be accessed by clicking here.

Product datasheet link: here.

Characteristics Documents and Downloads Technical FAQs Additional Information

Main	
product or component type	Starter
Type	S
Control Circuit Type	Common control circuit
Complementary	
Control Circuit Voltage	110 V AC 50 Hz 120 V AC 60 Hz
motor starter type	Non reversing
Line Rated Current	18 A
Number of Poles	2P
Phase	1 phase
Horsepower Rating	1 HP 115 V AC 2 HP 230 V AC
System Voltage	600 V AC
Control Units	No control units
thermal overload type	Melting alloy 1 Thermal Units
electrical connection	Screw clamp terminals
NEMA size	0
height	12.76 in (324 mm)
depth	8.54 in (217 mm)
width	6.38 in (162 mm)
Environment	
Enclosure Type	NEMA 12 painted sheet steel
product certifications	CSA NEMA UL listed

Link: {here}

P.3. Select a suitable Square D brand thermal overload relay from the web site www.schneider-electric.us Show the part number and screen shots of the various motor specs that will allow you to select the other components needed.

Sol.

The selected overload relay can be accessed by clicking here.

Product datasheet link: here.

< Range: 9065 Thermal Overload Relay

Overload Relays

9065SADR75

Bimetal Overload Relay Overload Relay Adapter 3 Phase Replacement

Show more characteristics >

Product availability

Non-Stock - Not normally stocked in distribution facility

Price

89.00 USD

> Where to Buy

> Sales support

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Characteristics | Documents and Downloads | Technical FAQs

Main	
range of product	Accessory
product destination	Overload relay
thermal overload type	Ambient compensated bimetallic

Complementary	
Phase	3 phases
System Voltage	600 V AC

Ordering and shipping details	
Category	21661 - 9065 A,C,F,G,S(NOT SS)
Discount Schedule	CP1
GTIN	00785901474326
Nbr. of units in pkg.	1

overload-relay-overload-relay-adapter-3-phase-replacement/?range=6...7-9065-thermal-overload-relay&node=166388679-overload-relays&parent-categc

Package weight(Lbs)	0.51000000000000001
Returnability	N
Country of origin	MX
Offer Sustainability	
RoHS (date code: YYWW)	Schneider Electric declaration of conformity
California proposition 65	WARNING: This product can expose you to chemicals including:
------- Substance 1	Lead and lead compounds, which is known to the State of California to cause cancer and birth defects or other reproductive harm.
------- More information	For more information go to www.p65warnings.ca.gov

Link: {here}

P.4. Select a suitable Siemens brand AC motor contactor from the web site www.grainger.com. Show the part number and screen shots of the various motor specs that will allow you to select the other components needed.

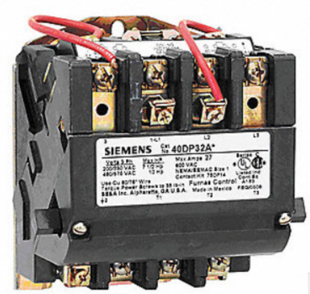
Sol.

The selected contactor can be accessed by clicking here.

SIEMENS

480VAC NEMA Magnetic Contactor; No. of Poles: 3, Reversing: No, 9 Full Load Amps

Item # **44F316** Mfr. Model # **40BP32AH** Catalog Page # **N/A** Catalog Group # **H3784** UNSPSC # **39121529**



Web Price
$220.50 / each

One Time Delivery
Auto Reorder

1 ADD TO CART

+ Add to List

Shipping Pickup

Ships from supplier to branch. Available for pickup on or before Fri. Nov 09.

DENVER Branch #216
Branch Info | Change

Be the first to write a review

Shipping Weight **2.84 lbs.**

Country of Origin **Mexico** | *Country of Origin is subject to change.*

Note: Product availability is real-time updated and adjusted continuously. The product will be reserved for you when you complete your order. More

How can we **improve our Product Images**?

Compare

Technical Specs

Item	**NEMA Magnetic Contactor**	Number of Poles	**3**
Full Load Amps	**9**	Enclosure NEMA Rating	**No Enclosure**
Coil Volts	**480VAC**	Auxiliary Contact Form	**1NO**
NEMA Contactor Size	**00**	Hz	**60**
Reversing	**No**	Height	**3.94"**
HP @ 3 Phase - 208V	**1-1/2**	Width	**4.31"**
HP @ 3 Phase - 240V	**1-1/2**	Depth	**4.25"**
HP @ 3 Phase - 480V	**2**	Frame / Series / Class / Code	**Class 40**
HP @ 3 Phase - 575V	**2**	Standards	**UL File Number E14900, CSA File Number LR6535**