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# Introduction

Welcome to another course in the STEP 2000 series, **Siemens Technical Education Program**, designed to prepare our distributors to sell Siemens Energy & Automation products more effectively. This course covers **Basics of AC Drives** and related products.

Upon completion of **Basics of AC Drives** you should be able to:

- Explain the concept of force, inertia, speed, and torque
- Explain the difference between work and power
- Describe the construction of a squirrel cage AC motor
- Identify the nameplate information of an AC motor necessary for application to an AC Drive
- Describe the operation of a three-phase rotating magnetic field
- Calculate synchronous speed, slip, and rotor speed
- Describe the relationship between V/Hz, torque, and current
- Describe the basic construction and operation of a PWM type AC drive
- Describe features and operation of the Siemens MICROMASTER, MICROMASTER Junior, MICROMASTER Vector, MIDIMASTER Vector, and MASTERDRIVES
- Describe the characteristics of constant torque, constant horsepower, and variable torque applications

This knowledge will help you better understand customer applications. In addition, you will be able to describe products to customers and determine important differences between products. You should complete **Basics of Electricity** before attempting **Basics of AC Drives**. An understanding of many of the concepts covered in **Basics of Electricity** is required for **Basics of AC Drives**.

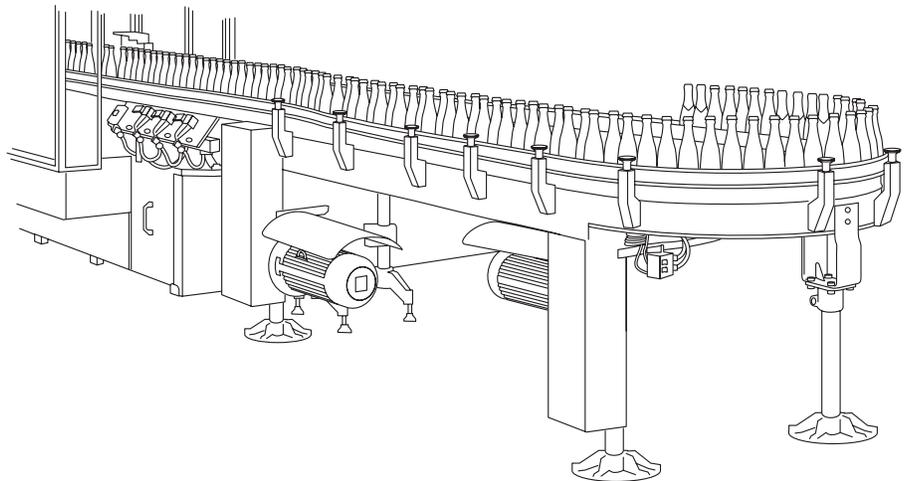
If you are an employee of a Siemens Energy & Automation authorized distributor, fill out the final exam tear-out card and mail in the card. We will mail you a certificate of completion if you score a passing grade. Good luck with your efforts.

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National Electrical Manufacturers Association is located at 2101 L. Street, N.W., Washington, D.C. 20037. The abbreviation "NEMA" is understood to mean National Electrical Manufacturers Association.

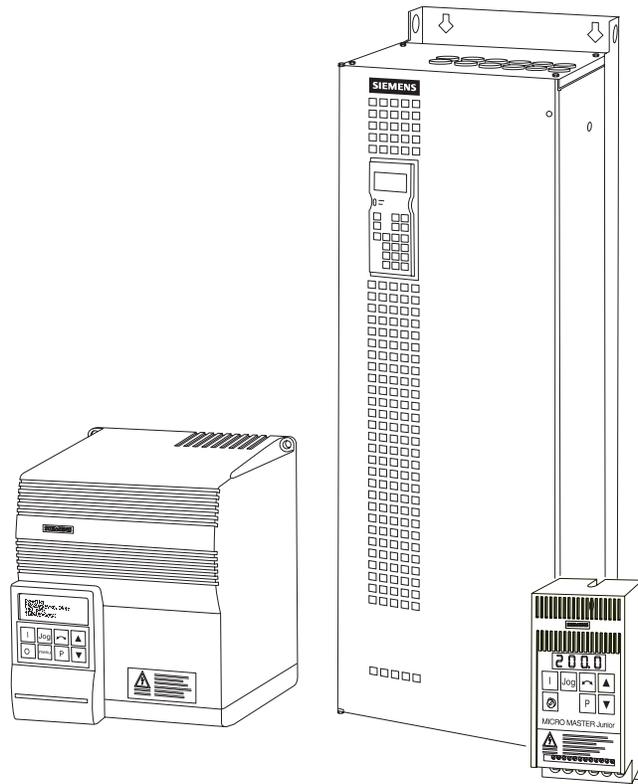
# Force and Motion

In many commercial, industrial, and utility applications electric motors are used to transform electrical energy into mechanical energy. Those electric motors may be part of a pump or fan, or they may be connected to some other form of mechanical equipment such as a conveyor or mixer. In many of these applications the speed of the system is determined primarily by its mechanical design and loading. For an increasing number of these applications, however, it is necessary to control the speed of the system by controlling the speed of the motor.



## AC drives

The speed of the motor can be controlled by using some type of electronic drive equipment, referred to as variable or adjustable speed drives. Variable speed drives used to control DC motors are called DC drives. Variable speed drives, like the Siemens MICROMASTER, MICROMASTER Junior, MICROMASTER Vector, MIDIMASTER Vector, and MASTERDRIVES, used to control AC motors are called AC drives. The term inverter is also used to describe an AC variable speed drive. The inverter is only one part of an AC drive, however, it is common practice to refer to an AC drive as an inverter.



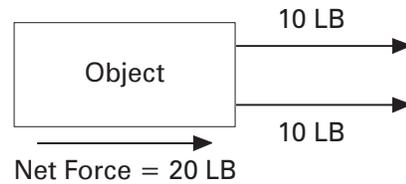
Before discussing AC drives it is necessary to understand some of the basic terminology associated with drive operation. Many of these terms are familiar to us in some other context. Later in the course we will see how these terms apply to AC drives.

## Force

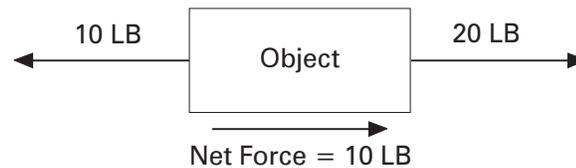
In simple terms, a force is a push or a pull. Force may be caused by electromagnetism, gravity, or a combination of physical means.

## Net force

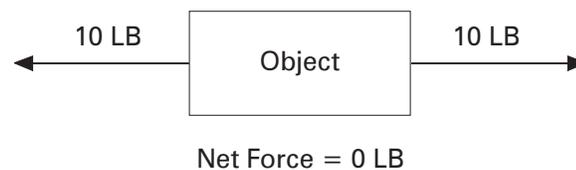
Net force is the vector sum of all forces that act on an object, including friction and gravity. When forces are applied in the same direction they are added. For example, if two 10 pound forces were applied in the same direction the net force would be 20 pounds.



If 10 pounds of force were applied in one direction and 20 pounds of force applied in the opposite direction, the net force would be 10 pounds and the object would move in the direction of the greater force.

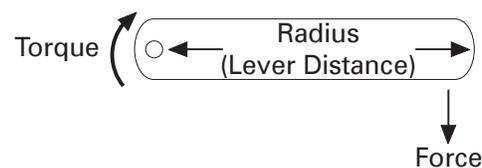


If 10 pounds of force were applied equally in both directions, the net force would be zero and the object would not move.



## Torque

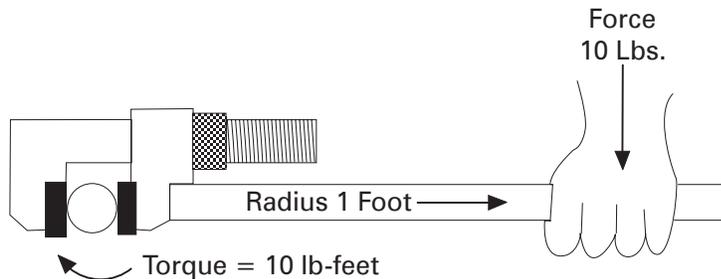
Torque is a twisting or turning force that causes an object to rotate. For example, a force applied to the end of a lever causes a turning effect or torque at the pivot point.



Torque (T) is the product of force and radius (lever distance) and is typically measured in lb-feet.

$$\text{Torque} = \text{Force} \times \text{Radius}$$

It can be seen that increasing force or increasing the radius increases torque. For example, if 10 pounds of force were applied to a lever 1 foot long there would be 10 lb-feet of torque. Increasing the force to 20 pounds, or the lever to two feet would increase the torque to 20 lb-feet.



## Inertia

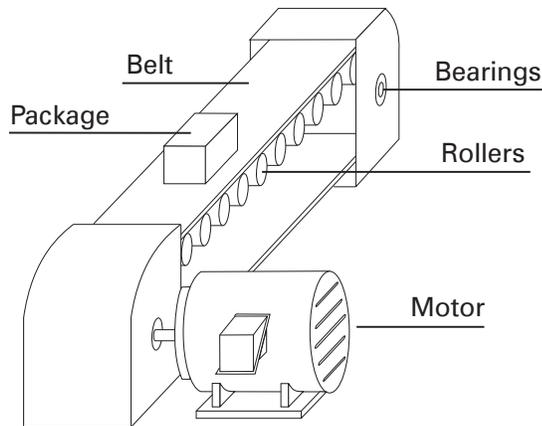
Mechanical systems are subject to the law of inertia. The law of inertia states that an object will tend to remain in its current state of rest or motion unless acted upon by an external force. A soccer ball, for example, remains at rest until a player applies a force by kicking the ball. The ball will remain in motion until another force, such as friction or the goal net, stops it.



## Friction

Because friction removes energy from a mechanical system, a continual force must be applied to keep an object in motion. The law of inertia is still valid, however, since the force applied is needed only to compensate for the energy lost. In the following illustration, a motor runs a conveyor. A large amount of force is applied to overcome inertia and start the system. Once the system is in motion only the energy required to compensate for various losses need be applied to keep the conveyor in motion. These losses include:

- Friction within motor and conveyor bearings
- Wind losses in the motor and conveyor
- Friction between conveyor belt and rollers

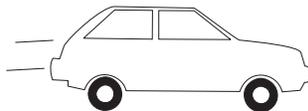


## Speed

An object in motion travels a distance in a given time. Speed is the ratio of the distance traveled and the time it takes to travel the distance.

$$\text{Speed} = \frac{\text{Distance}}{\text{Time}}$$

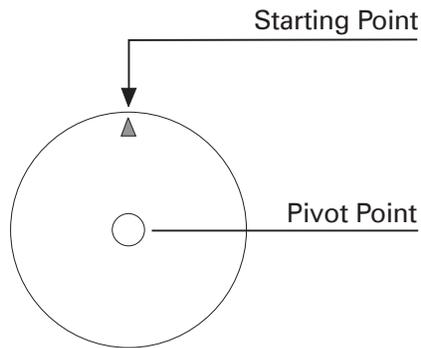
A car, for example, may travel 60 miles in one hour. The speed of the car is 60 miles per hour (MPH).



$$60 \text{ MPH} = \frac{60 \text{ Miles}}{1 \text{ Hour}}$$

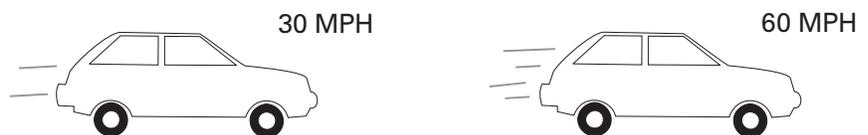
## Speed of a rotating object

Speed also applies to a rotating object, such as the tire of a car or the shaft of a motor. The speed of a rotating object is a measurement of how long it takes a given point on the rotating object to make one complete revolution from its starting point. Speed of a rotating object is generally given in revolutions per minute (RPM). An object that makes ten complete revolutions in one minute has a speed of 10 RPM.

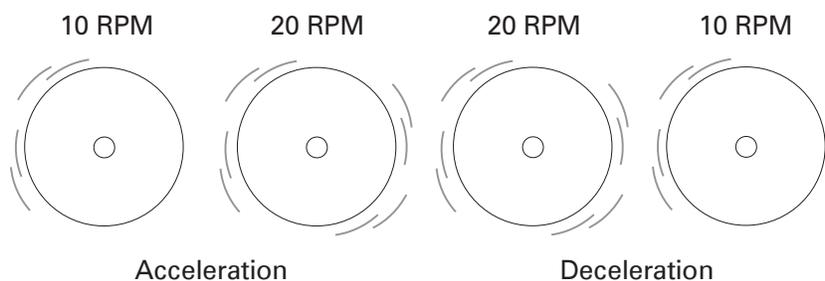


## Acceleration

An object can change speed. This change in speed is called acceleration. Acceleration only occurs when there is a change in the force acting upon the object. A car increases speed from 30 MPH to 60 MPH. There has been a change in speed of 30 MPH. An object can also change from a higher to a lower speed. This is known as deceleration (negative acceleration).



Acceleration and deceleration also apply to rotating objects. A rotating object, for example, can accelerate from 10 RPM to 20 RPM, or decelerate from 20 RPM to 10 RPM.



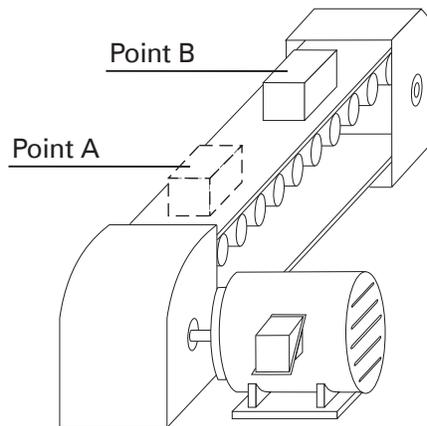
## Review 1

1. A \_\_\_\_\_ is a push or a pull.
2. An object has 20 pounds of force applied in one direction and 5 pounds of force applied in the opposite direction. The net force is \_\_\_\_\_ pounds.
3. A twisting or turning force that causes an object to rotate is known as \_\_\_\_\_ .
4. If 40 pounds of force were applied to a lever 2 feet long, the torque would be \_\_\_\_\_ lb-feet.
5. The law of \_\_\_\_\_ states that an object will tend to remain in its current state of rest or motion unless acted upon by an external force.
6. \_\_\_\_\_ is the ratio of distance traveled and time.
7. The speed of a rotating object is generally given in \_\_\_\_\_ per \_\_\_\_\_ .
8. \_\_\_\_\_ only occurs when there is a change in an object's state of motion.

# Energy

## Work

Whenever a force of any kind causes motion, work is accomplished. For example, work is accomplished when a conveyor belt moves a package from point A to point B.



Work is generally expressed in foot-pounds and is defined by the product of the net force ( $F$ ) applied and the distance ( $d$ ) moved. If twice the force is applied, twice the work is done. If an object moves twice the distance, twice the work is done.

$$W = F \times d$$

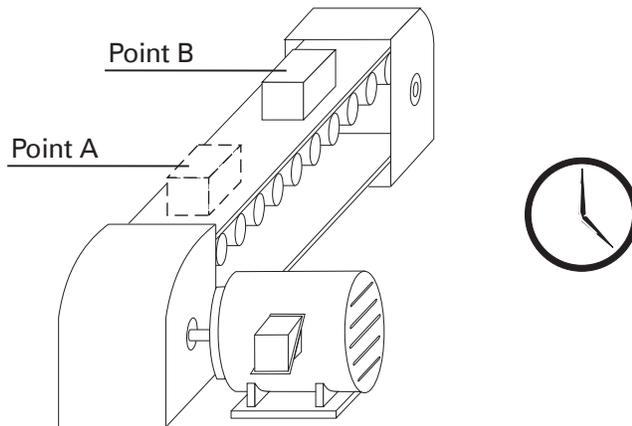
## Power

Power is the rate of doing work, or work divided by time.

$$Power = \frac{Force \times Distance}{Time}$$

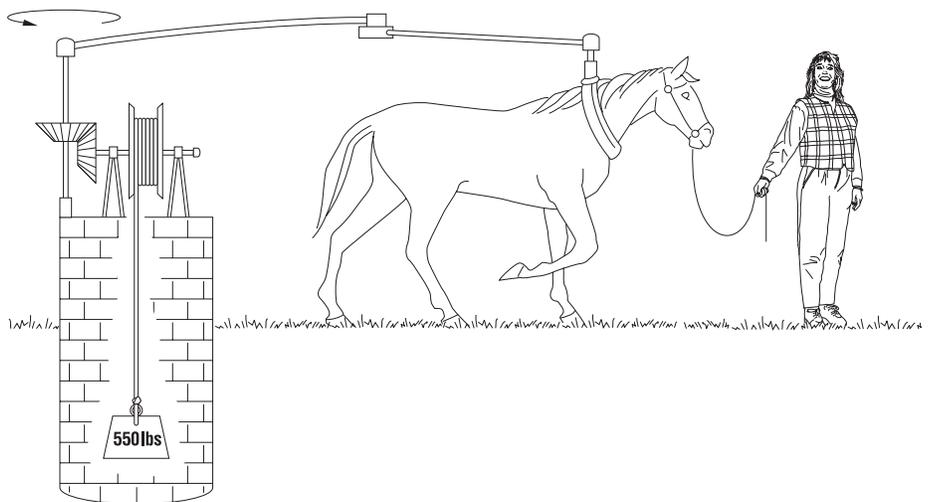
$$Power = \frac{Work}{Time}$$

In other words, power is the amount of work it takes to move the package from point A to point B, divided by the time.



## Horsepower

Power can be expressed in foot-pounds per second, but is often expressed in horsepower (HP). This unit was defined in the 18th century by James Watt. Watt sold steam engines and was asked how many horses one steam engine would replace. He had horses walk around a wheel that would lift a weight. He found that each horse would average about 550 foot-pounds of work per second. One horsepower is equivalent to 550 foot-pounds per second or 33,000 foot-pounds per minute.

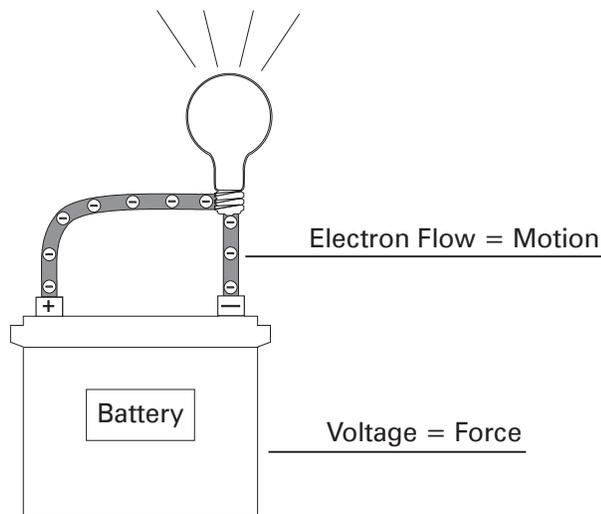


The following formula can be used to calculate horsepower when torque (in lb-ft) and speed are known. An increase of torque, speed, or both will cause an increase in horsepower.

$$HP = \frac{T \times RPM}{5250}$$

# Electrical Energy

In an electrical circuit, voltage applied to a conductor will cause electrons to flow. Voltage is the force and electron flow is the motion.



The rate at which work is done is called power and is represented by the symbol "P". Power is measured in watts represented by the symbol "W". The watt is defined as *the rate work is done in a circuit when 1 amp flows with 1 volt applied*.

## Power in a DC circuit

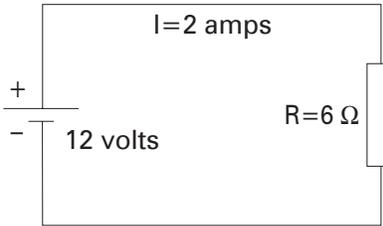
Power consumed in a resistor depends on the amount of current that passes through the resistor for a given voltage. This is expressed as voltage (E) times current (I).

$$P = E \times I$$

or

$$P = EI$$

In the following simple DC circuit power can be calculated.



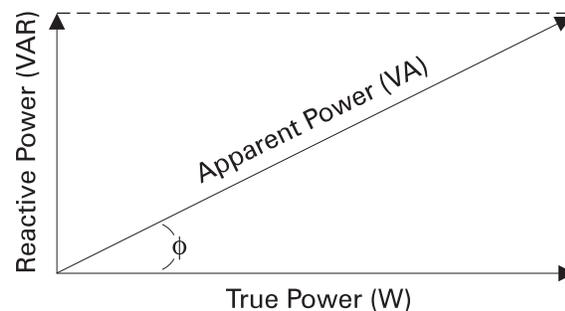
$$P = EI$$

$$P = 12 \text{ volts} \times 2 \text{ amps}$$

$$P = 24 \text{ watts}$$

### Power in an AC circuit

Resistance is not the only circuit property that effects power in an AC circuit. Power consumed by a resistor is dissipated in heat and not returned to the source. This power is used to do useful work and is called true power. True power is the rate at which energy is used and is measured in watts (W). Current in an AC circuit rises to peak values and diminishes to zero many times a second. The energy stored in the magnetic field of an inductor or plates of a capacitor is returned to the source when current changes direction. This power is not consumed and is called reactive power. Reactive power is measured in volt-amps reactive (VAR). Power in an AC circuit is the vector sum of true power and reactive power. This is called apparent power. Apparent power is measured in volt-amps (VA).



The formula for apparent power is:

$$P = EI$$

True power is calculated from a trigonometric function, the cosine of the phase angle ( $\cos \phi$  as shown on the previous page). The formula for true power is:

$$P = EI \cos \phi$$

## Power factor

Power factor is the ratio of true power to apparent power, or a measurement of how much power is consumed and how much power is returned to the source. Power factor is equal to the cosine of the phase angle.

$$PF = \cos \phi$$

In a purely resistive circuit where current and voltage are in phase, there is no angle of displacement between current and voltage. The cosine of a zero degree angle is one. The power factor is one. This means that all energy delivered by the source is consumed by the circuit and dissipated in the form of heat.

## Horsepower and kilowatts

AC drives and motors manufactured in the United States are generally rated in horsepower (HP). Equipment manufactured in Europe is generally rated in kilowatts (KW). Horsepower can be converted to kilowatts with the following formula:

$$KW = .746 \times HP$$

For example, a 25 HP motor is equivalent to 18.65 KW.

$$18.65 \text{ KW} = .746 \times 25 \text{ HP}$$

Kilowatts can be converted to horsepower with the following formula:

$$HP = 1.341 \times KW$$

The power formula for a single-phase system is:

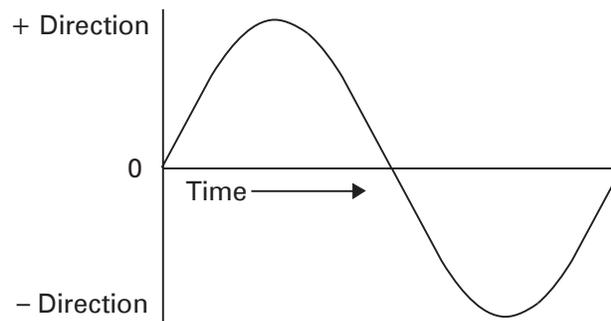
$$KW = \frac{V \times I \times PF}{1000}$$

The power formula for three-phase power is:

$$KW = \frac{V \times I \times PF \times 1.732}{1000}$$

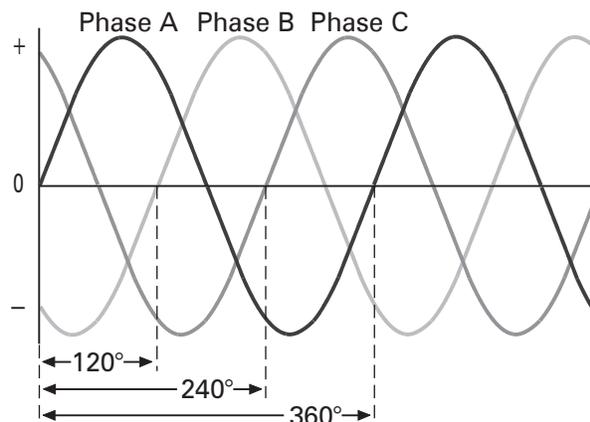
### Single-phase power

Power is considered single-phase when it is operated by one voltage source. Single-phase power is used for small electrical demands such as found in the home. Single-phase power can also be found in some light duty commercial and industrial applications.



### Three-phase power

Three-phase power is produced by three voltage sources. Three-phase power is a continuous series of three overlapping AC voltages. Each voltage wave represents a phase and is offset by 120 electrical degrees. Three-phase power is used where a large quantity of electrical power is required, such as commercial and industrial applications.

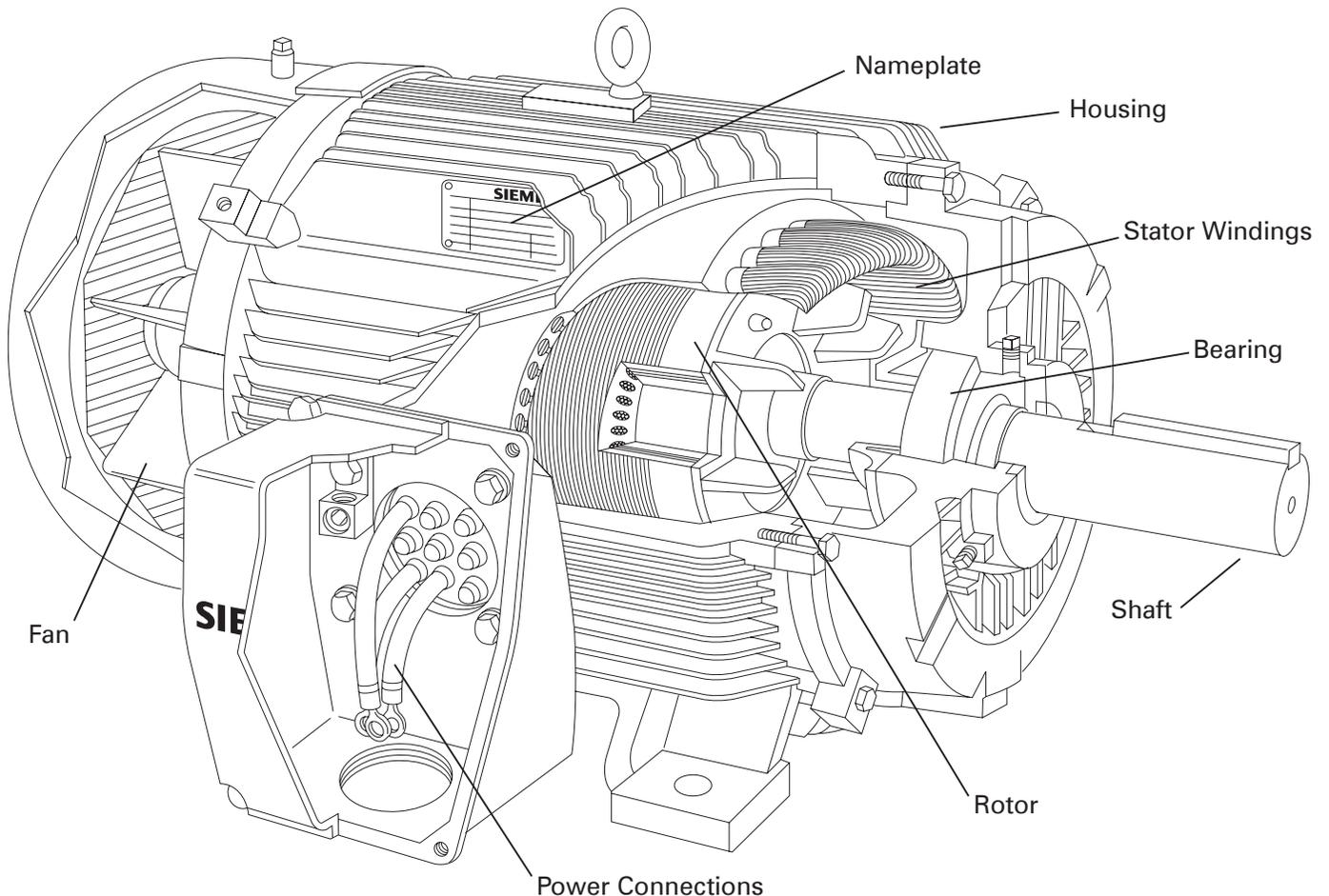


## Review 2

1. \_\_\_\_\_ is accomplished whenever force causes motion.
2. \_\_\_\_\_ is the rate of doing work.
3. In an electrical circuit the force required to cause electron flow is called \_\_\_\_\_ .
4. Power used to do work is called \_\_\_\_\_ power.
5. True power is measured in \_\_\_\_\_ and apparent power is measured in \_\_\_\_\_ .
6. The ratio of true power to apparent power is known as \_\_\_\_\_ .
7. 18 KW is equivalent to \_\_\_\_\_ HP.

# AC Motor Construction

AC induction motors are commonly used in industrial applications. The following motor discussion will center around three-phase, 460 VAC, asynchronous, induction motors. An asynchronous motor is a type of motor where the speed of the rotor is other than the speed of the rotating magnetic field. This type of motor is illustrated. Electromagnetic stator windings are mounted in a housing. Power connections, attached to the stator windings, are brought out to be attached to a three-phase power supply. On three-phase, dual-voltage motors nine leads are supplied for power connections. Three power connection leads are shown in the following illustration for simplicity. A rotor is mounted on a shaft and supported by bearings. On self-cooled motors, like the one shown, a fan is mounted on the shaft to force cooling air over the motor.



## Nameplate

The nameplate of a motor provides important information necessary when applying a motor to an AC drive. The following drawing illustrates the nameplate of a sample 25 horsepower AC motor.

<b>SIEMENS</b>										
PE ● 21 PLUS™					PREMIUM EFFICIENCY					
MILL AND CHEMICAL DUTY QUALITY INDUCTION MOTOR										
ORD.NO.	51-502-033				DATE CODE	017				
TYPE	RG Z ESD				FRAME	284T				
H.P.	25				SERVICE FACTOR	1.15				
AMPS.	56.8/28.4				VOLTS	230/460				
R.P.M.	1750				HERTZ	60				LOW VOLT. CONN.
DUTY	CONT. 40° C AMB.				3 PH				HIGH VOLT. CONN.	
CLASS INSUL	F	NEMA Design	B	K.V.A. CODE	G	NEMA NOM.EFF.	93.0			
SH. END BRG.	50BC03JPP3				OPP. END BRG.	458C02JPP3				
Siemens Energy & Automation, Inc. Little Rock, AR <span style="float: right;">MADE IN USA</span>										

## Voltage connections and amps

This motor can be used on either 230 VAC or 460 VAC systems. A wiring diagram indicates the proper connection of the input power leads for the desired voltage. The low voltage connection is intended for use on 230 VAC with a maximum full load current of 56.8 Amps. The high voltage connection is intended for use on 460 VAC with a maximum full load current of 28.4 Amps.

## Base speed

Base speed is the nameplate speed, given in RPM, where the motor develops rated horsepower at rated voltage and frequency. It is an indication of how fast the output shaft will turn the connected equipment when fully loaded and proper voltage is applied at 60 hertz. The base speed of this motor is 1750 RPM at 60 Hz. If the connected equipment is operating at less than full load, the output speed will be slightly greater than base speed.

It should be noted that with European and Asian motors and many special motors such as those used in the textile industry that base speed, frequency and voltage may be different than standard American motors. This is not a problem, however, because the voltage and frequency supplied to a variable speed drive does not have to be the same as the motor. The supply voltage to a variable speed drive has nothing to do with motor voltage, speed or frequency. A variable speed drive can be set up to work with any motor within a reasonable size range and rating.

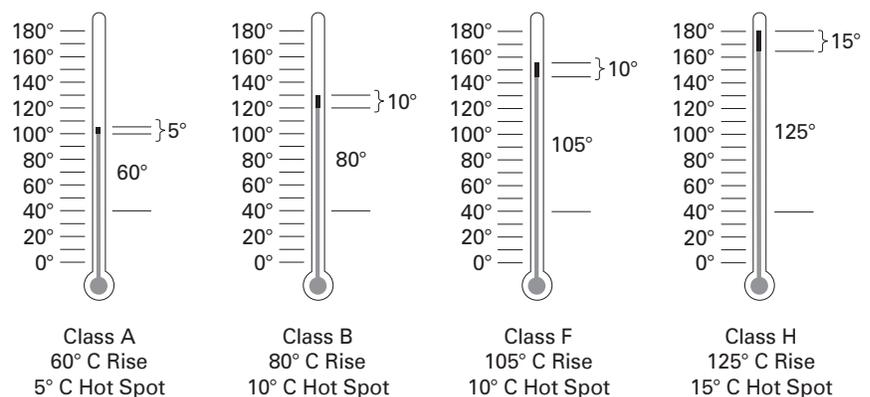
## Service factor

A motor designed to operate at its nameplate horsepower rating has a service factor of 1.0. Some applications may require a motor to exceed the rated horsepower. In these cases a motor with a service factor of 1.15 can be specified. The service factor is a multiplier that may be applied to the rated power. A 1.15 service factor motor can be operated 15% higher than the motor's nameplate horsepower. Motors with a service factor of 1.15 are recommended for use with AC drives.

## Insulation class

The National Electrical Manufacturers Association (NEMA) has established insulation classes to meet motor temperature requirements found in different operating environments. The four insulation classes are A, B, F, and H. Class F is commonly used. Class A is seldom used. Before a motor is started, its windings are at the temperature of the surrounding air. This is known as ambient temperature. NEMA has standardized on an ambient temperature of 40° C, or 104° F for all motor classes.

Temperature will rise in the motor as soon as it is started. Each insulation class has a specified allowable temperature rise. The combination of ambient temperature and allowed temperature rise equals the maximum winding temperature in a motor. A motor with Class F insulation, for example, has a maximum temperature rise of 105° C. The maximum winding temperature is 145° C (40° ambient plus 105° rise). A margin is allowed to provide for a point at the center of the motor's windings where the temperature is higher. This is referred to as the motor's hot spot.



The operating temperature of a motor is important to efficient operation and long life. Operating a motor above the limits of the insulation class reduces the motor's life expectancy. A 10° C increase in the operating temperature can decrease the life expectancy of a motor as much as 50%.

**NEMA design**

The National Electrical Manufacturers Association (NEMA) has established standards for motor construction and performance. The nameplate on page 20 is for a motor designed to NEMA B specifications. NEMA B motors are commonly used with AC drives. Any NEMA design (A, B, C, or D) AC motor will work perfectly well with a properly sized variable speed drive.

**Efficiency**

AC motor efficiency is expressed as a percentage. It is an indication of how much input electrical energy is converted to output mechanical energy. The nominal efficiency of this motor is 93.0%.

**Kilowatts and power factor**

Motor manufacturers may also use kilowatts (KW) instead of horsepower and power factor (Cos.  $\phi$ ) instead of efficiency. For example, a motor may be rated at 18 KW, 460 Volts, 30.5 Amps with a power factor of 0.83. To properly setup an AC drive it may be necessary to convert KW to horsepower and calculate efficiency.

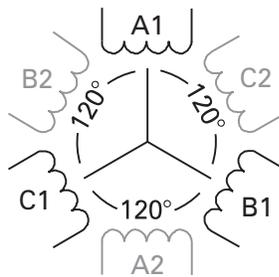
To convert KW to HP use the following equation:

$$HP = 1.341 \times KW$$

$$HP = 24$$

# Developing A Rotating Magnetic Field

A rotating magnetic field must be developed in the stator of an AC motor in order to produce mechanical rotation of the rotor. Wire is coiled into loops and placed in slots in the motor housing. These loops of wire are referred to as the stator windings. The following drawing illustrates a three-phase stator. Phase windings (A, B, and C) are placed  $120^\circ$  apart. In this example, a second set of three-phase windings is installed. The number of poles is determined by how many times a phase winding appears. In this example, each phase winding appears two times. This is a two-pole stator. If each phase winding appeared four times it would be a four-pole stator.



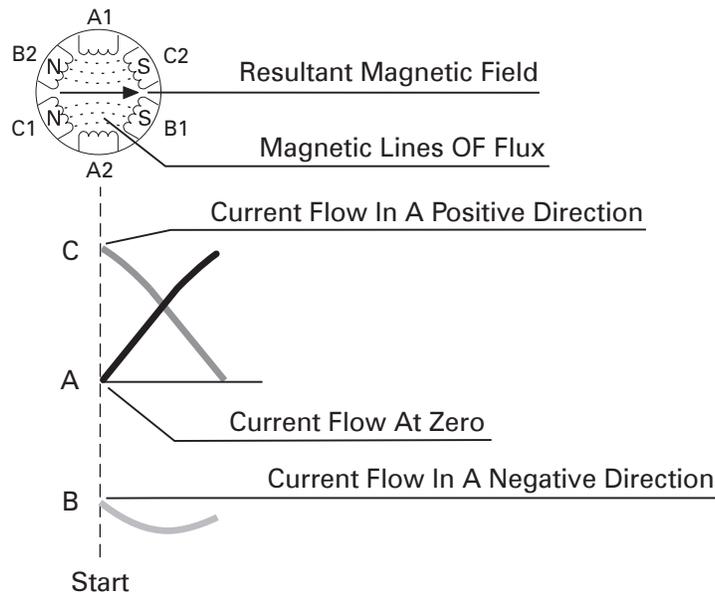
2-Pole Stator Winding

## Magnetic field

When AC voltage is applied to the stator, current flows through the windings. The magnetic field developed in a phase winding depends on the direction of current flow through that winding. The following chart is used here for explanation only. It assumes that a positive current flow in the A1, B1 and C1 windings result in a north pole.

Winding	Current Flow Direction	
	Positive	Negative
A1	North	South
A2	South	North
B1	North	South
B2	South	North
C1	North	South
C2	South	North

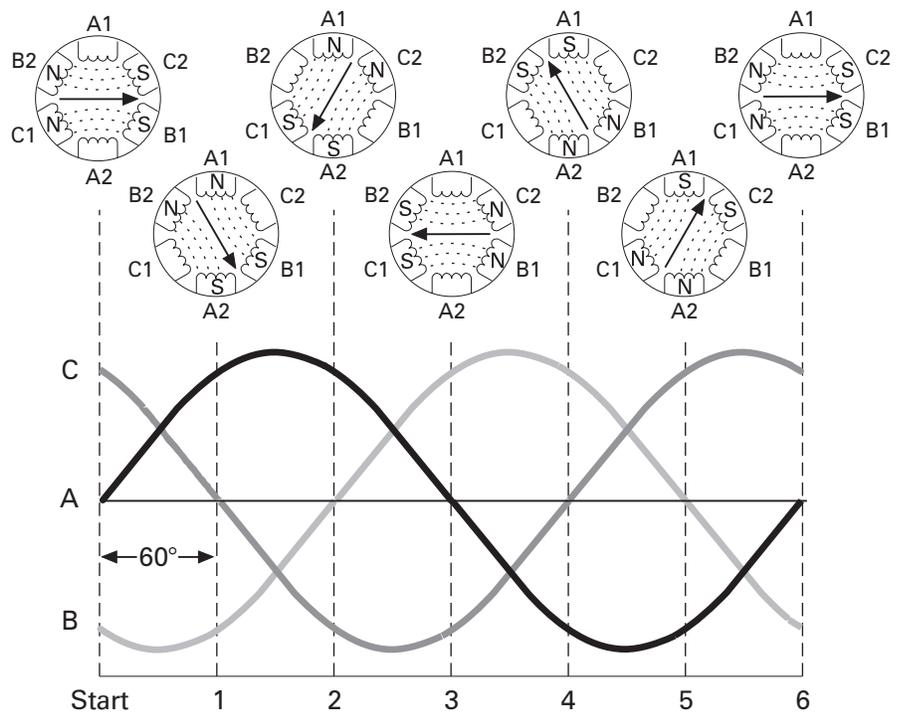
It is easier to visualize a magnetic field if a time is picked when no current is flowing through one phase. In the following illustration, for example, a time has been selected during which phase A has no current flow, phase B has current flow in a negative direction and phase C has current flow in a positive direction. Based on the above chart, B1 and C2 are south poles and B2 and C1 are north poles. Magnetic lines of flux leave the B2 north pole and enter the nearest south pole, C2. Magnetic lines of flux also leave the C1 north pole and enter the nearest south pole, B1. A magnetic field results indicated by the arrow.



The amount of flux lines ( $\Phi$ ) the magnetic field produces is proportional to the voltage (E) divided by the frequency (F). Increasing the supply voltage increases the flux of the magnetic field. Decreasing the frequency increases the flux.

$$\Phi \approx \frac{E}{F}$$

If the field is evaluated at 60° intervals from the starting point, at point 1, it can be seen that the field will rotate 60°. At point 1 phase C has no current flow, phase A has current flow in a positive direction and phase B has current flow in a negative direction. Following the same logic as used for the starting point, windings A1 and B2 are north poles and windings A2 and B1 are south poles. At the end of six such intervals the magnetic field will have rotated one full revolution or 360°.



## Synchronous speed

The speed of the rotating magnetic field is referred to as synchronous speed ( $N_s$ ). Synchronous speed is equal to 120 times the frequency ( $F$ ), divided by the number of poles ( $P$ ).

$$N_s = \frac{120F}{P}$$

If the applied frequency of the two-pole stator used in the previous example is 60 hertz, synchronous speed is 3600 RPM.

$$N_s = \frac{120 \times 60}{2}$$

$$N_s = 3600 \text{ RPM}$$

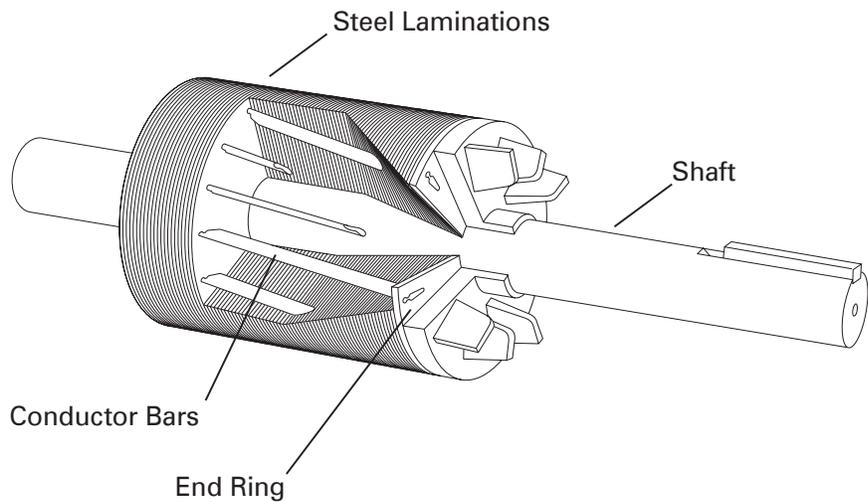
### Review 3

1. Given an AC motor with the following: a nameplate amps of 10/5, and volts of 230/460, the full load amps at 460 volts is \_\_\_\_\_ amps.
2. A motor which is permitted to exceed the rated horsepower by 15% has a service factor of \_\_\_\_\_.
3. A motor with a rating of 37 KW would have an equivalent horsepower rating of \_\_\_\_\_ HP.
4. Stator windings in a three-phase, two-pole motor are placed \_\_\_\_\_ degrees apart.
5. The synchronous speed of a four-pole stator with 60 Hertz applied is \_\_\_\_\_ RPM.  
  
The synchronous speed of a four-pole stator with 50 Hertz applied is \_\_\_\_\_ RPM.
6. An increase of stator voltage in a 3-phase AC motor will cause the magnetic lines of flux to \_\_\_\_\_ .
7. An increase of stator frequency in a 3-phase AC motor will cause the magnetic lines of flux to \_\_\_\_\_ .

# Rotor Construction

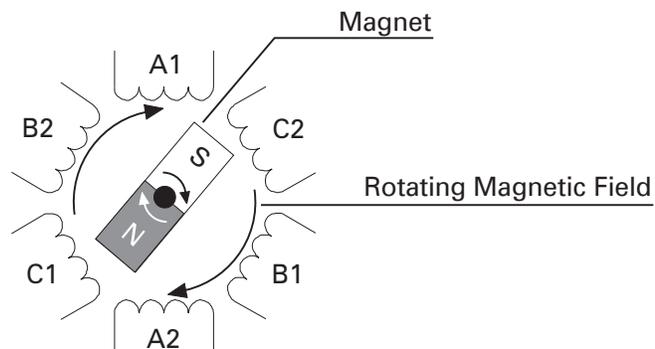
## Rotor construction

The most common type of rotor is the “squirrel cage” rotor. The construction of the squirrel cage rotor is reminiscent of rotating exercise wheels found in cages of pet rodents. The rotor consists of a stack of steel laminations with evenly spaced conductor bars around the circumference. The conductor bars are mechanically and electrically connected with end rings. A slight skewing of the bars helps to reduce audible hum. The rotor and shaft are an integral part.



## Rotating magnet

There is no direct electrical connection between the stator and the rotor or the power supply and the rotor of an induction motor. To see how a rotor works, a magnet mounted on the shaft can be substituted for the squirrel cage rotor. When the stator windings are energized a rotating magnetic field is established. The magnet has its own magnetic field that interacts with the rotating magnetic field of the stator. The north pole of the rotating magnetic field attracts the south pole of the magnet and the south pole of the rotating magnetic field attracts the north pole of the magnet. As the rotating magnetic field rotates, it pulls the magnet along causing it to rotate. This type of design is used on some motors and is referred to as a permanent magnet synchronous motor.

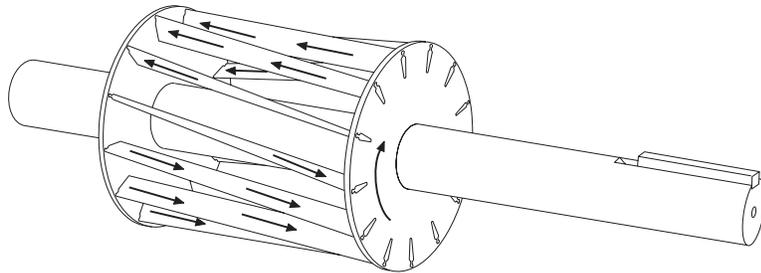


## Rotation of a squirrel cage rotor

The squirrel cage rotor of an AC motor acts essentially the same as the magnet. When a conductor, such as the conductor bars of the rotor, passes through a magnetic field a voltage (emf) is induced in the conductor. The induced voltage causes current flow in the conductor. The amount of induced voltage ( $E$ ) depends on the amount of flux ( $\Phi$ ) and the speed ( $N$ ) at which the conductor cuts through the lines of flux. The more lines of flux, or the faster they are cut, the more voltage is induced. Certain motor constants ( $k$ ), determined by construction also affect induced voltage. These constants, such as rotor bar shape and construction, do not change with speed or load.

$$E = k\Phi N$$

Current flows through the rotor bars and around the end ring. The current flow in the conductor bars produces magnetic fields around each rotor bar. The squirrel cage rotor becomes an electromagnet with alternating north and south poles. The magnetic fields of the rotor interact with the magnetic fields of the stator. It must be remembered that the current and magnetic fields of the stator and rotor are constantly changing. As the stator magnetic field rotates, the rotor and shaft follow.



## Slip

There must be a relative difference in speed between the rotor and the rotating magnetic field. If the rotor and the rotating magnetic field were turning at the same speed no relative motion would exist between the two, therefore no lines of flux would be cut, and no voltage would be induced in the rotor. The difference in speed is called slip. Slip is necessary to produce torque. Slip is dependent on load. An increase in load will cause the rotor to slow down or increase slip. A decrease in load will cause the rotor to speed up or decrease slip. Slip is expressed as a percentage. The percent of slip is calculated by subtracting the rotor (shaft) speed ( $N_R$ ) from the synchronous speed ( $N_S$ ) and then dividing the difference by the synchronous speed. To get a percentage the result is multiplied by 100.

$$\% \text{ Slip} = \frac{N_S - N_R}{N_S} \times 100$$

For example, a four-pole motor operated at 60 Hz has a synchronous speed of 1800 RPM. If the rotor speed at full load were 1750 RPM, the slip is 2.8%.

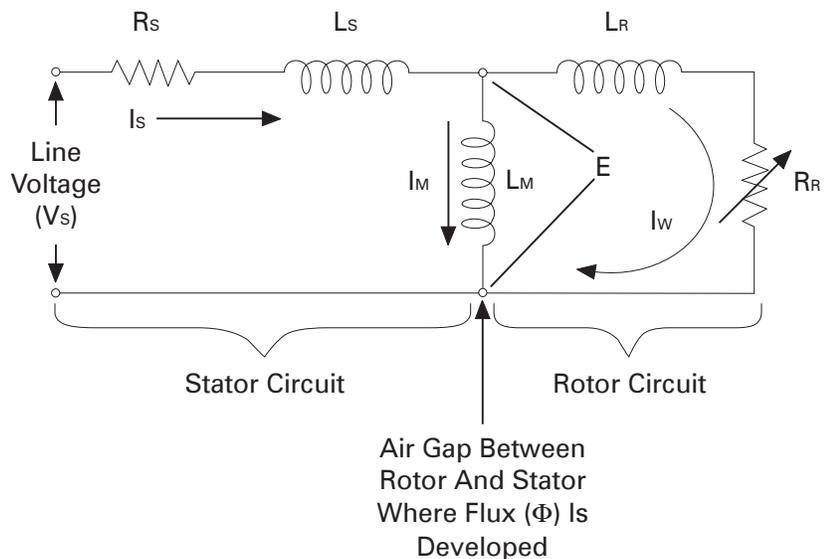
$$\% \text{ Slip} = \frac{1800 - 1750}{1800} \times 100$$

$$\% \text{ Slip} = 2.8\%$$

# Electrical Components Of A Motor

The following diagram represents a simplified equivalent circuit of an AC motor. An understanding of this diagram is important in the understanding of how an AC motor is applied to an AC drive.

- $V_s$  Line voltage applied to stator power leads
- $R_s$  Stator resistance
- $L_s$  Stator leakage inductance
- $I_s$  Stator current
- $E$  Air gap or magnetizing voltage
- $L_M$  Magnetizing inductance
- $I_M$  Magnetizing current
- $R_R$  Rotor resistance (varies with temperature)
- $L_R$  Rotor leakage inductance
- $I_w$  Working or torque producing current



**Line voltage**

Voltage ( $V_s$ ) is applied to the stator power leads from the AC power supply. Voltage drops occur due to stator resistance ( $R_s$ ). The resultant voltage ( $E$ ) represents force (cemf) available to produce magnetizing flux and torque.

**Magnetizing current**

Magnetizing current ( $I_M$ ) is responsible for producing magnetic lines of flux which magnetically link with the rotor circuit. Magnetizing current is typically about 30% of rated current. Magnetizing current, like flux ( $\Phi$ ), is proportional to voltage ( $E$ ) and frequency ( $F$ ).

$$I_M = \frac{E}{2\pi F L_M}$$

**Working current**

The current that flows in the rotor circuit and produces torque is referred to as working current ( $I_W$ ). Working current is a function of the load. An increase in load causes the rotor circuit to work harder increasing working current ( $I_W$ ). A decrease in load decreases the work the rotor circuit does decreasing working current ( $I_W$ ).

**Stator current**

Stator current ( $I_s$ ) is the current that flows in the stator circuit. Stator current can be measured on the supply line and is also referred to as line current. A clamp-on ammeter, for example, is frequently used to measure stator current. The full-load ampere rating on the nameplate of a motor refers to stator current at rated voltage, frequency and load. It is the maximum current the motor can carry without damage. Stator current is the vector sum of working current ( $I_W$ ) and magnetizing current ( $I_M$ ). Typically magnetizing current ( $I_M$ ) remains constant. Working current ( $I_W$ ) will vary with the applied load which causes a corresponding change in stator current ( $I_s$ ).

$$I_s = \sqrt{I_M^2 + I_W^2}$$

# NEMA Rotor Characteristics

The National Electrical Manufacturers Association (NEMA) classifies motors according to locked rotor torque and current, pull up torque, breakdown torque and percent slip. In addition, full-load torque and current must be considered when evaluating an application.

**Note:** Most NEMA terms and concepts apply to motors operated from 60 Hz power lines, not variable speed drive operation.

## Definitions

Locked rotor torque is also referred to as starting torque. This torque is developed when the rotor is held at rest with rated voltage and frequency applied. This condition occurs each time a motor is started. When rated voltage and frequency are applied to the stator there is a brief amount of time before the rotor turns.

Locked rotor current is also referred to as starting current. This is the current taken from the supply line at rated voltage and frequency with the rotor at rest.

Pull up torque is the torque developed during acceleration from start to the point breakdown torque occurs.

Breakdown torque is the maximum torque a motor develops at rated voltage and speed without an abrupt loss of speed.

Full-load torque is the torque developed when the motor is operating with rated voltage, frequency and load.

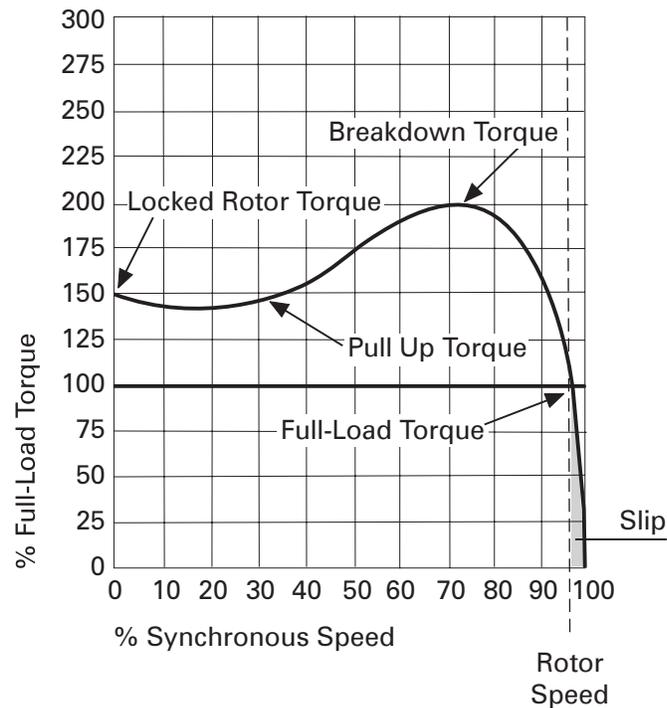
Full-load current is the current taken from the supply line at rated voltage, frequency and load.

## NEMA Classifications

Three-phase AC motors are classified by NEMA as NEMA A, B, C and D. NEMA specifies certain operating characteristics for motors when started by applying rated voltage and frequency (across the line starting). A NEMA B motor, for example, typically requires 600% starting current and 150% starting torque. These considerations do not apply to motors started with an AC drive. NEMA B design motors are the most common and most suitable for use on AC drives.

## NEMA B speed/torque curve

A graph similar to the one illustrated below is used to show the relationship between motor speed and torque of a NEMA B motor. When rated voltage and frequency are applied to the motor, synchronous speed goes to 100% immediately. The rotor must perform a certain amount of work to overcome the mechanical inertia of itself and the connected load. Typically a NEMA B motor will develop 150% torque to start the rotor and load. As the rotor accelerates the relative difference in speed between synchronous speed and rotor speed decreases until the rotor reaches its operating speed. The operating speed of a NEMA B motor with rated voltage, frequency and load is approximately 97% (3% slip) of synchronous speed. The amount of slip and torque is a function of load. With an increase in load there is a corresponding increase in slip and torque. With a decrease in load there is a corresponding decrease in slip and torque.



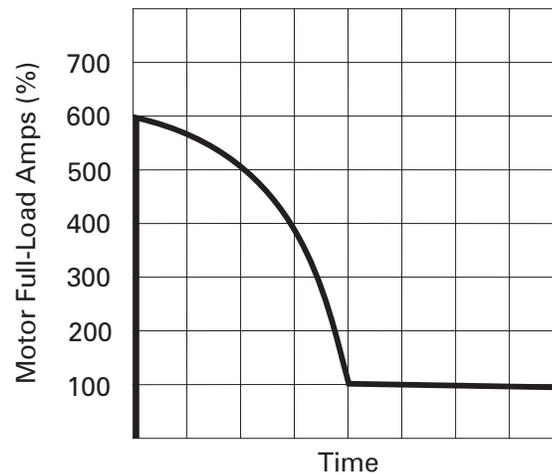
## Torque

Torque ( $T$ ) is equal to certain mechanical constants of the motor ( $k$ ) times flux ( $\Phi$ ) times working current ( $I_w$ ). An increase in flux or an increase in load will cause an increase in torque.

$$T = k\Phi I_w$$

## Starting current

When a motor is started, it must perform work to overcome the inertia of the rotor and attached load. The starting current measured on the incoming line ( $I_s$ ) is typically 600% of full-load current when rated voltage and frequency is first applied to a NEMA B motor. Stator current decreases to its rated value as the rotor comes up to speed. The following graph applies to “across the line” operation, not variable speed drive operation.



## Review 4

1. The \_\_\_\_\_ is the most common type of rotor in AC motors.
2. The difference in stator speed and rotor speed is known as \_\_\_\_\_.
3. A two-pole motor operating on 60 Hz power at 3450 RPM has \_\_\_\_\_ % slip.
4. An increase in load will cause an \_\_\_\_\_ in working current ( $I_w$ ) and slip.
5. Current that actually produces torque to turn the rotor is known as \_\_\_\_\_ current.
6. Stator current is the vector sum of \_\_\_\_\_ current and \_\_\_\_\_.
7. Starting torque of a NEMA B motor is approximately \_\_\_\_\_ % of full load torque, and starting current is approximately \_\_\_\_\_ % of full load current.

# Voltage And Frequency

Up to this point, the operation of an AC motor with rated voltage and frequency applied has been examined. Many applications require the speed of an AC motor to vary. The easiest way to vary the speed of an AC induction motor is to use an AC drive to vary the applied frequency. Operating a motor at other than the rated frequency has an effect on motor current and torque.

## Volts per hertz

A ratio exists between voltage and frequency. This ratio is referred to as volts per hertz (V/Hz). A typical AC motor manufactured for use in the United States is rated for 460 VAC and 60 Hz. The ratio is 7.67 volts per hertz. Not every motor has a 7.67 V/Hz ratio. A 230 Volt, 60 Hz motor, for example, has a 3.8 V/Hz ratio.

$$\frac{460}{60} = 7.67 \text{ V/Hz} \quad \frac{230}{60} = 3.8 \text{ V/Hz}$$

Flux ( $\Phi$ ), magnetizing current ( $I_M$ ), and torque are all dependent on this ratio. Increasing frequency ( $F$ ) without increasing voltage ( $E$ ), for example, will cause a corresponding increase in speed. Flux, however, will decrease causing motor torque to decrease. Magnetizing current ( $I_M$ ) will also decrease. A decrease in magnetizing current will cause a corresponding decrease in stator or line ( $I_s$ ) current. These decreases are all related and greatly affect the motor's ability to handle a given load.

$$\Phi \approx \frac{E}{F}$$

$$T = k\Phi I_w$$

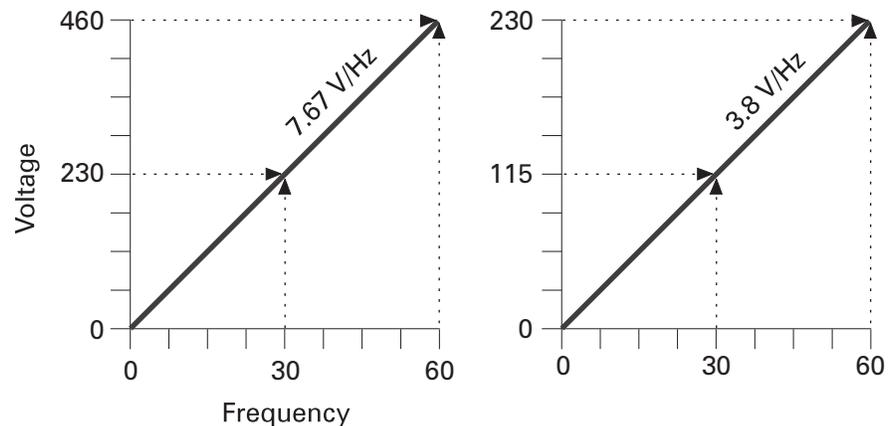
$$I_M = \frac{E}{2\pi F L_M}$$

## Constant torque

AC motors running on an AC line operate with a constant flux ( $\Phi$ ) because voltage and frequency are constant. Motors operated with constant flux are said to have constant torque. Actual torque produced, however, is determined by the demand of the load.

$$T = k\Phi/\omega$$

An AC drive is capable of operating a motor with constant flux ( $\Phi$ ) from approximately zero (0) to the motor's rated nameplate frequency (typically 60 Hz). This is the constant torque range. As long as a constant volts per hertz ratio is maintained the motor will have constant torque characteristics. AC drives change frequency to vary the speed of a motor and voltage proportionately to maintain constant flux. The following graphs illustrate the volts per hertz ratio of a 460 volt, 60 hertz motor and a 230 volt, 60 Hz motor. To operate the 460 volt motor at 50% speed with the correct ratio, the applied voltage and frequency would be 230 volts, 30 Hz. To operate the 230 volt motor at 50% speed with the correct ratio, the applied voltage and frequency would be 115 volts, 30 Hz. The voltage and frequency ratio can be maintained for any speed up to 60 Hz. This usually defines the upper limits of the constant torque range.



$$\frac{460}{60} = 7.67 \text{ V/Hz}$$

$$\frac{230}{30} = 7.67 \text{ V/Hz}$$

$$\frac{230}{60} = 3.8 \text{ V/Hz}$$

$$\frac{115}{30} = 3.8 \text{ V/Hz}$$

## Constant horsepower

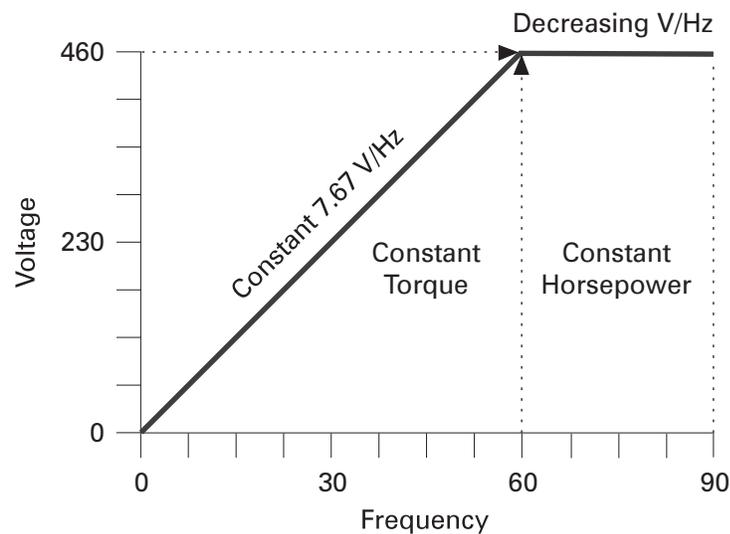
Some applications require the motor to be operated above base speed. The nature of these applications requires less torque at higher speeds. Voltage, however, cannot be higher than the available supply voltage. This can be illustrated using a 460 volt, 60 Hz motor. Voltage will remain at 460 volts for any speed above 60 Hz. A motor operated above its rated frequency is operating in a region known as a constant horsepower. Constant volts per hertz and torque is maintained to 60 Hz. Above 60 Hz the volts per hertz ratio decreases.

Frequency    V/Hz

30 Hz	7.67
60 Hz	7.67
70 Hz	6.6
90 Hz	5.1

Flux ( $\Phi$ ) and torque (T) decrease:

$$\Phi \approx \frac{E}{F} \quad T = k\Phi/\omega$$

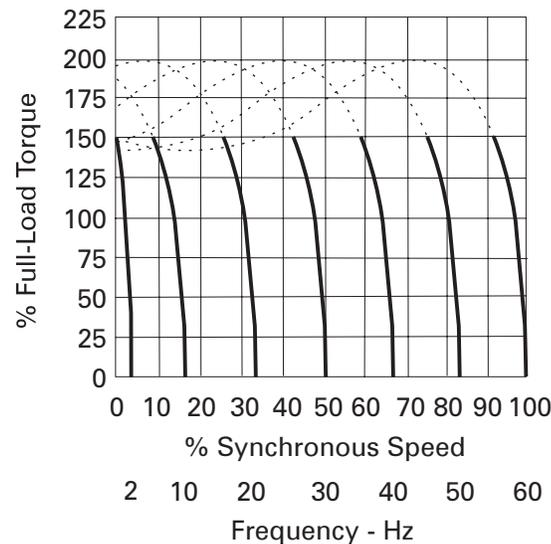


Horsepower remains constant as speed (N) increase and torque decreases in proportion. The following formula applies to speed in revolutions per minute (RPM).

$$HP \text{ (remains constant)} = \frac{T \text{ (decreases)} \times N \text{ (increases)}}{5250}$$

## Reduced voltage and frequency starting

A NEMA B motor that is started by connecting it to the power supply at full voltage and full frequency will develop approximately 150% starting torque and 600% starting current. AC drives start at reduced voltage and frequency. The motor will start with approximately 150% torque and 150% current at reduced frequency and voltage. The torque/speed curve shifts to the right as frequency and voltage are increased. The dotted lines on the torque/speed curve illustrated below represent the portion of the curve not used by the drive. The drive starts and accelerates the motor smoothly as frequency and voltage are gradually increased to the desired speed. An AC drive, properly sized to a motor, is capable of delivering 150% torque at any speed up to the speed corresponding to the incoming line voltage. The only limitations on starting torque are peak drive current and peak motor torque, whichever is less.

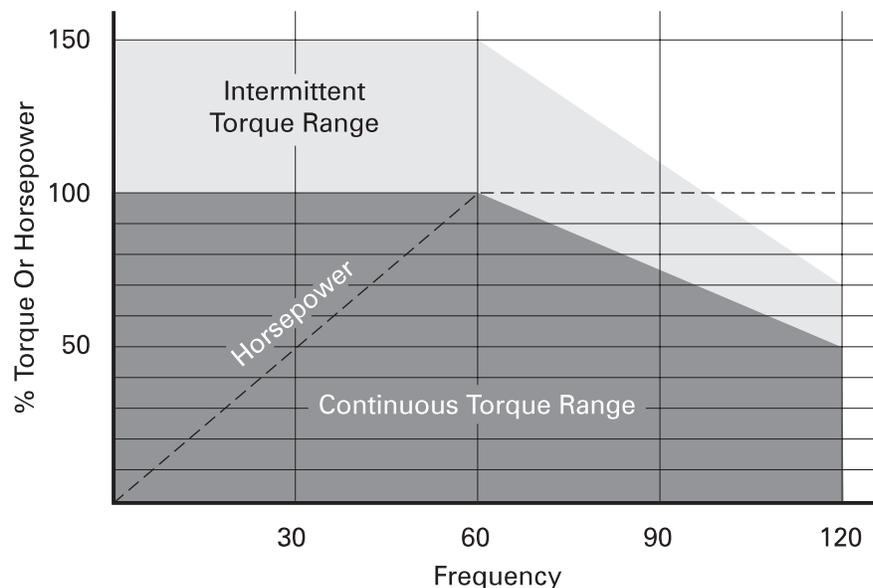


Some applications require higher than 150% starting torque. A conveyor, for example, may require 200% rated torque for starting. If a motor is capable of 200% torque at 200% current, and the drive is capable of 200% current, then 200% motor torque is possible. Typically drives are capable of producing 150% of drive nameplate rated current for one (1) minute. A drive with a larger current rating would be required. It is appropriate to supply a drive with a higher continuous horsepower rating than the motor when high peak torque is required.

## Selecting a motor

AC drives often have more capability than the motor. Drives can run at higher frequencies than may be suitable for an application. In addition, drives can run at low speeds. Self-cooled motors may not develop enough air flow for cooling at reduced speeds and full load. Consideration must be given to the motor.

The following graph indicates the speed and torque range of a sample motor. Each motor must be evaluated according to its own capability. The sample motor can be operated continuously at 100% torque up to 60 Hz. Above 60 Hz the V/Hz ratio decreases and the motor cannot develop 100% torque. This motor can be operated continuously at 50% torque at 120 Hz. The motor is also capable of operating above rated torque intermittently. The motor can develop as much as 150%\* torque for starting, accelerating or load transients, if the drive can supply the current. At 120 Hz the motor can develop 70% torque intermittently.

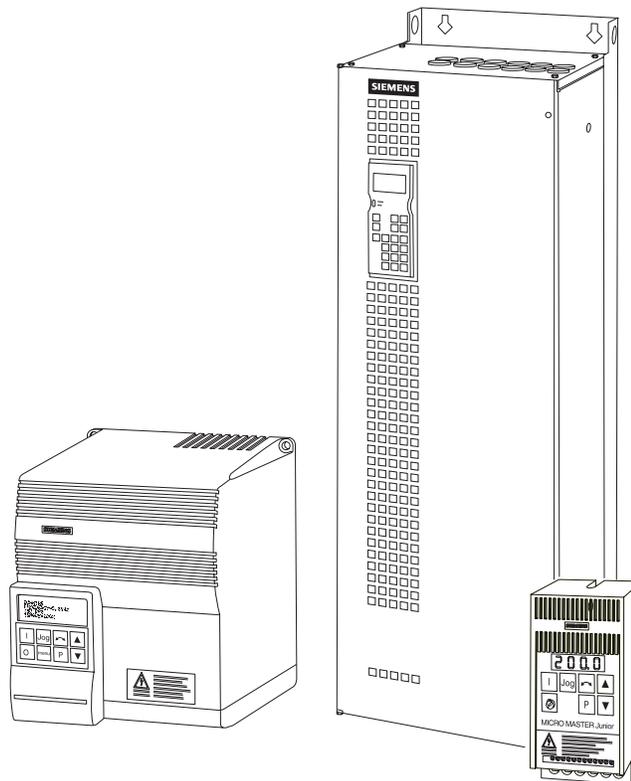


The sample motor described above is capable of operating at 100% rated torque continuously at low frequencies. Many motors are not capable of operating continuously at 100% continuous torque at low frequencies. Each motor must be evaluated before selecting it for use on an AC drive.

\* Torque may be higher than 150% if the drive is capable of higher current.

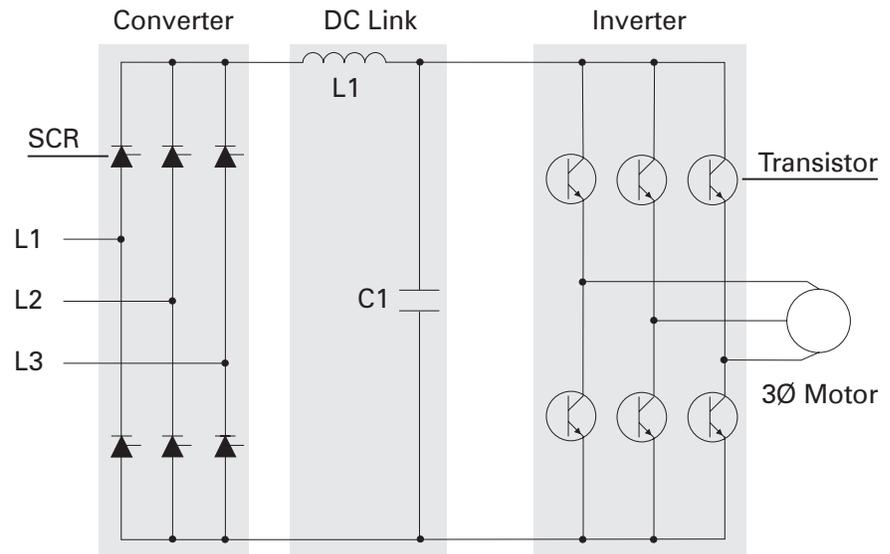
# Basic AC Drives

AC drives, inverters, and adjustable frequency drives are all terms that are used to refer to equipment designed to control the speed of an AC motor. The term SIMOVERT is used by Siemens to identify a **Siemens MOtor inVERTer** (AC drive). AC drives receive AC power and convert it to an adjustable frequency, adjustable voltage output for controlling motor operation. A typical inverter receives 480 VAC, three-phase, 60 Hz input power and provides power to the motor which can be steplessly adjusted through the speed range. The three common inverter types are the variable voltage inverter (VVI), current source inverter (CSI), and pulse width modulation (PWM). Another type of AC drive is a cycloconverter. These are commonly used for very large motors and will not be described in this course. All AC drives convert AC to DC, and then through various switching techniques invert the DC into a variable voltage, variable frequency output.

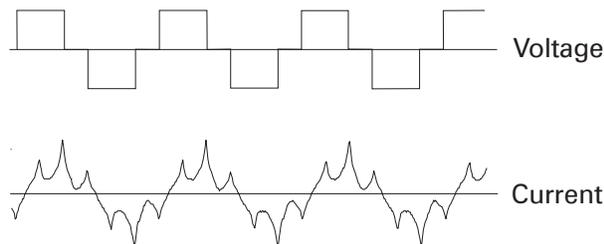


## Variable voltage inverter (VVI)

The variable voltage inverter (VVI) uses an SCR converter bridge to convert the incoming AC voltage into DC. The SCRs provide a means of controlling the value of the rectified DC voltage from 0 to approximately 600 VDC. The L1 choke and C1 capacitor(s) make up the DC link section and smooth the converted DC voltage. The inverter section consists of six switching devices. Various devices can be used such as thyristors, bipolar transistors, MOSFETS, and IGBTs. The following schematic shows an inverter that utilizes bipolar transistors. Control logic (not shown) uses a microprocessor to switch the transistors on and off providing a variable voltage and frequency to the motor.

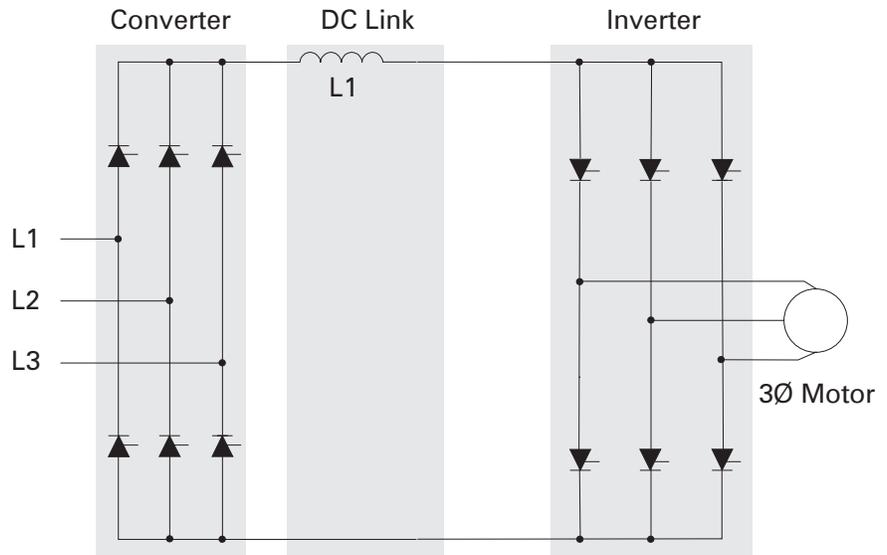


This type of switching is often referred to as six-step because it takes six  $60^\circ$  steps to complete one  $360^\circ$  cycle. Although the motor prefers a smooth sine wave, a six-step output can be satisfactorily used. The main disadvantage is torque pulsation which occurs each time a switching device, such as a bipolar transistor, is switched. The pulsations can be noticeable at low speeds as speed variations in the motor. These speed variations are sometimes referred to as cogging. The non-sinusoidal current waveform causes extra heating in the motor requiring a motor derating.

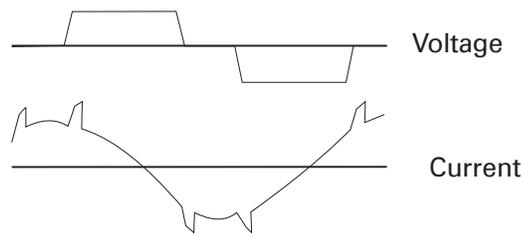


## Current source inverter (CSI)

The current source inverter (CSI) uses an SCR input to produce a variable voltage DC link. The inverter section also uses SCRs for switching the output to the motor. The current source inverter controls the current in the motor. The motor must be carefully matched to the drive.

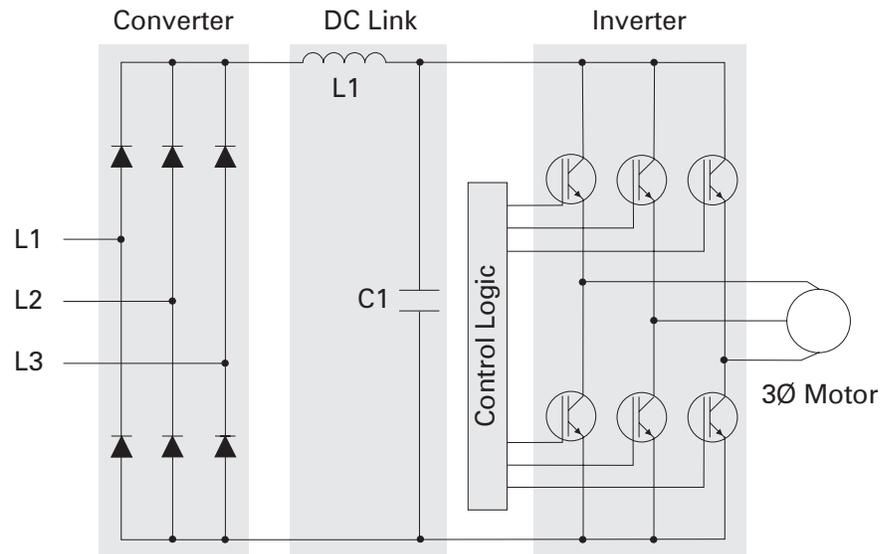


Current spikes, caused by switching, can be seen in the output. At low speeds current pulses can cause the motor to cog.



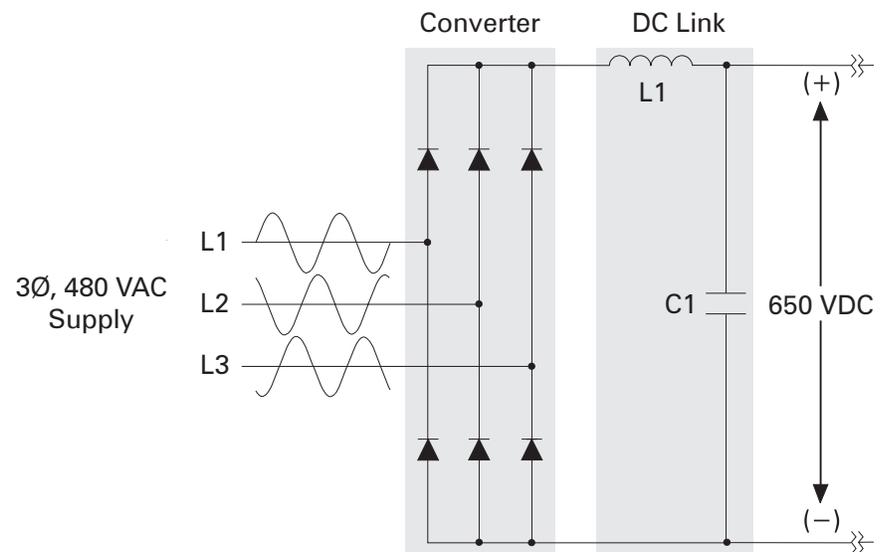
## Pulse width modulation

Pulse width modulation (PWM) drives, like the Siemens MICROMASTER, MICROMASTER Vector, MIDIMASTER Vector, and MASTERDRIVES, provide a more sinusoidal current output to control frequency and voltage supplied to an AC motor. PWM drives are more efficient and typically provide higher levels of performance. A basic PWM drive consists of a converter, DC link, control logic and an inverter.



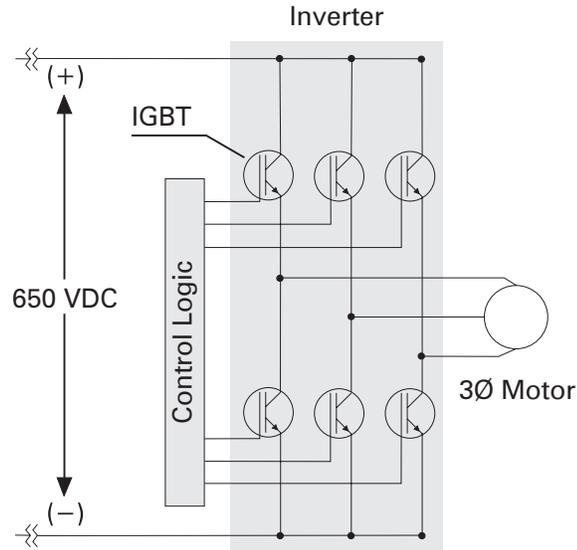
## Converter and DC link

The converter section consists of a fixed diode bridge rectifier which converts the three-phase power supply to a DC voltage. The L1 choke and C1 capacitor(s) smooth the converted DC voltage. The rectified DC value is approximately 1.35 times the line-to-line value of the supply voltage. The rectified DC value is approximately 650 VDC for a 480 VAC supply.



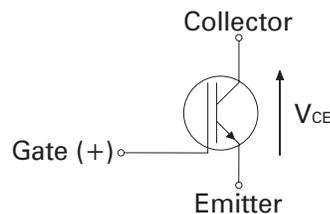
## Control logic and inverter

Output voltage and frequency to the motor are controlled by the control logic and inverter section. The inverter section consists of six switching devices. Various devices can be used such as thyristors, bipolar transistors, MOSFETs and IGBTs. The following schematic shows an inverter that utilizes IGBTs. The control logic uses a microprocessor to switch the IGBTs on and off providing a variable voltage and frequency to the motor.



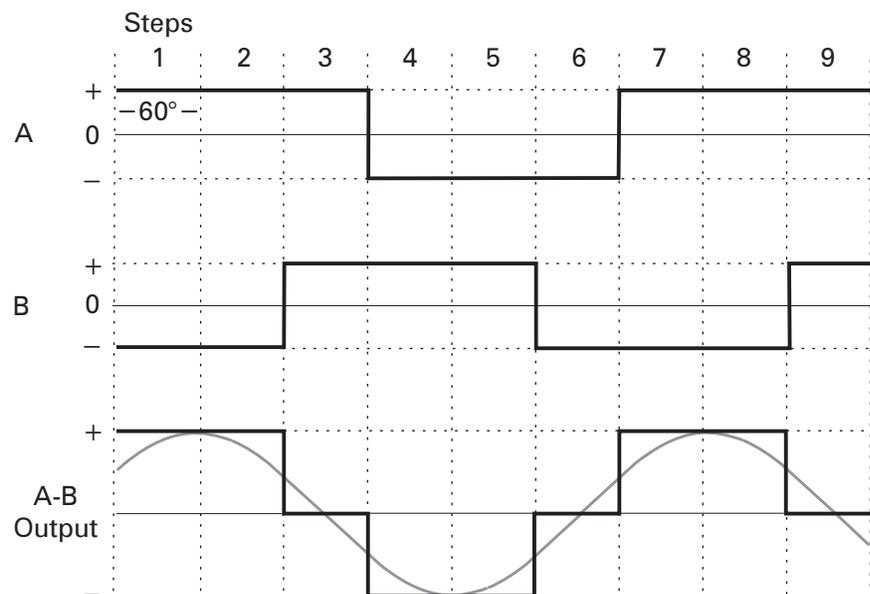
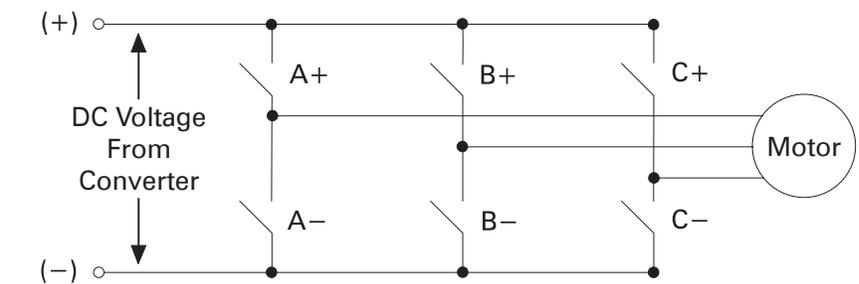
## IGBTs

IGBTs (insulated gate bipolar transistor) provide a high switching speed necessary for PWM inverter operation. IGBTs are capable of switching on and off several thousand times a second. An IGBT can turn on in less than 400 nanoseconds and off in approximately 500 nanoseconds. An IGBT consists of a gate, collector and an emitter. When a positive voltage (typically +15 VDC) is applied to the gate the IGBT will turn on. This is similar to closing a switch. Current will flow between the collector and emitter. An IGBT is turned off by removing the positive voltage from the gate. During the off state the IGBT gate voltage is normally held at a small negative voltage (-15 VDC) to prevent the device from turning on.



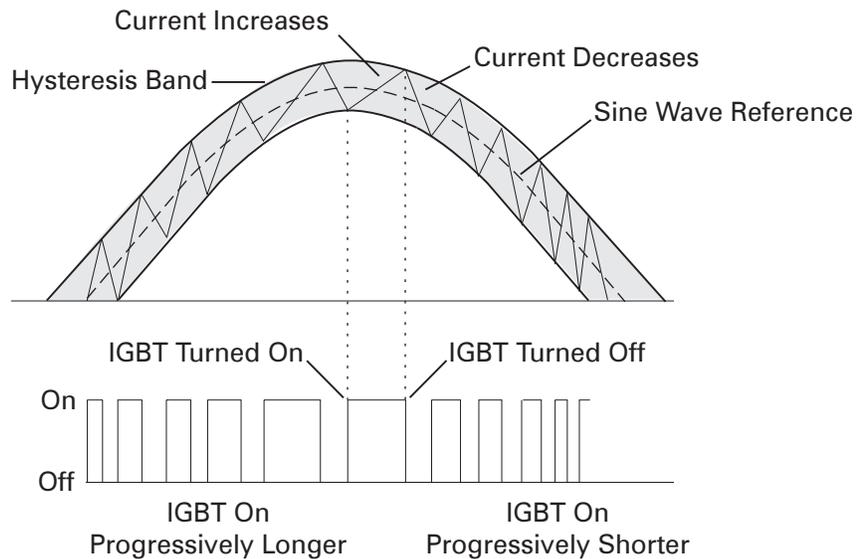
## Using switching devices to develop a basic AC output

In the following example, one phase of a three-phase output is used to show how an AC voltage can be developed. Switches replace the IGBTs. A voltage that alternates between positive and negative is developed by opening and closing switches in a specific sequence. For example, during steps one and two A+ and B- are closed. The output voltage between A and B is positive. During step three A+ and B+ are closed. The difference of potential from A to B is zero. The output voltage is zero. During step four A- and B+ are closed. The output voltage from A to B is negative. The voltage is dependent on the value of the DC voltage and the frequency is dependent on the speed of the switching. An AC sine wave has been added to the output (A-B) to show how AC is simulated.



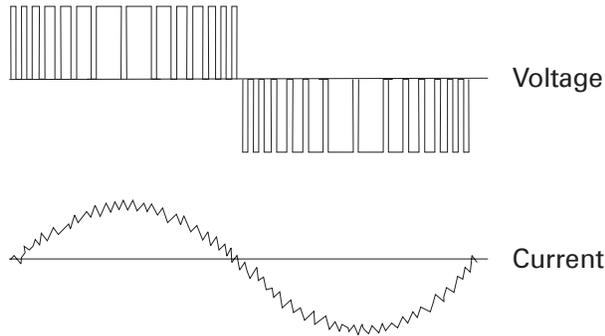
## Generating a PWM output

There are several PWM modulation techniques. It is beyond the scope of this book to describe them all in detail. The following text and illustrations describe a typical pulse width modulation method. An IGBT (or other type switching device) can be switched on connecting the motor to the positive value of DC voltage (650 VDC from the converter). Current flows in the motor. The IGBT is switched on for a short period of time, allowing only a small amount of current to build up in the motor and then switched off. The IGBT is switched on and left on for progressively longer periods of time, allowing current to build up to higher levels until current in the motor reaches a peak. The IGBT is then switched on for progressively shorter periods of time, decreasing current build up in the motor. The negative half of the sine wave is generated by switching an IGBT connected to the negative value of the converted DC voltage.

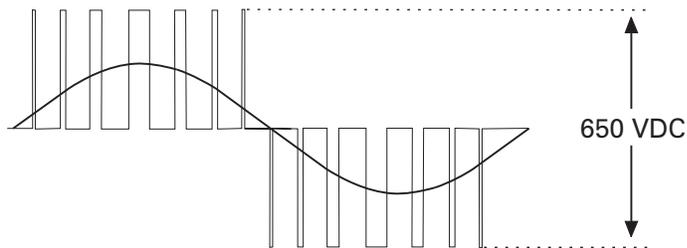


## PWM voltage and current waveforms

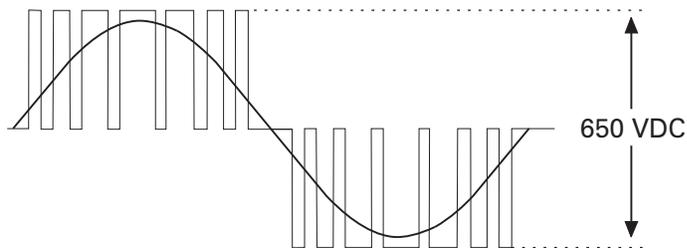
The more sinusoidal current output produced by the PWM reduces the torque pulsations, low speed motor cogging, and motor losses noticeable when using a six-step output.



The voltage and frequency is controlled electronically by circuitry within the AC drive. The fixed DC voltage (650 VDC) is modulated or clipped with this method to provide a variable voltage and frequency. At low output frequencies a low output voltage is required. The switching devices are turned on for shorter periods of time. Voltage and current build up in the motor is low. At high output frequencies a high voltage is required. The switching devices are turned on for longer periods of time. Voltage and current build up in the motor increases.



Shorter "On" Duration, Lower Voltage



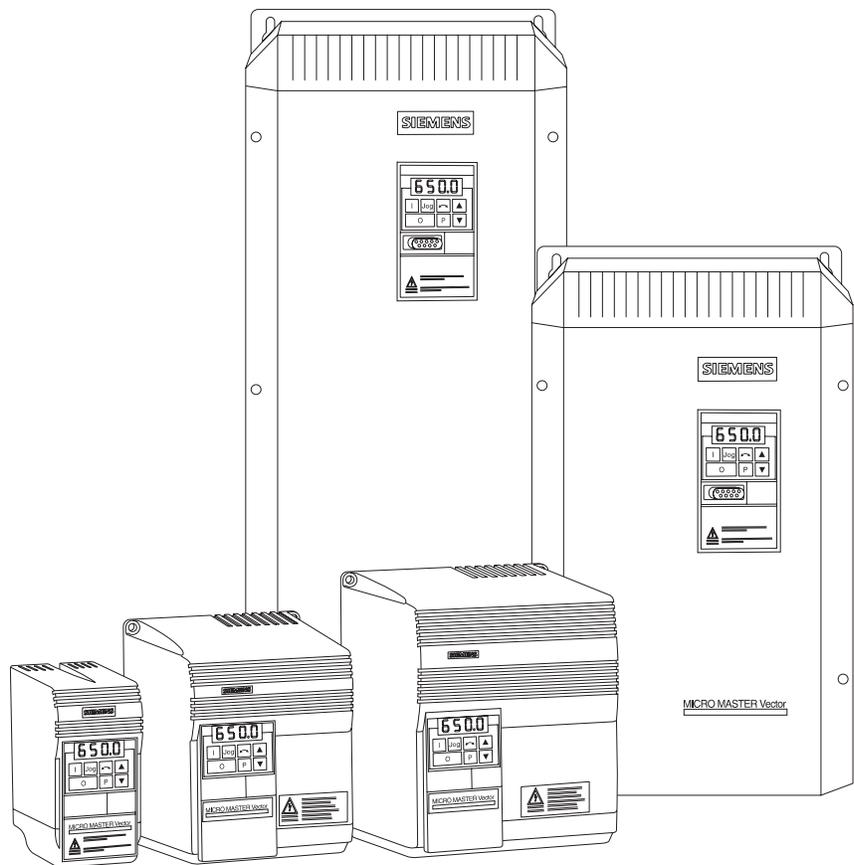
Longer "On" Duration, Higher Voltage

## Review 5

1. The volts per hertz ratio of a 460 volt, 60 Hz motor is \_\_\_\_\_.
2. An increase in voltage will cause flux ( $\Phi$ ) to \_\_\_\_\_, and torque (T) capability to \_\_\_\_\_.
3. A motor operated within a speed range that allows a constant volts per hertz ratio is said to be constant \_\_\_\_\_.
  - a. horsepower
  - b. torque
4. If torque decreases proportional to speed (RPM) increasing, then \_\_\_\_\_ is constant.
5. Siemens uses the term \_\_\_\_\_ to identify a Siemens inverter (AC drive).
6. On a PWM drive with a 480 VAC supply, the approximate voltage after being converted to DC is \_\_\_\_\_ VDC.
7. IGBTs are capable of being switched several \_\_\_\_\_ a second.
  - a. times
  - b. hundred times
  - c. thousand times
  - d. million times
8. A PWM output is preferred to a six-step output because \_\_\_\_\_.
  - a. PWM provides a more sinusoidal output
  - b. Cogging is more noticeable on a six-step
  - c. The non-sinusoidal waveform of a six-step increases motor heat
  - d. a, b, and c
9. To obtain a lower voltage and frequency output on a PWM inverter, control circuitry will switch IGBTs on for \_\_\_\_\_ periods of time.
  - a. shorter
  - b. longer

# Siemens MICROMASTER and MIDIMASTER

Siemens offers a broad range of AC drives. The Siemens MICROMASTER Junior, MICROMASTER, MICROMASTER Vector, and MIDIMASTER Vector are adjustable frequency AC drives that use a built-in microprocessor to control the operation of the drive. The inverters are very compact and designed for operation anywhere in the world.



**Enclosures**

The National Electrical Manufacturers Association (NEMA) has specified standards for equipment enclosures. The MICROMASTER and MICROMASTER Vector are supplied in a protected chassis and a NEMA Type 1 enclosure. NEMA Type 1 enclosures are a general purpose, indoor enclosure. The MIDIMASTER Vector is supplied in a NEMA Type 1 and NEMA Type 12/4 enclosure. The NEMA Type 12/4 enclosure is an industrial, dust-tight and drip-tight enclosure that can be wash downed. It is intended for indoor use. Contact your Siemens sales representative for more information.

**Ambient temperature**

The MICROMASTER and MICROMASTER Vector are rated for operation in an ambient temperature of 0 to 50° C. The MIDIMASTER Vector is rated for operation in an ambient temperature of 0 to 40° C.

**Elevation**

The MICROMASTER, MICROMASTER Vector, and MIDIMASTER Vector are rated for operation below 3300 feet. At higher elevations the air is thinner, consequently the drive can't dissipate heat as effectively and the drive must be derated.

**Distance between drive and motor**

Distance from the drive to the motor must also be taken into consideration. All motor cables have line-to-line and line-to-ground capacitance. The longer the cable, the greater the capacitance. Some types of cables, such as shielded cable or cables in metal conduit, have greater capacitance. Spikes occur on the output of all PWM drives because of the charging current of the cable capacitance. Higher voltage (460 VAC) and higher capacitance (long cables) result in higher current spikes. Voltage spikes caused by long cable lengths can potentially shorten the life of the inverter and the motor. The maximum distance between a motor and the MICROMASTER, MICROMASTER Vector, and the MIDIMASTER Vector is 50 meters (164 feet). If shielded cable is used, or if cable is run through a metal conduit, the maximum distance is 25 meters (82 feet). When considering an application where distance may be a problem, contact your local Siemens representative.

## Supply voltage and frequency

The MICROMASTER, MICROMASTER Vector, and MIDIMASTER Vector have an input voltage range that allows them to be used worldwide. The acceptable input frequency ranges from 47 Hz to 63 Hz. The following tables reflect ratings available at the time this book was printed. A MICROMASTER may also be referred to by a model series number, 6SE92. The MICROMASTER Vector and the MIDIMASTER Vector may also be referred to by a model series number, 6SE32. The following tables reflect available 6SE92s and 6SE32s.

## MICROMASTER

Part Number	Model Number	Motor Power HP	Rated Current <sup>1</sup> (NEC)	230V Nominal 60Hz Current <sup>2</sup>	230V Maximum Continuous Output Current <sup>3</sup>	Input Current (I <sub>rms</sub> 230V)
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### 1 ph 230V +/-15% with built in filter (class A)

6SE92107BA40	MM12	1/6	.76	0.76	0.9	1.8
6SE92115BA40	MM25	1/3	1.18	1.18	1.7	3.2
6SE92121BA40	MM37	1/2	2	2	2.3	4.6
6SE92128BA40	MM55	3/4	2.8	2.8	2.9	6.2
6SE92136BA40	MM75	1	3.6	3.6	3.9	8.2
6SE92152BB40	MM110	1.5	5.2	5.2	5.3	11
6SE92168BB40	MM150	2	6.8	6.8	7	14.4
6SE92210BC40	MM220	3	9.6	9.6	10	20.2
6SE92213BC40	MM300	4	na	11.8	13	28.3

### 1 ph/3 ph 230V +/-15% (unfiltered)

1 ph/3 ph 230V +/-15% (unfiltered)							1ph/3ph
6SE92107CA40	MM12/2	1/6	.76	0.76	0.9	1.8/1.1	
6SE92115CA40	MM25/2	1/3	1.18	1.18	1.7	3.2/1.9	
6SE92121CA40	MM37/2	1/2	2	2	2.3	4.6/2.7	
6SE92128CA40	MM55/2	3/4	2.8	2.8	2.9	6.2/3.6	
6SE92136CA40	MM75/2	1	3.6	3.6	3.9	8.2/4.7	
6SE92152CB40	MM110/2	1.5	5.2	5.2	5.3	11/6.4	
6SE92168CB40	MM150/2	2	6.8	6.8	7	14.4/8.3	
6SE92210CC40	MM220/2	3	9.6	9.6	10	20.2/11.7	
6SE92213CC40	MM300/2	4	na	11.8	13	28.3/16.3	
6SE92218CC13	MM400/2 *	5	15.2	15.2	17.5	21.1	

\* 3 Phase Only

Part Number	Model Number	Motor Power HP	460V 60Hz Nominal Current <sup>2</sup>	460V Maximum Continuous Output Current <sup>3</sup>	Input Current (I <sub>rms</sub> 400V)
<b>3 ph 400-500V +/-10% (unfiltered)</b>					
6SE92111DA40	MM37/3	1/2	1.1	1.2	2.2
6SE92114DA40	MM55/3	3/4	1.4	1.6	2.8
6SE92120DA40	MM75/3	1	1.9	2	3.7
6SE92127DA40	MM110/3	1.5	2.6	2.9	4.9
6SE92140DA40	MM150/3	2	3.4	3.8	5.9
6SE92158DB40	MM220/3	3	4.8	5.3	8.8
6SE92173DB40	MM300/3	4	6.3	7	11.1
6SE92210DC40	MM400/3	5	8.6	9.4	13.6
6SE92213DC40	MM550/3	7.5	11.0	12.1	17.1
6SE92215DC40	MM750/3	10	14.7	16.3	22.1

<sup>1</sup> NEC currents based upon typical 4 pole motors.

<sup>2</sup> Nominal current ratings with 150% overload for 60 seconds

<sup>3</sup> Maximum continuous current without overload capability.

# MICROMASTER Vector

Part Number	Model Number	Motor Power HP	Rated Current <sup>1</sup> (NEC)	230V Nominal 60Hz Current <sup>2</sup>	230V Maximum Continuous Output Current <sup>3</sup>	Input Current (I <sub>rms</sub> 230V)
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### 1 ph 230V +/-15% with built in filter (class A)

6SE32107BA40	MMV12	1/6	.76	0.76	0.9	1.8
6SE32115BA40	MMV25	1/3	1.18	1.18	1.7	3.2
6SE32121BA40	MMV37	1/2	2	2	2.3	4.6
6SE32128BA40	MMV55	3/4	2.8	2.8	2.9	6.2
6SE32136BA40	MMV75	1	3.6	3.6	3.9	8.2
6SE32152BB40	MMV110	1.5	5.2	5.2	5.3	11
6SE32168BB40	MMV150	2	6.8	6.8	7	14.4
6SE32210BC40	MMV220	3	9.6	9.6	10	20.2
6SE32213BC40	MMV300	4	na	11.8	13	28.3

### 1 ph / 3 ph 230V +/-15% (unfiltered)

						1ph/3ph
6SE32107CA40	MMV12/2	1/6	.76	0.76	0.9	1.8/1.1
6SE32115CA40	MMV25/2	1/3	1.18	1.18	1.7	3.2/1.9
6SE32121CA40	MMV37/2	1/2	2	2	2.3	4.6/2.7
6SE32128CA40	MMV55/2	3/4	2.8	2.8	2.9	6.2/3.6
6SE32136CA40	MMV75/2	1	3.6	3.6	3.9	8.2/4.7
6SE32152CB40	MMV110/2	1.5	5.2	5.2	5.3	11/6.4
6SE32168CB40	MMV150/2	2	6.8	6.8	7	14.4/8.3
6SE32210CC40	MMV220/2	3	9.6	9.6	10	20.2/11.7
6SE32213CC40	MMV300/2	4	na	11.8	13	28.3/16.3
6SE32218CC40	MMV400/2 *	5	15.2	15.2	17.5	21.1

\* 3 Phase Only

Part Number	Model Number	Motor Power HP	Rated Current <sup>1</sup> (NEC)	460V 60Hz Nominal Current <sup>2</sup>	460V Maximum Continuous Output Current <sup>3</sup>	Input Current (I <sub>rms</sub> )
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### 3 ph 400-500V +/-10% (unfiltered)

6SE32111DA40	MMV37/3	1/2	1	1.1	1.2	2.2
6SE32114DA40	MMV55/3	3/4	1.4	1.4	1.6	2.8
6SE32120DA40	MMV75/3	1	1.8	1.9	2.0	3.7
6SE32127DA40	MMV110/3	1.5	2.6	2.6	2.9	4.9
6SE32140DA40	MMV150/3	2	3.4	3.4	3.8	5.9
6SE32158DB40	MMV220/3	3	4.8	4.8	5.3	8.8
6SE32173DB40	MMV300/3	4	na	6.3	7.0	11.1
6SE32210DC40	MMV400/3	5	7.6	8.6	9.4	13.6
6SE32213DC40	MMV550/3	7.5	11	11.0	12.1	17.1
6SE32215DC40	MMV750/3	10	14	14.7	16.3	22.1

<sup>1</sup> NEC currents for typical 4 pole motors.

<sup>2</sup> Nominal current ratings with 150% overload for 60 seconds and 200% overload for 3 seconds.

<sup>3</sup> Maximum continuous current without overload capability.

# MIDIMASTER Vector

Part Number	Model Number	Motor Power HP	Rated Current <sup>1</sup> (NEC)	Nominal 60Hz Current <sup>2</sup>	Continuous Output Current <sup>3</sup>	Input Current (Irms)
<b>3 ph 230V +/-15% NEMA 1 IP21 (unfiltered)</b>			<b>230V</b>	<b>230V</b>	<b>230V</b>	
6SE32223CG40	MDV550/2	7.5	22	22	28	32
6SE32231CG40	MDV750/2	10	28	28	42	45
6SE32242CH40	MDV1100/2	15	42	42	54	61
6SE32254CH40	MDV1500/2	20	54	54	68	75
6SE32268CJ40	MDV1850/2	25	68	68	80	87
6SE32275CJ40	MDV2200/2	30	80	80	90	100
6SE32310CK40	MDV3000/2	40	104	104	130	143
6SE32313CK40	MDV3700/2	50	130	130	154	170
6SE32315CK40	MDV4500/2	60	154	154	170	187
<b>3 ph 400V-500V +/-10% NEMA 1 IP21 (unfiltered)</b>			<b>460V</b>	<b>460V</b>	<b>460V</b>	
6SE32224DG40	MDV1100/3	15	21	21	34	32
6SE32230DH40	MDV1500/3	20	27	27	40	41
6SE32235DH40	MDV1850/3	25	34	34	52	49
6SE32242DJ40	MDV2200/3	30	40	40	65	64
6SE32255DJ40	MDV3000/3	40	52	52	77	79
6SE32268DJ40	MDV3700/3	50	65	65	96	96
6SE32284DK40	MDV4500/3	60	77	77	124	113
6SE32310DK40	MDV5500/3	75	96	96	156	152
6SE32314DK40	MDV7500/3	100	124	124		185
<b>3 ph 550-575V +/-10% NEMA 1 IP21(unfiltered)</b>			<b>575V</b>	<b>575V</b>	<b>575V</b>	
6SE32138FG40	MDV220/4	3	3.9	3.9	6.1	7
6SE32161FG40	MDV400/4	5	6.1	6.1	9	10
6SE32180FG40	MDV550/4	7.5	9	9	11	12
6SE32211FG40	MDV750/4	10	11	11	17	18
6SE32217FG40	MDV1100/4	15	17	17	22	24
6SE32222FH40	MDV1500/4	20	22	22	27	29
6SE32227FH40	MDV1850/4	25	27	27	32	34
6SE32232FJ40	MDV2200/4	30	32	32	41	45
6SE32241FJ40	MDV3000/4	40	41	41	52	55
6SE32252FJ40	MDV3700/4	50	52	52	62	65

<sup>1</sup> NEC currents based upon typical 4 pole motors

<sup>2</sup> Nominal current ratings with 150% overload for 60 seconds and 200% for 3 seconds.

<sup>3</sup> Maximum continuous current without overload capability. These current ratings are only available when the inverter is programmed for variable torque mode.

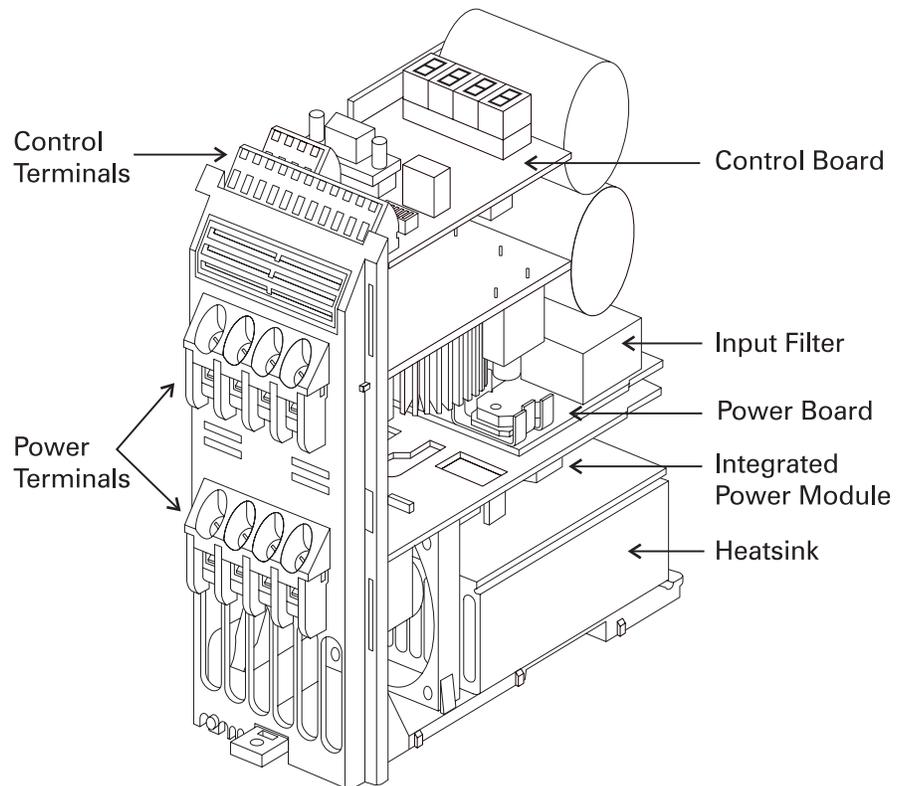
## Output voltage and frequency

Output voltage is adjustable from 0 volts to approximately input voltage. Depending on the drive, output frequency is adjustable from 0 to a maximum of 650 Hz. Consideration must be given to the motor and application, which may not be capable of operating at 650 Hz. The MICROMASTER and MIDIMASTER drives are capable of being set to a minimum and maximum speed appropriate for the application. If the minimum speed required is 10 Hz, and the maximum speed required is 60 Hz, then the drives can be programmed for a speed range of 10 to 60 Hz. Speed can be incremented in 0.01 Hz steps.

AC Drive	Output Frequency	Frequency Resolution
MICROMASTER	0 - 400 Hz	0.01 Hz
MICROMASTER Vector	0 - 650 Hz	0.01 Hz
MIDIMASTER Vector	0 - 650 Hz (50 HP) 0 - 200 Hz (100 HP)	0.01 Hz

## Internal layout

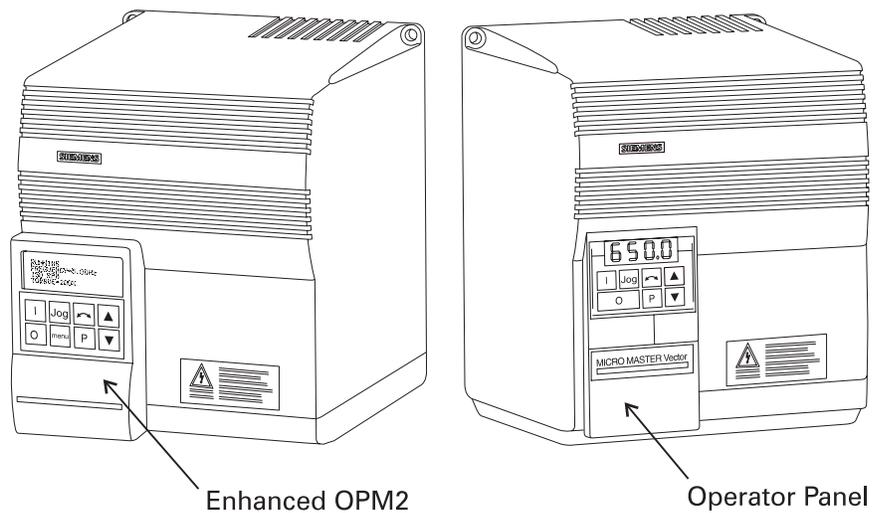
The following illustration shows a typical internal layout of the MICROMASTER and MIDIMASTER. Internal details vary from unit to unit.



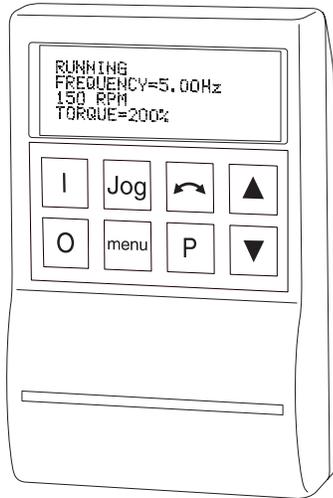
## Parameter

A parameter is a variable that is given a constant value. For example, ramp up time is parameter number P002. Ramp up time can be set for any value from 0 to 650 seconds. When setting up the drive a value of 10 seconds might be selected. When given a start command it would take 10 seconds for the drive to ramp up to full speed. Parameter adjustment on the MICROMASTER and MIDIMASTER is simple. Standard applications require no special settings, however, parameters can be easily modified for special applications.

Programming is done on the MICROMASTER and MIDIMASTER using an operator panel or an enhanced operator panel (OPM2). Up to 31 standard inverters may be simultaneously addressed through the OPM. Parameters, such as ramp times, minimum and maximum frequencies, and modes of operation are easily set. The "P" key toggles the display between a parameter number and the value of the parameter. The up and down pushbuttons scroll through parameters and are used to set a parameter value. In the event of a failure the inverter switches off and a fault code appears in the display.

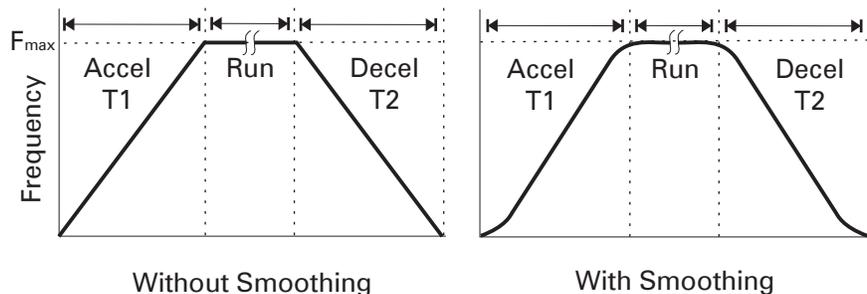


The MICROMASTER and MIDIMASTER have various parameters for proper drive and motor operation. It is beyond the scope of this book to describe in detail every parameter available. Some of the key parameters are described in the following text.



## Ramp function

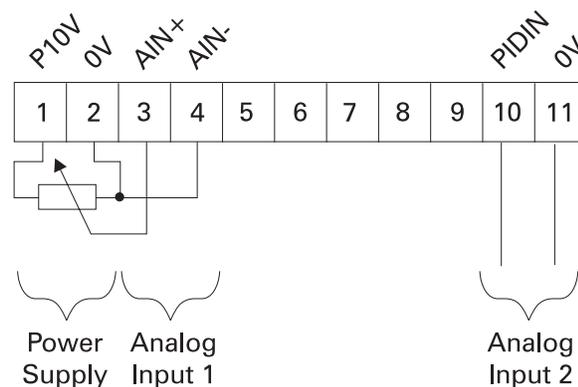
A feature of AC drives is the ability to increase or decrease the voltage and frequency to a motor gradually. This accelerates the motor smoothly with less stress on the motor and connected load. Parameters P002, P003 and P004 are used to set a ramp function. Acceleration and deceleration are separately programmable from 0 to 650 seconds. Acceleration, for example, could be set for 10 seconds and deceleration could be set for 60 seconds. Smoothing is a feature that can be added to the acceleration/deceleration curve. This feature smooths the transition between starting and finishing a ramp. Minimum and maximum speed are set by parameters P012 and P013.



## Analog inputs (AIN)

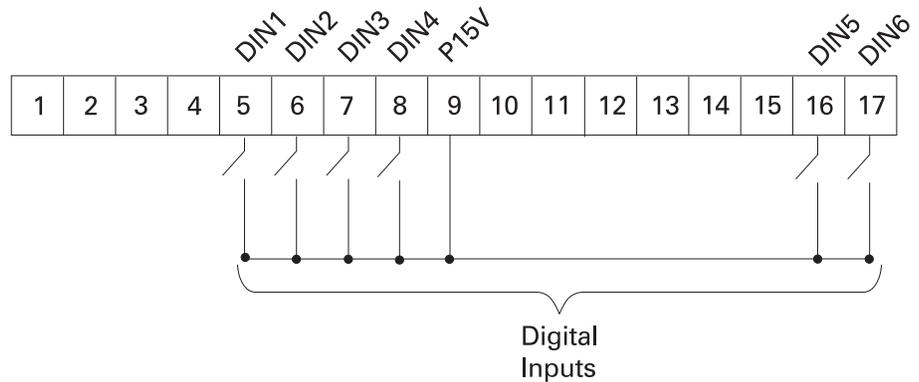
Parameter P006 is used to select either an analog or digital reference, or fixed frequency. Terminals one (1) through four (4) are used to provide an analog reference that controls the speed of the motor from 0 to 100%. Terminal one (1) is a +10 VDC power supply that is internal to the drive. Terminal two (2) is the return path, or ground, for the 10 Volt supply. An adjustable resistor can be connected between terminals one and two. Terminal three (3) is the positive (+) analog input to the drive. The drive can also be programmed to accept 0 to 20 mA, or 4 to 20 mA speed reference signal. These signals are typically supplied to the drive by other equipment such as a programmable logic controller (PLC). Note that a jumper has been connected between terminals two (2) and four (4). An analog input cannot be left floating (open). If an analog input will not be used it must be connected to terminal two (2).

The MICROMASTER Vector and the MIDIMASTER Vector have two analog inputs, allowing for a PID control loop function. PID control loops are used in process control to trim the speed. Examples are temperature and pressure control.



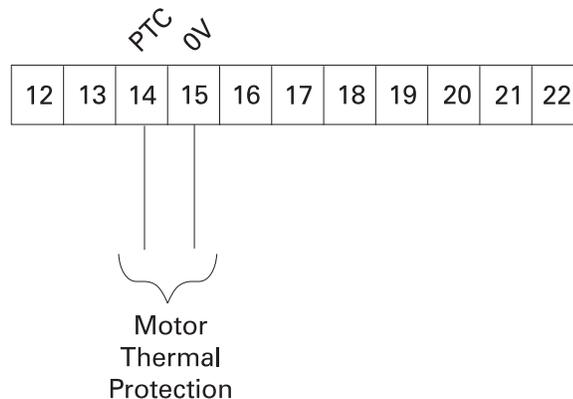
## Digital Inputs

The MICROMASTER has three digital inputs (DIN 1-3). The MICROMASTER Vector and the MIDIMASTER Vector have six digital inputs (DIN 1-6). A switch or contact is connected between +15 VDC (P15V) and a digital input (DIN1 - DIN6). The use of digital inputs is determined by parameters P051 through P055 and P356. These can be programmed for various functions. Digital input 1 (DIN1), for example, may be used to start and stop the drive. When the switch between P15+ is open the drive is stopped. When the switch between P15+ is closed the drive supplies power to the motor. Other inputs can be used for forward/reverse, preset speeds, jogging, or other functions.



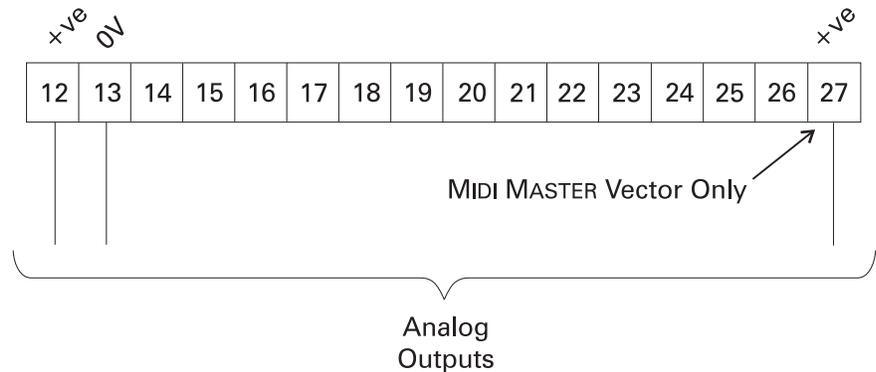
## Thermistor

Some motors have a built in thermistor. If a motor becomes overheated the thermistor acts to interrupt the power supply to the motor. A thermistor can be connected to terminals 14 (PTC) and 15 (0V). If the motor gets to a preset temperature as measured by the thermistor, the driver will interrupt power to the motor. The motor will coast to a stop. The display will indicate a fault has occurred. Parameter P087 will enable the thermistor. Virtually any standard thermistor as installed in standard catalog motors will work. Snap-action thermostat switches will also work.



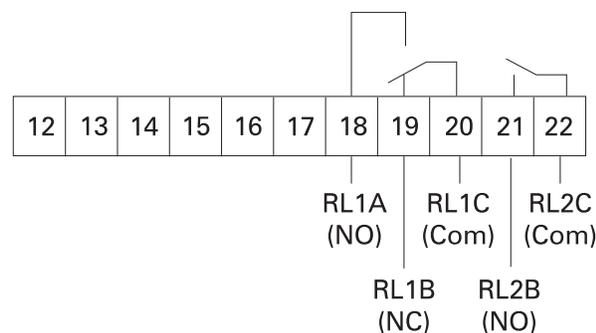
## Analog outputs

Analog outputs can be used to monitor output frequency, frequency setpoint, DC-link voltage, motor current, motor torque, and motor RPM. The MICROMASTER and MICROMASTER Vector have one analog output, connected to +ve (terminal 12) and 0v (terminal 13). The MIDIMASTER Vector has two analog outputs, connected to +ve (terminals 12 and 27) and 0v (terminal 13). These are controlled by parameter P025 and P026 (MIDIMASTER Vector).



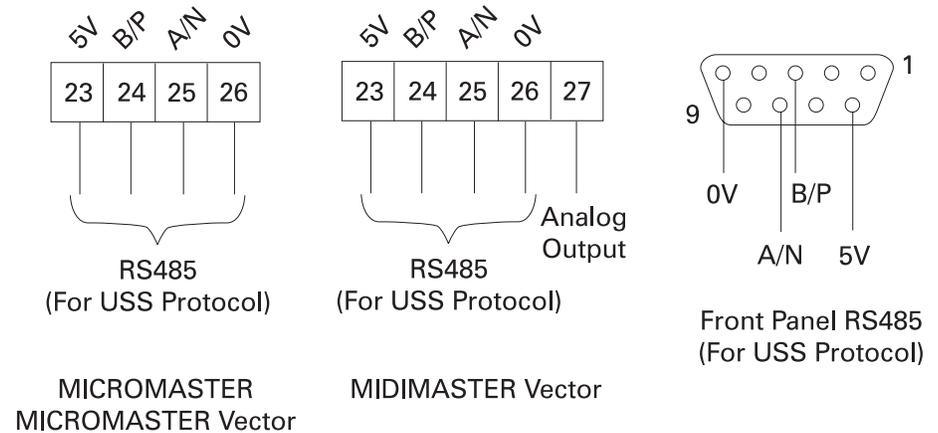
## Relay outputs

There are two programmable relay outputs (RL1 and RL2) for indication of system status. These are controlled by parameters P061 and P062. The RL1 output (terminals 18, 19, 20) can be used for one normally closed (NC) or one normally open (NO) output. The RL2 output (terminals 21, 22) can be used for a normally open output. The relays can be programmed to indicate various conditions such as the drive is running, a failure has occurred, converter frequency is at 0 or converter frequency is at minimum.



## Serial interface

The MICROMASTER and MIDIMASTER have an RS485 serial interface that allows communication with computers (PCs) or programmable logic controllers (PLCs). The standard RS485 protocol is called USS protocol and is programmable up to 19.2 K baud. Siemens PROFIBUS protocol is also available. It is programmable up to 12 M baud. Contact your Siemens sales representative for information on USS and PROFIBUS protocol.



## Current limit and motor overload

The MICROMASTER, MICROMASTER Vector, and the MIDIMASTER Vector are capable of delivering up to 150% of drive rated current for one minute in constant torque mode. The MICROMASTER Vector and the MIDIMASTER Vector are capable of delivering 200% of drive rated current for three seconds.

Sophisticated speed/time/current dependent overload functions are used to protect the motor. The monitoring and protection functions include a drive overcurrent fault, a motor overload fault, a calculated motor over temperature warning, and a measured motor over temperature fault (requires a device inside the motor).

## Low speed boost

Some applications, such as a conveyor, require more torque to start and accelerate the load at low speed. Low speed boost is a feature that allows the voltage to be adjusted at low speeds. This will increase/decrease the torque. Low speed boost can be adjusted high for applications requiring high torque at low speeds. Some applications, such as a fan, don't require as much starting torque. Low speed boost can be adjusted low for smooth, cool, and quiet operation at low speed. An additional starting boost is available for applications requiring high starting torque.

$$\Phi \approx \frac{E}{F} \quad T = k\Phi/w$$

## Control modes

The MICROMASTER has two modes of operation:

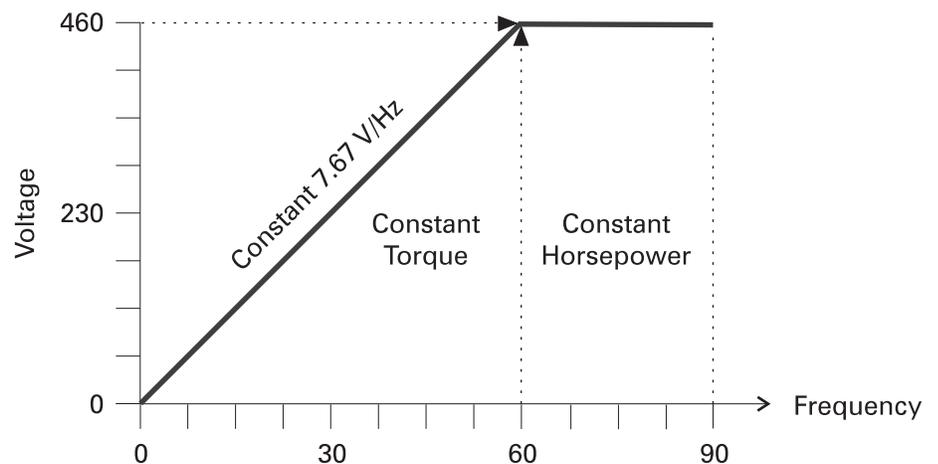
Linear voltage/frequency  
Quadratic voltage/frequency

The MICROMASTER Vector and the MIDIMASTER Vector have four modes of operation:

Linear voltage/frequency  
Quadratic voltage/frequency  
Flux Current Control (FCC)  
Sensorless vector frequency control

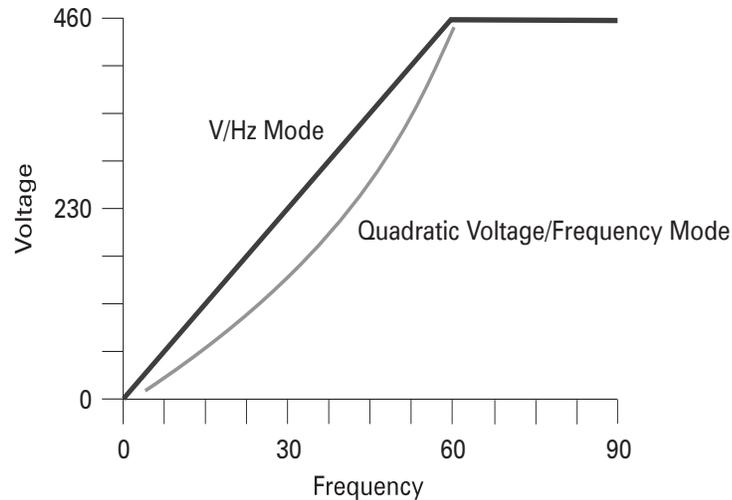
## Linear voltage/frequency

The MICROMASTER and MIDIMASTER can operate utilizing a standard V/Hz curve. Using a 460 VAC, 60 Hz motor as an example, constant volts per hertz is supplied to the motor at any frequency between 0 and 60 Hz. This is the simplest type of control and is suitable for general purpose applications.



## Quadratic voltage/ frequency

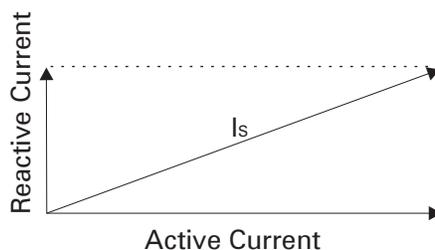
A second mode of operation is referred to as a quadratic voltage/frequency curve. This mode provides a V/Hz curve that matches the torque requirements of simple fan and pump applications.



## Flux current control

The third mode of operation, flux current control (FCC), is available in the MICROMASTER Vector and the MIDIMASTER Vector. Stator current ( $I_s$ ) is made up of active and reactive current. The reactive current component of stator current produces the rotating magnetic field. The active current produces work. Motor nameplate data is entered into the drive. The drive estimates motor magnetic flux based on the measured reactive stator current and the entered nameplate data. Proprietary internal computer algorithms attempt to keep the estimated magnetic flux constant.

If the motor nameplate information has been correctly entered and the drive properly set up, the flux current control mode will usually provide better dynamic performance than simple V/Hz control. Flux current control automatically adapts the drive output to the load. The motor is always operated at optimum efficiency. Speed remains reliably constant even under varying load conditions.



$$I_s = \sqrt{I_M^2 + I_W^2}$$

## **Sensorless vector control**

The fourth mode of operation is sensorless vector control (VC). This mode of operation is available in the MICROMASTER Vector and the MIDIMASTER Vector. In the past, the dynamic response of a DC motor was generally considered significantly better than an AC motor. An AC motor, however, is less expensive and requires less maintenance than a DC motor. Using a complex mathematical motor model and proprietary internal computer algorithms vector control is able to exert the necessary control over an AC motor so that its performance is equal to that of a DC motor. Vector control, flux vector, and field orientation are terms that describe this specialized control technique of AC drives.

Vector control systems facilitate independent control of flux producing and torque producing elements in an induction motor. Sensorless vector control calculates rotor speed based on the motor model, calculated CEMF, inverter output voltage, and inverter output current. This results in improved dynamic performance compared to other control methods.

When motor speed is calculated at very low speeds, based on a small CEMF and known corrections for stator resistance, slight variations in stator resistance and other parameters will have an effect on speed calculation. This makes vector control without a tachometer impractical below a few hertz.

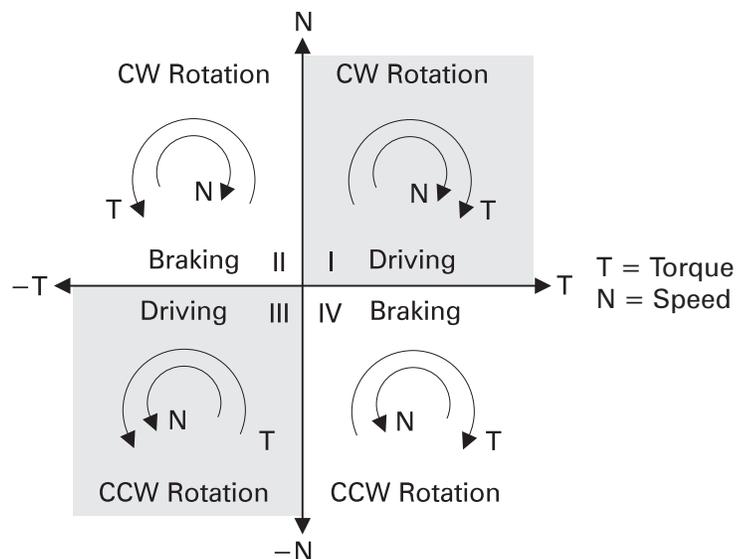
Siemens sensorless vector control drives do operate smoothly to low speed. Sensorless vector control drives will produce full torque below a few hertz, and 150% or more torque at all speeds.

There are some complicated techniques used to accomplish this low speed torque with sensorless vector control. Expert set-up and commissioning may be required to achieve desired operation at low speed.

Parameters for static torque, flux adaptation, slip compensation, and other concepts are complex and beyond the scope of this course.

## Single-quadrant operation

In the speed-torque chart there are four quadrants according to direction of rotation and direction of torque. A single-quadrant drive operates only in quadrants I or III (shaded area). Quadrant I is forward motoring or driving (CW). Quadrant III is reverse motoring or driving (CCW). Reverse motoring is achieved by reversing the direction of the rotating magnetic field. Motor torque is developed in the positive direction to drive the connected load at a desired speed (N). This is similar to driving a car forward on a flat surface from standstill to a desired speed. It takes more forward or motoring torque to accelerate the car from zero to the desired speed. Once the car has reached the desired speed your foot can be let off the accelerator a little. When the car comes to an incline a little more gas, controlled by the accelerator, maintains speed.



## Coast to stop

To stop an AC motor in single-quadrant operation voltage and frequency can simply be removed and the motor allowed to coast to a stop. This is similar to putting a car in neutral, turning off the ignition and allowing the car to coast to a stop.

## Controlled deceleration

Another way is to use a controlled deceleration. Voltage and frequency are reduced gradually until the motor is at stop. This would be similar to slowly removing your foot from the accelerator of a car. The amount of time required to stop a motor depends on the inertia of the motor and connected load. The more inertia the longer it will take to stop.

## DC injection braking

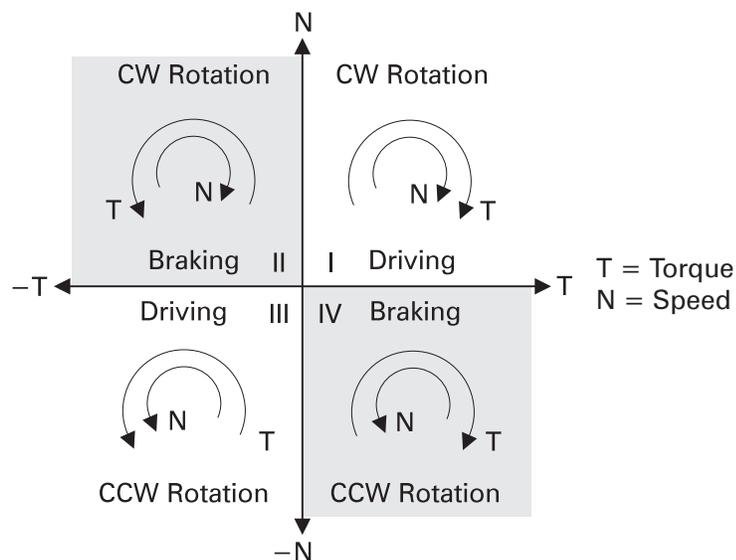
The DC injection braking mode stops the rotating magnetic field and applies a constant DC voltage to the motor windings, helping stop the motor. Up to 250% of the motor's rated current can be applied. This is similar to removing your foot from the accelerator and applying the brakes to bring the car to a stop quickly.

## Compound braking

Compound braking uses a combination of the controlled deceleration ramp and DC injection braking. The drive monitors bus voltage during operation and triggers compound braking when the bus exceeds a set threshold point. As the motor decelerates to a stop a DC voltage is periodically applied to the motor windings. The excess energy on the bus is dissipated in the motor windings. This is similar to alternately applying the brakes to slow a car, then allowing the mechanical inertia of the engine to slow the vehicle until the car is brought to a stop.

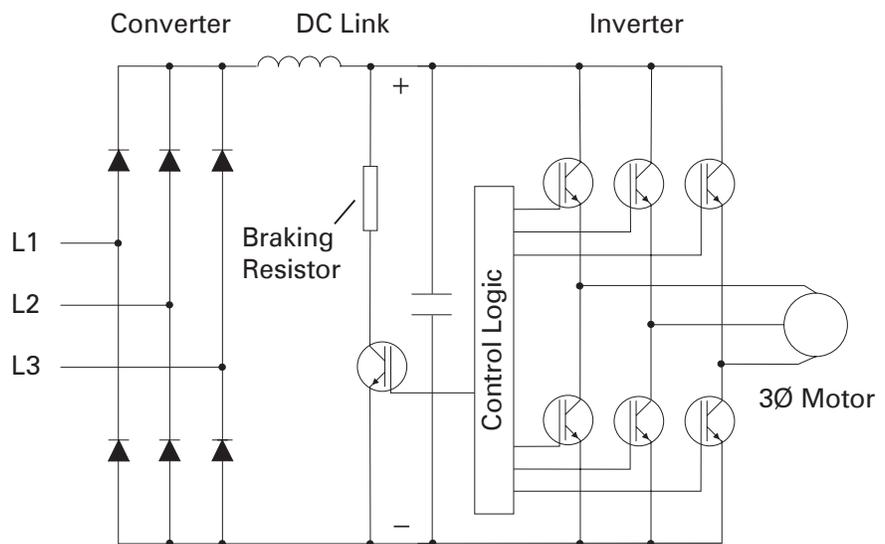
## Four-quadrant operation

The dynamics of certain loads may require four-quadrant operation. When equipped with an optional braking resistor the Siemens MICROMASTER and MIDIMASTER are capable of four-quadrant operation. Torque will always act to cause the rotor to run towards synchronous speed. If the synchronous speed is suddenly reduced, negative torque is developed in the motor. The motor acts like a generator by converting mechanical power from the shaft into electrical power which is returned to the AC drive. This is similar to driving a car downhill. The car's engine will act as a brake. Braking occurs in quadrants II and IV.



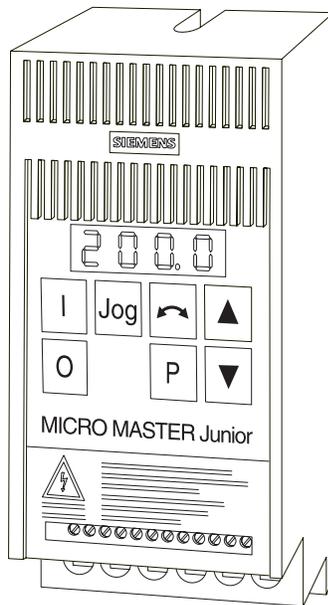
## Optional braking resistor

In order for an AC drive to operate in quadrant II or IV, a means must exist to deal with the electrical energy returned to the drive by the motor. Electrical energy returned by the motor can cause voltage in the DC link to become excessively high when added to existing supply voltage. Various drive components can be damaged by this excessive voltage. An optional braking resistor is available for the Siemens MICROMASTER and MIDIMASTER. The braking resistor is connected to terminals B+ and B-. The braking resistor is added and removed from the circuit by an IGBT. Energy returned by the motor is seen on the DC link. When the DC link reaches a predetermined limit the IGBT is switched on by the control logic. The resistor is placed across the DC link. Excess energy is dissipated by the resistor, reducing bus voltage. When DC link voltage is reduced to a safe level the IGBT is switched off, removing the resistor from the DC link. This is referred to as pulsed resistor braking. This process allows the motor to act as a brake, slowing the connected load quickly.



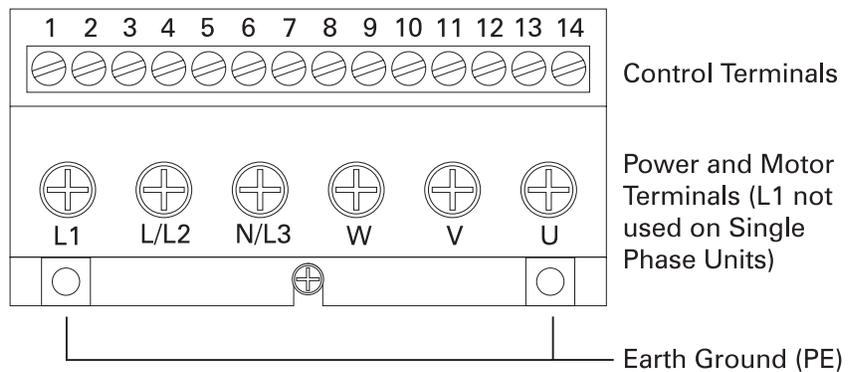
# MICROMASTER Junior

The MICROMASTER Junior is the smallest of the Siemens line of AC Drives. It is available in output power ranges from 1/6 HP (120 W) to 2 HP (1500W). The MICROMASTER Junior is integrated into the Siemens family of drives and the parameter set is compatible with the MICROMASTER and MIDIMASTER.



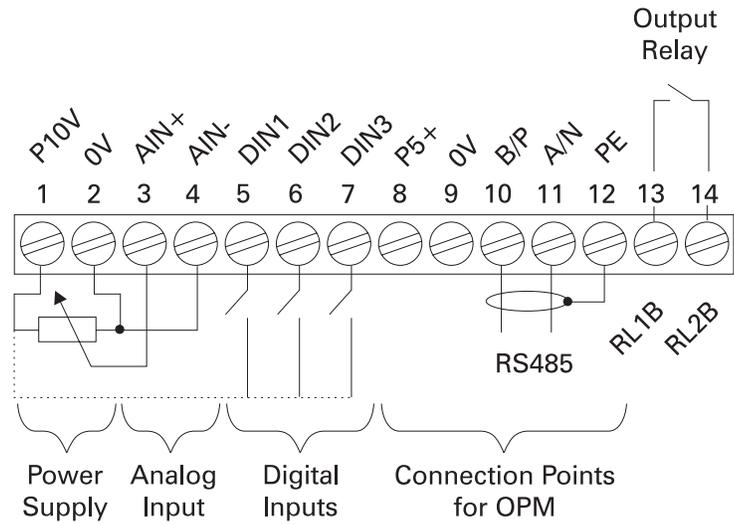
## Wiring

Control wiring, such as speed reference and start/stop control is connected to the control terminals. Power wiring, such as the AC supply and the motor, is connected to the power terminals.



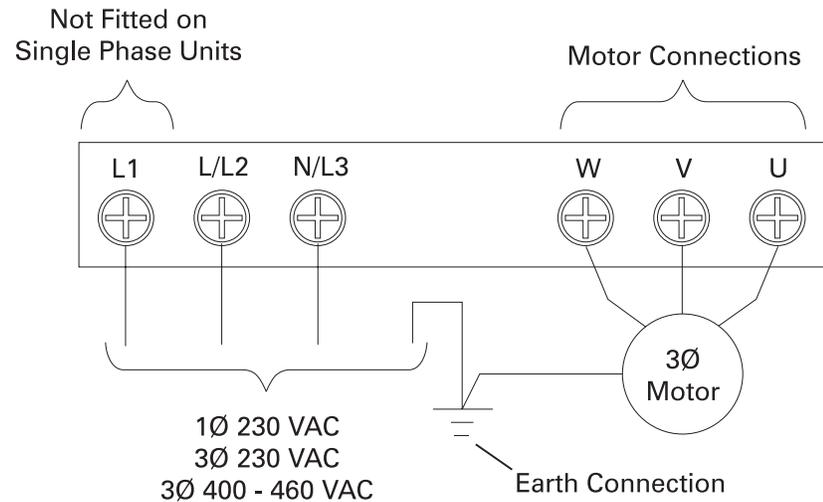
## Control wiring

The MICROMASTER Junior has provision for an analog input, three digital inputs, RS485 serial interface, and an output relay.



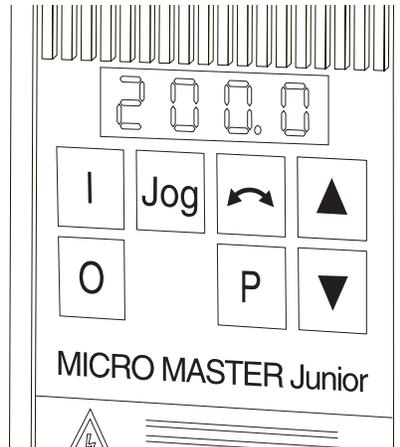
## Power wiring

Output voltage is adjustable from 0 volts to approximately input voltage. Output frequency is adjustable from 0.05 Hz to 200 Hz.



## Operator panel

The operator panel on the MICROMASTER Junior is identical to the operator panel on the MICROMASTER and MIDIMASTER. Parameters, such as ramp times, minimum and maximum frequencies, and modes of operation are easily set. The "P" key toggles the display between a parameter number and the value of the parameter. The up and down pushbuttons scroll through parameters and are used to set a parameter value. In the event of a failure the inverter switches off and a fault code appears in the display.



## Features and options

The MICROMASTER Junior has an input voltage range that allows worldwide usage. The acceptable input frequency ranges from 47 to 63 Hz. Acceptable input voltages are 1Ø or 3Ø 230 VAC, or 3Ø 400 to 460 VAC. The following table reflects ratings available at the time this book was printed. A MICROMASTER Junior may also be referred to by a model series number, 6SE91.

Model Number	Part Number			Output
	230 VAC 1Ø Class A Filter	230 VAC 1Ø, 3Ø w/o Class A Filter	400-460 VAC 1Ø, 3Ø w/o Class A Filter	
MMJ12	6SE9110-7BA53	6SE9110-7BA53		1/6 HP 120 W
MMJ25	6SE9111-5BA53	6SE9111-5CA13		1/3 HP 250 W
MMJ37	6SE9112-0BA53	6SE9112-0CA13	6SE9111-1JA13	1/2 HP 370 W
MMJ55	6SE9112-6BA53	6SE9112-6CA13	6SE9111-4JA13	3/4 HP 550W
MMJ75	6SE9113-4BA53	6SE9113-4CA13	6SE9113-4JA13	1 HP 750 W
MMJ110			6SE9112-7JA13	1.5 HP 1.1 KW
MMJ150			6SE9113-7JA13	2 HP 1.5 KW

## Features

- High Starting Torque
- Programmable Acceleration/Deceleration with Smoothing
- V/F Ratio, Linear or Fan Curve with Boost
- Silent Motor Operation Using Special Pulse Techniques
- Four Skip Frequencies
- Automatic Restart on the Fly Option
- Three Fixed Frequencies
- Hoist Brake Interface
- Most Recent Fault and Warning Memory
- Overload Rating of 150% for One Minute

## Options

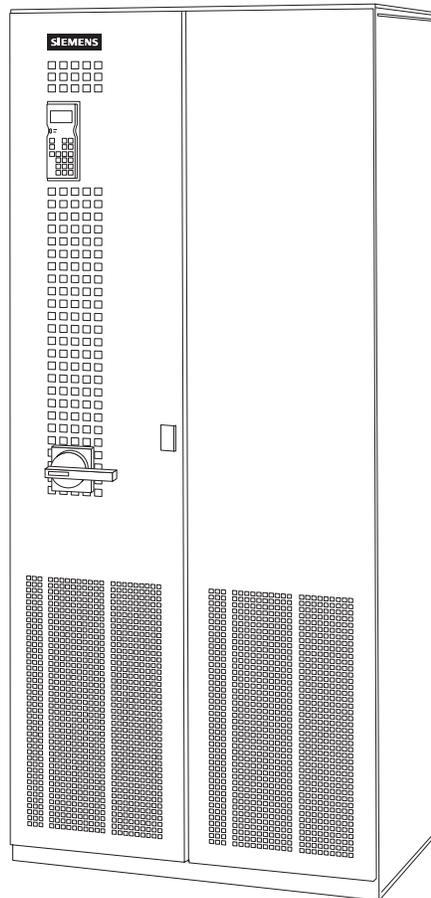
- Clear Text Operator Panel (OPM)
- PROFIBUS
- DIN Rail Mounting Bracket

## Review 6

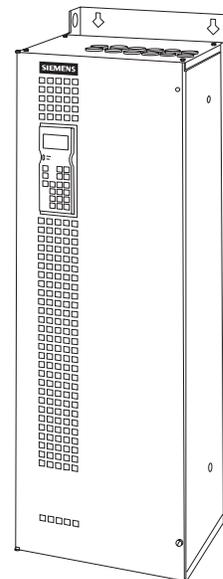
1. The \_\_\_\_\_ key on the Siemens MICROMASTER and MIDIMASTER is used to toggle between a parameter number and value.
2. The maximum acceleration/deceleration ramp time on the MICROMASTER, MICROMASTER Vector, and MIDIMASTER Vector is \_\_\_\_\_ seconds.
3. Terminals B+ and B- are used to connect an optional \_\_\_\_\_ .
4. The MICROMASTER Vector and MIDIMASTER Vector have \_\_\_\_\_ digital inputs.
5. The \_\_\_\_\_ mode of operation on the Siemens MICROMASTER Vector and MIDIMASTER Vector use internal computer algorithms to control an AC motor so that its performance is equal to that of DC motor.
6. Forward regeneration occurs in quadrant \_\_\_\_\_ .
7. The correct part number for a 2 HP MICROMASTER Junior, operated on a 460 VAC lines is \_\_\_\_\_ .

# Siemens MASTERDRIVES

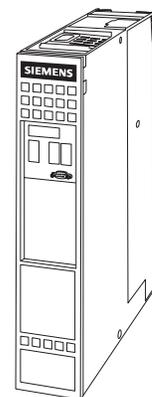
The Siemens MASTERDRIVES can be used for variable-speed control on motors rated from 1 to 5000 HP. MASTERDRIVES are available for all major worldwide 3-phase supply voltages: 208-230, 380-460, 500-575, 660-690 volts. The Siemens MASTERDRIVES can also be referred to by a model series number, 6SE70.



Cabinet



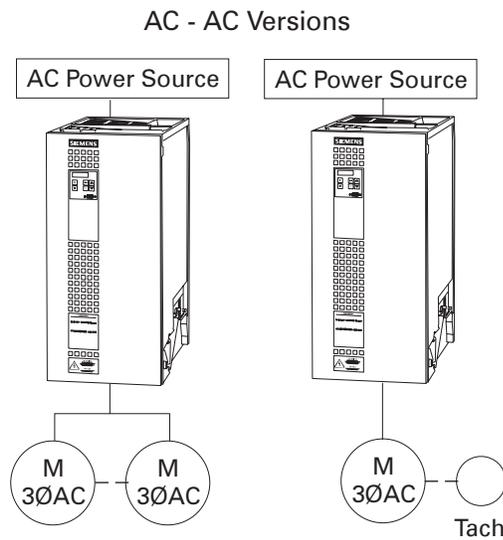
Chassis



Compact

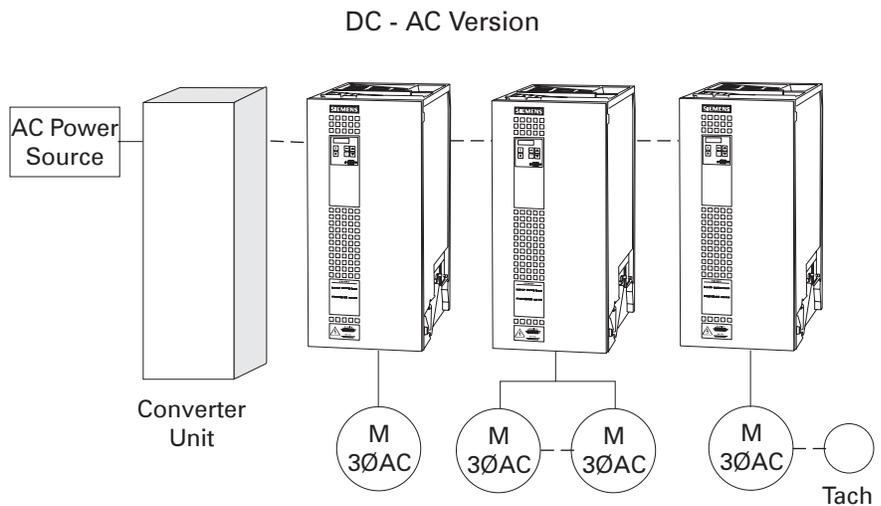
## AC - AC (AC - to - AC)

A single inverter can be used with single motor, single motor with a tach, and multimotor applications. This is referred to as the AC-AC version. Various options allow for analog and encoder tachometer types.



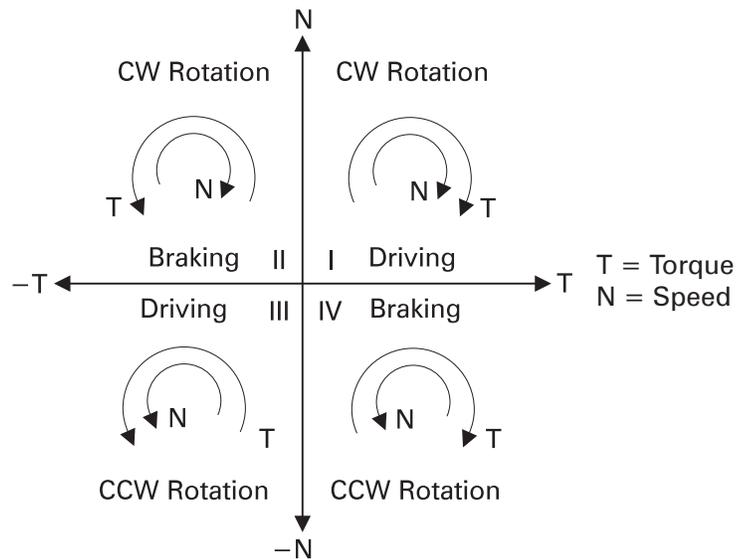
## DC - AC (DC - to - AC)

The Siemens MASTERDRIVES can also be configured so that a common DC bus supplies power to several AC inverters. Common DC bus systems also allow single and multimotor combinations. This is referred to as the DC-AC version.



## Braking unit

In the speed-torque chart there are four quadrants according to direction of rotation and direction of torque. Quadrant I is forward motoring or driving (CW). Quadrant III is reverse motoring or driving (CCW). Reverse motoring is achieved by reversing the direction of the rotating magnetic field. The dynamics of certain loads may require four-quadrant operation. When equipped with an optional braking unit Siemens MASTERDRIVES are capable of four-quadrant operation. Braking occurs in quadrants II and IV. Several regenerative rectifier products are also available which return braking energy to the power source instead of dissipating (wasting) it in resistors.



There are two versions of the MASTERDRIVES product: vector control (VC) and motion control (MC).

### **Vector control (VC)**

One mode of operation in the MASTERDRIVES is vector control (VC). In the past, the dynamic response of a DC motor was generally considered significantly better than an AC motor. An AC motor, however, is less expensive and requires less maintenance than a DC motor. Using a complex mathematical motor model and proprietary internal computer algorithms vector control is able to exert the necessary control over an AC motor so that its performance is equal to that of a DC motor. Vector control, flux vector, and field orientation are terms that describe this specialized control technique of AC drives.

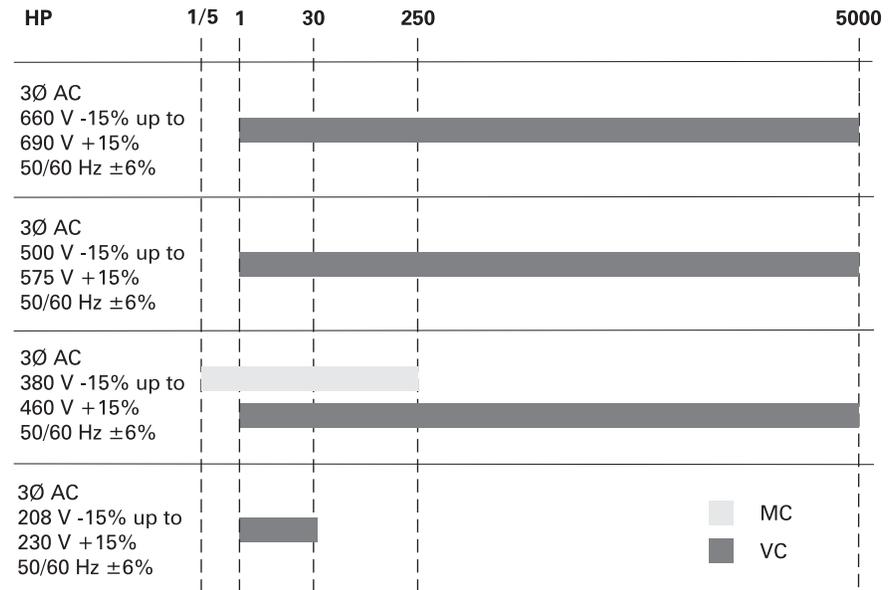
Vector control drives have 4-quadrant operation and control torque and speed continuously through zero speed, and can hold a motor stationary against an applied torque. Speed control is exact, even with varying loads. Speed control reaction time is  $\leq 45$  ms without tach feedback, and  $\leq 20$  ms with tach feedback. Maximum torque is available up to base speed. Torque control reaction time is  $\leq 10$  ms in torque control with feedback. Vector control is suitable on applications such as winders and rolling mills.

### **Motion control (MC)**

A second mode of operation available on the MASTERDRIVES is motion control (MC). Servo drives are designed to operate with a specific motor and are designed to achieve speed precision and fast response to a speed change. Servo applications typically have rapid start-stop cycles, require zero speed holding torque and high accelerating torque from zero speed, and are used positioning applications. In a packaging machine, for example, material may have to start and stop at various positions along a conveyor system.

## Ratings

The following graph shows horsepower ratings available for VC and MC MASTERDRIVES.



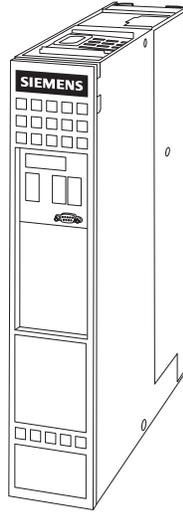
## IP and NEMA protection

Depending on the size of the unit, Siemens MASTERDRIVES are available in a variety of enclosures. IP protection is a European system of classification which indicates the degree of protection an enclosure provides against dust, liquids, solid objects, and personal contact. The IP system of classification is accepted internationally. IP00 offers no special protection. IP20 offers protection against solid objects greater than 12mm (0.47 inches) and dripping water when tilted up to 15°. IP45 offers protection against solid objects greater than 1mm (0.039 inches) and water projected from a nozzle against the enclosure from any direction.

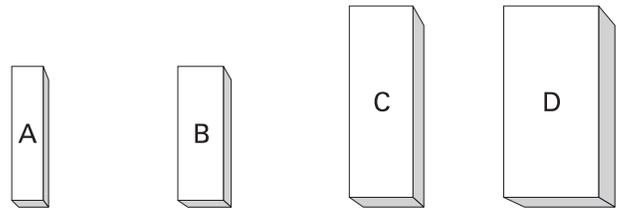
The National Electrical Manufacturers Association (NEMA) also designates, by means of a type number, environmental conditions an enclosure is suited for. MASTERDRIVES are available in NEMA 1, 4, and 12 enclosures. NEMA 1 is a general purpose indoor enclosure. NEMA 4 enclosures are intended for indoor or outdoor use and provide a degree of protection against windblown dust and rain, splashing water, and hose-directed water. NEMA 12 enclosures are intended for indoor use and are dust-tight and drip-tight. Contact your Siemens representative for more information.

## Compact units

Compact units require the smallest mounting space. Units can be DIN-G rail mounted side-by-side without spacing. There are four sizes: A, B, C, and D. Compact units are available with ratings from 3 to 50 HP (5.6 to 72 Amps) at 460 VAC.



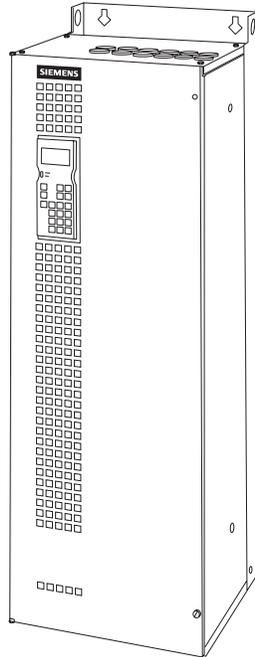
The following table shows the size in millimeters and maximum current ratings for compact units.



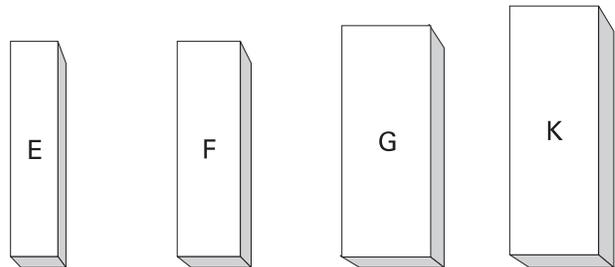
Depth in mm	350			
Width in mm	90	135	180	270
Height in mm	425	425	600	600
Current Rating at 460 Volts	5.6/6.1/7.3/ 8/9.3/10.2	12/13.2/ 15.9/17.5	23.2/25.5/ 30.9/34	34.1/37.5/ 42.8/47/53.7/ 59/65.5/72
Current Rating at 575 Volts		4.1/4.5/5.6/ 6.2/7.1/7.8/ 10/11/13.7/ 15.1	20/22	26.4/29/30.9/ 34/32/41/ 42.3/46.5

## Chassis units

Chassis units can also be mounted side-by-side without spacing. They are easily mounted on the wall when supplied in an IP20 enclosure. There are four sizes: E, F, G, and K. Chassis units are available with ratings from 60 to 500 HP (83.7 to 590 Amps) at 460 VAC.



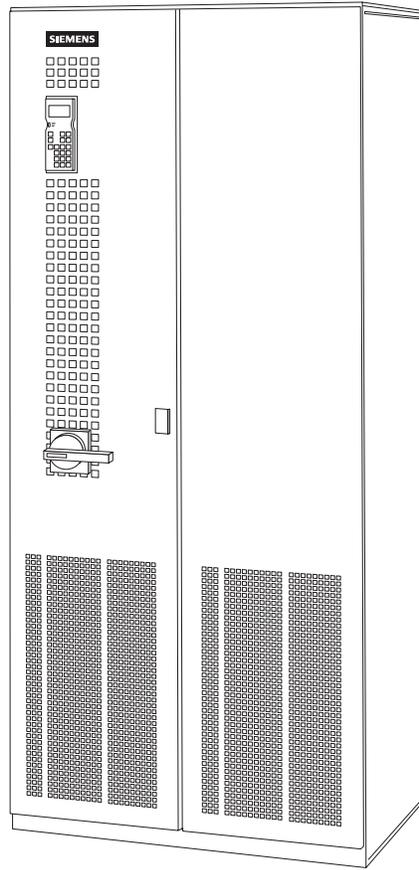
The following table shows the size in millimeters and maximum current ratings for the chassis units.



Depth in mm	350		450	
Width in mm	270	360	508	508
Height in mm	1000	1000	1450	1750
Current Rating at 460 Volts	83.7/92	112.8/124/ 132.9/146/ 169.3/186	191/210/237/ 260/287/315/ 337/370	361/414/464/ 477/510/537/ 590
Current Rating at 575 Volts	55.5/61/ 60.1/66	71.9/77/79/ 82/96.3/108	117/125/128/ 135/142/156/ 174/192/ 204.8/225	270/297/322/ 336/354/382/ 411/452

## Cabinet units

Cabinet units are ready-wired complete units for single and multimotor applications. All components are accessible from the front of the cabinet. Cabinet units are available with ratings from 50 to 5000 HP (45 to 4500 KW).



## Sinewave filter and dv/dt filter

Distance from the drive to the motor must also be taken into consideration. All motor cables have line-to-line and line-to-ground capacitance. The longer the cable, the greater the capacitance. Some types of cables, shielded cable for example, have greater capacitance. Spikes occur on the output of all PWM drives because of the charging current of the cable capacitance. Higher voltage (460 VAC) and higher capacitance (long cables) result in higher current spikes. Voltage spikes caused by long cable lengths can potentially shorten the life of the motor.

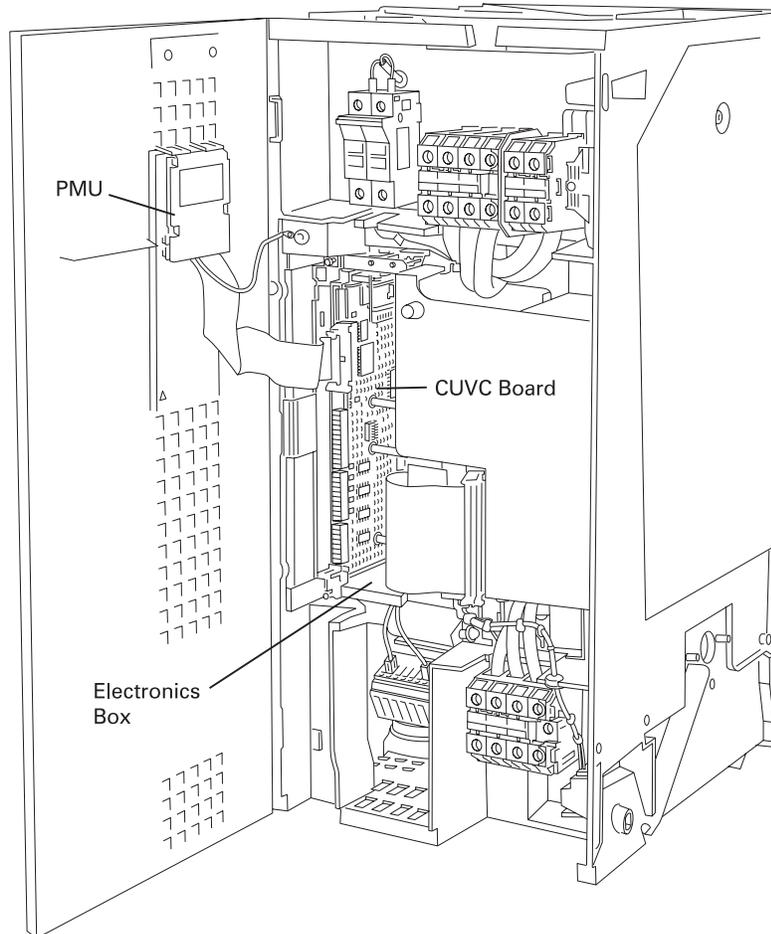
Various devices are available to protect the inverter and motor. A dv/dt filter, for example, limits motor voltage rise time (dv/dt) and maximum voltage spikes. This allows cable lengths greater than 300 meters. Another device designed to protect the motor from high voltage spikes is a sinewave filter. The sinewave filter generates a sinusoidal motor voltage and output current. It is very important to fully understand the chart, which shows the criteria for selecting the proper output reactor, dv/dt filter, or sinewave filter. If the guidelines in the chart are followed, trouble-free operation of motors and inverters will result. If the guidelines are ignored there will be problems.

Motor Cable Length	Supply Voltage Range					
	208 V to 230 V		380 V to 500 V		525 V to 575 V	
	Motors in acc. to DIN VDE 0530, attached sheet 2	1LA5-/1LA6-Motors	Motors in acc. to DIN VDE 0530, attached sheet 2	1LA5-/1LA6-Motors	Motors in acc. to DIN VDE 0530, attached sheet 2	1LA5-/1LA6-Motors
up to 50 m	Output reactor	—	Output reactor	—	Sinewave filter	dv/dt filter
50 m - 150 m	Output reactor	Output reactor	Output reactor	Output reactor	Sinewave filter	dv/dt filter
150 m - 300 m	2 Output reactors in series	2 Output reactors in series	2 Output reactors in series	2 Output reactors in series	Sinewave filter	Output reactor and dv/dt filter in series

**Note:** Filters are only available for vector control (VC) drives. Filters are not available for motion control (MC) drives. Motor and drive technology is continuously changing. Contact your Siemens representative for the latest information on motor cable length and drive output filter options.

## Internal layout

The following drawing illustrates the internal layout of a size D compact unit. The MASTERDRIVES can be controlled via a keypad and display, referred to as the Parametrization Unit (PMU). Customer control connections (start/stop, speed reference, etc.) are made on the control card (CUVC). The electronics box is equipped with three slots for the CUVC board and two option boards. The size D compact unit has a transformer to supply a cooling fan. Smaller units may not have a supply fan transformer.



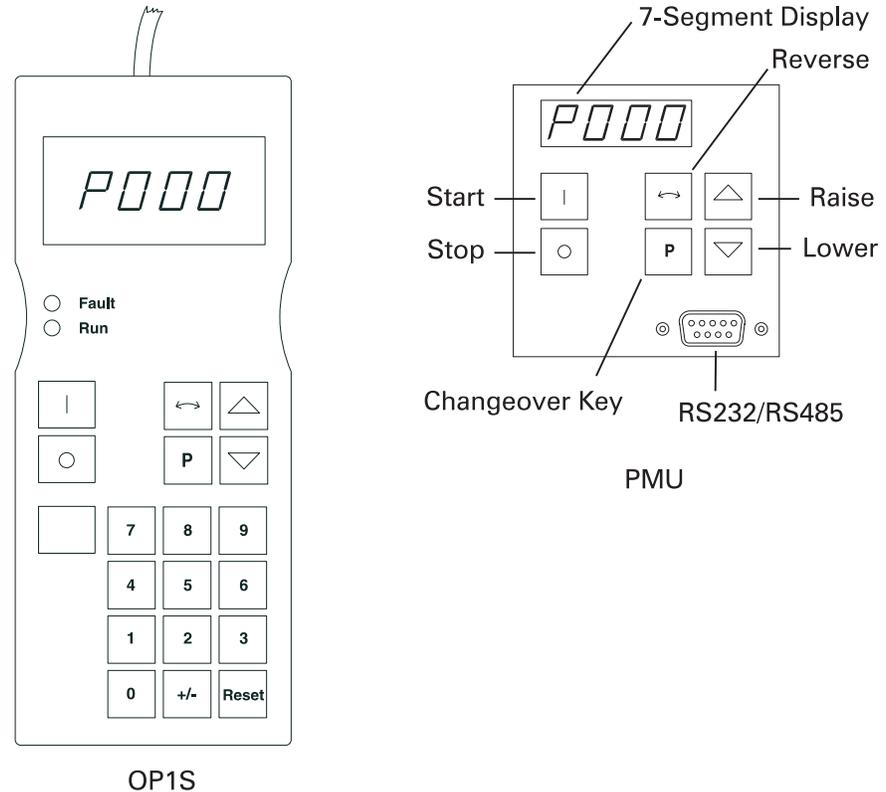
## Programming and operating sources

The MASTERDRIVES can be programmed and operated from the following sources:

Operator Control Panel (OP1S)  
Parameterization Unit (PMU)  
Terminal strips on the CU board  
Serial interface (various)

## PMU and OP1

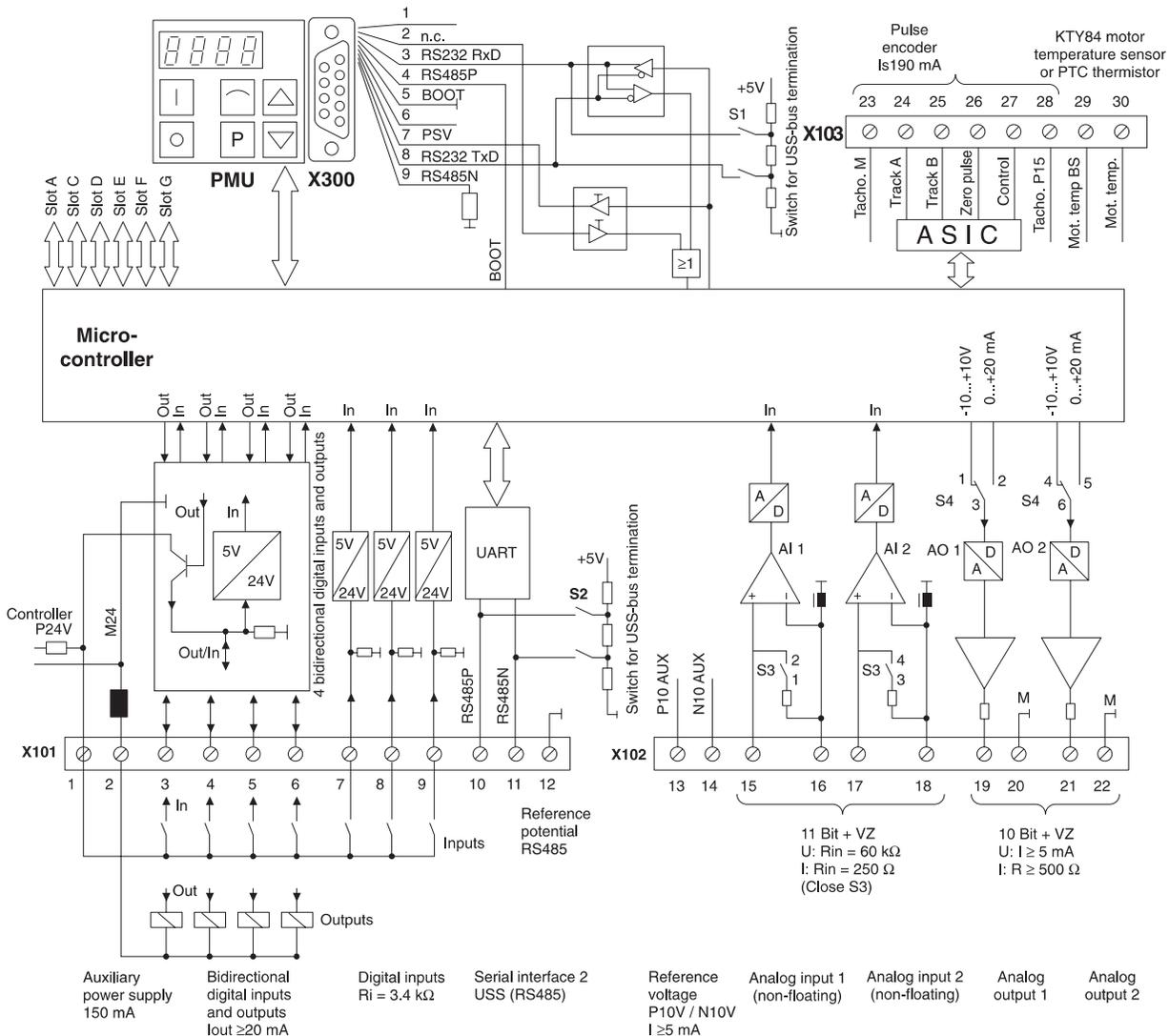
The MASTERDRIVES can be Programmed and controlled by the PMU or OP1S.



Parameters, such as ramp times, minimum and maximum frequencies, and modes of operation are easily set. The changeover key ("P") toggles the display between a parameter number and the value of the parameter. The up and down pushbuttons scroll through parameters and are used to select a parameter value, once the "P" key sets the parameter. The OP1S has a numbered key pad for direct entry. In the event of a failure the inverter switches off and a fault code appears in the display. In addition the drive can be started, stopped, and reversed. The serial port interface allows connection to RS232 or RS485 serial communications. The OP1S can be mounted directly on the PMU or up to 200 meters away. An additional 5 volt power supply is required for remote operation over 5 meters.

# CU Board

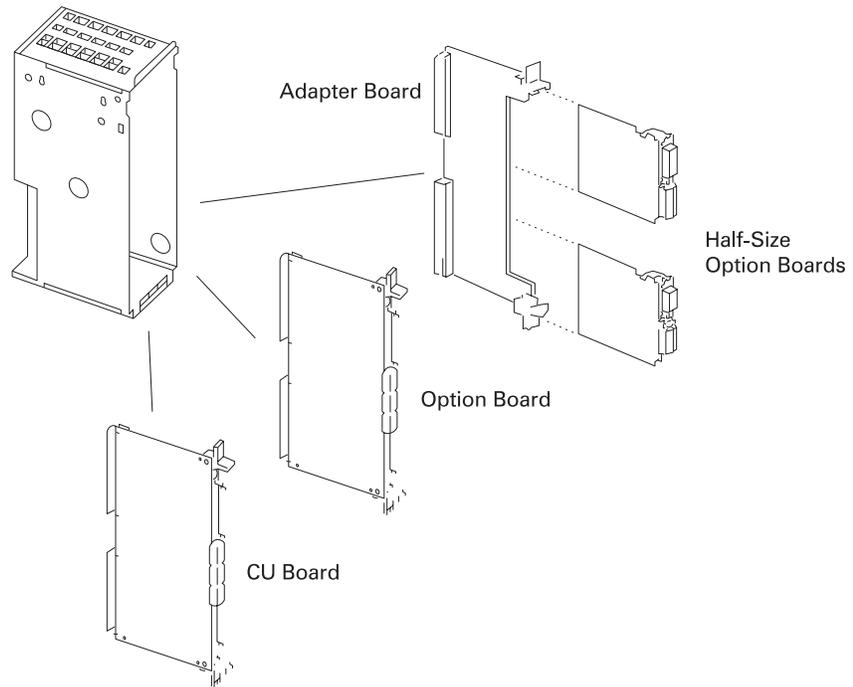
The Siemens MASTERDRIVE can also be programmed and operated from the terminal strip located on the CU board. The following drawing illustrates a typical terminal arrangement of the CUVC board (used in the MASTERDRIVE VC). RS 485 serial communication is available on X101. Programmable binary outputs, used to indicate a condition of the drive, are available on X101. Binary inputs are also available. Starting/stopping the drive and selecting preset speeds are examples of possible binary input functions. The MASTERDRIVE accepts analog inputs (voltage or current) for speed control on X102. There are programmable analog outputs for meter indication. A motor temperature switch can be connected on X103 and is used to stop a drive in the event a motor becomes overheated. Connections are also available for a digital tach. Not all features are available on all versions. Consult detailed product literature for more information.



## Electronics box and option boards

The electronics box is a rack with three slots. The CU board is plugged into slot 1. The CU board is the central electronic board. It has input and output connections for wiring the control devices of various functions such as start/stop pushbuttons and speed potentiometer. The CU board is self-optimizing and has comprehensive diagnostics. There are two versions of the CU board: CUVV for vector control and CUMC for motion control.

Option boards are plugged into slots 2 and 3. Half-sized boards can be used with an adapter board (ADB) and are plugged into lettered positions in the electronics box. A local bus adapter (LBA - not shown) must be purchased and installed if any option boards are to be used. The LBA is simply additional card guides and connectors. Option boards can also be plugged on the CU board. Option boards are automatically recognized by the drive.

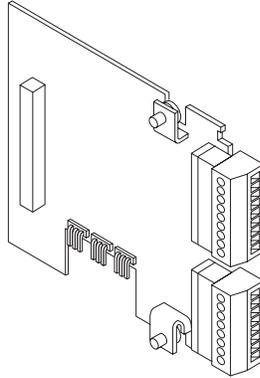


Communication option boards CBP, SLB, SCB1, and SCB2 allow high speed drive-to-drive (peer-to-peer) communication through RS 485 wires or fiber-optic cables. Peer-to-peer communication allows data to be exchanged between drives and is available using serial communication boards SLB, SCB1, and SCB2, and technology boards T100 and T300. PC and PLC communication is available with SCB2 (USS Protocol) and communication board CBP (PROFIBUS).

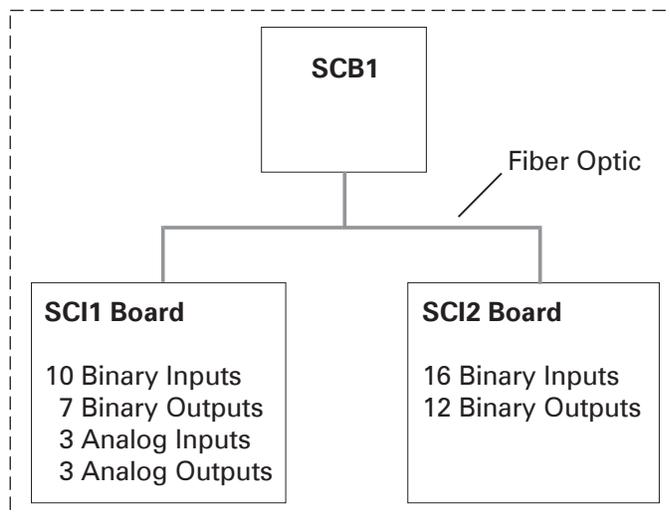
Technology boards (T100 and T300) provide application specific control and enhancement. Technology option boards can be selected for sectional drives, synchronized running, winders, and positioning.

## Expanding inputs and outputs

The number of digital and analog Inputs and outputs can be expanded in a number of ways. EB1 and EB2 are half-sized expansion boards that provide a number of additional I/O possibilities. A maximum of two half-sized EB boards can be used.



In addition to peer-to-peer drive communication the SCB1 can interface with one or two SCI boards. SCI boards provide additional inputs and outputs for drive control. SCI1 has 10 binary inputs, 7 binary outputs, 3 analog inputs, and 3 analog outputs. SCI2 has 16 binary inputs and 12 binary outputs. Inputs and outputs on the SCI1 and SCI2 boards provide more isolation and electromagnetic noise immunity than the standard I/O on the CU boards. SCI1 or SCI2 boards should be used in applications where noise immunity is a concern. The SCB2 board does not interface with SCI boards.



## Digital tachometers

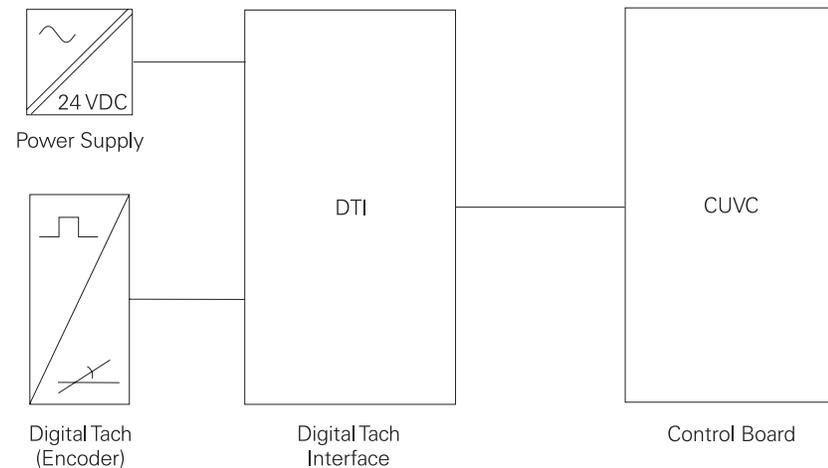
Digital tachometers (encoders) can be used to measure the actual speed of the motor. The Digital Tachometer Interface (DTI) is designed to be used with digital tachometers (encoders) that operate at a voltage other than 11-30 VDC. The DTI is also required if the following encoders are used:

HTL encoder with inverted channel

Floating HTL encoder

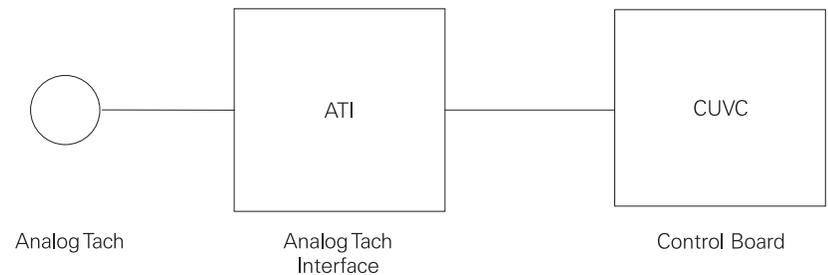
TTL encoder

Encoder with cables greater than 495 feet



## Analog tachometers

Analog tachometers can also be used to measure the actual motor speed. Analog tachometers generate a DC voltage which is proportional to the speed. The voltage at maximum speed is a function of the actual tachometer, and generally lies between 10 V and 300 V. Closed loop speed control with an analog tach can be applied to a speed range from 1 RPM to 6000 RPM. An analog tach interface (ATI) board is used to connect an analog tach to the CUVC board.

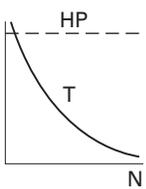
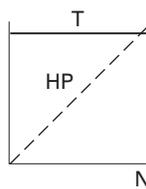
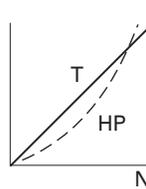
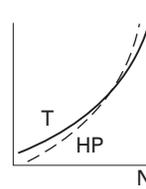


## Review 7

1. The Siemens MASTERDRIVES can be referred to by a model series number, \_\_\_\_\_ .
2. MASTERDRIVES configured so that a common bus supplies power to several AC drives are referred to as \_\_\_\_\_ .
3. A \_\_\_\_\_ \_\_\_\_\_ option returns braking energy to the power source instead of dissipating it in resistors.
4. Compact units are available from 3 to \_\_\_\_\_ HP.
5. Cabinet units are available from \_\_\_\_\_ to 5000 HP.
6. The SC12 board has \_\_\_\_\_ binary inputs and \_\_\_\_\_ binary outputs.
7. Half-sized boards \_\_\_\_\_ and \_\_\_\_\_ can be used to supply additional inputs and outputs.

# Applications

When applying an AC drive and motor to an application it is necessary to know the horsepower, torque, and speed characteristics of the load. The following chart shows characteristics of various loads.

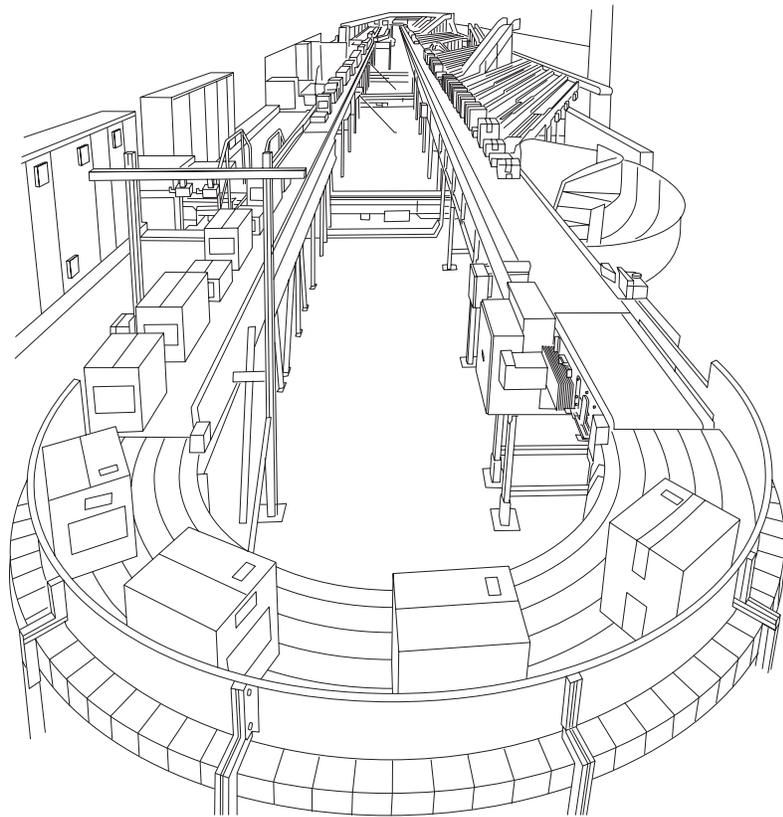
$T \approx \frac{1}{N}$	$T = \text{Constant}$	$T \approx N$	$T \approx N^2$
HP = Constant	HP $\approx$ N	HP $\approx$ N <sup>2</sup>	HP $\approx$ N <sup>3</sup>
			
Winders Facing lathes Rotary cutting machines	Hoisting gear Belt conveyors Process machines involving forming Rolling mills Planers	Calenders with viscous friction Eddy-current brakes	Pumps Fans Centrifuges

Loads generally fall into one of three categories:

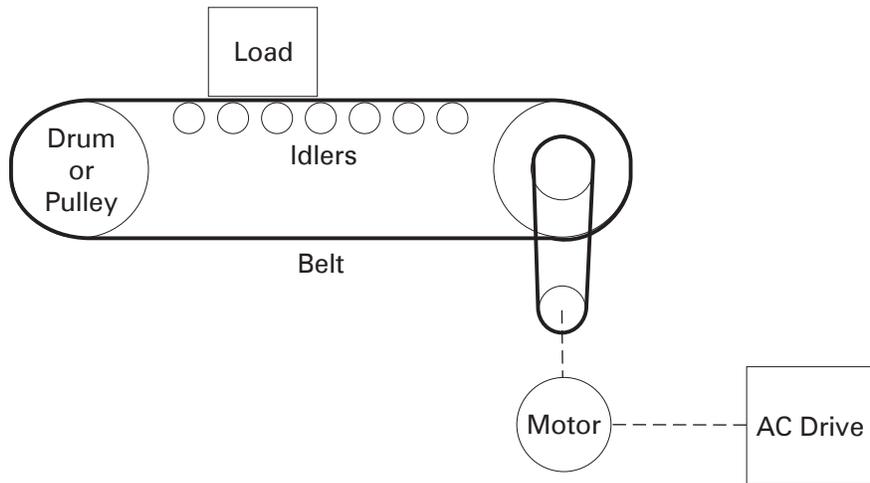
- |                     |   |
|---------------------|---|
| Constant torque     | The load is essentially the same throughout the speed range. Hoisting gear and belt conveyors are examples. |
| Variable torque     | The load increases as speed increases. Pumps and fans are examples.   |
| Constant horsepower | The load decreases as speed increases. Winders and rotary cutting machines are examples.                    |

# Constant Torque Applications

A constant torque load implies that the torque required to keep the load running is the same throughout the speed range. It must be remembered that constant torque refers to the motor's ability to maintain constant flux ( $\Phi$ ). Torque produced will vary with the required load. One example of a constant torque load is a conveyor similar to the one shown below. Conveyors can be found in all sorts of applications and environments, and can take many styles and shapes.



Conveyors are made up of belts to support the load, various pulleys to support the belt, maintain tension, and change belt direction, and idlers to support the belt and load.



### Determining motor speed

The speed and horsepower of an application must be known when selecting a motor and drive. Given the velocity in feet per minute (FPM) of the conveyor belt, the diameter in inches of the driven pulley, and the gear ratio (G) between the motor and driven pulley, the speed of the motor can be determined. The following formula is used to calculate conveyor speed.

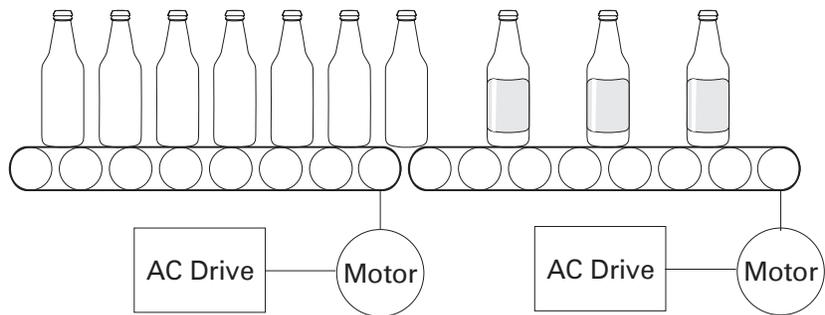
$$Motor\ RPM = \frac{Conveyor\ Velocity\ (FPM) \times G}{\pi \times \left( \frac{Diameter\ in\ Inches}{12} \right)}$$

If, for example, the maximum desired speed of a conveyor is 750 FPM, the driven pulley is 18" in diameter, and the gear ratio between the motor and driven pulley is 4:1, the maximum speed of the motor is 638.3 RPM. It would be difficult to find a motor that would operate at exactly this speed. An AC drive can be used with an eight-pole motor (900 RPM). This would allow the conveyor to be operated at any speed between zero and the desired maximum speed of 750 FPM.

$$Motor\ RPM = \frac{750 \times 4}{3.14 \times \left( \frac{18}{12} \right)}$$

$$Motor\ RPM = 637\ RPM$$

Another advantage to using AC drives on a conveyor is the ability to run different sections of the conveyor at different speeds. A bottle machine, for example, may have bottles bunched close together for filling and then spread out for labeling. Two motors and two drives would be required. One motor would run the filling section at a given speed and a second motor would run the labeling section slightly faster spreading the bottles out.



## Horsepower

Calculating motor horsepower is complicated with many variables, which is beyond the scope of this course. Someone with knowledge of, and experience with conveyor operation would be required to accurately calculate the required horsepower. The horsepower required to drive a conveyor is the effective tension ( $T_e$ ) times the velocity ( $V$ ) of the belt in feet per minute, divided by 33,000.

$$HP = \frac{T_e \times V}{33,000}$$

Effective tension ( $T_e$ ) is determined by several forces:

- Gravitational weight of the load
- Length and weight of belt
- Friction of material on the conveyor
- Friction of all drive components and accessories
  - pulley inertia
  - belt/chain weight
  - motor inertia
  - friction of plows
  - friction of idlers
- Acceleration force when new material is added to conveyor

If the effective tension of a conveyor were calculated to be 2000 pounds and the maximum speed is 750 FPM, then the required horsepower is 45.5.

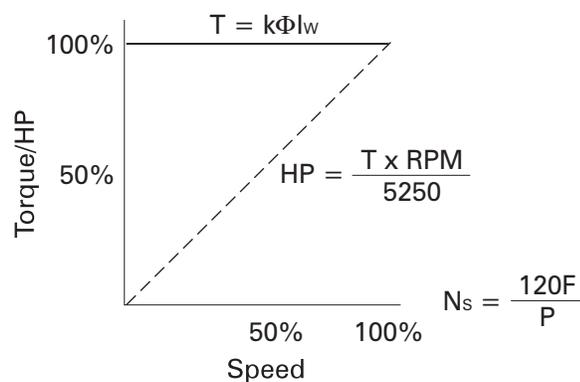
$$HP = \frac{2000 \times 750}{33,000}$$

$$HP = 45.5$$

Starting torque of a conveyor can be 1.5 to 2 times full load torque. A motor capable of driving a fully loaded conveyor may not be able to start and accelerate the conveyor up to speed. AC drives can typically supply 1.5 times full load torque for starting. An engineer may need to choose a larger motor and drive in order to start and accelerate the conveyor.

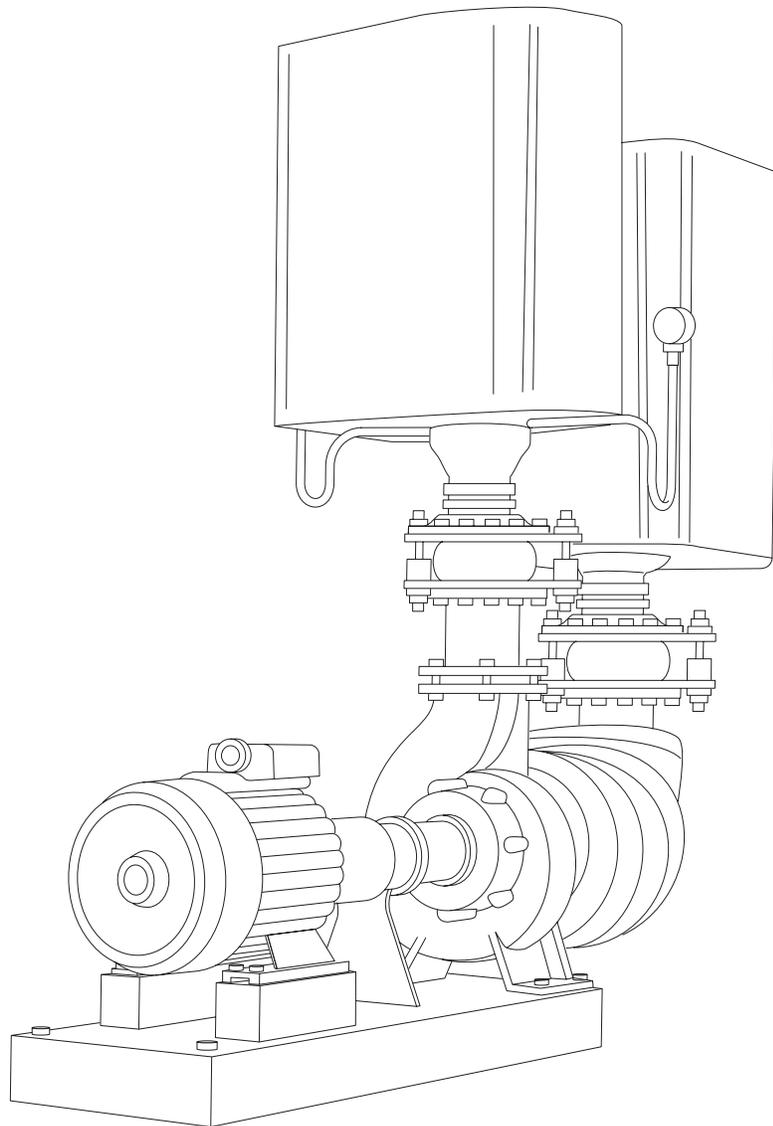
### Torque/HP and speed

The speed on a conveyor is increased by increasing the AC drive frequency (F) to the motor. Torque (T) is affected by flux ( $\Phi$ ) and working current ( $I_w$ ). The drive will maintain constant flux by keeping the voltage and frequency ratio constant. To do this the drive increases voltage and frequency in proportion. During acceleration working current will increase, however, causing a corresponding increase in torque. Once at its new speed the working current and torque will be the same as its old speed. The conveyor cannot be operated above the rated frequency of the motor (60 Hz) because the drive will no longer be able to provide constant flux. As a result, the motor will be unable to supply rated torque. Horsepower (HP) is affected by torque and speed. There will be a corresponding increase in horsepower as speed (RPM) increases.



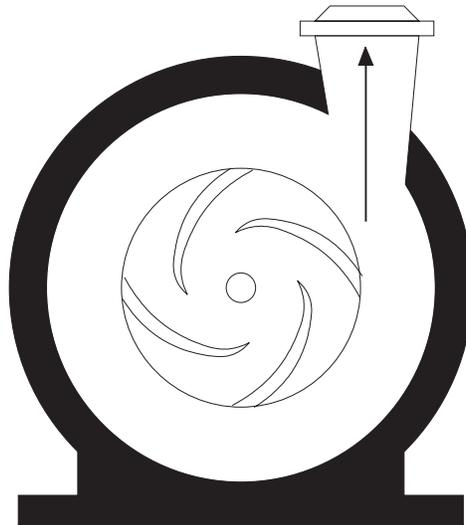
# Variable Torque Applications

A variable torque load implies that torque and horsepower increase with an increase in speed. Fans and pumps are examples of variable torque. A pump used on a chilled water system is shown below.



## Variable torque pumps

There are several types of pumps. The most common pump is the end-suction centrifugal pump illustrated below. There are variations of the centrifugal pump. Turbine and propeller pumps are examples. This section deals with variable torque loads. The faster a centrifugal pump turns, the more fluid it pumps and the more torque it requires. It should be noted that not all pumps are variable torque. Reciprocating pumps are constant torque.



## Calculating horsepower

Calculating horsepower for a pump application is an involved process that requires someone with a thorough knowledge of the application and pumps. The following information is for illustration only. There are three related horsepower calculations involved in pump applications: liquid, mechanical and electrical.

## Hydraulic head

Hydraulic head is the difference in hydraulic pressure between two points, which actually includes elevation, pressure and velocity. An increase in pump speed would cause increases in pressure and velocity which increases the hydraulic head.

## Liquid horsepower

Liquid horsepower is the hydraulic power transferred to the pumped liquid. The following formula can be used to calculate liquid energy.

$$\text{Liquid Energy in ft-lb} = \text{Total Head} \times (\text{Gallons} \times \text{Weight})$$

Water weighs 8.34 pounds per gallon. If 50 gallons of water per minute were required to be moved through 100 feet of head the energy required would be 41,700 ft-lb/minute.

$$100 \text{ feet} \times (50 \text{ gallons} \times 8.34) = 41,700 \text{ ft-lb/minute}$$

If the pumps speed were increased so that 100 gallons of water were being pumped through 100 feet of head the energy would be 83,400 ft-lb/minute. Twice the energy would be required. The hydraulic head would, in actuality, also increase.

$$100 \text{ feet} \times (100 \text{ gallons} \times 8.34) = 83,400 \text{ ft-lb/minute}$$

The common method of expression is horsepower. One horsepower is equal to 33,000 ft-lb/minute.

Therefore, 41,700 ft-lb/minute is 1.26 HP and 83,400 ft-lb/minute is 2.53 HP.

$$\frac{41,700}{33,000} = 1.26 \text{ HP} \quad \frac{83,400}{33,000} = 2.53 \text{ HP}$$

## Mechanical horsepower

Mechanical horsepower is the horsepower input to the pump and is equal to the liquid horsepower divided by the pump's efficiency. If the liquid horsepower is 2.53 and the pump is 75% efficient the brake horsepower is 3.4 HP.

$$\frac{1.26}{.75} = 1.7 \text{ HP} \quad \frac{2.53}{.75} = 3.4 \text{ HP}$$

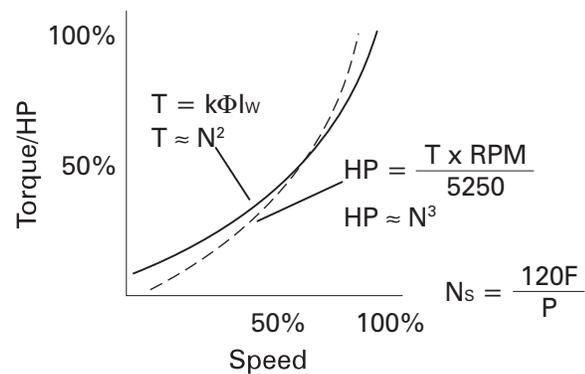
## Electrical horsepower

Electrical horsepower is the horsepower required to run the motor driving the pump and is equal to the mechanical horsepower divided by the motor's efficiency. If the motor is 90% efficient the electrical horsepower is 3.78 HP. It can be seen that with an increase of pump speed there is a corresponding increase in electrical horsepower.

$$\frac{1.7}{.90} = 1.9 \text{ HP} \quad \frac{3.4}{.90} = 3.8 \text{ HP}$$

## Torque/HP and speed

The speed on a pump is increased by increasing the AC drive frequency (F) to the motor. Torque (T) is affected by flux ( $\Phi$ ) and working current ( $I_w$ ). The drive will maintain appropriate flux by adjusting the voltage and frequency ratio dependent on speed. During acceleration, working current will increase causing a corresponding increase in torque. In this application, torque increases in proportion to the speed squared. This is due to the increase in hydraulic head as the pump works harder to pump more fluid. Horsepower increases in proportion to the speed cubed due to an increase of torque and speed. The pump cannot be operated above the rated frequency of the motor (60 Hz) because the drive will no longer be able to provide constant flux. As a result, the motor will be unable to supply rated torque. The load's torque requirements increase while the motor's ability to supply torque decreases.



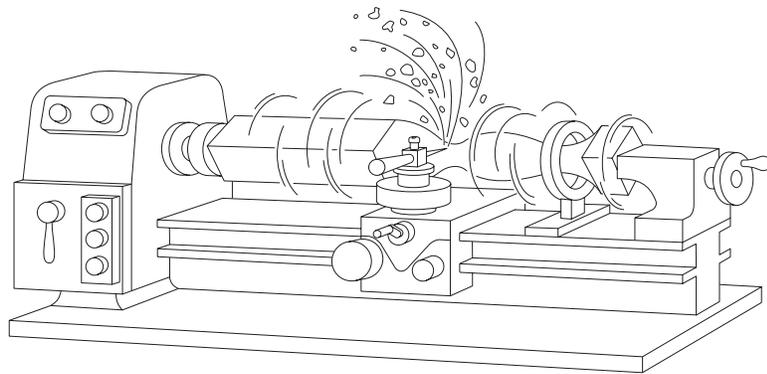
## Fans

This same principal applies to fan applications. The horsepower of a fan is determined by dividing the product of air flow (in cubic feet per minute) and pressure by the product of the constant 6356 and fan efficiency. Increasing the speed of the fan increases air flow and pressure, requiring the motor to work harder ( $I_w$  increases). Torque and horsepower increase.

$$HP = \frac{Flow \times Pressure}{6356 \times Fan \text{ Efficiency}}$$

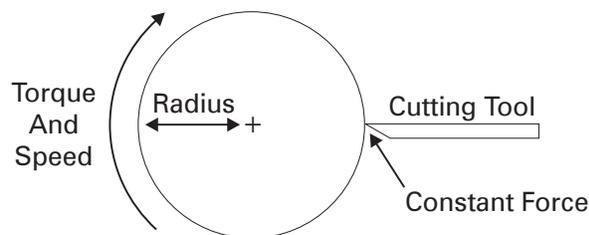
# Constant Horsepower Applications

Constant horsepower applications require a constant force as radius changes. A lathe, for example, starts out with a certain diameter object. As the object is cut and shaped the diameter is reduced. The cutting force must remain constant. Another example of a constant horsepower application is a winder where radius increases as material is added to a roll and decreases as material is removed.



## Relationship of speed, torque, and horsepower

Applications, such as lathes, that are driven in a continuous circular motion are sometimes referred to as spindle drives. Horsepower will remain constant in a spindle drive application. The surface speed in feet per minute (FPM) is equal to  $2\pi$  times the radius (in feet) of the material times the speed in RPM. Surface speed will remain constant as the material is shaped and the radius reduced. Torque is equal to force times radius. Horsepower is equal to torque times speed.

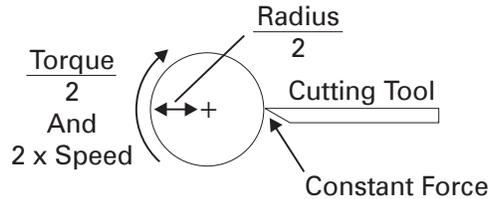


$$\text{Surface Speed (FPM)} = 2\pi \times \text{Radius} \times \text{Speed (RPM)}$$

$$\text{Torque} = \text{Force} \times \text{Radius}$$

$$\text{HP} = \text{Torque} \times \text{Speed}$$

The drive increases the speed (RPM) of the material as the radius is reduced. If the cutting tool has cut away half of the radius, for example, the RPM must double to maintain a constant surface speed (FPM). Reducing the radius by half will cause a corresponding reduction in torque. A doubling of speed (RPM) and a reduction of torque by half causes horsepower to remain constant.

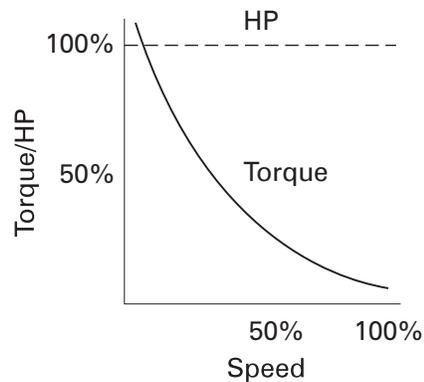


$$\text{Surface Speed (FPM)} = 2\pi \times \frac{\text{Radius}}{2} \times 2 \times \text{Speed (RPM)}$$

$$\text{Torque} = \text{Force} \times \frac{\text{Radius}}{2}$$

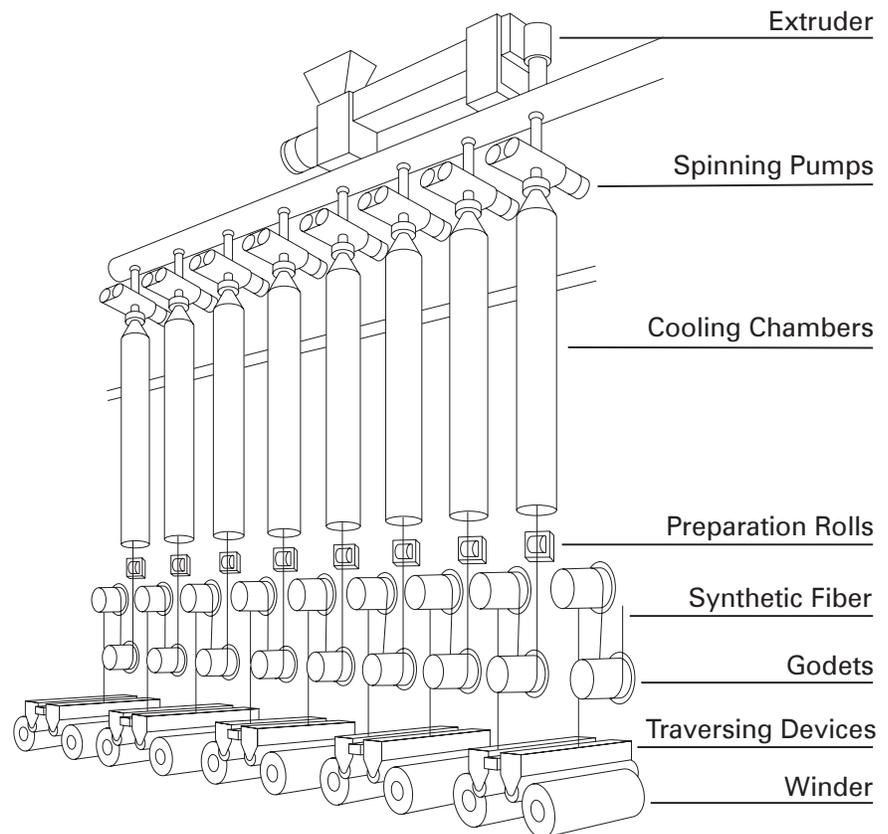
$$\text{HP} = \frac{\text{Torque} \times \text{Speed}}{2}$$

A smaller radius requires less torque to turn. Because torque decreases with a smaller radius, motors operating a constant horsepower application can be run above base speed. A 60 Hz motor, for example, could be run at 90 Hz when the radius is at minimum. RPM must increase to keep surface speed constant. An increase of speed (RPM) and a decrease in torque means horsepower will remain constant.



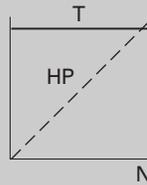
# Multimotor Applications

Many applications require more than one motor. In some instances, one drive can supply two or more motors. When this happens, the current rating of the motors added together cannot be greater than the current rating of the drive. Other applications require multiple motors and drives. A spinning machine for producing synthetic fibers, illustrated below, is one example of a multimotor, multidrive application. Various motors run the extruder, spinning pumps, preparation rolls, godets, traversing devices and winders. One drive may supply all the spinning pump motors or all the godet motors or individual motor control for each pump or godet may be used.

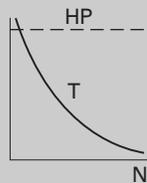


## Review 8

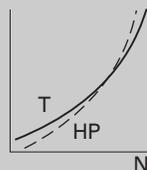
1. An application, such as a conveyor, where the torque remains essentially the same throughout the speed range is referred to as \_\_\_\_\_ torque.
2. Operating a motor above base frequency causes the motor's ability to produce torque to \_\_\_\_\_.  
a. increase      b. decrease
3. A variable \_\_\_\_\_ load implies that torque and horsepower increase with an increase in speed.
4. Fans and pumps are examples of \_\_\_\_\_ torque applications.
5. A constant \_\_\_\_\_ application implies that torque decreases as speed increases.
6. Identify the category of the following speed, torque, and horsepower graphs.



a. \_\_\_\_\_



b. \_\_\_\_\_



c. \_\_\_\_\_

# Review Answers

- Review 1** 1) force; 2) 15; 3) torque; 4) 80; 5) inertia; 6) Speed;  
7) revolutions per minute; 8) Acceleration
- Review 2** 1) Work; 2) Power; 3) voltage; 4) true; 5) watts, volt-amps;  
6) power factor; 7) 24
- Review 3** 1) 5; 2) 1.15; 3) 49.6; 4) 120; 5) 1800, 1500; 6) increase;  
7) decrease
- Review 4** 1) squirrel cage; 2) slip; 3) 4.2%; 4) increase; 5) working;  
6)  $I_w, I_M$ ; 7) 150%, 600%
- Review 5** 1) 7.67; 2) increase, increase; 3) b; 4) horsepower;  
5) SIMOVERT; 6) 650; 7) c; 8) d; 9) a
- Review 6** 1) "P"; 2) 650; 3) braking resistor; 4) 6; 5) sensorless vector  
control; 6) 3; 7) 6SE9113-7JA13
- Review 7** 1) 6SE70; 2) DC - AC; 3) regenerative rectifier; 4) 50; 5) 50;  
6) 16 and 12; 7) EB1 and EB2
- Review 8** 1) constant; 2) b; 3) torque; 4) variable; 5) horsepower;  
6) constant torque, constant horsepower, variable torque

# Final Exam

The final exam is intended to be a learning tool. The book may be used during the exam. A tear-out answer sheet is provided. If the tear-out answer sheet is missing, another may be obtained by contacting the training department at (770) 740-3061. After completing the test, mail the answer sheet in for grading. A grade of 70% or better is passing. Upon successful completion of the test a certificate will be issued.

## Questions

1. \_\_\_\_\_ is a twisting or turning force that causes an object to rotate.
  - a. Torque
  - b. Friction
  - c. Inertia
  - d. Acceleration
  
2. If 50 pounds of force were applied to a lever 3 feet long, the torque would be \_\_\_\_\_ lb-ft.
  - a. 16.7
  - b. 53
  - c. 47
  - d. 150
  
3. The rate of doing work is called \_\_\_\_\_ .
  - a. inertia
  - b. speed
  - c. power
  - d. energy
  
4. A motor with a rating of 60 KW would have an equivalent rating of \_\_\_\_\_ HP.
  - a. 45
  - b. 80
  - c. 65
  - d. 120
  
5. Magnetic lines of flux ( $\Phi$ ) in an AC motor are proportional to \_\_\_\_\_ .
  - a. voltage divided by frequency
  - b. frequency divided by voltage
  - c. rotor speed divided by synchronous speed
  - d. synchronous speed divided by rotor speed



14. The section of an AC drive that controls output voltage and frequency to an AC motor is the \_\_\_\_\_ .
- a. converter
  - b. DC link
  - c. inverter
  - d. L1 choke
15. A MICRO/MIDIMASTER is capable of delivering up to \_\_\_\_\_ % of drive rated current for one minute.
- a. 250%
  - b. 150%
  - c. 200%
  - d. 300%
16. To get four-quadrant operation with a Siemens MICROMASTER an optional \_\_\_\_\_ must be used.
- a. DC injection brake
  - b. converter bridge
  - c. 4-digit LED display
  - d. braking resistor
17. The \_\_\_\_\_ can interface with the SCB1 to provide additional binary and analog inputs and outputs on Siemens MASTERDRIVES?
- a. SCI1
  - b. SCI2
  - c. TSY
  - d. DTI
18. The \_\_\_\_\_ can be mounted directly on the PMU or up to 200 meters away.
- a. SCI1
  - b. DTI
  - c. OP1S
  - d. TSY
19. A centrifugal pump is a \_\_\_\_\_ application.
- a. constant torque
  - b. constant flux
  - c. constant HP
  - d. variable torque
20. If a conveyor has an effective tension ( $T_E$ ) of 1000 pounds, and a maximum speed of 100 FPM, the required horsepower is \_\_\_\_\_ HP.
- a. 3
  - b. 25
  - c. 10
  - d. 45