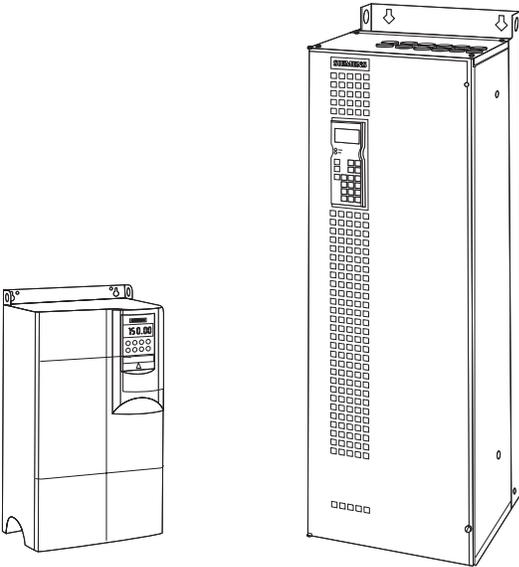


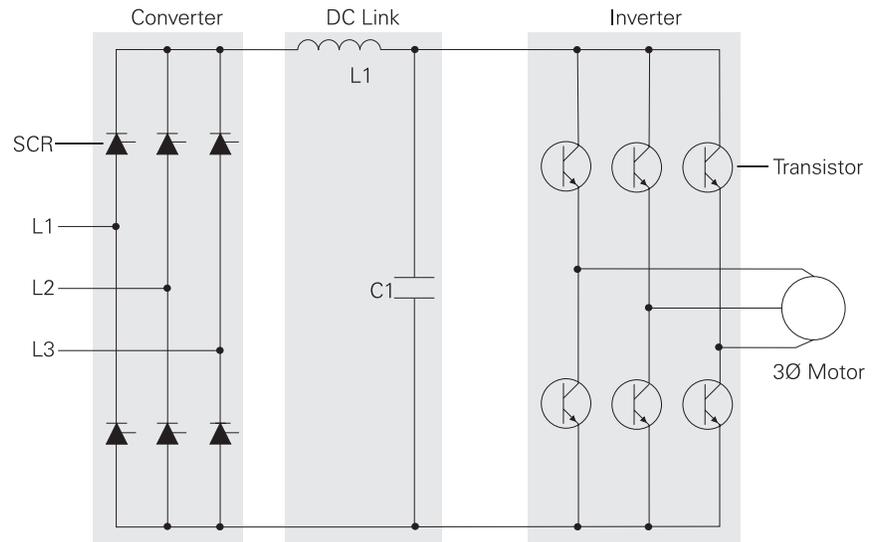
# Basic AC Drives

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 MO**tor in**VERT**er (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 in turn provides the proper voltage and frequency for a given speed to the motor. 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.

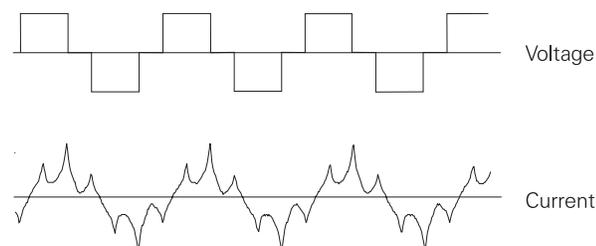


## Variable Voltage Inverter (VVI)

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.

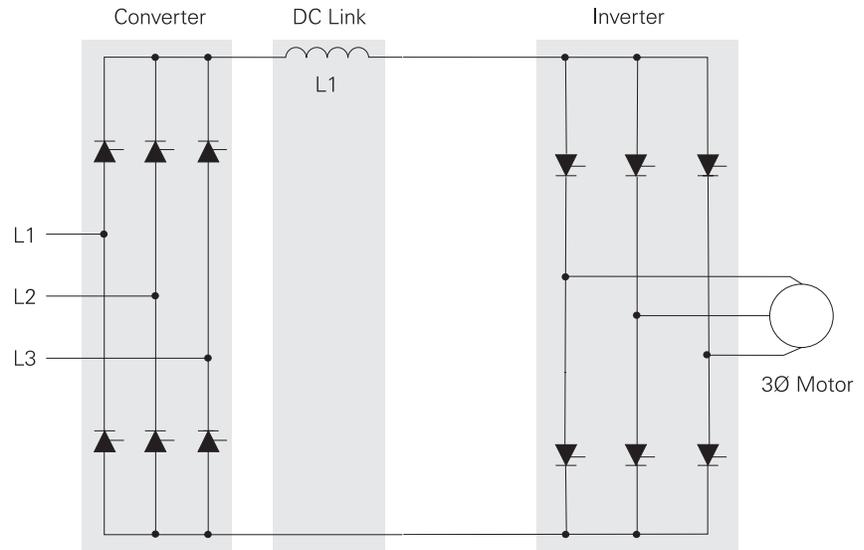


This type of switching is often referred to as six-step because it takes six  $60^\circ$  steps to complete one  $360^\circ$  cycle. Although the motor prefers a smooth sine wave, a six-step output can be satisfactorily used. The main disadvantage is torque pulsation which occurs each time a switching 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.

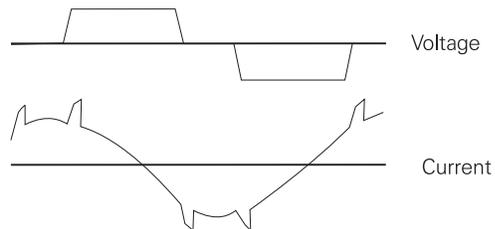


## Current Source Inverter

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.

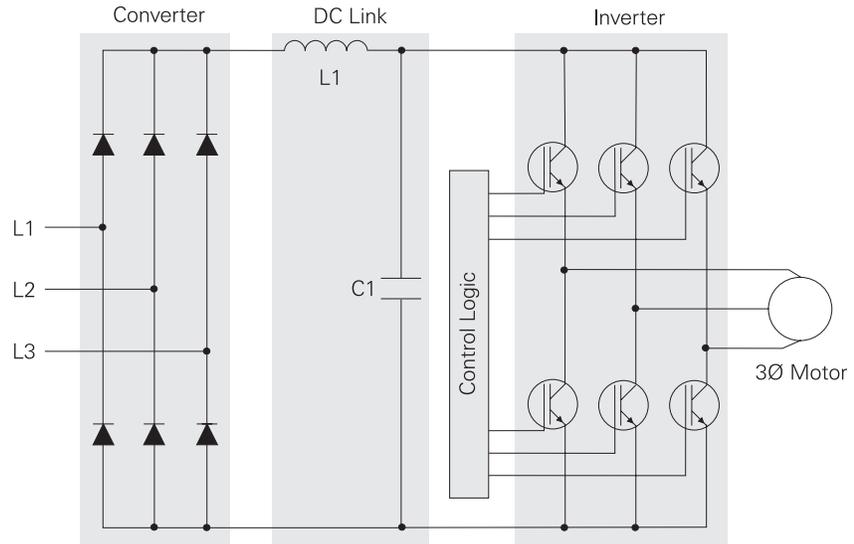


Current spikes, caused by switching, can be seen in the output. At low speeds current pulses can cause the motor to cog.



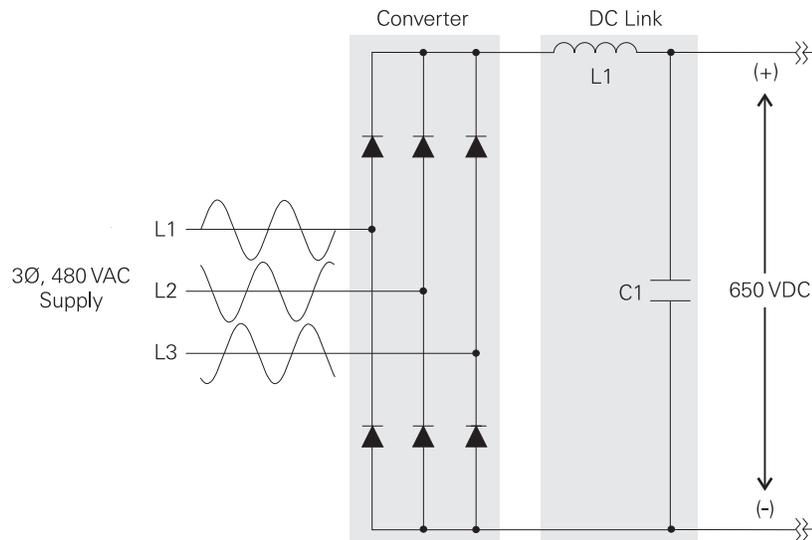
## Pulse Width Modulation

Pulse width modulation (PWM) drives, like the Siemens MICROMASTER and MASTERDRIVE VC, 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.



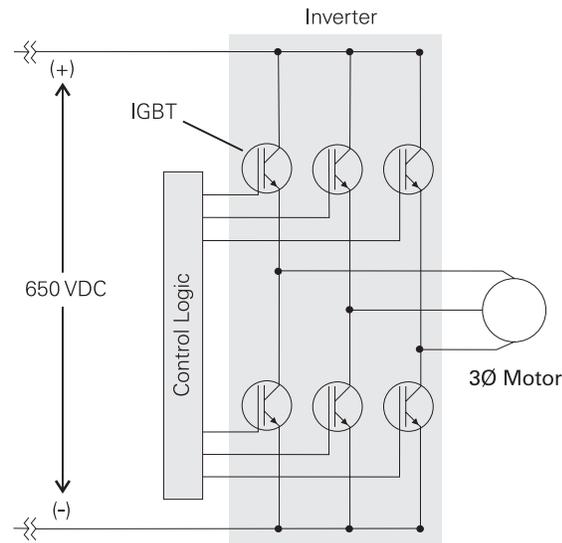
## Converter and DC Link

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.



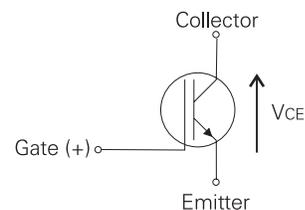
## Control Logic and Inverter

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.



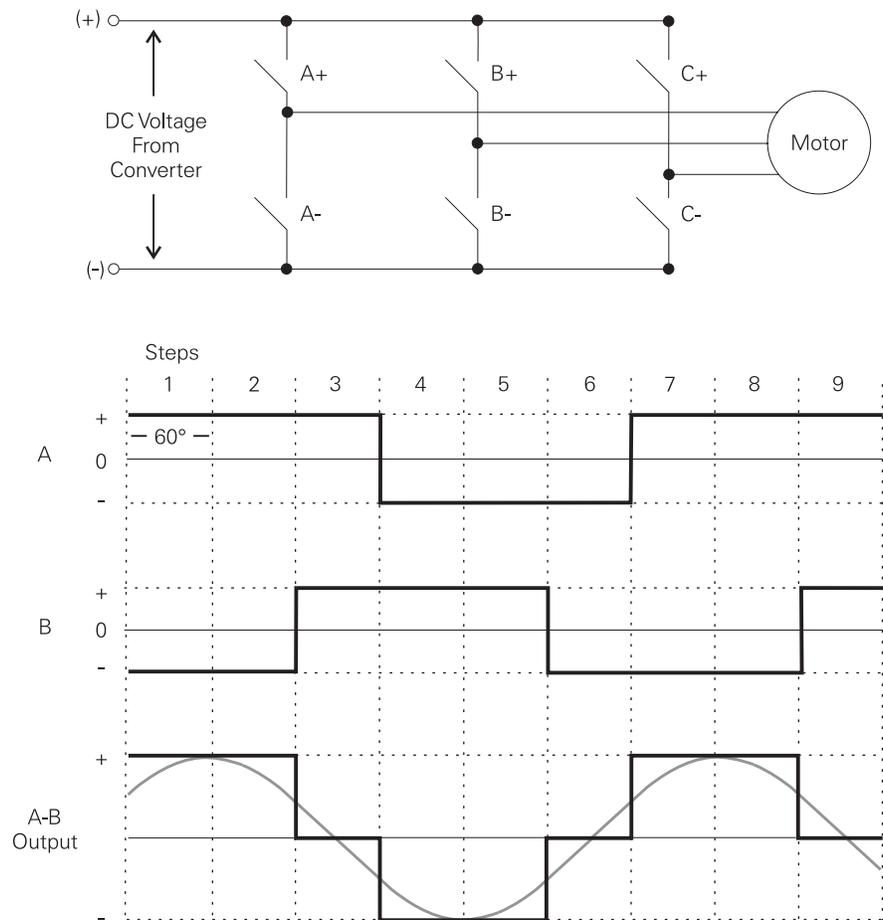
## IGBTs

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.



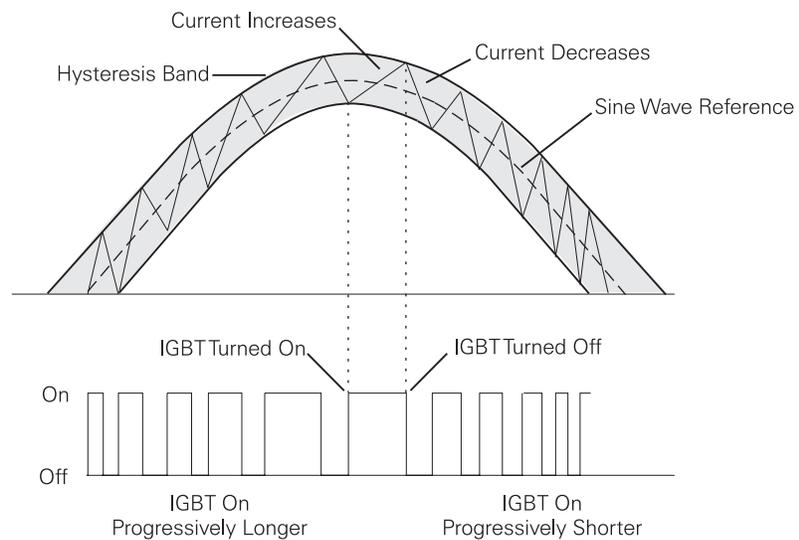
## Using Switching Devices to Develop AC Output

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.



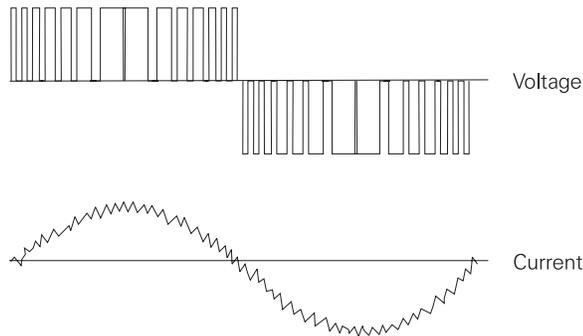
## PWM Output

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.

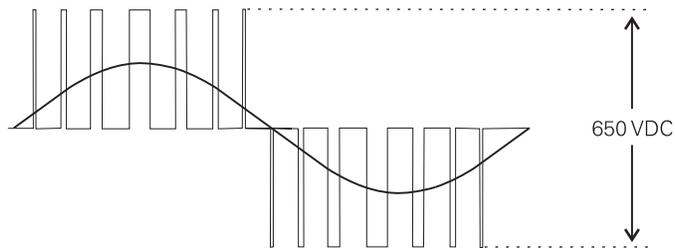


## PWM Voltage and Current

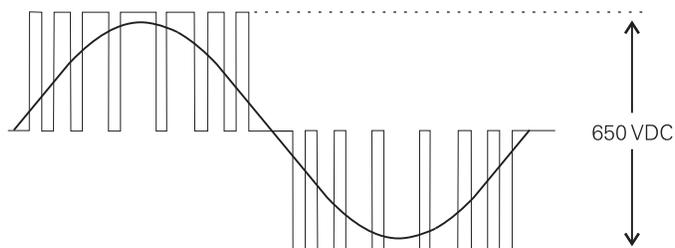
The more sinusoidal current output produced by the PWM reduces the torque pulsations, low speed motor cogging, and motor losses noticeable when using a six-step output.



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, allowing voltage and current to build up to higher levels in the motor.



Shorter "On" Duration, Lower Voltage



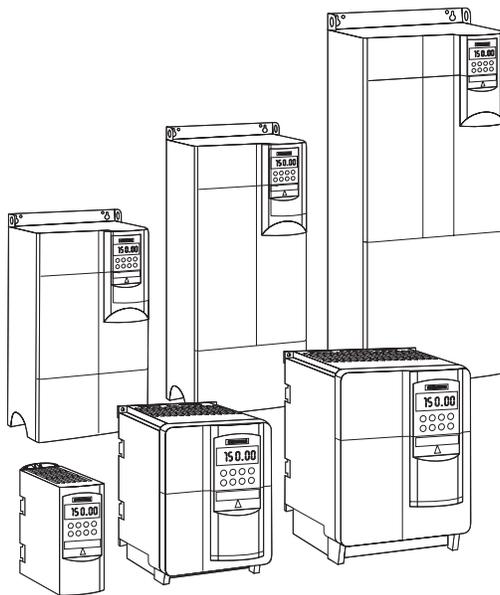
Longer "On" Duration, Higher Voltage

### Review 3

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

# Siemens MICROMASTER

Siemens offers a broad range of AC drives. In the past, AC drives required expert set-up and commissioning to achieve desired operation. The Siemens MICROMASTER offers “out of the box” commissioning with auto tuning for motor calibration, flux current control, vector control, and PID (Proportional-Integral-Derivative) regulator loops. The MICROMASTER is controlled by a programmable digital microprocessor and is characterized by ease of setup and use.



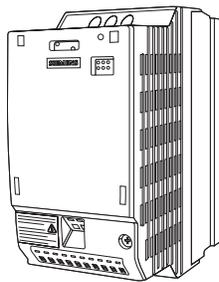
## Features

The MICROMASTER is suitable for a variety of variable-speed applications, such as pumps, fans, and conveyor systems. The MICROMASTER is compact and its range of voltages enable the MICROMASTER to be used all over the world.

Feature	MICROMASTER		
	410	420	440
Input Voltage	1Ø AC 100V to 120V ±10% 1Ø AC 200 to 240 VAC ±10%	1Ø AC 200V to 240V ±10% 3Ø AC 200V to 240V ±10% 3Ø AC 380V to 480V ±10%	1Ø AC 200V to 240V ±10% 3Ø AC 200V to 240V ±10% 3Ø AC 380V to 480V ±10% 3Ø AC 500V to 600V ±10%
Output Voltage	0 to Approximate Input Value	0 to Approximate Input Value	0 to Approximate Input Value
Input Frequency	47 to 63 Hz	47 to 63 Hz	47 to 63 Hz
Output Frequency	0 Hz to 650 Hz	0 Hz to 650 Hz	0 Hz to 650 Hz
Power Range	1/6 to 1 HP	1/6 to 15 HP	1/6 to 100 HP
Overload Capacity	Up to 150% of rated output current for 60 s, followed by 85 for 240 s, cycle time 300 s	150 s of rated load current for a period of 60 s within 300 s	150% of rated load current for a period of 60 s within 300 s or 200% of rated load current for a period of 3 s within 60 s.
Control	V/f	V/f, FCC	V/f, FCC, Vector (sensorless and optional closed loop), torque
Inputs	3 digital, 1 analog	3 digital, 1 analog	6 digital, 2 analog, 1 PTC
Outputs	1 relay	1 analog, 1 relay	2 analog, 3 relay
Serial Interface	RS-485 for use with USS protocol	RS-485 for use with USS protocol, optional RS232	RS-485 for use with USS protocol, optional RS232
Braking	DC braking, compound braking	DC Braking, compound braking	DC Braking, compound braking, fully-rated integral brake chopper

## MICROMASTER 410

The MICROMASTER 410 is available in two frame sizes (AA and AB) and covers the lower end of the performance range. It has a power rating of 1/6 HP to 1 HP. The MICROMASTER 410 features a compact design, fanless cooling, simple connections, an integrated RS485 communications interface, and easy startup.



### Frame Size AA

100 - 120 VAC 1Ø or  
200 - 240 VAC 1Ø or 3Ø  
1/6 HP to 1/2 HP

### Frame Size AB

100 - 120 VAC 1Ø  
3/4 HP  
200 - 240 VAC 1Ø or 3Ø  
3/4 HP to 1 HP

## MICROMASTER 420

The MICROMASTER 420 is available in three frame sizes (A, B, and C) with power ratings from 1/6 HP to 15 HP. Among the features of the MICROMASTER 420 are the following:

- Flux Current Control (FCC)
- Linear V/Hz Control
- Quadratic V/Hz Control
- Flying Restart
- Slip Compensation
- Automatic Restart
- PI Feedback for Process Control
- Programmable Acceleration/Deceleration
- Ramp Smoothing
- Fast Current Limit (FCL)
- Compound Braking



### Frame Size A

200 VAC to 240VAC 1/3Ø  
1/6 HP to 1 HP

380 VAC to 480VAC 3Ø  
1/2 HP to 2 HP



### Frame Size B

200 VAC to 240VAC 1/3Ø  
1.5 HP to 3 HP

380 VAC to 480VAC 3Ø  
3 HP to 5 HP



### Frame Size C

200 VAC to 240VAC 1/3Ø  
4 HP to 7.5 HP

380 VAC to 480VAC 3Ø  
7.5 HP to 15 HP

# MICROMASTER 440

The MICROMASTER 440 is available in six frame sizes (A - F) and offers higher power ranges than the 420, with a corresponding increase in functionality. For example, the 440 has three output relays, two analog inputs, and six isolated digital inputs. The two analog inputs can also be programmed for use as digital inputs. The 440 also features Sensorless Vector Control, built-in braking chopper, 4-point ramp smoothing, and switchable parameter sets.

**Frame Size A**



200 VAC to 240VAC 1/3Ø  
1/6 HP to 1 HP  
380 VAC to 480VAC 3Ø  
1/2 HP to 2 HP

**Frame Size B**



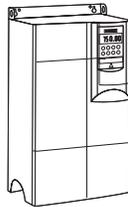
200 VAC to 240VAC 1/3Ø  
1.5 HP to 3 HP  
380 VAC to 480VAC 3Ø  
3 HP to 5 HP

**Frame Size C**



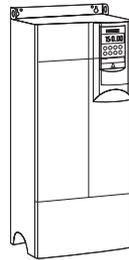
200 VAC to 240VAC 1/3Ø  
4 HP to 7.5 HP  
380 VAC to 480VAC 3Ø  
7.5 HP to 15 HP  
500 VAC to 600VAC 3Ø  
1 HP to 15 HP

**Frame Size D**



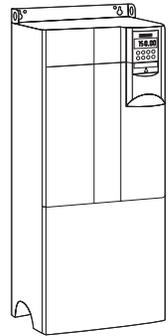
200 VAC to 240VAC 1/3Ø  
10 HP to 20 HP  
380 VAC to 480VAC 3Ø  
20 HP to 30 HP  
500 VAC to 600VAC 3Ø  
20 HP to 30 HP

**Frame Size E**



200 VAC to 240VAC 1/3Ø  
25 HP to 30 HP  
380 VAC to 480VAC 3Ø  
40 HP to 50 HP  
500 VAC to 600VAC 3Ø  
40 HP to 50 HP

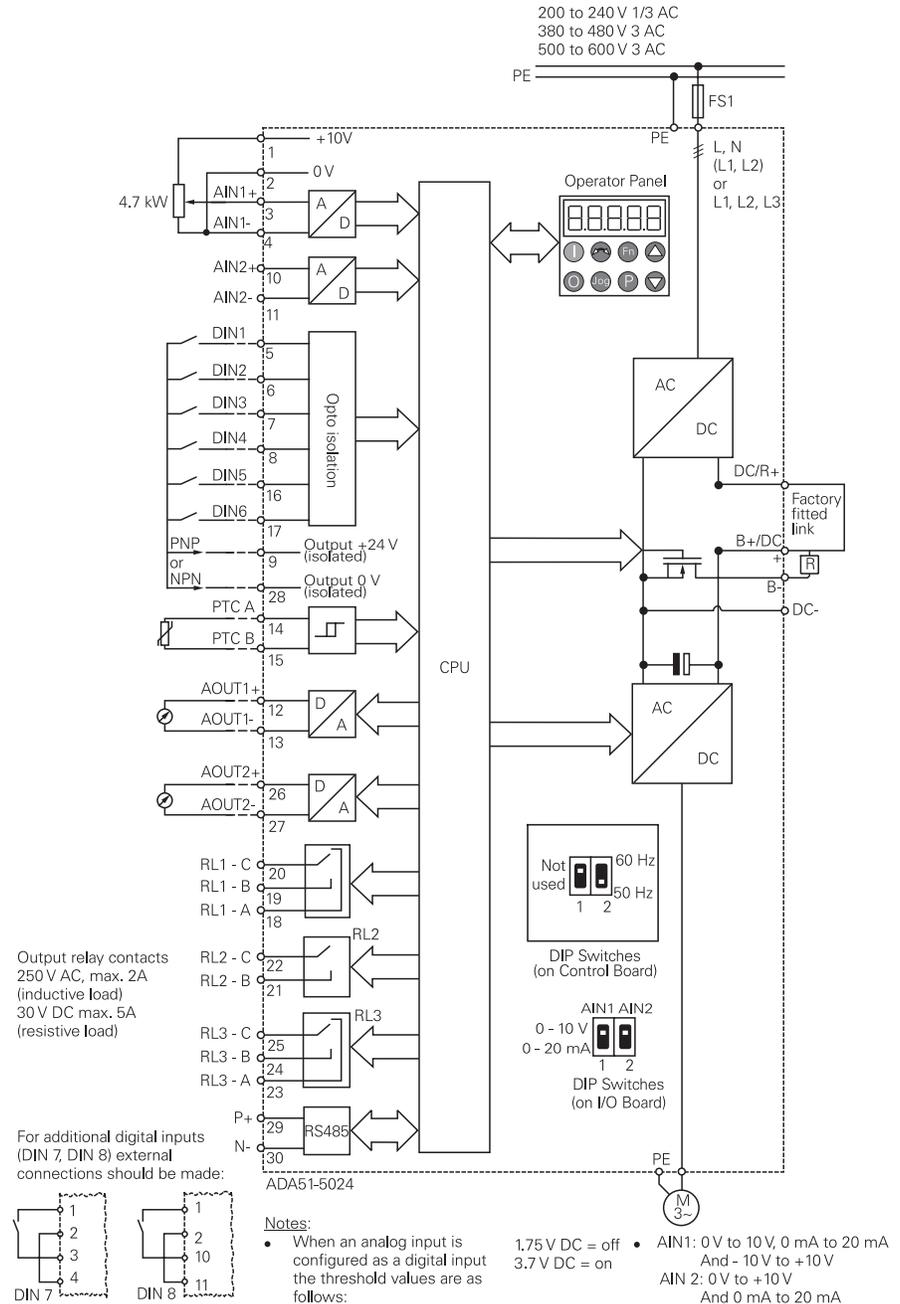
**Frame Size F**



200 VAC to 240VAC 1/3Ø  
50 HP to 60 HP  
380 VAC to 480VAC 3Ø  
60 HP to 100 HP  
500 VAC to 600VAC 3Ø  
60 HP to 100 HP

# Design

In order to understand the MICROMASTER's capabilities and some of the functions of an AC drive we will look at the 440. It is important to note; however, that some features of the MICROMASTER 440 are not available on the 410 and 420. The MICROMASTER has a modular design that allows the user configuration flexibility. The optional operator panels and PROFIBUS module can be user installed. There are six programmable digital inputs, two analog inputs that can also be used as additional digital inputs, two programmable analog output, and three programmable relay output.

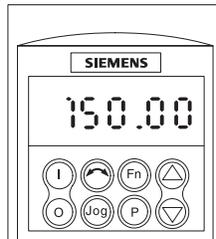


## Operator Panels

There are two operator panels, the Basic Operator Panel (BOP) and Advanced Operator Panel (AOP). Operator panels are used for programming and drive operation (start, stop, jog, and reverse).

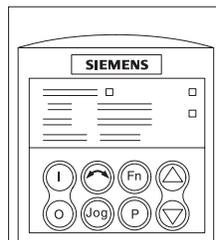
### BOP

Individual parameter settings can be made with the Basic Operator Panel. Parameter values and units are shown on a 5-digit display. One BOP can be used for several units.



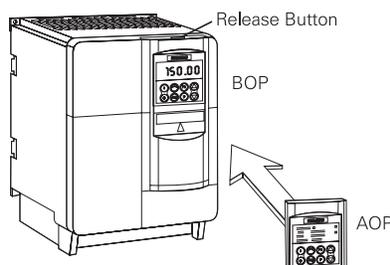
### AOP

The Advanced Operator Panel enables parameter sets to be read out or written (upload/download) to the MICROMASTER. Up to ten different parameter sets can be stored in the AOP. The AOP features a multi-line, plain text display. Several language sets are available. One AOP can control up to 31 drives.



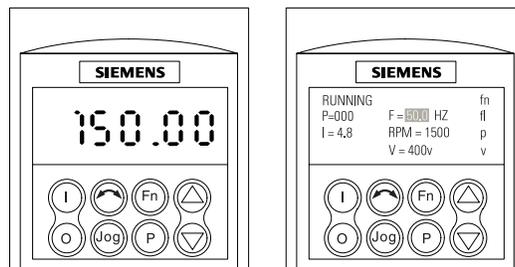
## Changing Operator Panels

Changing operator panels is easy. A release button above the panel allows operator panels to be interchanged, even under power.



## Parameters

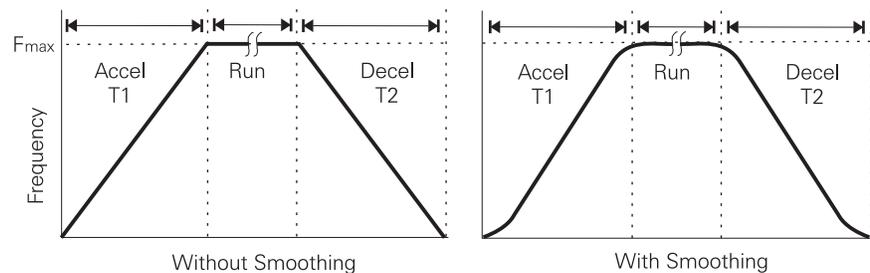
A parameter is a variable that is given a constant value. Standard application parameters come preloaded, which are good for many applications. These parameters can easily be modified to meet specific needs of an application. Parameters such as ramp times, minimum and maximum frequencies, and operation modes are easily set using either the BOP or AOP. 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.



## 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.

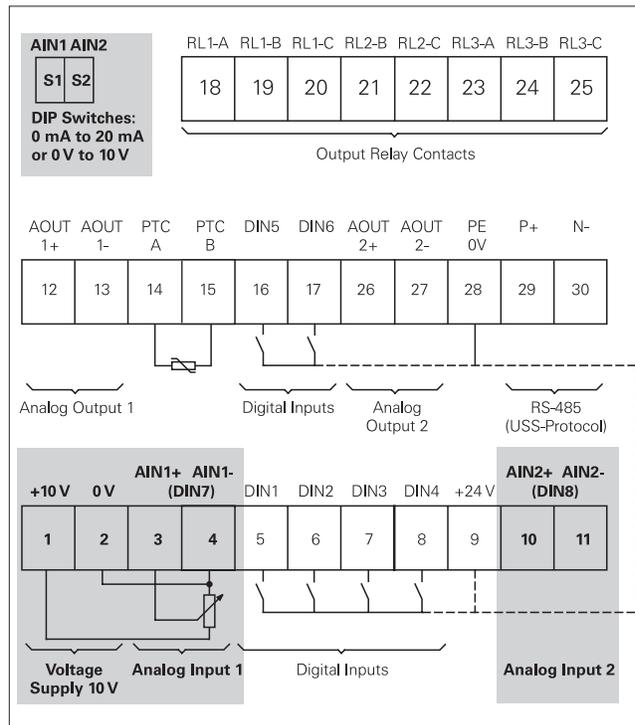
Smoothing is a feature that can be added to the acceleration/ deceleration curve. This feature smooths the transition between starting and finishing a ramp. Minimum and maximum speed are set by parameters P012 and P013.



## Analog Inputs

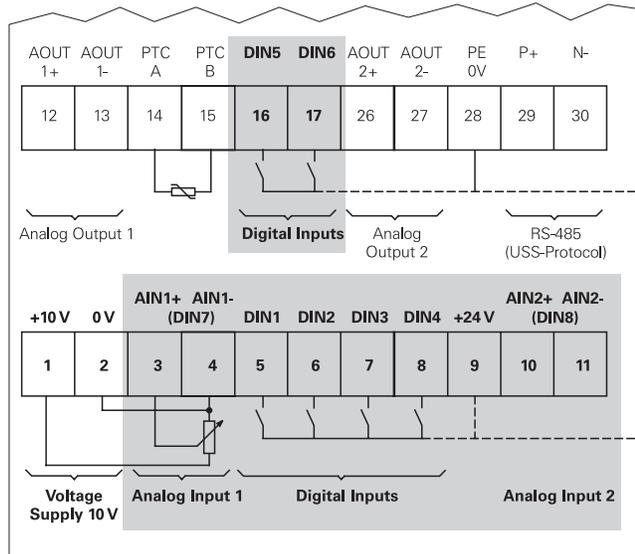
The MICROMASTER 440 has two analog inputs (AIN1 and AIN2), allowing for a PID control loop function. PID control loops are used in process control to trim the speed. Examples are temperature and pressure control. Switches S1 and S2 are used to select a 0 mA to 20 mA or a 0 V to 10 V reference signal. In addition, AIN1 and AIN2 can be configured as digital inputs.

In the following example AIN1 is set up as an analog reference that controls the speed of a 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 is connected between terminals one and two. Terminal three (3) is the positive (+) analog input to the drive. 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 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).



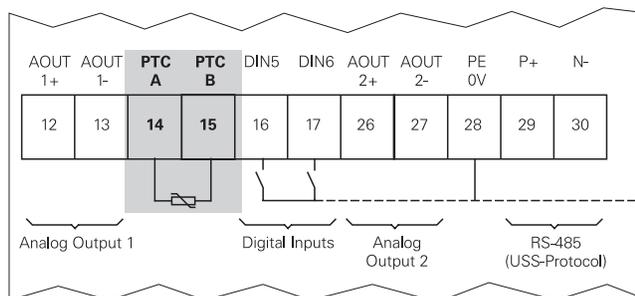
## Digital Inputs

The MICROMASTER 440 has six digital inputs (DIN1 - DIN6). In addition AIN1 (DIN7) and AIN2 (DIN8) can be configured as digital inputs. Switches or contacts can be connected between the +24 VDC on terminal 9 and a digital input. Standard factory programming uses DIN1 as a Start/Stop function. DIN 2 is used for reverse, while DIN3 is a fault reset terminal. Other functions, such as preset speed and jog, can be programmed as well.



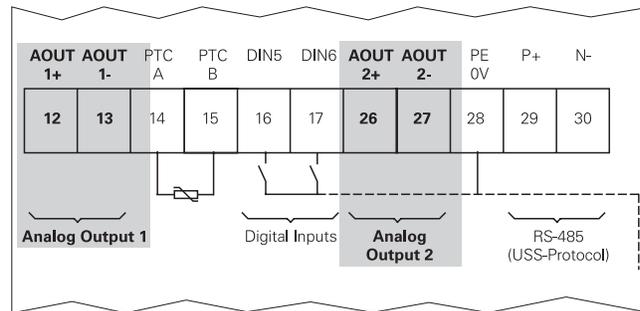
## Thermistor

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 and 15. 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. Virtually any standard thermistor as installed in standard catalog motors will work. Snap-action thermostat switches will also work.



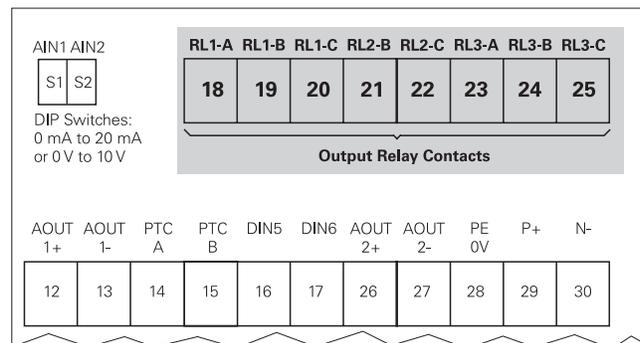
## Analog Outputs

Analog outputs can be used to monitor output frequency, frequency setpoint, DC-link voltage, motor current, motor torque, and motor RPM. The MICROMASTER 440 has two analog outputs (AOUT1 and AOUT2).



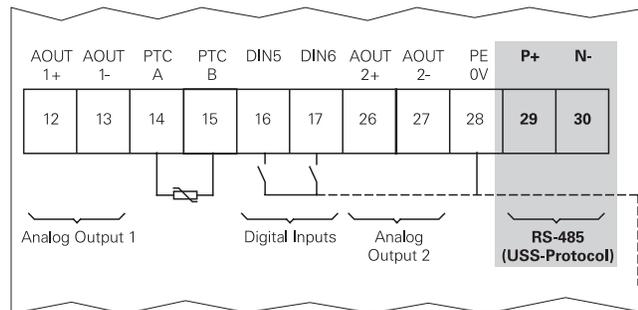
## Relay Output

There are three programmable relay outputs (RL1, RL2, and RL3) on the MASTERDRIVE 440. 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 Communication

The MICROMASTER 440 has 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 57.6 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

The MICROMASTER 440 is capable of delivering up to 150% of drive rated current for 60 seconds within a period of 300 seconds or 200% of drive rated current for a period of 3 seconds within a period of 60 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

We learned in a previous lesson that a relationship exists between voltage (E), frequency (F), and magnetising flux ( $\Phi$ ). We also learned that torque (T) is dependent on magnetising flux. An increase in voltage, for example, would cause an increase in torque.

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.

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