

# Siemens Standard Drives

## Application Handbook

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1. Introduction.....	4
1.1 What is a Variable Speed Drive?.....	4
1.2 The Variable Frequency Inverter.....	7
2. Siemens Standard Drives Product Range.....	9
2.1 Product Range.....	10
3. Selecting a Drive.....	11
3.1 Overall Considerations.....	11
3.2 Supply Side Requirements.....	12
3.3 Motor limitations.....	16
3.4 Load Considerations.....	18
3.5 Acceleration and Braking requirements.....	21
3.6 Environmental Considerations.....	21
4. Installing and Getting Started with an Inverter.....	22
4.1 Mounting the MICROMASTER.....	22
4.2 Cooling.....	22
4.3 Wiring up the MICROMASTER.....	23
4.4 First Switch On.....	26
4.5 If the motor does not start.....	27
5. Some Simple Applications and Possibilities.....	27
5.1 Using a Potentiometer with the Analog Input.....	28
5.2 Using a Digital Input.....	28
5.3 Using the Fixed Frequencies.....	29
5.4 Using other digital input features.....	30
5.5 Using the control outputs.....	31
5.6 Current Limit and Protection Systems.....	31
5.7 Other Protection Features.....	33
5.8 Some Additional Features.....	35
6. Electromagnetic Compatibility (EMC).....	39
6.1 What is EMC?.....	39
6.2 Minimising the problem of EMI.....	40
6.3 EMC Rules and Regulations.....	43
7. Some Real Applications.....	44
7.1 A simple Fan Application.....	44
7.2 A Closed Loop Controller using a Fan.....	46
7.3 Controlling Lift Door Operation.....	49
7.4 A Lift system for Industrial Applications.....	51
7.5 A Conveyer Application using several MICROMASTERs.....	54
7.6 A Material Handling Application.....	56
7.7 An Industrial Washing Machine.....	58
7.8 An Exercise Machine Application.....	60
8. Advanced Applications Information.....	63
8.1 Using Closed Loop Control.....	63
8.2 Braking and Slowing down using Inverters.....	67
8.3 Using the Serial Interface.....	71
8.4 Using PROFIBUS.....	72
8.5 Vector and FCC Control.....	73
9. Options for Siemens Standard Drives.....	75
9.1 Introduction.....	75

9.2 Clear Text Operating Panel OPm2.....	75
9.3 Braking Modules and Braking Resistors. ....	76
9.4 RFI Suppression Filters. ....	77
9.5 PROFIBUS Module.....	77
9.6 Input and Output Chokes.....	77
10. APPENDIX 1: Using the USS Protocol .....	78
10.1 Introduction.....	78
10.2 Overview.....	78
10.3 Hardware Connection.....	78
10.4 Overview of the USS Protocol .....	79
10.5 Message Timeout .....	79
10.6 Detailed Description of the USS Protocol Message .....	80
10.7 Examples of using the USS Protocol.....	87
11. APPENDIX 2: Environmental Protection Levels (IP rating) .....	88
12. APPENDIX 3: Some Useful Formulae.....	89

## **1. Introduction.**

This manual is intended to help users of variable speed drives successfully install and utilise Siemens Standard Drives.

It includes an introduction to drives, which may be informative to first time users.

*Advanced information is shown in italics, and may be skipped on first reading.*

Detailed technical information and complete parameter descriptions are available in the handbook.

### **1.1 What is a Variable Speed Drive?**

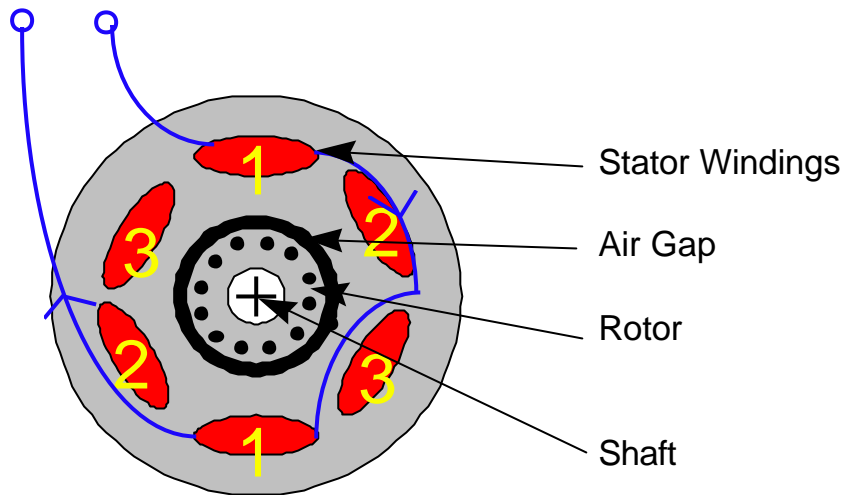
A Variable Speed Drive (VSD) consists of a Motor and some form of controller. Early electric VSDs consisted of AC and DC motors combinations which were used as rotating controllers. The first electronic controllers used Thyristor (SCR) Rectifiers which controlled the voltage, and therefore the speed of DC motors. These DC VSDs are still widely used and offer very sophisticated control capability.

However, the DC motor is large, expensive and requires periodic brush maintenance. The AC induction motor is simple, low cost, reliable and widely used throughout the world.

In order to control the speed of an AC induction motor a more complex controller, usually called an inverter is required.

In order to understand how an inverter works, it is necessary to understand how an induction motor works.

An induction motor works like a transformer. When the stator (the fixed, outer winding) is connected to a three phase power source, a magnetic field which rotates at the frequency of the supply is set up.

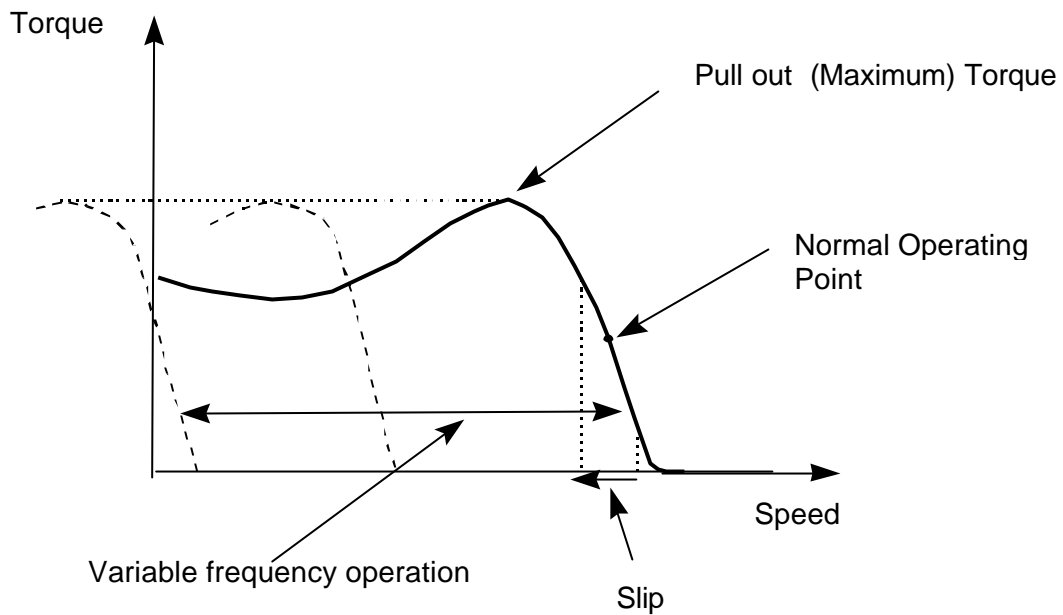


### Simplified Induction Motor - Cross Section

This field crosses the air gap between the stator and rotor and causes currents to flow in the rotor windings. This produces a force on the rotor as the current interacts with the changing magnetic field, and the rotor turns.

*If the windings are arranged in several pairs (or poles), the frequency of the rotating field will be less than the applied frequency (e.g. two pole = 50/60Hz = 3000/3600rpm, but four pole = 50/60Hz = 1500/1800 rpm).*

However, if the rotor runs at the same speed as the rotating field, there will be no changing magnetic field, and therefore no torque. Therefore the rotor always runs a little slower than the rotating field in order to generate torque. This difference in speed is known as slip.

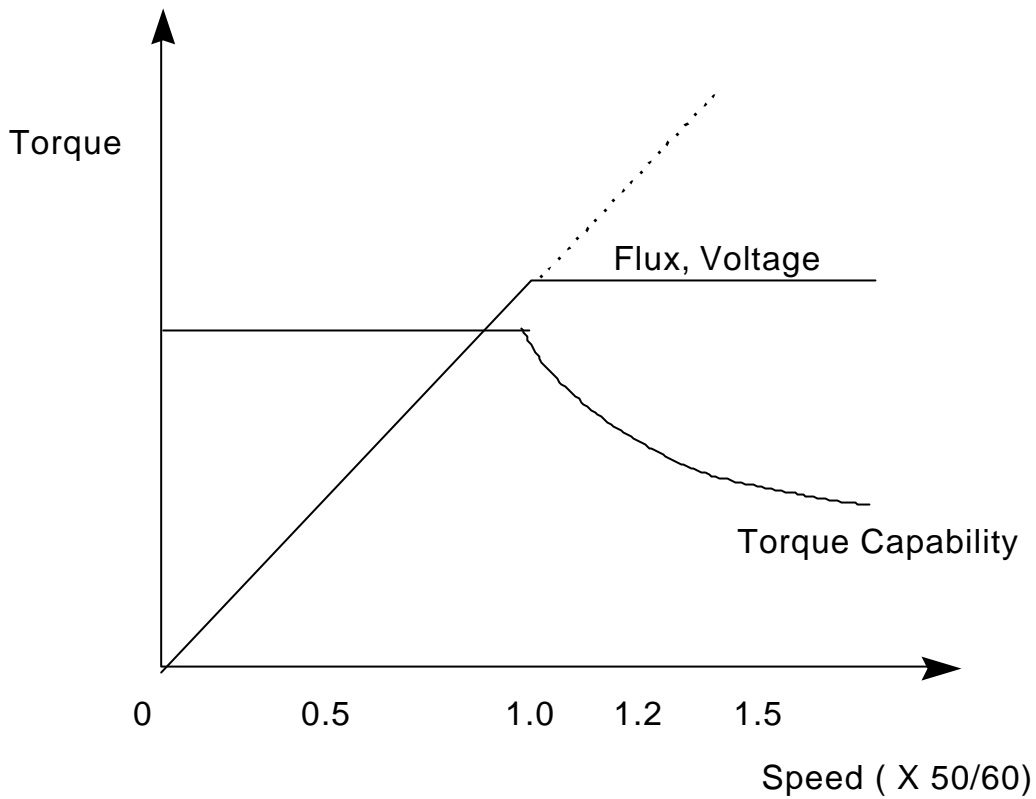


Torque Speed Characteristic of An Induction Motor

Hence the speed of the motor depends on the applied frequency, as well as the winding arrangement, and a little on the load.

Therefore in order to control the motor speed it is necessary to control the frequency of the supply.

If the frequency is reduced, the voltage must be reduced or the magnetic flux will be too high and the motor will saturate. Hence the voltage must be controlled as well. If the frequency is increased above normal, more voltage would normally be needed to maintain maximum flux; this is not usually possible, so less torque is available at high speed.



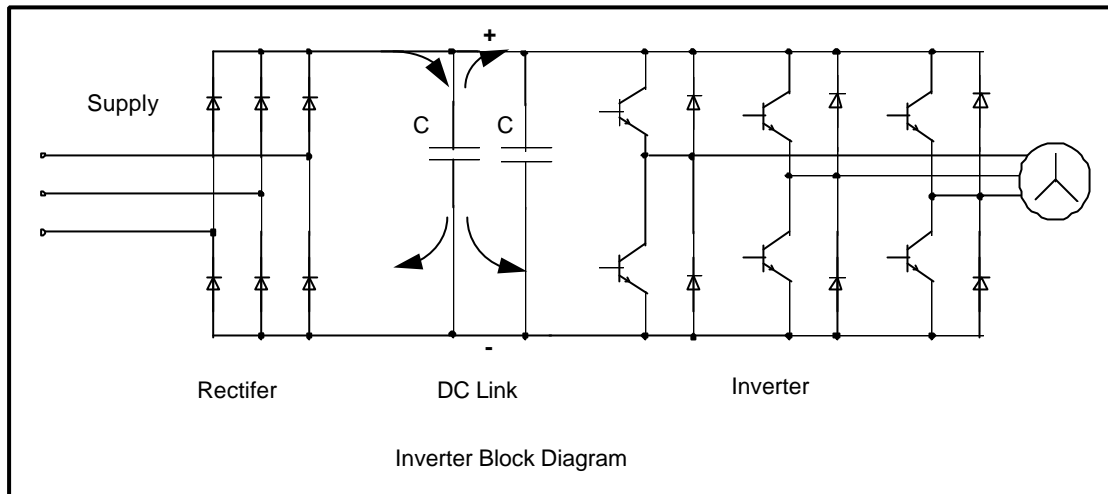
### Torque Reduction above Base speed

Therefore in order to control the speed of a standard AC motor, the applied frequency and voltage must be controlled.

Although it is difficult to control voltage and frequencies at these high powers, the use of a standard induction motor allows a cost effective speed control system to be built.

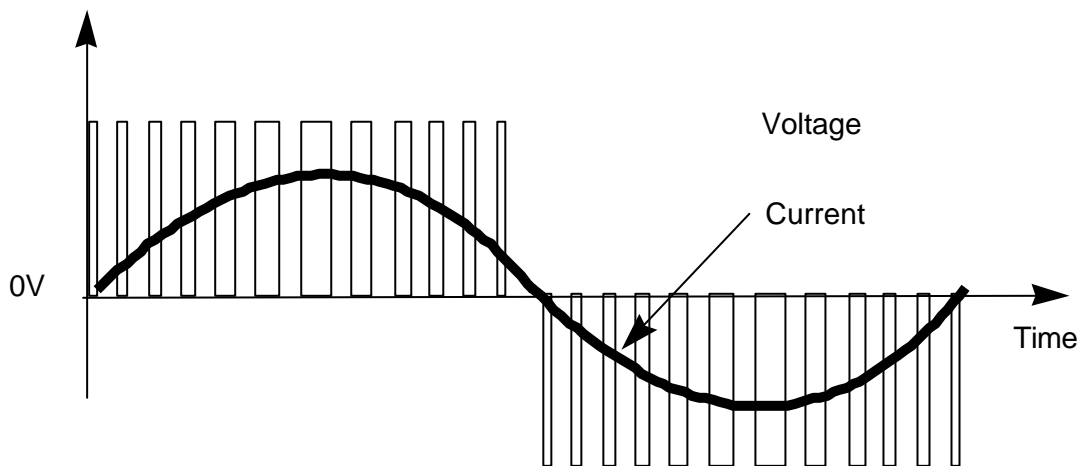
### **1.2 The Variable Frequency Inverter.**

An electronic converter which converts Direct Current (DC) to Alternating Current (AC) is known as an inverter. Electronic speed controllers for AC motors usually convert the AC supply to DC using a rectifier, and then convert it back to a variable frequency, variable voltage AC supply using an inverter bridge. The connection between the rectifier and inverter is called the DC link. The block diagram of a speed controller (often called an inverter) is shown below:



The supply, which can be single phase (usually at low power) or three phase is fed to a full wave rectifier which supplies the DC link capacitors. The capacitors reduce the voltage ripple (especially on single phase supplies) and supply energy for short mains breaks. The voltage on the capacitors is uncontrolled and depends on the peak AC supply voltage.

The DC voltage is converted back to AC using Pulse Width Modulation (PWM). The desired waveform is built up by switching the output transistors (Insulated Gate Bipolar Transistors; IGBTs) on and off at a fixed frequency (the switching frequency). By varying the on and off time of the IGBTs the desired current can be generated, but the output voltage is still a series of square wave pulses. Pulse Width Modulation is shown in the figure below.



Pulse Width Modulation

*There are many complex aspects of inverters which need to be considered during the design:*



- *The control system to calculate the PWM requirements is very complex and specially designed integrated circuits (ASICs) are needed.*
- *The control electronics are often connected to the DC link, which is connected to the supply, so the customer connections, display etc. must be safely isolated from this.*
- *The output current must be carefully monitored to protect the inverter and the motor during overload and short circuit.*
- *At first switch on the DC link capacitors are discharged, and the inrush current must be limited, usually using a resistor which is bypassed by a relay after a few seconds.*
- *All connections to the inverter, especially the supply and control connections, may carry a lot of interference and must be fitted with suitable protection components.*
- *An internal power supply with several different output voltages is needed for the to supply the control electronics.*
- *The inverter, especially the IGBTs and rectifier diodes, produce heat which must be dissipated using a fan and heatsink.*
- *The PWM output voltage contains many high frequency harmonics (because of the fast switching) and can be a major source of EMI.*
- *The input rectifier draws current only at the peak of the supply waveform, so the input currents have a poor form factor ( i.e. the RMS value can be quite high - this does not mean the inverter is inefficient!)*

A practical inverter needs to be designed for ease of use and installation. Large inverters are often specially designed or engineered for each application; smaller inverters are designed for general purpose use and are of standard design. Siemens Standard Drives division manufacture standard inverters up to 90kW for this purpose.

## **2. Siemens Standard Drives Product Range.**

The current product range consists of four different product types:

The MICROMASTER Vector. A VSD high performance inverter for general purpose applications available in various voltage ranges and power up to 7.5kW.

The MICROMASTER. A similar range with fewer features for simple applications.

The MIDIMASTER Vector. A higher power version of the MICROMASTER Vector with output capability of up to 90kW.

The COMBIMASTER. An induction motor with an inverter mounted in place of the terminal box.

The following information refers to the operation of the MICRO and MIDIMASTER Vector products, but may prove useful with reference to COMBIMASTER as well.

## **2.1 Product Range**

The details of the MICROMASTER Vector product range are shown below. The power range available varies from 120W (MMV12) to 7.5kW (MMV750) :

1/3 AC 230V +/- 15% (187-265V).

1 AC 230V +/- 15% (187-265V) with integrated RFI Filter

Type	Power	Width	Height	Depth	Size
MMV12-75, MMV12/2-75/2	120-750W	73	147	141	A
MMV110-150,MMV110/2-150/2	1,1-1,5kW	149	184	172	B
MMV220-300,MMV220/2-300/2	2,2 - 3,0kW	185	215	195	C
MMV400/2	4,0kW	185	215	195	C

3AC 380-500V +/- 10% (342-550V)

Type	Power	Width	Height	Depth	Size
MMV37/3-150/3,	0,37-1,5kW	73	147	141	A
MMV220/3 - 300/2	2,2 - 3,0kW	149	184	172	B
MMV400/3 - MMV750/3	4,0kW - 7,5kW	185	215	195	C

The same power range and voltage variants are available with reduced performance; types MM12 etc. The are known as the standard, or MICORMASTER Basic types.

The MIDIMASTER is available in four different frame sizes and three different voltage ranges. Power ratings up to 90kW Variable Torque (see Section 3.4.1) are available.

### **3 AC 400-500V +/- 10% IP21/NEMA1**

Type	Power CT/VT	Frame Size
MDV750/3	7.5/11	4
MDV1100/3	11/15	4

MDV1500/3	15/18.5	5
MDV1850/3	18.5/22	5
MDV2200/3	22/30	6
MDV3000/3	30/37	6
MDV3700/3	37/45	6
MDV4500/3	45/55	7
MDV5500/3	55/75	7
MDV7500/3	75/90	7

### **3 AC 230V +/- 10% IP21/NEMA1**

Type	Power CT/VT	Frame Size
MDV550/2	5.5/7.5	4
MDV750/2	7.5/11	5
MDV1100/2	11/11	5
MDV1500/2	15/18.5	6
MDV1850/2	18.5/22	6
MDV2200/2	22/27	6
MDV3000/3	30/37	7
MDV3700/3	37/45	7

Frame Size	Width	Height	Depth
4	275	450	200
5	275	550	202
6	275	650	278
7	420	850	310

575V units and IP56 units are also available.

Full details of the product range are available in catalogue DA64.

The following information refers to the MICROMASTER and MIDIMASTER Vector products. Some features may not be available on basic MICROMASTER or COMBIMASTER units.

### **3. Selecting a Drive.**

Often drive selection is straight forward, as a motor is already installed and the speed range requirement is not excessive. However, when a drive system is selected from first principles, careful consideration may avoid problems in installation and operation, and may also save significant cost.

#### **3.1 Overall Considerations.**

- Check the Current rating of the inverter and the motor. Power rating is only a rough guide.
- Check that you have selected the correct operating voltage. 230V three phase input MICROMASTERS will operate with single or three phase inputs; 400V MICROMASTERS are for three phase application only. Single phase input units can be more cost effective in some cases, but note that 230V units will be damaged if operated at 400V. See section 3.2.1.
- MIDIMASTERS will operate with three phase only, and are available for 230V, 400V or 575V supplies.
- Check the speed range you require. Operation above normal supply frequency (50 or 60Hz) is usually only possible at reduced power. Operation at low frequency and high torque can cause the motor to overheat due to lack of cooling.
- Synchronous motors require de-rating, typically by 2-3 times. *This is because the power factor, and hence the current, can be very high at low frequency.*
- Check overload performance. The inverter will limit current to 150 or 200 % of full current very quickly - a standard, fixed speed motor will tolerate these overloads.
- Do you need to stop quickly? If so, consider using a braking resistor (braking unit on MIDIMASTERS) to absorb the energy.
- Do you need to operate with cables longer than 50m, or screened or armoured cables longer than 25m? If so, it may be necessary to de-rate, or fit a choke to compensate for the cable capacitance.

### **3.2 Supply Side Requirements**

In order to achieve reliable operation, the main power supply to the inverter system must be suited to the inverter and the anticipated power supplied. The following points should be considered:

#### **3.2.1 Supply Tolerance.**

The inverters are designed to operate on a wide range of supply voltages as follows:

Low Voltage units	208 - 240 V +/- 10% i.e. 187-264V
High Voltage units	380 - 500 V +/- 10% i.e. 342-550V
Very high Voltage units	525 - 575 V +/- 10% i.e. 472-633V

Inverters will operate over a supply frequency of 47 - 63 Hz

Many supplies vary outside these levels. For example:

- Supplies at the end of long power lines in remote areas can rise excessively in the evening and weekends when large loads are no longer present.
- Industries with locally controlled and generated supplies can have poor regulation and control.

- Power systems in certain parts of the world may not meet expected tolerances.

In all installations, check that the supply will remain within the tolerances stated above. Operation outside of the stated supply levels will probably cause damage.

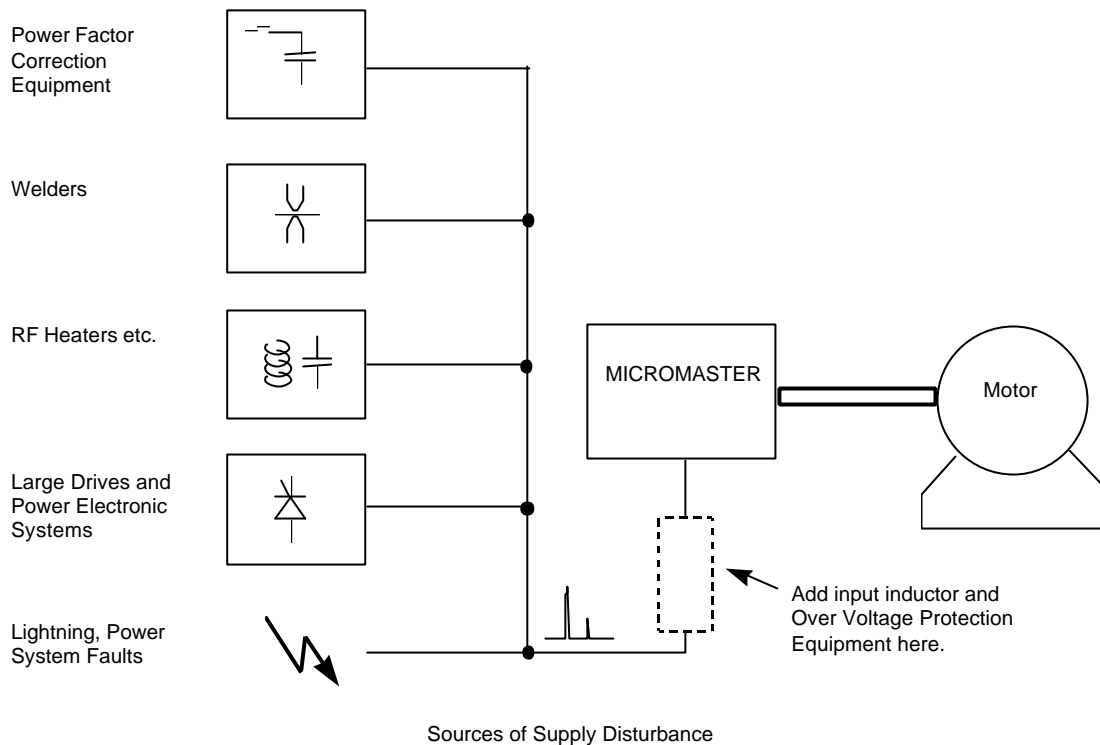
### 3.2.2 Supply Disturbance.

Many supplies are well controlled and remain in tolerance, but are affected by local disturbances. These can cause faulty operation and damage to inverters. In particular, check for:

- Power Factor Correction equipment. Unsuppressed switching of capacitor banks can produce very large voltage transients and is a common cause of inverter damage.
- High power welding equipment, especially resistance and RF welders.
- Other drives, semiconductor heater controllers etc.

*The inverter is designed to absorb high level of supply disturbance - for instance, voltage spikes up to 4kV. However, the above equipment can cause power supply disturbances in excess of this. It will be necessary to suppress this interference - preferably at source - or at least by the installation of an input choke in the inverter supply. EMC filters do not suppress disturbances with this level of energy; over voltage protection products such as metal oxide varistors should be considered.*

Damage can also be caused by local supply faults and the effects of electrical storms. In areas where these are expected, similar precautions are recommended.



### 3.2.3 Ungrounded Supplies

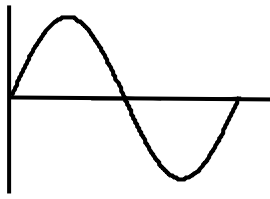
Certain industrial installations operate with supplies that are isolated from the protective earth (IT supply). This permits equipment to continue to run following an earth fault. However, MICROMASTERS and MIDIMASTERS are designed to operate on grounded supplies and are fitted with interference suppression capacitors between the supply and ground. Hence operation on ungrounded supplies must be restricted. Please consult Siemens for clarification.

### 3.2.4 Low Frequency Harmonics.

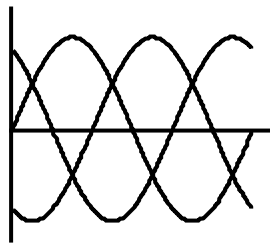
The inverter converts the AC supply to DC using an uncontrolled diode rectifier bridge. The DC link voltage is close to the peak AC supply voltage, so the diodes only conduct for a short time at the peak of the AC waveform.

The current waveform therefore has a relatively high RMS value as a high current flows from the supply for a short time.

Input Voltage

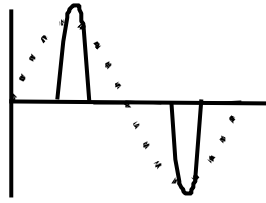


Single Phase

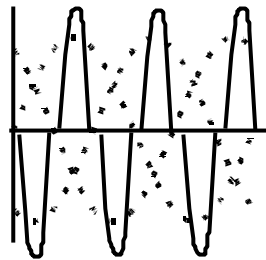


Three Phase

Input Current

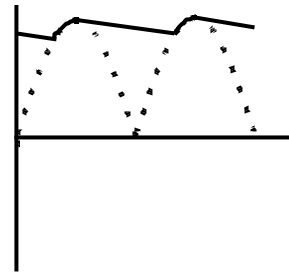


Single Phase

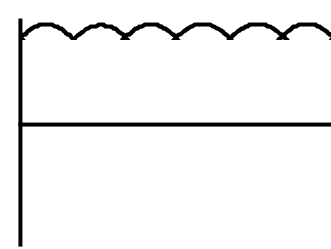


Three Phase

DC link Voltage



Single Phase

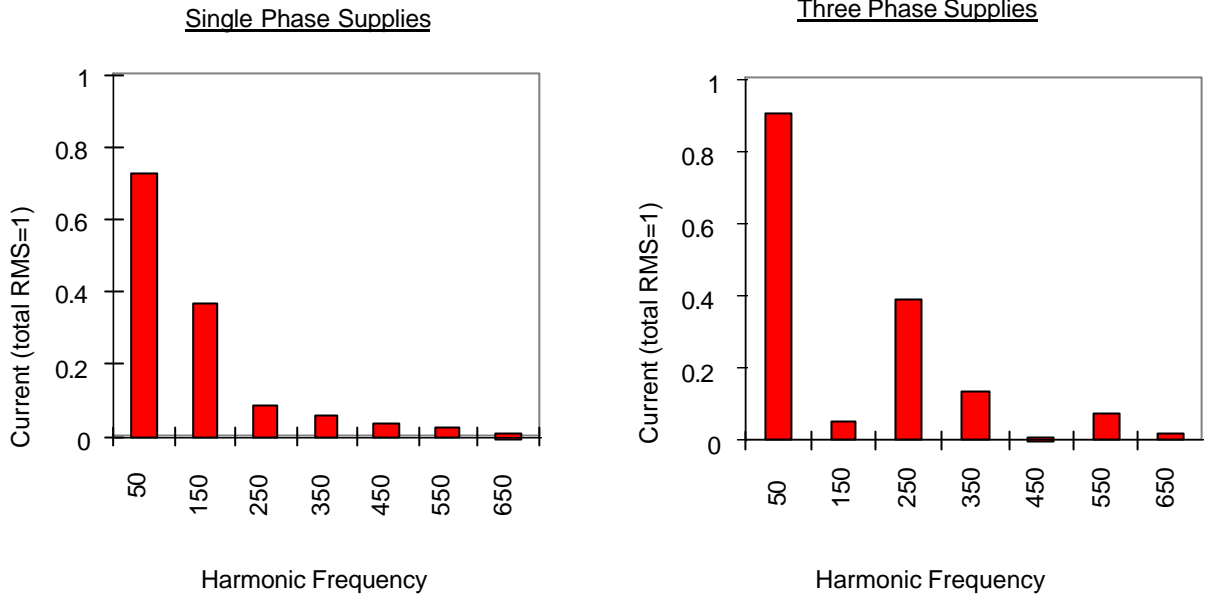


Three Phase

### Rectifier Input Voltages and Currents

This means that the current waveform consists of a series of low frequency harmonics, and this may in turn cause voltage harmonic distortion, depending on the supply impedance.

Sometimes these harmonics need to be assessed in order to ensure that certain levels are not exceeded. Excessive harmonic levels can cause high losses in transformers, and may interfere with other equipment. In any case, the rating and selection of cabling and protection equipment must take into account these high RMS levels. Some measured harmonic levels are shown below.



Typical Harmonic content - Measured Results

In order to calculate the harmonics in a particular supply system it is essential that the supply impedance is known. This is usually stated in terms of fault current levels, transformer size, and installed impedance such as line inductors etc. Computer programs are available to calculate the current and voltage harmonic levels, dependent on the load, type and number of inverters in the system. In general, industrial supplies do not require this level of assessment.

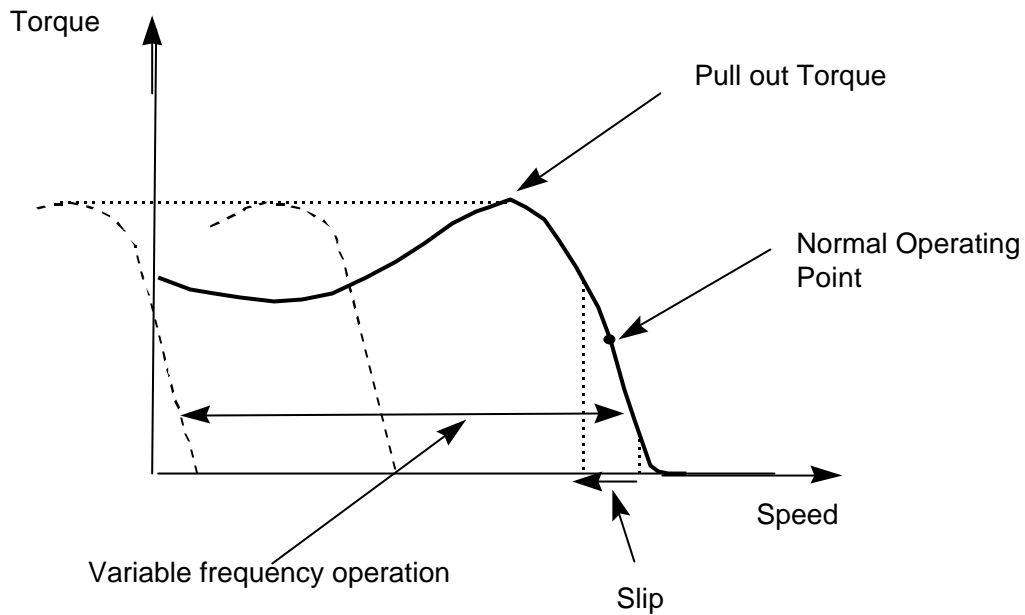
Where supplies have very low impedance (such as below 1%) an input inductor is recommended in any case to limit peak currents in the drive.

### **3.3 Motor limitations.**

*For more information concerning calculation of Power requirements, Torque, and Moment of Inertia, see section 12.*

The motor speed is determined mainly by the applied frequency. The motor slows down a little as the load increases and the slip increases. If the load is too great the motor will exceed the maximum torque and stall or 'pull out'. Most motors and inverters will operate at 150% load for a short time, for instance, 60 seconds.

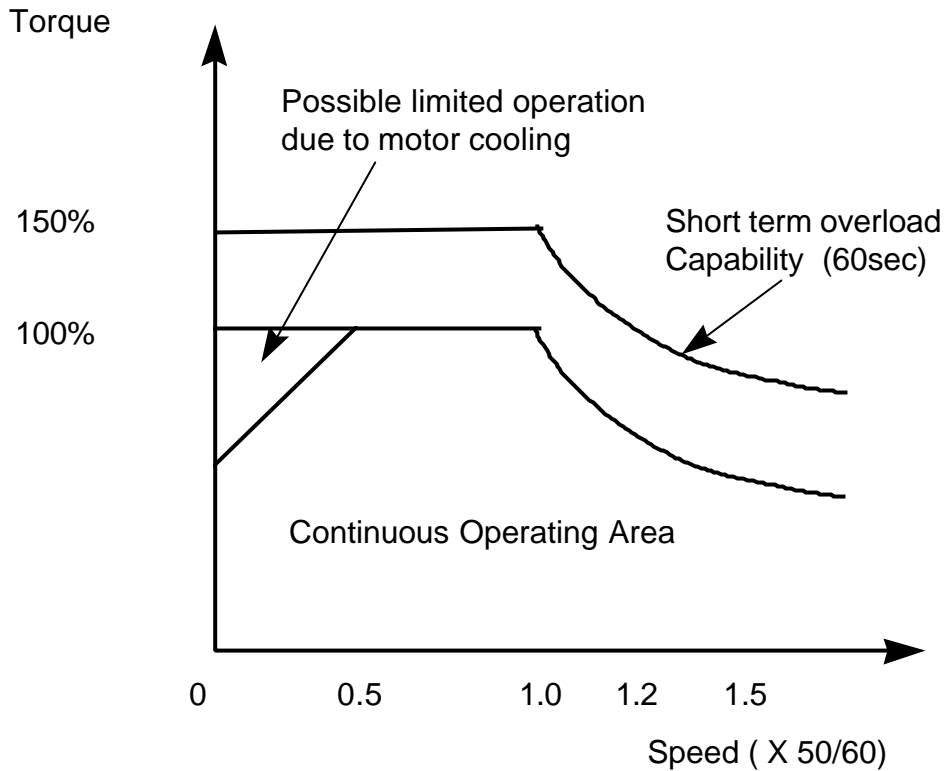




Torque Speed Characteristic of An Induction Motor

The motor is usually cooled by a built in fan that runs at motor speed. This is designed to cool the motor at full load and base speed. If a motor runs at a lower frequency and full torque - that is high current - cooling may be inadequate. Motor manufacturers will give the necessary de-rating information, but a typical derating curve would limit output torque to 75% at zero frequency rising to full capability at 50% of base speed (see diagram). Ensure that these limitations are not exceeded for long term operation.

*Consider using the  $i^2t$  function to help protect the motor (P074 see section 5.7.1) or consider using a motor with built in protection such as a PTC.*



Operating Capabilities of Motor/Inverter Combinations

*High speed operation of standard motors is usually limited to twice the normal operating speed (i.e up to 6000 or 7200 rpm) of a two pole motor because of bearing limitations. However, because the flux level will reduce above base speed (because the output voltage is limited to approximately the input voltage) the maximum torque will also fall in inverse proportion to the speed above base speed.*

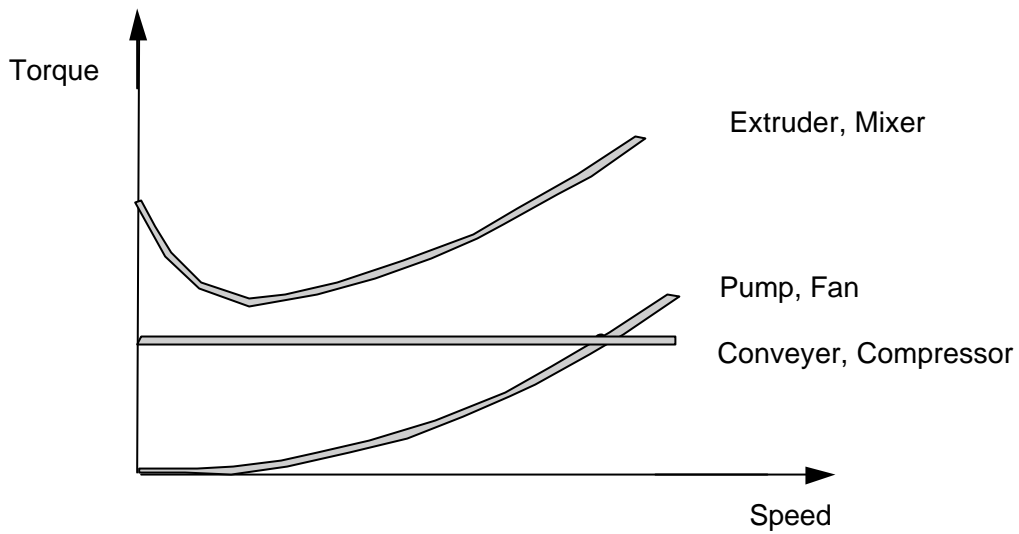
*However, if a motor is connected as a low voltage motor (delta) and operated on a higher voltage inverter full torque full torque may be obtained up to 1.7 times base frequency if the inverter is correctly set up. The correct voltage/frequency curve by setting the motor parameters as follows:*

*P081= 87*

*P084= 400 (or to suit supply)*

### **3.4 Load Considerations.**

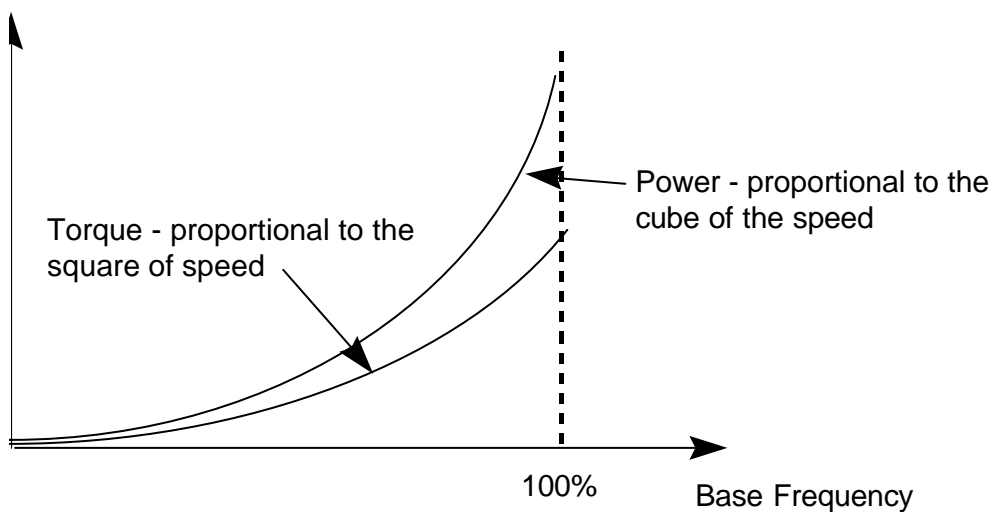
The inverter and motor requirements are determined by the speed range and torque requirements of the load. The relationship between Speed and Torque is different for different loads. Many loads can be considered to be Constant Torque loads. That is, the torque remains the same over the operating speed range. Typical constant torque loads are conveyers, compressors, positive displacement pumps.



Torque Speed Characteristics of some loads

### 3.4.1 Variable Torque Applications

Some loads have a Variable Torque characteristic, that is, the torque increases with the speed. Typical variable torque loads are centrifugal pumps and fans. In these applications the load is proportional to the square of the speed, and therefore the power is proportional to the cube of the speed. This means that at reduced speeds there is a great reduction in power and therefore energy saving - a major advantage of variable speed drives applied to pumps and fans. For example, a 10% reduction in speed will give a theoretical 35% reduction on power!



Variable Torque Load Characteristics

Because the power is greatly reduced, the voltage applied to the motor can also be reduced and additional energy saving achieved. A separate 'quadratic' or 'pump and fan' voltage to frequency relationship is available by setting P077=2.

It is not generally useful to run pumps or fans above base speed as the power will rise excessively and the fan or pump may become inefficient. Therefore when P077=2 is selected, the overload capability of the MIDIMASTERS is automatically reduced (P086=100). This allows a higher continuous rating to be selected (i.e the maximum permitted value of P083 is increased)

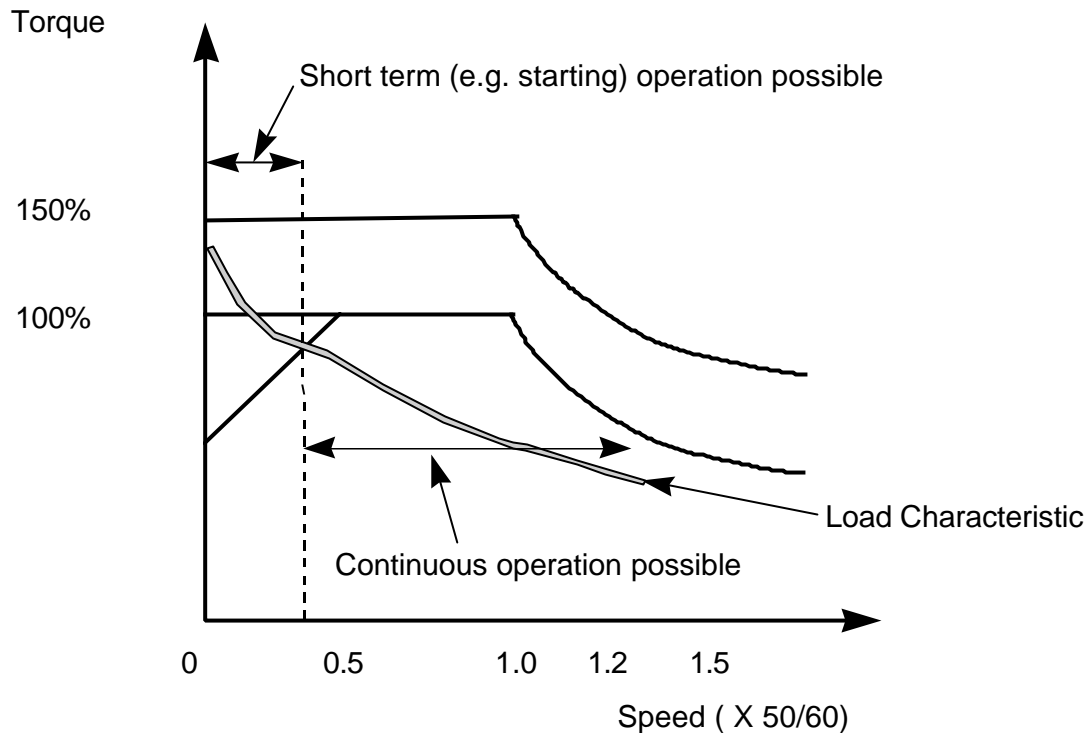
MIDIMASTERS are therefore **dual rated**, and the higher rating available for pump and fan operation can give an additional capital cost saving in these applications.

#### 3.4.2 Other Loads.

Many other loads have non linear or varying torque relationships. The torque requirement of the load should be understood before the inverter and motor is selected.

By comparing the load/speed requirement with the motor capability, the correct motor can be selected. Remember a different pole pair arrangement may give a better match to the load needs.

Starting torque may need special consideration. If a high starting torque is required this must be considered during rating.



Matching the load to the Motor/Inverter Capabilities

### **3.5 Acceleration and Braking requirements.**

If the load has high inertia and there is a requirement for fast acceleration or braking, the load due to the inertia must be considered.

During acceleration, additional torque will be needed. The total torque needed will be the sum of the steady state torque and the this additional torque. Details of these calculations are described in section 12.

*During braking, the inertial energy of the load must be dissipated. If a mechanical brake is used this is no problem, providing the inverter is disabled during brake operation. If the motor is decelerated by reducing the inverter output frequency, then the energy from the load will be returned to the inverter. Other options such as DC braking and Compound braking will minimise regeneration to the inverter, but in this case the energy will be dissipated in the motor windings. Braking method and options are described in detail in section 8.2.*

### **3.6 Environmental Considerations.**

The inverter is designed for operation in an industrial environment. However there are certain limitations which must be considered; the following check list should help:

- Check that the airflow through the inverter will not be blocked by wiring etc.
- Make sure the temperature of the air does not exceed 50°C. Remember to allow for any temperature rise inside the box or cubicle.
- The inverters are available with protection levels of IP20 (MICROMASTER), IP21 or IP56 (MIDIMASTER). IP20 and IP21 units need additional protection against dust, dirt, and water. For a detailed description of IP rating see section 11.
- The inverter is designed for fixed installation and is not designed to withstand excessive shock and vibration.
- The inverter will be damaged by corrosive atmospheres.
- Protect the unit from dust; dust can build up inside the unit, damage the fans, and prevent proper cooling. Conductive dust, such as metal dust, will damage the unit.
- Give due consideration to Electromagnetic Compatibility (EMC), such as:
  - Will the inverter be protected from the effects of power equipment such as Power Factor Correction equipment, Resistance Welding Equipment etc.?
  - Will the inverter be well grounded?
  - How will the inverter and any control equipment ( contactors, PLCs, relays sensors etc.) interact?

IF IN DOUBT, consult the guidelines and specification information in the handbook, or see section 6.1 .

## **4. Installing and Getting Started with an Inverter.**

### **4.1 Mounting the MICROMASTER.**

- Mount the MICROMASTER using the mounting holes provided as described in the handbook. Ensure the correct torque ratings for the fixing bolts are not exceeded.
- The unit may be mounted horizontally, vertically, or sideways without derating. Do not mount the units upside down, as the fan cooling will oppose natural convection cooling.

### **4.2 Cooling.**

- The MICROMASTER will operate in a temperature of 50°C without de-rating.
- The MIDIMASTER's maximum temperature is 40°C.
- Make sure that the inlet and outlet ducts are not blocked, for example by cable ducts.

- *It is very important to ensure that the maximum operating temperatures are not exceeded inside a cubicle. When installing an inverter in a cabinet, it is necessary to calculate the heat rise:*

*1. Calculate total heat loss ( $P_{Loss}$ ) for all units inside the cabinet. Use manufacturers data or assume 3% loss.*

*2. For a sealed cabinet, calculate temperature rise using the formula:*

$$T_{rise} = P_{Loss} / (5.5 \times A)$$

*Where A is the total exposed area of the cabinet in square metres.*

*For a fan cooled cabinet:*

$$T_{rise} = (0.053 \times P_{Loss}) / F$$

*Where F is the air flow in cubic metres /minute.*

*3. Add the Temperature rise to the external ambient temperature. If this is greater than the operating temperature of the drive, additional cooling will be needed, or the units must be de-rated.*

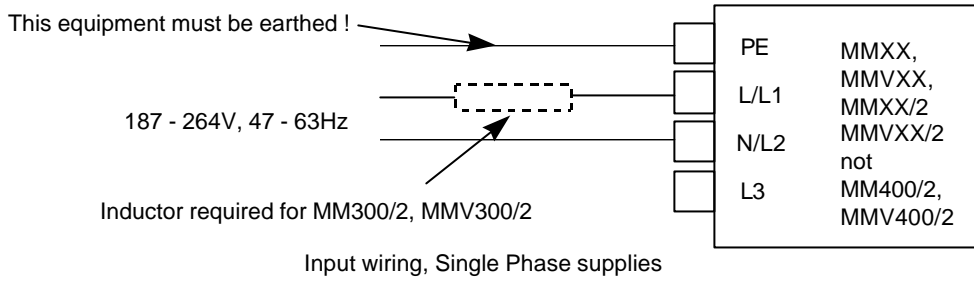
*It will also be necessary to de-rate at altitudes above 1000m. De-rate as follows:*

<i>2000m</i>	<i>85% of full load rating.</i>
<i>3000m</i>	<i>75% of full load rating.</i>
<i>4000m</i>	<i>65% of full load rating.</i>

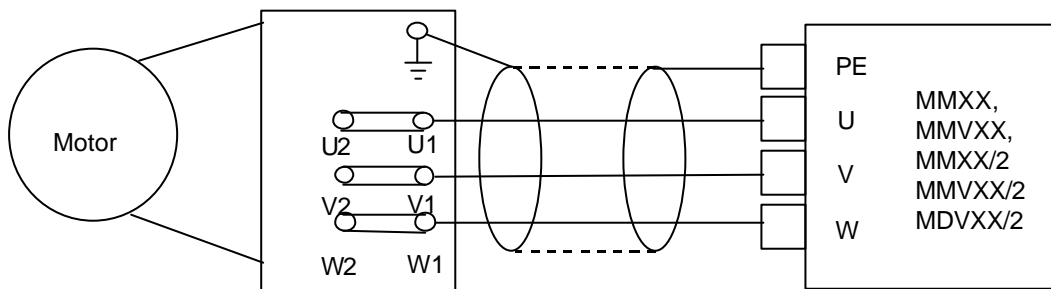
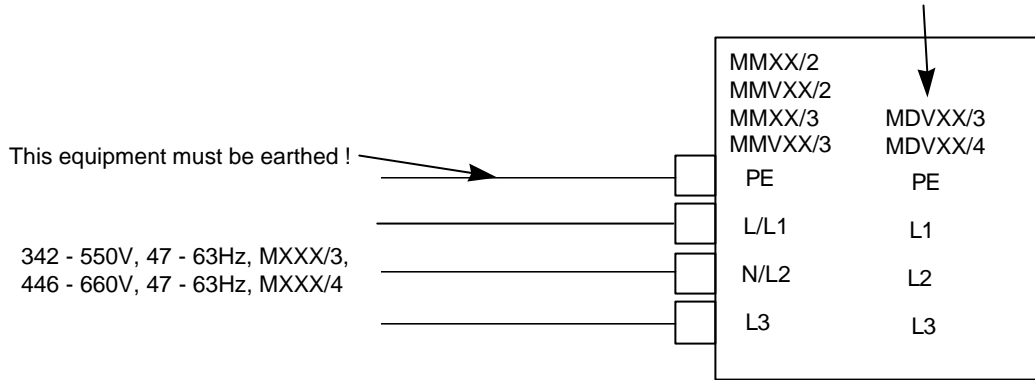
*For more information consult the DA64 catalogue.*

### **4.3 Wiring up the MICROMASTER.**

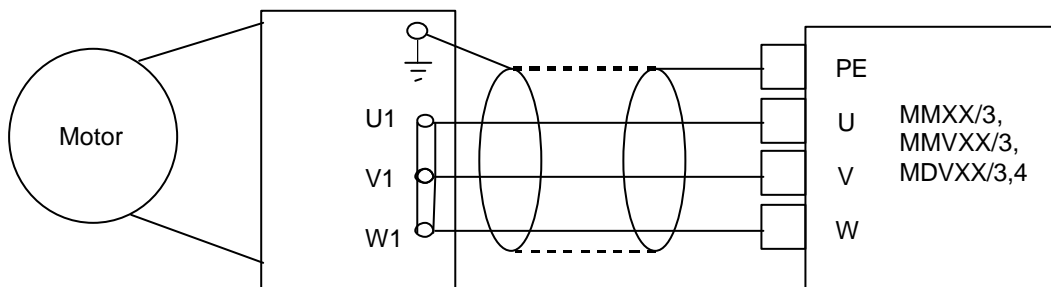
- Note the warning guidelines in the manual, and ensure all safety regulations are complied with. **THIS EQUIPMENT MUST BE EARTHED!**
- If the supply is connected to the motor/output terminals, the inverter will be damaged.
- Follow the wiring instructions in the manual, including the EMC guidelines.
- Check the wiring before switching on. In particular, is the unit connected to the correct supply, (low voltage units will be damaged if connected to a higher voltage) and is the protective earth connected?



Terminal layout varies on MIDIMASTERS



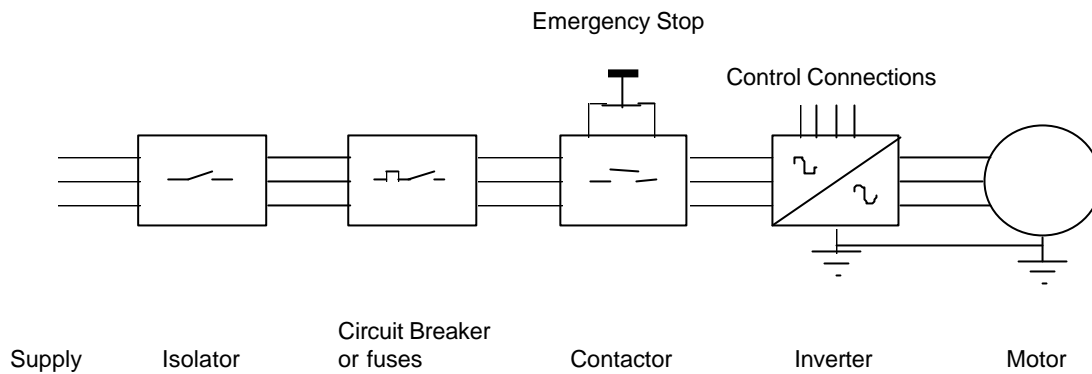
1AC or 3AC 230V Input: Low Voltage Outputs - Motor usually connected in Delta



3AC 400,575V Input: High Voltage Outputs - Motor usually connected in Star

#### 4.3.1 A Typical Installation





### Supply

The supply may be either single or three phase, depending on the inverter type. The recommended wire sizes are stated in the manual.

### Isolator

An isolator is usually required for safety reasons.

### Circuit breaker or Fuses.

The protection rating is based on the input current as stated in the manual. The input current is higher than the output current because the form factor of the current is high. Do not use fast acting circuit breakers or semiconductor fuses. Motor Circuit Breakers are usually recommended for use with inverters.

*Inrush currents on the latest inverters are typically only two or three times full load current, so nuisance tripping is less of a problem.*

### Contactor

A contactor, with an emergency stop function connected may be required both for auxiliary control and safety isolation. Do not use the contactor as a stop start function This will cause unnecessary wear on the contactor and there will always be a slight delay while the inverter initialises. Use the control terminals or push buttons to do this. It is not permitted to use the Run/Stop control of the inverter as an emergency stop function. It is not recommended to fit a contactor between the output of inverter and the motor.

### Motor

As shown in previous diagrams, many motors, particularly at low powers, are designed for low voltage (230V) or high voltage (400V) operation. The voltage is usually selected by fitting links at the motor terminals. Instructions for low voltage (star) connection or high voltage (delta) connection are usually shown on the inside of the terminal cover. Clearly an inverter with a low voltage single or three

phase input will produce a low voltage three phase output, and the motor should be connected accordingly. See also section 3.3

#### **4.4 First Switch On.**

- Apply power to the unit. The display should light up and flash 0.0, 5.0. When the inverter is stopped it flashes between 0.0 and the frequency it will run to when started (The set point).
- Changing Parameters. The correct parameters can now be set for the motor. Parameters P080 to P085 should be changed as described in the handbook to suit the motor. To change a parameter, proceed as follows:

Press P	Display shows P000
Press up or down arrow	Display scrolls.
When desired parameter shows...	
Stop, press P again	Display shows parameter value
Press up or down arrow	Display scrolls.
When desired value shows...	
Press P to set value.	
Press up or down arrow to return to P000	
Press P again	Display flashes as before.

Remember that to access parameter greater than P009, P009 must be set to 3. If the display flashes instead of changing, the parameter cannot be changed, either because it is fixed, or the inverter is running and the parameter cannot be changed during running.

- If the unit does not show the expected display, it may be that parameters have been changed for some reason. To change them back to the factory settings, set parameter 941 to 1.

Press P	display shows P000
Press down arrow	display scrolls P971, P944 etc.
When P944 shows...	
Press P	display shows 0000
Press up arrow	display shows 0001
Press P	display shows P000
Press P	display shows 0.0/5.0

Always reset to factory defaults if unsure what parameters have been changed and set.

- Now press the green button on the front panel. The motor should turn as the inverter outputs 5.0Hz.
- If the motor goes in the wrong direction, switch off at the supply, wait five minutes for the internal capacitors to discharge, and swap any two motor connections. Of course, the motor can also be reversed using the front panel controls, digital inputs etc.

- If the motor is heavily loaded, or if the parameters have not been correctly set it may not turn. Set the motor parameters as described in the handbook.

#### **4.5 If the motor does not start.**

Check through the following table. In general, if the inverter operates without the motor and load connected, it is probable the inverter is undamaged and the fault is in the load. Remember, if in doubt, reset parameters to Factory defaults and start again.

Trouble Shooting Summary			
Action	Display	Possible Cause	Remedy; stop and ...
Apply Power	no display	no Power, low supply, faulty unit	Check supply is in tolerance. Check fuses etc.
Apply Power	---, 8888	Low supply, faulty unit	Check supply is in tolerance.
Apply Power	FXXX	Faulty parameter settings, internal fault	Switch off, Switch on, disconnect load. Try again. Check fault type in Manual.
Run Command	Flashes	overload or similar warning.	Check warning type in Manual. Reset parameters, check load and reduce if necessary. Try again.
Run Command	F002	overload, faulty unit.	Reset Fault (Press P button twice). Reset parameters, disconnect load and motor if needed. Try again.
Run Command	000.0	Run command not received or Set Point equal to 000.0	Reset parameters, Try using front panel controls, check set point setting e.g. P005.
Run Command	FXXX	Other Fault	Reset fault, Reset parameters, disconnect load. Try again.

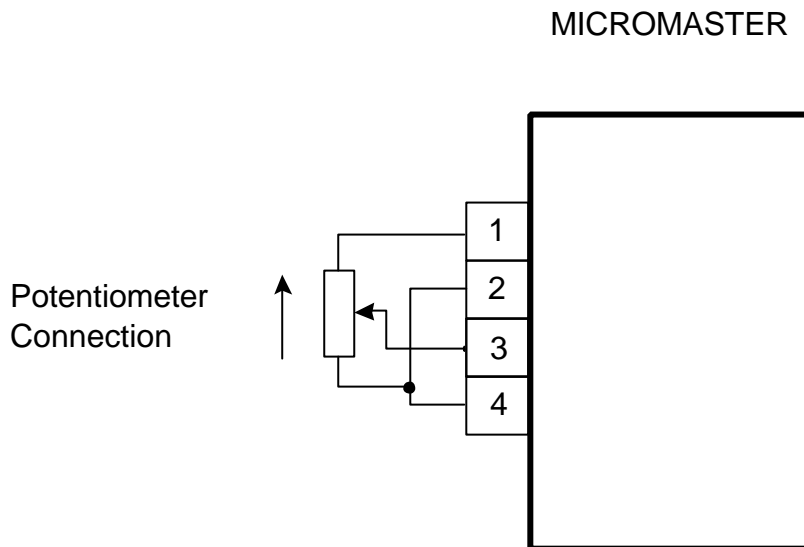
### **5. Some Simple Applications and Possibilities**

Most inverters used in industry are controlled via the control terminals, not the front panel as described above. This section describes some simple control possibilities using these inputs, and some of the programmable features that may prove useful. The following descriptions include terminal numbers and parameter values which are valid for MICROMASTER Vector and MIDIMASTER

Vector inverters; if other products are used please check the terminal numbers in the handbook.

### **5.1 Using a Potentiometer with the Analog Input.**

Set Parameter P006 = 001 and connect a potentiometer (between 5kohm and 100kohm) to the analog input as shown in the handbook. The Potentiometer is wired as shown:



The inverter can be started using the front panel controls, and the output frequency adjusted using the potentiometer.

The default maximum and minimum settings for the analog input are 50 (P022) and 0Hz (P021) respectively, so the inverter will run at a frequency somewhere between these frequencies, depending on the potentiometer position.

*Changing P021 and P022 will change the range of the potentiometer accordingly, but remember the absolute maximum and minimum settings are set by parameters P012 and P013. Note that many parameters cannot be changed while the inverter is running. The display will flash if this is attempted.*

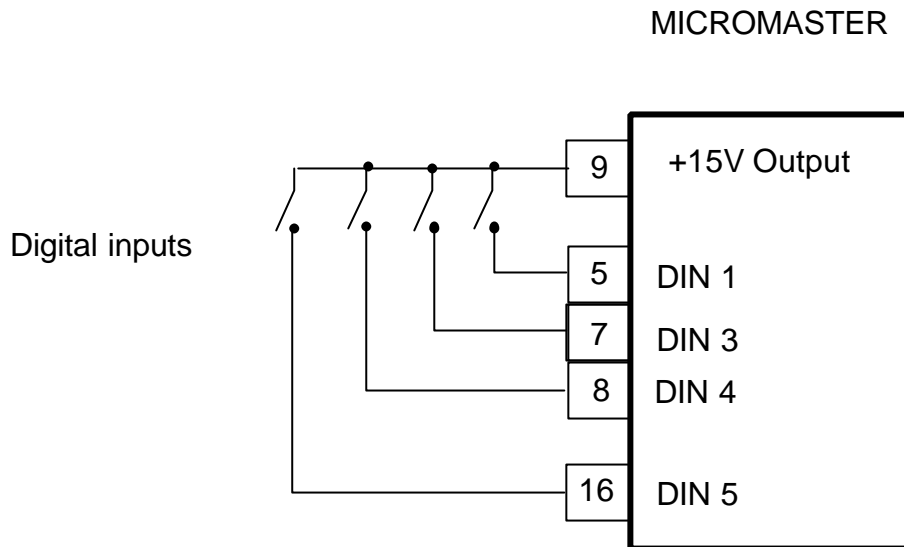
Note that the Run and Stop control is still via the front panel buttons.

### **5.2 Using a Digital Input.**

The digital inputs on the inverter are programmable and many different functions can be selected. The digital inputs have default settings which are used below, but can be easily changed.

With the potentiometer still connected, set parameter P007 to 0 to disable the front panel controls, and connect a switch between terminals 5 (digital input 1, default function ON right) and 9 (15V supply for this purpose). Closing the switch

should start the inverter, which will run at a frequency set by the potentiometer as before.



### **5.3 Using the Fixed Frequencies.**

Fixed Frequencies can be selected using digital inputs. Set parameter P006 to 2 (select fixed frequency operation), and connect additional switches from terminal 5 to terminals 7,8,16 (digital inputs 3,4 and 5). These switches can now be used to select fixed frequencies 1,4 and 5 (default values 5,20,25 Hz). A separate Run and Stop signal is still needed using the existing switch connected to terminal 5.

Closing more than one switch will simply add the two fixed frequencies together.

Forward and reverse functions can be implemented using parameter P045 and 50. Changing Parameter P045 to 7 will reverse the direction of fixed frequencies 1 and 4. Again, closing more than one switch will add or subtract fixed frequency values.

In Summary:

P006=2 selects fixed frequencies

P053,54,55 etc = 6 selects digital inputs to fixed frequency control

P045,50 selects run direction options.

*More Complex Uses of Fixed frequencies.*

*If the corresponding digital inputs are reprogrammed from 6 to 17, the inputs will selected fixed frequencies in binary coding, allowing the three inputs to select up to 8 digital inputs.*

*Setting the digital inputs to 18 will allow Run/Stop control via these digital inputs as well, so a separate Run/Stop control is not needed. I.e the inverter will start when any input is enabled.*

*The Fixed frequencies can be added or scaled to the fixed frequencies by changing parameter P024.*

*Please consult the handbook for additional details.*

#### **5.4 Using other digital input features.**

The digital inputs are activated by a high voltage (7.5-33V) on the corresponding terminal, or by using a switch and the 15V supply as described above.

All the digital inputs have many different functions, which can be programmed by setting parameters P051-53, (and P054,55, and P356 on Vector units).

Simple Uses include:

- 001 Run right
- 002 Run left
- 003 Reverse
- 007 Jog right

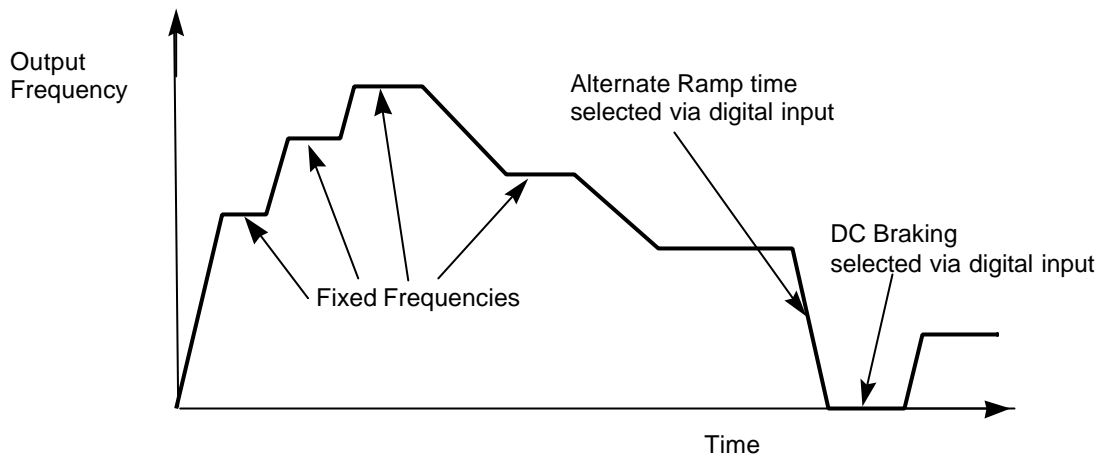
Other settings that may prove useful:

- 006 Select fixed frequency (see above)
- 010 Fault reset
- 019 External trip

*Advanced Features:*

- 009 Local/remote operation. Allows switching between remote operation (as set by P910) and local control. Motor stops in between.*
- 014 Disable 'P' Button. Using this setting with a wire link instead of a switch prevents tampering with the parameters by uninformed users.*
- 015 Enable DC brake. The DC brake feature can be enabled to provide a holding torque if required. See section 8.2.*

*Please consult the handbook for additional details.*



Possible control cycle using fixed frequencies, DC Braking, and Variable Ramp Rates

## **5.5 Using the control outputs.**

There are several control outputs which can be used to control external indicators or warn of potential problems.

Analog Output (Vector units only). The Analog output may be set to give several different indications as described in parameter P025. The output is 0/4-20mA, but can be easily converted to a voltage by fitting a resistor (500 ohms for 0-10V for instance). The MIDIMASTER Vector has two Analog outputs.

Relays. An indicator relay ( two on Vector Units) is provided which maybe programmed to give a variety of indications using parameter P061. The relay is often used to indicate set point reached (P061=7) warning active (P061=8) output current exceeding a set value (P061=9).

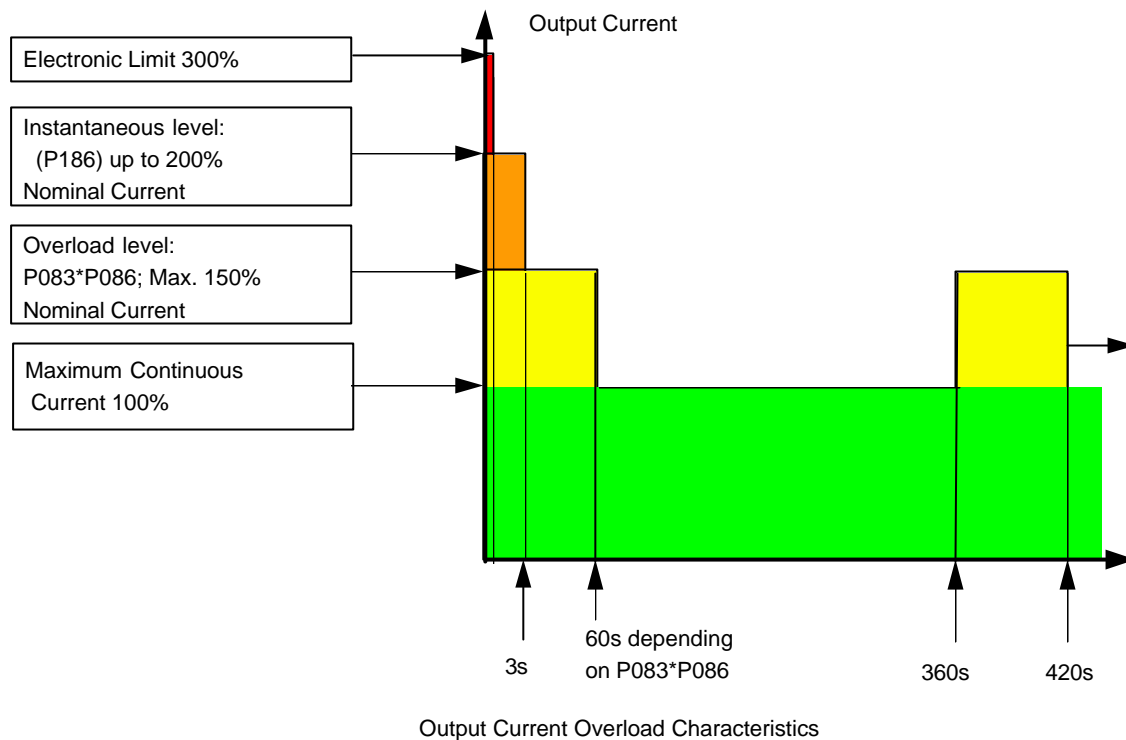
*The relays can be used to control an external brake. In this case, a timer function can be used to start the inverter and release the brake as described in parameter P063. In this case, the relay must be suppressed and a contactor used to switch the brake itself. See section 5.8.6.*

**The relay contacts should be suppressed where inductive loads such as contactor coils or electromagnetic brakes are switched.**

## **5.6 Current Limit and Protection Systems**

The inverter must protect itself, the motor and system from overload and possible damage. Current limit now operates very rapidly, limiting the current and preventing a trip occurring.

The inverter has several levels of current limiting:



**Electronic Trip.** This is a very fast current limit which operates if there is a short circuit (line to line or line to earth) on the output. It is a fixed level trip and operates within a few microseconds. Fault F002 indicates this trip.

**Overload Limit.** This is a fast limit, which is set by parameter P186, and may be as high as 200% of the nominal current level set in P083. If the output current lies between the level set by P186, and the level set by P086 (see below) the inverter will reduce its output frequency after three seconds until the current falls to that in P086. The long term overload limit may then become active after some time (see below).

**Long term Overload limit.** This is a slower limit, which allows an overload of at least 60 seconds when the current lies between P083 and P086. *The actual time is dependent on the amount of overload, but is at least 60 seconds. After this time, the output frequency is reduced until the level set by P083 is reached.*

**Continuous Limit.** This is the level set in P083. The inverter will control the current to this level after the overloads described above have timed out.

*In the above all cases, except electronic trip, the inverter will reduce the output frequency in order to reduce the load. Some settings of P074 will cause a trip to occur instead of current limit.*



Alternatively, the output relays can be used to warn of current limit (P061 or 2 = 10) or that the inverter is below a minimum frequency for instance (P061 or 2 = 5).

If P086 and P186 are set to 100%, then the current limit set in P083 will operate instantly.

If P083 is set lower than the nominal value then P086 can be set higher - e.g. up to 250%, representing the capability of the inverter, but not necessarily the motor or load. I.e. the maximum permitted value  $P083 \times P086$  is constant for any one inverter type.

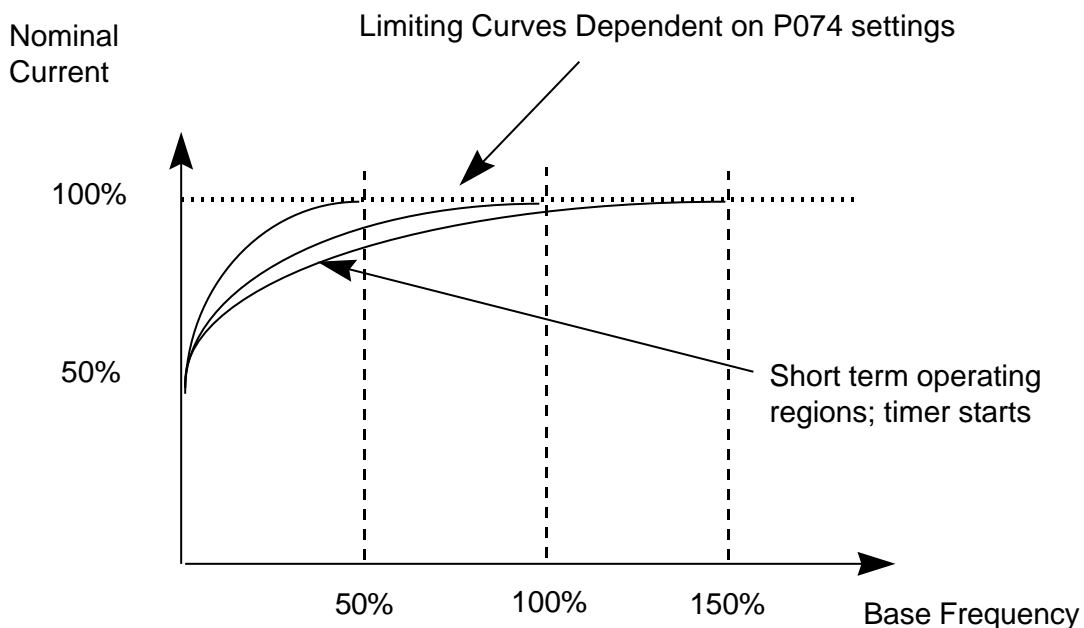
When Vector operation (P077=3) is selected, the current limit effectively operates as a torque limit between 5 and 50Hz.

If the Current limit is active the display flashes and the warning code 002 is written to parameter P931 (most recent warning).

The current is limited by reducing the output frequency; fast current limit - for instance during ramping - is controlled by reducing output voltage.

## **5.7 Other Protection Features**

### **5.7.1 $I^2t$ Protection.**



$i^2t$  Motor Protection Characteristics

When the motor is running at low speed and high load the built in cooling fan may not provide enough cooling and the motor may overheat. Parameter P074 allows a frequency dependent  $I^2t$  limit to be enabled to protect the motor.

*When the inverter is operating in the region above the selected curve (i.e at low frequency and high current), a timer is started, and after some time (based on the current, the motor size and previous operating history) the inverter will trip or reduce output frequency, depending on parameter setting. Further information is given in the hand book.*

### 5.7.2 PTC Resistor Protection.

Many motors are available with a PTC ( Positive Temperature Coefficient ) resistor built into the windings. The resistance of the PTC rises rapidly at a particular temperature, and this change can be detected by the inverter. If the PTC is connected to terminals 14 and 15, and the PTC input enabled by setting parameter P087=001, then if the PTC resistance rises above 2kohm, the inverter will trip and F004 displayed.

*Most Motor Protection PTCs have a resistance of 2-300 ohms when cold. This value rises rapidly at the 'knee point' to typically 10kohms and greater. The PTC input is set so that it will operate at 1kohm minimum, 1.5kohm nominal, and 2kohm maximum. The input has considerable filtering because the PTC connection usually carries considerable EMI. On this basis two or three PTCs may be connected in series when a motor has more than one PTC built in, or if two or three motors are connected to the inverter output and require individual protection.*

### 5.7.3 Overvoltage

If the inverter is connected to a high voltage, or if the internal voltage is forced high by energy from an external load, then the inverter will trip and F001 will be displayed. Overvoltage usually occurs as a result of a braking or regenerative load, see section 8.2.

If the supply voltage is too high the inverter may be damaged even if it trips.

### 5.7.4 Internal Overtemperature

The inverter is protected from overheating. The heatsink temperature is monitored using a PTC and if the maximum temperature exceeded the inverter will trip. F005 will be displayed.

*Overtemperature in the inverter is usually caused by a high ambient temperature, a faulty or blocked fan, or blocked air inlet or outlet.*

## 5.8 Some Additional Features

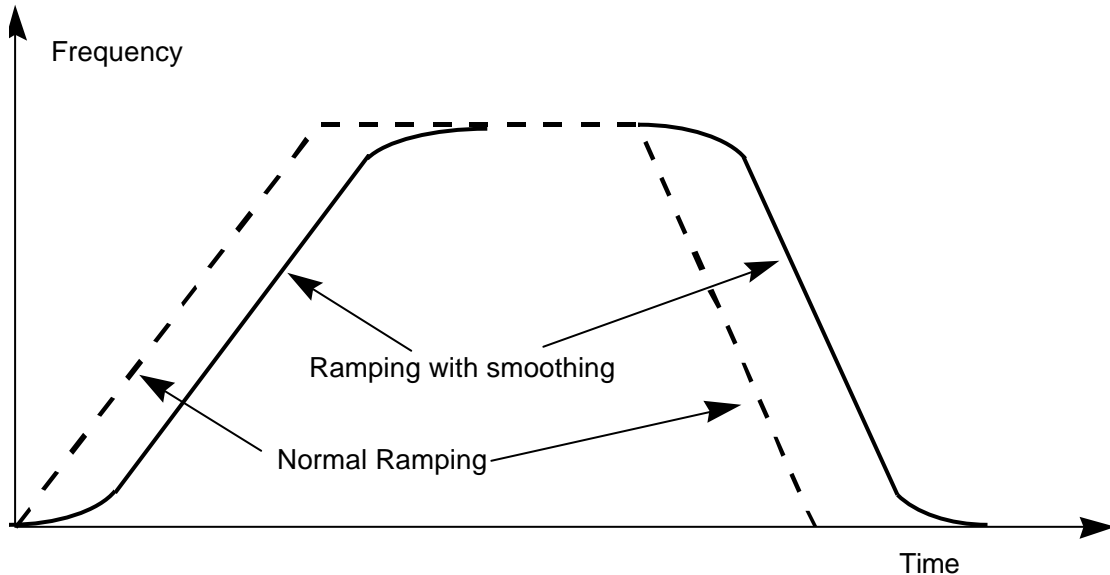
The MICROMASTER has many useful features built into the software and available for the user. Some of these are briefly described below; the manual gives details of how to select and use these features. Advanced features such as Serial Interface, Closed loop Control, Braking operation etc. are described section 8.

### 5.8.1 Display Mode P001.

The display normally shows the output frequency, but output current, motor speed etc. can be selected instead.

### 5.8.2 Ramp Smoothing P004.

The rate of change of ramp can be limited to limit 'jerk'. The smoothing is calculated from the Ramp up time, so if the ramp down time is very different smoothing will not be so effective during ramp down. Smoothing is not effective at ramp rates of less than 0.3 seconds. *Smoothing has the effect that if the inverter is ramping up and a stop signal given, there will be a delay before the inverter begins to ramp down again. This effect can be optionally disabled using parameter P017 .*



Smoothing applied to up and down Ramps.

### 5.8.3 Display Scaling P010.

The value in display can be scaled to match the process and show 'Litres per minute' or 'Metres per second' etc.

5.8.4 Skip Frequencies. P014 etc.

If these frequencies are set, the inverter will not run at these output frequencies; resonance problems can be avoided using this feature.

*The bandwidth can be adjusted by setting parameter P019. That is, if P019 is set to 2, and P014 set to 15, the inverter will not run between 13 and 17Hz. However, during ramping the inverter will ramp through these frequencies normally to avoid a 'step'.*

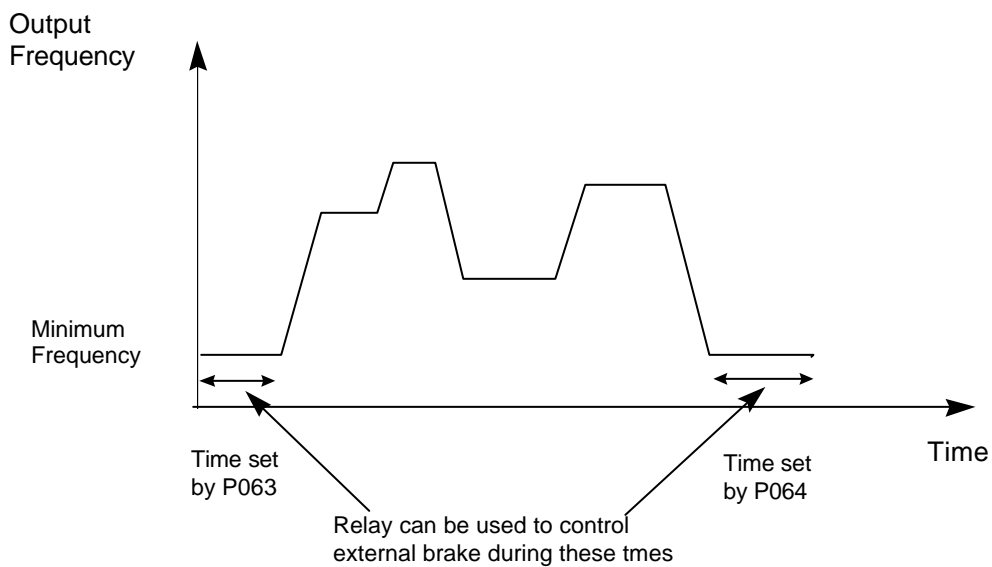
5.8.5 Start on the Fly P016.

Normally if the inverter attempts to start on a motor that is already rotating it will current limit, stall or slow the motor down. If Start on the Fly is selected it will sense the speed of the motor and ramp the motor from that speed back to the set point. This is useful if the motor is already turning for some reason, such as following a short mains break.

*Start on the fly can operate when the load is rotating in the reverse direction, for instance when a fan is rotating due to reverse pressure. In this case, the motor direction is tested at low torque in forward and reverse directions. This can have the undesirable effect that the motor rotates in both directions at start up. Parameter P016 offers options to test operation in one direction only to prevent this.*

5.8.6 Electro-Mechanical Brake Control P063, P064.

The relays can be programmed to control a separate brake (P061 or 62 = 4) and a delay set (P063, P064) so the motor can be energised prior to relay release. During the time set in P063 and P064 the inverter runs at it's minimum frequency while the brake is energised, so that when the brake is released the motor will move immediately.



Possible control cycle using brake control relay and times

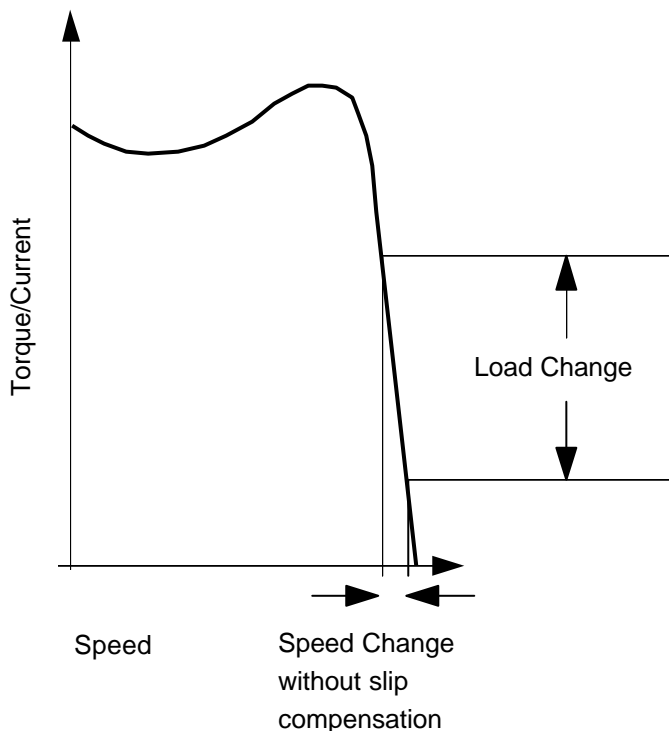
Even if no brake is connected, this timer feature can prove useful if operation at low speed, or even zero speed ( which has the same effect as DC braking - see section 8.2.2) is required for a defined time (P063,P064) at the beginning or end of a sequence.

#### 5.8.7 Slip Compensation P071.

The motor speed is reduced depending on the load, due to the slip as described earlier. Slip can cause a speed regulation by as much as 10% with small motors. The inverter can compensate for this by increasing the output frequency slightly as the load increases. The inverter measures the current and increases the output frequency to compensate for the expected slip. This can give speed holding of better than 1%.

Slip compensation has no effect during Sensorless Vector Operation as compensation is inherent.

*Slip compensation is a positive feedback effect (increasing load increases output frequency), and too much compensation may cause slight instability. It is set up on a trial and error basis.*



#### 5.8.8 Pulse Frequency selection P076.

The switching, or pulse width modulation frequency does not change with output frequency (see section 1.2); it is set by P076. The switching frequency of the inverter can be selected between 2 and 16kHz. A high switching frequency has higher losses and produces more Electromagnetic Interference (EMI). A lower switching frequency may produce audible noise. The switching frequency can be

changed to suit the application, but some derating (as described in the handbook) may be necessary on certain units.

*The acoustic noise generated has a frequency of twice the switching frequency, except at light loads, where there is some fundamental frequency content. Therefore a switching frequency of 8kHz will often be inaudible.*

#### 5.8.9 Boost. P078 and P079.

At low output frequencies the output voltage is low to keep the flux level constant, as described earlier. However, the voltage may be too low to overcome losses in the system. The voltage can be increased using parameter P078. Parameter P079 will only produce boost during ramping, and is therefore useful for additional torque during starting. Boost has no effect during vector operation because the inverter calculates continuously the optimum operating conditions. Parameter P078 is set to 100% as factory default.

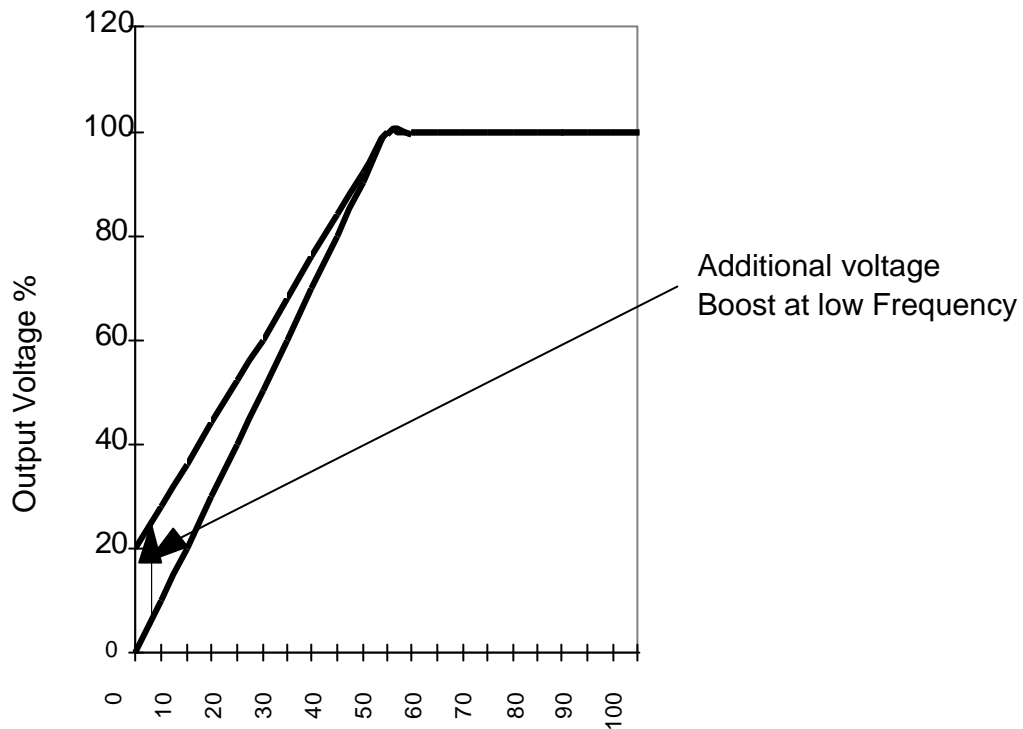
The sum of P078 and P079 is limited to 250%.

*The amount of boost is calculated from the stator resistance value (P089) and the Nominal Current setting (P083), such that:*

*Voltage Boost X (P078 + P079) = P083 X P089.*

*That is, if P078 + P079 = 100%, the boost level will be sufficient to supply nominal current into the stator, even at zero frequency. Above zero frequency the boost levels reduce as base speed is approached*

*This means that if P083 or P089 are changed, the boost voltage changes as well.*



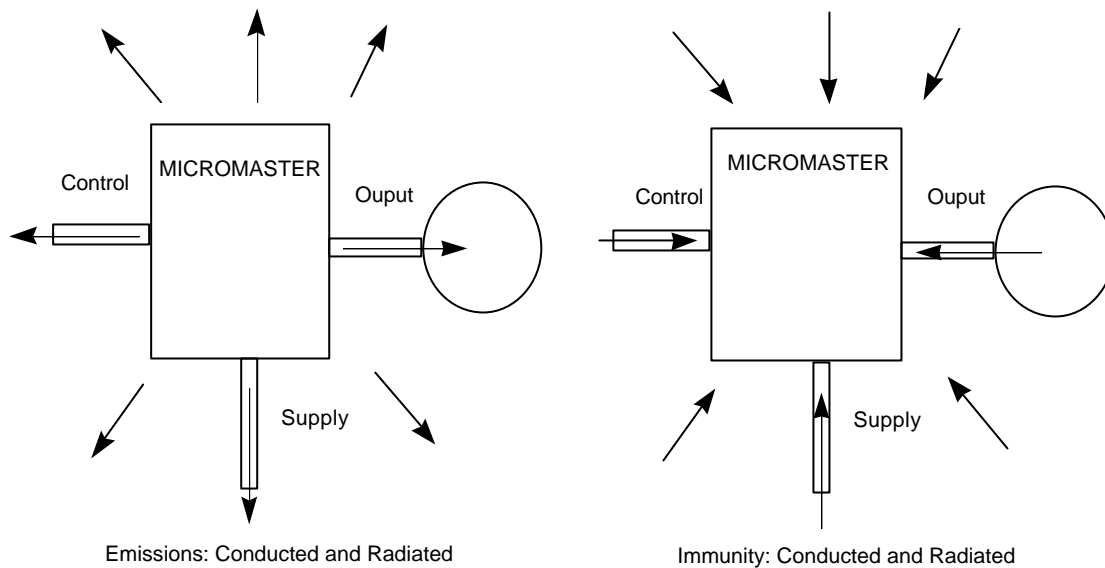
#### 5.8.10 Serial Interface P910.

The inverter can be controlled via a serial interface using the 'D' type connector on the front panel. This connector and serial interface is also used by the Enhanced Operating Panel (OPm2) and the Profibus module. The serial interface is described in detail in section 10.

## **6. Electromagnetic Compatibility (EMC)**

### **6.1 What is EMC?**

All electronic and electrical equipment generate unwanted signals. These signals can be emitted from the product either via cables that are connected to the product (Input, output, signal etc.) or via electromagnetic radiation 'radio transmission'. These signals can be received by other products (via the same routes) and can interfere with the correct operation of the product.



Any particular product gives out a certain level of emissions, and has a certain level of immunity to incoming signals from other products. If the immunity of all products are higher than their emissions, all is well. If this is not the case, severe problems can occur, causing quality problems, damage, or in extreme cases injury.

Electromagnetic Compatibility concerns how equipment works together; Electromagnetic Interference (EMI) refers to the unwanted signals themselves.

EMI has become a more serious problem recently as more electronic systems (which may prove to have low immunity) are used in industrial applications, and as power electronic products such as drives, generate high frequency signals which can produce high levels of interference.

## **6.2 Minimising the problem of EMI.**

EMI and EMC are much better understood than a few years ago, and most manufacturers of electronic equipment take care during design and installation to minimise emissions and maximise immunity. Siemens inverters are carefully designed with this in mind, and optional filters can be specified (either built in or as an external option) to reduce the emissions in the supply.

Before describing the practical solutions to EMI, it is important to understand the practical problems associated with EMC and inverters.

- The output of all inverters generates high frequency, high voltage switching waveforms in the output cables between the motor and inverter.
- A lot of EMI occurs at high frequency. At high frequencies the shape and length of the cable has a big effect on it's impedance. Therefore short, thick,



braided leads will be most effective in grounding, and high quality screened cable, grounded at both ends, will be needed to limit effects on signal leads.

- If equipment is badly grounded high levels of EMI may connect from the power part of equipment into the control connections. Similar effects can occur when badly grounded equipment is connected together and EMI is conducted via the control cables.
- Particular care is needed when equipment is used with low signal sensors such as load cells and capacitive sensors.
- Conducted interference is more likely to cause problems than radiated interference.
- The signal and control leads in any electronic system are generally low voltage, high impedance, and are therefore particularly sensitive to the high level of EMI present in industrial systems.
- Switching inductive loads, such as electro-mechanical brakes, relay and contactor coils generate severe EMI.

### 6.2.1 Immunity and Immunity testing

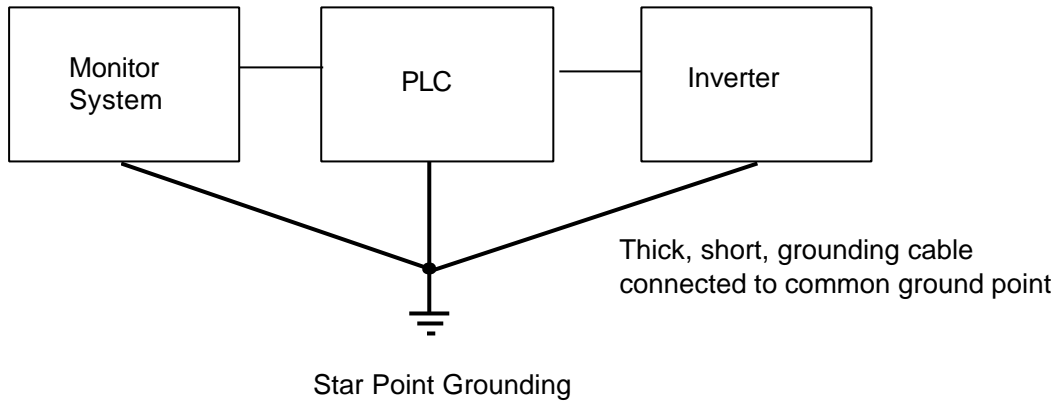
Immunity is very important as damage and nuisance tripping will cause failure and service costs irrespective of where the fault lies. Therefore the tests carried out during product development are quite severe, and represent conditions encountered in industry.

*Tests include:*

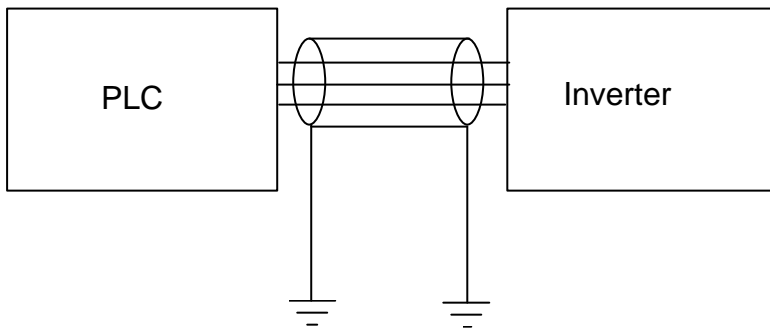
- *Electrostatic Discharge testing of all exposed surfaces, terminal and buttons using high voltage discharge gun. This simulates the effect of discharge from a human body electrostatically charged from a carpet for example.*
- *High voltage very high frequency discharges capacitively coupled into the control lines. This simulates the interference that couples from power switching (contactors etc.) into control leads.*
- *Similar discharges directly into the supply leads, line to line and line to ground. This simulates conducted interference from arcing contacts in other equipment.*
- *High energy, lower frequency interference in the supply leads, line to line and line to earth. This simulates lightning strike interference and similar supply disturbance.*

### 6.2.2 EMC Guidelines:

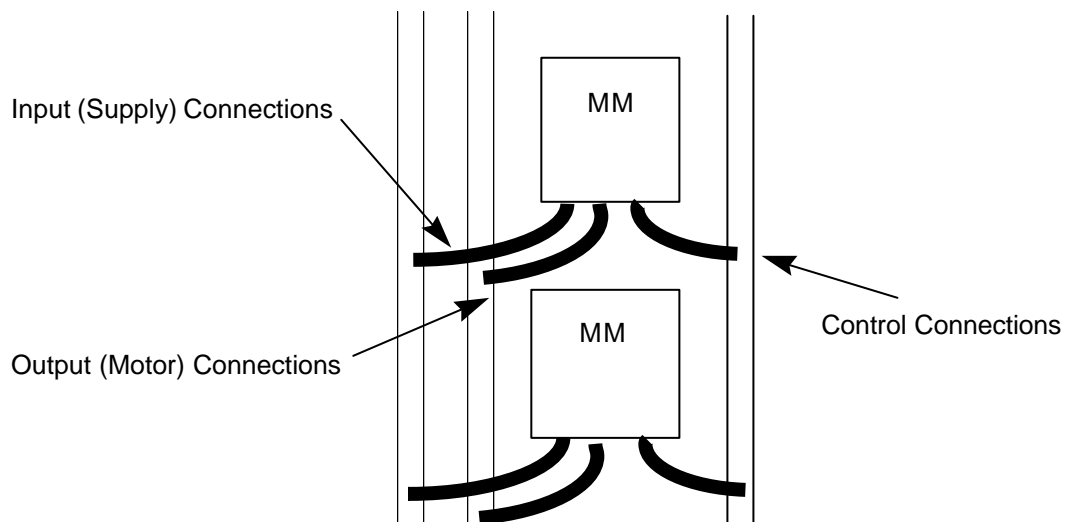
The guidelines for installation and wiring are detailed in the handbook, but the key points are as follows:



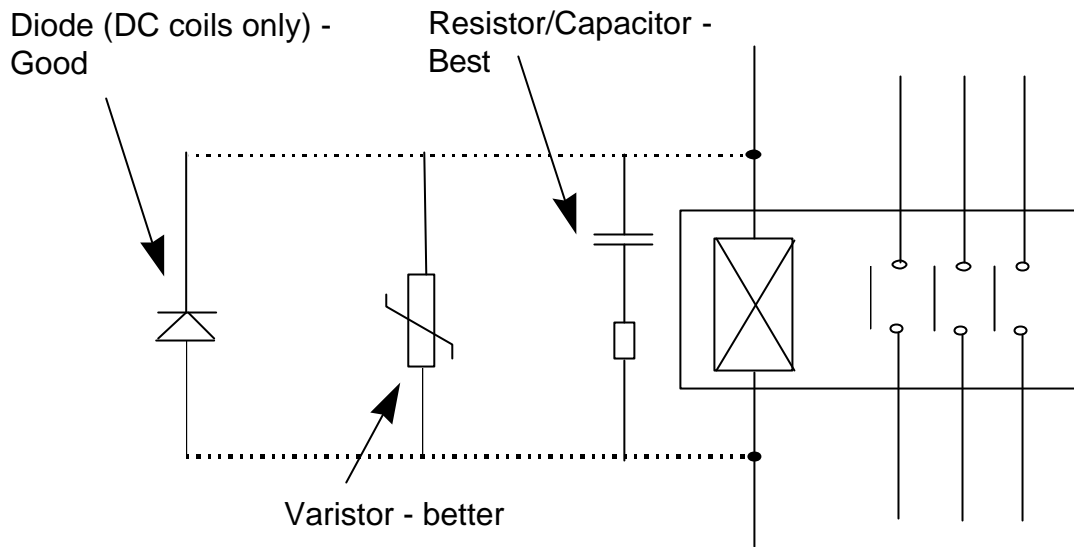
1. Ensure all equipment in the cubicle is well earthed, using thick, short earthing cable. Earth control equipment in the same way to the same earth point. Star point grounding, shown above, is ideal, but a solid bussbar is acceptable provided it is well grounded.



2. Use screened leads for connections to the control circuitry. Ground the screen at both ends.

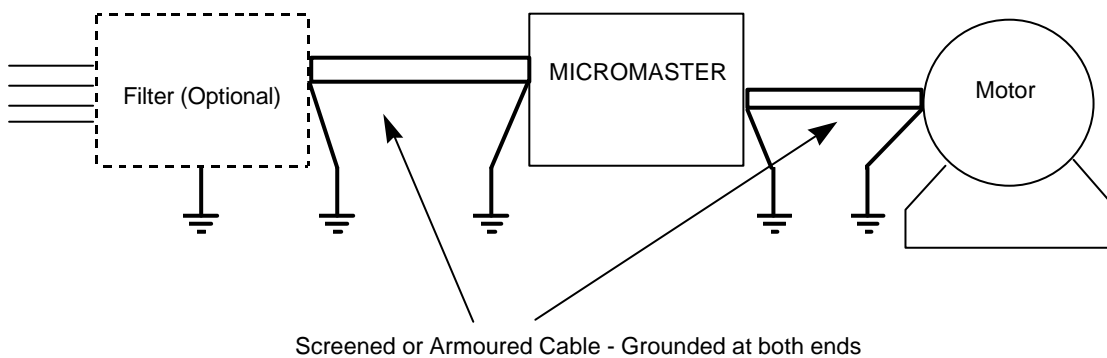


3. Separate the control cables from the power connections (e.g. supply and motor connections) as much as possible, using separate trunking etc.



Suppression of Contactor Coils

4. Suppress relay, contactor coils etc. using R-C, flywheel diode, or varistor suppressers fitted at the coils.



5. Use screened or armoured cables for the power connections; ground the screen at both ends.

6. Consider using an RFI filter in the supply to the converter.

7. Consider connecting the 0V of the inverter to the protective earth. This can often reduce noise in the 0V system.

### **6.3 EMC Rules and Regulations.**

The regulations concerning EMC are complex, changing and vary from country to country. The most important point to remember is that if there is no problem there is unlikely to be a legal issue, and in any case prevention is better - and cheaper - than cure.

### 6.3.1 European Regulations.

The rules in Europe are complex, because they depend on the type of product, how it is sold, and who installs it.

Legislation, which came into force 1<sup>st</sup> January 1996, was designed to control emissions and immunity of many types of electrical and electronic equipment for both domestic and industrial applications. This is the EMC directive EEC/89/336, which refers to many Euronorms (such as EN55011, EN55022 etc.) to set the required levels.

However, separate EMC Product standard - EN 61800-3 has now been introduced which overrules these standards for drives products. This is also a complex regulation, but it does define two 'environments' - basically Domestic and Industrial, and two distribution methods - Restricted and Unrestricted. Restricted distribution means that the product is sold to a customer with some EMC competence. For Restricted distribution and Industrial installations there are essentially no limits on emission levels. For Domestic installations Class A1 or B1 levels apply, for Restricted and Unrestricted distribution respectively.

As the MICROMASTER is sold via restricted distribution for industrial applications, no limits for emissions apply; however, customers may require the MICROMASTER, or the final installation or equipment to meet other specifications such as the EMC directive. In practice the majority of low voltage MICROMASTERs are sold in Europe with a built in filter because of this.

## **7. Some Real Applications.**

The following examples are based on applications where Siemens Drives have been successfully applied. In some cases the circuitry and parameter settings have been simplified.

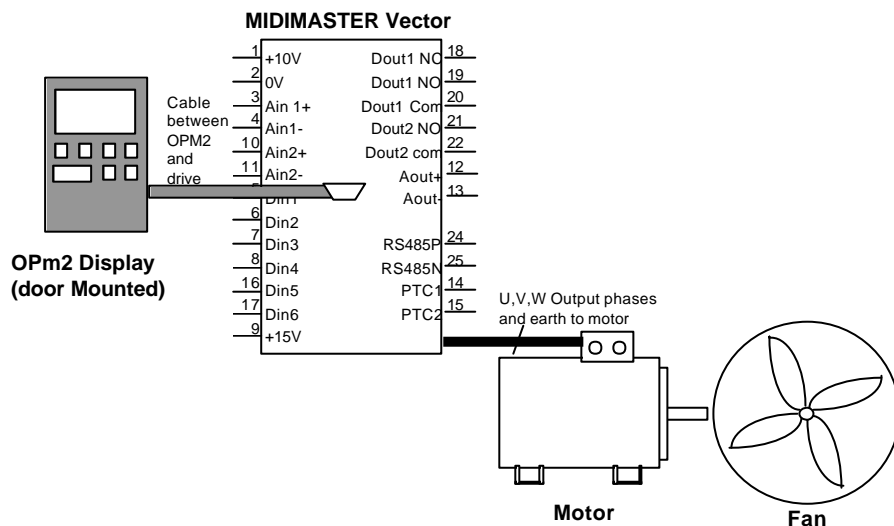
### **7.1 A simple Fan Application**

The Application uses a MIDIMASTER to control a ventilator fan in an application where the fan is manually adjusted. By using the Enhanced Operator panel OPm2, mounted on the cubicle door a simple control solution without additional cabling is achieved. The operator can then adjust the fan speed to suit ventilation requirements simply by pressing the buttons on the panel.

### 7.1.1 Advantages.

- At frequencies below 50Hz there is significant energy saving. Power is proportional to the cube of speed, so a reduction in frequency to 45Hz will result in a saving of about 30%. Mechanical systems offer little or no saving.
- Acoustic noise is reduced when the fan is run below base speed.
- The complete assembly can offer IP54 protection when the MIDIMASTER is mounted in a suitable cubicle.
- The Enhanced Operating Panel (OPm2) offers a simple control solution; panel labelling, additional switches etc. are not needed.
- Closed loop control can be easily enabled using on board PID controller.

### 7.1.2 Application Details



#### System Specifications:

Motor	18.5kW 400V 3 phase induction motor
Control System	Clear Text Display unit
Drive	MIDIMASTER Vector 6SE32 15/18.5kW 400V
Drive Control Interface	Keypad control with start, stop and motorised potentiometer (reverse and jog functions disabled).

### 7.1.3 Key Parameter Details:

Number	Value	Meaning
P006	2	Motorised potentiometer enabled. This allows the push

		buttons on the OPm2 to be used to control the speed.
P009	3	Allows all parameters to be adjusted and set.
P011	1	Motorised potentiometer settings stored on power down. The inverter will restart at the previous selected frequency.
P016	3	Flying Start in forward direction enabled. This ensures that if the fan is rotating the inverter will sense it's speed and ramp back to the desired speed.
P077	2	Quadratic V/F curve selected. Selecting the quadratic curve allows a higher continuous output, but limits the overload capability, which is not needed in this case. The quadratic curve also reduces the power consumption because it is optimised for fan and pump applications.
P122	0	Reverse Key disabled. Reverse function is not needed.
P123	0	Jog Key disabled
P125	0	Reverse direction disabled

Note that the default settings of minimum and maximum speeds (0 - 50Hz) are used in this case.

All required information such as speed, current and drive status is on the display.

If resonance is experienced in the system these can be suppressed by using the skip frequency bands P014, P027, P028 and P029.

## **7.2 A Closed Loop Controller using a Fan.**

The application uses a 75/90kW MIDIMASTER driving a 90kW motor which operates the main extractor fan in a chemical plant. The extractor maintains a constant flow rate by measuring flow downstream of a burner system. The MIDIMASTER is installed in a cubicle close to the fan system, and a simple run/stop signal used for control.

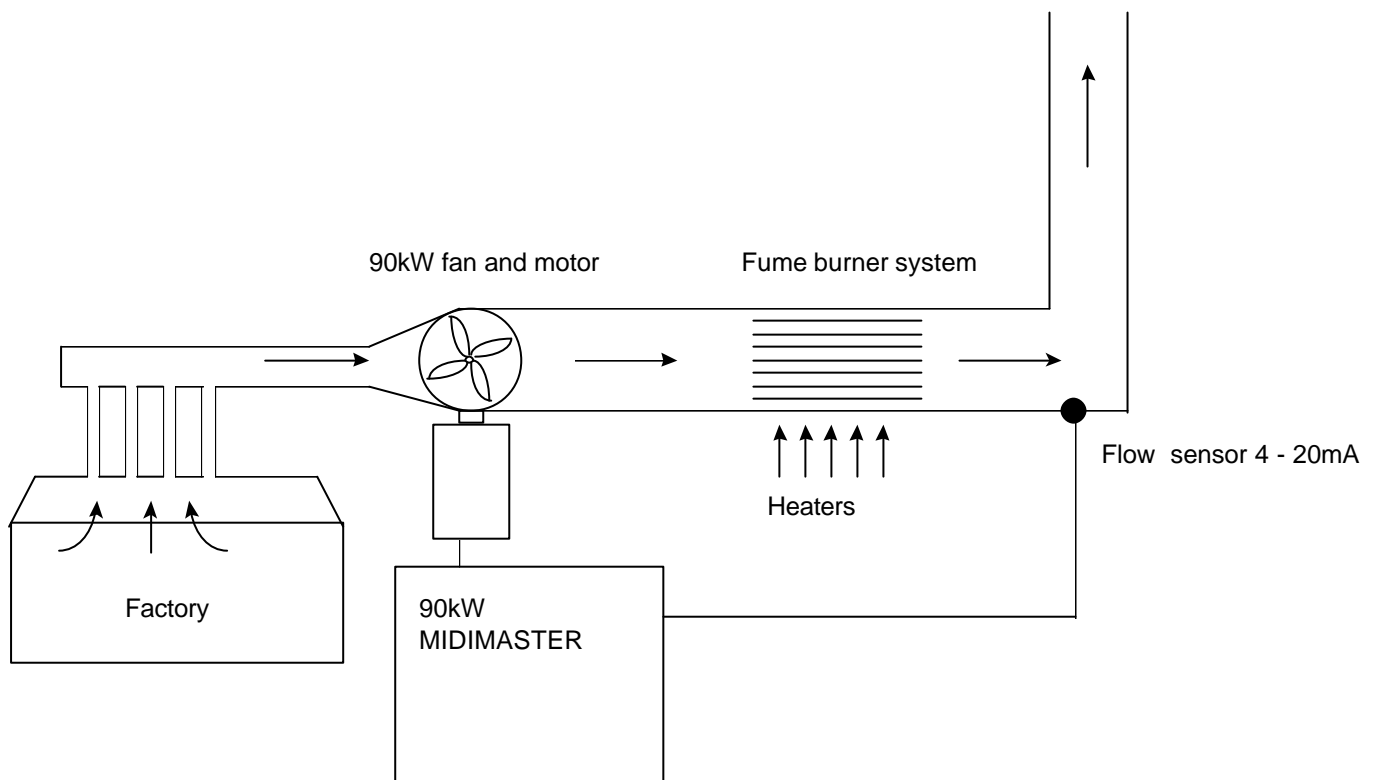
### **7.2.1 Advantages**

- Very significant energy savings compared with fixed speed running.
- Improved process control - in this case, reduced pollution as burner operates at maximum efficiency.

- Built in PID means no additional controllers etc.
- No manual adjustment needed; simple run/stop commands

### 7.2.2 System Specifications:

Motor	4 pole 90kW 420V 3 phase induction motor
Control System	Closed loop PID system
Sensor	4 -20mA flow rate sensor
Drive	MIDIMASTER Vector 6SE32 75/90kW 400V



Extractor System using Closed Loop Flow Control

### 7.2.3 Key Parameter Details:

Number	Value	Meaning
P006	0	Digital set point preset in MIDIMASTER. Manual adjustment not normally required.
P007	0	Control via input terminals; front panel disabled.

P009	3	Allows all parameters to be adjusted and set.
P012	10	Minimum fan speed
P013	30	Maximum fan speed
P025	100	Analog output 4 - 20mA indicating output frequency. This signal is used as part of the overall factory management system.
P077	2	Quadratic V/F curve selected. Selecting the quadratic curve allows a higher continuous output, but limits the overload capability, which is not needed in this case. The quadratic curve also reduces the power consumption because it is optimised for fan and pump applications.
P080-85	***	Settings to suit motor
P089	0.06	Stator resistance - large motor, low resistance.
P201	1	PID enabled. The following parameters give the best overall stability in this particular application.
P202	0.3	P Gain
P203	0.06	I Gain
P204	0	D Gain
P205	1	Sample Interval
P206	0	Sensor Filtering
P207	100	Integral capture range
P208	1	Sensor type
P211	25	0% set point
P212	80	100% set point
P220	1	Switch off at minimum frequency
P323	1	PID (analog input 2) 4 -20mA to suit flow transducer



### **7.3 Controlling Lift Door Operation.**

Lift doors need to close at varying speeds; starting slowly, accelerating fast, and slowing again as they approach closure. In this case, the doors are held closed by the motor running at low frequency at zero speed. The load can vary considerably due to mechanical changes as the lift moves, and variations in door weight as external doors are operated as well. A very good result has been obtained using micro switches to select the various speeds.

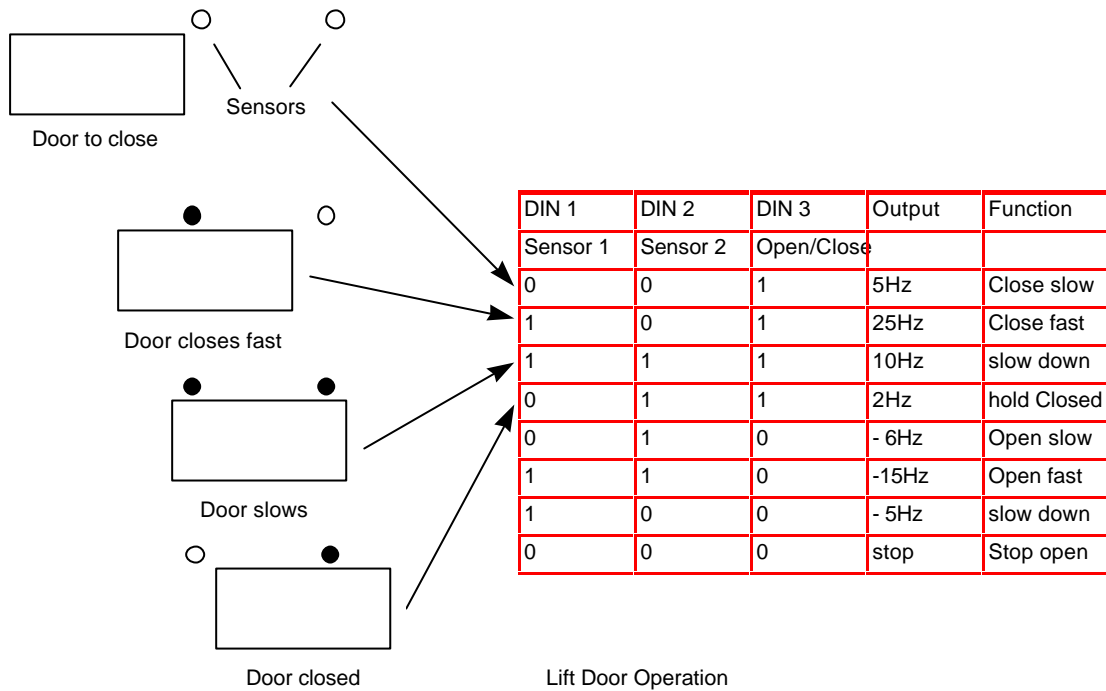
#### **7.3.1 Advantages**

- Very simple system provides the desired speed profile. Doors operate smoothly and silently.
- Torque at zero speed holds doors closed.
- Speed profile can be easily adjusted.

#### **7.3.2 System Specification**

Motor	4 pole 80W 230V 3 phase induction motor. Oversize with no external cooling fan - allowing zero speed operation
Control System	Two Microswitches selecting fixed frequencies; open/close signal on third digital input
Drive	MICROMASTER 6SE92 750W 230V

Note : The following diagrams and tables refer to Settings and parameters used on MICROMASTER; settings for MICROMASTER Vector may be different.



### 7.3.3 Key Parameter Details:

Note that careful selection of the inputs is needed to ensure the correct combination of forward and reverse frequencies is possible.

Number	Value	Meaning
P006	2	Fixed Frequencies selected
P007	0	Control via input terminals; front panel disabled.
P009	3	Allows all parameters to be adjusted and set.
P041	- 5	Fixed Frequency 1. Setting the following parameters allows the complex selection of fixed frequencies, forward and reverse, to be selected using only the two microswitch inputs and the open/close signal. Picking the correct combination of forward and reverse is a little complex.
P042	-6	Fixed Frequency 2
P043	- 15	Fixed Frequency 3
P044	5	Fixed Frequency 4
P045	6	Fixed frequencies 1,2 and 3 reverse.
P046	+25	Fixed Frequency 5

P047	+2	Fixed Frequency 6
P048	+10	Fixed Frequency 7
P050	0	Fixed frequencies 5,6,7 forward
P053-5	17	Binary selection of fixed frequencies
P080-85	***	Settings to suit motor

## **7.4 A Lift system for Industrial Applications**

A lift system incorporating a SIMATIC controller and a MICROMASTER Vector operates a simple lift system. A braking resistor is included to provide regenerative braking to the system. The motor drives the lift and counter weight through a reduction Gearbox.

### **7.4.1 Advantages**

- MICROMASTER Vector performance ensures excellent torque at low speed, good transient load response, and speed holding independent of load.
- MICROMASTER Vector offers 200% overload for up to three seconds - essential for smooth starting and acceleration.
- Ramp smoothing for controlled acceleration and deceleration.
- Built in Braking resistor control; low cost external braking resistor.
- DC braking can be controlled by external digital input allowing precise control of braking and holding before mechanical brake is applied.
- The Mechanical brake can be controlled using the built in relay on the MICROMASTER.

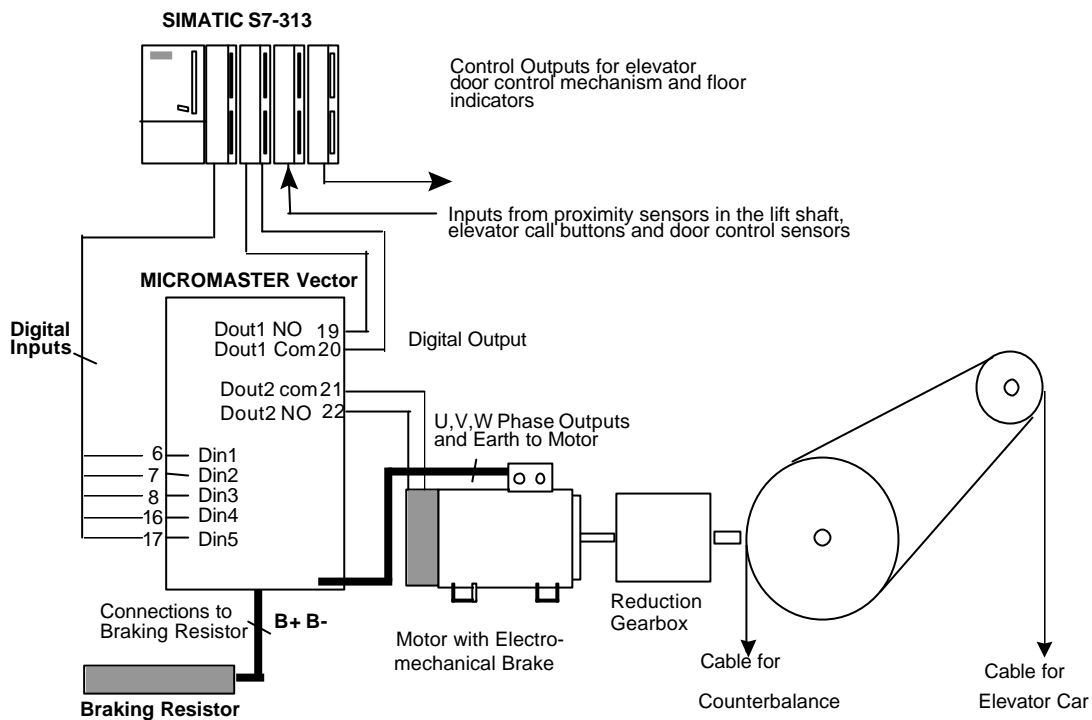
### **7.4.2 System Specifications.**

Motor: 7.5kW 400V 3 phase induction motor with electromechanical brake.

Control System: SIMATIC S7-313 PLC, with I/O Modules, 64 digital inputs, 32 digital outputs

Drive: MICROMASTER Vector 6SE32 7.5kW 400V

Drive Control Interface: Digital input control with Run Right, Run Left, 2 fixed frequencies, DC Brake Enable.



A simple Lift Controller

In the example shown, a MICROMASTER Vector is used in a small (3 floor) lift system. A braking resistor is used to enhance the stopping performance of the elevator system. There are 2 fixed frequencies, 15Hz equating to 1m/s and 3.5Hz for when the lift is approaching a stop. The ramp times are 3 seconds with 0.7 seconds of ramp smoothing. Control is over the digital inputs which are used to select run direction (Din1, Din2), fixed frequency (Din4, Din5) and in this case, DC injection brake enable (Din3). One output relay is used for operating the motor brake, the other is configured to report faults to the lift controller. After releasing the motor brake, the DC brake is released and the lift is accelerated along the shaft, reaching its 15Hz operating speed. There are proximity sensors in the lift shaft which are connected to the PLC and which inform the system that the elevator car is approaching a floor and that it should slow down and then stop. When the car passes the first proximity sensor, the lift is decelerated to its lower speed. When the second is passed, the lift stops and the motor brake is reapplied.

A SIMATIC S7-313 was selected as a controller with the performance and expansion capability to handle all the I/O from proximity sensors, request switches in the lift and floors, indicators, etc.

The motor brake should be fitted with a suitable suppressor, or the brake controlled via a contactor, in which case both should be suppressed.

### 7.4.3 Key parameter settings

Number	Value	Meaning
P002	3	Ramp up
P003	3	Ramp down
P004	0.7	Ramp smoothing
P006	2	Fixed frequency operation
P007	0	Control via input terminals; front panel disabled.
P009	3	Allows all parameters to be adjusted and set.
P012	2	Minimum Output Frequency
P041	15	Fixed Frequency 1 via DIN 5
P042	3.5	Fixed Frequency 2 via DIN 4
P051	1	Run right via DIN 1
P052	2	Run left via DIN 2
P053	15	D C Braking Enable via DIN 3
P054	6	Fixed Frequency 2 via DIN 4
P055	6	Fixed Frequency 1 via DIN 5
P061	4	Output Relay 1 - Operate External Brake
P062	6	Output Relay 2 -- Fault indication
P063	0.5	Brake applied for 0.5 sec before starting
P064	1.0	Brake applied for 1.0 sec before stopping. These delays ensure the motor is fully controlled and generating torque before the brake is released or re-applied.
P070	3	Braking Resistor Duty Cycle 50% (to suit resistor). With a large resistor it is possible to operate with a high duty cycle. However, if a small resistor is used care must be taken when setting this parameter.
P075	1	Braking resistor enabled.
P077	3	Sensorless vector control mode. In order to get the

		necessary control for low speed sensorless Vector Control is essential in this application.
P080-85	***	Settings to suit motor

## **7.5 A Conveyor Application using several MICROMASTERS**

MICROMASTERS are used to control short conveyers. Each conveyer is used as a holding point while products are sorted; they products are moved forward by rapid acceleration of the conveyers under computer control.

### 7.5.1 Advantages

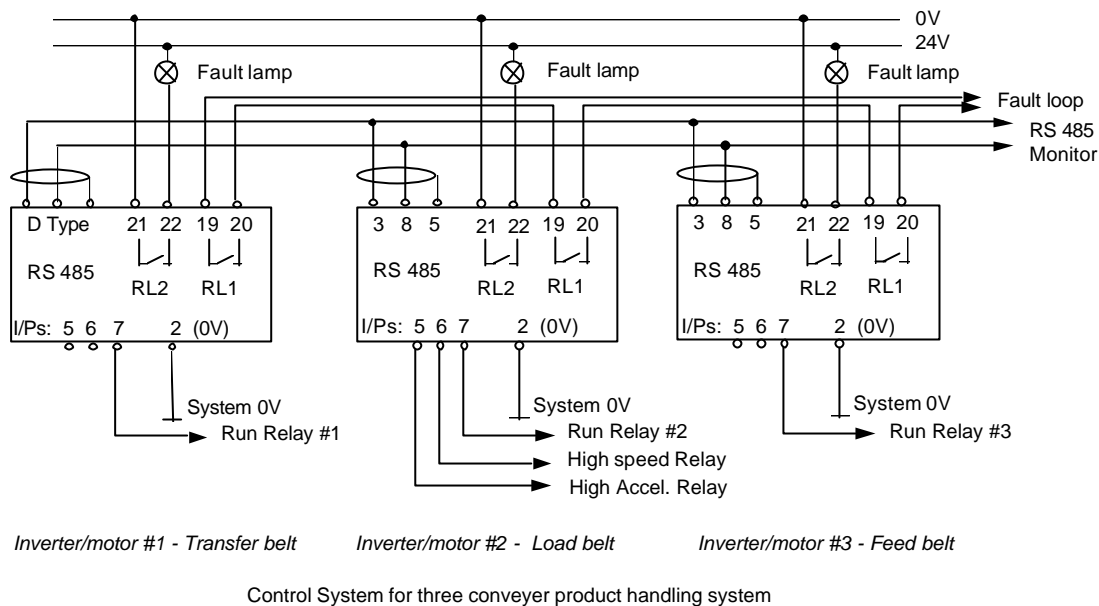
- Controlled acceleration rates ensure product is moved as fast as possible without damage.
- No direct on line switching of motor; no shock loading or current inrush.
- Drive status and parameters can be continuously monitored via serial link.
- Settings can be changed via serial link.
- Small size allows drive and control system to be mounted under conveyer and close to motor.

### 7.5.2 System Specifications.

Motor: 750W 400V 3 phase induction motor.  
Control System: Custom computer system communicating with central controller.  
Drive: MICROMASTER Vector 6SE32 750W 400V  
Drive Control Interface: Digital input control with 1 or 2 fixed frequencies, alternative ramp rate selection, output relays.

### 7.5.3 Application Details

Up to five inverters and motors are used in conjunction with five conveyers and a local computer controller. Three are shown below. The computer is used to set the parameters and to monitor drive operation. Actual control and fault monitoring is via the digital inputs and relay outputs.



#### 7.5.4 Key Parameter Settings.

Number	Value	Meaning
P002	0.6	Ramp up
P003	0.6	Ramp down. Fast ramping possible with these settings
P006	002	Fixed frequency operation
P007	000	Control via input terminals; front panel disabled.
P009	003	Allows all parameters to be adjusted and set.
P013	110	Maximum Output Frequency. High speed operation possible in certain circumstances.
P033	0.3	Jog (alternative) ramp up rate
P034	0.3	Jog (alternative) ramp down rate
P044	40	Fixed frequency 4
P046	45	Fixed frequency 5
P051	18	Run at fixed frequency 5
P052	18	Run at fixed frequency 4
P053	16	Use jog ramp times

P062	6	Output Relay 2 -- Fault indication
P077	3	Sensorless vector control mode
P080-85	***	Settings to suit motor
P910	4	Local control, but read and write to Parameters

By setting P051 and P052 to 18, the drive starts and runs to the selected frequency.

## **7.6 A Material Handling Application**

Several MICROMASTERS are used to handle sheets of large, fragile pieces of material. The system is controlled by a Programmable Logic Controller (PLC) using the digital and analogue inputs. Relays are used to monitor the inverter state and to control the DC Brake.

### **7.6.1 Advantages**

- Electromechanical brake controlled directly from inverter with fail safe control.
- Analog and digital outputs from PLC easy to set up and monitor.
- PTC input can be used to monitor motor temperature and prevent motor damage; in this case a over temperature switch detects the overheating rather than a PTC.
- Boost during ramp up ensures good torque at low speed.
- Smooth operation with controlled ramp rates ensures material is not damaged during handling.

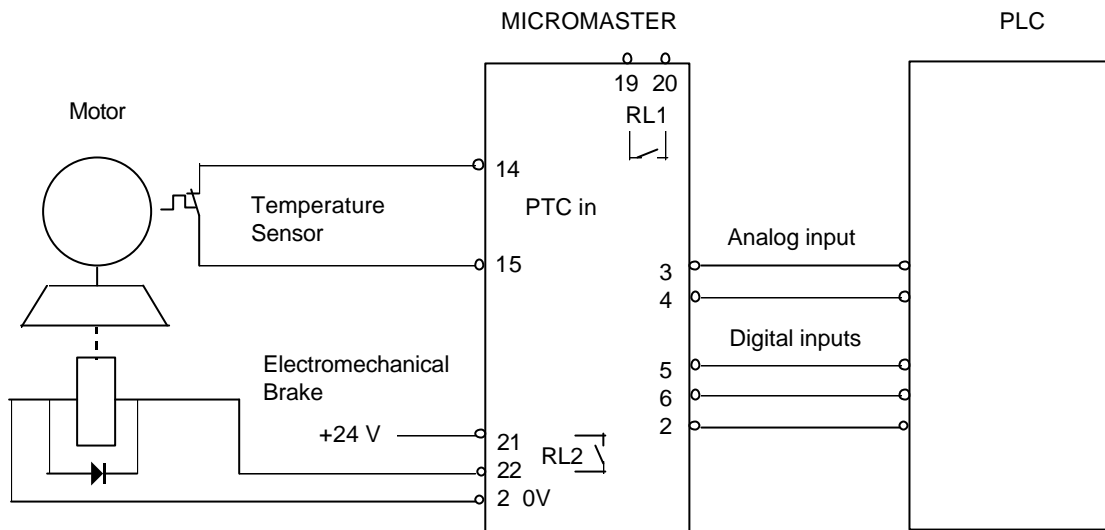
### **7.6.2 System Specifications.**

Motor: 550W 230V 3 phase induction motor.  
Control System: PLC.  
Drive: MICROMASTER Vector 6SE32 550W 230V  
Drive Control Interface: Analog input control, fault indication via output relays, brake control, Motor temperature protection

### **7.6.3 Application Details**



Each machine is controlled by a PLC which controls the inverter via an Analog input and digital controls.



Control connections for Material Handling System

#### 7.6.4 Key Parameter settings

Number	Value	Meaning
P002	0.3	Ramp up
P003	0.3	Ramp down
P006	001	Analog input frequency control.
P007	000	Control via input terminals; front panel disabled.
P009	003	Allows all parameters to be adjusted and set.
P013	100	Maximum Output Frequency. This wide speed range is possible because torque requirements are not excessive at high speed.
P022	100	Maximum Analog Frequency.
P051	2	Run left
P052	1	Run right
P061	6	Output Relay 1 Fault indication
P062	4	Output Relay 2 Brake control. Here the brake control

		operates immediately as P063 and P064 are set to 0.
P063	0	Brake release time
P064	0	Brake stop time
P078	0	Continuous boost. In this application starting boost (P079) proved more useful than continuous boost.
P079	100	Starting boost
P080-85	***	Settings to suit motor
P087	1	PTC Enabled. The temperature sensing switch uses this input.

## **7.7 An Industrial Washing Machine**

A MICROMASTER is used to control the main drum motor on a large industrial washing machine. A wide speed range allows control at wash and spin speeds.

### **7.7.1 Advantages**

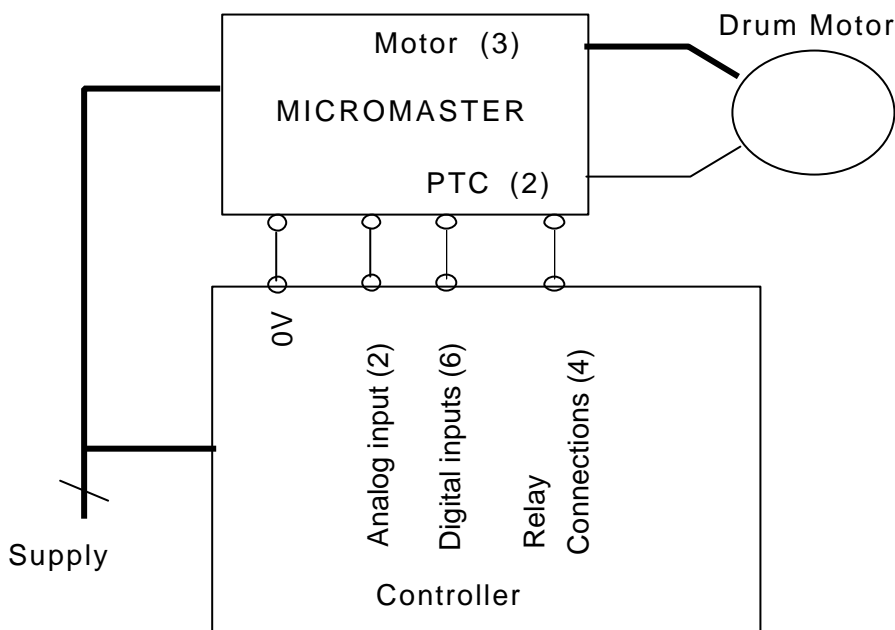
- Vector control at low speed gives excellent performance and consistent speed control during wash cycle.
- selectable Ramp rates allow different ramp rate during spin cycle.
- Built in EMC filter for light industrial applications.
- Shock free starting and running.
- Motor protection using PTC.
- Analog addition used for speed trimming.

### **7.7.2 System Specifications.**

Motor: 750W 230V 3 phase induction motor.  
Control System: Built in Microprocessor control system.  
Drive: MICROMASTER Vector 6SE32 750W 230V  
Drive Control Interface: Analog and digital input controls, fault indication via output relays , Motor temperature protection.

### 7.7.3 Application Details

The washing machine system is controlled by a Microprocessor system that controls and selects the various wash cycles. The control system selects the fixed frequencies of the MICROMASTER using binary coding on the digital inputs. One of the relays is programmed to indicate that the set point is reached, the other used to indicate a fault. A PTC in the motor is connected to the MICROMASTER to protect the motor from overheating. This is a real possibility as the wash cycle operates at low frequency with a high load. During the spin cycle a faster ramp rate is selected via a digital input. Out of balance loads can cause problems at certain speeds, so the analog input is used to trim the speed if excessive vibration is detected.



Washing Machine Drum motor control

### 7.7.4 Key Parameter Settings

Number	Value	Meaning
P002	40.0	Ramp up. Slow ramp rates here because ramp rate is based on the maximum frequency and fast ramping not required.
P003	40.0	Ramp down
P006	002	Fixed frequency control.
P007	000	Control via input terminals; front panel disabled.

P009	003	Allows all parameters to be adjusted and set.
P013	170	Maximum Output Frequency. High for spin operation.
P022	10	Maximum Analogue Frequency. Trim use only.
P024	001	Set point Addition. This allows the analog input to adjust the fixed speed to avoid resonance.
P033	20	Jog (alternative) ramp up rate. These ramp rates are used for spin.
P034	20	Jog (alternative) ramp down rate.
P041	8	Fixed Frequency 1 (Wash 1)
P042	10	Fixed Frequency 2 (Wash 2)
P043	40	Fixed Frequency 3 (Slow Spin)
P044	160	Fixed Frequency 4 (Fast Spin)
P046	15	Fixed Frequency 5 (Sort and Separate)
P051	1	Run right
P052	2	Run left
P053	18	Fixed frequency select (Binary Coded)
P054	18	Fixed frequency select (Binary Coded)
P055	18	Fixed frequency select (Binary Coded)
P356	16	Select Jog Ramp rates
P061	7	Output Relay 1 Set point reached
P062	6	Output Relay 2 Fault indication
P077	3	Sensorless Vector Operation
P080-85	***	Settings to suit motor
P087	1	PTC Enabled

## **7.8 An Exercise Machine Application.**

A running machine uses a variable speed drive to control the running belt speed from a slow walk to a fast run.

### 7.8.1 Advantages

- Sensorless Vector control ensures smooth operation even at low belt speeds with a heavy step.
- Wide speed range makes good use of motor.
- External filter meets domestic and light industrial requirements.
- Automatic motor protection due to continuous current monitoring.

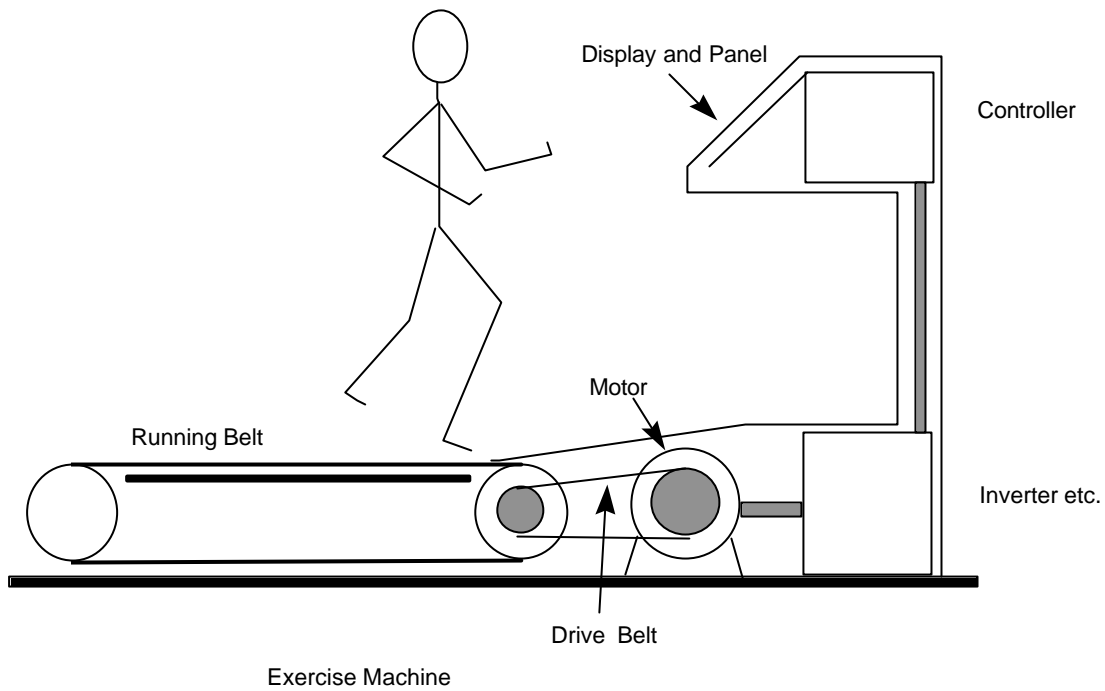
### 7.8.2 System Specifications.

Motor:	2.2kW 230V 3 phase induction motor.
Control System:	Microprocessor control system with display, keypad etc.
Drive:	MICROMASTER Vector 6SE32 2.2kW 230V
Drive Control Interface:	Analogue and digital input controls, fault indication via output relays.

### 7.8.3 Application Details

A 2.2kW motor drives a pulley and flywheel system via a toothed belt. The motor is controlled by a 2.2kW inverter with an external input filter to reduce EMI. The inverter is connected to the main controller via an analogue frequency control and digital inputs. The digital inputs are used to run, stop and reset invert faults.

*The  $I^2t$  is enabled in order to protect the motor. Continuous high load operation is unlikely, but the inverter will trip if the motor is in danger of overheating. This is acceptable in this application. The fault relay is used to alert the user of this condition.*



#### 7.8.4 Key Parameter Settings:

Number	Value	Meaning
P006	001	Analogue frequency control.
P007	000	Control via input terminals; front panel disabled.
P009	003	Allows all parameters to be adjusted and set.
P012	3	Minimum Output Frequency
P013	83	Maximum Output Frequency
P022	83	Maximum Analogue Frequency
P051	1	Run right
P052	10	Reset Fault
P061	6	Output Relay 1 Fault indication
P062	8	Output Relay 2 Warning indication
P074	5	i <sup>2</sup> t Enabled Inverter trips.
P077	3	Sensorless Vector Operation

P080-85	***	Settings to suit motor
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## **8. Advanced Applications Information**

### **8.1 Using Closed Loop Control**

#### **8.1.1 What is Closed Loop control?**

Closed loop control is widely used in industrial applications to control a wide variety of processes. Control engineering is a complex subject, but a simple closed loop control uses a feedback signal from the process (such as temperature, pressure, speed) a desired value from a set point (often set manually) and a control system that compares the two and derives an error signal. The error signal is then processed and used to control the inverter and motor (in this case) to try to reduce the error.

The error signal processing can be very complex because of delays in the system. The signal is usually processed using a Proportional, Integral and Differential (PID) calculator, and these parameters can be adjusted to optimise the performance and stability of the system. Once a system is set up and stable very efficient and accurate control can be achieved.

#### **8.1.2 Closed Loop Control using MICROMASTER.**

A standard PID control loop function has been incorporated in the MICROMASTER, requiring only the connection of a suitable feedback transducer, and configuration of parameters P201-P212.

The control loop is not suitable for fast response control systems, but is ideal where the controlled variable changes very slowly, or where transient errors are not critical (for example temperature or pressure control).

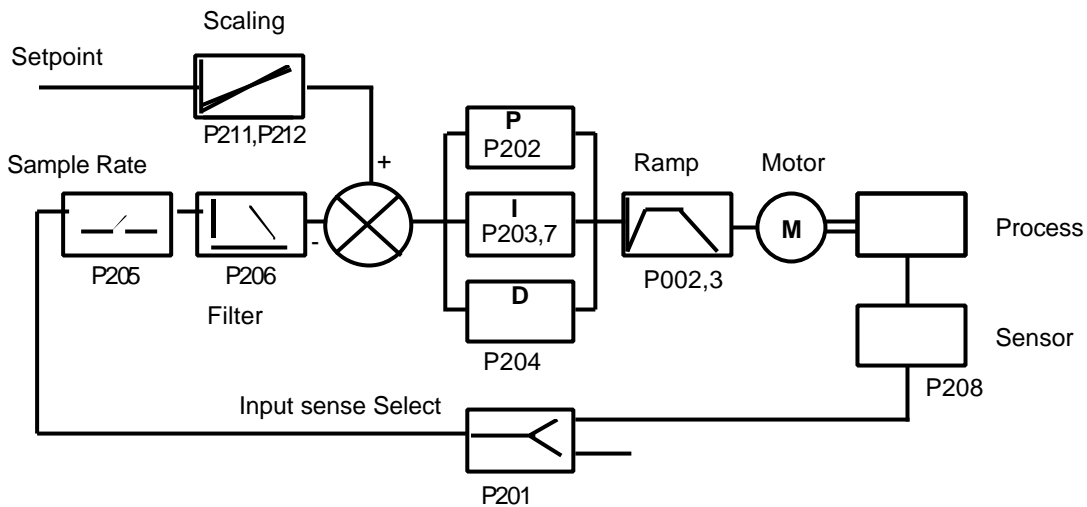
Note that the system is not intended specifically for speed control but can be used in this way, provided fast response is not required.

When closed loop control is enabled (P201=1) all set points are from 0 to 100% (Set point of 50.0 means 50%). This allows general purpose control of any process actuated by motor speed and for which a suitable feedback transducer is available.

Setpoints may be given either via the analogue input or digital inputs. In each case the setpoint given is a percentage of the feedback transducer full scale value.

e.g. transducer capable of 0-250 mbar

250 mbar = 100%, 20 mA  
 0 mbar = 0%, 4 mA



### Feedback Connections

The external feedback signal will normally be connected to the dedicated input on terminals 10 and 11.

This input accepts a 0-10V (0(/4) to 20mA selected by DIP selector switches) feedback signal and has 10 bit resolution.

On standard MICROMASTER (e.g. non Vector units) it is possible to connect the feedback signal to X501 terminals 3 and 4 (P201 = 2). If this option is used, then all 'analogue' options of P006, P023 and P024 become invalid and should not be used.

### Setting Up

See parameter list P201 to P212 for description of the parameters for setting up the PID system. In addition P000, P010, and P220 provide functions useful in closed loop applications.

### Typical Procedure:

Remember that once you have enabled Closed Loop Operation values such as the setpoint are now displayed in percent of full scale.

- If possible run the drive open loop first, to check, in particular, the sensor feedback voltage or current.
- Check P208 value for the correct 'sense' operation. Set P208 according to the sensor/actuator types; if the feedback signal reduces as the motor speed increases, select P208=1. Otherwise, use P208=0.
- Set P206 to zero; this display should not flicker too much. Slow response systems benefit from a longer time interval between feedback signal readings if D-gain is applied. This interval can be adjusted in steps of 25 msec up to 1 minute via P205.
- Start with the PID gains still on their factory settings - P gain =1, no integral or differential action.



- Set P001 to 7 to display %. Enable the closed loop operation by setting P201.
- Select fast ramp up and down times (P002, P003), as otherwise these will limit closed loop performance. Try 1 second.  
Check P210 to confirm the feedback value is within reasonable scaling limits. Use P211 and P212 to set the scaling. Note that offsets can be accommodated using P211 (e.g. feedback is 4-20mA for 0 - 100% setpoint variation; P211= 20(%), P212 = 100(%) i.e of 20mA. If no sensible values appear in P210, try reversing the feedback signal connections, and repeating the above process.

Further detail is shown in the following example:

Consider an application using a temperature sensor. Sensor output is 0-10 V from 30 °C - 150 ° C, i.e. a 120 °C range. We want to control the temperature in the range 50 °C to 80 °C . This means that 50 °C is setpoint 0%, and 80 °C is setpoint 100%.

Now P211 is calculated

$$\frac{(50-30)}{(150-30)} = 16,6\% \quad \frac{(\text{Min.} - \text{Sensor Min.})}{\text{Sensor Range}}$$

P212 is calculated

$$\frac{(80-30)}{(150-30)} = 41,6\% \quad \frac{(\text{Max.} - \text{Sensor Min.})}{\text{Sensor Range}}$$

The process is to run at say 70 °C.

The setpoint which is a percentage of the difference between P211 and P212. So:

$$\frac{(70^{\circ} - 50^{\circ})}{(150^{\circ} - 30^{\circ})} = \frac{(20)}{(30)} = 66\%.$$

To use an analogue 0-10V setpoint, and an input of 6.6 Volts, and with a digital setpoint a value of 66% would be loaded (not a frequency or temperature).

- Increase the Pgain (P202) until the system starts to oscillate, possibly looking at the value in P210 if the physical effects are not obvious. Reduce the value of P202 to 35% of that where oscillation started.
- Increase the integral gain P203 until the system oscillates again. Reduce the value to 50% of that where oscillation started. This quick setting method will give good results in most applications. Often D gain is not required; it may be used in applications where setting the P and I gains does not give a stable response in all situations. More precise setting methods would normally involve using an oscilloscope to look at the sensor signal response to step changes in the setpoint.
- Use the Integral Capture Range P207 so that during ramping to set point the error does not build up and cause instability. If excessive overshoot occurs

from STOP to RUN 100% (during ramping to set point), try using  $P207 = 5 + 100/P202$ .

This parameter is intended to reduce the effects of integral saturation by disabling the integral gain until the feedback/setpoint difference is less than P207 percent. Setting P207=100 effectively disables this feature, whilst reducing it decreases the period over which the integral gain is active.

- Note that systems such as fan cooling may require the motor to be 'off' most of the time. Set P220=1 in such cases to avoid excessive DC current heating of the motor.

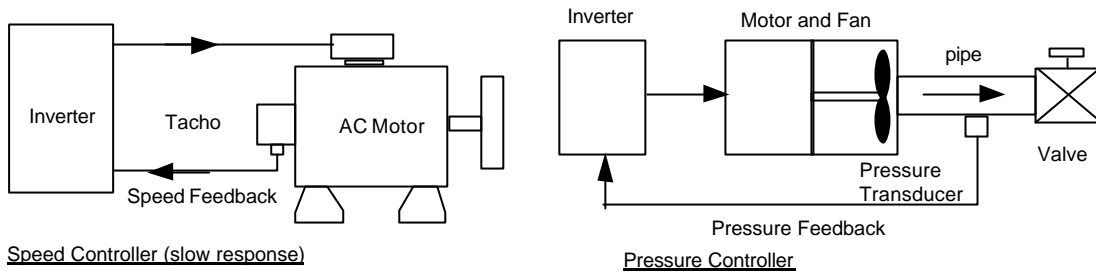
### Closed Loop Parameters

P201	Closed loop mode	0-2 [0]	0 = Normal operation. (PID disabled) 1= Closed loop control (MMV,MDV) 2= Closed loop control using analog input (MM)	Examples ( see below) 1,1
P202	P gain	0.0-999.9 [1.0]	Proportional gain	20,0.2
P203	I gain	0.00-99.99 [0.00]	Integral gain - 0.00 corresponds to the longest integral action time, 99.99 to the shortest time.	0.2,0.05
P204	D gain	0.0-999.9 [0.0]	Derivative gain; with this set at 0.0 there is no derivative action.	0,0
P205	Sample interval	1-2400 [1]	Sampling interval of feedback sensor in multiples of 25 ms	1,1
P206	Sensor filtering	0-255 [0]	0 = Filter off 1-255 = Low pass filtering applied to sensor	5,0
P207	Integral capture range	0-100 [100]	Percentage error above which integral term is reset to zero	5,100
P208	Sensor type	0-1 [0]	0 = in open loop operation, an increase in motor speed would lead to an increase in sensor voltage (or current) 1 = in open loop operation, an increase in motor speed leads to a decrease in sensor voltage (or current)	0,0
P210	Sensor reading	0.00-100.00 [-]	Read only. Value is percentage full scale of selected input (5V, 10V or 20mA)	(40),(20)
P211	0% set point	0.00-100.00 [0.00]	Value of P210 to be maintained for 0% set point	0,20
P212	100% set point	0.00-100.00 [100.00]	Value of P210 to be maintained for 100% set point	80,100
P220	Minimum	0-1	0 = Normal operation	0,0

	frequency mode	[0]	1 = Switch off motor voltage at or below minimum frequency	
--	----------------	-----	--	--

## Examples

Two example values are shown in the above table. The first set of values were used with a DC tacho system on a 7.5kW MIDImaster. The second set of values were used with a Flow/pressure transducer (output 1 -5 V hence P211= 20% to allow for offset), fitted to a 0.4kW motor and blower pump.



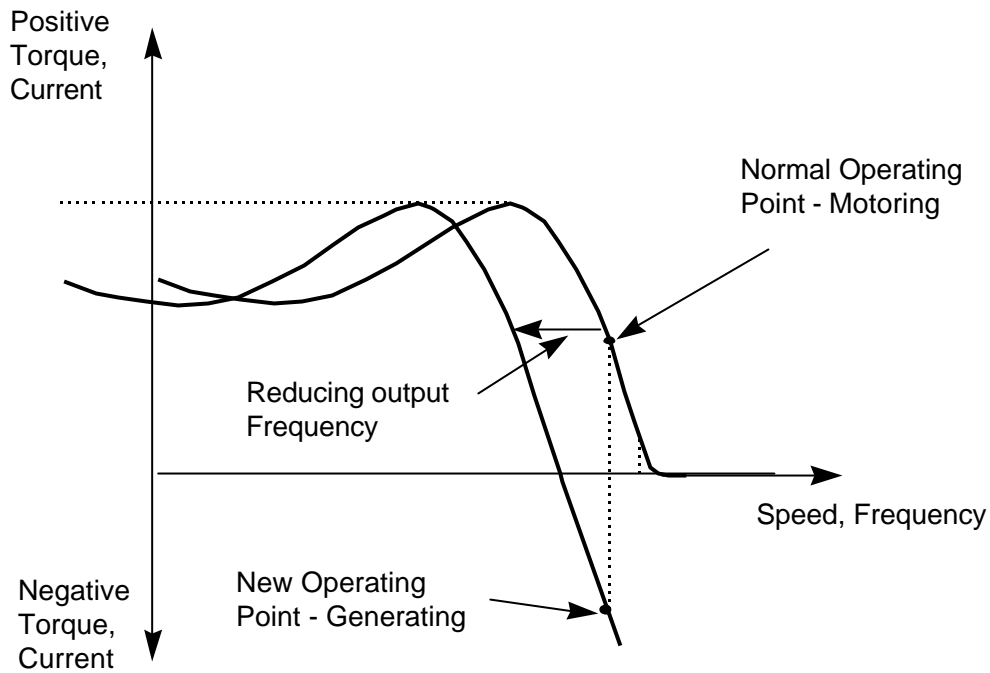
## Closed loop control values in other Parameters

P001	*	Display selection	0-7 [0]	7 = Closed loop display mode
P061		Selection relay output RL1	0-13 [6]	12 = Closed loop motor LOW speed limit i.e output freq < or = P012, relay active 13 = Closed loop motor HIGH speed limit i.e output freq > or = P013, relay active This function could be used for starting and stopping a fixed speed motor operating in parallel with the inverter driven motor.
P062		Selection relay output RL2	0-13 [8]	as above

## 8.2 Braking and Slowing down using Inverters.

### 8.2.1 What happens when a motor is stopped?

When the output frequency of the inverter is reduced, the motor will slow down. If the output frequency of the inverter falls rapidly, the motor may no longer 'motor', but may act as a generator.



If the motor and load have a high inertia, the motor will take longer to slow down so generation is more likely to occur. The generated energy returns to the inverter (i.e regenerates) as a negative current. This is known as regeneration. The current is returned to the DC link, but cannot return to the supply because of the blocking action of the input rectifier. Therefore the current charges the DC link capacitors and if the DC link voltage becomes too high the inverter will protect itself from overvoltage by tripping. If the inverter trips there is no more motor flux, so it no longer regenerates and comes to an uncontrolled stop. However, there are several possibilities to control braking and stopping using an inverter.

### 8.2.2 Braking and Stopping with an Inverter.

#### Ramping Down and Braking.

As stated above, if the inverter reduces the output frequency (i.e. Ramps down) the motor and load will slow down. If the load and motor inertia is high, regeneration will occur. In many cases there is insufficient regeneration to cause excessive voltage; in fact very fast ramp down rates can often be used in certain processes without problems. In many cases the energy is absorbed by other losses, such as gearbox or rolling friction. The ramp down time, controlled by the inverter allows predictable deceleration and stopping times.

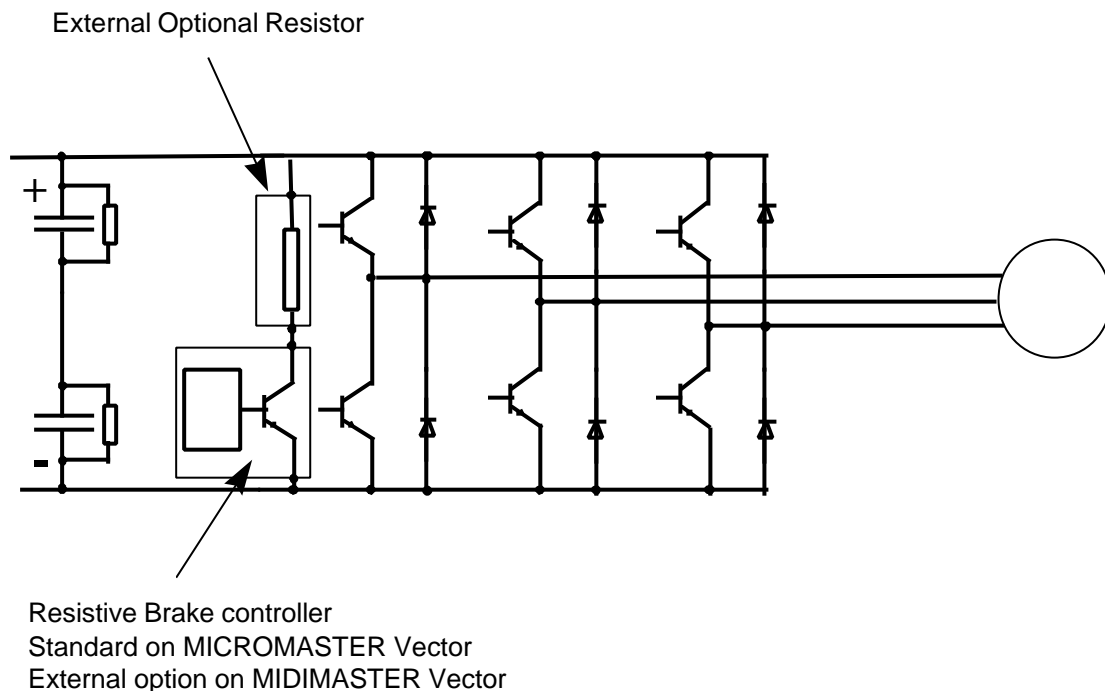
Where regeneration does cause trips, several solutions are possible. An external brake, DC braking or Compound braking may be used. These are described in section 8.2.2.

However, a simple solution is to connect a resistor across the DC link of the inverter to dissipate the regenerated energy.

The MICROMASTER Vector incorporates a controller which switches the resistor on and off to maintain the DC link voltage at a constant level.

The MICROMASTER basic has no controller and the use of an external controller or resistor is not possible.

The MIDIMASTER requires an external controller as well as an additional resistor. This method of braking gives very good control and dissipates the energy efficiently without wearing parts.



*It is sometimes necessary to calculate the resistor power rating based on the braking duty cycle and the amount of energy to be dissipated. Optional braking resistors, designed to operate with the MICROMASTER, will dissipate the full power of the drive on a 5% duty rating. That is, a 750W inverter fitted with a standard resistor will dissipate 750W for (say) 10seconds in 200seconds, or 37W continuous. In order to prevent damage to these resistors the duty cycle of the resistor is limited in software, controlled by parameter P070. Parameter P070 is set to 5% to suit the standard resistor, but can be adjusted if bigger duty cycles are needed and larger resistors used.*

*In practice, because of system losses and short duty cycle, the resistors are usually operated well within their rating.*

### DC Braking.

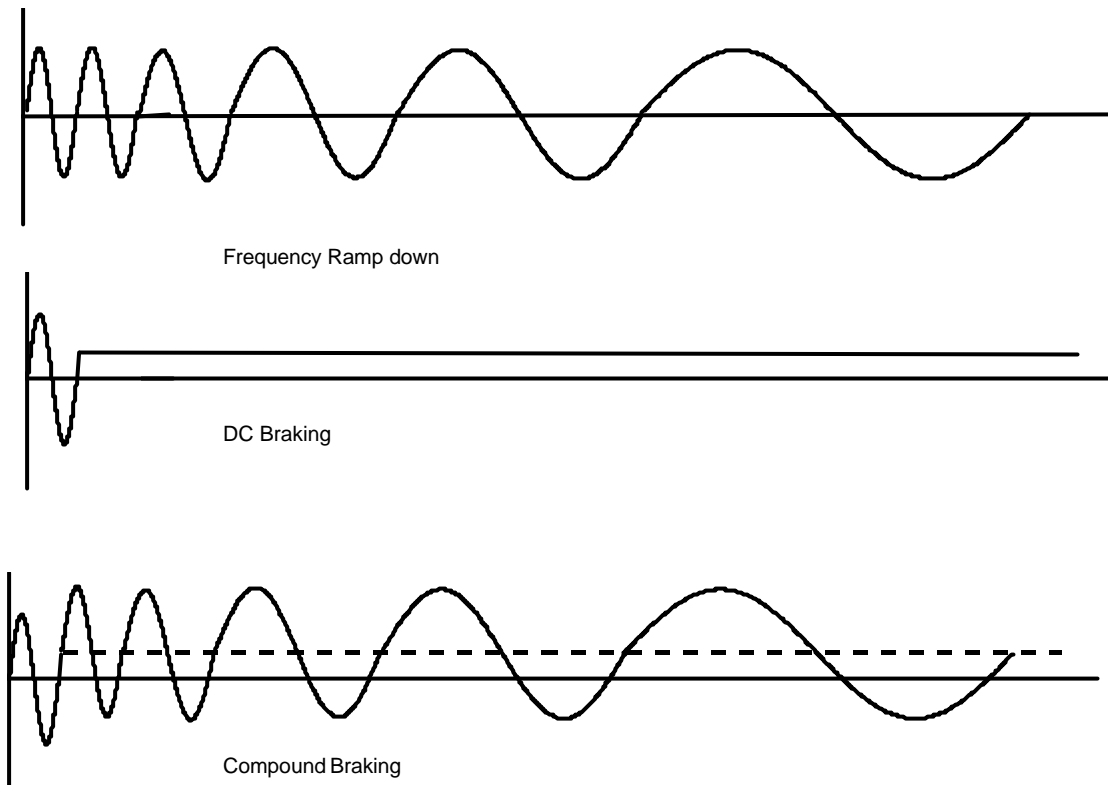
If a controlled DC voltage is applied to the motor, a braking and holding torque is produced in the rotor. During DC braking the stored energy of the motor and load is dissipated in the rotor itself, so there is no regeneration back to the inverter. However, because no frequency is applied, there is no control over motor speed, and it is not possible to predict the stopping time of the motor and load. The torque on the rotor is maintained even at standstill, so DC braking can be used to hold the rotor and load for short periods if required.

*Parameter P073 sets the DC Braking level, and braking will be applied for the ramp down time irrespective of the motor speed. The parameter value corresponds to a percentage of the voltage needed to generate full load current in the motor windings. In practice it is not possible to calculate the braking torque this will produce. Continuous use of the DC braking will cause overheating in the motor and suitable protection systems must be considered. The braking can also be activated by an external switch.*

### Compound Braking

If DC braking and regenerative braking are combined, braking with minimal regeneration but with controlled motor speed is possible. This consists of a reducing frequency with DC component added to it. This braking system, developed by Siemens for the MICROMASTER and MIDIMASTER, is known as Compound braking. Compound braking can prove very effective, combining the best of DC braking and Regenerative braking. As with DC braking, the load energy is dissipated in the motor, and therefore excessive, frequent braking can lead to overheating.

The above braking methods are summarised in the diagram below.



### **8.3 Using the Serial Interface**

All Siemens Drives include a serial interface as standard. The serial interface uses a RS485 two wire connection which is designed for industrial applications.

Up to 30 drives may be connected on a single RS485 link, and drives addressed individually or with a broadcast message. A separate master controller is required, and the drives act as slaves.

A communications protocol known as the USS protocol has been developed by Siemens and is common to all Siemens drive products. It will operate up to 19kbaud and uses telegrams of fixed length, usually 14 bytes. Each inverter can be set up using parameters to receive and respond to USS protocol telegrams.

Using a serial interface has several advantages:

- Wiring can be greatly reduced.
- Control functions can be changed without re-wiring.
- Parameters can be set up and changed via the interface
- Performance can be continuously monitored and controlled.

Details of the serial interface protocol are given in Appendix 1.

## **8.4 Using PROFIBUS**

### **8.4.1 What is PROFIBUS?**

PROFIBUS is an open standard communication protocol which has been designed and developed for use in general industrial applications. The standard is defined in EN50170 (volume 2) and has been developed, agreed and adopted by many manufacturers worldwide.

PROFIBUS control is now available for a wide variety of products, from many different companies such as drives, actuators, valves, as well as programmable logic controllers (PLCs) and other system controllers. PROFIBUS operates over a variety of hardware interconnections such as fibre optics and RS 485.

There are three versions of PROFIBUS: FMS, DP and PA; these versions will work together. The most commonly used version is the DP version, intended for general industrial applications. This is the version supported by Siemens Drives.

### **8.4.2 Using PROFIBUS with Siemens Standard Drives**

In order to connect to a PROFIBUS system a PROFIBUS adapter module is required. This module mounts on the front of the drive in the same way as the OPm2, and uses the RS485 serial port to communicate to the drive.

A nine way 'D type' connector, which is a PROFIBUS standard, is incorporated into the front of the module.

The drive may be controlled and monitored via the main PROFIBUS system in a similar way to the USS. The PROFIBUS protocol is more complex than the USS protocol (in fact, the USS is a simplified version) and control programmes are best developed using proprietary software.

Although a PROFIBUS system is more complex than for instance, the USS Protocol, it offers the following advantages:

- Open, clearly defined system.
- Many different products from many different manufacturers.
- Well proven in many industrial applications.
- Reduced wiring; easy set up re-programming, monitor and control.
- Very fast; up to 12Mbaud..
- Up to 125 slaves on one DP system
- Single or Multi-master operation possible.
- One to one or broadcast communications
- Support and development software available.



## **8.5 Vector and FCC Control**

### **8.5.1 What is a Vector Drive?**

Vector control is a complex mathematical control function that improves the performance of an AC drive. It is necessary to understand conventional Voltage to frequency control and Flux current control in order to understand Vector Control.

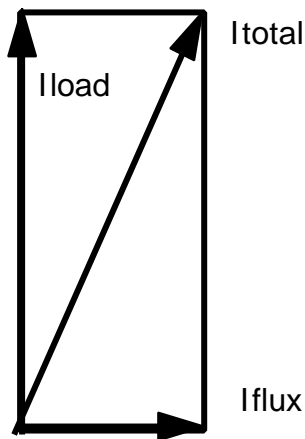
#### **Voltage to Frequency Control**

A simple inverter drive outputs a variable frequency and voltage to the motor, with an additional voltage boost (see section 5.8.9) to overcome losses and non linearity at low frequency. In this case, the voltage rises linearly as the frequency increases, which theoretically maintains the correct flux level in the motor up to the base frequency (P077=0). For pump and fan applications the load is reduced at frequencies below base frequency, so a reduced voltage is acceptable. In these cases a quadratic (pump and fan curve) can be specified (P077=2).

These voltage levels are suitable for many applications. However, for higher performance a better control strategy is needed. In particular, to offer the same capability as a DC drive and motor (fast response, torque control, low speed operation) complex mathematical models of the motor are needed. The processing power to achieve this has only become available recently at low cost. Siemens standard drives have offered different solutions such as Flux Current Control and now offer Sensorless Vector control in MICROMASTER and MIDIMASTER Vector.

### **8.5.2 What is Flux Current Control?**

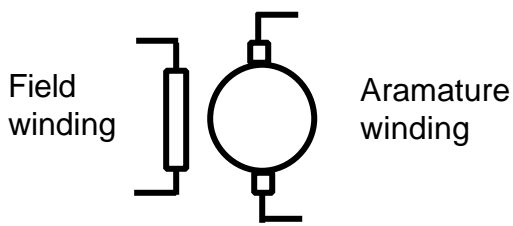
The Siemens Standard Drives have developed an improved current monitoring system which allows accurate measurement of the output current with reference to the motor voltage. This enables the monitoring system to separate the total output current into the real (load) and imaginary (flux) part.



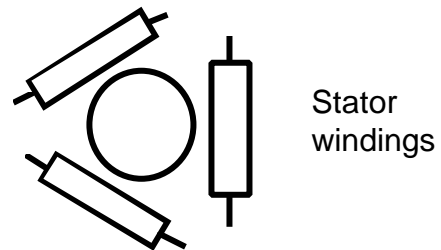
The flux part can then be controlled, and therefore the flux on the motor optimised for all conditions. This is flux current control (FCC;  $P077=1$ ). It has proved very successful in a wide variety of applications. It offers improved motor efficiency and better torque and transient response compared to standard Voltage to frequency operation. It is not as effective as full vector control or sensorless vector control.

### 8.5.3 Vector Control

Vector control is best understood by considering the operation of a DC machine. A DC machine consists of a field winding and armature winding. Therefore the armature Current (Torque) and field current (Flux) can be controlled independently. Independent control of the Flux and Torque producing currents permits optimum performance - Torque at zero speed, rapid response to load changes etc.

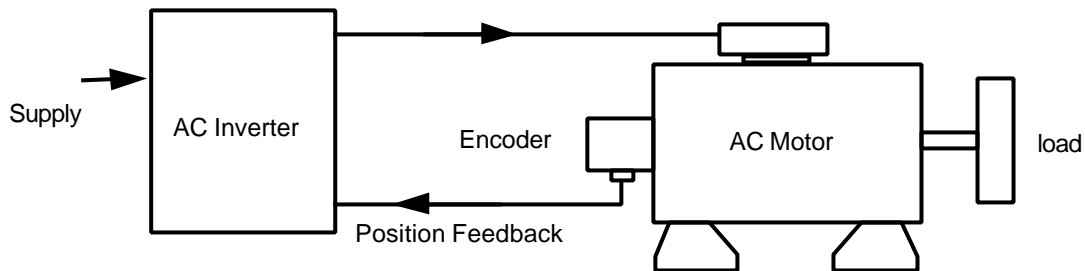


DC Machine



AC Machine

In an AC Machine, the stator winding currents set the Flux and the Torque; therefore it is difficult to control the torque and flux separately. Hence it is necessary to control the magnitude and phase - *the Vector* - of the current. To control the phase with reference to the rotor, the rotor position must be known. Hence for full vector control, an encoder **must** be used to tell the inverter the rotor position.



With the above arrangement, it is possible to achieve performance equal to that of a DC Machine provided the full parameters of the motor are known and the inverter is able to model its performance.

However, most AC motors are not fitted with encoders, and the additional cost and complexity is an unnecessary expense.

Recent developments in motor control and modelling have allowed sensorless (that is without encoder feedback) vector operation to be possible. Sensorless Vector Control (P077=3) predicts the rotor position by mathematically modelling the motor. To do this the inverter must:

- Monitor the output voltage and current very accurately.
- Know the motor parameters (Rotor, Stator resistance, leakage reactance etc.)
- Know the motor history; that is, the previous load etc. in order to predict the motor temperature.
- Be able to calculate very rapidly.

At low speeds it is *very difficult* to predict the motor performance and hence the rotor position. Siemens standard vector drives use a complex mathematical system, first developed for their engineered drives, which gives very good Sensorless Vector performance.

Flux Current Control and conventional voltage to frequency control is available in addition to Sensorless vector performance.

## **9. Options for Siemens Standard Drives**

### **9.1 Introduction**

Several options are available for use with Siemens Standard drives. These are intended to assist product selection, installation and commissioning in certain applications.

### **9.2 Clear Text Operating Panel OPm2**

The clear text operating panel consists of a control and display unit that fits directly on top of the MICROMASTER or MIDIMASTER Control panel. A D Type socket connects directly onto the D type on the front of the unit, so the OPm2 can take power from and communicate with the drive via the RS485 interface. The OPm2 offers the following features:

- Seven language ( English, German, French, Italian, Spanish, Dutch, Danish) text operation with explanation of parameters, faults etc.
- Diagnostics - help with fault finding.
- Upread/download up to 9 parameter sets from units to OPm and back. This allows fast, reliable programming and copying of parameter sets.
- OPm2 mounts directly on MICROMASTER and MIDIMASTER.
- Door mounting kit with IP54 protection included.
- Built in RS232 to RS485 Converter for simple connection to computer.
- External supply connector for remote operation and off line programming.

The OPm2 has several practical uses; for example:

- The OPm2 may be mounted directly onto the inverter and used to control the drive directly.
- The OPm2 can be mounted on a separate panel (using an optional cable of up to 5m) to enable remote control and monitoring of the drive.
- If an external power supply is connected to the OPm2, remote control over distances greater than 5m is permissible
- The built in RS232 to RS485 connector can be used to allow communication between a PC and the drive.
- Parameter sets can be stored in the OPm2 and uploaded or downloaded as required. This is particularly useful where many inverters require programming in production.

### **9.3 Braking Modules and Braking Resistors.**

During regeneration (see section 8.2.2) it may be necessary to dissipate the energy that is returned to the inverter. MICROMASTER basic units do not have the capability to dissipate regenerated energy.

MICROMASTER Vector units have a built in 'braking chopper' and require only an external resistor to allow controlled dissipation. The resistors can be supplied as optional parts to the inverters, and fit alongside the inverters. They are specially designed to operate with the high voltages present in the DC link, and are of metalclad, IP54 design. Braking resistors for operation with earlier MICROMASTERs were designed to mount underneath the inverters. Other resistors can also be used, but care must be taken to ensure they are of adequate voltage and power rating.

MIDIMASTERs require a External Braking Unit (EBU) and an external resistor. The external braking unit requires connection to the mains supply as well as connection to the DC link of the MIDIMASTER. 240V and 400V versions are available. 575V MIDIMASTERs are operated with MASTERDRIVE braking units. External braking resistors (in this case IP00) may be purchased with the EBU or suitable units selected by the customer.

#### **9.4 RFI Suppression Filters.**

MICROMASTER and MIDIMASTER inverters are designed to minimise conducted and radiated interference. However, they are power electronic products and generate significant levels of interference over a wide electromagnetic spectrum.

In many applications it is possible to operate without filters or with the built in filter. However, in order to achieve higher levels of attenuation an external filter may be required. In particular, in order to meet residential, commercial and light industrial levels, an external filter will be needed.

The purpose of RFI filters is to reduce the conducted levels of interference from the inverter to the supply. It is not intended to reduce radiated interference or attenuate interference into the inverter. It should be fitted to the mains input to the inverter and will be damaged if installed in the inverter output.

The filters are designed to mount underneath the MICROMASTER to minimise space requirements. MIDIMASTERs have external separate filters; units are also available with built in filters. Full installation instructions and information concerning the appropriate filters are given in the handbook.

#### **9.5 PROFIBUS Module.**

Siemens Standard Drives incorporate an RS485 serial interface as standard. In order to operate on a PROFIBUS system a separate conversion module is required. The PROFIBUS module, and the PROFIBUS system is described in section 8.4.2.

#### **9.6 Input and Output Chokes.**

Chokes can be fitted to the input of the inverter to reduce harmonic distortion and to reduce the effect of supply disturbance on the inverter. Chokes are also recommended where supply impedance are less than 1%.

Chokes are fitted to the output of the inverter to allow operation with long cables. The choke compensates for the stray capacitance of the cables. Recommended chokes for different cable lengths and inverters are available.

## **10. APPENDIX 1: Using the USS Protocol**

### **10.1 Introduction**

This document describes how to connect and communicate with the MICROMASTER range of Inverters.

### **10.2 Overview**

The Inverter can be fully controlled via the serial link including on/off, frequency demand, parameterisation, etc.

Up to 30 MICROMASTERS may be connected together on the serial link. These can then be controlled from a Master device such as a PC or SIMATIC.

The communication system is the SIEMENS USS Protocol which is a communications protocol common to all of Siemens Drives Products.

Each drive on the link is given a unique slave number ( set in a parameter ) which is used by the Master to identify each Inverter.

The protocol has a Master-Slave system, whereby the Slave Inverter will only send a message in reply to a message received from the Master.

A broadcast facility exists, whereby one message can be sent to all Inverters simultaneously,

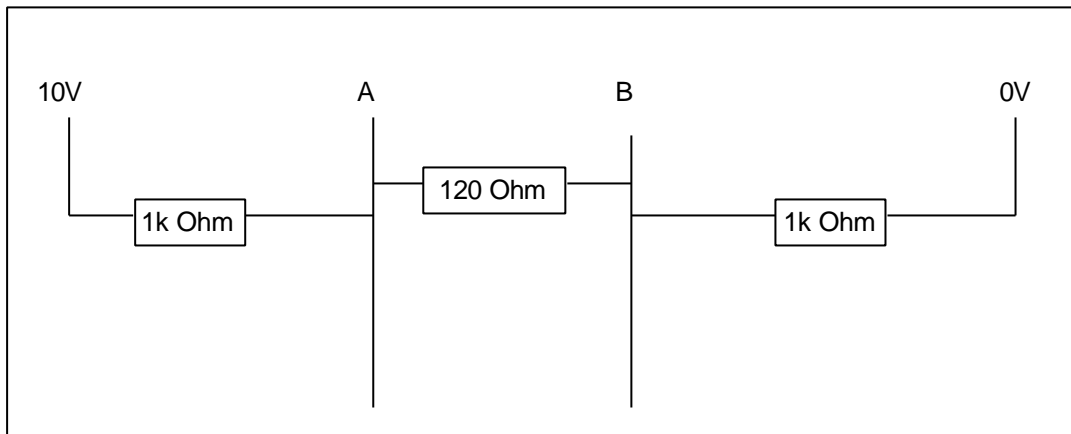
### **10.3 Hardware Connection**

The MICROMASTER has a RS485 interface using a D type connector

If the master unit has a four wire connection, connect the positive receive and the positive transmit together, and the negative receive and negative transmit together.

In order to reduce noise on the serial link it is advisable to tie the positive and negative lines to 10V and 0V respectively on the last Inverter in the chain.

This can be achieved by connecting a 1k ohm resistor between 10V and A and a 1k ohm resistor between 0V and B. Additionally, a 120 ohm resistor should be connected between the two terminals. This is illustrated below.



## **10.4 Overview of the USS Protocol**

The 6SE21 can communicate at upto 9600 Baud and the MicroMaster at upto 19.2 kBaud,

All messages between the Master and Slaves consist of 14 bytes. Each data byte is in standard UART format and consists of 1 start bit, 8 data bits, 1 even parity bit and 1 stop bit.

The data bytes in the messages are constructed as follows ;

### **10.4.1 Master to Slave Telegram**

STX	LGE	ADR	PKE	IND	VAL	STW	HSW	BCC
-----	-----	-----	-----	-----	-----	-----	-----	-----

### **10.4.2 Slave to Master Telegram**

STX	LGE	ADR	PKE	IND	VAL	ZSW	HIW	BCC
-----	-----	-----	-----	-----	-----	-----	-----	-----

## **10.5 Message Timeout**

All the data bytes in the Master to Slave telegram must be transmitted within 1.5 x the shortest time for the message. If the bytes are not transferred within this time, the message will be ignored by the slave.

For example, at 9600 Baud ;

- Byte Size is 11 bits
- Message Size is 14 bytes
- Shortest time is  $11 \times 14 / 9600 = 16 \text{ msec}$

Hence timeout period =  $16 \times 1.5 = 24 \text{ msec}$

After receiving a valid message the slave will transmit its reply within 20 msec. If the master does not receive a reply in this time it should re-transmit the message.

## **10.6 Detailed Description of the USS Protocol Message**

### **10.6.1 STX**

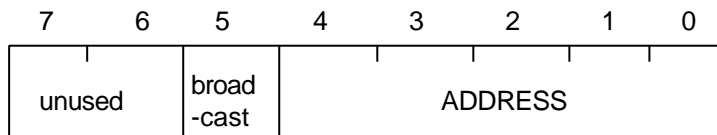
The STX field is a single byte ASCII STX character ( value 02 ) used to indicate the start of a message.

### **10.6.2 LGE**

The LGE is a single byte field which indicates the number of bytes to follow in this the message. This is normally fixed at 12 for the MicroMaster and 6SE21 Inverters.

### **10.6.3 ADR**

The ADR field is a single byte containing the address of the Slave Inverter. It is structured as shown below ;



Bit 5 is the broadcast bit. If it is set to 1, the message is a broadcast message and will be acted upon by all Inverters on the serial link. The unused bits should be set to 0.

### **10.6.4 BCC**

The BCC field is a byte sized checksum used to validate messages. It is calculated by XORing together all the previous bytes in the message. If the Inverter receives a message with an invalid message it will discard the message and not send a reply.

### **10.6.5 IND**

The IND field is a 16 bit field which is unused on the MicroMaster and 6SE21. It should always be set to 0.



### 10.6.6 VAL

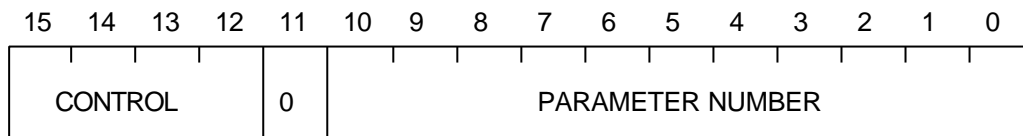
The VAL field is a 16 bit field containing the value for the parameter specified in the PKE field.

The format of the data is scaled to either 1 or 0.1 depending on the parameter type. Consult the Inverter manual to determine the data type for a particular parameter.

In general, parameters that are adjusted in 0.1 steps will have the VAL field scaled in 0.1 steps. e.g. the value 232 in the VAL field represents 23.2.

### 10.6.7 PKE

The PKE field is a 16 bit field used to control parameterisation of the Inverter. It is structured as shown below ;



The following control bit patterns have the functions ;

	6SE21	MicroMaster
0 0 0 0	no action	no action
0 0 0 1	Read Parameter	Read Parameter
0 0 1 0	Write Parameter to RAM only	Write Parameter to RAM and EEPROM
1 1 1 0	Write Parameter to RAM and EEPROM	not implemented

Bit 11 is unused and should be set to 0.

In Slave to Master Telegrams the control bits have the following meanings ;

0 0 0 0	no action
0 0 0 1	parameter value in VAL field
0 1 1 1	Error in received command
1 0 0 0	Inverter is in Local Control

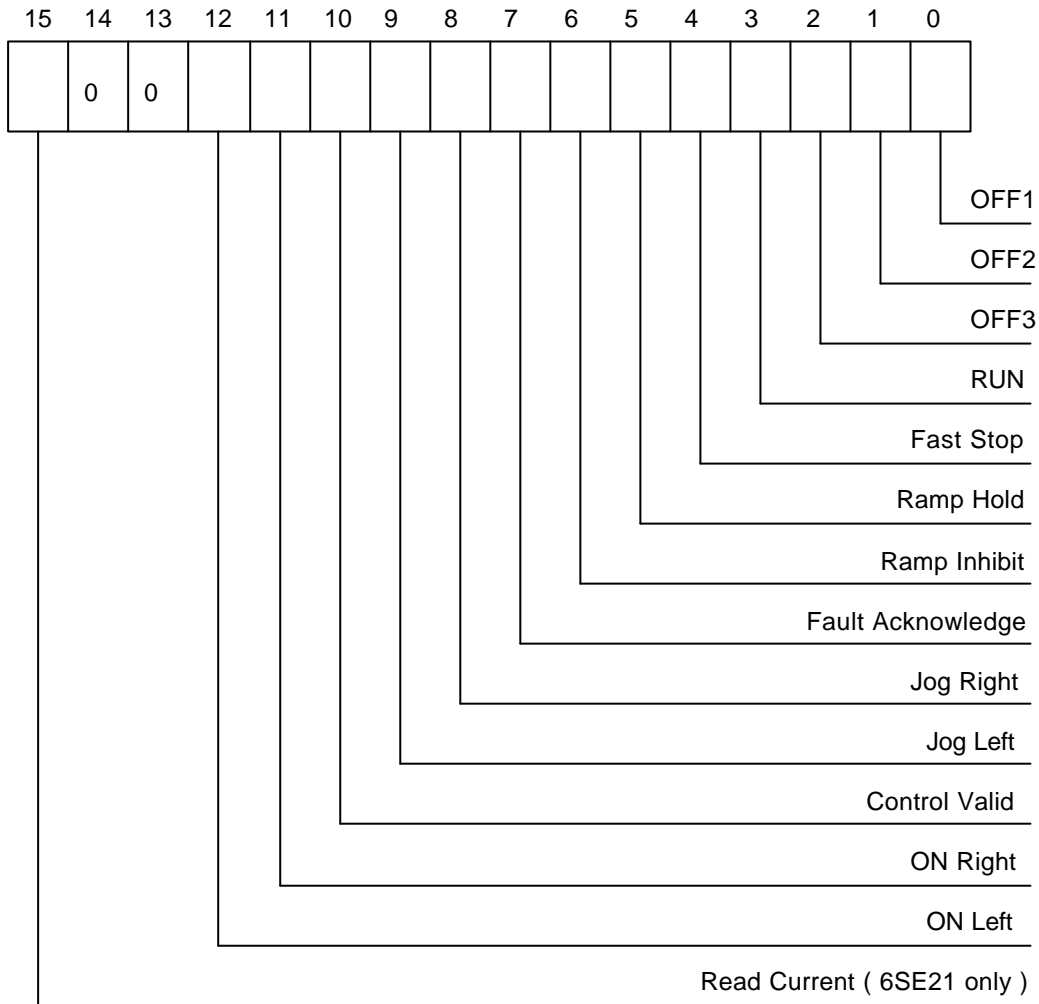
All other values are unused.

If the value 0 1 1 1 is returned then the VAL field contains an error code. The possible error codes are ;

0	Illegal Parameter Number
1	Read Only Parameter ( not supported on 6SE21 )

### 10.6.8 STW

The STW is a 16 bit field used to control the operation of the Inverter. It is structured as shown below ;



Bits 13, 14 and 15 are unused and should be set to 0.  
The function of the control bits is explained overleaf.

#### OFF1

- 0 activates the OFF1 condition, i.e. ramp down.
- 1 allows the Inverter to run.

#### OFF2

- 0 activates the OFF2 condition, i.e. immediate switch off.
- 1 allows the Inverter to run.

**NOTE :** Following an OFF2 the Inverter will be in Switch On Inhibit State. To clear the switch on inhibit, send an OFF1 command to the Inverter.

### OFF3

- 0 activates the OFF3 condition, i.e. fast ramp down with DC Link Voltage.
- 1 allows the Inverter to run.

**NOTE :** Following an OFF2 the Inverter will be in Switch On Inhibit State. To clear the switch on inhibit, send an OFF1 command to the Inverter.

This function is not implemented on the 6SE21 and returns the code 0 1 1 1 in PKE and the value 101 in the VAL field.

### RUN

- 0 switches the Inverter output off immediately.
- 1 allows the Inverter to run.

Note: The 6SE21 requires either bit 11 or bit 12 to be set to specify direction. The MicroMaster has a default direction of On Right.

### Fast Stop

- 0 Decelerates the Inverter as fast as possible along the DC Link Voltage.
- 1 allows the Inverter to run.

### Ramp Hold

- 0 Holds the ramp rate generator at its present frequency.
- 1 Allows the Inverter to ramp normally.

### Ramp Inhibit

- 0 Ramp to 0.0 Hz.
- 1 Ramp normally.

### Fault Acknowledge

A 0 to 1 transition of this bit between two consecutive messages will clear the Inverter from a TRIPPED or FAULT state.

### Jog Right

- 0 no action.
- 1 Jog Right.

**NOTE :** On 6SE21 this bit means JOG, with the direction selected in bits 11 and 12.

### Jog Left

- 0 no action.
- 1 Jog Left.

**NOTE :** On 6SE21, this bit means JOG, with the direction selected in bits 11 and 12.

Control Valid

- 0 Ignore control bits.
- 1 Control Bits are valid.

On Right

- 0 no action
- 1 Requested direction is right.

On Left

- 0 no action.
- 1 Requested direction is left.

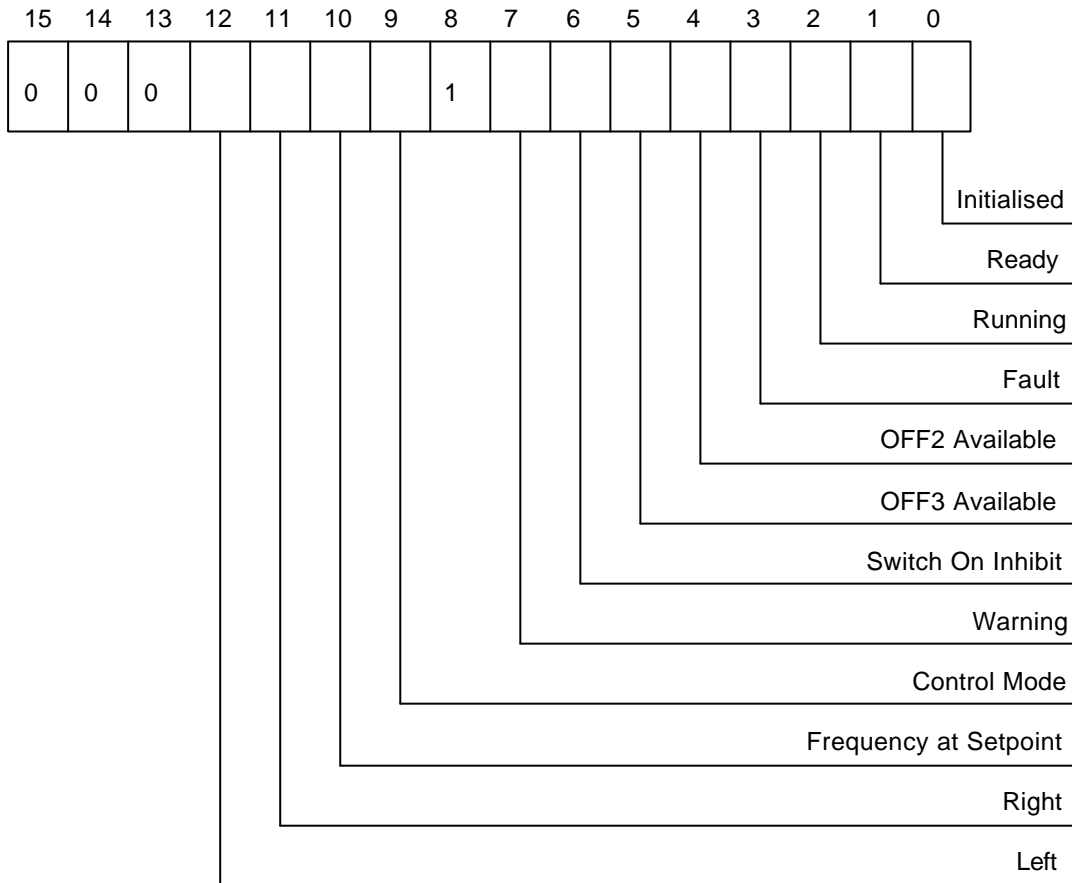
Read Current ( 6SE21 Only )

On the 6SE21, if this bit is set to 1, then the value returned in HIW will be the current scaled to 0.1 Amps.

To read the current on the MicroMaster, set parameter 1 to Current Display and do a parameter read of Parameter 0.

### 10.6.9 ZSW

The ZSW is a 16 bit field from the Inverter indicating the current status of the Inverter. Its structure is shown below ;



Bit 8 is unused and is always returned as 1.

Bits 13, 14 and 15 are unused and always returned as 0.

The meaning of each of the Status Bits is explained below.

#### Initialised

- 0 Indicates Inverter is initialising.
- 1 Indicates Inverter has initialised.

#### Ready

- 0 Indicates Inverter is not ready to run
- 1 Indicates Inverter is ready to run

#### Running

- 0 Indicates Inverter Output is switched Off.
- 1 Indicates Inverter Output is switched On.

### Fault

- 0 Indicates no Fault.
- 1 Indicates Inverter has a fault condition.

### OFF2 Available

- 0 Indicates OFF2 is available.
- 1 Indicates OFF2 is not available.

Note : 6SE21 implementation indicates OFF2 active or not active.

### OFF3 Available

- 0 Indicates OFF3 is available.
- 1 Indicates OFF3 is not available.

Note : 6SE21 implementation indicates OFF3 active or not active.

### Switch On Inhibit

- 0 Indicates Inverter is not in switch on inhibit state.
- 1 Indicates Inverter is in switch on inhibit state.

Following an OFF2, OFF3, or trip, the Inverter will enter Switch On Inhibit state. This prevents the Inverter from running.

Switch On Inhibit state is cleared by sending an OFF1 command to the Inverter.

### Warning

- 0 No warning.
- 1 Inverter Warning, e.g. over current.

**NOTE** : Not supported on 6SE21.

### Control Mode

- 0 Inverter is under Local Control.
- 1 Inverter is under Remote Control.

### Frequency at Setpoint

- 0 Inverter Output Frequency is less than the requested setpoint.
- 1 Inverter Output Frequency is at or greater than the requested setpoint.

### Right

- 0 Output direction is not right.
- 1 Output direction is right.

### Left

- 0 Output direction is not left.

1 Output direction is left.

### HSW

Is a 16 bit field containing the frequency demand to the Inverter. It is scaled such that a value of 16384 ( 4000H ) represents 100%. The scaling is set in a Parameter on the Inverter.

The HSW can be upto 32767 ( i.e. 200% ).

Values 32768 to 65535 represent a negative ( i.e. reverse ) frequency demand 0 to 200%. This value is in two's compliment form.

**NOTE** : Negative demand is not supported on the 6SE21.

On the MicroMaster, the scaling parameter is P094.

On the 6SE21, the scaling parameter is P08. This is also the maximum frequency parameter, hence 6SE21 frequency demands above 100% are clipped to 100%.

The accuracy of the frequency output can be controlled in 0.02 Hz steps on the MicroMaster and 0.1 Hz steps on the 6SE21.

The output frequency of the MicroMaster is calculated as follows ;

$$\text{Output frequency} = ( \text{HSW} * \text{P094} ) / 16384$$

The output frequency of the 6SE21 is calculated as follows ;

$$\text{Output frequency} = ( \text{HSW} * \text{P08} ) / 16384$$

ON both the 6SE21 and MicroMaster the returned frequency value will always be in the range 0 to 200%, irrespective of the Inverter direction.

### HIW

This field is 16 bits and represents the output frequency of the Inverter. It is formatted in an identical manner to the HSW field.

**NOTE** : The 6SE21 will return the current scaled to 0.1 Amps in the HIW field if the STW field bit 15 was set to 1.

## **10.7 Examples of using the USS Protocol**

Here are some example messages that could be sent to an Inverter.

### **10.7.1 Run Inverter #3 at 50% Frequency**

STX	LGE	ADR	PKE	IND	VAL	STW	HSW	BCC
02	0C	03	0000	0000	0000	0C7F	2000	5E

Set Parameter 12 on Inverter #15 to 30.0 Hz

STX	LGE	ADR	PKE	IND	VAL	STW	HSW	BCC
02	0C	0F	200C	0000	012C	0400	0000	04

### 6.1.3 Broadcast Immediate Switch Off to all Inverters

STX	LGE	ADR	PKE	IND	VAL	STW	HSW	BCC
02	0C	20	0000	0000	0000	0C7D	0000	5F

## **11. APPENDIX 2: Environmental Protection Levels (IP rating)**

The tables below give the definitions of DIN40050, BS EN 60529 and IEC529. These refer to the I P numbers and the different levels of protection available.

### IP X X

	FIRST NUMBER	
0	No protection	No special protection of persons from direct contact with active or moving parts. No protection of the object from access of solid foreign matter.
1	Protection against large foreign bodies	Protection of persons from accidental large-area direct contact with active or internal moving parts (e.g. hand contact), but no guard against intentional access to such parts. Protection of the object from access of solid foreign matter larger than 50mm in diameter.
2	Protection against medium-size foreign bodies	Protection of persons from finger contact with active or internal moving parts. Protection of the object from access of solid foreign matter larger than 12mm.
3	Protection against small foreign bodies	Protection of persons from touching active or internal moving parts with tools, wires or similar foreign bodies thicker than 2,5mm. Protection of the object from access of solid foreign matter larger than 2,5mm..
4	Protection against very	Protection of persons from touching active or internal



	small foreign bodies	moving parts with tools, wires or similar foreign bodies thicker than 1 mm.
5	Limitation of ingress of dust	Total protection of persons from touching voltage-carrying or internal moving parts. Protection of the object from harmful deposit of dust. Although ingress is not completely prevented, dust will not enter in sufficient quantity to impair the operation or safety of the apparatus.
6	Prevention of ingress of dust	Total protection of persons from contacting voltage-carrying or internal moving parts. Total protection of the object from ingress of dust.
	<b>SECOND NUMBER</b>	
0	No protection	No special protection.
1	Protection against water dripping vertically	Water drops falling vertically must not have any harmful effect.
2	Protection against water dripping non-vertically	Water drops falling at any angle up to 15° with the vertical must not have any harmful effect.
3	Protection against spray water	Water hitting the object at any angle up to 60° with the vertical must not have any harmful effect.
4	Protection against splash water	Water splashing against the object from all directions must not have any harmful effect.
5	Protection against jet water	A jet of water projected from a standard nozzle at 12.5 litres per minute against the object from all directions must not have any harmful effect.
6	Protection against powerful water jets	A water jet projected at 100 litres per minute from all directions shall have no harmful effect.
7	Protection against temporary submersion	If the enclosure is immersed between 0.15 and 1 m in water for 30 minutes, water must not enter it in any harmful quantity.
8	Protection against continuous submersion	If the enclosure remains submerged in water, under agreed conditions which are more severe than those of IPX7, water must not enter it in any harmful quantity.

## **12. APPENDIX 3: Some Useful Formulae.**

### 12.1.1 Torque and Power Relationships

If the steady state torque is known, the power requirement can be calculated:

$$\text{Power [kW]} = (\text{Torque [Nm]} \times \text{Speed [rev/min]}) / 9550$$

or

$$\text{Torque [Nm]} = (9550 \times \text{Power [kW]}) / \text{Speed [rev/min]}$$

### Acceleration Torque.

The amount of torque needed to accelerate (or decelerate) a rotating body is dependent on its moment of inertia:

$$\text{Acceleration Torque [Nm]} =$$

$$\text{Moment of Inertia [kg.m.m]} \times \text{Acceleration [m/s.s]} \times 2\pi/60.$$

Often it is necessary to calculate the total torque requirement in order to determine the motor type and inverter power.

$$\text{Total Torque} = \text{Acceleration Torque} + \text{Steady State Torque}$$

### Moment of Inertia

The moment of inertia is often specified for motors, gearboxes etc. It can be calculated for simple bodies, for example:

Solid Cylinder, Radius R, Length l, Mass m:

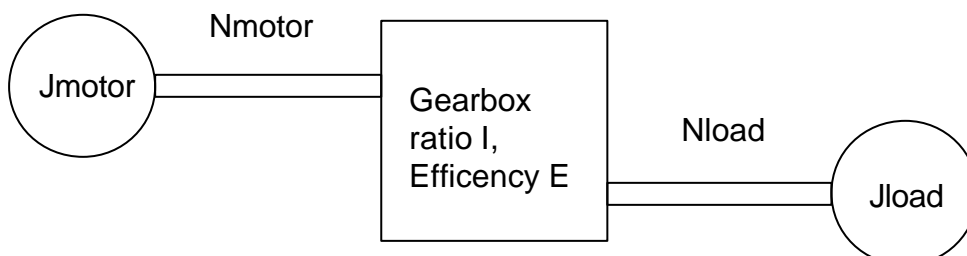
$$\text{Moment of inertia} = J = m.R^2/2$$

If the cylinder is hollow, with inner radius r, outer radius R:

$$\text{Moment of inertia} = J = m.(R^2 - r^2)/2$$

### Torque, Power and Moment of Inertia of Practical Assemblies

#### Gearbox



$$\text{Gearbox Ratio } I = \text{Nmotor} / \text{Nload}$$

#### Moment of Inertia

The load moment of inertia can be referred to the motor shaft

$$J^*load = Jload/l^2$$

or

$$J^*load = Jload. (Nload)^2 / (Nmotor)^2$$

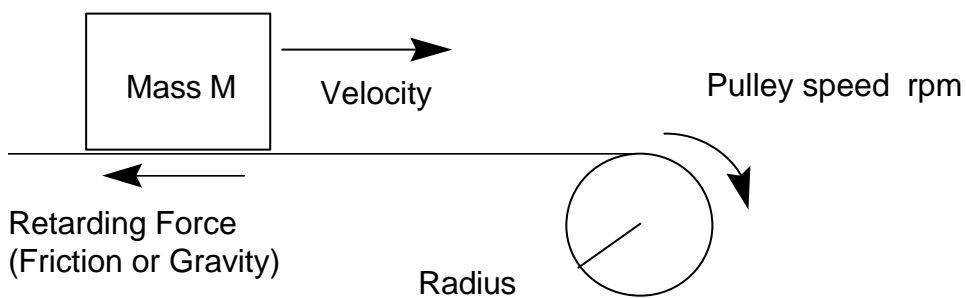
### Output Power

$$Output Power = (Input Power) \times (Gearbox efficiency)$$

### Output Torque

$$Output Torque = (Input Torque) \times (Gearbox efficiency) / (Gearbox Ratio)$$

### Conveyer Applications



$$Accelerating Torque = Mass \times Velocity$$

$$Steady state Torque = Retarding Force \times Radius$$

$$Velocity = 2.\pi.Radius \times Pulley Speed.$$

$$Power = Retarding Force \times Velocity$$

$$Moment of inertia = Mass \times (Velocity)^2 + Pulley etc.$$

### Hoist Applications.

A hoist is a vertical conveyer where the Retarding force is gravity.

$$Steady state Torque = Retarding Force \times Radius$$

$$= Mass \times g \times Radius.$$

$$Power = Mass \times g \times Velocity$$

Moment of inertia = Mass X (Velocity)<sup>2</sup> + Pulley etc.