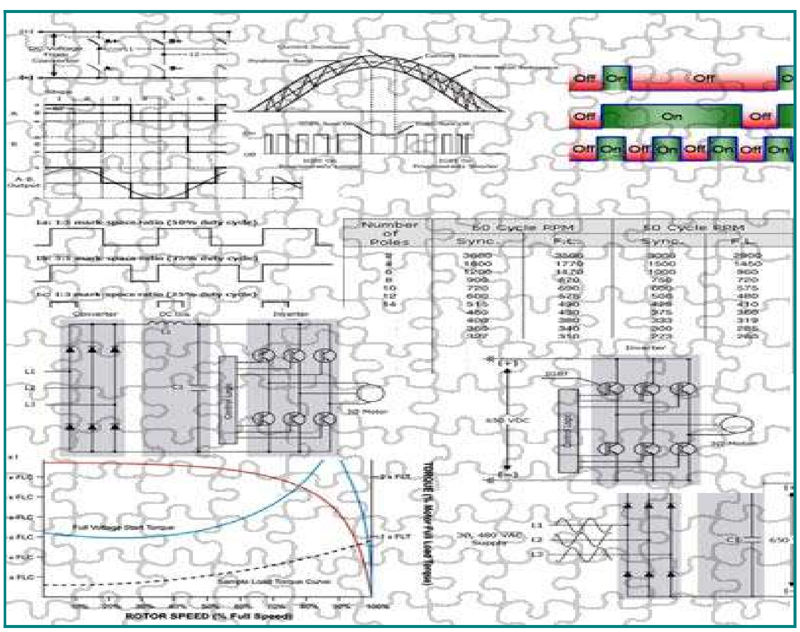
Section 5

Variable Frequency Drives



1 Equipment Overview

Up until recent times the preferred drive system for drilling equipment has been DC traction motors, primarily because of the high torque and speed control ability of this equipment from zero to full speed, regardless of whether the power source was DC to DC, or AC to DC systems.

1.1 DC System

A DC generator is used to drive DC motors which in turn drive the drilling equipment, using the Ward Leonard type system of speed control. This is achieved by varying the field of the generator which controls the output voltage feeding the DC traction motors.

1.2 AC System

Alternatively in the case of the AC system, AC generators supply AC to an SCR system, which converts AC to DC to drive the DC traction motors on the drilling equipment. These SCRs convert 600 volts AC to a 0 to 750 volt DC output for the control of the DC traction motors.

1.3 DC Traction Motors

Shunt Motors: Can be controlled by the field windings to refine their control and are good for constant speed.

Series Motors: Are high torque from the initial start, as the field windings are in series with the armature, but are able to reach destructive speeds if unloaded without protective devices installed.

1.4 Variable Frequency Drives System

In recent years there has been a move to VFDs or Variable Frequency Drives to drive AC induction motors as the power medium on modern drilling equipment. The voltage and frequency are controlled to perform the same duty as the previous DC systems and give the same degree of control ability with a reduced level of maintenance from that of the DC motors.

The DC motors require constant attention to keep them trouble free, especially at the commutator end. But the AC motor used on Top Drives is basically a three phase squirrel cage induction motor refined for use with this system, so it does not require the same level of maintenance as the DC motors.

1.5 Advantages of VFD

There are advantages from the safety point of view, in that with the DC motors, there will always be commutator sparking and the risk that poses in hazardous locations, even with air purging and spark arrestors. Where as no such problems exist with the AC motors, although they still need cooling to prevent overheating. Another advantage with the AC motors is the fact that the insulation is fully sealed against the offshore environment situation of damp salt air.

The DC motor has always been a high maintenance item with the need for cleaning to remove carbon residue from the brush gear and commutator area, to reduce the risk of flash over and maintain the insulation value of the motor as high as possible when it becomes cool and damp.

Also there is the need to replace the carbon brushes, due to wear or broken pig tails. The brushes need to be “bedded in” to match the contour of the surface of the commutator to reduce sparking. The brush spring arms can often create problems where the pivots become tight or partly seize and this reduces the spring pressure on the top of the brushes resulting in excessive sparking.

1.6 AC Top Drives

With respect to Top Drives the main advantage of the AC VFD system is a much better load power factor. This is important as many rigs are running out of kVA, and would need more generator power to cure this problem. AC motors have a better speed range and can be run at 200% of base speed and above. This allows for more suitable gear ratios and therefore produces a substantially better torque curve that delivers better performance over a broader speed range.

1.7 AC/DC Motor Characteristics

The AC motor horsepower characteristics are far better than the DC motor, where the DC motor can only maintain maximum horsepower at one speed, the AC motor will maintain full horsepower from base speed up to approximately 150% of base speed.

AC top drives can maintain continuous stall torque, whereas the DC motor in an extended stall situation will have reduced torque capacity due to brush/commutator current limitations. The AC induction motor can be stalled at its continuous rating indefinitely because it has no brushes or commutator, to create arcing or sparking, and can supply continuous torque in this situation without doing harm to the motor or installation.

1.8 Parameters

The AC Top Drives have a lifting capacity of up to 750 tons, and a drive capacity of up to 1150 horse power. They are normally equipped with instrumentation to monitor various parameters such as, lube oil pressure, lube oil temperature, blower cooling air pressure and temperature. Along with an RPM sensor to monitor the rotating speed of the Top Drive, and gauges to monitor hydraulic oil pressures on the unit.

1.9 Comparisons

Comparing the AC unit against the DC unit for torque, the AC unit comes is superior with the AC unit producing a max continuous torque of 51,000 ft/lbs, and a max intermittent torque of 72,000 ft/lbs with a gear ratio of 6.808:1.

Where as the DC unit, limited by commutation, produces about 33,000 ft/lbs of maximum continuous torque with a gear ratio of 4.971:1. So, if the motor is not well maintained and kept in 100% condition, this figure would not be obtainable. To continue the comparison, the GE 752 High Torque DC motor develops 1130 horse power, and this unit has a lifting capacity of 650 tons, with a max speed of 267 RPM, compared to the AC motors 265 RPM.

1.10 Permanent Magnet Synchronous AC Motors

The move to AC power for Top Drives has been further advanced by the development of liquid cooled, brushless permanent magnet synchronous AC motors, which has been made possible with a reduction in the cost of rare earth magnets. Effectively replacing the conventional three phase squirrel cage type induction motors.

1.10.1 Performance Characteristics

Now that the high performance brushless permanent magnet motors can be constructed to heavy industrial or military specifications, they are now suitable for rig operations where conditions are harsh and there are stringent explosion-proof requirements. New single motor arrangements up to 1000hp and beyond are planned for the future and this makes these motors ideally suitable for top drive service in the oil exploration industry.

1.10.2 No Gearbox Required

One of the main attractions of these motors is high speed torque where the motor can be used for direct drive without a gear box, in a situation where the maintenance cost of gearboxes is considered higher than that of motors. Gearboxes require constant monitoring and are difficult as well as time consuming to replace in the event of failure.

1.10.3 Construction

These motors are constructed with the use of rare earth magnetic materials such as Neodymium-iron-boron (Nd-Fe-B) or samarium-cobalt. The materials are similar but the later has better high temperature characteristics although at a higher price. The cost of Nd-Fe-B has fallen over the last five years making it more attractive, but the low production numbers keep the cost of motors high.

As demand grows and unit production rates increase the sale price of the motors will become more attractive.

1.10.4 Performance Benefits

The development of the magnets and the variable frequency drives (VFDs) using insulated-gate bipolar transistors (IGBTs) and integrated gate-commutated thyristors (IGCTs) have made it possible to build this type of motor in the larger sizes for applications such as drilling, where the VFD cost is outweighed by the performance benefits.

1.10.5 Motor Cooling

Motor cooling is simplified due to the fact that heat is not generated in the rotor. Only the stator or outer structure needs to be cooled, where a water/glycol mix can be readily used to cool the exterior of the motor. With the compact permanent magnet motors there is a weight and size reduction of thirty to fifty percent on an induction or synchronous motor when compared to the heavier DC traction motors.

1.10.6 Greater Number of Poles

The brushless permanent magnet motors superior power development results from a greater number of poles. These motors can have as many as three times the number of poles of a conventional induction motor of the same diameter. This concept allows for a lighter, smaller, and more flexible motor layout.

1.10.7 Accept Higher Frequency

With the higher pole numbers in the motors, the VFD can operate at higher electrical frequencies. A permanent magnet motor at a particular speed can require an input of up to 415Hz in a high speed, high rating application. This can be from a designed driver for the VFDs power topology and control band width.

1.10.8 Application

Moving away from the top drive situation to the other main drives on the rig such as the drawworks, mud pumps, and rotary table drives. These equipments are now being driven via VFDs and AC induction motors in place of the traditional DC to DC and SCR systems. VFD units have increased in size to be able to cope with large squirrel cage induction motors as used in AC top drives. These newer VFDs are now able to be used in modified form to drive new larger liquid cooled brushless permanent magnet synchronous AC motors.

These brushless PM motors are currently rated up to 450 HP when liquid cooled, and though more expensive due to the manufacturing material cost, offer smaller size, higher power density, higher dynamic performance, and higher efficiency without rotor losses.

A European company is producing a high performance permanent magnet motor rated to 1341HP at speeds up to 2600RPM. In most cases a permanent magnet motor is 1-2% more efficient than an AC induction motor or synchronous motor at full load, and 10-15% more efficient at partial loadings. These efficiencies are derived from full rotor excitation without current and without losses.

1.10.9 Manufacturers

There are several manufacturers of the VFD control systems such as:

Siemens, DRS Technologies, Square D, Allen Bradley, General Electric, Cutler Hammer, ABB etc.

Figure 1 Cutler Hammer Variable Frequency Drive

2 How Does It Work

2.1 VFD Basic Principle

The Variable Frequency Drive system is used for the speed control of the AC or Alternating Current motors. It does this by controlling the frequency and voltage of the power supplied to the motor. This is used in the same way as the SCR system is used to control the DC motor, so that the AC motor speed can be controlled over the full range from zero to full speed during drilling operations.

Variable Frequency Drives operate on the principle that the synchronous speed of an AC motor is determined by the frequency of the applied AC supply and the number of poles in the stator winding. The motors used in this type of system are normally three phase induction motors which are suitable to most applications, and are generally the most economical choice of motor. In some cases enhancements are made to improve the motors VFD performance and reliability, and the AC motor is well suited to situations where the environment is wet, corrosive, and explosive.

The Variable Frequency Drive controller is a solid state electronic power conversion type device. This converts AC input power to DC power by the use of a three phase bridge rectifier, and then the DC power is converted to quasi- sinusoidal AC power by using an inverter switching circuit. These are called insulated gate bipolar transistors (IGBTs) and are used in most inverter circuits.

Variable frequency AC motor drives, called inverters are generally more complex than the normal SCR type DC controllers, as they must perform two distinct functions. They must convert AC line power to DC and filter/smooth it. Then an inverter stage is required to convert the DC to a controlled adjustable frequency and voltage output to the AC motor.

2.2 Advantage of VFD

The advantage of the adjustable frequency drive is in the use of the AC induction motor, with its simplicity, reliability and low maintenance requirements. Without the high maintenance moving parts of a DC motor in the normal DC system, the complexity of the AC control system is a small disadvantage. The low cost of the AC motors is another attraction when considering the initial cost of a system, and ongoing running costs.

The AC motors require the supply voltage to be adjusted proportionally when the frequency is changed. If the motor was designed to operate at 480 volt 60Hz, then the applied voltage must be reduced to 240 volt when the frequency is 30Hz, to keep the ratio of volts per hertz at a constant regulated value (480/60 = 8 in this case). For the best performance some voltage adjustment may have to be made, but normally the constant volts/hertz ratio is the rule.

2.3 Characteristics of VFD

The main function of variable speed drive is the control of speed, torque, acceleration, deceleration, and direction of rotation of the AC induction motor to the same level of control as that of the DC motor drives.

The drive can control two main functions of the induction motor, speed and torque, and to understand how the AC drive controls this performance we need to look at the principals of the AC induction motor, which has two basic parts, the Stator and the Rotor which create a magnetic interaction while operating.

2.4 Squirrel Cage Induction AC Motor

A squirrel cage induction motor Stator contains pairs of poles. These are laminated iron cores located inside the Stator, with the insulated single core cable wound into it to create electromagnets in pairs. They provide North and South poles and in doing so create a revolving North and South field. The ends of these coils are brought out to the junction box of the motor for termination in the correct order to determine the polarity of each coil in the system.

2.5 Base Speed/Slip

Base speed is the nameplate speed, given in RPM, where the motor develops rated horsepower at rated voltage and frequency. It is an indication of how fast the output shaft will turn the connected equipment when fully loaded with proper voltage and frequency applied. Consideration has also to be given to slip, where slip is the difference in speed between the Rotor and the rotating magnetic field in the Stator.

When a magnetic field passes through the rotor, the conductors in the Rotor take on a field of their own. This Rotor field will try and catch up to the Main rotating field in the Stator, but it will never catch up. This difference is called slip, and the motion of the Rotor field chasing the Stator field is the cause of the motors rotation.

2.6 Motor Speed

The speed of the motor can be adjusted by altering the frequency of supply to the motor, but the speed could also be adjusted by changing the number of poles in the motor. However, this change would be permanent and require a rewind.

Number of Poles	60 Cycle RPM		50 Cycle RPM	
	Sync.	F.L.	Sync.	F.L.
2	3600	3500	3000	2900
4	1800	1770	1500	1450
6	1200	1170	1000	960
8	900	870	750	720
10	720	690	600	575
12	600	575	500	480
14	515	490	429	410
16	450	430	375	360
18	400	380	333	319
20	360	340	300	285
22	327	310	273	260
24	300	285	240	230
26	277	265	231	222
28	257	245	214	205
30	240	230	200	192

Chart 1 Poles / Frequency / Speed

2.7 Motor Torque

To change the torque characteristics of a motor the Volts per Hertz ratio needs to be changed, so if we take a 460 Volt 60Hz motor with a source ratio of 7.67 and as long as this stays the same the motor will develop the rated torque for that ratio, but the AC inverter drive develops many different frequency outputs, and at any given output you will get a new torque curve.

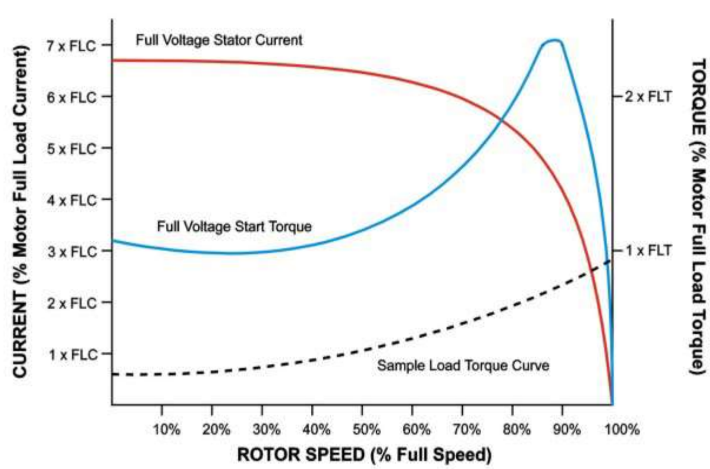


Chart 2 Speed / Torque / Current

2.8 Pulse Width Modulation

The method used normally to adjust the motor voltage is called pulse width modulation or PWM, in which the inverter switches are used to divide the quasi-sinusoidal output waveform into a series of narrow voltage pulses and modulate the width of pulses. Changes to the switching frequency will correspond to a change in motor speed when comparing a,b, & c.

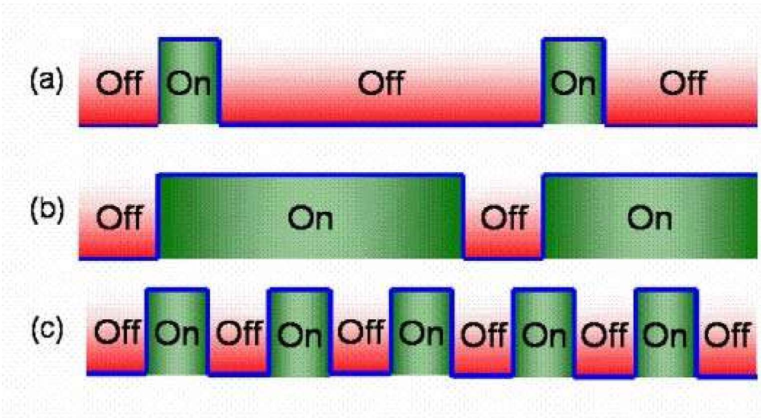


Figure 2 Example of PWM On/Off Cycles

An embedded microprocessor is used to control the overall operation of the VFD, and the main microprocessor programming is in firmware that is not accessible to the VFD user. Some degree of configuration programming and parameter adjustment is usually provided so that users can customise the VFD controller to suit specific motor and drive equipment requirements.

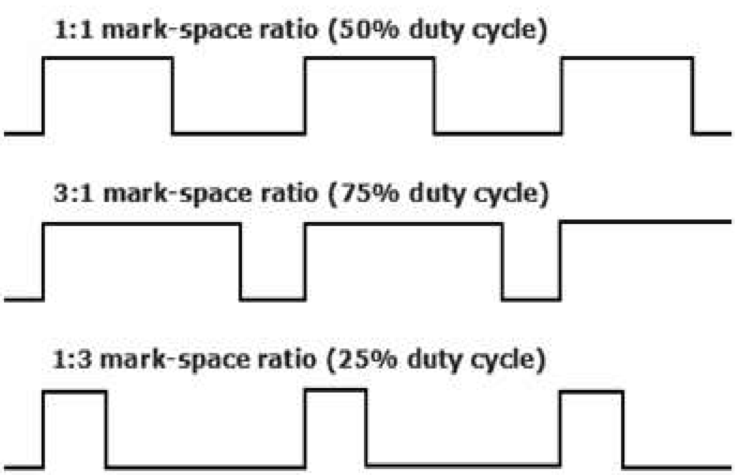


Figure 3 Pulse Width Duty Cycles

2.9 Basic principle

Below are the components of a basic PWM (Pulse Width Modulation) Drive, showing the three phase supply to the bridge which will rectify the AC current to DC current and then the inductor or choke L 1 and capacitors C1 to filter and smooth the AC before it reaches the inverter which converts the DC back to AC for the control of the motor with the aid of the control logic, and all PWM drives will contain these main components, with some differences in hardware and software components.

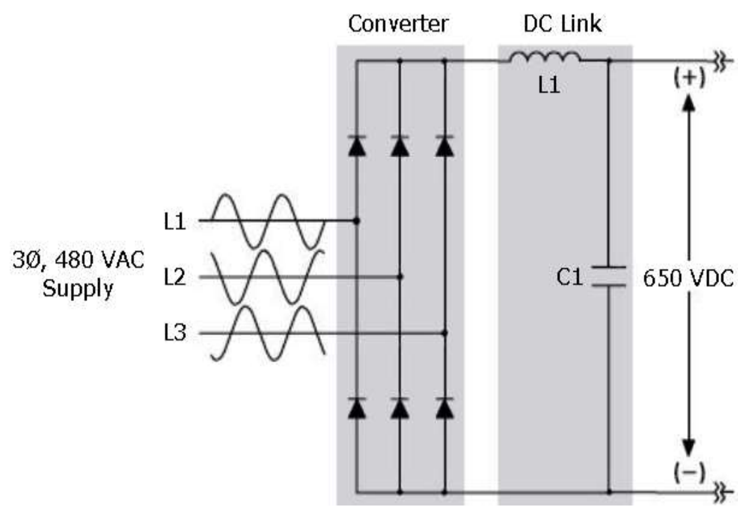


Figure 1 AC/DC Converter

2.10 Explanation of Power Path

In the drilling exploration industry for our main drives we are only interested in three phase units of high capacity, but to make the following schematics better understood we will follow a single phase through the system. If we take L 1 phase and follow it through the diode where the current will flow in the positive half of the cycle but stop flowing when the cycle reverses, so one gets half cycles only through each diode. Then on to the DC link which is an inductor or choke (L 1) and the capacitors (C 1) will work together to filter out any AC wave form left over from the bridge rectifier. This will leave the rectifier as a DC flow, formed by a continuous flow of positive waves that are formed by the positive halves from all three phases passing through the diodes.

The inductor or choke by its nature will resist change in voltage or current which tends to remove the ripple, and the capacitors by their nature charge and discharge into the system. In doing so they too remove ripple left over from the half-wave DC created by the rectifier section, taking the positive half waves from the three phase alternating current supply and smoothing them to remove the ripple.

The smoother the DC into the inverter the better the wave form out of it to the motor, and the rectified DC value is approximately 1.35 times the line to line value of the supply voltage, and the rectified DC value will be approximately 650 volts DC for a 480VAC input supply.

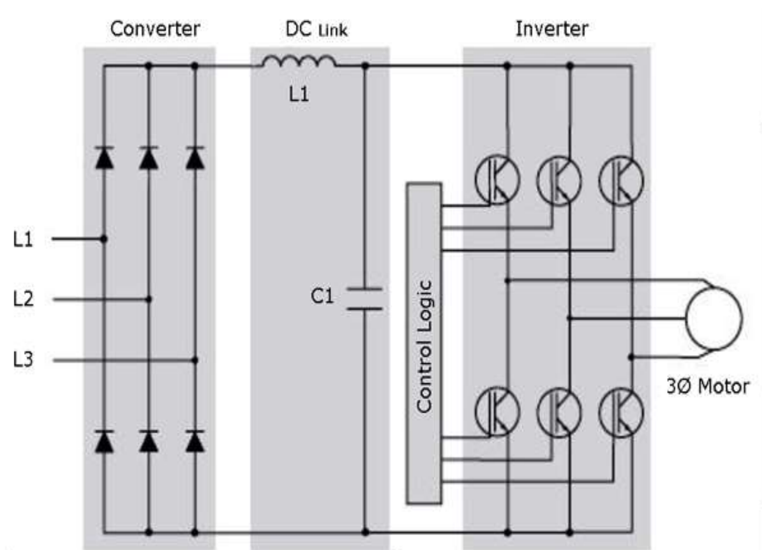


Figure 2 AC/DC Converter

2.11 Insulated Gate Bipolar Transistor (IGBT)

The Inverter will convert the DC back into AC, with a variable voltage and frequency output to control the motor. This is achieved by using Insulated Gate Bipolar Transistor (IGBT) technology, to switch the DC supply on and off at specific intervals, and in doing so creates a variable voltage and frequency output. However the output does not provide an AC sine wave the same as the input sine wave from the original supply, but creates voltage pulses of a constant magnitude.

The output voltage and frequency to the motor are controlled by the control logic and inverter section. This section consists of 6 IGBTs and the following schematic, shows the inverter circuit in which the control logic uses a microprocessor to switch the IGBTs on and off, providing a variable voltage and frequency to the motor.

The drives control system, signals the control circuits to turn "on" the wave form positive half or negative half of the inverter, this alternating of positive and negative switching recreates the three phase output. The longer the inverter stays on, the higher the voltage output, and conversely the shorter the period, the lower the voltage. Consequently the longer the device is in the off position, the lower the output frequency.

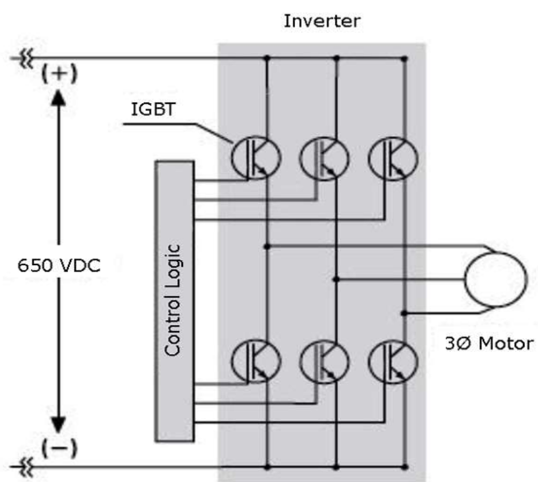


Figure 3 DC/AC Converter

2.12 IGBT Composition

The IGBTs provide the high switching speed required for the PWM inverter to operate, and are capable of switching on and off ***several thousand times per second***. An IGBT can turn on in less than 400 nanoseconds and off in approximately 500 nanoseconds.

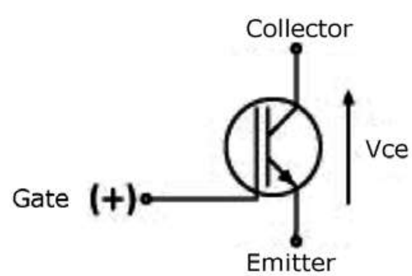


Figure 4 Symbol of IBGT

The IGBT consists of a gate, collector and emitter, which when a + 15VDC is applied will turn on, which is equivalent to turning on a switch. Current will flow from the collector to the emitter, but will turn off if the positive voltage is removed. It is normally held in the off position by applying a – 15VDC to the device to prevent it turning on until required.

2.13 Frequency

The speed at which the inverter switches on and off is referred to as the carrier frequency, or switching frequency, and the higher the switching frequency the more resolution each PWM pulse contains. These frequency are normally 3000 to 4000 times per second or 3KHz or 4KHz, compared with SCR type systems which are normally 250 to 500 times per second. The higher the switch frequency the smoother the output wave form and the higher the resolution, but the higher frequencies will decrease the drive efficiency because of increased heat in the power devices. An indication of the switching used in the inverter process is shown in the schematic below. Using switches instead of IGBTs and following a single phase example, an alternating voltage is developed by opening and closing switches in a set sequence.

Looking at the generated sine wave from the VFD to the three phase motor windings, across Line 1 and Line 2, it can be shown that;

- Step 1 & 2, by closing A+ & B- a positive voltage will be seen across L1 & L2.
- Step 3, by opening B- and closing A+ & B+ the voltage across L1 & L2 is zero.
- Step 4 & 5, by opening A+ and closing A- a negative voltage will be seen across L1 & L2.

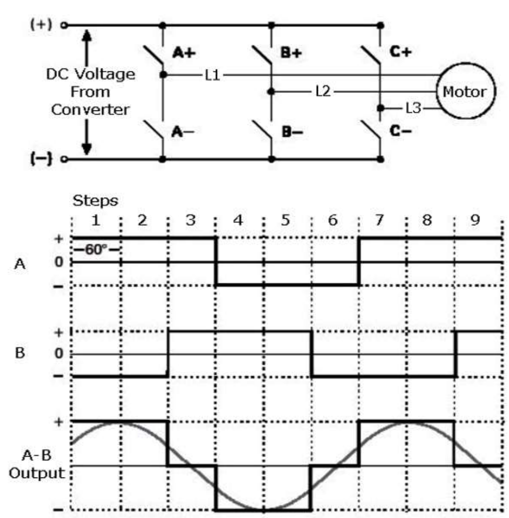


Figure 5 Graphical Representation of Switching

This represents one cycle across L1 and L2 and is repeated in sequence across all L1, L2 and L3 phases that supply the motor.

2.13.1 VFD Voltage

Is dependant on the value of the DC voltage supplied from the rectifier.

2.13.2 VFD Frequency

The frequency is dependant on the speed of the switching, and an AC sine wave has been added to the output (A-B) to show how the AC is simulated.

2.14 SCR Compared To IGBT's

The SRC or Thyristor differs from the IGBT in that the SCR is controlled by the use of the "Gate" by which the SCR can be switched on allowing it to fully conduct, and will continue to conduct until the polarity reverses. It will then automatically turn off. The out put of the SCR depends on how soon in the cycle the gate turns on.

With the IGTB it is much the same as the SCR, in that the output is controlled by the amount of time the gate is on, but it can be turned off at any time in the control cycle, and thereby providing a more precise output waveform. The IGTB requires control circuitry connected to the gate, but it is less complex than the SCR and does not require reversal of polarity to switch it off.

There are several PMW modulation techniques. The following text and illustrations describe a typical pulse width modulation method. An IGBT (or other type switching device) can be switched on connecting the motor to the positive value of DC voltage (650 VDC from the converter). Current flows in the motor. The IGBT is switched on for a short period of time, allowing only a small amount of current to build up in the motor and then switched off.

The IGBT is switched on and left on for progressively longer periods of time, allowing the current to build up to higher levels until the current in the motor reaches a peak. The IGBT is then switched on for progressively shorter periods of time, decreasing the current build up in the motor. The negative half of the sine wave is generated by switching an IGBT connected to the negative value of the converter DC voltage.

The more sinusoidal current output produced by the PWM, the greater the reduction of torque pulsation, or low speed motor cogging, and motor losses, usually noticeable when using a six step output.

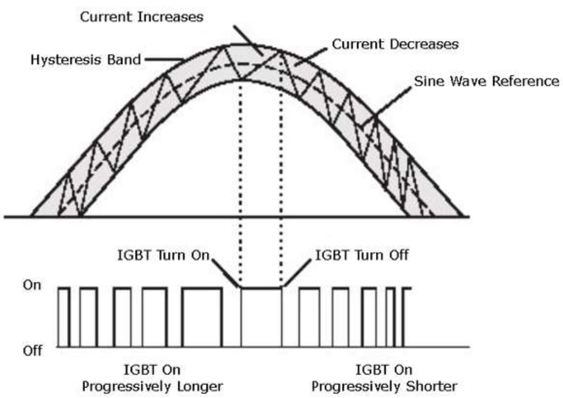


Figure 6 Pulse Width & Wave Form Comparison

The 650 volt DC output from the rectifier section is modulated by the IGBT section to provide variable frequency and voltage. When the IGBTs are turned on for *shorter periods of time*, lower frequency and voltage are produced and the motor voltage and current build up is low resulting in lower motor speed. If the IGBTs are turned on for *longer periods of time*, which results in higher frequency and voltage output. With this increase in the voltage and current build up, the motor speed will increase.

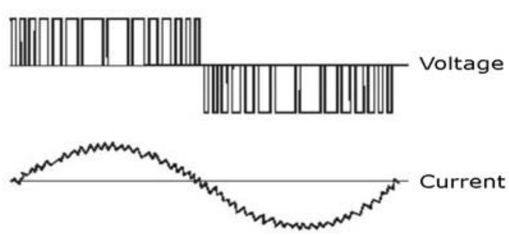


Figure 7 Voltage & Current Comparison

2.15 AC/DC Motor Comparison

In the past the dynamic response of the DC motor has always been considered superior to that of the AC motor. However the cost of the AC motor is significantly less than the DC motor and the AC motor requires much less maintenance. By using a complex motor model and internal computer algorithms, vector control is able to exert dynamic control over the AC motor so that its control is equal or better than that expected of a DC motor.

2.16 Vector Control

Vector control, flux vector, and field orientation are terms that describe this specialised control technique of AC drives. Vector control makes possible the control of the flux and torque in a squirrel cage induction motor. Sensorless vector control system calculates the base speed of the motor based on the specifications of that motor. Calculated counter electromotive force, inverter output voltage, inverter input current, and the results are improved dynamic control compared with other systems of control.

Vector control without a tachometer becomes impractical below a few hertz due to slight variations in stator resistance, a small counter electromotive force and other parameters which have an effect on accurate speed calculations. Sensor less vector control will operate at low speed, and will produce full torque at a few hertz, with 150% or more torque available at all speed. But there are some complicated techniques required to achieve low speed torque, and this may require expert commissioning to get the best results for your operation.

2.17 Speed Torque

In the speed-torque charts there are four sectors which are governed by the direction of rotation and torque. A single quadrant drive operates in quadrant 1 or 3 where quadrant 1 is for forward motion, clockwise, and sector 3 is for reverse motion, counter clockwise. Where reverse motion is achieved by reversing the direction of the rotating magnetic field in the stator.

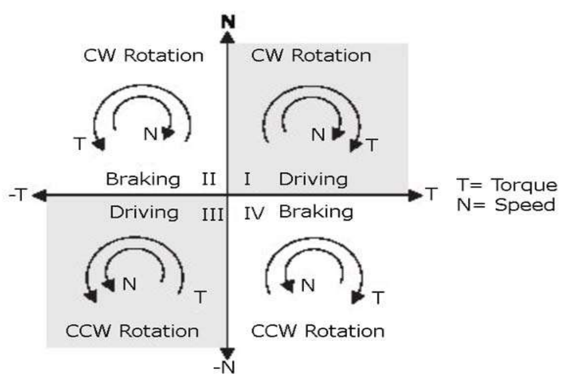


Figure 9 Speed Torque Graphic

The motor torque is developed in a positive direction to drive the load at the required speed, and this is the same as any load in that the maximum amount of torque is required to move the load from standstill. Once it is up to the required speed the torque can be reduced to the amount required to maintain that speed at a constant, but if the load increases then more torque will be required to maintain the speed at the preset level.

2.18 Controlled Braking

Stopping the motor in a quadrant 1 situation is achieved by simply removing the power from the motor and allowing it to coast to a standstill, as would happen with any motor with the power supply removed.

Controlled deceleration can be achieved by gradually reducing the voltage and frequency until the motor is at a standstill. The time taken will depend on the amount of inertia in the rotor and the connected load, to dissipate its energy, the greater the inertia the greater the time to stop.

2.19 DC Injection Braking

The motor can also be stopped by DC injection braking, which will stop the rotating magnetic field, and apply a constant voltage to the stator windings which will help to stop the motor. Where in this method up to 250% of the motors rated current can be applied to the windings, which will rapidly bring the motor to a standstill.

2.20 Compound Braking

Compound braking can be used with a combination of controlled deceleration and DC injection braking, and this is achieved where the drive monitors the bus voltage during operation. Which triggers braking when the bus exceeds a set threshold point, as the motor decelerates a DC voltage is applied to the motor windings periodically, and the excess energy is dissipated into the motor windings until it comes to a standstill.

With certain dynamic loads quadrant 4 operation may be required when an additional resistor is employed for braking, torque will tend to cause the motor rotor to run towards synchronous speed, and if synchronous speed is suddenly reduced, negative torque is developed in the motor. Where at this point the motor will act like a generator, converting mechanical energy at the shaft into electrical power which is returned to the drive and braking occurs in quadrant 2 and 4.

2.21 Pulse Resistor Braking

For a drive to operate in quadrant 2 and 4, a path must be created to channel the electrical energy returned to the drive by the motor. This motor energy can cause voltage in the DC link to become extremely high when added to the existing supply voltage, at which point various drive components can be damaged by excessive voltage.

So in the case of companies such as Siemens an optional braking resistor can be supplied.

The braking resistor is added and removed from circuit by an IGBT, and the energy returned by the motor is seen on the DC link. So that when the DC link reaches a predetermined limit the IGBT is switched on by the control logic, and the resistor placed across the DC link.

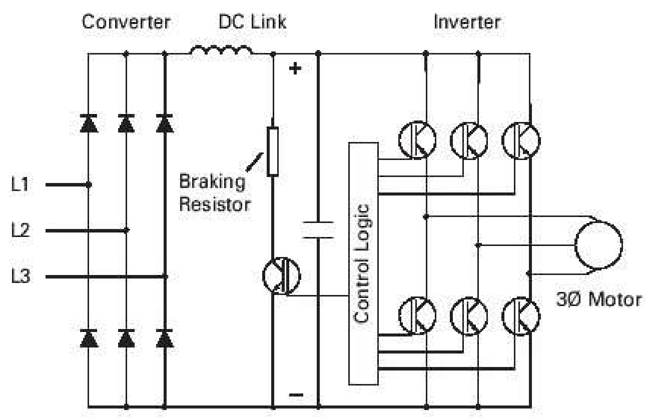


Figure 10 Braking resistor & IGBT

The excess energy is dissipated by the resistor reducing the bus bar voltage. When the voltage is reduced to a safe level the IGBT is switched off, removing the resistor from the DC link.

This mode of braking is referred to as *pulse resistor braking*, and this allows the motor to work as a brake slowing the connected loads quickly.

2.22 Protective Features

The VFD shall include the following protective features:

- Protection against input transient voltage spikes.
- Separate overload protection for each motor controlled.
- Protection against input power under voltage, over voltage, and phase loss.
- Protection against output current overload and over current.
- Protection against over temperature within the VFD enclosure.
- Protection against over voltage on the DC bus.
- DC bus discharge circuit for protection of service personnel.
- Insensitive to incoming power phase sequence.

3 How Do I Operate It

3.1 General Guide

Controls are provided for the operator to start and stop the motor, adjust the motor speed to their requirement and switching for a reversing function. The operator interface will have all the usual drill console control and indication. This will also provide information about the drive operation while drilling.

When the motor is started with the VFD, it is normally low frequency and low voltage, with a starting frequency of 2 Hz or less is common, starting with such a low frequency avoids the high inrush currents typical of DOL starters, so when the VFD starts, the applied frequency and voltage are increased at a controlled rate, or ramped up accelerating the load without drawing excessive current, the range is from about 2 Hz to 90 Hz for the range from 0 to max speed.

This starting method allows the motor to develop 150% of the rated torque while drawing only 150% of the rated current. Instead of the normal 300% plus current of a normal DOL starter, with less than 150% of the rated torque, and the load accelerates with 150% torque which can remain constant from standstill to full speed while still only drawing 150% of the current.

The VFD stop sequence is the opposite of the starting sequence, where the frequency and voltage are ramped down at a controlled rate, and when the frequency approaches zero the motor is shut off, and a small amount of braking torque is available to help decelerate the load a little faster than if the motor was just switched off and allowed to coast to a stand still, additional braking can be obtained by adding a braking circuit to dissipate the braking energy or return it to the power source.

4 Inspection

4.1 Daily General Rig Inspections

Check inside all the cabinets and make sure they clean and dust free, and that any filters on the cooling systems are clean, to maintain a good air flow for cooling and prevent the entry of dust and dirt into the cabinets, in the VFD power supply system

Check all the normal interlocks to make sure they are operating and all the auxiliaries are operating as they should, such as motor cooling blowers, lube oil pumps, and cooling pumps, when the assignments are made to start the Top Drive to provide all the ancillaries for the operation of the Top Drive

There should be a daily visual inspection of the Top Drive unit during the morning walk round inspection of the rig, to make sure there has been no overnight damage that is obvious on the Top Drive, or service loops during the operation, and that there are no obvious lose nuts and bolts on the assembly.

Check the alignment cylinder operation weekly. Also, inspect all moving parts and check the accumulator pressures on a weekly basis.

Varco installs exhaust mufflers on the exhaust ports of the multi-gang solenoid valve manifold for noise abatement. All such mufflers reduce noise, ***and*** collect contaminates that can eventually restrict the air passage. Air passage restriction can result in back pressure on all of the solenoid valves, and erratic valve operation.

Check the operating controls and instrumentation for the unit on the Drillers Console on the daily walk round inspection and check with the Driller to see if there are any problems that have occurred over night that needs to be attended to at the next drilling break.

Service loops are always a concern and should be observed for any signs of damage from drilling equipment on the morning walk around in case they are no longer being restrained to keep them clear of rotating equipment during their travel up and down the derrick and being kept out of harms way, as failure can be expensive and time consuming.

In the case of Drawworks, Mud Pump, and Rotary Table motors, these need to be kept clean, and cooling systems inspected to be sure that adequate cool air is circulating to maintain the motors normal working temperature and prevent overheating of the motor.

5 Maintenance

5.1 General Maintenance

The VFD can be considered to be two sections, power and control, with the power section controlling high current and variable voltage and frequency to deal with the output to the traction motor to drive the drilling equipment on the rig. With the control section the control is left to a Digital Signal Processor which meets the logic and decision making requirements.

5.1.1 Cleaning

With the maintenance on these units there are several things to consider as basics, in that they need to be kept clean to reduce the risk of tracking or flash over in the components which will occur if dust and dirt are allowed to accumulate. The units need to be blown out with clean dry air, paying attention to the dry part, as some air systems on a rig if the air driers are not working, will be carrying a lot of moisture and in some cases oil, which can be dumped in the equipment with unwanted results.

There is always the risk when blowing equipment out with compressed air of generating electrostatic charges which can damage components as well. There are cans of non static generating sprays, and purpose built vacuum cleaners that will reduce static build up, and these are available from companies that specialise in static control equipment to prevent damage to static sensitive equipment.

For the same reasons the units need to be kept dry, even more so if there is a build up of dirt or dust which can become mud with a little moisture. This can provide paths for tracking or flash over which will leave a lot of damage if it should occur, and may be difficult to repair quickly, so it is better if it never occurs.

5.1.2 Termination Tightness

A check should be kept on all terminations to make sure there are no loose connections that can become hot joints in the future as these too can cause damage that may be difficult to repair. Vibration and heat cycling can lead to terminations that are not as tight as they should be and these should be checked occasionally to make sure they are tight, but re-torquing is not recommended as this can lead to stretched bolts if performed too often, and the deformation of the contact faces and reduction of current carrying capacity.

5.1.3 Filter System Checks

As with most equipment of this type cooling is critical, so any air filter systems that are there to keep the dirt and dust out, need to be kept clean to maintain the air flow to the equipment for cooling purposes. The filters should never be left off the intakes, as once the dust or dirt gets into the heat sinks it can be very hard to remove, and cause a fall in the performance of the system and risk loosing components to overheating

5.1.4 Air Conditioning Checks

In most situations if the rooms are air conditioned this will remove much of the moisture from the air and dump the condensate outside the switch room. But if the air conditioning system fails, the cold parts will suffer from condensation when the warmer air hits them as the room warms up to the outside temperature.

Because the VFD is controlled by what is basically a computer, and that computers are temperature sensitive, and should be in an environment where the temperature is controlled for them so they do not become subjected to extremes of temperature. As with any electronic equipment if this is observed one can expect trouble free operation for a long period of time.

5.1.5 Space Heater Checks

If the system is operating continuously the warmth of the components will drive out any moisture, and in some early systems there was condensation protection installed that would not allow the system to start if the temperature was below 32° F. But very few have this now, but space heaters can be used if the equipment stands idle for long periods of time so the components are kept warm and free of condensation.

5.1.6 Temperature Checks

The heat sink temperatures should be monitored, and most manufacturers have made this easy by installing a temperature readout on the key pad or display. It should be part of the normal routine to check these readings on a weekly or monthly basis to monitor the VFD operation, and perhaps keep a record of these readings in a log book.

6 Spare Parts

6.1 General Spares to be Kept

There should always be spares kept available for critical items to the operation either on the rig or in a warehouse nearby where they can be obtained quickly in the event of failure. At the top of this list should be a spare motor which should be available if required to replace the unit in service. Also any control modules that are critical to the operation so they can be changed as quickly as possible in the event of failure.

6.2 Spare Components

Also there should be a stock of critical items such as throttles, switches, solenoids, micro-switches, sensors, and printed circuit boards, and any other items where failure is not an option in the Top Drive system. If repairs are to be attempted on the rig then there needs to be a stock of components to affect the repairs, although if there are spare printed circuit boards, and the fault has been found on the damaged board removed, then the components required can be ordered to repair it. Bear in mind the fact that other items may have been stressed when that component failed, so there may be more than one fault on that PCB.

It is not normally necessary to carry the complete recommended spare parts list the manufacturer would have you carry in stock, as some of these items will never be used and take up valuable warehouse space on the rig, and only time will confirm which parts should be kept on the rig at all times.

It is the custom with most major manufacturers to do the same with spare parts, where they try to have major distribution centres where they can dispatch parts within 24 hours via air or road freight anywhere in the World, but this may not be quick enough for your situation so critical parts need to be within easy reach.

Spare VFDs should be stored in a clean, dry environment with no condensation allowed, and it should be placed in the PM system so that it is powered up every 6 months to keep the DC bus capacitors at their peak performance condition or their charging ability will be significantly diminished. A capacitor is much like a battery in that it needs to be used as quickly after its purchase as possible or it will suffer a loss of usable life.

7 Trouble Shooting

7.1 What If It Breaks Down

Depending on what motor the VFD is controlling and what is happening with the drilling operation at the time of the failure will dictate the impact.

Generally if no redundancy exists with the equipment, for example the Top Drive motor. It is critical to the safe operation of the rig to diagnose and repair the fault as soon as possible. It cannot be stressed more highly that any equipment that falls into this category should be the first that you should familiarise and become conversant with.

7.2 Fault Finding

With VFDs the essence of keeping it in good working order is to " keep it clean" " keep it dry" and " keep the connections tight", which will normally give trouble free operation for many years if the preventative maintenance is maintained. Whenever work needs to be done on the VFD great care should be taken that there is no stored voltage present in the form of the DC capacitors, which will need to be discharged before work is commenced to make the unit safe, and the DC bus capacitors should be checked to see if they are swollen or leaking, and in either case it could be a sign of component stress, or electrical misuse and they will need to be replaced.

If measurements are taken of the voltage in the DC bus while the unit is running, any fluctuations can indicate degradation of the DC Bus capacitors, as one of the functions of the capacitors is to act as a filter to smooth out the AC ripple in the bus, so any AC ripple or abnormal AC voltage on the DC bus indicates the capacitors are starting to fail and will need to be replaced. Measurements at these points in the DC system of more than 4VAC can indicate a capacitor filtering problem, or a possible problem with the diode bridge section ahead of the bus, and if such voltage levels exist, consult the VFD manufacturer before taking further action.

Most VFDs are equipped with terminal blocks at which these test measurements can be taken and also for the connection of the dynamic braking resistors. With the VFD in start at zero speed, one should read an output voltage of 40VAC phase to phase or less, and if you read more than this, you may have a transistor leaking, and at zero speed the power components should not be operating, but if your readings are 60VAC or more you can expect power component failure.

8 Questions

1. What is the name of the twisting or turning force that causes a motor to rotate?

   a. Torque b. Inertia c. Friction d. Acceleration

2. The rate of doing work is called?

   a. Inertia b. power c. speed d. energy

3. A motor with the rating of 60 kW would have an equivalent horsepower rating of?

a. 16.7 b. 47 c. 53 d. 150

4. Magnetic lines of flux in an AC motor are proportional to

   a. voltage/frequency b. frequency/voltage
   c. rotor speed/synchronous speed
   e. synchronous speed/rotor speed.

5. A four pole motor operating at 50 Hz has a synchronous speed of rpm

   a. 1500 b. 3000 c. 1800 d. 3600

6. A motor operated within a speed range that allows a constant volts per hertz ratio is said to be

   a. constant HP. b. variable torque c. constant torque
   d. variable flux

7. The section of an AC drive that controls output voltage and frequency to an AC motor is the

   a. converter b. DC link c. inverter d. L1 choke

8. A centrifugal pump is what kind of application.

   a. constant torque b. constant flux
   c. constant HP d. variable torque

9. IGBT's are capable of being switched how many times a second

   a. 60 times b. hundred times
   c. several thousand times d. million times

9 Reference Material

The best reference material for any equipment is the manufacturer's service manuals that are usually supplied with the drives when they new.

These manuals cover everything from installation to the commissioning when it is newly installed to trouble shooting and fault finding when the system is in normal operation.

In most cases there are people employed with the manufacturers who can assist in time of need by email or by telephone who can talk over a problem with you on the company technical support line.

9.1 References

Institute of Electrical and Electronic Engineers:

IEEE C62.41 - Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits.

9.1.1 Compliance

National Electrical Manufacturers Association:

NEMA ICS 7.1 Safety standards for construction and guide for selection, installation, and operation of adjustable speed drive systems.

NEMA ICS 7 Industrial control and systems: adjustable speed drives.

NEMA FU1 Low voltage cartridge fuses.

NEMA 250 Enclosures for electrical equipment (1000 volts maximum).

9.2 Web Sites

http://www.sea.siemens.com/step/default.html

http://www.vfdsystems.com/

http://www.nov.com/Archives/c2orange.pdf

http://www.mielectric.com/brochures/AcDc.pdf

10 Work Place Assignments

Note.

This assignment is to make you aware of all the AC driven equipment that is supplied and controlled by a VFD that makes up your work place systems. It will lead you to the main source of supply being the VFD Panel (variable speed drive) and then onto the motor and control equipment that is supplied from this equipment.

1. Find all VFD Control Cubicles (VFD) associated with the AC motors being supplied and controlled from this equipment. Write down the description and tag number that is displayed on the VFD.

2. Go out into the field and locate the associated motor that this drive controls. It should be clearly identified with the same description and tag number that you found on the VFD cubicle.

3. If you look closely there should be a Stop/Start station with the ability to adjust the speed of the equipment nearby clearly marked with the same ID. This device should also have the ability to lock out the motor from starting for maintenance. Be aware that this motor may also be controlled from a remote location.

4. Look for all of the documentation including schematics and layout diagrams associated with this equipment. Make yourself conversant with type of systems you have discovered and the AC motors that are controlled and feed from this equipment.

5. Particular attention should be given to the trouble shooting documentation. Read carefully all of the information given covering this area and familiarise yourself with the locations of fault indications and test points.

6. If your rig has an AC top drive ask your drilling supervisor to show you the driller's controls and to explain the functions that are common to this system.

11 Glossary

Variable Frequency Drive (sometimes abbreviated VFD) Is electronic equipment that allows an electric motor to be run at varying rotational speeds. VFDs are frequently used to start large three-phase AC synchronous motors. These motors cannot be started simply by applying line frequency mains power; the rapidly rotating magnetic field would be unable to overcome the inertia of the rotor (and any connected load). Using a VFD provides one possible means to start these motors: the VFD will start using a low frequency that the rotor can follow, ramping up the frequency as the rotor accelerates. And unlike other starting methods, the VFD also allows very efficient speed control once the motor is running (simply by varying the ultimate frequency of the supplied power).

Adjustable speed The concept of varying the speed of a motor either manually or automatically. The desired operating speed (set speed) is relatively constant regardless of load.

Base speed Base speed is the manufacturers nameplate rating where the motor will develop rated HP at rated load and voltage. With DC drives, it is commonly the point where full armature voltage is applied with full rated field excitation. With AC systems it is commonly the point where 60 Hz is applied to the induction motor.

Bi-Directional Motors have equal performance characteristics in CW and CCW rotation.

Breakaway Torque The torque required to start a machine from standstill. It is always greater than the torque needed to maintain motion.

Breakdown Torque The breakdown torque of an AC motor is the maximum torque which it will develop with rated voltage applied at rated frequency

Constant voltage range (AC Drives) The range of motor operation where the drive's output voltage is held constant as output frequency is varied. This speed range produces motor performance similar to DC drive constant horsepower range.

Constant volts per Hertz This relationship exists in AC drives where the output voltage is varied directly proportional to frequency. This type of operation is required to allow the motor to produce constant rated torque as speed is varied.

Current Limiting An electronic method of limiting the maximum current available to the motor. This is adjustable so that the motors maximum current can be controlled. It can also be preset as a protective device to protect both motor and control from extended overloads.

Duty Cycle Is a ration of operating time to total cycle time, expressed in percent.

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Efficiency Of a motor is the ratio of output power to input power, and is expressed in percent.

IGBTs Insulated Gate Bipolar Transistor Is a four-layer (n-p-n-p) device with an MOS-gated channel connecting the two n-type regions. In the normal mode of operation, a positive voltage is applied to the anode (A) relative to the cathode (K).

Inverter A term commonly used for an AC adjustable frequency drive. An inverter is also a term used to describe a particular section of Ac drive. This section uses the DC voltage from a previous circuit stage (intermediate DC circuit) to produce an AC current or voltage having the desired frequency.

MOSFETs Metal Oxide Silicon Field Effect Transistor A common type of transistor in which charge carriers, such as electrons, flow along channels. The width of the channel, which determines how well the device conducts, is controlled by an electrode called the gate, separated from channel by a thin layer of oxide insulation. The insulation keeps current from flowing between the gate and channel.

No Load Speed Expressed in RPM, represents rotational speed of the motor when no force is applied to the output shaft.

Open Loop A system in which there is no feedback. Motor motion is expected to faithfully follow the input command. Stepping motor systems are an example of open-loop control.

PWM (pulse width modulation) Type of AC adjustable frequency drive that accomplishes frequency and voltage control at the output section (inverter) of the drive. The drive's output voltage is always a constant amplitude and by chopping (pulse width modulating), the average voltage is controlled.