Induction motors & AC drive Theory

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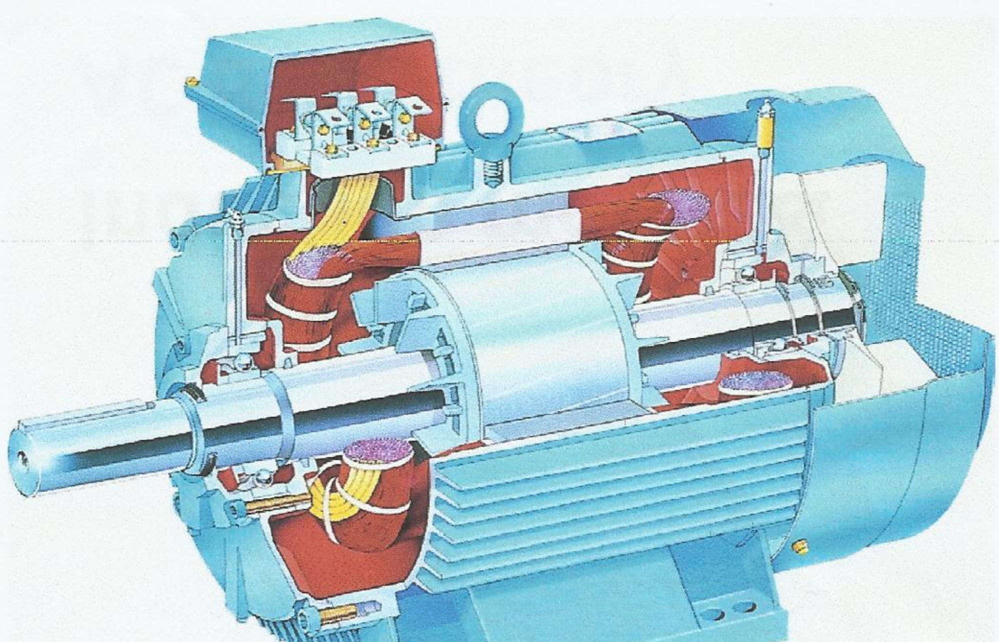

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AC DRIVE:-

Also called by terms a variable frequency drive, variable speed drive, adjustable – frequency drive and it is used to control AC motor speed and torque by varying motor input voltage and frequency and it can be used to control small motors and big motors in low voltage and medium voltage systems.

Advantages of the variable frequency drives:

1- power saving.

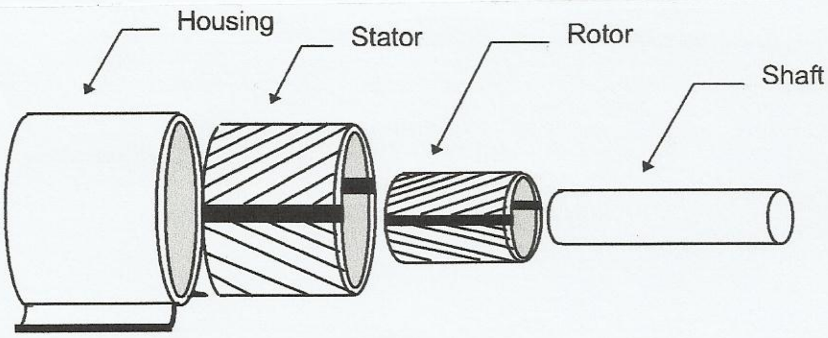
2- Accurate speed control.

3- Low maintenance.

To understanding AC drive theory we should review the principles for AC motor operation

AC MOTOR FUNDAMENTALS

Components of Electric Motor



Electric motors are really quite simple. There are only four basic parts to an electric motor:

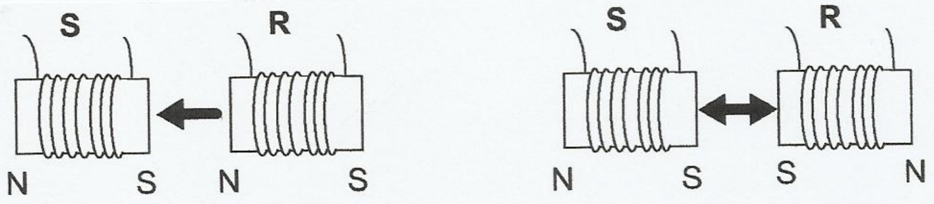
• Housing or external case that surrounds the other components.

• Mounted inside the housing is the stator. The stator is the stationary or non-moving part of the motor's interior, it is made up of wire winding, the moving parts of the motor are the rotor and the shaft.

• The rotor, like the stator, also has windings.

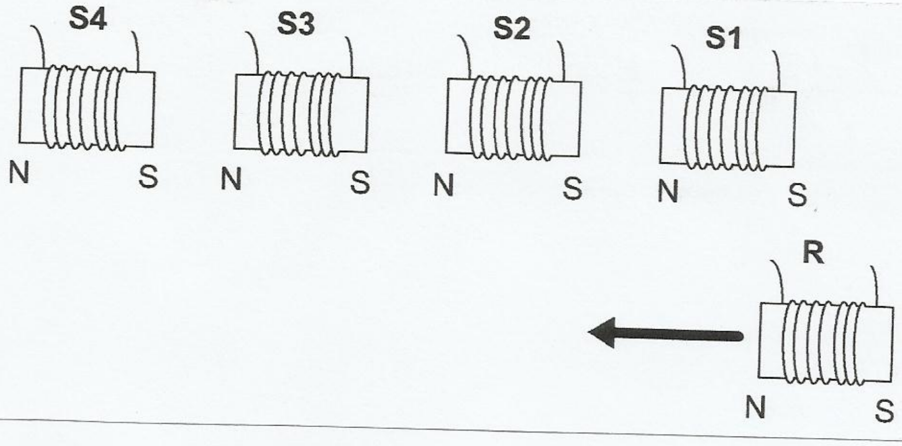
• The rotor is connected to the fourth components, the shaft, the shaft is a metal rod held in position within the stator by bearing connected to the case, the bearings allow the shaft to rotate inside the stator, and the rotor and shaft are often referred to as the armature of the motor.

How an Electric Motor Operates:

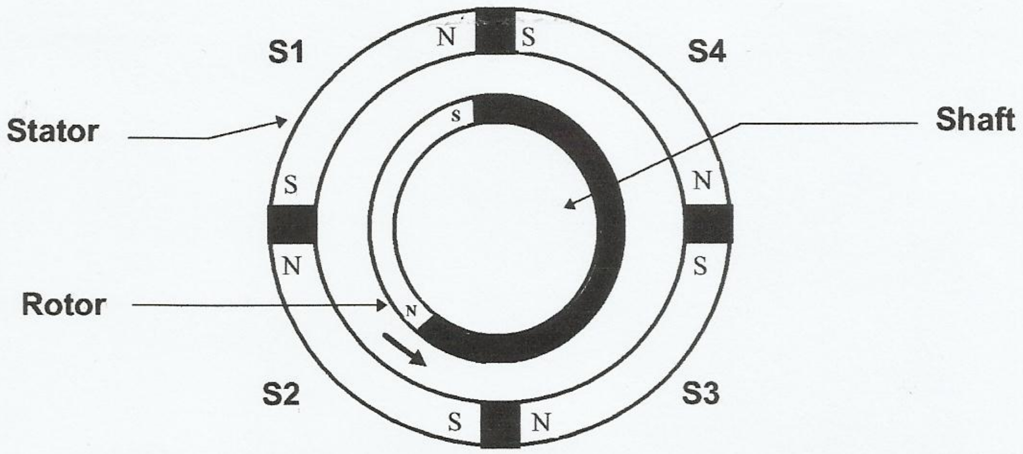


The electric motor operates by converting electrical energy into mechanical energy, let's represent the Motors's stator as an iron block "S" and the rotor as an "R", both of these iron blocks are wrapped with wire coils, when electrical current is passed through the wire coils, an electromagnetic field is created and the iron blocks became magnetized, all magnets have a North and South pole. A north pole is always trying to get next to south pole and visa versa, two North or two South poles will push away or repel each other, in other meaning , opposite poles attract and like poles repel, it's this magnetic pull and push principle that makes an electric motor operate.

Suppose that "S" is fastened such that it cannot move , on the other hand , "R" is allowed to move freely ,When electricity is passed through the coils and the blocks are magnetized , the opposite poles try to pull together , block "R" will move towards block "S" if the blocks get together the movement will stop , What if block "S" were mounted in such a way that block "R" couldn't contact it ? Block "R" would move until its pole were as close as it could get to block "S" and then motion would stop.



Let's add more "S" blocks (S1,S2,S3, and S4) if S1 were demagnetized just as "R" reached it , and S2 is magnetized , "R" would continue moving toward "S2" , if this same process of demagnetizing and magnetizing S1 , then S2 , then S3 and finally S4 , were continued then block "R" would be moving all the time until it reach S4.



In electric motors the "S" magnets are formed in a circle and the "R" magnet placed inside this circle and is attached to shaft. The stator and the rotor are magnetized as current flows through the coil winding, the rotor moves so that the opposite poles of the winding s can tray to move closer to the stator magnets, just as the magnets are close the magnet field moves on in the stator, and the rotor chases after it, since the rotor and shaft are fastened together, the shaft moves, the rotation of the shaft is the mechanical energy created by the conversion of the electrical energy by the motor.

To summarize , the rotor "chases after" the changing magnetic field of the stator which causes the rotor and the shaft to rotate , the magnetic field of the stator and rotor are changed according to the frequency of the AC voltage applied to the motor , changing the frequency of the voltage applied will alter the speed at which the stator's magnetic field change , this will in turn , change the speed of the rotor , changing the current will alter the strength of the magnetic field s of the rotor and stator , the stronger the magnetic fields the grater the turning force applied by the rotor to the shaft , this twisting or turning force called torque.

Types of AC Motors:

The four principle types of motors (not including single phase types) found in commercial and industrial applications are:

- Squirrel cage induction motors.
- Wound rotor induction motors.
- Synchronous motors.
- Direct current motors (DC).

The squirrel cage induction motors is by the far most widely used motor because its low cost and proven reliability, the wound rotor induction motor has been used in applications that require high starting toque, or speed control, the synchronous separately exited motor has been used in high – horsepower applications were it is advantageous to overexcite the motor to provide power factor correction in an industrial facility.

The synchronous permanent magnet and reluctance motor is used in applications that need precise speed for a number of motors operating in combination.

But the squirrel cage motor is by far the simplest, most reliable, least expensive, most readily available and easiest to maintain, in addition with improvements in AC drives, squirrel cage motors are now applied in the majority of applications.

MOTOR TERMS AND CONCEPTS

- **Electric service :** is a term used to describe or define electric power supplied to a motor the selection of the control products depends upon the information that is included as part of electric service , this information includes:

  a- Current - the current used by the motor is either AC or DC.
  b- Phase – a motor can be powered by either single or three phases.
  c- Frequency – is the number of electric pulses that are transmitted over a given period of time, frequency is measured in hertz (Hz).

d- **Voltage** – electric motors are designed to operate a specific voltage, motor control devices are also rated according to the voltage that can be applied to them.

• **Locked rotor current** (LRC) - is the current flow required by motor in order to start motion.

• **Full Load Amps** (FLA) - this is the current flow required by a motor during normal operation to produce it is designed HP.

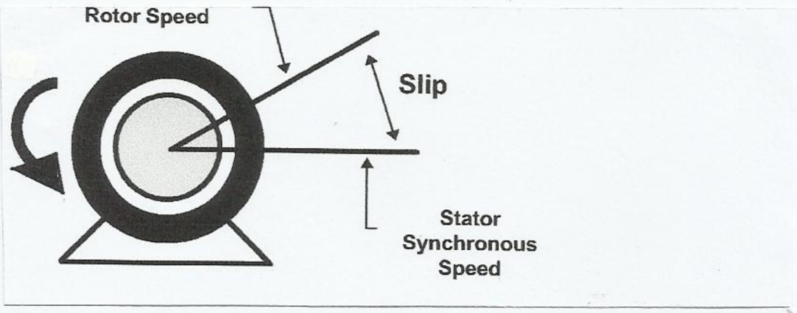
• **Speed** - (revolution per minute) Synchronous Speed is the speed of AC induction motor's rotating magnetic field, it is determined by the frequency applied to the stator and the number of magnetic poles present in each phase of the stator winding this is can be expressed by the formula :

Synchronous Speed $= \frac{120 \times Frequency}{Number\ of\ poles}$

Motor Slip: Slip is the difference between the rotating magnetic field speed in the stator and the rotor speed in AC induction motors , this is usually expressed as a percentage of synchronous speed , if the rotor were rotating at exactly the same speed as the stator's rotating magnetic field (for example , 1500 rpm) then no lines of magnetic force would be cut, no voltage would be generated in the rotor and no current would present , However , if the rotor slows down by 50rpm it would now be running at 1450 rpm vs 1500 rpm of the stator field , the rotor bars are now cutting the rotating field at a 50rpm rate , Now voltage and current would be generated in the rotor , with a resulting magnetic flux pattern , the interaction of these magnetic field would produce torque , the difference between the synchronous and actual rotor speed is called slip and it is represented by :

Slip $= \frac{Synchronous\ Speed - Rotor\ speed}{Synchronous\ Speed} \times 100$

$= \frac{1500-1450}{1500} \times 100$, Slip = 3.3%



• **Torque**- ft.lbs : is formally defined as " the force tending to rotate an object , multiplied by the perpendicular radius arm through which the force acts" in the case of motor , torque is the force which acts on the shaft and causes rotation and the amount of the torque created is directly related to the amount of the current applied to the motor , a motor is a dumb device as the load is increased on the shaft the will draw more current (to increase the torque) to try and keep the load moving , if the load were to continue to be increased the motor will literally destroy itself trying to create the necessary torque to move the load .

• Torque VS Speed Relationship:

Torque is a force exerted on the Motors's shaft when a load is added to the rotor, the tendency is for the rotor to slow down , which will create more slip (difference between the stator magnetic field speed and rotor speed), thus creating more torque within the motor ,as the load is increased the rotor will continue to slow down , which would result in even greater slip as the rotor lags behind the synchronous speed of the rotor the increased resistance to rotation increases the slip and therefore increases the torque.

• **Horsepower**: motors and engines are measured in horsepower , horsepower is a standard unit of power which is used to measure the rate at which work is done , one horsepower is the equivalent of 550 foot-pounds per second , that is the ability to lift 550 pounds one foot in one second, then the motor has a horsepower rating of 1 hp.

In any electric motors the motor torque can be multiplied by the motor speed and the product divided by 5250 (a constant) to determined the rated horsepower.

$$HP=\frac{Torque(ft.lbs.)\times Speed(RPM)}{5250}$$

This formula will help us to select the proper motor for application , the relationship between torque and speed , it is obvious that a 5 hp motor designed to run at high speed will have very little torque , to maintain the equation , torque must decrease as speed increases:

$$Hp = \frac{\text{Torque (ft.lbs.)} \times \text{Speed (RPM)}}{5250}$$

Conversely, a 5 hp motor with high torque must run at slow speed:

$$Hp = \frac{\text{Torque (ft.lbs.)} \times \text{Speed (RPM)}}{5250}$$

From the previous information we will get important relationship:

SPEED IS RELATED TO FREQUNCY

AND

TORQUE IS RELATED TO CURRENT

Horsepower can express in electric terms as:

HP (output) = $\frac{Volts \times Apms \times 1.73 \times Powerfactor \times Efficiency}{746}$

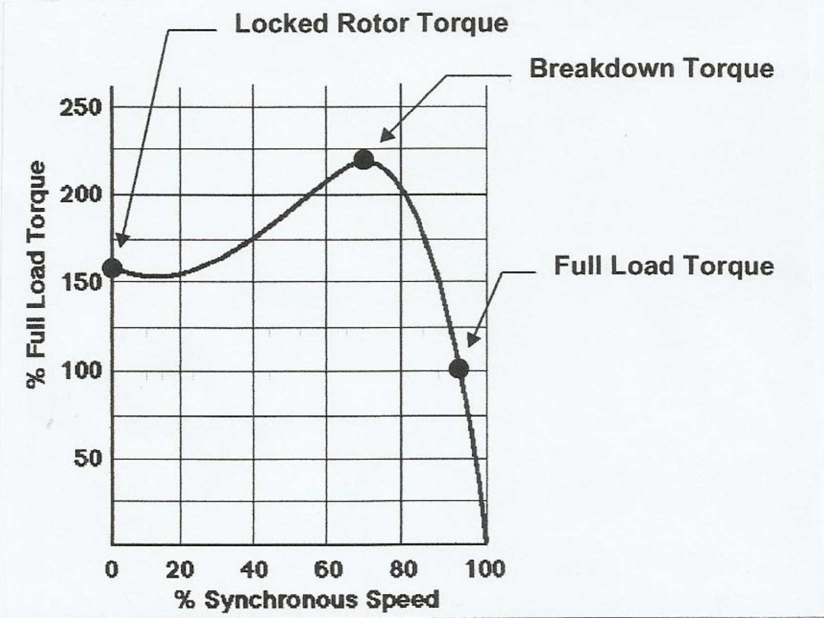
- **Constant and Variable Torque:**

If we look at a motor's usage based on the torque requirements of an application, we will find that we may need constant torque or variable torque, one application might require normal starting torque and normal running torque, for example, a drill machine, this category requires that a motor starts with normal amount of torque and then continues to run at the required speed.

Another application category might require a high starting torque but a normal running torque, for example a conveyor that is first loaded up and then started the motor must provide a big push of torque to get the conveyor and its load moving, once moving inertia has been overcome and the resistance of friction falls, therefore normal running torque provides adequate power to keep the conveyor running.

The third torque category would be an application that requires a very high starting torque, and a normal running torque.

Starting and running torque can be plotted, as the starting torque increases, motor speed decreases.



• **Breakdown torque:** is the maximum torque that a motor can produce, higher torque requirement will slow motor speed to a stop, breakdown torque is the point where speed stops as torque requirement increases.

•**Full load torque:** is the amount of torque developed by the motor at rated speed and rated current, the rated speed and current values can be found on the motor nameplate.

MOTOR NAMEPLATE DATA

Squirrel cage induction motor, like any other type of electrical equipments, require proper application for successful operation, understanding the nameplate information, which identifies the motor's important features and characteristics, will aid considerably in proper application.

A nameplate is attached to each AC motor and includes information such as:

- Full load speed.
- Type of enclosure.
- Type of insulation.
- Temperature rise rating.
- Service factor.
- Time rating.

• **Full Load Speed:** the motor nameplate identifies the rated full load speed, this speed is one of the key considerations in determining the motor horsepower required for a given load, and the motor synchronous speed is influenced by the number of magnetic poles in the stator.

The synchronous speed is slightly higher than the motor shaft speed, as the number of poles in a motor design is increased; the rated synchronous speed is decreased per the formula:

Synchronous Speed $= \frac{120 \times Frequency}{Number\ of\ poles}$

• **Type of enclosure:** the motor nameplate usually identifies the type of enclosure and ventilation system, such as open type self- ventilated, totally enclosed fan cooled (TEFC), totally enclosed non ventilated (TENV), and others.

• **Insulation and Temperature Rise Rating:** the motor nameplate identifies the class of insulation material used in the motor and its rated ambient temperature, various types of materials can be used for insulation which is defined as Class A, Class B, Class F and Class H, IEEE Standards list temperature rating as follows:

Class A - 105° C , Class B - 130° C, Class F - 155° C, Class H - 180° C.

When the rated temperature of the insulation materials is exceeded, it is estimated that the insulation life is decreased by ½ for every 10 degree above the rating.

• **Service Factor:** a motor is rated by the manufacturer to produce a certain HP over a long period of time without damage to the motor, however, occasionally a motor might be operated intentionally or unintentionally above the rated HP, to protect against motor damage caused by the occasional excess current an electric motor is usually built with a margin of safety, the margin of safety is called the motor's service factor.

The nameplate identifies a service factor; 1.0 or 1.15 this indicates overloads which may be carried by a motor under nameplate conditions without exceeding the maximum temperature recommended for the insulation, For example, a 100 hp motor with a 1.15 service factor can sustain a 15% over load (100X 1.15= 115hp) continuously and will not exceed the temperature rating of the insulation in the motor.

• **Time Rating:** the motor nameplate identifies its time rating which can be continuous duty or short time , such as 60 minutes , 30 minutes , 15 minutes and 5 minutes, obviously, at a specified horsepower , a motor operating continuously will generate more total losses and will require a larger frame size , compared to a motor operating intermittently , the short time rating indicates the motor can carry the nameplate loads for the time specified without exceeding the rated temperature rise , after the short time , the motor must be permitted to cool to room temperature .

AC Drive

 # Fundamentals

 # Difference between soft starters and AC Drives

 # Advantages of AC Drives

 # Applications for AC drives

 # How AC drives work

 # Load consideration

 # Braking

PRIMARY PURPOSE OF MOTOR CONTROL

All electric motor s require a control system, that control may be as simple as an ON/OFF switch, such as for an exhaust fan. Or, the operation may be so complex that a computer must be used in the control system, such as in an automobile assembly plant application. Both the exhaust fan and assembly plant electric motors are provided with start and stop control by their control system , but the difference between their control system is how they provide that control, in addition to start / stop control, a motor control system may also provide motor overload protection as well as motor speed and torque regulation.

Difference between soft starters and AC Drives

A soft start device reduces the voltage, thus reducing the current, at startup to relieve the stress on the motor and machinery there are many applications where it is critical to do just this, in addition the soft start can allow a motor to have smooth acceleration up to 100% operating speed and can control a motor's smooth deceleration back down to zero as well.

An AC drive can also be a "soft start" device but it can also vary the speed and torque of the motor according to changing machine requirements, in the other words, after start up, the motor does not have to run at 100% speed and torque but these elements can provide to suit the application.

The soft start device reduces the voltage thus reducing the current at startup, While an AC drive does not reduce the startup torque, this can be a very significant factor depending upon the load application.

In short words **"an AC drive can act as a soft start, but a soft start cannot act as AC drive"**

Advantages of AC Drives:

- Energy saving, particularly for fans and pumps.
- Extended equipment life through reduced mechanical stress (belts, bearings).
- Elimination of excessive motor inrush current which in turn, extends useful motor life.
- Standard AC motors can be used, which are easier to repair, purchase and maintain.
- Solid state device which has no moving parts or contact to wear out.

Applications for AC drives:

AC drives can be used in many industrial fields to control pumps, fans, conveyors, compressors, etc. like:

1- Automotive assembly.

2- Food and Beverage.

3- Chemical.

4- Textile.

5- Paper.

6- Wood.

7- Metallurgy.

And in my work place (Delta Cement Plant, in Bazian), many AC drives used to control equipment operation like:

1- Kiln Main Fan (3000KW, 6.6 KV), 2- Apron feeders for main crusher (50KW, 400 V),

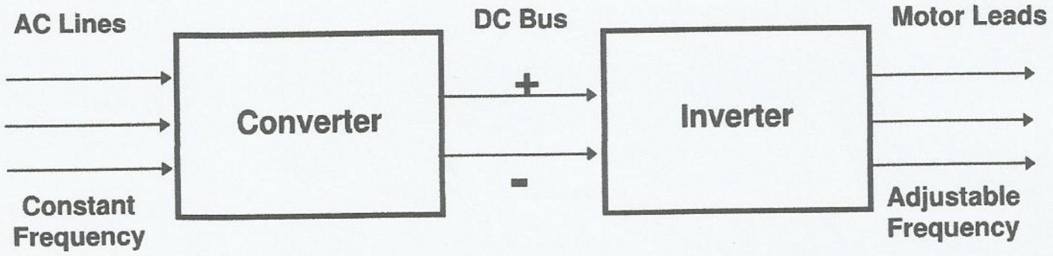
3- Kiln main drive (800KW, 1000V), 4- Weigh feeders in different sizes, 4- Hydraulic pumps for clinker grate cooler, and many another types of equipments.

AC DRIVE THEORY

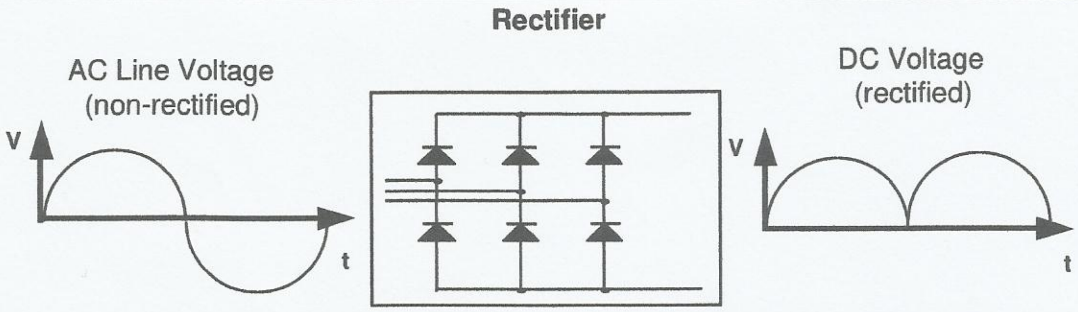
AC motor speed is controlled by frequency , **An AC drive is a device for controlling the speed of an AC motor by controlling the frequency of the voltage supplied to the motor ,** it does this by first converting 3 phase 50 Hz AC power to DC power , then by various switching mechanisms , it inverts the DC power into pseudo sine wave 3 phase adjustable frequency alternating current for connected motor, Because of this , some people call AC drives " inverters" , although this is technically incorrect.

There are two general types of solid state frequency control system available: six steps and pulse width modulation (PWM) control, and we will concentrate on PWM.

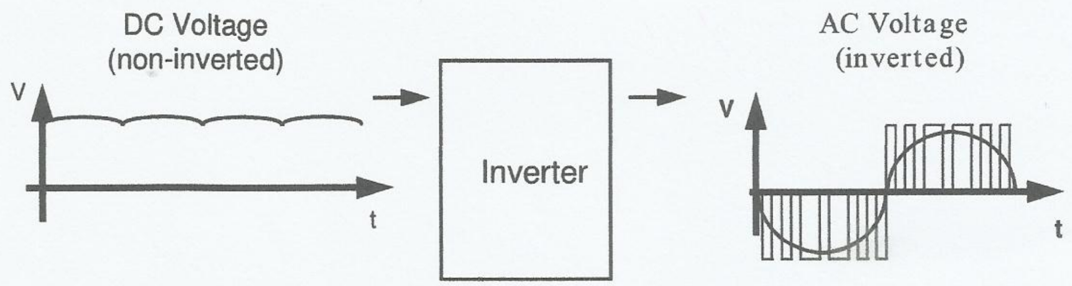
Let's look at how an AC drive function in more detail, the two main section of a PWM drive is the converter and the inverter.



Three phase 50 Hz AC power is coming into the converter, the converter typically uses a rectifier (which is a solid state device that changes AC to DC) to change the incoming 50 Hz AC into a rectified DC voltage.



The DC voltage coming out of the converter is rather rough, different types of filtering can be used to smooth out the rectified DC so that it is of a more or less constant voltage value , this takes place between the converter and the inverter stages , this smoothed DC is then sent on to the inverter.

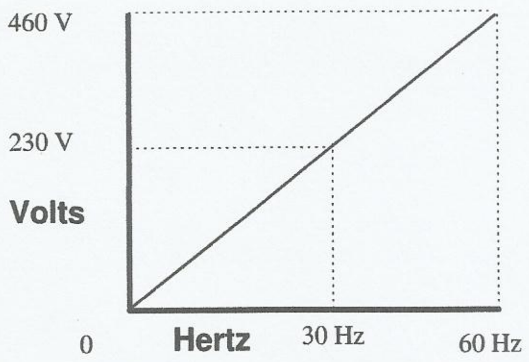


The inverter section produces an AC output which is fed to the motor, positive and negative switching occurs within the inverter which produces groups of voltage pulses , the output frequency of an PWM drive is the controlled by applying positive pulses in one half cycle , and negative pulses in the next half cycle, the pulses within each group have varying widths that correspond to voltage values , on the output side of the inverter that the narrow voltage pulses represent the lower voltage values on the sine wave and the wider voltage pulses represent pulse Width Modulation (PWM).

The diagram is only showing 6 pulses per half cycle, for each specific frequency, there is an optimum number of pulses and pulse widths that will closely simulate a pure sine wave.

Volts per Hertz Ratio

When current is applied to an induction motor it generates magnetic flux in its rotating field and torque is produced , this magnetic flux must remain constant in order to produce full-load torque , this is most important when running a motor at less than full speed, and since AC drives are used to provide slower running speeds , there must be a means of maintaining a constant magnetic flux in the motor, this method of magnetic flux control is called the volts-per-hertz ratio , with this method , the frequency and voltage must increase in same proportion to maintain good torque production at the motor.



For Example, if the frequency is 60 Hz and the voltage is 460 V, and then the volts per Hertz ratio (460divided by 60) would be 7.6 V/Hz. So at half speed on 460V supplied system, the frequency would be 30 Hertz and the voltage applied to the motor would be 230 V and the ratio would still be maintained at 7.6 V/Hz.

This ratio pattern saves energy going to the motor, but is very critical to performance; the variable-frequency drive tries to maintain this ratio because if the ratio increase or decrease as motor speed changes, motor current can became unstable and torque can decrease, on the other hand, excessive current could damage the motor.

In a PWM drive the voltage change required to maintain a constant Volts-per-Hertz ratio as the frequency is changed is controlled by increasing or decreasing the width of the pulses created by the inverter, and a PWM drive can develop rated torque in the range of about 0.5Hz and up. Multiple motors can be operated within the amperage rating of the drive (all motors will operate at the same frequency), this can be an advantage because all the motors will change speed together and control will be greater.

LOAD CONSIDRATION

The type of load that that a motor drives is one of the most important applications when applying any type of AC drive, for some types of loads ,the application consideration may be minimal , for other types of loads , extensive review may be required , generally , loads can be grouped into three different categories:

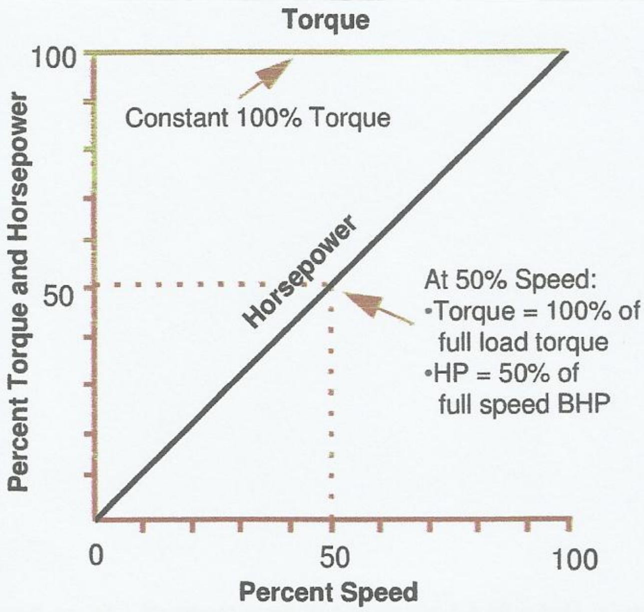
Constant Torque Loads: conveyors, hoists, drill presses, extruders, positive displacement pumps (torque of these pups may reduced at low speeds).

 # Variable Torque Loads: fans, blowers, propellers, centrifugal pumps.

 # Constant Horsepower Loads: grinders, turret lathes, coil winders.

Constant Torque Loads:-

Constant torque loads are where applications call for the same amount of driving torque throughout the entire operating speed range , in other words , as the speed changes the load torque remains the same .



as the speed changes , horsepower is effected , and varies proportionately with speed , constant torque applications includes everything that are not variable torque applications, in fact , almost everything but centrifugal fans and pumps are constant torque.

Variable Torque Loads:

As was mentioned, there are only two kind of variable torque loads, centrifugal pumps and fans, with a variable torque load, the loading is a function of the speed, and variable torque loads generally require low torque at low torque at low speeds and higher torque at higher speeds.

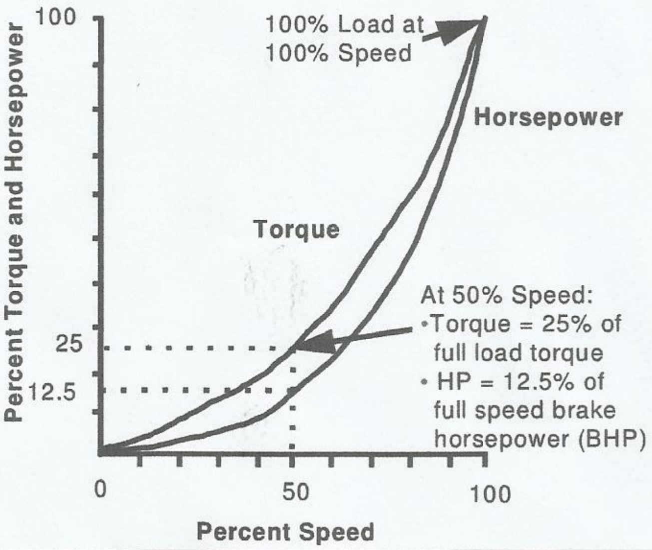
Fans and pumps are designed to make air or water flow, As the rate of flow increases, the water or air has a greater change in speed put into it by the fan or pump, increasing its inertia, in addition to the inertia change, increased flow means increased friction from the pipes or ducts, an increase in friction requires more force (or torque) to make the air or water flow at that rate.

The effects that reduced speed control has on a variable torque fan or pump are summarized by a set of rules known as the Affinity Laws; the basic interpretation of these laws is quite simple:

1- Flow produced by the device is proportional to the motor speed squared.

2- Pressure produced by the device is proportional to the motor speed squared.

3- Horsepower required by the device is proportional to the motor speed cubed.



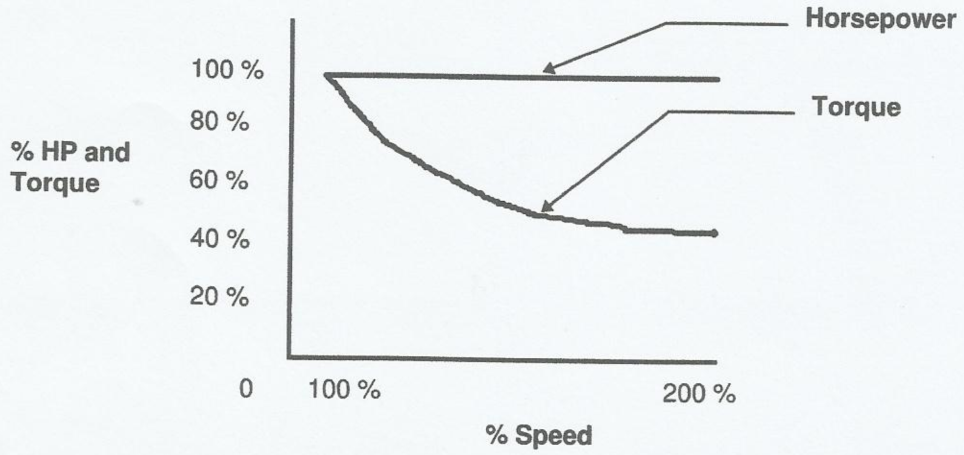
The cube low (third item) load is at the heart of energy saving , the change in speed is equal to the horsepower cubed, for example , you might expect a 50% change in speed would produce a 50% change in volume, and would required 50% of the horsepower, luckily for us , this 50% change in speed must be cubed, representing only 12.5% of the horsepower required to run it at 100% speed , the reduction of horsepower means that it costs less to run the motor, when these saving are applied over yearly hours of operation , significant saving accumulated.

This table will help show these relationships:

% Speed	%Torque	%HP
100	100	100
90	81	72.9
80	64	51.2
70	49	34.3
60	36	21.6
50	25	12.5

Constant Horsepower:

A constant horsepower load is when a motor torque required is above the motor's base speed (50 Hz), with a constant horsepower type of load, the torque loading is a function of the changing physical dimensions of the load, these types of applications would include grinders, turret lathes and winding reels, constant horsepower loads require high torque at low speeds and low torque at high speed, while the torque and speed changes the horsepower remain constant.



For example, an empty reel winding a coil will require the least amount of torque, initially, and will be accelerated to the highest speed, as the coil builds up on the reel, the torque required will increase and the speed will be decreased.

BRAKING

An electric motor moves its load and demand whatever amount of power is required to get the load moving and keep it moving, once the load is in motion it has inertia and will tend to want to stay in motion. So, while we must add energy to get the load into motion, we must somehow remove energy to stop it.

Some large motor loads develop high inertia forces when they are operating at high speed , if voltage is simply disconnected from the motor the load may coast for several minutes before the shaft comes to a full stop. This is true in applications such as those involving large saw blades and grinding wheels, it is important for safety reasons to bring these loads to smooth stop quickly.

In other load applications, such as elevators and cranes, the location where the load stops is as important as moving the load this means that the motor shaft must stop moving at a precise time to place the load at its proper location.

There are several different types of braking techniques used, and we will mention tow most used types:-

DC braking:

DC current is applied to the stationary field of an AC motor when the stop button is depressed, since the field is fixed and it replaces the rotating stator field, the rotor is quickly stopped by the alignment of the unlike magnetic field between the rotating and stationary windings, the attraction between the rotating and stationary field is so strong that the rotor is stopped quickly.

Dynamic braking:

When the voltage is removed from the motor and the inertia of the load continues on in motion , the motor is being driven by the load until it coasts to a stop , since the rotor will continue to spin , it will produce voltage and current in a manner similar to a generator , this generator action can be used to bring the rotor to a quick stop by sending the generated energy out to resistor , there the energy is dissipated as heat through the resistor , the resistor will cause the rotor to generate very high levels of current which produces magnetic forces on the shaft and causes it to stop quickly, this method used by most AC drives in the applications like big fans and separators.

References:-

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3- ABB AC Drives.