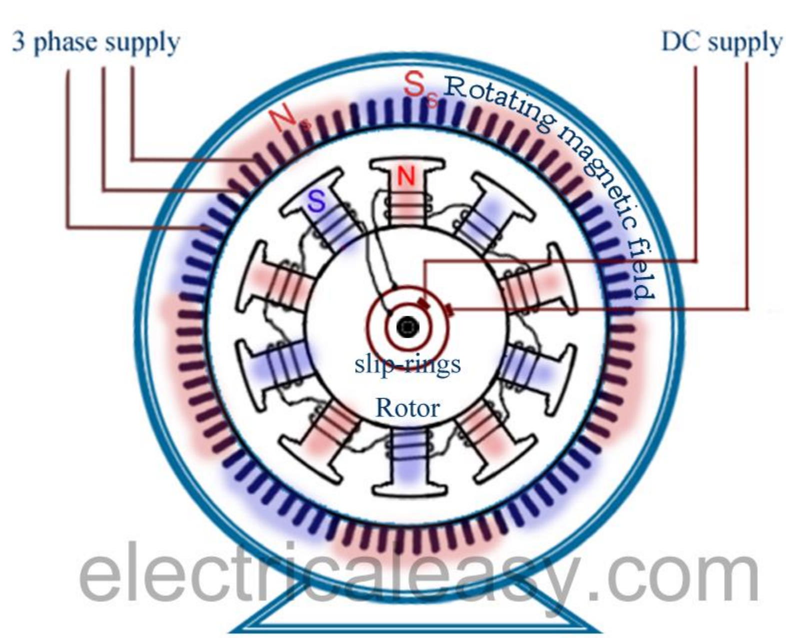
ROBOTICS AND AUTOMATION
Drives and Control System for Automation
UNIT-1

Synchronous Motor:

Synchronous motor and induction motor are the most widely used types of AC motor. Construction of a synchronous motor is similar to an alternator (AC generator). A same synchronous machine can be used as a synchronous motor or as an alternator. Synchronous motors are available in a wide range, generally rated between 150kW to 15MW with speeds ranging from 150 to 1800 rpm.

Construction Of Synchronous Motor



Similar to d.c machine where there is no constructional difference between a generator and motor, there is no difference between the construction of synchronous motor and the alternator, both being the synchronous machines.

The synchronous motor construction is basically similar to rotating field type alternator. The important parts of the Synchronous Machine are given below.
Stator
Rotor
Miscellaneous

Stator Construction

The stationary part of the machine is called Stator. It includes various parts like stator frame, stator core, stator windings and cooling arrangement. They are explained below in detail.

Stator Frame

It is the outer body of the machine made of cast iron, and it protects the inner parts of the machine.

Stator Core

The stator core is made of silicon steel material. It is made from a number of stamps which are insulated from each other. Its function is to provide an easy path for the magnetic lines of force and accommodate the stator winding.

Stator Winding

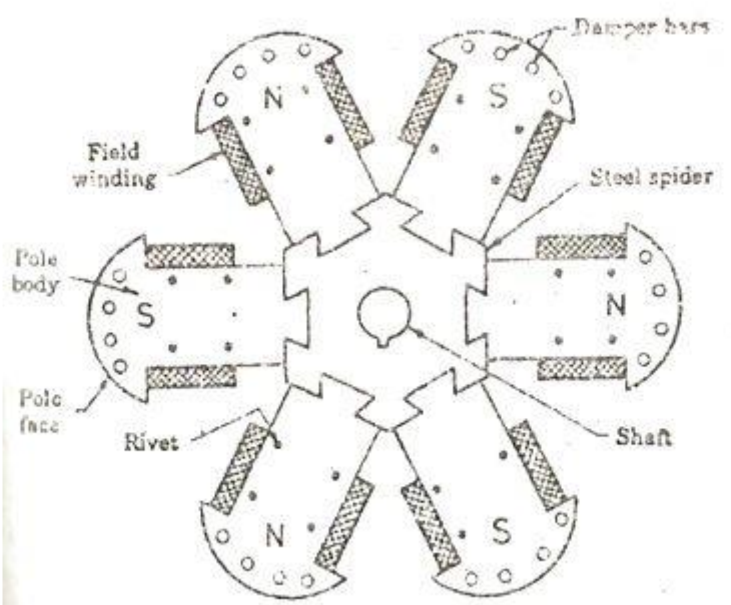
Slots are cut on the inner periphery of the stator core in which 3 phase or 1 phase winding is placed. Enameled copper is used as winding material. The winding is star connected. The winding of each phase is distributed over several slots. When the current flows in a distributed winding it produces an essentially sinusoidal space distribution of EMF.

Rotor Construction

The rotating part of the machine is called Rotor. There are two types of rotor construction, namely the salient pole type and the cylindrical rotor type.

Salient Pole Rotor

The term salient means projecting. Thus, a salient pole rotor consists of poles projecting out from the surface of the rotor core. They used in hydro power plant. The end view of a typical 6 pole salient pole rotor is shown below in the figure.



Since the rotor is subjected to changing magnetic fields, it is made of steel laminations to reduce eddy current losses. Poles of identical dimensions are assembled by stacking laminations to the required length. A salient pole synchronous machine has a non uniform air gap. The air gap is minimized under the pole centers and it is maximum in between the poles.

They are constructed for the medium and low speeds as they have a large number of poles. A salient pole generator has a large diameter. The salient pole rotor has the following important parts.

Spider

It is made of cast iron to provide an easy path for the magnetic flux. It is keyed to the shaft and at the outer surface, pole core and pole shoe are keyed to it.

Pole Core and Pole Shoe

It is made of laminated sheet steel material. Pole core provides least reluctance path for the magnetic field and pole shoe distributes the field over the whole periphery uniformly to produce a sinusoidal wave.

Field Winding or Exciting Winding

It is wound on the former and then placed around the pole core. DC supply is given to it through slip rings. When direct current flow through the field winding, it produces the required magnetic field.

Damper Winding

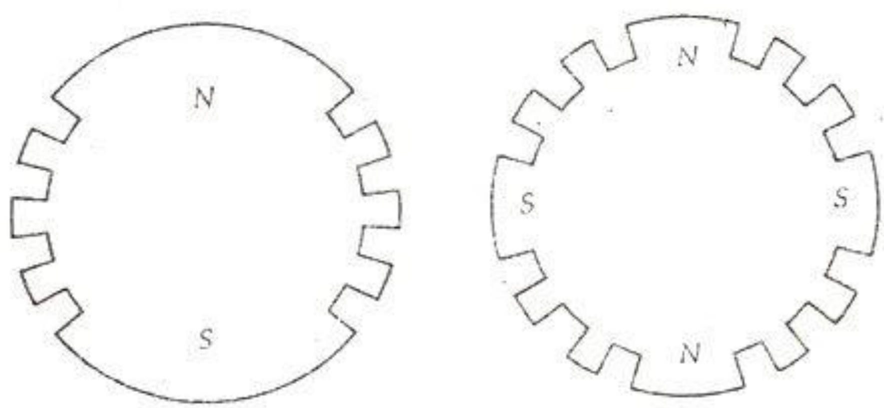
At the outermost periphery, holes are provided in which copper bars are inserted and short-circuited at both the sides by rings forming Damper winding.

Non- Salient Pole Rotor or Cylindrical Rotor

In this type of rotor, there are no projected poles, but the poles are formed by the current flowing through the rotor exciting winding. Cylindrical rotors are made from solid forgings of high-grade nickel chrome molybdenum steel. It has a comparatively small diameter and long axial length.

They are useful in high-speed machines. The cylindrical rotor type alternator has two or four poles on the rotor. Such a construction provides a greater mechanical strength and permits more accurate dynamic balancing. The smooth rotor of the machine makes less windage losses and the operation is less noisy because of the uniform air gap. They used in nuclear, gas and thermal power plant.

The figure below shows the end view of the 2 pole and 4 pole cylindrical rotors.



They are driven by steam or gas turbines. Cylindrical synchronous rotor synchronous generators are called turbo alternators and turbo generators. The machines are built in a number of rating from 10 MVA to over 1500 MVA. The biggest size used in India has a rating of 500 MVA installed in the super thermal power plant.

Non salient pole type rotors have the following parts. They are as follows

Rotor Core

The rotor core is made of silicon steel stampings. It is placed on the shaft. At the outer periphery, slots are cut in which exciting coils are placed.

Rotor Winding or Exciting Winding

It is placed on the rotor slots, and current is passed through the winding in such a way that the poles are formed according to the requirement.

Slip Rings

Slip rings provide DC supply to the rotor windings.

Miscellaneous Parts

The miscellaneous parts are given below.

Brushes

Brushes are made of carbon, and they slip over the slip rings. A DC supply is given to the brushes. Current flows from the brushes to the slip rings and then to the exciting windings.

Bearings

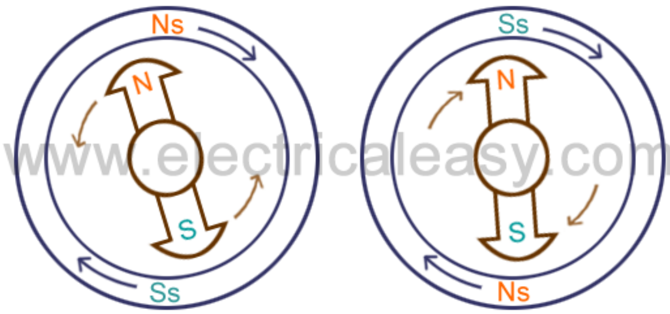
Bearings are provided between the shaft and the outer stationary body to reduce the friction. They are made of high carbon steel.

Shaft

The shaft is made of mild steel. Mechanical power is taken or given to the machine through the shaft.

Working Of Synchronous Motor:

The stator is wound for the similar number of poles as that of rotor, and fed with three phase AC supply. The 3 phase AC supply produces rotating magnetic field in stator. The rotor winding is fed with DC supply which magnetizes the rotor. Consider a two pole synchronous machine as shown in figure below.



Consider a three-phase synchronous motor, whose stator is wound for 2 poles.The two magnetic fields are produced in the synchronous motor by exciting both the windings stator and rotor with three phase a.c. supply and d.c. supply respectively.When three phase winding is excited by a three phase a.c. supply then the flux produced by the three-phase winding is always of rotating type.Such a magnetic flux rotates in space at a speed called synchronous speed.This magnetic is called rotating magnetic field.

The rotating magnetic field creates the effect similar to the physical rotation of magnets in space with a synchronous speed. So stator of the synchronous motor produces one magnet which is as good as rotating in space with the synchronous speed. The synchronous speed of a stator rotating magnetic field depends on supply frequency and the number of poles for which stator winding is wound. If the frequency of the a.c supply is f Hz and stator is wound for P number of poles, then the speed of the **rotating magnetic field** is synchronous given by,

$N_s = 120f/p$ r. p. m

In this case, as the stator is wound for say 2 poles, with 50 Hz supply, the speed of the rotating magnetic field will be 3000 r.p.m. This effect is similar to the physical rotation of two poles with a speed of Ns r.p.m. For simplicity of understanding let us assume that the stator poles are N1 and S1 which are rotating at a speed of Ns.

The direction of rotation of rotating magnetic field is say clockwise. When the field winding on the rotor is excited by a d.c supply, it also produces two poles, assuming rotor construction to be two poles, salient type. Let these poles be N2 and S2.

Now one magnet is rotating at Ns having poles N1 and S1 while at start rotor is stationary i.e. second magnet is stationary having poles N2 and S2. If somehow the unlike poles N1 and S2 or S1 and N2 are brought near each other, the magnetic locking may get established between stator and rotor poles.

As stator poles are rotating, due to magnetic rotor will also rotate in the same direction as that of stator poles i.e. in the direction of **rotating magnetic field**, with the same speed i.e. Ns.

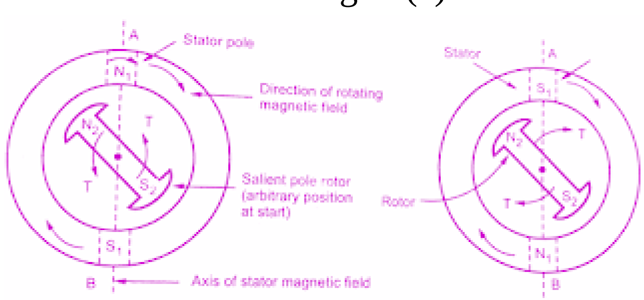
Hence synchronous motor rotates at one and only one speed i.e. synchronous speed. But this all depends on the existence of magnetic locking between stator and rotor poles. Practically it is not possible for stator poles to pull the rotor poles from their stationary position into magnetic locking condition. Hence synchronous motors are not self starting.

Why Synchronous Motor is not self starting?

Consider the rotating magnetic field as equivalent to the physical rotation of two stator poles N1 and S1.

Consider an instant when two poles are at such a position where stator magnetic axis is vertical, along A-B as shown in the below figure(a).At this instant, rotor poles are arbitrarily positioned as shown in the below figure.

At this instant, the rotor is stationary and unlike poles will try to attract each other.Due to this rotor will be subjected to an instantaneous torque in the anti-clockwise direction as in figure(a).



(a) Action of Synchronous Motor (b) Action of Synchronous Motor

Now stator poles are rotating very fast i.e. at a speed Ns r.p.m. Due to inertia, before rotor hardly rotates in the direction of anticlockwise torque, to which it is subjected, the stator poles change their positions. Consider an instant half a period latter where stator poles are exactly reversed but due to inertia rotor is unable to rotate from its initial position. This is shown in figure(b).

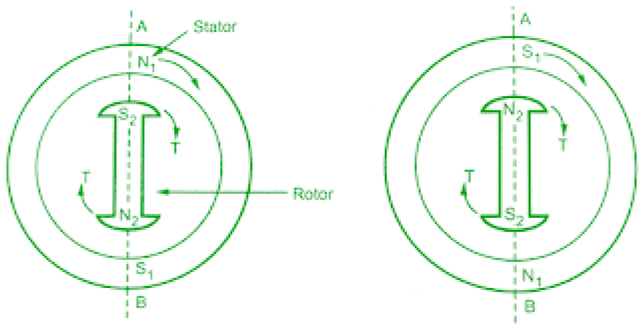
At this instant, due to the unlike poles trying to attract each other, the rotor will be subjected to a torque in the clockwise direction. This will tend to rotate the rotor in the direction rotating magnetic field. But before this happens, stator poles again change their positions reversing the direction of the torque exerted on the rotor.
Key Point: *As a result, the average torque, exerted on the rotor is zero. And hence the **synchronous motor is not self-starting***.
Note: The question is obvious that what will happen if by chance the rotor position is in such a way that the unlike rotor and stator poles are facing each other? But owing to the large inertia of the rotor, the rotor fails to rotate along with the stator poles. Hence again the difference of position of magnetic axes gets created and rotor gets subjected to reversing torque.

This is because the speed with which rotating magnetic field is rotating is so high that it is unable to rotate the rotor from its initial position, due to the inertia of the rotor. So under any case, whatever may be the starting position of the rotor, the synchronous motor is not self-starting.

Procedure to start a Synchronous Motor:

Now suppose the rotor is rotated by some external means at a speed almost equal to synchronous speed. And then the rotor is excited to produce its poles. At a certain instant now, the stator and rotor, unlike poles, will face each other such that their magnetic axes near each other. Then the force of attraction between the two pulls both of them into magnetic locking condition.
Once magnetic locking is established, the rotor and stator poles continue to occupy the same relative positions. Due to this, rotor continuously experiences a unidirectional torque in the direction of the rotating magnetic field. Hence rotor rotates at synchronous speed said to be in synchronism with the **rotating Magnetic field**.

The external device used to rotate rotor near synchronous speed can be removed once synchronism is established. The or then continues its rotation at Ns due to magnetic locking. This is the reason why synchronous motor runs only at synchronous speed and does not rotate at any speed other than the synchronous. This operation is shown in the below figures (a) and (b).



Unidirectional torque experienced by rotor

It is necessary to keep field winding i.e. rotor excited from d.c supply to maintain the magnetic locking, as long as the motor is operating.

Armature Windings in Alternator and Types of Armature Windings

So a general procedure to start a synchronous motor can be stated as:

1. Give a three phase a.c. supply to the rotor. This will produce rotating magnetic field rotating at synchronous speed Ns r.p.m.
2. Then drive the rotor by some external means like diesel engine in the direction of the rotating magnetic field, at a speed very near or equal to synchronous speed.
3.By using squirrel cage winding of induction motor . Now there are two fields one is rotating magnetic field produced by stator while the other is produced by the rotor which is physically rotated almost at the same speed as that of **rotating magnetic field**.

Key Point: *So the essence of the discussion is that to start the synchronous motor, it needs some device rotate the rotor at a speed very near or equal to the synchronous speed.*

Characteristic Features Of A Synchronous Motor

Synchronous motor will run either at synchronous speed or will not run at all.

The only way to change its speed is to change its supply frequency. (As $Ns = 120f / P$)

Synchronous motors are not self starting. They need some external force to bring them near to the synchronous speed.

They can operate under any power factor, lagging as well as leading. Hence, synchronous motors can be used for power factor improvement.

Application Of Synchronous Motor

As synchronous motor is capable of operating under either leading and lagging power factor, it can be used for power factor improvement. A synchronous motor under no-load with leading power factor is connected in power system where static capacitors can not be used.

It is used where high power at low speed is required. Such as rolling mills, chippers, mixers, pumps, pumps, compressor etc.

INDUCTION MOTOR (ASYNCHRONOUS MOTOR):

An electrical motor is an electromechanical device which converts electrical energy into mechanical energy. In the case of three phase AC (Alternating Current) operation, the most widely used motor is a **3 phase induction motor**, as this type of motor does not require an additional starting device. These types of motors are known as self-starting induction motors.

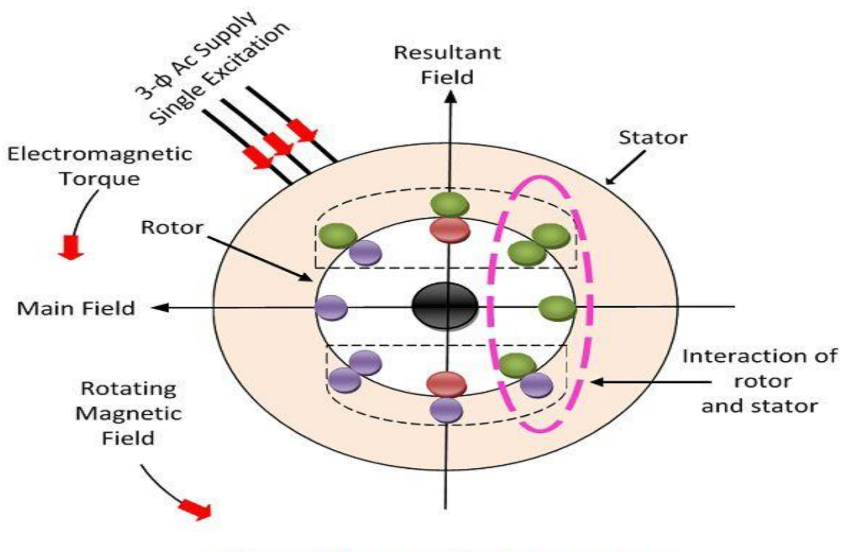
Working Principle of an Induction Motor:

The motor which works on the principle of electromagnetic induction is known as the induction motor. The electromagnetic induction is the phenomenon in which the electromotive force induces across the electrical conductor when it is placed in a rotating magnetic field.

The stator and rotor are two essential parts of the motor. The stator is the stationary part, and it carries the overlapping windings while the rotor carries the main or field winding. The windings of the stator are equally displaced from each other by an angle of 120°.

The induction motor is the single excited motor, i.e., the supply is applied only to the one part, i.e., stator. The term excitation means the process of inducing the magnetic field on the parts of the motor.

When the three phase supply is given to the stator, the rotating magnetic field produced on it. The figure below shows the rotating magnetic field set up in the stator.



Three Phase Induction Motor

In a DC motor, supply is needed to be given for the stator winding as well as the rotor winding. But in an induction motor only the stator winding is fed with an AC supply.
Alternating flux is produced around the stator winding due to AC supply. This alternating flux revolves with synchronous speed. The revolving flux is called as "Rotating Magnetic Field" (RMF).
The relative speed between stator RMF and rotor conductors causes an induced emf in the rotor conductors, according to the Faraday's law of electromagnetic induction. The rotor conductors are short circuited, and hence rotor current is produced due to induced emf. That is why such motors are called as induction motors.
(This action is same as that occurs in transformers, hence induction motors can be called as **rotating transformers**.)
Now, induced current in rotor will also produce alternating flux around it. This rotor flux lags behind the stator flux. The direction of induced rotor current, according to Lenz's law, is such that it will tend to oppose the cause of its production.
As the cause of production of rotor current is the relative velocity between rotating stator flux and the rotor, the rotor will try to catch up with the stator RMF. Thus the rotor rotates in the same direction as that of stator flux to minimize the relative velocity. However, the rotor never succeeds in catching up the synchronous speed. This is the basic

working principle of induction motor of either type, single phase of 3 phase.

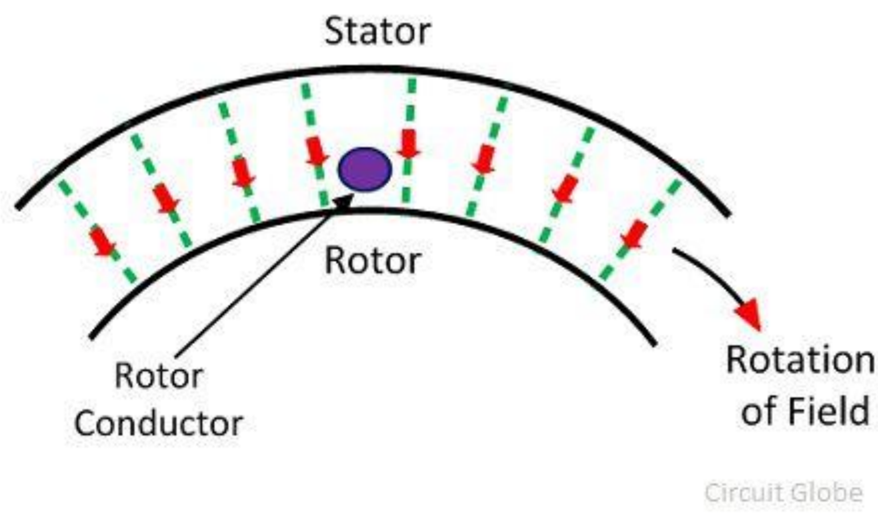
Why Rotor never runs at Synchronous Speed?

If the speed of the rotor is equal to the synchronous speed, no relative motion occurs between the rotating magnetic field of the stator and the conductors of the rotor. Thus the EMF is not induced on the conductor, and zero current develops on it. Without current, the torque is also not produced.

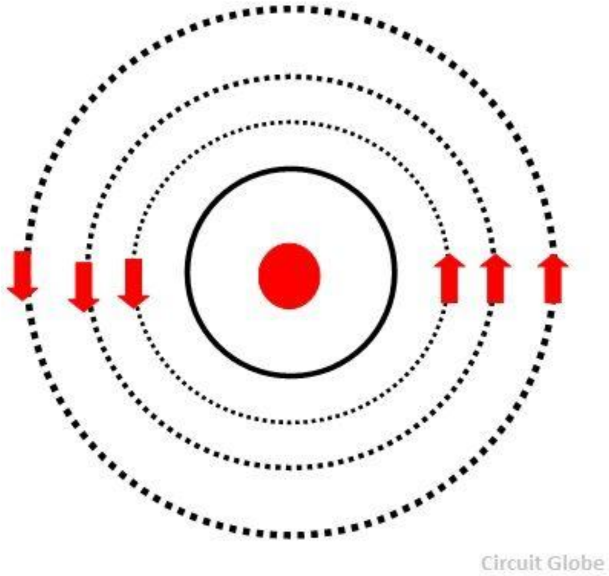
Because of the above mention reasons the rotor never rotates at the synchronous speed. The speed of the rotor is always less than the speed of the rotating magnetic field.

Alternatively, the method of the working principle of Induction Motor can also be explained as follows.

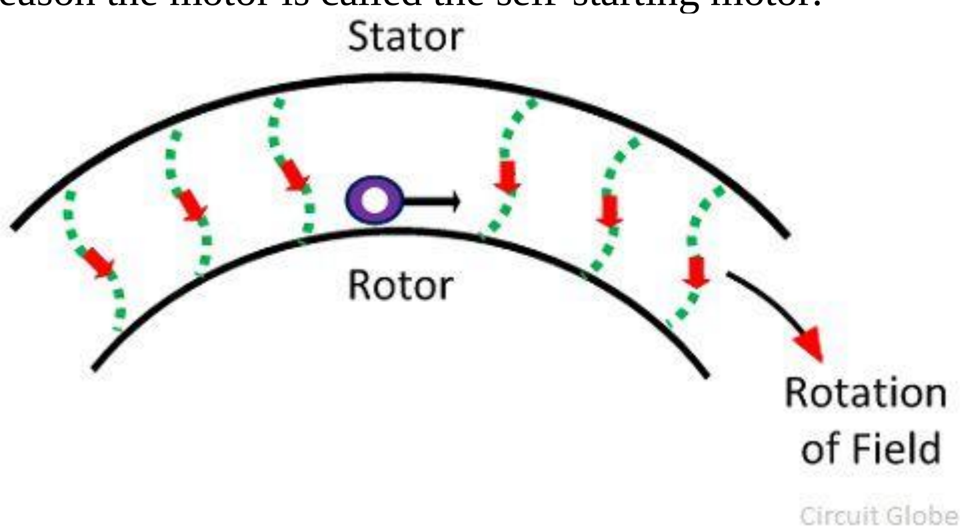
Let's understand this by considering the single conductor on the stationary rotor. This conductor cuts the rotating magnetic field of the stator. Consider that the rotating magnetic field rotates in the clockwise direction. According to Faraday's Law of electromagnetic induction, the EMF induces in the conductor.



As the rotor circuit is completed by the external resistance or by end ring, the rotor induces an EMF which causes the current in the circuit. The direction of the rotor induces current is opposite to that of the rotating magnetic field. The rotor current induces the flux in the rotor. The direction of the rotor flux is same as that of the current.



The interaction of rotor and stator fluxes develops a force which acts on the conductors of the rotor. The force acts tangentially on the rotor and hence induces a torque. The torque pushes the conductors of the rotor, and thus the rotor starts moving in the direction of the rotating magnetic field. The rotor starts moving without any additional excitation system and because of this reason the motor is called the self-starting motor.

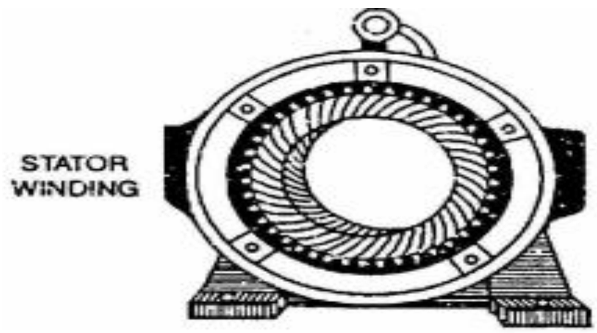


The operation of the motor depends on the voltage induced on the rotor, and hence it is called the induction motor.

Construction of Three Phase Induction Motor:

Figure 8.1 shows the construction of three phase induction motor. A 3 phase induction motor has two main parts (i) stator and (ii) rotor. The rotor is separated from the stator by a small air-gap which ranges from 0.4 mm to 4 mm, depending on the power of the motor.

1. Stator :



It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current losses. A number of evenly spaced slots are provided on the inner periphery of the laminations.[See Fig.(8.1)].The insulated connected to form a balanced 3-phase star or delta connected the circuit.

The 3-phase stator winding is wound for a definite number of poles as per requirement of speed.Greater the number of poles, lesser is the speed of the motor and vice-versa.When 3-phase supply is given to the stator winding, a rotating magnetic field(See Sec. 8.3) of constant magnitude is produced.This rotating field induces currents in the rotor by electromagnetic induction.

2**. Rotor:**

The rotor, mounted on a shaft, is a hollow laminated core having slots on its outer periphery.The winding placed in these slots (called rotor winding) may be one of the following two types:

(i) Squirrel cage type (ii) Wound type

(i) **Squirrel cage rotor:** It consists of a laminated cylindrical core having parallel slots on its outer periphery.One copper or aluminum bar is placed in each slot. All these bars are joined at each end by metal rings called end rings.

This forms a permanently short circuited winding which is indestructible. The entire construction (bars and end rings) resembles a squirrel cage and hence the name. The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator.

Those induction motors which employ squirrel cage rotor are called squirrel cage induction motors. Most of 3 phase induction motors use squirrel cage rotor as it has a remarkably simple and robust construction enabling it to operate in the most adverse circumstances.

However, it suffers from the disadvantage of a low starting torque. It is because the rotor bars are permanently short-circuited and it is not possible to add any external resistance to the rotor circuit to have a large starting torque.

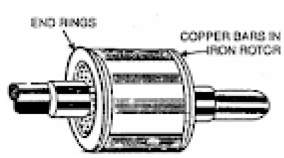


Fig.(8.2)

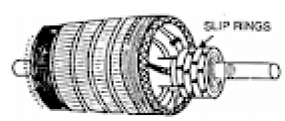


Fig.(8.3)

(ii) Wound rotor: It consists of a laminated cylindrical core and carries a 3-phase winding, similar to the one on the stator [See Fig. (8.3)].The rotor winding is uniformly distributed in the slots and is usually star-connected. The open ends of the rotor winding are brought out and joined to three insulated slip rings mounted on the rotor shaft with one brush resting on each slip ring.

The three brushes are connected to a 3-phase star-connected rheostat as shown in Fig. (8.4).At starting, the external resistances are included in the rotor circuit to give a large starting torque. These resistances are gradually reduced to zero as the motor runs up to speed.

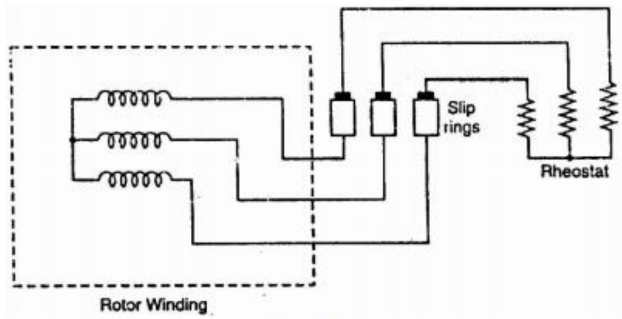


Fig.(8.4)

The external resistances are used during starting period only. When the motor attains normal speed, the three brushes are short-circuited so that the wound rotor runs like a squirrel cage rotor.

$$\therefore \quad \text{Cycles of current} = \frac{P}{2} \times \text{revolutions of field}$$

or $$\text{Cycles of current per second} = \frac{P}{2} \times \text{revolutions of field per second}$$

Since revolutions per second is equal to the revolutions per minute (N_s) divided by 60 and the number of cycles per second is the frequency f,

$$\therefore \quad f = \frac{P}{2} \times \frac{N_s}{60} = \frac{N_s P}{120}$$

or $$N_s = \frac{120\,f}{P}$$

The speed of the rotating magnetic field is the same as the speed of the alternator that is supplying power to the motor if the two have the same number of poles. Hence the magnetic flux is said to rotate at synchronous speed.

Three Phase Induction Motor Advantages:

(i) It has simple and rugged construction.
(ii) It is relatively cheap.
(iii) It requires little maintenance.
(iv) It has high efficiency and reasonably good power factor.
(v) It has self starting torque.

Three Phase Induction Motor Disadvantages:

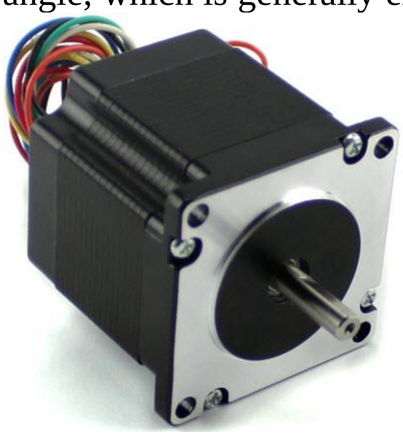
(i) It is essentially a constant speed motor and its speed cannot be changed easily.
(ii) Its starting torque is inferior to dc shunt motor.

Applications of Induction Motors:

1. Wound rotor motors are suitable for loads requiring high starting torque and where a lower starting current is required.
2. The Wound rotor induction motors are also used for loads having high inertia, which results in higher energy losses.
3. Used for the loads which require a gradual buildup of torque.
4. Used for the loads that require speed control.
5. The wound rotor induction motors are used in conveyors, cranes, pumps, elevators and compressors, fan.
6. The maximum torque is above 200 percent of the full load value while the full load slip may be as low as 3 percent. The efficiency is about 90 %.

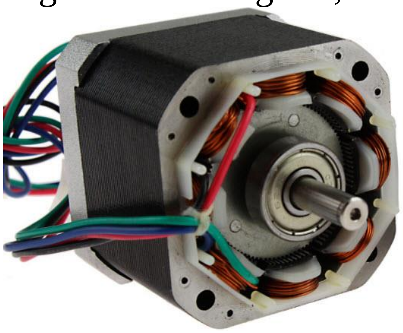
STEPPER MOTOR

Stepper Motor is a brushless electromechanical device which converts the train of electric pulses applied at their excitation windings into precisely defined step-by-step mechanical shaft rotation. The shaft of the motor rotates through a fixed angle for each discrete pulse. This rotation can be linear or angular. It gets one step movement for a single pulse input.
When a train of pulses is applied, it gets turned through a certain angle. The angle through which the stepper motor shaft turns for each pulse is referred as the step angle, which is generally expressed in degrees.



The number of input pulses given to the motor decides the step angle and hence the position of motor shaft is controlled by controlling the number of pulses. This unique feature makes the stepper motor to be well suitable for open-loop control system wherein the precise position of the shaft is maintained with exact number of pulses without using a feedback sensor.

If the step angle is smaller, the greater will be the number of steps per revolutions and higher will be the accuracy of the position obtained. The step angles can be as large as 90 degrees and as small as 0.72 degrees, however, the commonly used step angles are 1.8 degrees, 2.5 degrees, 7.5 degrees and 15 degrees.



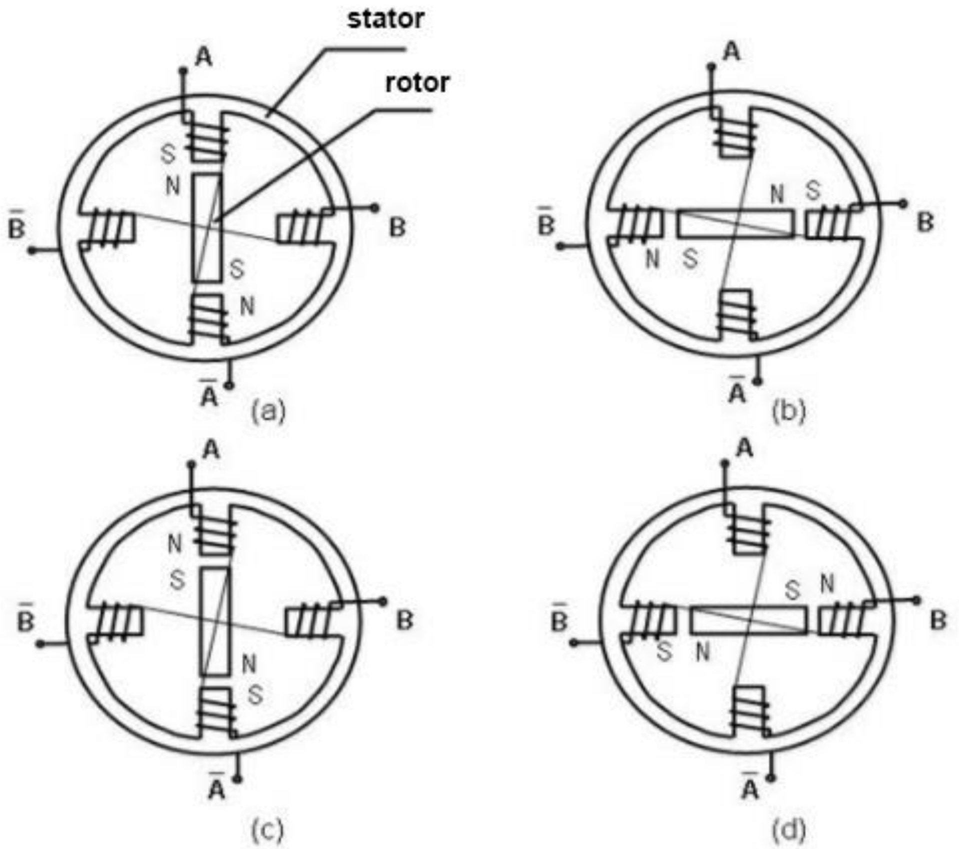
The direction of the shaft rotation depends on the sequence of pulses applied to the stator. The speed of the shaft or the average motor speed is directly proportional to the frequency (the rate of input pulses) of input pulses being applied at excitation windings. Therefore, if the frequency is low, the stepper motor rotates in steps and for high frequency, it continuously rotates like a DC motor due to inertia.

Like all electric motors, it has stator and rotor. The rotor is the movable part which has no windings, brushes and a commutator. Usually the rotors are either variable reluctance or permanent magnet kind. The stator is often constructed with multipole and multiphase windings, usually of three or four phase windings wound for a required number of poles decided by desired angular displacement per input pulse.

Unlike other motors it operates on a programmed discrete control pulses that are applied to the stator windings via an electronic drive. The rotation occurs due to the magnetic interaction between poles of sequentially energized stator winding and poles of the rotor.

Stepper motor working principle:

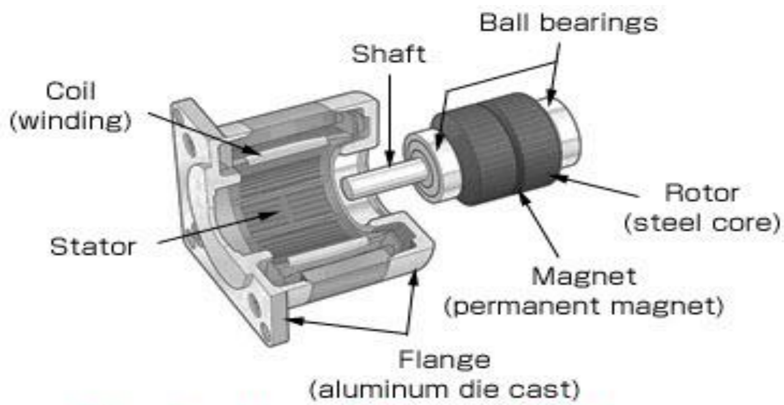
The stepper motor rotor is a permanent magnet, when the current flows through the stator winding, the stator winding to produce a vector magnetic field. The magnetic field drives the rotor to rotate by an angle so that the pair of magnetic fields of the rotor and the magnetic field direction of the stator are consistent. When the stator's vector magnetic field is rotated by an angle, the rotor also rotates with the magnetic field at an angle. Each time an electrical pulse is input, the motor rotates one degree further. The angular displacement it outputs is proportional to the number of pulses input and the speed is proportional to the pulse frequency. Change the order of winding power, the motor will reverse. Therefore, it can control the rotation of the stepping motor by controlling the number of pulses, the frequency and the electrical sequence of each phase winding of the motor.



<u>Construction of a Stepper Motor</u>:

There are several types of stepper motors are available in today's market over a wide range of sizes, step count, constructions, wiring, gearing, and other electrical characteristics. As these motors are capable to operate in discrete nature, these are well suitable to interface with digital control devices like computers.

Due to the precise control of speed, rotation, direction, and angular position, these are of particular interest in industrial process control systems, CNC machines, robotics, manufacturing automation systems, and instrumentation.

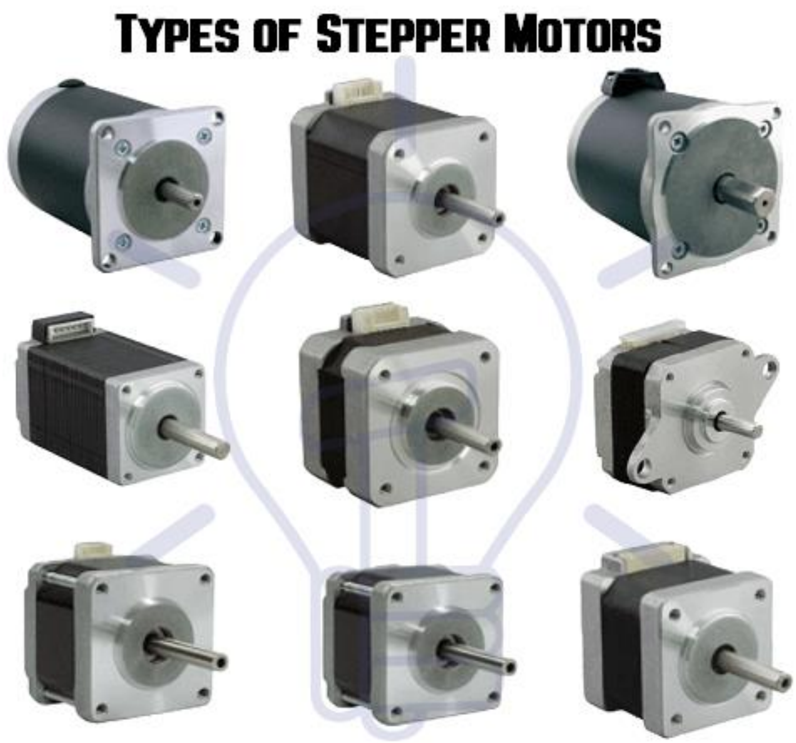


Construction of Stepper Motor

Types of Stepper Motors:

There are three basic **categories of stepper motors**, namely
Permanent Magnet Stepper Motor
Variable Reluctance Stepper Motor
Hybrid Stepper Motor

In all these motors excitation windings are employed in stator where the number of windings refer to the number of phases.
A DC voltage is applied as an excitation to the coils of windings and each winding terminal is connected to the source through a solid state switch. Depends on the type of stepper motor, its rotor design is constructed such as soft steel rotor with salient poles, cylindrical permanent magnet rotor and permanent magnet with soft steel teeth. Let us discuss these types in detail.



Variable Reluctance Stepper Motor:

It is the basic type of stepper motor that has been in existence for a long time and it ensures easiest way to understand principle of operation from a structural point of view. As the name suggests, the angular position of the rotor depends on the reluctance of the magnetic circuit formed between the stator poles (teeth) and rotor teeth.

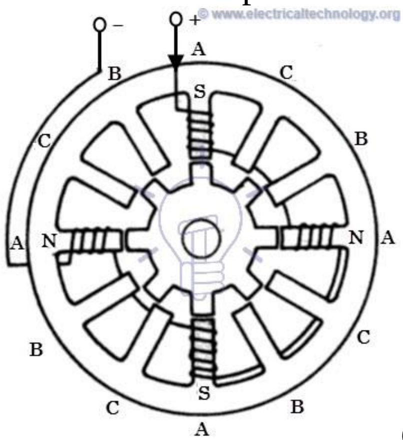

Variable Reluctance Stepper Motor

Construction of Variable Reluctance Stepper Motor:

It consists of a wound stator and a soft iron multi-tooth rotor. The stator has a stack of silicon steel laminations on which stator windings are wound. Usually, it is wound for three phases which are distributed between the pole pairs.
The number of poles on stator thus formed is equal to an even multiple of the number of phases for which windings are wounded on stator. In the figure below, the stator has 12 equally spaced projecting poles where each pole is wound with an exciting coil. These three phases are energized from of a DC source with the help of solid state switches.

The rotor carries no windings and is of salient pole type made entirely of slotted steel laminations. The rotor pole's projected teeth have the same width as that of stator teeth. The number of poles on stator differs to that of rotor poles, which provides the ability to self start and bidirectional rotation of the motor.

The relation of rotor poles in terms of stator poles for a three phase stepper motor is given as, $Nr = Ns \pm (Ns / q)$. Here $Ns = 12$, and $q= 3$, and hence $Nr = 12 \pm (12 / 3) = 16$ or 8. An 8-pole construction rotor without any excitation is illustrated below.



Construction of Variable Reluctance Stepper Motor

Working of Variable Reluctance Stepper Motor:

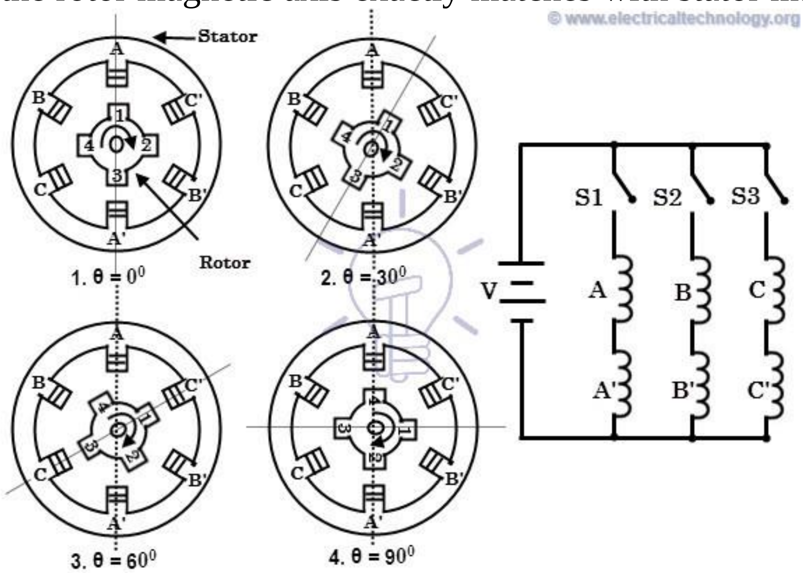
The stepper motor works on the principle that the rotor aligns in a particular position with the teeth of the excitation pole in a magnetic circuit wherein minimum reluctance path exist. Whenever power is applied to the motor and by exciting a particular winding, it produces its magnetic field and develops its own magnetic poles.

Due to the residual magnetism in the rotor magnet poles, it will cause the rotor to move in such a position so as to achieve minimum reluctance position and hence one set of poles of rotor aligns with the energized set of poles of the stator. At this position, the axis of the stator magnetic field matches with the axis passing through any two magnetic poles of the rotor.

When the rotor aligns with stator poles, it has enough magnetic force to hold the shaft from moving to the next position, either in clockwise or counter clockwise direction.

Consider the schematic diagram of a 3-phase, 6 stator poles and 4 rotor teeth is shown in figure below. When the phase A-A' is supplied with a DC supply by closing the switch -1, the winding become a magnet which results one tooth become North and other South. So the stator magnetic axis lies along these poles.

Due to the force of attraction, stator coil North Pole attracts nearest rotor tooth of opposite polarity, i.e., South and South Pole attract nearest rotor tooth of opposite polarity, i.e., North. The rotor then adjusts to its minimum reluctance position where the rotor magnetic axis exactly matches with stator magnetic axis.



Working of Variable Reluctance Stepper Motor

When the phase B-B’ is energized by closing switch -2 keeping phase A-A’ remain de-energized by opening switch-1, winding B-B’ will produce the magnetic flux and hence the stator magnetic axis shifts along the poles thus formed by it. Hence the rotor shifts to the least reluctance with magnetized stator teeth and rotates through an angle of 30 degrees in the clockwise direction.

When the switch-3 is energized after opening switch-2, the phase C-C’ is energized, the rotor teeth align with new position by moving through an additional angle of 30 degrees. By this way, the rotor moves clockwise or counterclockwise direction by successively exciting stator windings in a particular sequence. The step angle of this 3-phase 4-pole rotor teeth stepper motor is expressed as,

$360/ (4 \times 3) = 30$ degrees (as step angle $= 360 / Nr \times q$).

The step angle can be further reduced by increasing the number of poles on the stator and rotor, in such case motors are often wound with additional phase windings. This can also be achieved by a adopting different construction of stepper motors such as multistack arrangement and reduction gear mechanism.

<u>Permanent Magnet Stepper Motor:</u>

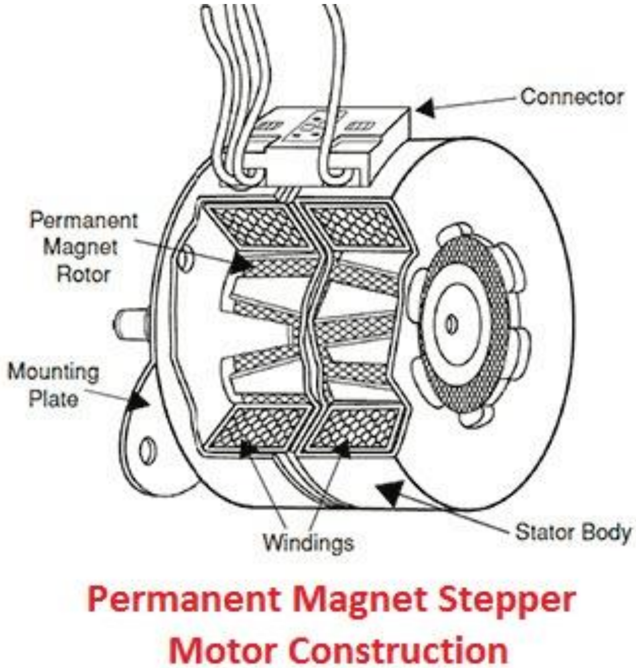
The permanent magnet design motor is perhaps the most common among several types of stepper motors. As the name implies, it adds permanent magnets to the motor construction. This type of stepper motors is also referred as **can-stack motor** or **tin-can motor**. The main advantage of this motor is its low manufacturing cost. This type of motor has 48-24 steps per revolution.

Permanent Magnet Stepper Motor

Construction Permanent Magnet Stepper Motor:

In this motor, the stator is of multipolar and its construction is similar to that of variable reluctance stepper motor as discussed above. It consists of slotted periphery on which stator coils are wound. It has projected poles on the slotted structure where the wound windings can be two or three or four-phase.

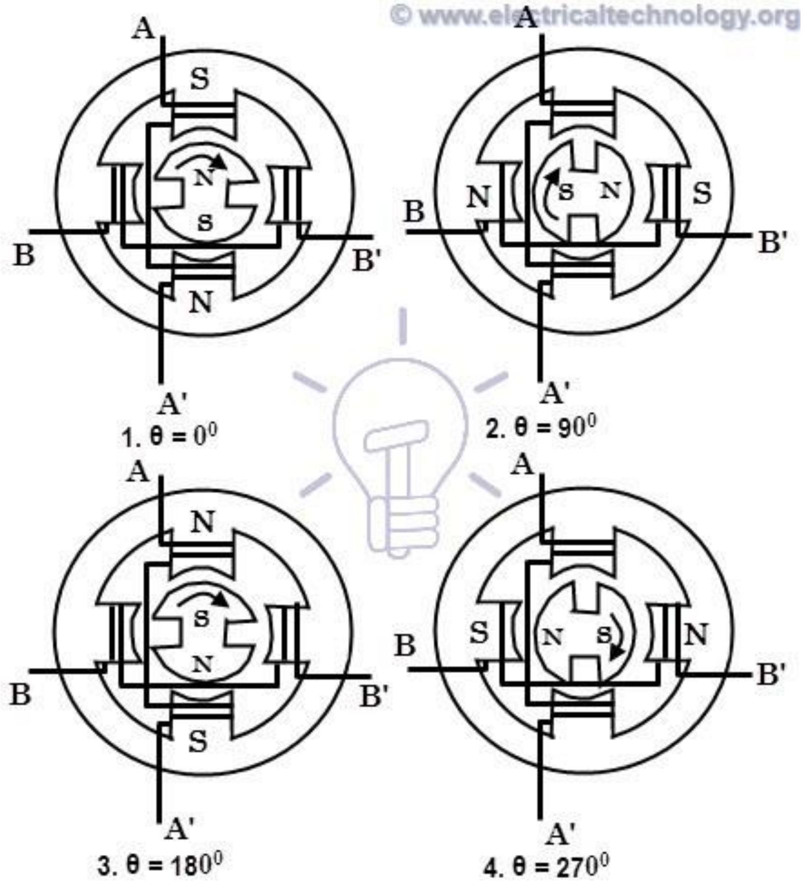
The end terminals of all these windings are bought out and connected to the DC excitation via solid state switches in the drive circuit.



The rotor is made up of a permanent magnet material like a ferrite that can be in the shape of either cylindrical or salient pole, but usually it is of smooth cylindrical type. The rotor designed to have an even number of permanent magnetic poles with alternate North and South polarities.

Working of Permanent Magnet Stepper Motor:

The operation of this motor works on the principle that unlike poles attract each other and like poles repel each other. When the stator windings are excited with a DC supply, it produces magnetic flux and establishes the North and South poles. Due to the force of attraction and repulsion between permanent magnet rotor poles and stator poles, the rotor starts moving up to the position for which pulses are given to the stator.
Consider a 2-phase stepper motor with two permanent magnetic rotor poles as shown in the figure below.



When the phase A is energized with a positive with respect to the A’, the windings establish North and South poles. Due to the force of attraction, the rotor poles align with stator poles such that the magnetic pole axis of rotor adjusts with that of stator as shown in figure.
When the excitation is switched to B phase and switching off phase A, the rotor further adjusts to magnetic axis of phase B, and thus rotates through 90 degrees in clockwise direction.

Next, if the phase A is energized with a negative current with respect to A', the formation of stator poles causes the rotor to move through another 90 degrees in clockwise direction.
In the same way, if the phase B is excited with negative current by closing phase A switch, the rotor rotates through another 90 degrees in the same direction. Next, if the phase A is excited with positive current, the rotor comes to the original position thus making a 360 degrees complete revolution. This implies that, whenever the stator is excited, the rotor tends to rotate through 90 degrees in clockwise direction. The step angle of this 2-phase 2-pole permanent magnet rotor motor is expressed as, 360/ (2 × 2) = 90 degrees. The step size can be reduced by energizing two phases simultaneously or a sequence of 1-phase ON and 2-phase ON modes with a proper polarity.

Hybrid Stepper Motor:

It is the most popular type of stepper motor as it provides better performance than permanent magnet rotor in terms of step resolution, holding torque and speed. However, these motors are more expensive than PM stepper motors. It combines the best features of both variable reluctance and permanent magnet stepper motors. These motors are used in applications that require very small stepping angle such as 1.5, 1.8 and 2.5 degrees.

Hybrid Stepper Motor

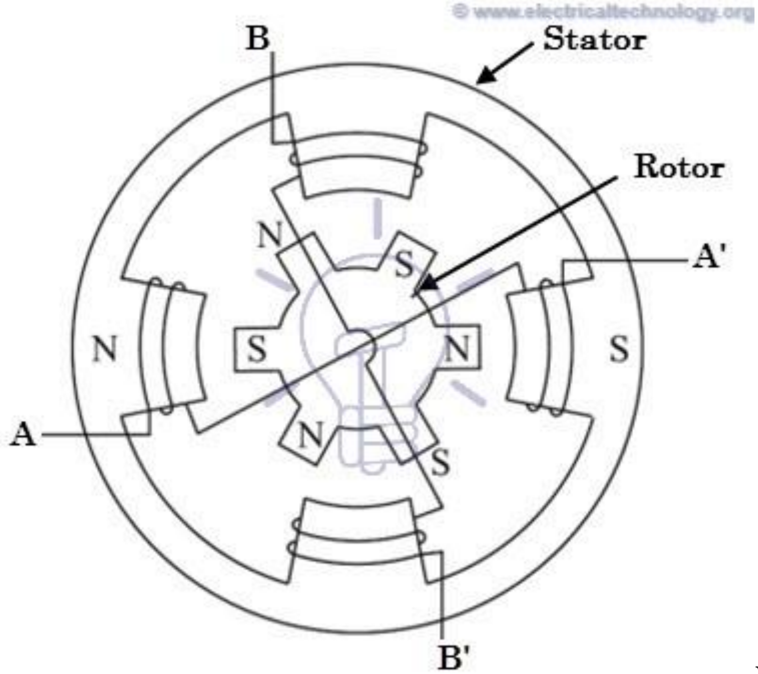
Construction of Hybrid Stepper Motor:

The stator of this motor is same as its permanent magnet or reluctance type counterpart. The stator coils are wound on alternate poles. In this, the coils of different phases are wound on each pole, usually two coils at a pole which is referred as a bifilar connection.
The rotor consists of a permanent magnet which is magnetized in axial direction to create a pair of magnetic poles (N and S poles). Each pole is covered with uniformly spaced teeth. The teeth are made up of soft steel and two section, of which on each pole are misaligned each other by a half-tooth pitch.

Working of Hybrid Stepper Motor:

This motor works similar to that of permanent magnet stepper motor. The figure above shows 2-phase, 4-pole, 6-tooth rotor hybrid stepper motor. When the phase

A-A’ is excited with a DC supply, keeping B-B’ unexcited, the rotor aligns such that the south pole of the rotor faces north pole of the stator while north pole of rotor faces south pole of the stator.



Working of Hybrid Stepper Motor

Now, if the phase B-B’ is excited, keeping A-A’ switched off in such a way that upper pole becomes north and lower becomes south, then the rotor will align to a new position by moving through counterclockwise direction. If the phase B-B’ is oppositely excited such that the upper pole becomes south and lower becomes north, then the rotor will turn clockwise direction.

By a proper sequence of pulses to the stator, the motor will turn in desired direction. For every excitation, rotor will get locked into new position, and even if excitation is removed motor still maintains its locked condition due to the permanent magnet excitation. The step angle of this 2-phase, 4-pole, 6-tooth rotor motor is given as 360/ (2 × 6) = 30 degrees. In practice, hybrid motors are constructed with more number of rotor poles in order to get high angular resolution.

motor in half stepping is given below.

Step	Coil A	Coil B	Coil C	Coil D
1	ON	OFF	OFF	OFF
2	ON	ON	OFF	OFF
3	OFF	ON	OFF	OFF
4	OFF	ON	ON	OFF
5	OFF	OFF	ON	OFF
6	OFF	OFF	ON	ON
7	OFF	OFF	OFF	ON
8	ON	OFF	OFF	ON

Advantages of Stepper Motor:

1. At standstill position, the motor has full torque. No matter if there is no moment or changing position.
2. It has a good response to starting, stopping and reversing position.
3. As there is no contact brushes in the stepper motor, It is reliable and the life expectancy depends on the bearings of the motor.
4. The motor rotation angle is directly proportional to the input signals.
5. It is simple and less costly to control as motor provides open loop control when responding to the digital input signals.
6. The motor speed is directly proportional to the input pulses frequency, this way a wide range of rotational speed can be achieved.
7. When load is coupled to the shaft, it is still possible to realize the synchronous rotation with low speed.
8. The exact positioning and repeatability of movement is good as it has a 3-5% accuracy of a step where the error is non cumulative from one step to another.

9. Stepper motors are safer and low cost (as compared to servo motors), having high torque at low speeds, high reliability with simple construction which operates at any environment.

Disadvantages of Stepper Motors:

1. Stepper motors having low Efficiency.
2. It has low Accuracy.
3. Its torque declines very quickly with speed.
4. As stepper motor operates in open loop control, there is no feedback to indicate potential missed steps.
5. It has low torque to inertia ratio means it can’t accelerate the load very quickly.
6. They are noisy.

Applications of Stepper Motors:

1. Stepper motors are used in automated production equipment’s and automotive gauges and industrial machines like packaging, labeling, filling and cutting etc.
2. It is widely used in security devices such as security & surveillance cameras.
3. In medical industry, stepper motors are widely used in samples, digital dental photography, respirators, fluid pumps, blood analysis machinery and medical scanners etc.
4. They are used in consumer electronics in image scanners, photo copier and printing machines and in digital camera for automatic zoom and focus functions and positions.
5. Stepper motors also used in elevators, conveyor belts and lane diverters

SERVO MOTOR

A **servo motor** is an electrical device which can push or rotate an object with great precision. If you want to rotate and object at some specific angles or distance, then you use servo motor. It is just made up of simple motor which run through **servo mechanism**. If motor is used is DC powered then it is called DC servo motor, and if it is AC powered motor then it is called AC servo motor. We can get a very high torque servo motor in a small and light weight packages. Due to these features they are being used in many applications like toy car, RC helicopters and planes, Robotics, Machine etc.

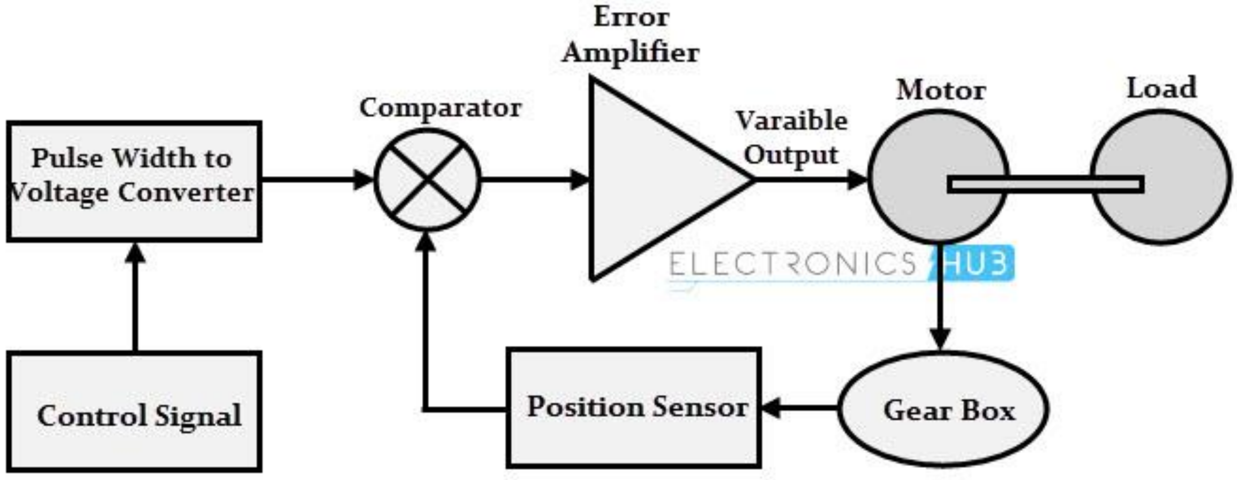
Construction of Servo Motor:

Servo motor is Dc motor which consist of following parts
Stator winding
Rotor winding
Bearing
Shaft
Encoder
The servo motor consists of two winding stator and rotor winding. The stator winding is wound on stationary part of the motor and this winding is also called field winding of the motor, this winding could the permanent magnets. The rotor winding is wound on the rotating part of the motor and this winding is also called the armature winding of the motor. The motor consists of two bearing on front and back side for the free movement of shaft. Shaft is basically the iron rod on which the armature winding is coupled. The encoder has the approximate sensor for telling the rotational speed and revolution per minute of the motor.

Working principle of Servo Motors:

Servo motors is actually the dc motor and all dc motors work on the principle of Fleming s left hand rule. This rule is used for determining the direction of force which act on the DC motor armature conductor. This rule tells us if we extend our left hand,index finger, middle finger and thumb.
Then the index finger shows the magnetic field which is perpendicular to direction of current, shows the middle finger in figure. When the current carrying conductor is placed in magnetic field then the conductor experience a force in the direction, which is perpendicular to the both direction of magnetic field and direction of current that is shows by the thumb in figure 3
The Servo Motor basically consists of a DC Motor, a Gear system, a position sensor and a control circuit. The DC motors get powered from a battery and run at high speed and low torque. The Gear and shaft assembly connected to the DC motors lower this speed into sufficient speed and higher torque. The position sensor senses the position of the shaft from its definite position and feeds the information to the control circuit. The control circuit accordingly decodes the

signals from the position sensor and compares the actual position of the motors with the desired position and accordingly controls the direction of rotation of the DC motor to get the required position. The Servo Motor generally requires DC supply of 4.8V to 6 V.



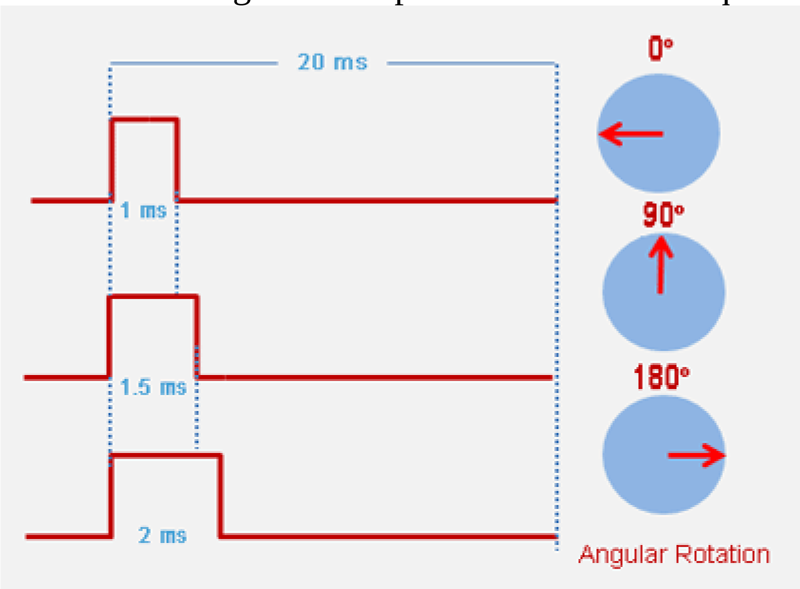
A servo consists of a Motor (DC or AC), a potentiometer, gear assembly and a controlling circuit. First of all we use gear assembly to reduce RPM and to increase torque of motor. Say at initial position of servo motor shaft, the position of the potentiometer knob is such that there is no electrical signal generated at the output port of the potentiometer. Now an electrical signal is given to another input terminal of the error detector amplifier. Now difference between these two signals, one comes from potentiometer and another comes from other source, will be processed in feedback mechanism and output will be provided in term of error signal. This error signal acts as the input for motor and motor starts rotating. Now motor shaft is connected with potentiometer and as motor rotates so the potentiometer and it will generate a signal. So as the potentiometer's angular position changes, its output feedback signal changes. After sometime the position of potentiometer reaches at a position that the output of potentiometer is same as external signal provided. At this condition, there will be no output signal from the amplifier to the motor input as there is no difference between external applied signal and the signal generated at potentiometer, and in this situation motor stops rotating.

Controlling Servo Motor:

All motors have three wires coming out of them. Out of which two will be used for Supply (positive and negative) and one will be used for the signal that is to be sent from the MCU.

Servo motor is controlled by PWM (Pulse width Modulation) which is provided by the control wires. There is a minimum pulse, a maximum pulse and a repetition rate. Servo motor can turn 90 degree from either direction form its neutral position. The servo motor expects to see a pulse every 20 milliseconds (ms) and the length of the pulse will determine how far the motor turns. For example, a 1.5ms pulse will make the motor turn to the 90° position, such as if pulse is shorter than 1.5ms shaft moves to 0° and if it is longer than 1.5ms than it will turn the servo to 180°.

Servo motor works on **PWM (Pulse width modulation)** principle, means its angle of rotation is controlled by the duration of applied pulse to its Control PIN. Basically servo motor is made up of **DC motor which is controlled by a variable resistor (potentiometer) and some gears**. High speed force of DC motor is converted into torque by Gears. We know that WORK= FORCE X DISTANCE, in DC motor Force is less and distance (speed) is high and in Servo, force is High and distance is less. Potentiometer is connected to the output shaft of the Servo, to calculate the angle and stop the DC motor on required angle.



Servo motor can be rotated from 0 to 180 degree, but it can go up to 210 degree, depending on the manufacturing. This degree of rotation can be controlled by applying the **Electrical Pulse** of proper width, to its Control pin. Servo checks the pulse in every 20 milliseconds. Pulse of 1 ms (1 millisecond) width can rotate servo to 0 degree, 1.5ms can rotate to 90 degree (neutral position) and 2 ms pulse can rotate it to 180 degree.

All servo motors work directly with your +5V supply rails but we have to be careful on the amount of current the motor would consume, if you are planning to use more than two servo motors a proper servo shield should be designed.

Advantages:

1. If a heavy load is placed on the motor, the driver will increase the current to the motor coil as it attempts to rotate the motor. Basically, there is no out-of-step condition.
2. High-speed operation is possible.

Disadvantages:

1. Since the servomotor tries to rotate according to the command pulses, but lags behind, it is not suitable for precision control of rotation.
2. Higher cost.
3. When stopped, the motor's rotor continues to move back and forth one pulse, so that it is not suitable if you need to prevent vibration

Applications of Servo Motor:

1. It is used in **robotic industry of position control**.
2. It is used in robotic arms.
3. It is used in press and cutting industry for the cutting and pressing the piece precisely.
4. It is used in conveyer belt for start and stop the conveyer belt at every position.
5. It is used in digital cameras for auto focusing.
6. It is used in **solar tracking system for tracking** the sun at every precise moment of time.
7. It is used in labeling and packing industry for labels the monogram and packing the things

Difference between Induction and servo motors

1.) Servo motors is used to control speed systems. It varies the field current applied to the generator which in turn controls the speed of the motor connected. Induction motor will work on synchronous speed.

2.) Servo motor is closed loop system where as induction motor is an open loop system.

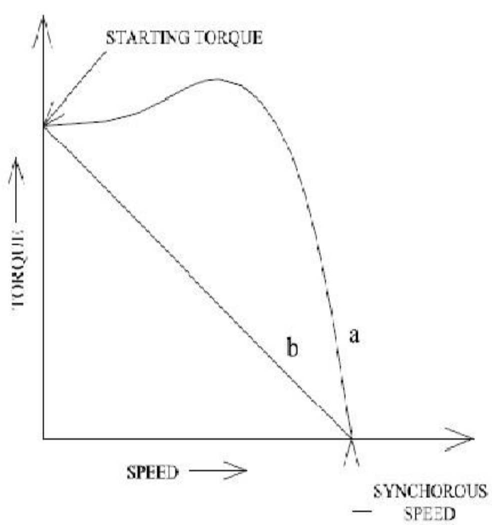
3.) An induction motor has high inertia and servo motor has a very low inertia. Hence servo motors are used in applications where instant and accurate positioning of load is required.

4.) Speed is constant in servo motor.

5.) As in induction motor stator is formed by coils while in servo motor stator is formed with permanent magnet. So in induction motor very high inertia is there while in servo inertia is low. Due to that servo is very easy to stop at instant. So it is used in position control while in application where at instant position stop is not required induction motor is used.

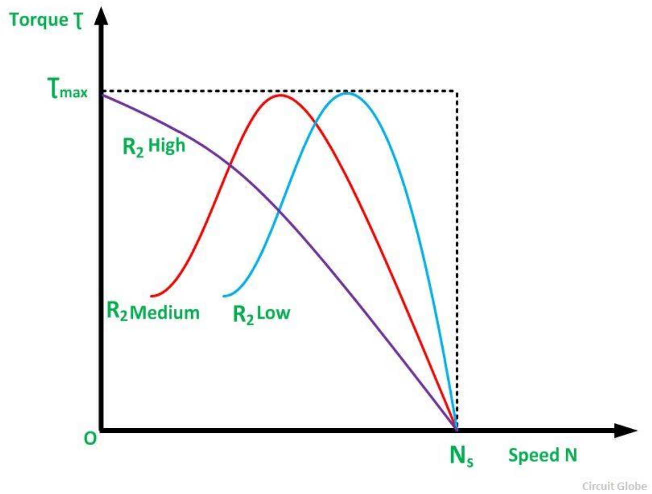
6.) The motors are selected according to the torque requirement and based on the application, for normal industrial application Induction motors are economical. For some application which requires high torque, positioning and breaking control, we can use servo motor. Servo needs and drive package and requires lengthy program.

7.) The rotor of the servomotor is built with high resistance, so that its X/R (Inductive reactance / Resistance) ratio is small which results in linear speed torque characteristics.(But conventional induction motors will have high value of X/R which results in high efficiency and non-linear speed- torque characteristics). The Speed-torque characteristics of normal induction motor (Curve-a) and AC servomotor (Curve-b) are shown in figure.



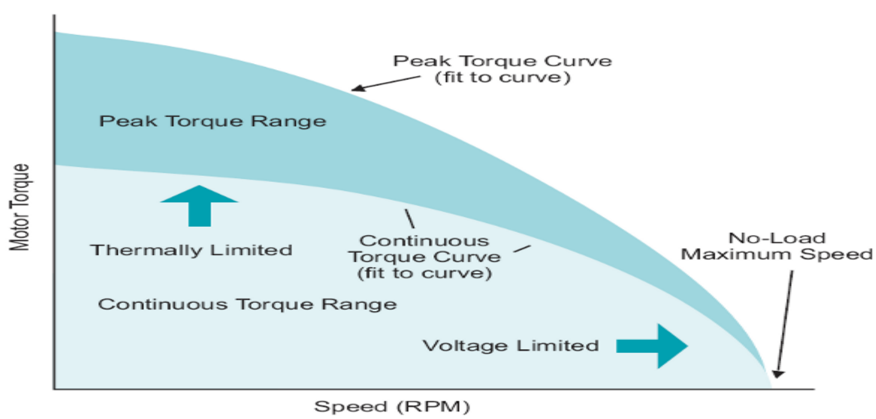
Speed Torque characteristics of

a) **Normal induction motor**
b) **AC Servomotor**



Induction motor

The maximum torque is independent of the rotor resistance. But the exact location of the maximum torque τ_{max} is dependent on it. Greater, the value of the R_2, the greater is the value of the slip at which maximum torque occurs. As the rotor resistance increases, the pullout speed of the motor decreases. In this condition, the maximum torque remains constant.

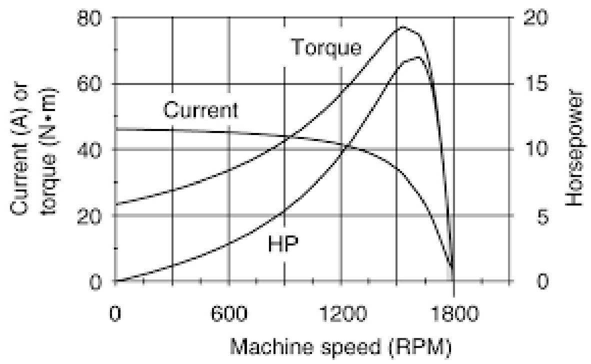


Servo motor

Servo motor torque curves are relatively flat up to the motor's maximum speed, unlike stepper motors, whose torque drops sharply beyond a certain operating speed.

The maximum torque required by the motor is typically the sum of torque during acceleration, torque due to the load, and torque to overcome friction. Because maximum torque is required for only a short amount of time, it can fall outside of the motor's continuous operating zone, but must fall within the intermittent duty zone.

Power v/s. Speed characteristics:



The fundamental relation between speed and power in a motor is
$P=2\pi NT/60$
where P is output power of rotor
N is speed of motor in rpm
T is the torque developed in rotor

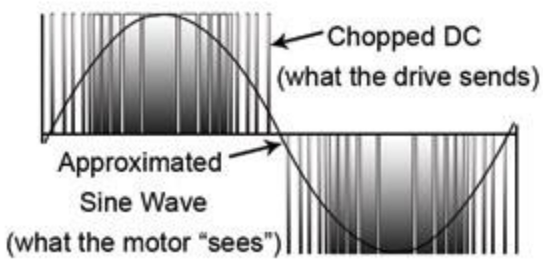
Vector duty Induction motor: or Inverter/Vector Duty

Inverter/Vector Duty motors designed specifically for variable speed control. They are designed to handle the additional heat generated when running at lower speeds. Vector Duty motors typically provide continuous constant torque performance across the entire speed range from zero speed to base speed.
Electronic adjustable speed drives, known as variable frequency drives (VFD), used to be marketed as "usable with any standard motor." However, premature failures of motor insulation systems began to occur as fast-switching, pulse-width-modulated (PWM) VFDs were introduced. The switching rates of modern power semiconductors can lead to voltage overshoots. These voltage spikes can rapidly damage a motor's insulation system, resulting in premature motor failure.
Background: AC motors can be driven by across-the-line contactors and starters. The electricity sent to the motor is a very clean (true) sine wave at 60Hz. Noise and voltage peaks are relatively small. However, there are drawbacks: the motors can only run electrically at one speed (speed reduction is usually handled by gearboxes or some other, usually inefficient, mechanical means) and the inrush of electrical current (when the motor is first turned on) is usually 5 to 6 times the normal

current that the motor consumes. The speed reduction apparatus is expensive and bulky, and the inrush can wreak havoc with power systems and loading (imagine an air conditioning system in an old house - when the compressor kicks on, the lights dim; now imagine the same circumstances with a motor the size of a small car).

VFDs (variable frequency drives):

Drives were introduced to allow the speed of these motors to be changed while running and to lessen the inrush current when the motor first starts up. To do this, the drive takes the incoming 60Hz AC power and rectifies it to a DC voltage. Every drive has a DC bus that is around 1.414 (sqrt of 2) * incoming AC Line Voltage.



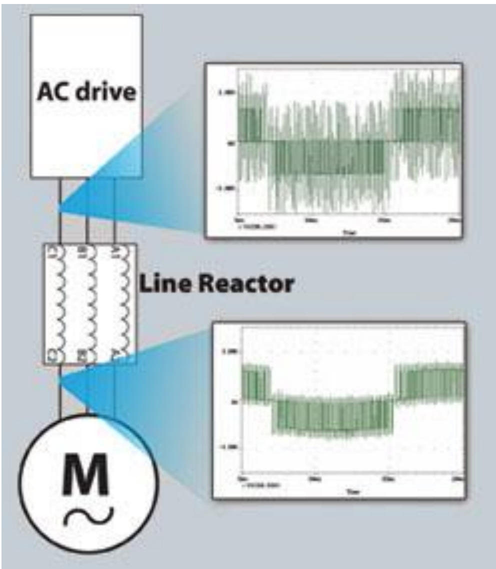
This DC voltage is then "chopped" by power transistors at very high frequencies to simulate a sine wave that is sent to the motor. By converting the incoming power to DC and then reconverting it to AC, the drive can vary its output voltage and output frequency, thus varying the speed of a motor. Everything sounds great, right? We get to control the frequency and voltage going out to the motor, thus controlling its speed.

Some things to watch out for:

A VFD-driven general purpose motor can overheat if it is run too slowly. (Motors can get hot if they're run slower than their rated speed.) Since most general purpose motors cool themselves with shaft-mounted fans, slow speeds mean less cooling. If the motor overheats, bearing and insulation life will be reduced. Therefore there are minimum speed requirements for all motors.

The voltage "chopping" that occurs in the drive actually sends high-voltage spikes (at the DC bus level) down the wire to the motor. If the system contains long cabling, there are actually instances where a reflected wave occurs at the motor. The reflected wave can effectively double the voltage on the wire. This can lead to premature failure of the motor insulation. Long cable lengths between the motor and drive increase the harmful effects of the reflected wave, as do high chopping frequencies (listed in drive manuals as carrier frequencies). Line reactors, 1:1

transformers placed at the output of the drive, can help reduce the voltage spikes going from the drive to the motor. Line reactors are used in many instances when the motor is located far from the drive.

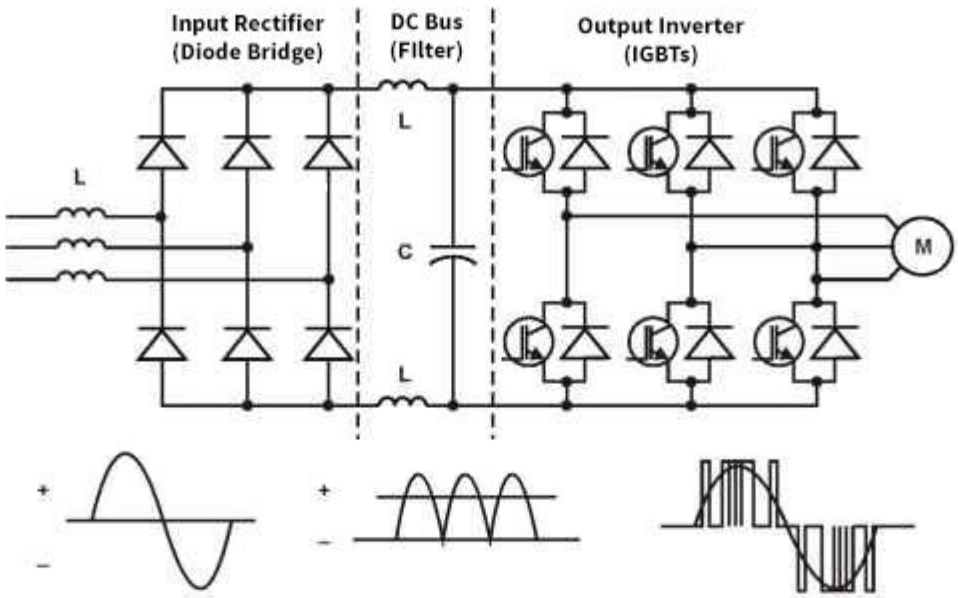


In summary, general purpose motors can be run with drives in many applications; however inverter-duty motors are designed to handle much lower speeds without overheating and they are capable of withstanding higher voltage spikes without their insulation failing. With the increased performance comes an increase in cost. This additional cost can be worth it if you need greater performance.

But when speed control is required, an AC motor is paired with a variable frequency drive (VFD), which regulates the motor's speed by using one of two control methods

— scalar control or vector control — to vary the frequency of the supplied voltage.

A ***scalar*** is a quantity that has ***only magnitude***, such as mass or temperature. A ***vector*** is a quantity that has ***both magnitude and direction***, such as acceleration or force.



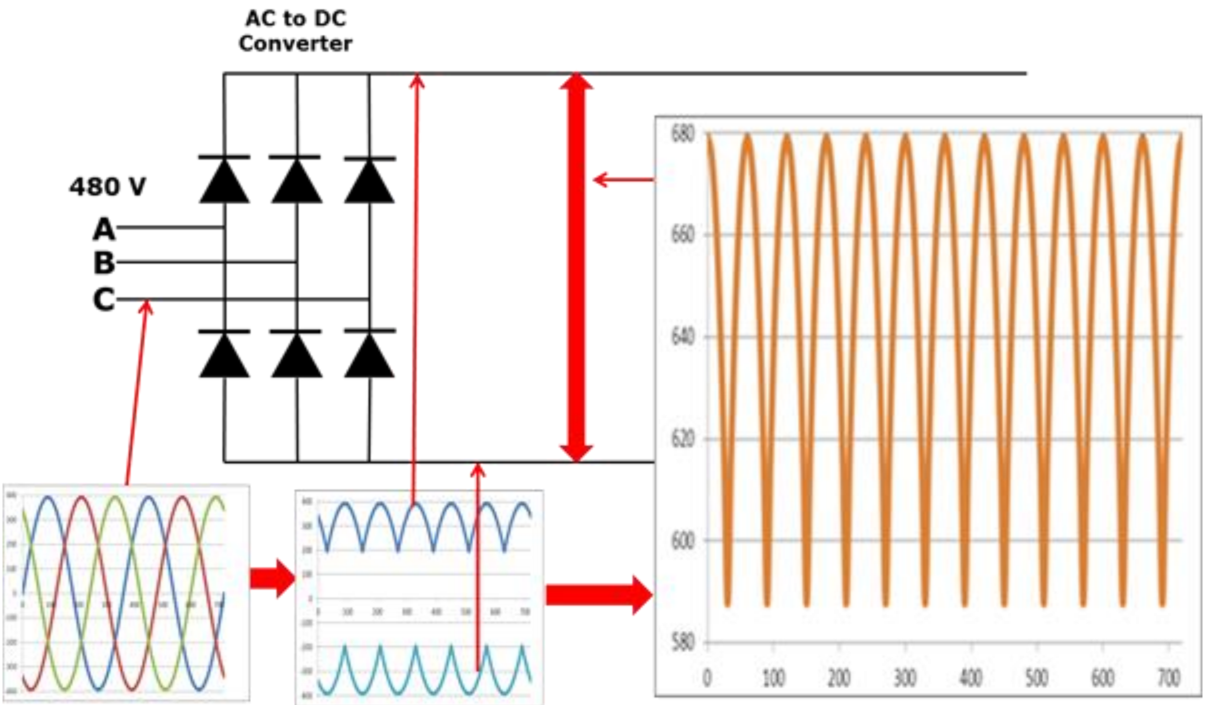
In a VFD, AC power is converted to DC through the rectifier. The rectified power is then filtered and stored in the DC bus (link). The inverter converts it back to AC power with the proper frequency and voltage via pulse-width modulation

A Variable Frequency Drive (VFD) is a type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor. Other names for a VFD are variable speed drive, adjustable speed drive, adjustable frequency drive, AC drive, microdrive, and inverter.

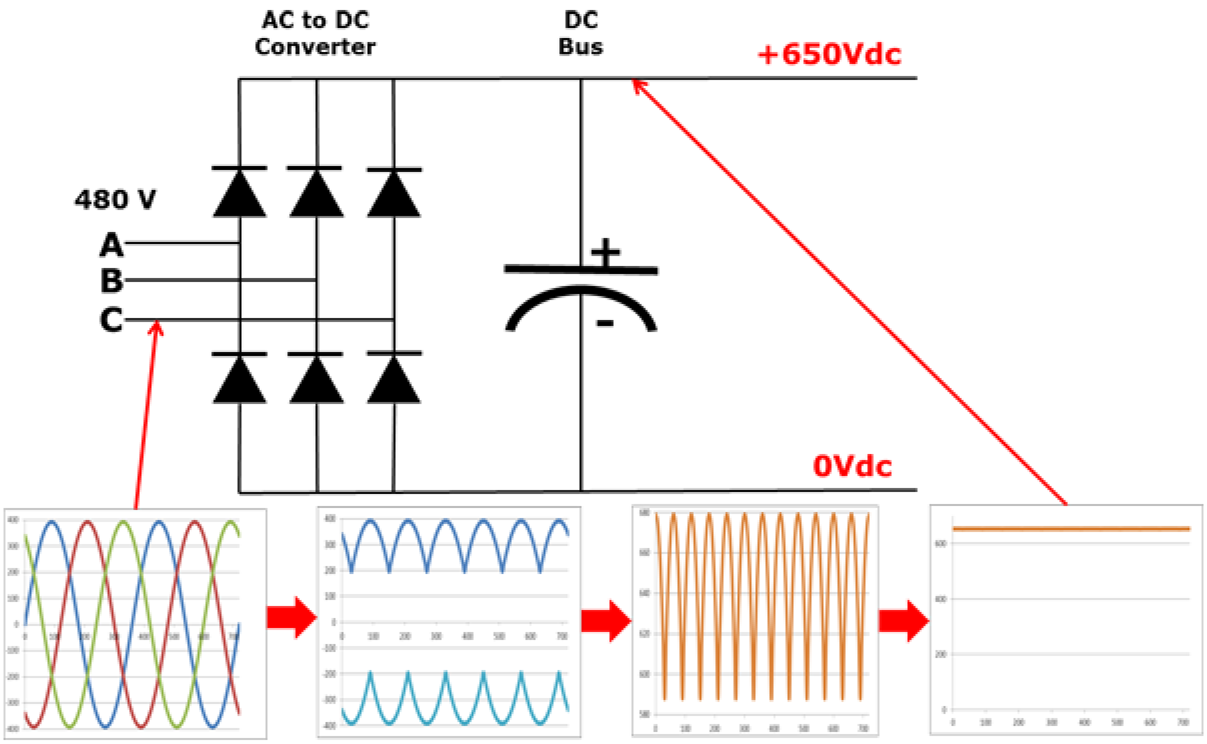
Frequency (or hertz) is directly related to the motor's speed (RPMs). In other words, the faster the frequency, the faster the RPMs go. If an application does not require an electric motor to run at full speed, the VFD can be used to ramp down the frequency and voltage to meet the requirements of the electric motor's load. As the application's motor speed requirements change, the VFD can simply turn up or down the motor speed to meet the speed requirement.

Working of VFD:

The first stage of a Variable Frequency AC Drive, or VFD, is the Converter. The converter is comprised of six diodes, which are similar to check valves used in plumbing systems. They allow current to flow in only one direction; the direction shown by the arrow in the diode symbol. For example, whenever A-phase voltage (voltage is similar to pressure in plumbing systems) is more positive than B or C phase voltages, then that diode will open and allow current to flow. When B-phase becomes more positive than A-phase, then the B-phase diode will open and the A-phase diode will close. The same is true for the 3 diodes on the negative side of the bus. Thus, we get six current "pulses" as each diode opens and closes. This is called a "six-pulse VFD", which is the standard configuration for current Variable Frequency Drives.

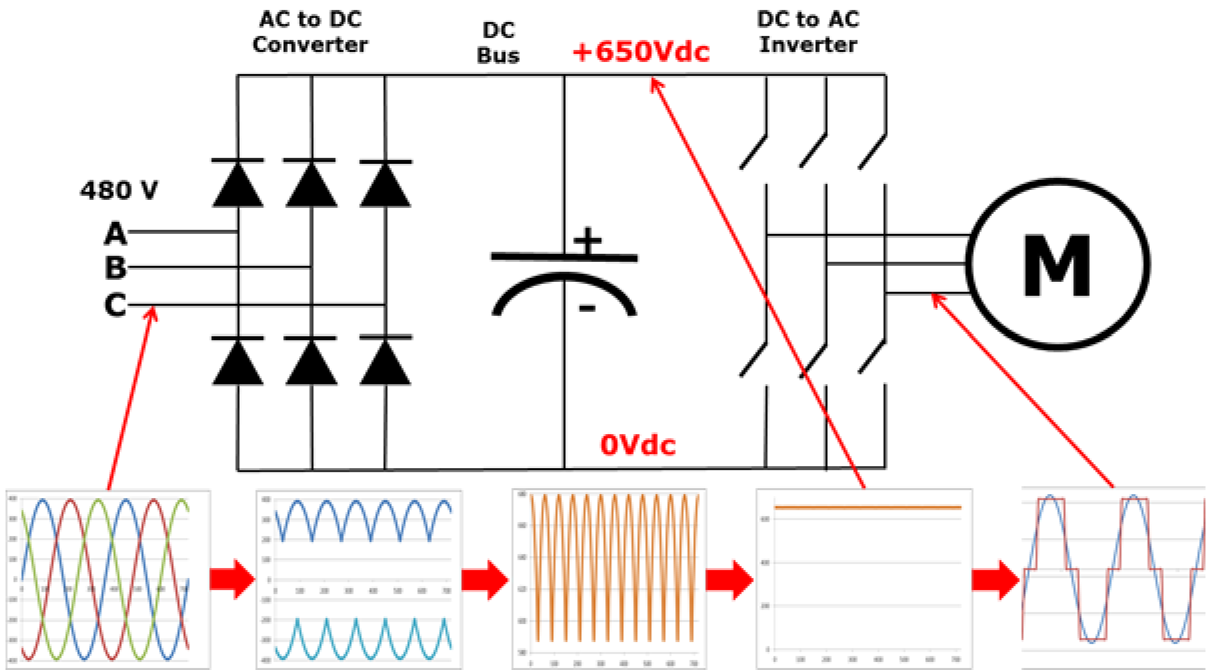


Let us assume that the drive is operating on a 480V power system. The 480V rating is "rms" or root-mean-squared. The peaks on a 480V system are 679V. As you can see, the VFD dc bus has a dc voltage with an AC ripple. The voltage runs between approximately 580V and 680V.



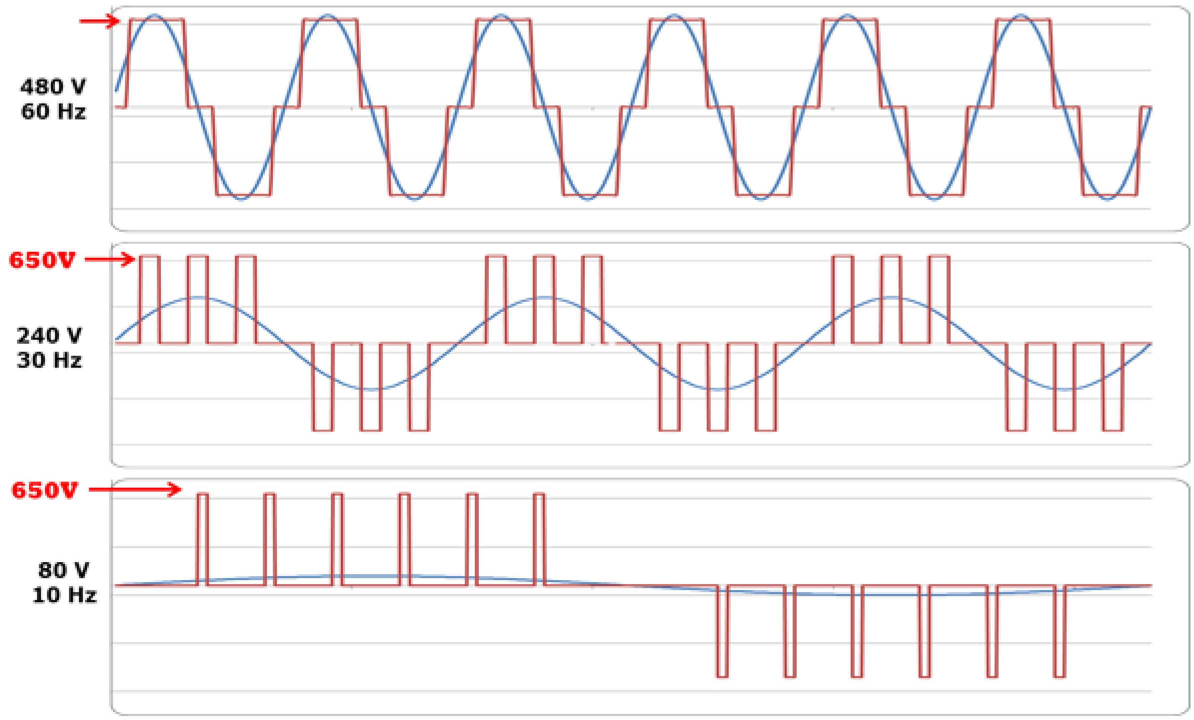
We can get rid of the AC ripple on the DC bus by adding a capacitor. A capacitor operates in a similar fashion to a reservoir or accumulator in a plumbing system. This capacitor absorbs the ac ripple and delivers a smooth dc voltage. The AC ripple on the DC bus is typically less than 3 Volts. Thus, the voltage on the DC bus becomes “approximately” 650VDC. The actual voltage will depend on the voltage level of the AC line feeding the drive, the level of voltage unbalance on the power system, the motor load, the impedance of the power system, and any reactors or harmonic filters on the drive.

The diode bridge converter that converts AC-to-DC, is sometimes just referred to as a converter. The converter that converts the dc back to ac is also a converter, but to distinguish it from the diode converter, it is usually referred to as an “inverter”. It has become common in the industry to refer to any DC-to-AC converter as an inverter.



Note that in a real VFD, the switches shown would actually be transistors.

When we close one of the top switches in the inverter, that phase of the motor is connected to the positive dc bus and the voltage on that phase becomes positive. When we close one of the bottom switches in the converter, that phase is connected to the negative dc bus and becomes negative. Thus, we can make any phase on the motor become positive or negative at will and can thus generate any frequency that we want. So, we can make any phase be positive, negative, or zero.



The blue sine-wave is shown for comparison purposes only. The drive does not generate this sine wave.

Notice that the output from the VFD is a “rectangular” wave form. VFD’s do not produce a sinusoidal output. This rectangular waveform would not be a good choice for a general purpose distribution system, but is perfectly adequate for a motor.

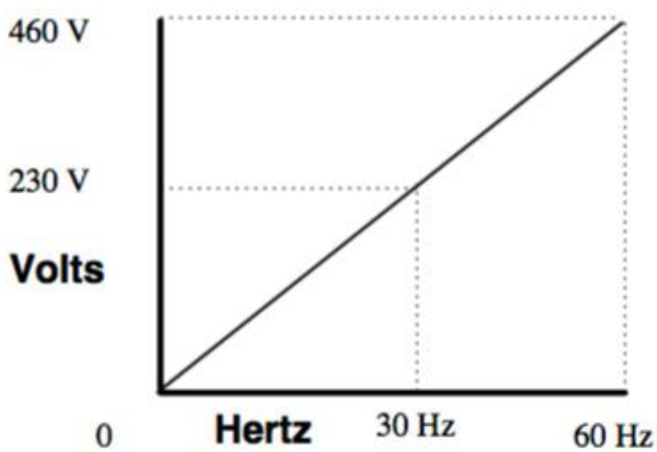
How frequency control: If we want to reduce the motor frequency to 30 Hz, then we simply switch the inverter output transistors more slowly. But, if we reduce the frequency to 30Hz, then we must also reduce the voltage to 240V in order to maintain the V/Hz ratio . How are we going to reduce the voltage if the only voltage we have is 650VDC?

This is called Pulse Width Modulation or PWM. Imagine that we could control the pressure in a water line by turning the valve on and off at a high rate of speed. While this would not be practical for plumbing systems, it works very well for VFD’s. Notice that during the first half cycle, the voltage is ON half the time and OFF half the time. Thus, the average voltage is half of 480V or 240V. **By pulsing the output, we can achieve any average voltage on the output of the VFD.**

Scalar control methods (V/F control):

Scalar methods for VFD control work by optimizing the motor flux and keeping the strength of the magnetic field constant, which ensures constant torque production. Often referred to as V/Hz or V/f control, scalar methods vary *both* the voltage (V) and frequency (f) of power to the motor in order to maintain a fixed, constant ratio between the two, so the strength of the magnetic field is constant, regardless of motor speed.

The appropriate V/Hz ratio is equal to the motor's rated voltage divided by its rated frequency. V/Hz control is typically implemented without feedback (i.e. open-loop), although closed-loop V/Hz control — incorporating motor feedback — is possible.



V/Hz control maintains a constant ratio between voltage (V) and frequency (Hz).

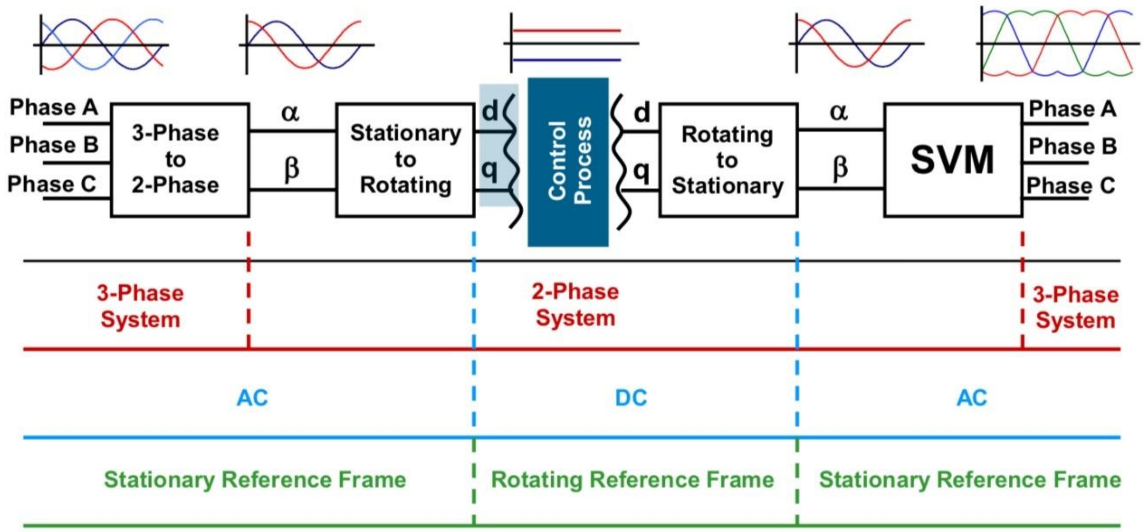
V/Hz control is simple and low-cost, although it should be noted that the closed-loop implementation increases cost and complexity. Control tuning is not required but can improve system performance.

Speed regulation with scalar control is only in the range of 2 to 3 percent of rated motor frequency, so these methods aren't suitable for applications where precise speed control is required. Open-loop V/Hz control is unique in its ability to allow one VFD to control multiple motors and is arguably the most-commonly implemented VFD control method.

Vector control methods (SLE):

Vector control — also referred to as field oriented control (FOC) — controls the speed or torque of an AC motor by controlling the stator current space vectors, in manner similar to (but more complicated than) DC control methods. Field oriented

control uses complex mathematics to transform a three-phase system that depends on time and speed to a two-coordinate (d and q) time-invariant system.
The stator current in an AC motor is made up of two components: the magnetizing component (d) of the current and the torque-producing component (q). With FOC, these two current components are controlled independently (each with its own PI controller). This allows the torque-producing component, q, to be kept orthogonal to the rotor flux for maximum torque production, and therefore, optimum speed control.



Vector control, or field-oriented control, converts 3-phase currents in a stationary reference frame to a 2-phase system (consisting of a flux component, d, and torque-producing component, q) with a rotating reference frame. Here, the torque-producing current (q) can be independently controlled to ensure maximum torque production. The system is then transformed back into a 3-phase system in a stationary reference frame for output to the motor.
Like scalar methods, vector VFD control methods can be open-loop or closed-loop.
Open-loop vector control (also referred to as sensorless vector control) uses a mathematic model of the motor operating parameters, rather than using a physical feedback device. The controller monitors voltage and current from the motor and compares them to the mathematical model. It then corrects any errors by adjusting the current supplied to the motor, which adjusts the motor's torque production accordingly. With senseless vector control, it's important to have a very accurate mathematical model of the motor, and the controller must be tuned for proper operation.
Closed-loop vector control uses an encoder to provide shaft position feedback, and this information is sent to the controller, which adjusts the supplied voltage to increase or decrease torque. This is the only method that allows direct torque control in all four quadrants of motor operation for dynamic braking or regeneration.

Vector control methods are more complex than scalar VFD control methods, but they offer significant benefits over scalar methods in some applications. For example, open-loop vector control enables the motor to produce high torque at low speeds, and closed-loop vector control allows a motor to produce up to 200 percent of its rated torque at zero speed, useful for holding loads at standstill. Closed-loop vector control also provides very accurate torque and speed control for industrial applications.

Advantage of using VFD:

1 - **Reduce Energy Consumption and Energy Costs**

If you have an application that does not need to be run at full speed, then you can cut down energy costs by controlling the motor with a variable frequency drive, which is one of the benefits of Variable Frequency Drives. VFDs allow you to match the speed of the motor-driven equipment to the load requirement. There is no other method of AC electric motor control that allows you to accomplish this.

Electric motor systems are responsible for more than 65% of the power consumption in industry today. Optimizing motor control systems by installing or upgrading to VFDs can reduce energy consumption in your facility by as much as 70%. Additionally, the utilization of VFDs improves product quality, and reduces production costs. Combining energy efficiency tax incentives, and utility rebates, returns on investment for VFD installations can be as little as 6 months.

2 - **Increase Production Through Tighter Process Control**

By operating your motors at the most efficient speed for your application, fewer mistakes will occur, and thus, production levels will increase, which earns your company higher revenues. On conveyors and belts you eliminate jerks on start-up allowing high through put.

3 - **Extend Equipment Life and Reduce Maintenance**

Your equipment will last longer and will have less downtime due to maintenance when it's controlled by VFDs ensuring optimal motor application speed. Because of the VFDs optimal control of the motor's frequency and voltage, the VFD will offer better protection for your motor from issues such as electro thermal overloads, phase protection, under voltage, overvoltage, etc.. When you start a load with a VFD you will not subject the motor or driven load to the "instant shock" of across the line starting, but can start smoothly, thereby eliminating belt, gear and bearing wear. It also is an excellent way to reduce and/or eliminate water hammer since we can have smooth acceleration and deceleration cycles.

Selection of feedback control systems:

Feedback Systems process signals and as such are signal processors. The processing part of a feedback system may be electrical or electronic, ranging from a very simple to a highly complex circuits.

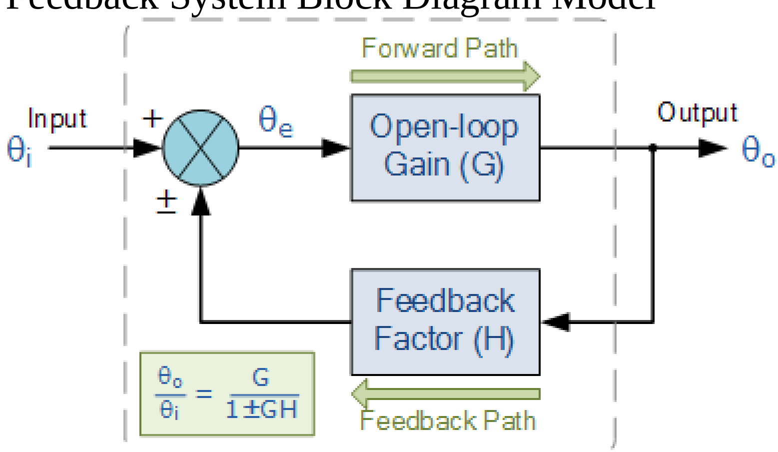
Simple analogue feedback control circuits can be constructed using individual or discrete components, such as transistors, resistors and capacitors, etc, or by using microprocessor-based and integrated circuits (IC's) to form more complex digital feedback systems.

As we have seen, open-loop systems are just that, open ended, and no attempt is made to compensate for changes in circuit conditions or changes in load conditions due to variations in circuit parameters, such as gain and stability, temperature, supply voltage variations and/or external disturbances. But the effects of these "open-loop" variations can be eliminated or at least considerably reduced by the introduction of **Feedback**.

A feedback system is one in which the output signal is sampled and then fed back to the input to form an error signal that drives the system. In the previous tutorial about Closed-loop Systems, we saw that in general, feedback is comprised of a sub-circuit that allows a fraction of the output signal from a system to modify the effective input signal in such a way as to produce a response that can differ substantially from the response produced in the absence of such feedback.

Feedback Systems are very useful and widely used in amplifier circuits, oscillators, process control systems as well as other types of electronic systems. But for feedback to be an effective tool it must be controlled as an uncontrolled system will either oscillate or fail to function. The basic model of a feedback system is given as:

Feedback System Block Diagram Model



This basic feedback loop of sensing, controlling and actuation is the main concept behind a feedback control system and there are several good reasons why feedback is applied and used in electronic circuits:

- Circuit characteristics such as the systems gain and response can be precisely controlled.
- Circuit characteristics can be made independent of operating conditions such as supply voltages or temperature variations.
- Signal distortion due to the non-linear nature of the components used can be greatly reduced.
- The Frequency Response, Gain and Bandwidth of a circuit or system can be easily controlled to within tight limits.

Types of feedback:

Positive Feedback :

In a “positive feedback control system”, the set point and output values are added together by the controller as the feedback is “in-phase” with the input. The effect of positive (or regenerative) feedback is to “increase” the systems gain, i.e, the overall gain with positive feedback applied will be greater than the gain without feedback. For example, if someone praises you or gives you positive feedback about something, you feel happy about yourself and are full of energy, you feel more positive.
However, in electronic and control systems to much praise and positive feedback can increase the systems gain far too much which would give rise to oscillatory circuit responses as it increases the magnitude of the effective input signal.
An example of a positive feedback systems could be an electronic amplifier based on an operational amplifier, or op-amp as shown.

Negative Feedback Systems

In a “negative feedback control system”, the set point and output values are subtracted from each other as the feedback is “out-of-phase” with the original input. The effect of negative (or degenerative) feedback is to “reduce” the gain. For example, if someone criticises you or gives you negative feedback about something, you feel unhappy about yourself and therefore lack energy, you feel less positive.
Because negative feedback produces stable circuit responses, improves stability and increases the operating bandwidth of a given system, the majority of all control and feedback systems is degenerative reducing the effects of the gain.
An example of a negative feedback system is an electronic amplifier based on an operational amplifier as shown.

Feedback systems typical are servo control systems used to control position, velocity, and/or acceleration. Figure 8.15 is a graphical representation of a typical servo control system. The controller and industrial digital drives contain the algorithms to close the desired loop (typically position or speed) and also handle machine interfacing with inputs/outputs, terminals, etc. The drive or amplifier closes another loop (typically speed or current) and represents the electrical power converter that drives the motor according to the controller reference signals. The motor can be DC or AC, rotary or linear. It is the actual electromagnetic actuator, generating the forces or torques required to move the load. Feedback elements such as tachometers, transmitters, encoders and resolvers are mounted on the motor and/or load in order to close the various servo loops.

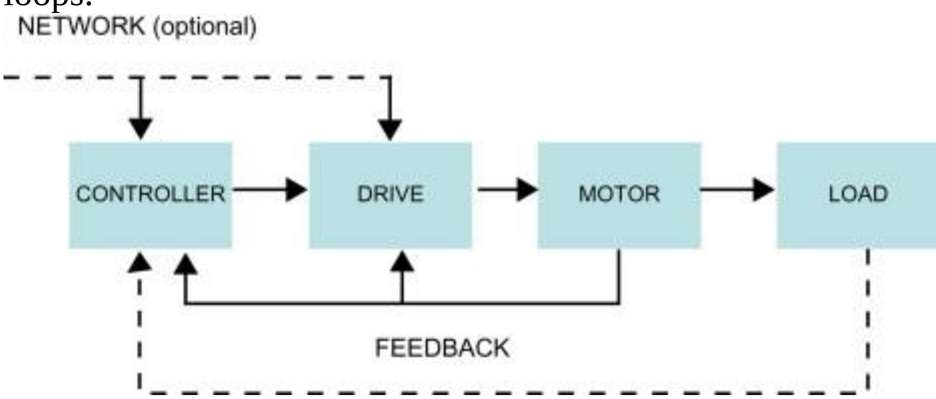


Figure 8.15. Typical servo control system: architecture and components.

(1) **Controller**

The controller is the brains of a servo control system. It is responsible for generating the motion paths and for reacting to changes in the outside environment. Typically, the controller sends a command signal to the drive; the drive provides power to the motor; and the feedback from the motor is sent back to the controller and drive. Feedback from the load is also routed to the controller. The controller analyzes the feedback signal and sends a new signal to the amplifier to correct for errors. The controller is considered to be the intelligent part of the servo, closing the speed and/or position loops while the amplifier closes the current loop, but may also close the speed and/or position loops, placing less demand on the controller. Controllers come in a variety of forms, selected on the basis of cost, performance, convenience, and ease of use. Most controllers fall into the category of microcontrollers, which include PIC and R/C controllers, PLCs, and motion controllers.

In a servo system, the controller is the device that activates motion by providing a command signal to start, or change speed, or position, or both. This command is amplified and applied to the motor, and motion commences. Systems that assume the motion has taken place (or is in the process of taking place) are termed "open loop". An open loop drive (Figure 8.16(a)) is one in which the signal goes in only one direction from the control to the motor–no signal returns from the motor or load to inform the control that action or motion has occurred.

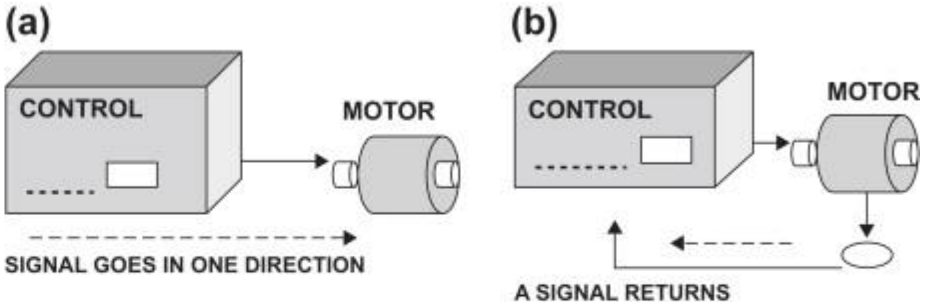


Figure 8.16. Servo control types: (a) open-loop drive; (b) closed-loop drive.

If a signal is returned, then the system is described as having a signal that goes in two directions; the command signal goes out (to move the motor), and a signal is returned (the feedback) to the control to inform the control of what has occurred. The information flows back, or returns, and this is termed "closed loop" (Figure 8.16(b)).

The open loop approach is not good for applications with varying loads; it is possible for a stepper motor to lose steps; its energy efficiency level is low; and it has resonance areas that must be avoided. Applications that use the closed loop technique are those that require control over a variety of complex motion profiles. **These may involve tight control of either speed and/or position; high resolution and accuracy; very slow, or very high velocity; and the application may demand high torques in a small package size.**

(2**) Drive:**

The servo drive is the link between the controller and motor. Also referred to as servo amplifiers, their job is to translate the low-energy reference signals from the controller into high-energy power signals to the motor. Originally, drives were simply the power stage that allowed a controller to drive a motor. They started out as single quadrant models that powered brushed motors. Later they incorporated four quadrant capabilities and the ability to power brushless motors. Four quadrants means the ability to both drive and regenerate from a motor in both directions.

Special servo drives and amplifiers are designed and manufactured for advanced motion control. They are used extensively where precise control of position and/or velocity is required. The drive or amplifier simply translates the low-energy reference signals from the controller into high-energy signals to provide motor voltage and current. In some cases a digital drive replaces either the controller/drive or controller/amplifier control system. The reference signals represent either a motor torque or a velocity command, and can be either analog or digital in nature.

The current trend is to add more features and abilities to drives. Today drives can be expected to handle all of the system feedback including encoders, resolvers and tachometers, as well as limit switches and other sensors. Drives are also being asked to close the torque loop, speed loop and position loop and being given the responsibility of path generation. As the line between controller and drive blurs, the drive will take on many of the more complex control functions that used to be the sole domain of the controller.

(3) **Motor**

The motor converts the current and voltage from the drive into mechanical motion. Most motors are rotary, but linear motors are also available. Many types of motors can be used in servo applications.

(4) **Load**

Load considerations should include the object that is being moved, the moving parts in the machine and anything that may cause unwanted instabilities, such as couplings and backlash. The total mass of the moving parts in the machine all have inertias that the motor will need to overcome. Friction points such as from linear stages and bearings will add to the motor load. Flexible couplings will add resonances that have to be considered.

(5) **Feedback**

In modern control systems, feedback devices are used to ensure that the motor or load reaches the commanded (required) position or speed. Servo amplifiers and controllers use this feedback to determine how much current to deliver to the motor at any given time, based on its present, actual position and speed compared with that required. There are two main types of feedback; absolute and relative (also known as incremental-only).

1.Absolute feedback: absolute devices provide definitive position within a specified range without any movement (without a homing routine).

2.Relative feedback (incremental): these devices provide only incremental position updates. In order to know the motor or load's position, this incremental feedback needs to be used in conjunction with some type of absolute feedback (a limit switch, for example).

<u>Motor Duty Cycle and its Classification</u>

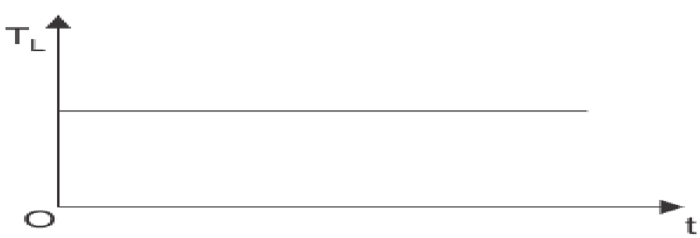
A **duty cycle** or power **cycle** is the fraction of one period in which a signal or system is active. **Duty cycle** is commonly expressed as a percentage or a **ratio**. ... Thus, a 60% **duty cycle** means the signal is on 60% of the time but off 40% of the time.

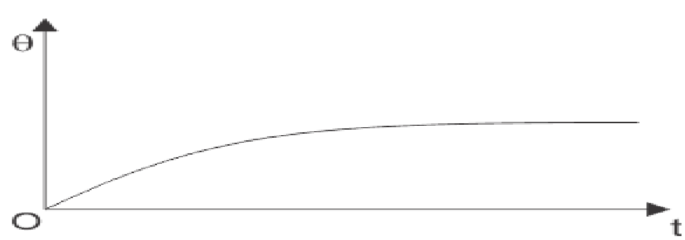
Now a days, in almost every applications, electric motors are used, and to control them electrical drives are employed. But the operating time for all motors are not the same. Some of the motors runs all the time, and some of the motor’s run time is shorter than the rest period. Depending on this, concept of **motor duty class** is introduced and on the basis of this duty cycles of the motor can be divided in eight categories such as

1. Continuous duty
2. Short time duty
3. Intermittent periodic duty
4. Intermittent periodic duty with starting
5. Intermittent periodic duty with starting and braking
6. Continuous duty with intermittent periodic loading
7. Continuous duty with starting and braking
8. Continuous duty with periodic speed changes

Continuous Duty

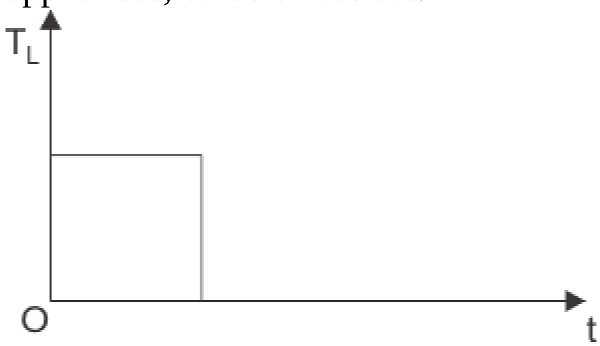
This duty denotes that, the motor is running long enough and the electric motor temperature reaches the steady state value. These motors are used in paper mill drives, compressors, conveyors etc.

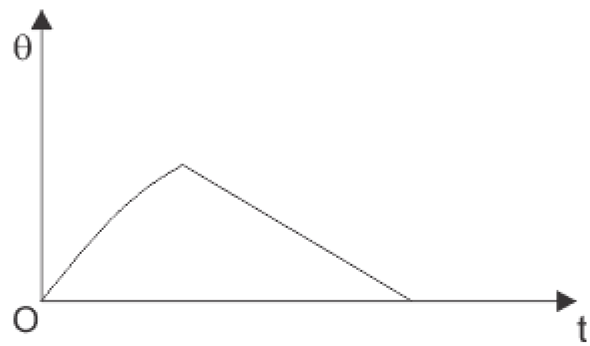




Short Time Duty

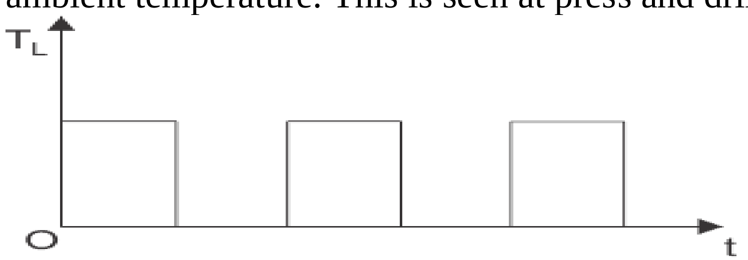
In these motors, the time of operation is very low and the heating time is much lower than the cooling time. So, the motor cooks off to ambient temperature before operating again. These motors are used in crane drives, drives for house hold appliances, valve drives etc.



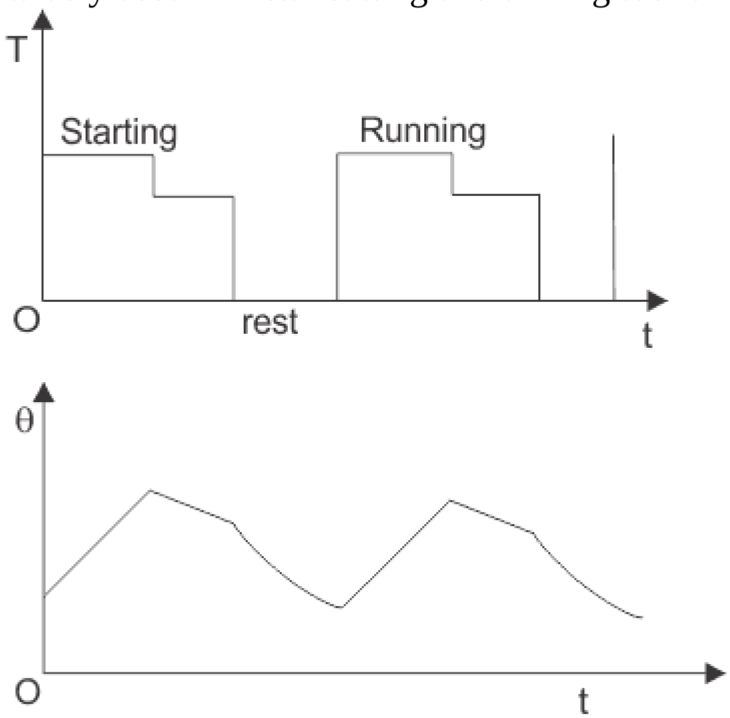


Intermittent Periodic Duty

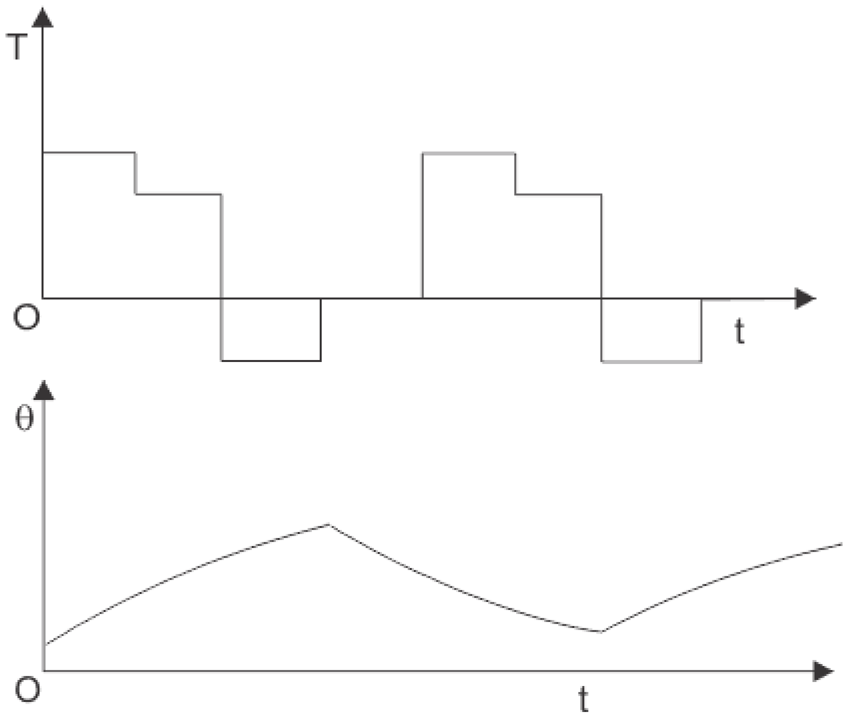
Here the motor operates for some time and then there is rest period. In both cases, the time is insufficient to raise the temperature to steady state value or cool it off to ambient temperature. This is seen at press and drilling machine drives.



Intermittent Period Duty with Starting
In this type of duty, there is a period of starting, which cannot be ignored and there is a heat loss at that time. After that there is running period and rest period which are not adequate to attain the steady state temperatures. This motor duty class is widely used in metal cutting and drilling tool drives, mine hoist etc.



Intermittent Periodic Duty with Starting and Braking
In this type of drives, heat loss during starting and braking cannot be ignored. So, the corresponding periods are starting period, operating period, braking period and resting period, but all the periods are too short to attain the respective steady state temperatures, these techniques are used in billet mill drive, manipulator drive, mine hoist etc.



Continuous Duty with Intermittent Periodic Loading
In this type of motor duty, everything is same as the periodic duty but here a no load running period occurs instead of the rest period. Pressing, cutting are the examples of this system.
Continuous Duty with Starting and Braking
It is also a period of starting, running and braking and there is no resting period. The main drive of a blooming mill is an example.
Continuous Duty with Periodic Speed Changes
In this type of motor duty, there are different running periods at different loads and speeds. But there is no rest period and all the periods are too short to attain the steady state temperatures.

V / f Control or Frequency Control(Scaler control):

Whenever three phase supply is given to three phase induction motor rotating magnetic field is produced which rotates at synchronous speed given by

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

In three phase induction motor emf is induced by induction similar to that of transformer which is given by

$$E\ or\ V = 4.44\phi K.T.f\ or\ \phi = \frac{V}{4.44KTf}$$

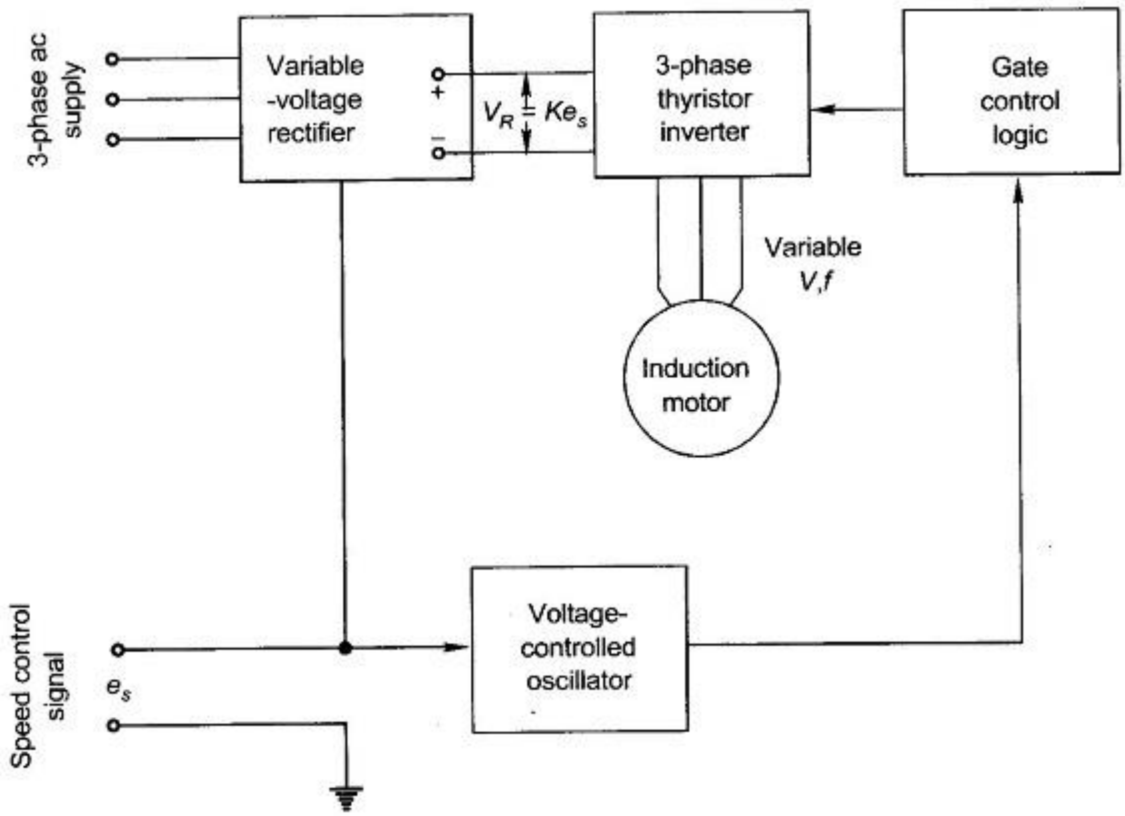


Fig. 11.38 *Frequency-control of induction motor speed; speed ∝ e_s, flux/pole constant*

Where, K is the winding constant, T is the number of turns per phase and f is frequency. Now if we change frequency synchronous speed changes but with decrease in frequency flux will increase and this change in value of flux causes saturation of rotor and stator cores which will further cause increase in no load current of the motor . So, its important to maintain flux , φ constant and it is only possible if we change voltage. i.e **if we decrease frequency flux increases but at the same time if we decrease voltage flux will also decrease causing no change in flux and hence it remains constant. So, here we are keeping the ratio of V/f as constant.** Hence its name is V/ f method. For controlling the speed of three phase induction motor by V/f method we have to supply variable voltage and frequency which is easily obtained by using converter and inverter set.
Demand for low-cost, robust motor drives has spurred increased use of sensor less vector control of induction and BLDC motors — in everything from consumer products to industrial applications, in myriad sizes and power ratings. It is a open loop system.

1. Introduction about V/F Control

V/F is abbreviated from voltage/frequency. V/F control is an induction motor control method which ensures the output voltage proportional with the frequency, so it maintains a constant motor flux, preventing weak magnetic and magnetic saturation phenomenon from happening.

2. Control Principle

V/F control principle is to produce a circuit called voltage-controller oscillator with oscillator frequency. It is a voltage-dependent capacitance, when subjected to a change in voltage, its capacity will change, and then the change in capacity will cause changes in the oscillation frequency, resulting in variable frequency. This controlled frequency is used to control the frequency of the output voltage, in order to achieve speed changes of the controlled electric motors.

3. Applications of V/F Control:

Asynchronous electric motor torque is a result of the interaction of flux and rotor flux. At a rated frequency, if voltage is set to a certain value and only reduce the frequency, then there will be large magnetic flux and magnetic circuit saturation (severely, it will burn motor). Therefore, the frequency and voltage must be changed proportionally. When changing the frequency, we should control the output voltage of AC drive, in order to keep constant flux and avoid weak magnetic and magnetic saturation phenomenon. This control method is commonly applied for fans and pumps.

4. Pros and Cons of V/F Control

Currently, most of the general purpose are using the V/F control method.

The VFDs which are of V/F control usually features simple structure. But this kind of VFD adopts open-loop control, so it is difficult to achieve high control performance, moreover, at low frequency, it requires for torque compensation in order to change the low frequency torque characteristics.

The below image shows the motor control modes supported by Veichi AC70: V/F control and vector motor control mode:

A control method that enables preventing reductions in the power factor or efficiency of a motor in a wide range of variable speed operation for changes in the frequency for speed control by outputting a voltage (V/f characteristic) corresponding to the frequency set by a parameter in an Inverter. The revolution speed of an induction motor is proportional to the frequency, which can reduce the power factor and efficiency of a motor even with a variable frequency because changes to the frequency cause the internal impedance of a motor to change. Therefore you must change the voltage corresponding to the frequency. V/f control reduces the torque in low-speed operation with the primary resistance voltage drop even through it attempts to keep the torque stable regardless of the frequency. A torque boost can increase the torque somewhat in low-speed operation, but it never produces optimized control, causing the current-torque ratio to drop and resulting in an inability to get the same torque as the base frequency. It also requires the troublesome boost adjustment.

Flux Vector control:

The three phase alternating current (AC) induction motor are mechanically simple, rugged, highly reliable, lower in cost per horsepower than DC motors and capable of more torque and efficiency than single-phase AC motors. A three phase AC induction motor can be controlled by varying its input according to a mathematical model of the rotor flux field in a complex vector space (Vector Control).

1. Introduction

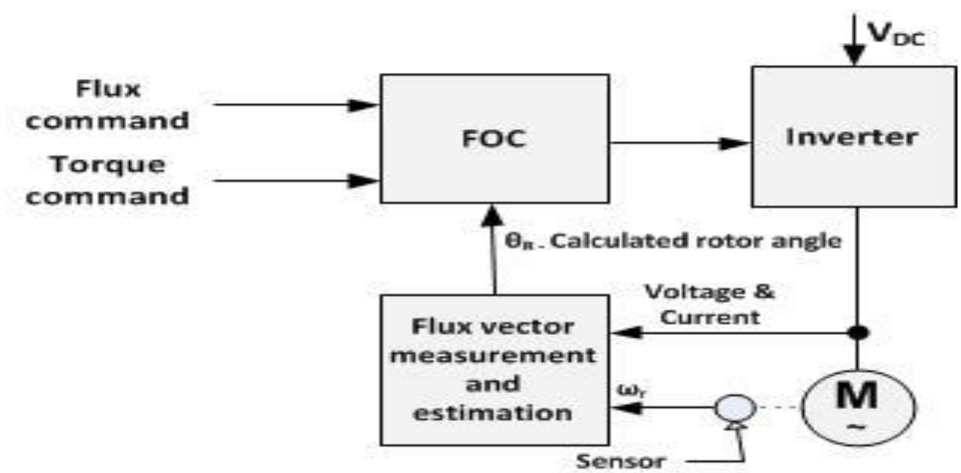
Vector control implies that an ac motor is forced to behave dynamically as a dc motor by the use of feedback control. The induction motors are very common because they are inexpensive and robust, finding use in everything from industrial applications such as pumps, fans, and blowers to home appliances. Traditionally, induction motors have been run at a single speed, which was determined by the frequency of the main voltage and the number of poles in the motor. Controlling the speed of an induction motor is far more difficult than controlling the speed of a DC motor since there is no linear relationship between the motor current and the resulting torque as there is for a DC motor. For a long time, the induction motors were not a technical solution for adjustable control (driving), even though they are superior to the continuous current motor considering dimensions, weight, rotor ineptness, effective power, cost, reliability, exploitation expenses, etc.

The technique called Vector Control can be used to vary the speed of an induction motor over a wide range. It was initially developed by Blaschke (1971-1973). In the vector control scheme, a complex current is synthesized from two quadrature components, one of which is responsible for the flux level in the motor, and another which controls the torque production in the motor. **Vector control offers a number of benefits including speed control over a wide range, precise speed regulation, fast dynamic response, and operation above base speed**.

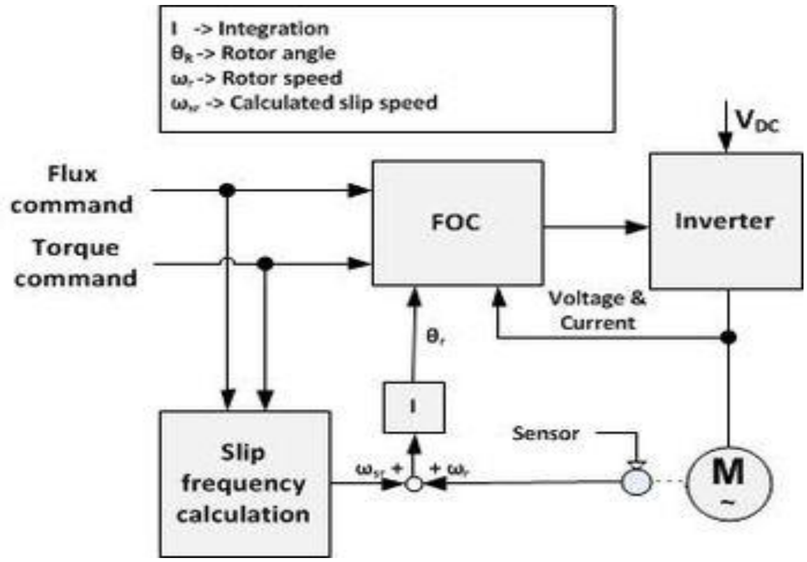
2. Review of Related Works

The vector control algorithm is based on two fundamental ideas. The first is the flux and torque producing currents. An induction motor can be modelled most simply (and controlled most simply) using two quadrature currents rather than the familiar three phase currents actually applied to the motor. These two currents called direct (Id) and quadrature (Iq) are responsible for producing flux and torque respectively in the motor. **Id is flux producing current and Iq is torque producing current.**

Field orientation control (FOC) Vector control techniques have made possible the application of induction motors for high performance applications where traditionally only DC drives were applied (Holtz - 1995). **The vector control scheme enables the control of the induction motor in the same way as separately excitation DC motors.** As in the DC motor, torque control of induction motor is achieved by controlling the torque current component and flux current component independently. **The basic schemes of indirect and direct methods of vector control are shown in figures below**.



Simplified Direct FOC Block Diagram



Simplified Indirect FOC Block Diagram

Direct vector control method : it depends on the generation of unit vector signals from the stator or air-gap flux signals. The air-gap signals can be measured directly or estimated from the stator voltage and current signals. The stator flux components can be directly computed from stator quantities. In these systems, rotor speed is not required for obtaining rotor field angle information.

Indirect vector control method: The rotor field angle and thus the unit vectors are indirectly obtained. In the indirect vector control method, the rotor field angle and thus the unit vectors are indirectly obtained by summation of the rotor speed and slip frequency. In this rotor speed is required for obtaining rotor field angle.

The most modern technique is direct torque and stator flux vector control method (DTC). It has been realized in an industrial way by ABB, by using the theoretical background proposed by Blashke and Depenbrock during 1971-1985. This solution is based both on field oriented control (FOC) as well as on the direct self-control theory.

Starting with a few basics in a variable speed drive the basic function is to control the flow of energy from the mains to a process via the shaft of a motor. Two physical quantities describe the state of the shaft: torque and speed. Controlling the flow of energy depends on controlling these quantities. In practice either one of them is controlled and we speak of "torque control" or "speed control". When a variable speed drive operates in torque control mode the speed is determined by the load. Torque is a function of the actual current and actual flux in the machine. Likewise when operated in speed control the torque is determined by the load.

Variable speed drives are used in all industries to control precisely the speed of electric motors driving loads ranging from pumps and fans to complex drives on paper machines rolling mills cranes and similar drives.
The idea is that **motor flux and torque are used as primary control variables then** which is contrary to the way in which traditional **AC drives control input frequency and voltage,** but is in principle similar to what is done with a DC drive, where it is much more straightforward to achieve. In contrast, traditional PWM and flux vector drives use output voltage and output frequency as the primary control variables but these need to be pulse width modulated before being applied to the motor. This modulator stage adds to the signal processing time and therefore limits the level of torque and speed response time possible from the PWM drive.

Advantage of DTC:

In contrast, by controlling motor torque directly, DTC provides dynamic speed accuracy equivalent to closed loop AC and DC systems and torque response times that are 10 times faster. It is also claimed that the DTC does not generate noise like that produced by conventional PWM AC drives. And the wider spectrum of noise means that amplitudes are lower which helps to control EMI and RFI emissions.

Using FOC it becomes possible to control, directly and separately, the torque and flux of the induction motors. Field oriented controlled induction machines obtain every DC machine advantage: instantaneous control of the separate quantities allowing accurate transient and steady state management.
As a control strategy used in variable frequency drives, vector control provides a feasible solution to torque/speed control of AC machines by controlling the phase currents into the machine even if it gives rise to a considerable computation burden for the processor where the control algorithms are implemented. The most noticeable merit of vector control is to get rid of machine speed dependency on power grid frequency and make it possible to reach the desired machine speed within safety and power limits.

(SLE: Current control (sensor less vector control):

Sensorless vector control, also known as field-oriented control, outputs performance comparable to that of a motor drive using position/velocity feedback — in turn decreasing drive-system cost.
Some applications require a compact design; others in corrosive, extremely hot, or otherwise hostile environments necessitate that designs be free of additional wiring (for sensors or devices mounted on the shafts and so on.) Sensorless vector control benefits designs in both of these situations.
Demand for low-cost, robust motor drives has spurred increased use of sensorless vector control of induction and BLDC motors — in everything from consumer products to industrial applications, in myriad sizes and power ratings.

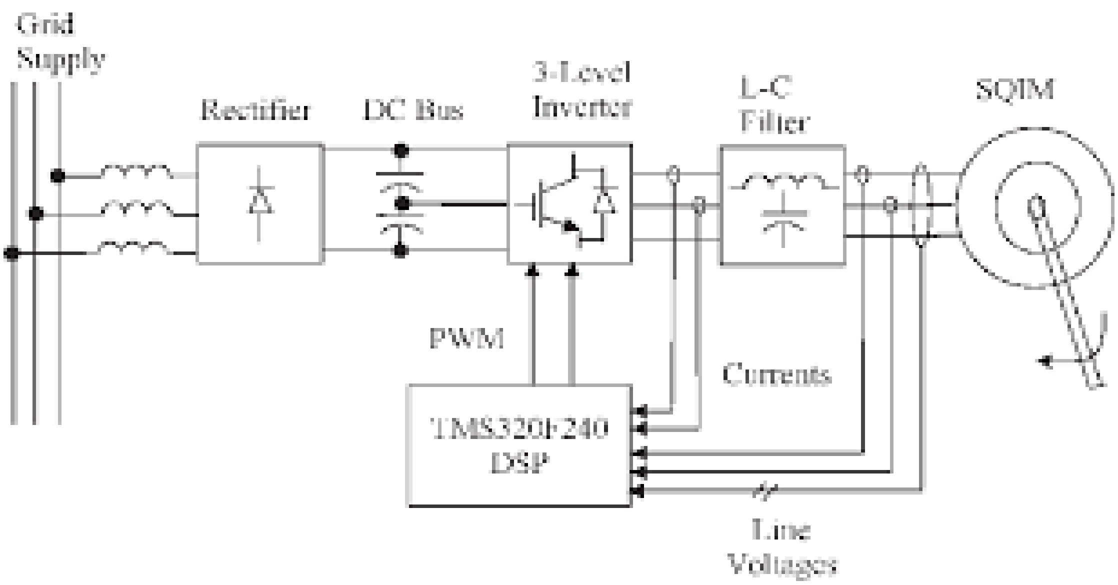
How does it work?

Control of electrical motors without position or velocity sensors usually utilizes one of three methodologies: Constant volts per hertz control, open-loop flux-vector control, or sensorless flux-vector control.
Volts-per-hertz control is only used for control of an ac induction motor. It is based on the principle that to maintain constant magnetic flux in the motor, the ratio between terminal voltage magnitude and applied frequency must remain roughly constant. The volts-per-hertz method works well in applications with slowly varying and predictable load.
For better torque control, flux vector techniques were developed to control not only the magnitude of the ac excitation, but also the orientation (or vector.) The principle of field orientation, upon which they're based, states that if the current vector is controlled relative to the rotor flux vector, then the flux vector magnitude and motor torque can be independently controlled.
Finally, sensorless vector control modulates the frequency, amplitude, and phase of the motor drive voltage. The aim is to generate modulated three-phase voltage to control the three-phase stator current — which in turn controls the rotor flux vector and torque independently.
Both open loop and sensorless flux vector control can be applied to induction and BLDC motors alike.
In vector control method, the flux and torque currents are separated to linearly control the output torque of an induction motor. In order to achieve this, vector control requires precise information of the angle of the rotor flux. The angle of the rotor flux is indirectly predicted by vector control using the motor speed measured from a speed sensor attached to the rotor shaft. Although a vector controller using a speed sensor could accurately control a servo mechanism, some problems occur

because of the speed sensor. Therefore, sensorless speed control has been taken great interest due to fact that it can control torque without a speed sensor

Flux vector control improves on the basic V/Hz control technique by providing both a magnitude & angle between the voltage & current. Volts per hertz variable frequency drives control only the magnitude. Vector VFDs come in two types, open loop & closed loop , based on the way they get their feedback information. Open loop is actually a misnomer because it's actually a closed loop system, but the feedback loop comes from within the variable frequency drive itself instead of an external encoder. For this reason there is a trend to refer to open-loop VFDs as sensor less vector VFDs. Sensor less vector control removes a major source of complexity & simplifies the variable frequency drive installation.

The block diagram of a sensor less flux vector control VFD is shown as:



A pulsewidth-modulated (PWM) voltage applied to a squirrel-cage induction motor (SQIM) can cause high bearing currents, heating of rotor shaft, voltage spike across the motor terminals, etc. Filtering of this PWM voltage to obtain a sinusoidal output voltage can be a solution to this problem. However, a passive L-C filter makes the dynamic performance of the drive poor for high-performance control application. In this a feed-forward control strategy for the L-C filter is proposed to have a good bandwidth for the filter output voltage. This filter control strategy is introduced along with a sensorless vector control strategy for the SQIM drive. This complete strategy retains the high dynamic performance of the drive even with the L-C filter. In this paper, a three-level converter is used as a voltage source inverter for the drive to have a less filter-size requirement.

sensorless vector control modulates the frequency, amplitude, and phase of the motor drive voltage. The aim is to generate modulated three-phase voltage to control the three-phase stator current — which in turn controls the rotor flux vector and torque independently.