Module-5

5a.Synchronous Generator

Electric power is generated using three phase alternators.

Principle: Whenever a coil is rotated in a magnetic field an EMF will be induced in the coil. This is called the dynamically induced EMF.

Alternators are also called as Synchronous Generators due to the reason that under normal conditions the generator is to be rotated at a definite speed called "SYNCHRONOUS SPEED", Ns R.P.M. in order to have a fixed frequency in the output EMF wave.

Ns is related with the frequency as Ns = 120f / P, where f is the frequency and P is the total number of poles.

The following table gives the idea of the various synchronous speeds for various numbers of poles for the fixed frequency of 50 Hz.

P	**2**	**4**	**6**	**8**	**10**	**12**	**16**	**……….**
Ns rpm	**3000**	**1500**	**1000**	**750**	**600**	**500**	**375**	**……….**

Working principle of alternator :

The alternators work on the principle of electromagnetic induction. When there is a relative motion between the conductors and the flux, e.m.f. gets induced in the conductors. The d.c. generators also work on the same principle. The only difference in practical alternator and a d.c. generator is that in an alternator the conductors are stationary and field is rotating. But for understanding purpose we can always consider relative motion of conductors with respect to the flux produced with respect to the flux produced by the field winding.

Consider a relative motion of a single conductor under the magnetic field produced by two stationary poles. The magnetic axis of the two poles produced by field is vertical, shown dotted in the fig. 34.

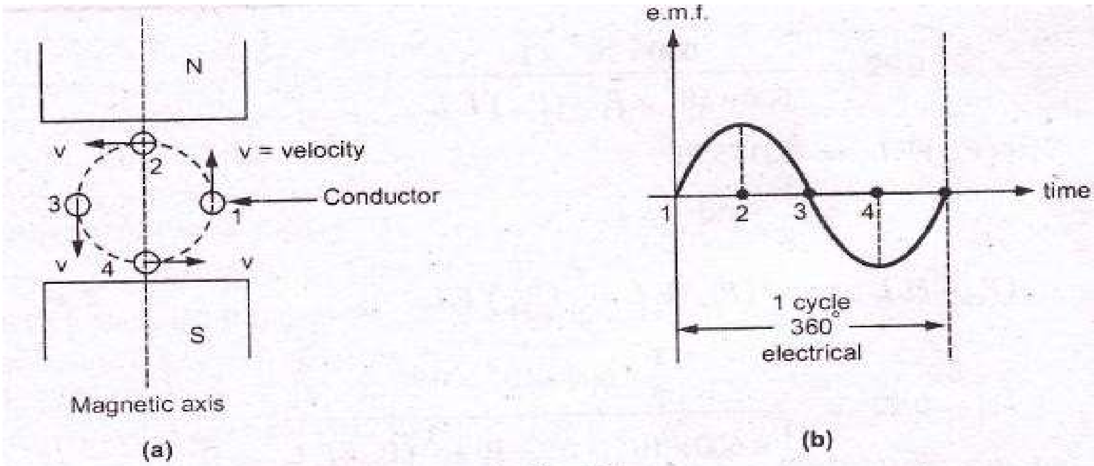


Fig. 34

Let the conductor starts rotating from position 1. At this instant, the entire velocity component is parallel to the flux lines. Hence there is no cutting of flux lines by the conductor. So $\frac{d\emptyset}{dt}$ at this instant is zero and hence induced e.m.f. in the conductor is also zero.

As the conductor moves from position 1 to position 2, the part of the velocity component becomes perpendicular to the flux lines and proportional to that e.m.f. increases as the conductor moves from position 1 towards 2.

At position 2, the entire velocity component is perpendicular to the flux lines. Hence there exists maximum cutting of the flux lines. And at this instant, the induced e.m.f. in the conductor is at its maximum.

As the position of the conductor changes from 2 towards 3, the velocity component perpendicular to the flux starts decreasing and hence induced e.m.f. magnitude also starts decreasing. At position 3, again the entire velocity component is parallel to the flux lines and hence at this instant induced e.m.f. in the conductor is zero.

As the conductor moves from position 3 towards 4, the velocity component perpendicular to the flux lines again starts increasing. But the direction of velocity component now is opposite to the direction of velocity component existing during the movement of the conductor from position 1 to 2. Hence induced e.m.f. in the conductor increases but in the opposite direction.

At the position 4, it achieves maxima in the opposite direction, as the entire velocity component becomes perpendicular to the flux lines.

Again from position 4 to 1, induced e.m.f. decreases and finally at position 1,again becomes zero. This cycle continues as conductor rotates at a certain speed.

So if we plot the magnitudes of the induced e.m.f. against the time, we get alternating nature of the induced e.m.f. as shown in the fig. 34 (b).This is the working principle of an alternator.

<u>TYPES AND THEIR CONSTRUCTION</u>:

Their two basic parts in an alternator:

(i) Stator,

(ii) Rotor.

Stator is the stationary part and Rotor is the revolving part.

There are two possibilities that (i) The armature can be the stator and the field system can be the rotor, and (ii) The armature can be the rotor and the field system be the stator. In practice large alternators are of the first type where in the stator is the armature and the rotor is the field system. And this type is called the "REVOLVING FIELD TYPE".

Revolving field types are preferred due to the following reasons:

(i) More conductors can be easily accommodated and with these high voltage and higher power capacity can be achieved.

(ii) Armature conductors can be easily braced over a rigid frame.

(iii) It is easier to insulate a stationary system.

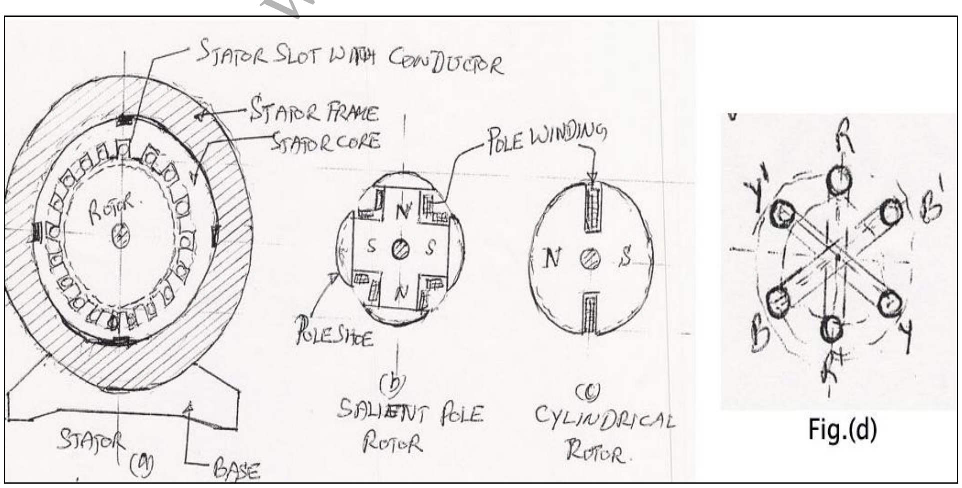


Fig.(d)

(iv) Cooling of the conductors will be very effective with proper cooling ducts / vents in the stationary part.

(iv) Power can be tapped easily without any risk from the stationary part through terminal bushings.

(v) The armature conductors are totally free from any centrifugal force action which tends to drag the conductors out of the slots.

CONSTRUCTION:

Revolving field type alternators are further classified into two types:

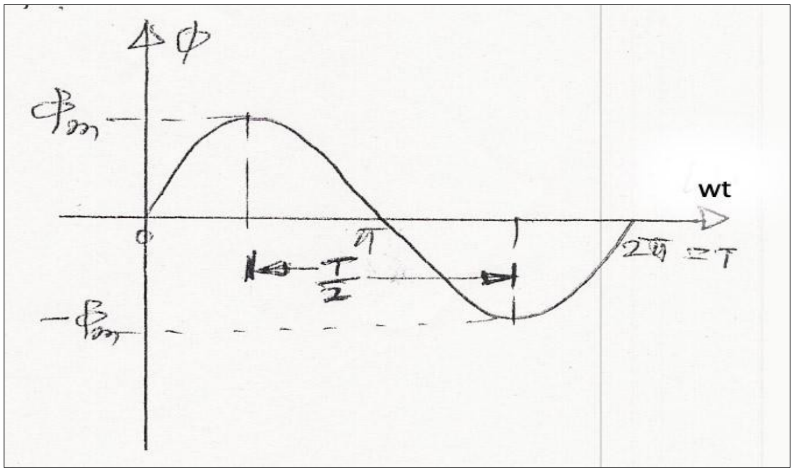
(i) Salient pole type,

(ii) (ii) Non-salient pole type or cylindrical rotor type.

Figs. (a), (b) and (c) shows the constructional features of the Alternator. Fig. (a) Represents the stator, the core of which is made of steel laminations with slots cut in its inner periphery and all the stator stampings are pressed together and are fixed to the stator frame. Three phase windings are accommodated in these slots. These coils are identical to each other and are physically distributed such that they are displaced from each other by 120 degrees as shown in fig. (d).Fig. (b) Represents the structure of a salient pole rotor where the poles are of projected type and are mounted on a spider and the field or the pole windings are wound over the pole core as shown. This type is preferred where the running speeds are low. Fig.(c) represents the structure of a non-salient pole rotor where the overall structure is like a cylinder having 2 or 4 poles. This type is preferred where the running speeds are very high. The armature windings in the stator are made of copper and are normally arranged in two layers and are wound for lap or wave depending on the requirements and are usually connected in star with the neutral terminal brought out.

EMF Equation:

Let P be the total number of poles, Ns be the synchronous speed, f be the frequency of the induced EMF and the flux Φ considered to be sinusoidally distributed.



As we know that the induced emf is due to the rate of change of flux cut by coils, the average induced emf in Tph number of turns is

Eavg = Tph dΦ / dt volts.

For a flux change from Φm to Φm is d Φ = 2 Φm in time dt= T / 2 seconds,

The average induced Emf = Tph. 2 Φ m / (T/2) = 4 Tph .f. m volts.

For a sine wave we know that the form factor is of value 1.11= Erms / Eavg.

Therefore, Erms = 1.11.Eavg.

Erms = 4.44 f Φm Tph volts per phase .... (1)

If the armature windings are connected in star the line emf is El = 3 Ephase.

If the armature windings are connected in delta the line emf is the phase emf itself.

Equation (1) represents the theoretical value of the induced emf in each phase but in practice the Induced emf will be slightly less than the theoretical value due to the following reasons:

(i) The armature windings are distributed throughout the armature in various slots and this is accounted by a factor called the “Distribution factor” Kd and is given by

Kd = (Sin(mα / 2) / mSin(α / 2)), where m is the number of slots per pole peer phase

and α is the slot angle.

α = 180^0 / no. of slots per pole.

(ii) The span of the armature coil is less than a full pitch – This is done deliberately to eliminate some unwanted harmonics in the emf wave, this fact is accounted by a factor called the coil span factor or the pitch factor, Kp and is given by

Kp = Cos (β / 2), where β is the angle by which the coils are short chorded.

The modified Emf equation with these two factors taken into account will be

E = 4.44 Kd.Kp.f Tph volts per phase.

The product of K_d and K_p is called as the winding factor Kw .which is of value around 0.95.

Voltage regulation of an alternator:

Under the load condition, the terminal voltages of alternator is less than the induced e.m.f. E_{ph}. So if the load is disconnected, V_{ph} will change from V_{ph} to E_{ph}, if flux and speed is maintained constant. This is because when load is disconnected I_a is zero hence there are no voltage drops and no armature flux to cause armature reaction. This change in the terminal voltage is significant in defining the voltage regulation.

The voltage regulation of an alternator is defined as the change in its terminal voltage when full load is removed, keeping field excitation and speed constant, divided by the rated terminal voltage.

So if, V_{ph} = Rated thermal voltage

E_{ph} = No load induced e.m.f.

Then voltage regulation is defined as,

$$\% \text{ Reg} = \frac{Eph - Vph}{Vph} \times 100$$

5b. Three Phase Induction Motors:

INTRODUCTION

The asynchronous motors or the induction motors are most widely used ac motors in industry. They convert electrical energy in AC form into mechanical energy. They work on the principle of electromagnetic induction. They are simple and rugged in construction, quite economical with good operating characteristics and efficiency, requiring minimum maintenance, but have a low starting torque. They run at practically constant speed from no load to full load condition. The 3 - phase induction motors are self-starting while the single phase motors are not self- starting as they produce equal and opposite torques (zero resultant torque) making the rotor stationary. The speed of the squirrel cage induction motor cannot be varied easily.

CLASSIFICATION -

They are basically classified into two types based on the rotor construction

1. Squirrel cage motor
2. Slip ring motor or phase wound motor

CONSTRUCTION

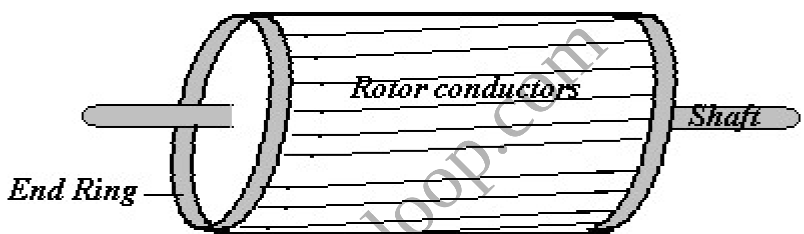
Three phase induction motor consists of two parts (1) Stator (2) rotor

1. Stator

It is the stationary part of the motor supporting the entire motor assembly. This outer frame is made up of a single piece of cast iron in case of small machines. In case of larger machines they are fabricated in sections of steel and bolted together. The core is made of thin laminations of silicon steel and flash enameled to reduce eddy current and hysteresis losses. Slots are evenly spaced on the inner periphery of the laminations. Conductors insulated from each other are placed in these slots and are connected to form a balanced 3 - phase star or delta connected stator circuit. Depending on the desired speed the stator winding is wound for the required number of poles. Greater the speed lesser is the number of poles.

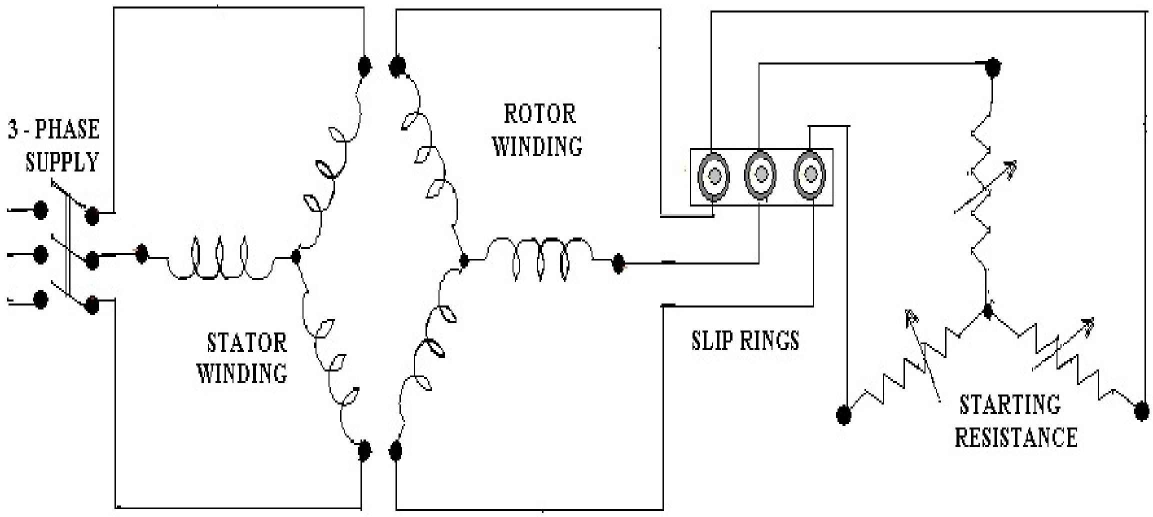
2. Rotor

Squirrel cage rotors are widely used because of their ruggedness. The rotor consists of hollow laminated core with parallel slots provided on the outer periphery. The rotor conductors are solid bars of copper, aluminium or their alloys. The bars are inserted from the ends into the semi- enclosed slots and are brazed to the thick short circuited end rings. This sort of construction resembles a squirrel cage hence the name “squirrel cage induction motor”. The rotor conductors being permanently short circuited prevent the addition of any external resistance to the rotor circuit to improve the inherent low starting torque. The rotor bars are not placed parallel to each other but are slightly skewed which reduces the magnetic hum and prevents cogging of the rotor and the stator teeth.



Squirrel cage induction rotor

The rotor in case of a phase wound/ slip ring motor has a 3-phase double layer distributed winding made up of coils, similar to that of an alternator. The rotor winding is usually star connected and is wound to the number of stator poles. The terminals are brought out and connected to three slip rings mounted on the rotor shaft with the brushes resting on the slip rings. The brushes are externally connected to the star connected rheostat in case a higher starting torque and modification in the speed torque characteristics are required. Under normal running conditions all the slip rings are automatically short circuited by a metal collar provided on the shaft and the condition is similar to that of a cage rotor. Provision is made to lift the brushes to reduce the frictional losses. The slip ring and the enclosures are made of phosphor bronze.



SLIP RING INDUCTION MOTOR

In both the type of motors the shaft and bearings (ball and roller) are designed for trouble free operation. Fans are provided on the shaft for effective circulation of air. The insulated (mica and varnish) stator and rotor windings are rigidly braced to withstand the short circuit forces and heavy centrifugal forces respectively. Care is taken to maintain a uniform air gap between the stator and the rotor.

Comparison of the squirrel cage and slip ring rotors

The cage rotor has the following advantages:

1. Rugged in construction and economical.
2. Has a slightly higher efficiency and better power factor than slip ring motor.
3. The absence of slip rings and brushes eliminate the risk of sparking which helps in a totally enclosed fan cooled (TEFC) construction.

The advantages of the slip ring rotor are:

1. The starting torque is much higher and the starting current much lower when compared to a cage motor with the inclusion of external resistance.
2. The speed can be varied by means of solid state switching

CONCEPT OF SLIP (*S*)

According to Lenz‟s law, the direction of rotor current will be such that they tend to oppose the cause producing it. The cause producing the rotor current is the relative speed between the rotating field and the stationary rotor. Hence, to reduce this relative speed, the rotor starts running in the same direction as that of stator field and tries to catch it. In practice the rotor can never reach the speed of the rotating magnetic field produced by the stator. This is because if rotor speed equals the synchronous speed, then there is no relative speed between the rotating magnetic field and the rotor. This makes the rotor current zero and hence no torque is produced and the rotor will tend to remain stationary. In practice, windage and friction losses cause the rotor to slow down. Hence, the rotor speed (N) is always less than the stator field speed (N_S).

Thus the induction motor cannot run with **ZERO SLIP. The frequency of the rotor current**

$f_r = sf$. The difference between the synchronous speed (N_S) of the rotating stator field and the actual rotor speed (N) is called the **slip speed.**

Slip speed = $N_S - N$ depends upon the load on the motor

$$\% \text{ Slip } (s) = \frac{N_S - N}{N_S} * 100$$

Note: In an induction motor the slip value ranges from 2% to 4%

APPLICATIONS OF INDUCTION MOTORS

Squirrel cage induction motor

Squirrel cage induction motors are simple and rugged in construction, are relatively cheap and require little maintenance. Hence, squirrel cage induction motors are preferred in most of the industrial applications such as in

i) Lathes

ii) Drilling machines

iii) Agricultural and industrial pumps

iv) Industrial drives.

Slip ring induction motors

Slip ring induction motors when compared to squirrel cage motors have high starting torque, smooth acceleration under heavy loads, adjustable speed and good running characteristics.They are used in

i) Lifts

ii) Cranes

iii) Conveyors , etc.,

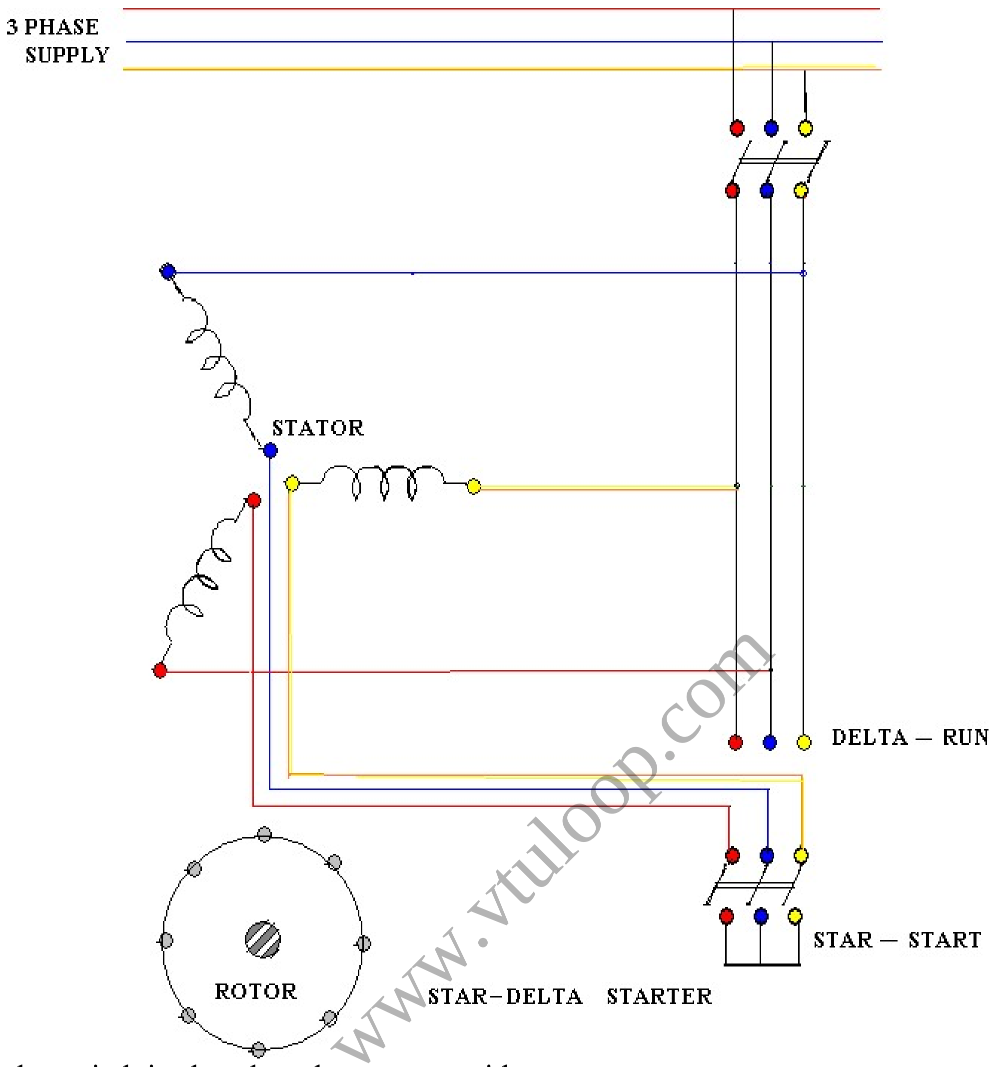
Necessity of starters for 3 phase induction motor

When a 3- phase motor of higher rating is switched on directly from the mains it draws a starting current of about 4 -7 times the full load (depending upon on the design) current. This will cause a drop in the voltage affecting the performance of other loads connected to the mains. Hence starters are used to limit the initial current drawn by the 3 phase induction motors.

The starting current is limited by applying reduced voltage in case of squirrel cage type induction motor and by increasing the impedance of the motor circuit in case of slip ring type induction motor. This can be achieved by the following methods.

1. Star –delta starter

The star delta starter is used for squirrel cage induction motor whose stator winding is delta connected during normal running conditions. The two ends of each phase of the stator winding are drawn out and connected to the starter terminals as shown in the following figure.



When the switch is closed on the star-start side

(1) The winding is to be shown connected in star

(2) The current I = 1/3 * (I $_{\text{direct switching}}$)

(3) Reduction in voltage by1/ √3

$$V = V_{supply} * \sqrt{3}$$

When the switch is closed on to delta –run side

(1) the winding to be shown connected in delta

(2) (2) application of normal voltage V $_{supply}$ (3) normal current I

During staring the starter switch is thrown on to the **STAR - START**. In this position the stator winding is connected in star fashion and the voltage per phase is $\sqrt{3}$ of the supply voltage. This will limit the current at starting to **1/3** of the value drawn during direct switching. When the motor accelerates the starter switch is thrown on to the **DELTA - RUN** side. In this position the stator winding **Δ** connected in the fashion and the motor draws the normal rated current.