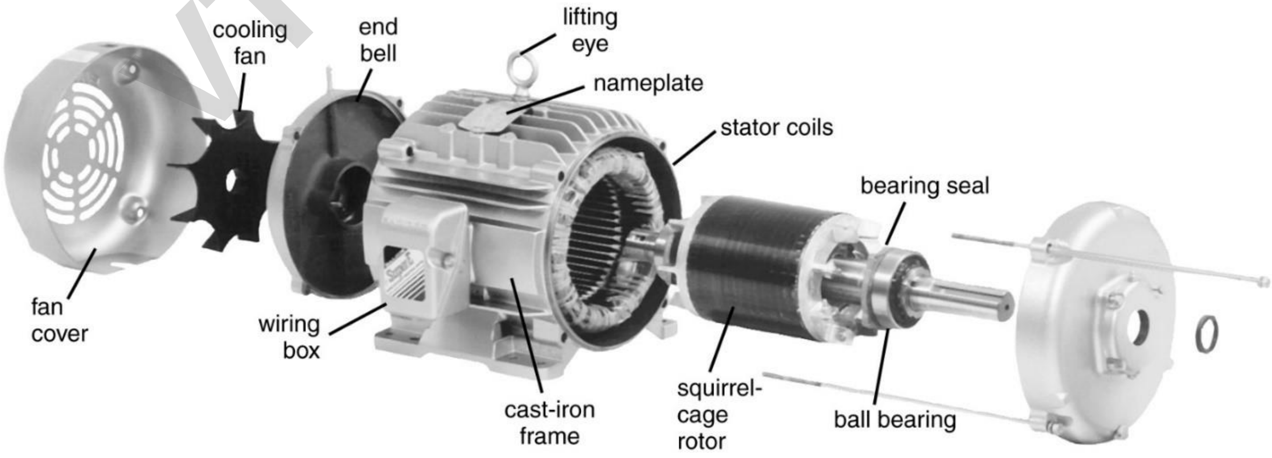
Module-4a_Three Phase Induction Motor



By, Maria Sushma S

Assistant Professor

Dept of EEE, ATMECE

VTU Updates

Content

Module – 4
Three-phase induction Motors: Concept of rotating magnetic field, Principle of operation, constructional features of motor, types – squirrel cage and wound rotor, slip and problems on the slip, significance of slip, applications. **Three-phase synchronous generators:** Principle of operation, constructional details of salient and non-salient pole generators, synchronous speed, frequency of generated voltage, emf equation, with the concept of winding factor (excluding the derivation and calculation of winding factors).

10.1 Introduction . . . . 10 - 2

10.2 Rotating Magnetic Field . . . . 10 - 2
Jan.-03,05,07,10,13, July-03,05,06,08,15,17,Dec.-11, Marks 8

10.3 Construction . . . . 10 - 3
Jan.-03,05,08,16, July-17, Marks 8

10.4 Principle of Operation . . . . 10 - 6
Jan.-03,04,06,07,08,09,10,11,13,14,15,16,17,18,
July-03,04,05,06,07,08,09,10,11,12, Aug.-06,13,15,16,
Dec.-11, Marks 8

10.5 Effect of Slip on the Rotor Frequency . . . . . . 10 - 9
Dec.-11, Jan.-14,15,16,18, Feb.-06,08, July-12,15,17,
Aug.-07, Marks 8

10.6 Applications . . . . 10 - 11
July-09, Marks 4

10.7 Advantages of Induction Motors . . . . 10 - 11

10.8 Limitations of Induction Motors . . . . 10 - 11

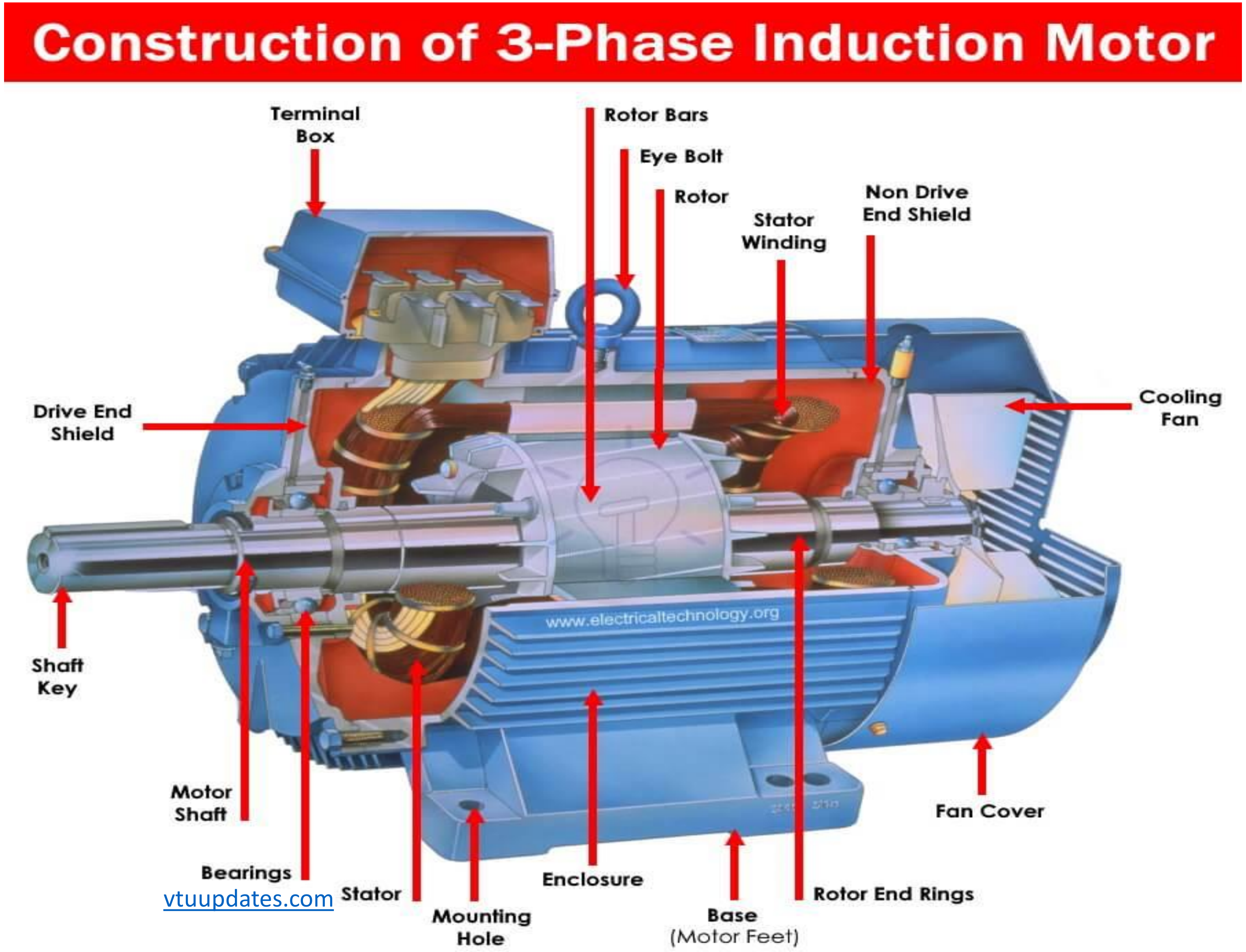
10.9 Necessity of Starter in Induction Motor . . . . 10 - 11
Jan.-04,06,07,16; July-03,04,05,06,08,10, Dec.-11, Marks 4

10.10 Star-Delta Starter . . . . 10 - 12
July-03, 04, 05, 06, 16, June-13, Jan.-04, 06, 14, Marks 8

10.11 University Questions with Answers . . . . 10 - 13

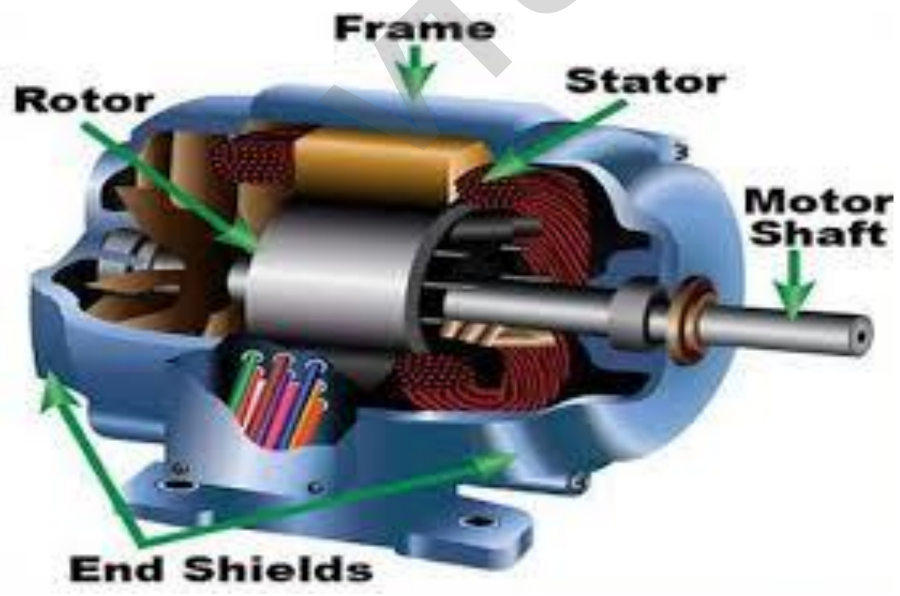
Introduction to 3 phase Induction Motor

- *An electrical motor is an electromechanical device which converts electrical energy into mechanical energy.*
- *They work on the principle of electromagnetic induction. The necessary voltage and current in the rotor circuit are produced by induction from the stator winding, hence it is known as induction motor.*
- *They are simple and rugged in construction, quite economical with good operating*



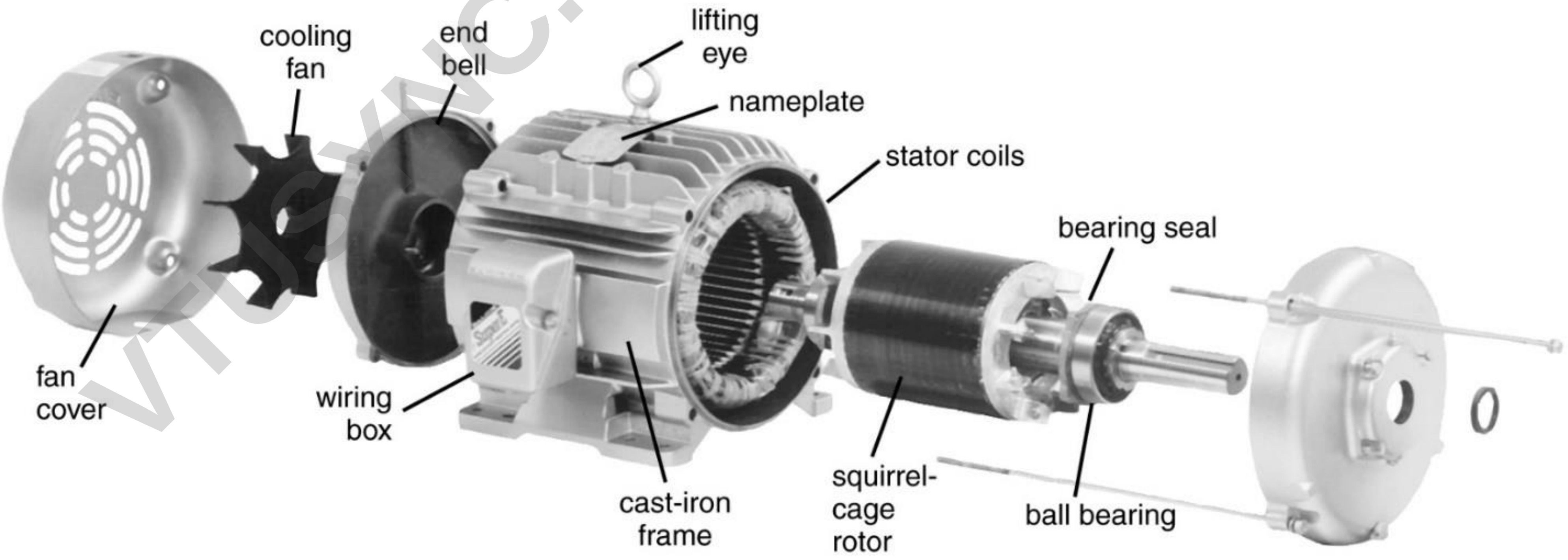
Introduction to 3 phase Induction Motor cntd.

- *The asynchronous motors or the induction motors are most widely used ac motors in industry.*
- *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.*



There basically 2 **types of induction motor** depending upon the type of input supply –
(i) Single phase induction motor and
(ii) Three phase induction motor.

Working Principle of 3 phase Induction Motor

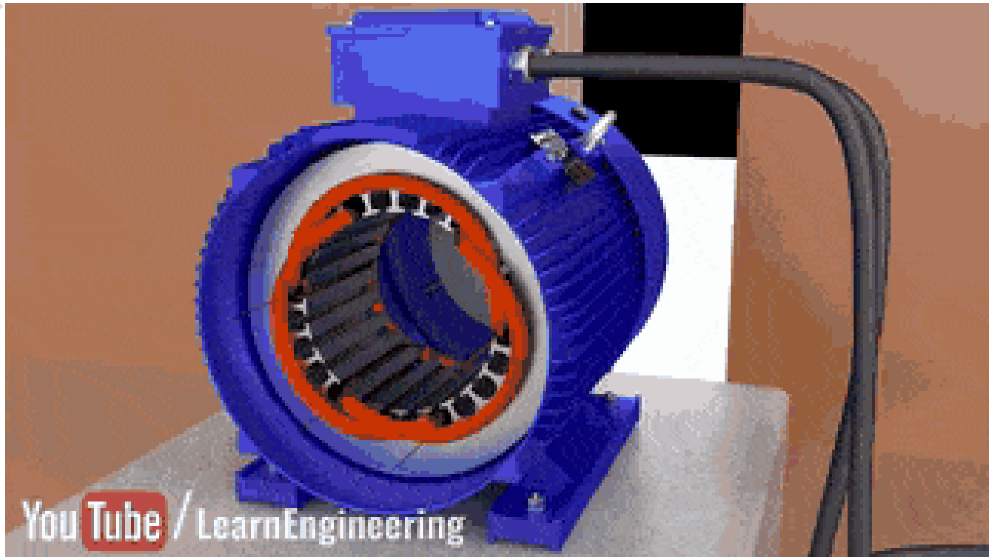


- These are also called as **Asynchronous Motors**, because an **induction motor** always runs at a speed lower than synchronous speed. Synchronous speed means the speed of the rotating magnetic field in the stator

- 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**.

Working Principle of 3 phase Induction Motor

- 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.

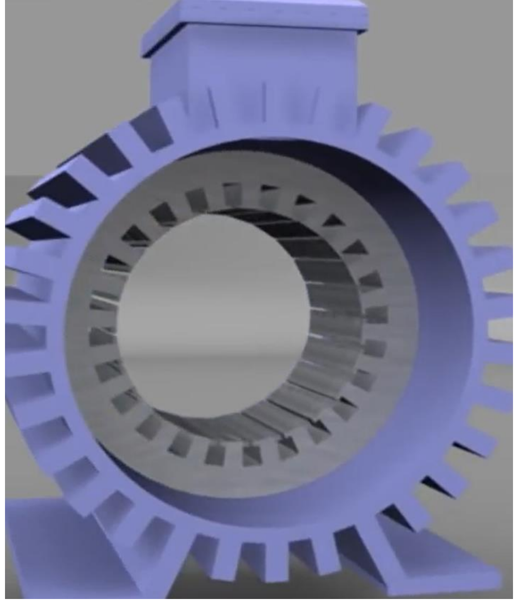


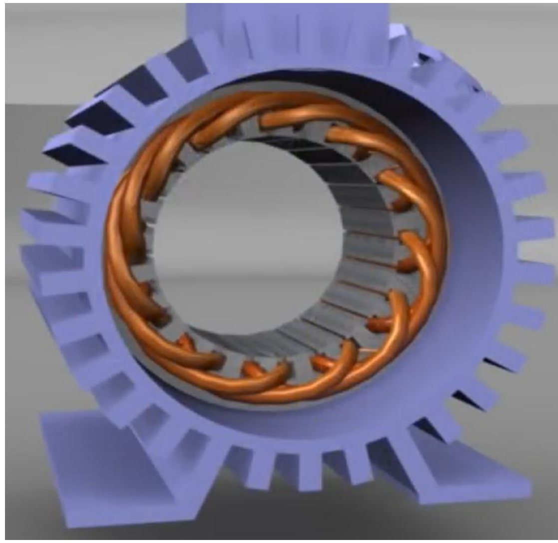
- As the cause of production of rotor current is the relative velocity between rotating stator flux and the rotor, the rotor will try to catch up with the stator RMF. Thus the rotor rotates in the same direction as that of stator flux to minimize the relative velocity. However, the rotor never succeeds in catching up the synchronous speed.
- This is the **basic working principle of induction motor** of either type, single phase of 3 phase.

Construction

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

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



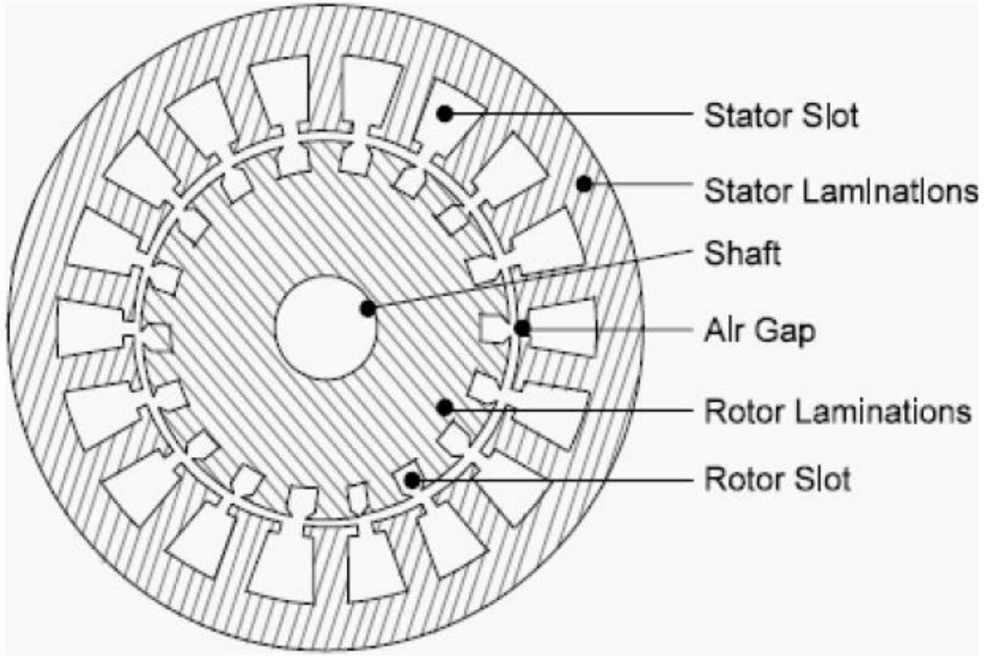


Induction motor consists of two parts (1) stator (2) rotor

Stator

It is the stationary part of the motor supporting the entire motor assembly.

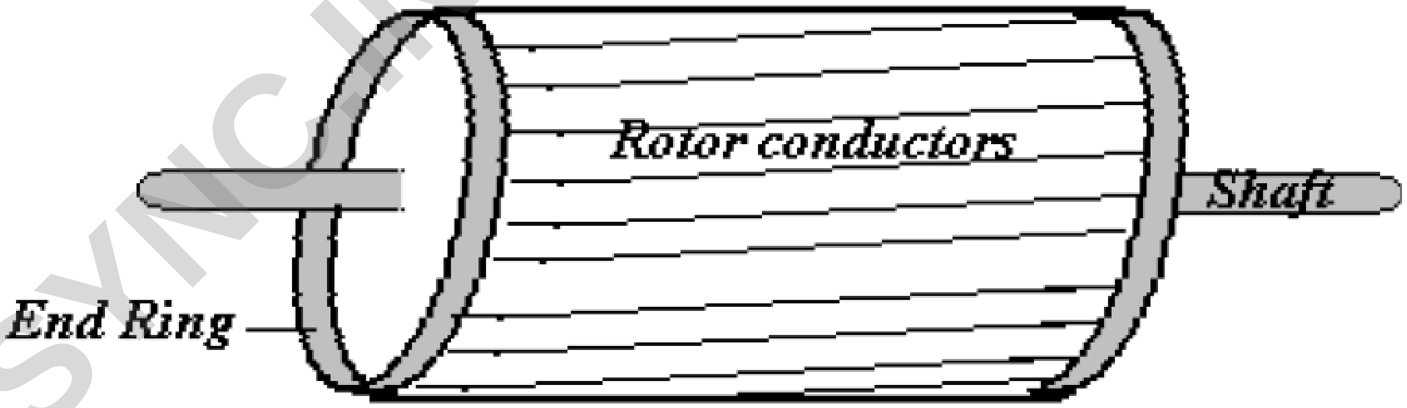
- This outer frame is made up of a single piece of cast iron in case of small machines.
- In case of larger machines they are fabricated in sections of steel and bolted together.



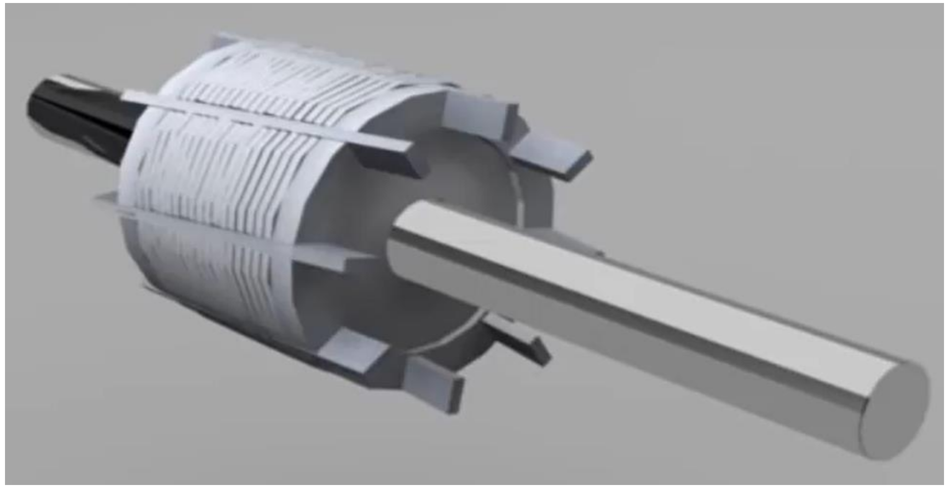
- The core is made of thin laminations of silicon steel and flash enameled to reduce eddy current and hysteresis losses.
- Slots are evenly spaced on the inner periphery of the laminations.
- Conductors insulated from each other are placed in these slots and are connected to form a balanced 3 - phase 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.

Rotor

1. **Squirrel cage motor :**

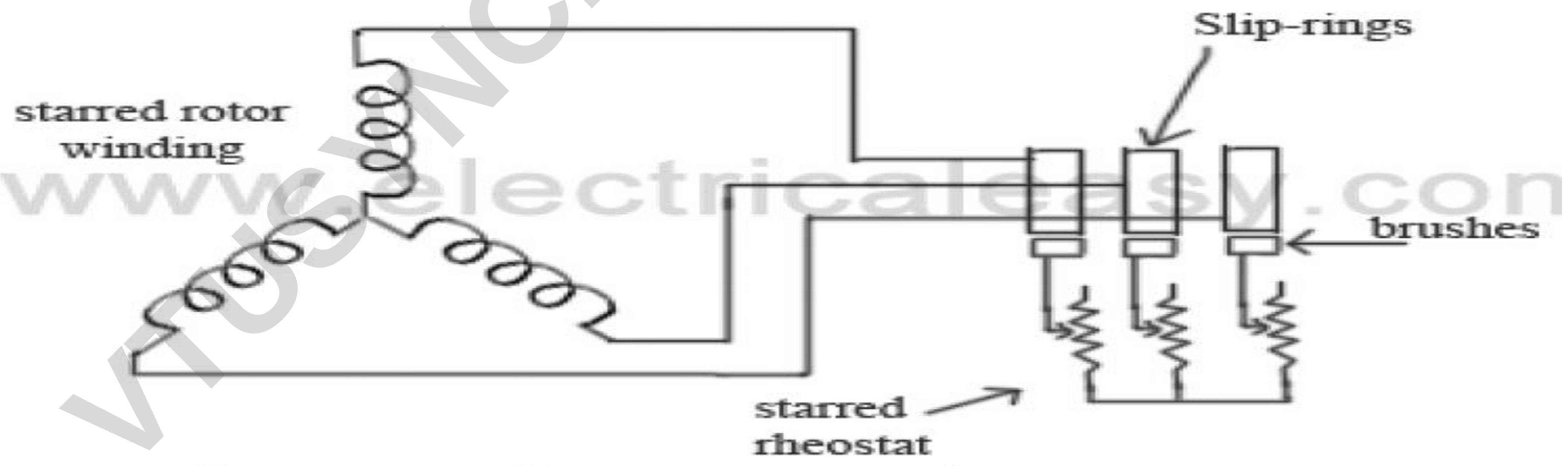


Squirrel cage induction rotor



- 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, aluminum 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.

2. **Slip ring motor or phase wound motor**



Phase wound rotor connections

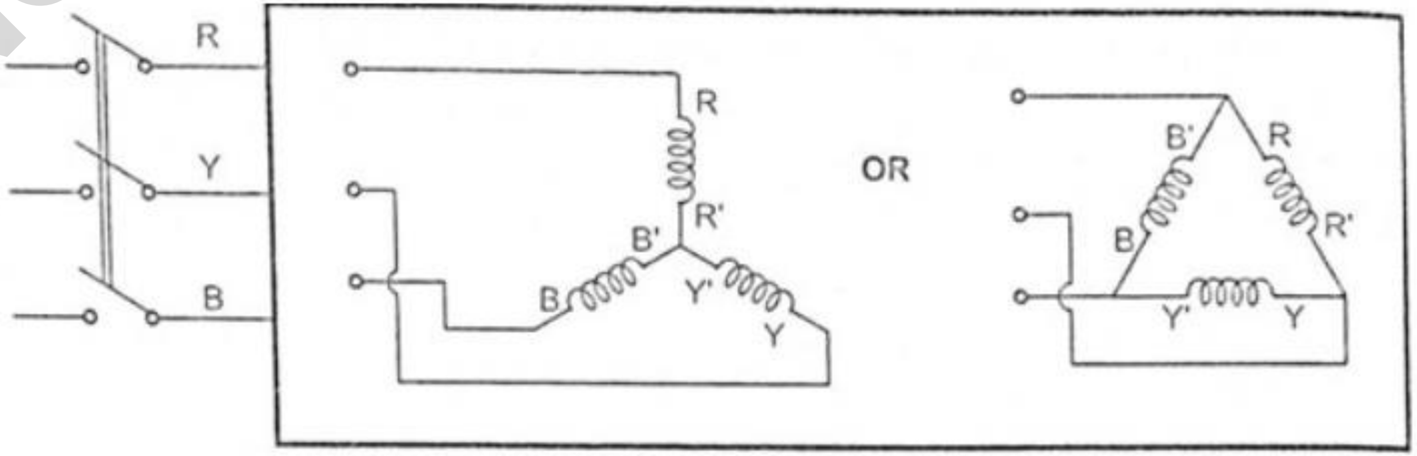
- The rotor winding is usually star connected and is wound to the number of stator poles. The terminals are brought out and connected to three slip rings mounted on the rotor shaft with the brushes resting on the slip rings.
- The brushes are externally connected to the star connected rheostat in case 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.

Squirrel cage v/s Slip ring Induction Motor

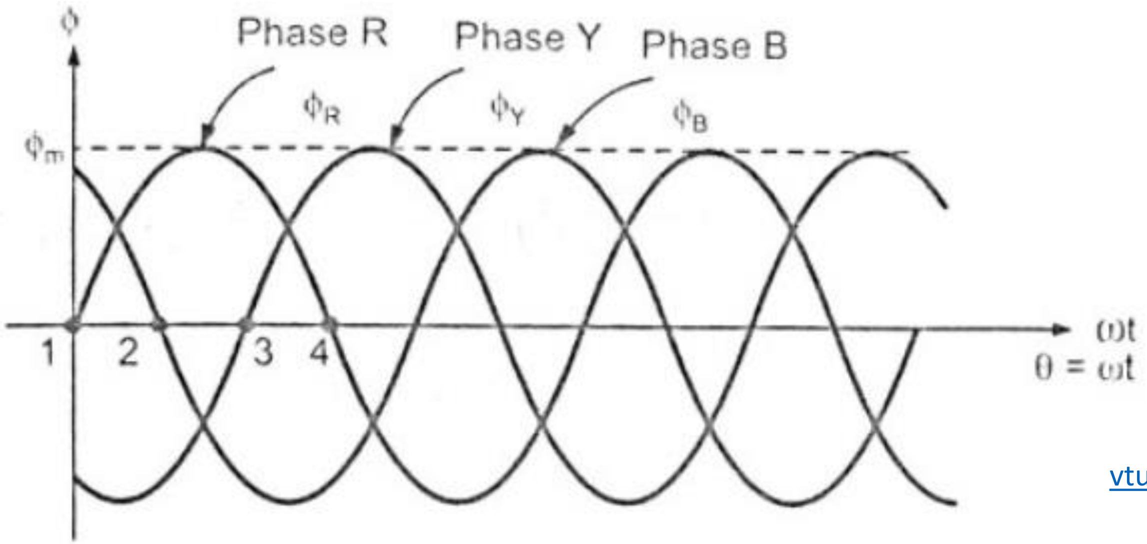
Squirrel cage rotor	Slip ring rotor
1) Rotor consists of bars which are shorted at the ends with the help of end rings.	1) Rotor consists of 3Φ winding similar to the stator winding.
2) Construction is very simple.	2) Construction is complicated.
3) Slip rings & brushes are absent.	3) Slip rings & brushes are present to add external resistance.
4) Rotor copper losses are less hence have higher efficiency.	4) Rotor copper losses are high hence efficiency is less.
5) The construction is robust & maintenance free.	5) The construction is delicate & due to brushes, frequent maintenance is necessary.
6) Due to simple construction, the rotors are cheap.	6) The rotors are very costly.
7) Moderate starting torque, which cannot be controlled.	7) High starting torque can be obtained.
8) Used for lathes, drilling machines, fans, blowers, water pumps, grinders, printing machines etc.	8) Used for lifts, hoists, cranes, elevators, compressors etc.

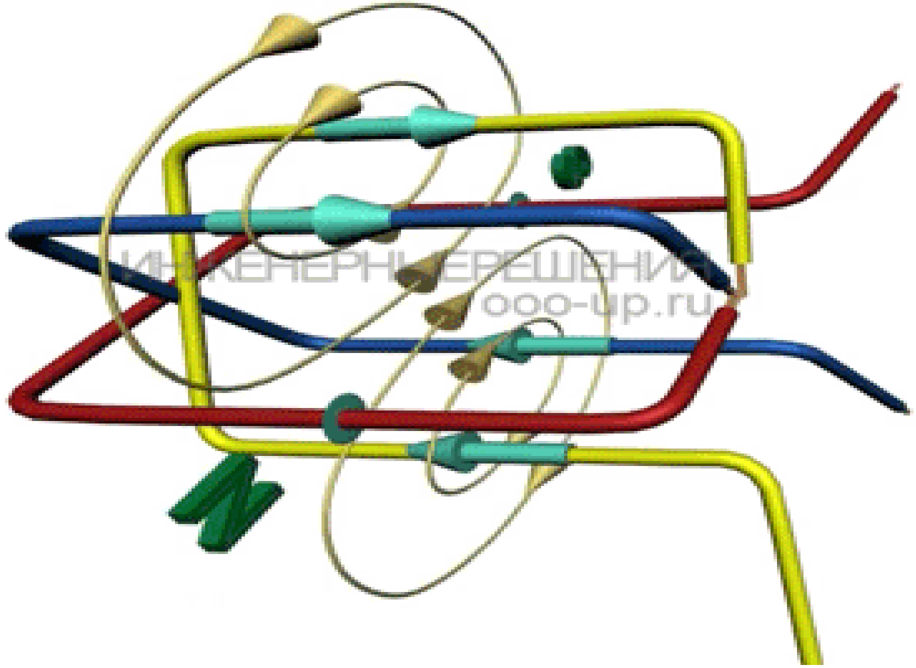
RMF (Rotating Magnetic Field)

RMF (Rotating Magnetic Field): *When 3Φ windings, displaced 120^{0} electrical relative to one another are supplied with 3Φ currents, they produce a resultant magnetic flux which rotates in space as if actual magnetic poles were being rotated mechanically.*



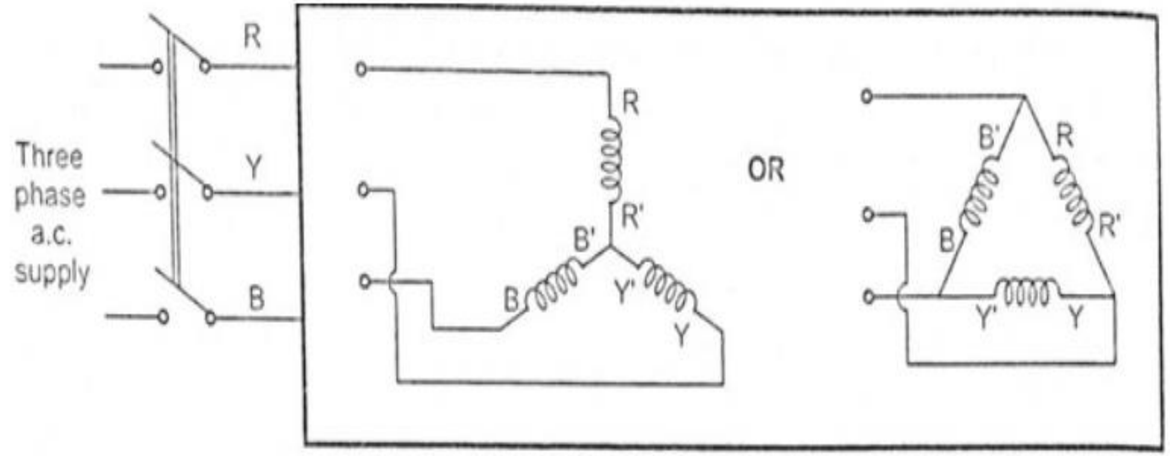
Star or delta connected 3 phase winding





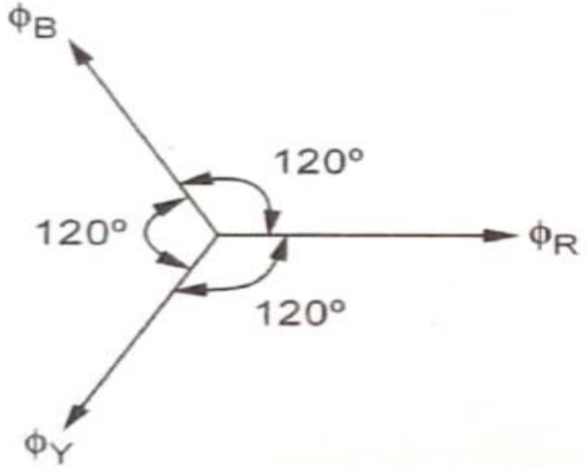
Generation of rotating magnetic field.

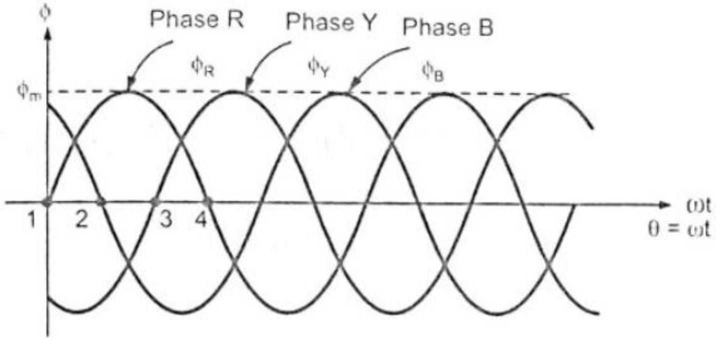
- Consider a 3Φ Induction motor.
- The Stator of a three phase induction motor carries a three phase star or delta connected winding, to which three phase ac supply is given.



Star or delta connected 3 phase winding

- The three phase currents flow simultaneously through the windings and are displaced by 120^0 from each other.
- If the phase sequence is RYB, the three phase currents produce the three fluxes ϕ_R, ϕ_Y, ϕ_B which are displaced by 120^0 from each other.





Let the magnitude of each flux is ϕ_m

- The equations of the three fluxes are,

$$\phi_R = \phi_m \sin \theta,$$

$$\phi_Y = \phi_m \sin (\theta - 120°),$$

$$\phi_B = \phi_m \sin (\phi - 240°)$$

- The total flux ϕ_T is the vector sum of ϕ_R, ϕ_Y and ϕ_B for various values of θ.

Case 1 : $\theta = 0°$ and use in the flux equations
$\therefore\ \phi_R = 0,\ \ \phi_Y = -\,0.866\ \phi_m,\ \phi_B = +\,0.866\ \phi_m$

- The phasor addition is shown in the Fig
- The negative ϕ_Y is indicated in opposite direction to the assumed positive direction of ϕ_Y, shown

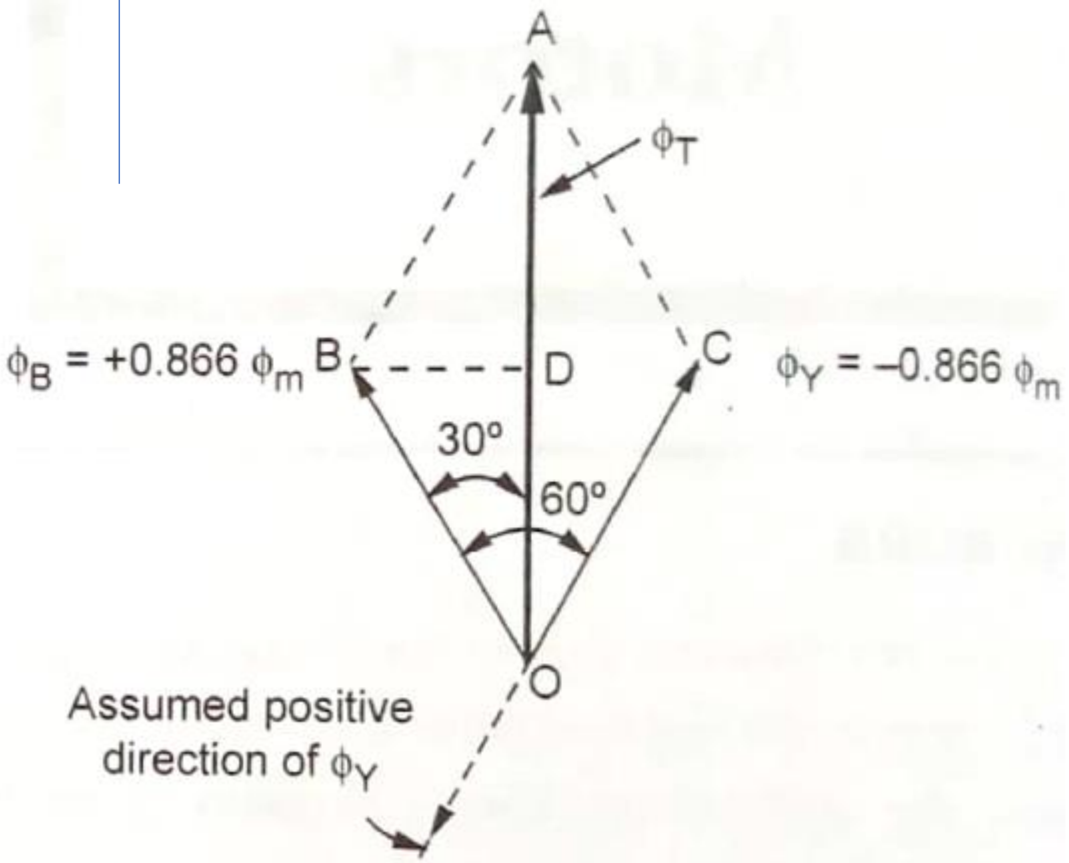


Fig. Vector diagram for $\theta = 0°$

- BD is perpendicular drawn from B on ϕ_T which bisects ϕ_T.

$\therefore$ $OD = DA = \frac{\phi_T}{2}$ and in Δ OBD,

$\angle BOD = 30°$

$\therefore$ $\cos 30° = \frac{OD}{OB} = \frac{\phi_T / 2}{0.866\, \phi_m}$

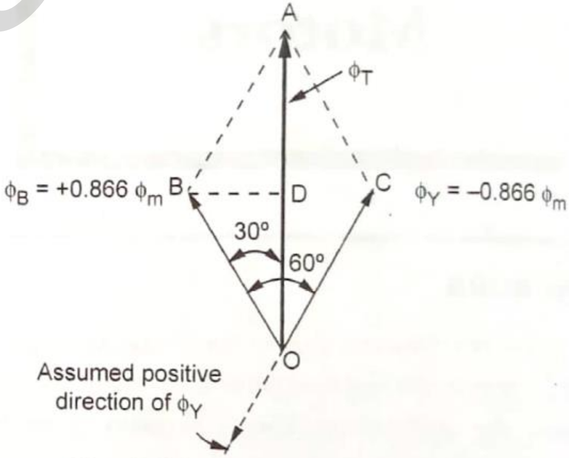


Fig. 10.2.2 Vector diagram for $\theta = 0°$

i.e. $\phi_T = 1.5\ \phi_m$ ...$\cos 30° = 0.866$

- Thus $\phi_T = 1.5\ \phi_m$ in magnitude and its position is vertically upwards at $\theta = 0°$.

Case 2 : $\theta = 60°$ and use in the flux equations

$\therefore$ $\phi_R = 0.866\ \phi_m$, $\phi_Y = -0.866\ \phi_m$, $\phi_B = 0$

- Thus ϕ_R is positive and ϕ_Y is negative hence phasor diagram is as shown in the Fig. 10.2.3.

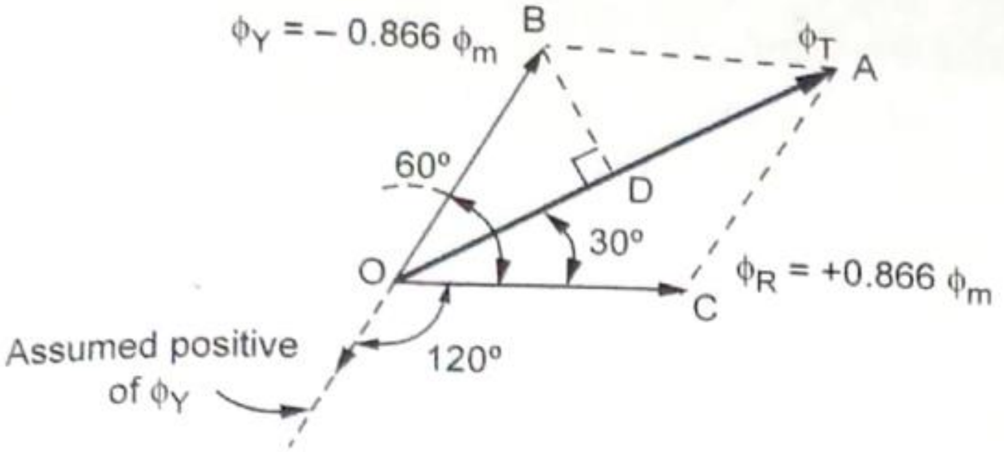


Fig. 10.2.3 Vector diagram for $\theta = 60°$

- By same geometrical construction, it can be seen that $\phi_T = 1.5\ \phi_m$.
- But though magnitude of ϕ_T is same, **it is rotated through 60° in space in clockwise direction.**

Refer the derivation solved in class for 4 cases: $\Theta=0$, $\Theta=60$, $\Theta=120$, $\Theta=180$

- For a standard frequency whatever speed of R.M.F. results is called **synchronous speed**, in case of induction motors. It is denoted as N_s.

$$\therefore \qquad \boxed{N_s = \frac{120\,f}{P} = \textbf{Speed of R.M.F.}}$$

where f = Supply frequency in Hz

P = Number of poles for which winding is wound.

- The direction of rotating magnetic field depends on the phase sequence of the three phase supply.

- Thus by changing the supply phase sequence, the direction of three phase induction motor can be reversed.

Slip & its significance

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

- The difference between the synchronous speed NS and the actual speed N of the rotor is called slip.
- Even though the rotor follows the stator field, but rotor can never reach the speed of the stator field.
- As the load increases , IM speed(N) will reduce, hence slip increases & with it rotor current will increase & also increases the torque till the driving torque.
- In an induction motor, the change in slip from no-load to full-load is hardly 3-6%, so that the IM is essentially a constant speed motor.

- The **induction motor never rotates at synchronous speed.**
- The speed at which it rotates is hence called **subsynchronous speed** and motor sometimes called **asynchronous motor.**

$$\therefore \quad N < N_s$$

- So it can be said that rotor slips behind the rotating magnetic field produced by stator.
- The difference between the two is called **slip speed** of the motor.

$$N_s - N = \text{Slip speed of the motor in r.p.m.}$$

- This speed decides the magnitude of the induced e.m.f. and the rotor current, which in turn decides the torque produced.

- In terms of slip, the actual speed of motor (N) can be expressed as,

$$\boxed{N = N_s(1 - s)} \quad \text{... (From the expression of slip)}$$

Frequency of rotor current

- When the rotor is at standstill, the frequency of rotor current is the same as supply frequency.
- When there is relative speed between the rotor and the stator field, the frequency of the induced voltage & hence the current in the rotor varies with the rotor speed i.e., slip.

$$N_s - N = \frac{120f'}{P} \longrightarrow (1)$$

$$N_s = \frac{120f}{P} \longrightarrow (2)$$

$$\boxed{\frac{f'}{f} = \frac{N_s - N}{N_S} = S}$$

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.,

Advantages of rotating field over rotating armature

1) We use AC power which has generation level around 11 kV to 33 kV, it is difficult to get induced emf in armature because we can't mount as many as conductors as required on rotating armature hence we prefer stationary armature.

2) As said in above point large conductors posses high centrifugal forces while rotating. So there will be chance of conductors slipping out from slots. So by using rotating field over rotating armature we can reduce mechanical and electrical stresses.

3) The problem of sparking at the slip rings can be avoided by keeping field rotating which is low voltage circuit and high voltage armature as stationary.

4) It is not easy to collect larger currents at very high voltages from rotating armature.

5)It is better to rotate low inertia system than high inertia system so we use low voltage on rotor side so that inertia can be reduced along with insulation on the rotor side which also reduces cost of the system

6) As we collect power from armature a rotating field type makes it easier to collect power from the armature, and greater output can be collected at low losses compared to that of rotating armature.