

3- ϕ induction motor

- * Slip ring induction motor has high starting torque.
- * Autotransformer can start both star and delta connected.
- * Starting torque of squirrel cage induction motor is low.
- * Best method to increase starting torque of 3phase slip ring induction motor is by increasing the rotor resistance.
- * 3 ϕ induction motor is constant speed motor.
- * Has self starting low torque.

DC machine

① EMF equation

$$V = \frac{\phi P N}{60} \times \frac{Z}{A} = E_b \rightarrow \text{back emf}$$

② Torque equation

$$T = \frac{\phi P}{2\pi} \times \frac{Z}{A} \times I_a$$

③ Lap winding

- * Large current small voltage
- * Electric welding
- * No of || Path = No of Brushes
= No of Poles.

Wave winding

- * Small current large voltage.
- * Household
- * No of || Path = 2

* Direction of Rotation of dc motor can be changed by changing reversing either polarities of the supply to the armature or pole.

* Speed of DC motor is $\propto \frac{\text{Back emf}}{\text{flux}}$.

* Relation b/w Z and armature current

$$T \propto I_a^2 \rightarrow \text{dc series motor.}$$

$$T \propto I_a \rightarrow \text{dc Shunt motor}$$

* Efficiency of DC machine is less than that of equivalent transformer because both friction and winding loss in machine.

Alternator

* AC generator $\rightarrow$ synchronous machine $\rightarrow$ doubly excited machine.

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

• Rotor speed synchronous speed machine are one and the same.

1. Construction of alternator

@ Stator (armature winding)

- Stator frame.
- Stator core.
- Stator winding.

@ Rotor (field winding).

- Salient pole type.
 - * concentrated windings
 - * lamination.
 - * Non uniform air gap
 - * Large diameter small length
 - * Hydroalternator or hydro generator.

- cylindrical type Rotor
 - * Non salient type winding
 - * No physical poles
 - * Cylindrical laminations slots at regular intervals
 - * nickel-chrome-molybdenum steel
 - * large length small diameter
 - * Distributed winding
 - * Turbo alternator/generators

- ② Excitation of generator
- Doubly excited machine
 - DC supply by dc generator
 - Slip Ring and Brushes

- ③ Operation of alternator.
- Explanation.

- ④ Advantages of Rotating field winding on Rotor.
- easy insulation of armature winding [33kv].
 - less centrifugal force less wear & tear.
 - Easy cooling of armature winding.
 - Output of 3 ϕ AC can be easily taken without using slip rings and Brushes from armature winding (stator).

- ⑤ EMF equation of alternator.

$$[E_{rms}]_{ph} = 4.44 f \phi_m T_{ph} \quad K_p K_d$$

f = frequency of generated EMF (Hz)

ϕ = flux per pole (wb)

T_{ph} = Turns per phase.

- as armature winding star connected

$$E_L = \sqrt{3} E_{ph}$$

$$[E_{rms}]_L = 7.69 f \phi T_{ph} \quad K_p K_d$$

- ⑥ Voltage Regulation.

- Definition.

$$\% \text{ Regulation} = \frac{|V_t| - |E|}{|V_t|} \times 100$$

V_t = Terminal voltage at full load

E = Voltage when load removed.

$$\text{Per unit voltage Regulation} = \frac{|V_t| - |E|}{|V_t|}$$

- * In alternator damper winding is used to prevent hunting. ~~increases~~ stability.
- * For a synchronous machine with concentrated winding with full pitch coil $K_p = 1$; $K_d = 1$
 $K_p = \text{Pitch factor}$
 $K_d = \text{Distribution factor.}$
- * Voltage Regulation of synchronous generator will always be positive when load power factor is lagging.
- * 500MW alternator manufactured in India.
- * Non Salient pole type $\rightarrow$ high speed.
- * SaliEnt pole alternator is used in low and medium speed prime movers.
- * Two third portion of Rotor wound in case of cylindrical Rotor
- * Hydro alternator/generators :- Hydroelectric power plants
SaliEnt pole type Rotor
- * Turbo alternator/Generator :- Steam power plant (thermal)
Non salient pole type Rotor.

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THREE PHASE INDUCTION MOTOR

NOTES.

1. Introduction.

A. AC motor.

AC motor is an electromechanical device that converts alternating electrical to mechanical energy.

@ Following are the type of AC motor.

- Synchronous motor
- Single phase motor
- Three phase induction motor
- Special purpose motor

* Out of these AC motors, three phase induction motor is most widely used.

Because

- It is cheap, robust, efficient and reliable.
- Good speed regulation using thyroister
- Don't require additional mechanism for starting because it is self starting.
- It requires little maintainence
- Reasonable overload capacity.

2:] Synchronous speed.

The speed with which rotating magnetic field (RMF, stator) of three phase induction motor rotates is known as synchronous speed

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

N_s = Synchronous speed in rpm

f = supply frequency in Hz.

P = Number of poles.

* In synchronous motor magnetic field is generated by both stator and Rotor, due to interlocking of both magnetic fields both stator and rotor rotates with the same synchronous speed.

* If pole increases then speed of motor decreases

$$N_s \propto \frac{1}{P}$$

* If frequency increases then speed of motor increases

$$N_s \propto f$$

$$N_s \propto \frac{f}{P}$$

⑥ Wire wound / slip ring type Rotor.

* Wire wound rotor is also called slip ring rotor or phase wound rotor.

* This type of rotor is made of laminated cylindrical core containing slots at the outer periphery, these slots contain insulated 3-phase rotor windings. These rotor windings are always star connected.

* The number of poles of rotor are always kept same as number of poles of stator.

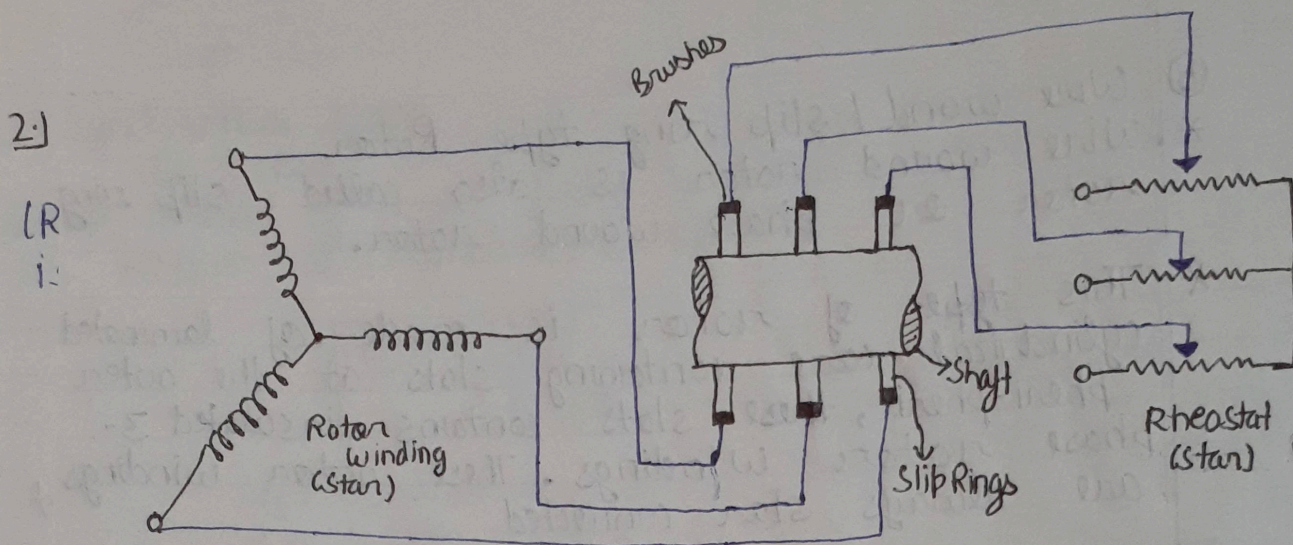
* The rotor is always wound in 3-phase even if stator is wound in 2-phase.

* The three terminals of Rotor winding are connected to slip rings, slip rings and brushes are mounted on shaft. These brushes are connected to external star connected rheostat.

This arrangement is done to introduce an external resistance to the rotor circuit.

* These external Rheostat serves following purposes:

- To increase starting torque and decrease starting current
- To control the speed of motor.



2.1.2 Wound Rotor

Advantage of Both type of Rotors

- | Squirrel Cage | Wire wound |
|--|---|
| <ul style="list-style-type: none"> • Cage Rotor is cheaper, robust and easy to maintain • The absence of brushes reduces risk of sparking. • Have high power factor. • Have higher efficiency. | <ul style="list-style-type: none"> • Starting torque higher and lesser starting current • Speed of motor can be easily controlled by adding external resistance to the circuit. |

B. Rotor.

Rotor is the rotating part of the 3 phase induction motor.

- * Rotor is made up of same material as stator.

There are two types of Rotor.

① Squirrel Cage Rotor.

② Wire wound Rotor.

① Squirrel Cage Rotor.

It consists of cylindrical core made up of thin lamination of high grade alloy steel containing slots nearly parallel to shaft axis or skewed.

- * Each slot contains uninsulated bar of copper or aluminium shorted at both ends by the end rings of copper or aluminium, these bars act as rotor conductors.

- * This forms a cage type structure which was once used for keeping squirrels and hence its name.

- * The rotor bars are brazed or welded at the both ends. Thus rotor conductors

2.) are permanently short circuited hence it is not possible to add any external resistance to the circuit.

* Skewing of Rotor conductors (bars) give following advantage.

- It reduces humming noise
- It results in uniform torque curve
- It reduces locking tendency of rotor bars to Stator.

Yft for more on
squirrel cage type
Rotor and diagram

③ Construction of three phase induction motor.
The three phase induction motor essentially consists of two parts:-

A. Stator

B. Rotor.

A. Stator.

A- Stator.
A stator is the stationary part of a electrical motor.

* The stator is made up of three parts

@ Outer frame.

② Outer frame.
The outer frame of 3- ϕ induction motor is made up of cast iron. For small machines outer frame is casted, but for large machines outer frame is fabricated.

The main function of outer frame is to provide support to stator core and to protect the inner part of machines.

Outer frame of motor also contains fins which increase cross section area and hence increase rate of dissipation (transfer) of heat.

⑥ Stator core.

Stator core is built from high grade silicon steel stampings. Laminated core reduces hysteresis and eddy current losses.

- 2.) a Stampings consist of number of slots punched to it
These slots carries 3 phase windings.
- LR b * Each stamping is insulated from each other by thin
i- varnish layer
- * * Thickness of stampings varies from 0.3 to 0.5 mm.

© Stator winding.

- Stator winding is made up of insulated copper wire. This winding is wound in the slots of Stator core.
- * * Stator winding is a 3 phase winding which is usually supplied from 3-phase supply
- * * Stator winding is wound around core to form poles.
- If number of poles is greater speed will be less and vice versa.
- * * Phase winding or stator winding may be either star or delta connected.

4. Working principal of three phase induction motor.

* Working principal of three phase induction motor is based on principal of mutual induction

* When three phase supply is given to the stator three phase winding then rotating magnetic field is produced with 120° displacement and of constant magnitude which rotates with synchronous speed (n_s)

This rotating magnetic field cuts the rotor conductors flux linked with conductor regularly changes and hence EMF will be induced in conductor. As both ends of the conductor is shorted by end rings and circuit is complete this EMF causes a current to flow in conductors.

Hence here a current carrying conductor is placed in magnetic field so a force is experienced by conductor, since the rotor conductor is in slot on the circumference of rotor, this force acts in tangential direction to Rotor and develops a torque in rotor. Similar torque is produced in all Rotor conductors.

Hence finally rotor starts rotating in the same direction as rotating magnetic

field of stator.

* Thus a three phase induction motor is called self starting.

* Since rotor starts rotating due to induced voltage the motor is called induction motor.

(A) Explanation.

* Let us consider a rotor conductor placed in rotating magnetic field

* Magnetic field is of constant magnitude rotating clockwise

* A stationary conductor, in magnetic field moving clockwise has same effect as magnetic field stationary and conductor moving anticlockwise.

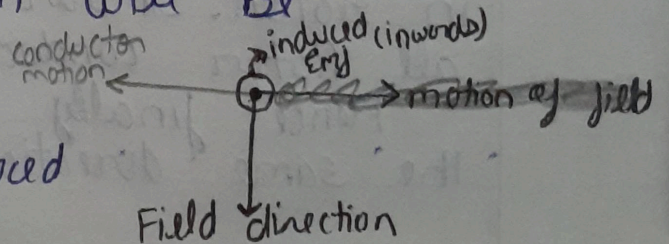
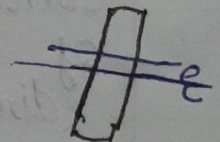
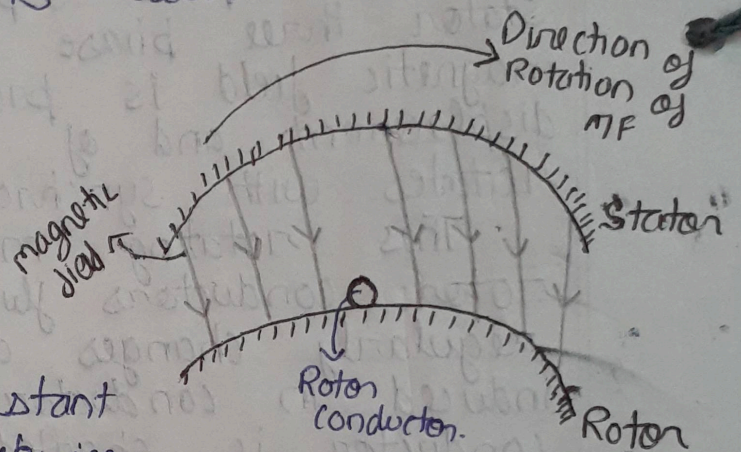
EMF direction.

* By Right hand Rule (MFE)

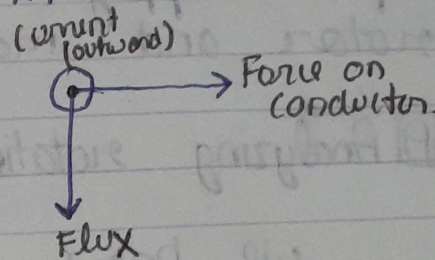
Emf induced in outward direction
Hence current direction will be inward

$$\mathcal{E} = (\mathbf{v} \times \mathbf{B}) \cdot d\mathbf{l}$$

* $\mathbf{v} \times \mathbf{B}$ will be direction of induced EMF



Force on conductor.
By Left hand Rule (FBI)
force felt by conductor in
clockwise direction



$$F = (I \times B) \cdot dl$$

• $(I \times B)$ will give direction of force experienced by conductor

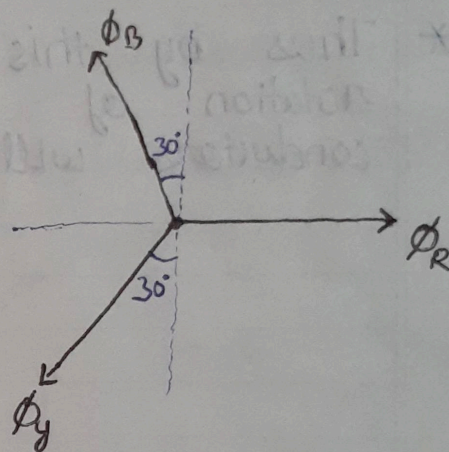
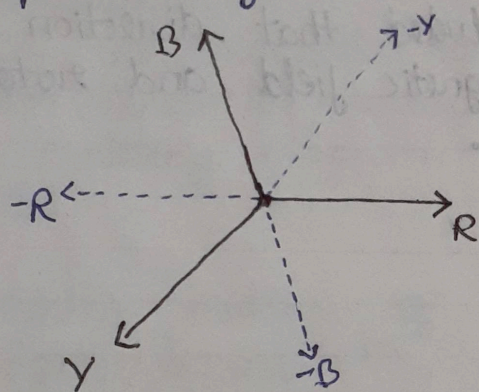
* Thus by this we concluded that direction of rotation of rotating magnetic field and rotor conductors will be same.

⑤ Rotating magnetic field.

As soon as stator winding is provided with 3 phase supply the magnetic flux starts cutting the rotor and motor gets started.

→ [A] Analyzing rotating magnetic field (RMF) by analytical method.

We know, three phases are R, Y, B. and are separated by 120° .



* Here phase sequence is considered to be rotating in clockwise direction

We know, $\Phi_R = \Phi_m \sin \omega t$

$$\Phi_Y = \Phi_m \sin(\omega t - 120^\circ)$$

$$\Phi_B = \Phi_m \sin(\omega t - 240^\circ) = \Phi_m \sin(\omega t + 120^\circ)$$

Let's break down the resultant into their components

$$\phi_H = ? \quad \phi_V = ?$$

* Horizontal component

$$\begin{aligned} \phi_H &= \phi_R - \phi_B \sin 30 - \phi_Y \sin 30 \\ &= \phi_R - \frac{(\phi_B + \phi_Y)}{2} \end{aligned}$$

Putting values.

$$\phi_H = \phi_m \sin \omega t - \left[\frac{\phi_m \sin(\omega t - 120) + \phi_m \sin(\omega t + 120)}{2} \right]$$

$$\phi_H = \phi_m \left[\sin \omega t - \frac{\sin \omega t \cos 120 - \cos \omega t \sin 120 + \sin \omega t \cos 120 + \cos \omega t \sin 120}{2} \right]$$

$$\phi_H = \phi_m \left[\sin \omega t - \sin \omega t \cos 120 \right] \cdot \left[\cos 120 = \cos(180 - 60) = -\frac{1}{2} \right]$$

$$\phi_H = \phi_m \left[\sin \omega t + \frac{\sin \omega t}{2} \right]$$

$$\phi_H = \frac{3 \sin \omega t}{2} \phi_m$$

Horizontal component of flux $= \phi_H = \frac{3}{2} \phi_m \sin \omega t$

* Vertical component.

$$\phi_v = \phi_B \cos 30 - \phi_r \cos 30$$

$$= (\phi_B - \phi_r) \cos 30$$

$$= [\phi_m \sin(\omega t + 120) - \phi_m \sin(\omega t - 120)] \frac{\sqrt{3}}{2}$$

$$\phi_v = \frac{\sqrt{3}}{2} \phi_m [\sin \omega t \cos 120 + \cos \omega t \sin 120 - \sin \omega t \cos 120 + \cos \omega t \sin 120]$$

$$\phi_v = \frac{\sqrt{3}}{2} \phi_m \times 2 \cos \omega t \sin 120$$

$$\boxed{\phi_v = \frac{3}{2} \phi_m \cos \omega t}$$

Resultant flux

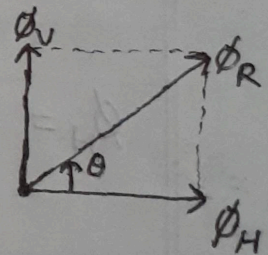
$$\phi_n = \sqrt{\phi_H^2 + \phi_v^2}$$

$$\phi_n = \sqrt{\frac{9}{4} \phi_m^2 \sin^2 \omega t + \frac{9}{4} \phi_m^2 \cos^2 \omega t}$$

$$\boxed{\phi_n = \frac{3}{2} \phi_m}$$

$$\tan \theta = \frac{\phi_v}{\phi_H} = \cot \omega t = \tan\left(\frac{\pi}{2} - \omega t\right)$$

$$\boxed{\theta = \frac{\pi}{2} - \omega t}$$



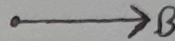
Case 1. At $\theta = 0^\circ = \omega t$
 $\phi_A = \phi_n = \frac{3}{2} \phi_m$

$$\theta = \frac{\pi}{2}$$



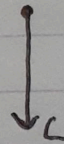
Case 2] At $\theta = 90^\circ = \omega t$
 $\phi_B = \phi_n = \frac{3}{2} \phi_m$

$$\theta = 0^\circ$$



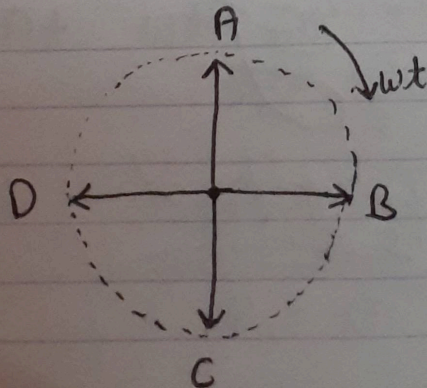
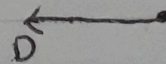
Case 3] At $\omega t = 180^\circ$
 $\phi_C = \phi_n = \frac{3}{2} \phi_m$

$$\theta = -\frac{\pi}{2}$$



Case 4] At $\omega t = 270^\circ$
 $\phi_D = \phi_n = \frac{3}{2} \phi_m$

$$\theta = -\pi$$



Following conclusions

- * Three phase current of a balanced supply system produce a resultant flux of constant magnitude in air gap of motor. The magnitude of flux at every instant is $\frac{3}{2} \phi_m$.
- * The resultant flux is of constant magnitude and rotating in nature with synchronous speed (N_s)
- * The direction of rotation of RMF is same as phase sequence. If any two of phase sequence are interchanged the direction of rotation of RMF becomes opposite.

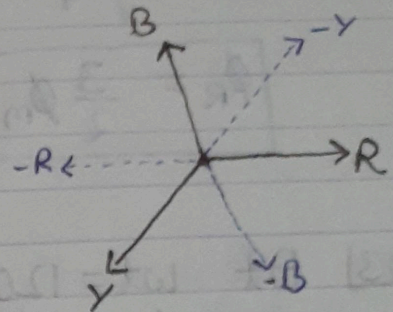
Let's see more
on conclusions
or diagrams of
graphical method

B. Analyzing RMF by graphical method.

$$\phi_R = \phi_m \sin \omega t$$

$$\phi_Y = \phi_m \sin(\omega t - 120^\circ)$$

$$\phi_B = \phi_m \sin(\omega t + 120^\circ)$$



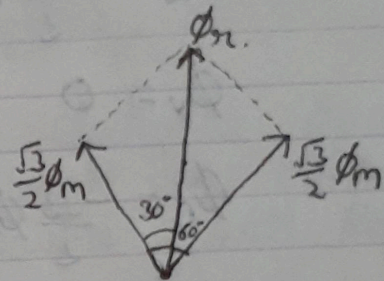
* Phase sequence = clockwise.

Case 1] At $\theta = 0^\circ = \omega t$

$$\phi_R = 0$$

$$\phi_Y = -\frac{\sqrt{3}}{2} \phi_m$$

$$\phi_B = \frac{\sqrt{3}}{2} \phi_m$$



$$\phi_R = 2 \times \frac{\sqrt{3}}{2} \phi_m \cos 30^\circ$$

$$\phi_R = \frac{3}{2} \phi_m$$

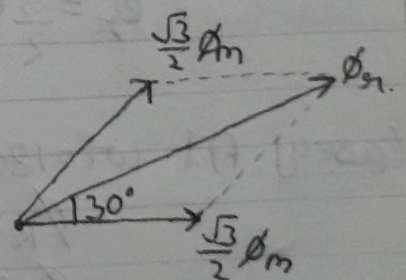


Case 2] At $\omega t = 60^\circ$

$$\phi_R = \frac{\sqrt{3}}{2} \phi_m$$

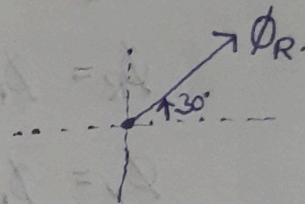
$$\phi_Y = -\frac{\sqrt{3}}{2} \phi_m$$

$$\phi_B = 0$$



$$\phi_R = \sqrt{\frac{3}{4} \phi_m^2 + \frac{3}{4} \phi_m^2 + \frac{3}{4} \phi_m^2}$$

$$\phi_R = \frac{3}{2} \phi_m$$

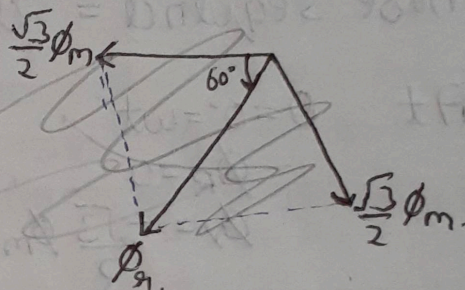


(Case 3) At $\omega t = 120^\circ$

$$\phi_R = -\frac{\sqrt{3}}{2} \phi_m$$

$$\phi_y = 0$$

$$\phi_B = -\frac{\sqrt{3}}{2} \phi_m$$



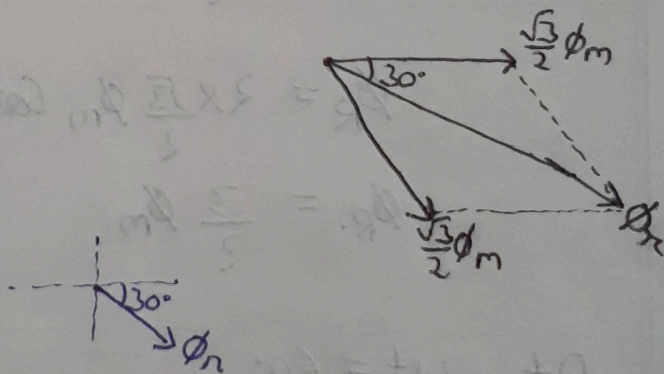
(Case 3) At $\omega t = 120^\circ$

$$\phi_R = \frac{\sqrt{3}}{2} \phi_m$$

$$\phi_y = 0$$

$$\phi_B = -\frac{\sqrt{3}}{2} \phi_m$$

$$\phi_n = \frac{3}{2} \phi_m$$



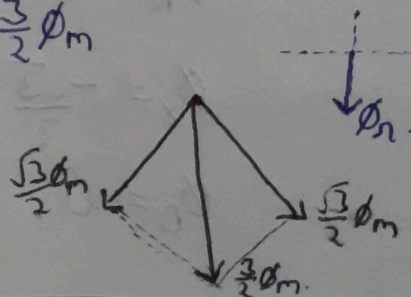
(Case 4) At $\omega t = 180^\circ$

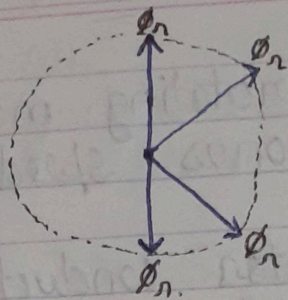
$$\phi_R = 0$$

$$\phi_y = \frac{\sqrt{3}}{2} \phi_m$$

$$\phi_B = -\frac{\sqrt{3}}{2} \phi_m$$

$$\phi_n = \frac{3}{2} \phi_m$$





- * Hence the magnitude of resultant will be $1.5\phi_m$ and will be rotating in clockwise sense same as phase sequence.
- * If phase sequence is in clockwise direction then RMF will also rotate in clockwise and hence the rotor conductor will rotate in clockwise direction.
- * If phase sequence is rotating in anticlockwise direction then RMF will rotate in anticlockwise and hence rotor conductor rotate in anticlockwise direction.
- * If any two phase sequence are interchange then direction of rotation of RMF reverses.

⑤ Concept of Slip.

The speed with which rotating magnetic field (RMF) rotates is called synchronous speed $[N_s]$.

* The speed with which Rotor conductor rotates is known as Rotor speed $[N_r]$.

* The difference between synchronous speed and rotor speed is known as slip speed.

$$\text{Slip speed} = N_s - N_r$$

* The Ratio of slip speed to the synchronous speed is called as fractional slip.

$$\text{fractional slip}_{(s)} = \frac{N_s - N_r}{N_s}$$

* When fractional slip is multiplied by 100 it is called as percentage slip.

$$\text{Percentage slip} = \frac{N_s - N_r}{N_s} \times 100$$

* If capital N then rpm (rotation per minute)

* If small n then rps (rotation per second)

* Hence during operation of motor the speed of rotor always lags behind speed of RNF // (Synchronous Speed).

(Case 1) If $N_s > N_r$.
The synchronous speed is always greater than rotor speed.

$$0 < S \leq 1$$

(Case 2) If $N_r = 0$
The rotor is not rotating means the rotor is standstill

$$\text{Slip} = 1$$

we will get maximum slip.

(Case 3) If $N_r = N_s$

$$\text{Slip} = 0$$

As Both rotor and stator magnetic field is Rotating with same speed there will be no relative motion and hence no flux will cut the conductor and motor will not perform its action.

* Hence during the operation of 3 phase induction motor the rotor rotates at speed less than synchronous speed hence this motor is known as Asynchronous motor.

⑥ Factor dependent on slip.

Ⓐ Rotor frequency

$$f_r = S \times f$$

f = frequency of applied voltage to stator.

* As the slip increases then the rotor frequency increases

* The frequency of current and voltage in stator must be same as given supply frequency (f).

$$f = \frac{PN_s}{120}$$

* But the rotor frequency is variable and dependent upon the difference between synchronous and slip speed ($N_s - N_r$) or slip speed.

$$f_r = \frac{P(N_s - N_r)}{120}$$

$$\frac{f_r}{f_s} = \frac{N_s - N_r}{N_s}$$

$$f_r = S f_s$$

S = fractional slip

* The frequency of Rotor varies from $f_r = f$ at standstill to $f_r = 0$ at synchronous speed.

More factors on slip add
Pages.

7. Comparison of Induction motor and Transformer

Induction motor	Transformer
* Flux will be rotating in nature (RMF)	* Flux will be alternating in nature
* Frequency of stator and rotor is not same in running condition $f_r = s f$	* Frequency of Both primary and secondary winding will be same all the time.
* Rotor EMF is not constant and dependent upon slip.	* If number of turns are fixed then EMF will be constant.

More on comparison.

Left types of starting DOL, star delta etc

6-10-2020

ALTERNATORS.

* A machine which generates AC current is known as alternator.

* Alternator is a synchronous machine that convert mechanical power into AC electrical power.

* Alternator is said to be a synchronous machine because it runs at a constant synchronous speed.

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

• Rotor speed, Machine speed and shaft speed is same as synchronous speed.

* A synchronous generator is a doubly excited machine means its rotor field winding is excited by DC current source and stator armature winding gives 3 phase AC output.

* Alternator is also known as the synchronous generator.

① Construction of Alternator.

The alternator consist of ~~two~~ main parts

① Stator.

② Rotor.

① Stator.

The Stator is the stationary part of the alternator. Stator consist of three parts.

① Stator frame.

The outermost protective covering of alternator which provides support to stator core is known as stator frame.

* For small machine stator frame is made of cast iron and for large machine it is made of fabricated steel.

* Also stator frame consist of holes on its base so that it can be easily bolted to the ground.

* The alternator is bolted on cement concrete flooring because it produces lots of vibration during its operation.

⑥ Stator core.

- * Stator core is made up of high grade silicon steel laminations.

- * These laminations contains slots in their inner periphery containing 3 phase stator winding.

- * These laminations reduces eddy current and the hysteresis losses. is reduced by silicon steel material.

⑦ Stator winding.

- * Stator winding is wound in the slots of the stator core.

- * Stator winding is a 3 phase winding, One end of windings is star connected and 3- ϕ AC supply is taken from remaining three ends.

- * Stator winding is generally made of copper wires.

- * Stator winding is also known as the armature winding.

* The empty space between inner part of stator and outer part of rotor is known as (Air gap).

[B] Rotor.

Rotor is the rotating part of an alternator.

Types of Rotor * Rotor is mounted on stiff rod of steel called shaft. This shaft is also connected directly to external prime mover.

@ Salient pole type Rotor.

* Salient means projecting.

* Salient pole type rotor consist of poles projecting outwards from the Rotor surface.

* Salient pole type rotor core consist of sheet steel lamination stacked together to required length and riveted together. Field windings are then fitted around each pole body. These poles are then fitted by dove tail joint to steel spider keyed to shaft.

* Salient pole type rotor contains concentrated windings on poles.

* Damper bars or Damper windings are usually placed in pole face to damp out rotor oscillation during sudden change in load condition.

* A salient pole type machine contains non uniform air gap. Air gap is maximum at pole centre and minimum at the pole face.

- * The individual field pole windings are connected in series to give alternate north south polarities. The ends of the field windings are connected to a DC source (a DC generator or a rectifier) through the brushes on the slip rings.

The slip rings are metal rings mounted on the shaft and insulated from it. They are used to carry current to or from the rotating part of the machine (usually AC machine) via carbon brushes.

- * Salient pole generator operates at lower speeds and have large number of poles

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

- If speed of rotor is high then the field windings will experience high centrifugal force which is not desirable.

- * A salient pole generator has comparatively large diameter and short axial length.

The large diameter can accommodate large number of poles.

- * Salient pole alternators driven by water turbines are called hydro alternators or hydrogenerators.

• High speed $\rightarrow$ horizontal configuration

• Low speed $\rightarrow$ Vertical configuration

⑥ Cylindrical type Rotor.

A cylindrical type rotor is also known as the non salient pole type Rotor, because it does not contain any physical pole to be seen as salient pole construction.

* The cylindrical rotors are made from solid forging of high grade nickel-chrome-molybdenum steel.

* In about two third of rotor periphery, slots are cut at regular intervals and parallel to shaft. The DC field winding are accommodated in these slots.

In this field winding is of distributed type.

* The unslotted portion of the rotor forms two (or four) pole faces

* The cylindrical rotor machine has a comparatively smaller diameter and long axial length. Such construction provides a greater mechanical strength and limits the centrifugal forces.

* Due to uniform air gap its operation is less noisy

* Cylindrical pole type rotor rotates at high speeds. These are driven by steam or gas turbines, hence known as turboalternators or turbogenerators.

2. Excitation of Generator.

Alternator field windings is excited by passing DC current through them. This DC current can be given by small DC generator mounted on shaft, This DC generator is called exciter.

The DC current is given to synchronous machine field winding through brushes and Slip rings.

3. Operation of Alternator.

The principle of alternator is based on Faraday's law of electromagnetic induction.

* When DC current is supplied to field windings present on Rotor the magnetic field is generated (stationary). Then by the help of prime mover rotor is rotated due to which magnetic field also starts to rotate. Then this rotating magnetic field when links to armature winding, produces EMF in it.

This EMF produced is of alternating nature and due to 3- ϕ winding we get 3- ϕ alternating EMF.

* Here note that field winding is placed on Rotor and armature winding is placed on stator.

(A) Advantages of Rotating field alternator.

- The stationary armature can be more easily insulated even for voltage as high as 33KV.
- The armature winding being stationary is not subjected to high centrifugal forces.
- The armature can be cooled easily as cooling ducts are provided in it.
- The weight of armature windings is very high if these are provided on Rotor then there will be high centrifugal force on it which causes wear.
- The output current can be taken directly from the fixed terminals of armature without using slip ring or brushes.

more Advantages

3. EMF Equation of Alternator.

F = Frequency of induced EMF in Hz.

P = Number of poles.

ϕ = Useful flux per pole in weber.

N_s = Synchronous speed / Rotor speed (RPM).

Z_{ph} = No of conductor in series per phase.

T_{ph} = Turns per phase.

We know, $Z_{ph} = 2 \times T_{ph}$.

ε = Average induced EMF per conductor.

and, $\varepsilon = \frac{d\phi}{dt} = \frac{\text{Net flux}}{\text{time for one rotation}}$

$$\text{Net flux} = P\phi.$$

$$N_s \text{ Rotation} \rightarrow 60 \text{ sec.}$$

$$1 \text{ Rotation} \rightarrow \frac{60}{N_s} \text{ sec.}$$

$$\varepsilon_{\text{cond}} = \frac{P\phi N_s}{60}.$$

We know, $N_s = \frac{120f}{P}$

$$\left(\varepsilon_{\text{avg}} \right)_{\text{cond}} = \frac{P\phi}{60} \times \frac{120f}{P} = 2f\phi.$$

$$E_{avg/cond} = 2f\phi$$

* for Z_{ph} conductor, $E_{avg} = 2f\phi Z_{ph}$.

* for T_{ph} turns, $E_{avg} = 4f\phi T_{ph}$.

we know $RMS = AVG \times FF$.

The Sinusoidal wave is generated hence for sin wave $FF = 1.11$.

$$(E_{RMS})_{ph} = 4.44 f \phi T_{ph}$$

* For line voltage.

• Because armature winding are star connected.

$$(E_{RMS})_L = \sqrt{3} (E_{RMS})_{ph}$$

$$(E_{RMS})_L = 7.69 f \phi T_{ph}$$

4. Voltage Regulation.

It is ratio of change in terminal voltage when load is suddenly removed to the terminal voltage at full load provided speed and field current remain constant.

$$\% \text{ Regulation} = \frac{|\mathcal{E}| - |V_t|}{|V_t|} \times 100$$

$\mathcal{E}$ = Voltage after sudden removing of load.

V_t = terminal voltage at full load.

$$\text{Per unit voltage regulation} = \frac{|\mathcal{E}| - |V_t|}{|V_t|}$$