		Determine the excitation required when the machine supplies full load at 0.8 pf lagging by using the leakage reactance and drawing the MMF phasor diagram. What is the voltage regulation of the machine? Also calculate the voltage regulation for this loading using the adjusted synchronous reactance. Compare and comment upon the results.			
		UNIT-V			
10	a)	Explain the construction and working principle of Synchronous Motor.	L4	CO3	5 M
	b)	Explain the variation of current and power factor of a synchronous motor with excitation.	L4	CO3	5 M
		OR			
11		Explain the procedure for constructing 'V' curves and Inverted 'V' curves of Synchronous motor.	L4	CO5	10 M

PVP 23

Code: 23EE3402

II B.Tech - II Semester – Regular Examinations - MAY 2025

INDUCTION AND SYNCHRONOUS MACHINES
(ELECTRICAL & ELECTRONICS ENGINEERING)

Duration: 3 hours Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level CO – Course Outcome

PART – A

		BL	CO
1.a)	Infer why the induction motor never runs at synchronous speed.	L2	CO1
1.b)	State the reason of skewed rotor bars in 3 phase squirrel cage induction motor.	L2	CO1
1.c)	Identify the condition for maximum torque developed in three phase induction motor.	L2	CO2
1.d)	Write the relation of speed with respect to poles. How it is employed in speed control of induction motor?	L2	CO2
1.e)	Identify why single phase induction motor is not a self-starting?	L2	CO4
1.f)	List the application of a shaded pole single phase induction motor.	L2	CO4
1.g)	List the types of synchronous machines with respect to its rotor construction.	L2	CO3

1.h)	State the conditions for connecting two alternators in parallel.	L2	CO5
1.i)	What do mean by damper windings? Mention its function and where it is located.	L2	CO5
1.j)	Infer the role of synchronous condenser in power system application.	L2	CO5

PART – B

			BL	CO	Max. Marks
		UNIT-I			
2		Explain the constructional features of Squirrel cage induction motor and compare with the slip ring induction motor.	L2	CO2	10 M
		OR			
3		The power input to a 3phase induction motor is 60 kW. The stator losses are 1 kW. Calculate the mechanical power developed and rotor copper loss per phase if the motor is running with a slip of 3 %.	L3	CO2	10 M
		UNIT-II			
4	a)	Derive the torque equation of three phase induction motor.	L3	CO4	5 M
	b)	Interpret the V/F speed control method of induction machine.	L3	CO4	5 M
		OR			
5		Predetermine the efficiency of the three phase induction machine and examine the performance parameters with the procedure to draw the circle diagram.	L4	CO2	10 M

	UNIT-III			
6	Explain the double field revolving theory and infer the construction and working principle of single phase induction motor.	L4	CO2	10 M
	OR			
7	Illustrate the operation of split phase and shaded pole induction machine with its characteristics.	L3	CO4	10 M
	UNIT-IV			
8	Explain the construction and working principle of Synchronous generator and infer the difference between the two rotors.	L4	CO3	10 M
	OR			
9	The following data were obtained for the OCC of a 10 MVA, 13 kV, 3 Phase, 50 Hz, Y connected synchronous generator:	L4	CO5	10 M

Field current (A)	50	75	100	125	150	162.5	200	250	300
O.C voltage (kV)	6.2	8.7	10.5	11.8	12.8	13.2	14.2	15.2	15.9

An excitation of 100 A causes the full loads current to flow during the short circuit test. The excitation required giving the rated current at zero pf and total voltage is 290 A.

(i) Calculate the adjusted synchronous reactance of the machine.

(ii) Calculate the leakage reactance of the machine assuming the resistance to be negligible.

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II B. Tech – II Semester – Regular Examinations – May 2025
INDUCTION AND SYNCHRONOUS MACHINES
(Electrical & Electronics Engineering)

Scheme of valuation

	PART-A	
1. a to j	**Each Question carries 2 Marks**	
	PART-B	
2.	Diagram of squirrel cage induction motor Explanation of constructional features of squirrel cage IM Comparison of squirrel cage and slip ring induction motor	3 M 3 M 4 M
3	Calculation of Rotor input Calculation of mechanical power developed	5 M 5 M
4. a)	Deriving expression for torque equation of three phase induction motor	5 M
4. b)	Explanation of V/F speed control method of induction machine	5 M
5.	Procedure to draw the circle diagram. Drawing of circle diagram Explanation of performance parameters	5 M 3 M 2 M
6.	Explanation of double field revolving theory Construction and working principle of single phase induction motor.	5 M 5 M
7.	Explanation of the operation of split phase induction machine. Explanation of the operation of shaded pole induction machine	5 M 5 M
8.	Explanation of construction and working principle of Synchronous generator Difference between the two rotors	5 M 5M
9.	Calculation of adjusted synchronous reactance of the machine. Calculation of leakage reactance of the machine. Calculation of V.R using leakage reactance and MMF phasor diagram. Calculation of V.R using the adjusted synchronous reactance	2 M 2 M 3 M 3M

10.a)	Diagram of Synchronous Motor Explanation of working principle of Synchronous Motor	2 M 3 M
10.b)	Phasor Diagram with different excitations Explanation of variation of current and power factor of a synchronous motor with excitation	2 M 3 M
11.	Circuit Diagram of 'V' curves and Inverted 'V' curves of Synchronous motor Explanation of the procedure for constructing 'V' curves and Inverted 'V' curves of Synchronous motor	4 M 6 M

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II B. Tech – II Semester – Regular Examinations – May 2025
INDUCTION AND SYNCHRONOUS MACHINES
(Electrical & Electronics Engineering)

PART-A

Each Question carries 2 Marks

1.a) Infer why the induction motor never runs at synchronous speed.

When induction motor is rotating at synchronous speed, Under this condition, there is no relative speed between rotor and stator field flux. Therefore, there would be no cutting of flux by the rotor conductors. Hence, no rotor emf, no rotor current and no torque to maintain rotation.

1.b) State the reason of skewed rotor bars in 3 phase squirrel cage induction motor.

Skewing helps to reduce magnetic locking and magnetic hum

1.c) Identify the condition for maximum torque developed in three phase induction motor.

Rotor resistance = slip X Standstill rotor reactance

$$R_2 = s X_2$$

1.d) Write the relation of speed with respect to poles. How it is employed in speed control of induction motor?

The synchronous speed (Ns) of an induction motor can be calculated using the formula:
Ns = 120f / P
Where P = number of poles

The speed of an induction motor depends upon the number of poles for which the stator is wound. If instead of one stator winding, two independent windings, for different number of poles are made on the stator, two definite rotor speeds can be obtained.

1.e) Identify why single phase induction motor is not a self-starting?

When a single-phase induction motor is connected to a single-phase supply, two fields of magnitude Φm / 2 are developed. At start an equal in magnitude but rotate opposite in direction torques are set up by the these two fields. Thus, net torque experienced by the rotor is zero at start. And hence the single phase induction motor is not self starting.

1.f) List the application of a shaded pole single phase induction motor.

shaded pole single phase induction motors are used for the small fans, toy motors, advertising displays, film projectors, record players, gramophones, hair dryers, photo copying machines.

(Note : Any four of the above application)

1.g) List the types of synchronous machines with respect to its rotor construction.

Synchronous machines with respect to its Rotor construction is of two types, namely;

(i) Salient (or) projecting pole type
(ii) Non-salient (or) cylindrical pole type

1.h) State the conditions for connecting two alternators in parallel.

Terminal voltage, frequency and the phase sequence of the two alternators must be the same.

1.i) What do mean by damper windings? Mention its function and where it is located.

Damper windings consist of short-circuited copper bars embedded in the rotor poles shoes. The function of damper windings is to minimize hunting and make the synchronous motor self-starting. Damper windings are located in the rotor pole shoes of salient-pole synchronous machines.

1. j) Infer the role of synchronous condenser in power system application.

An over-excited synchronous motor running on no-load in known as synchronous condenser.
synchronous condenser improves power factor.

PART-B

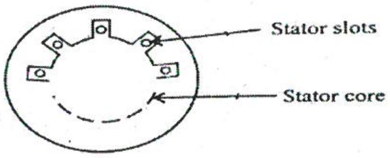
UNIT-I

2. **Explain the constructional features of Squirrel cage induction motor and compare with the slip ring induction motor. [10 M]**

Construction of a 3-phase induction motor

- ✓ A 3-phase induction motor has two main parts (i) stator and (ii) rotor.

Stator:



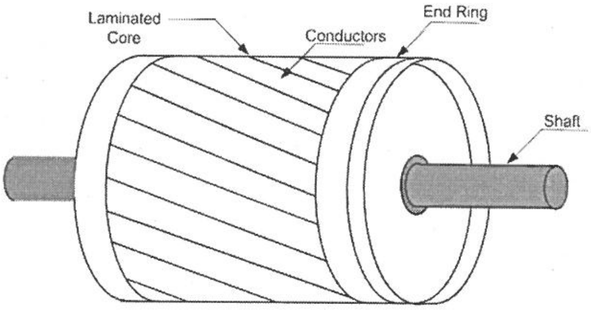
- ✓ It consists of a steel frame which encloses a hollow, cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current losses.
- ✓ A number of evenly spaced slots are provided on the **inner periphery** of the laminations
- ✓ The insulated conductors are placed in the stator slots and are suitably connected to form a balanced 3-phase star or delta connected circuit.
- ✓ When 3-phase supply is given to the stator winding, a **rotating magnetic field of constant magnitude is produced.**
- ✓ This rotating field induces currents in the rotor by electromagnetic induction.

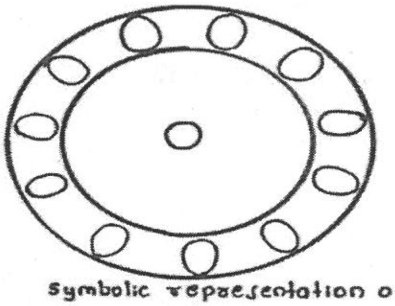
Rotor: -

- ✓ Two types of rotors namely squirrel cage rotor and slip ring rotor or phase wound rotor can be used for the construction of 3-phase induction motor.
- ✓ Thus, due to the two different types of rotor, there are two types of 3-phase induction motor i.e, 1. squirrel cage induction motor 2. slipring induction motor

Squirrel cage Rotor:

- ✓ It is a laminated steel cylindrical core having slots on the **outer periphery**.
- ✓ one copper bar is placed in each slot. All these bars are short circuited at both ends by copper rings.
- ✓ The rotor slots are not quite parallel to the shaft but are purposely given a slight deviation known as Skewing.
- ✓ The figure shows the construction of squirrel cage rotor
- ✓ The rotor is not connected electrically to the supply but has current induced in it by transformer action from the stator.





Symbolic representation of rotor

- ✓ 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.

Comparison of slip ring induction motor and squirrel cage induction rotor

S.No	Wound or Slip ring rotor	Squirrel cage rotor
1.	Rotor consists of a three phase winding similar to the stator winding.	Rotor consists of bars, which are shorted at the ends with the help of end rings.
2.	Construction is complicated.	Construction is simple
3.	Resistance can be added externally:	As permanently shorted, external resistance cannot be added
4.	Slip rings and brushes are present to add external resistance.	Slip rings and brushes are absent
5.	Frequent maintenance is necessary	Maintenance free
6.	Rotors are costly	Rotors are cheap
7.	High starting torque can be obtained	Moderate starting torque
8.	Rotor must be wound for same number of poles	The rotor automatically adjusts itself for the same number of poles as that of stator
9.	Rotor resistance starter can be used	Rotor resistance starter cannot be used
10.	Rotor copper losses are high hence efficiency is less	Rotor copper losses are less hence efficiency is high
11.	Speed control by rotor resistance is possible	Speed control by rotor resistance is not possible
12.	Used for lifts, hoists, cranes, elevators, compressors etc.	Used for lathes, drilling machines, fans, blowers, waterpumps, grinders, printing machines etc.

3. **The power input to a 3phase induction motor is 60 kW. The stator losses are 1 kW. Calculate the mechanical power developed and rotor copper loss per phase if the motor is running with a slip of 3%. [10M]**

Stator Power input= 60 kW

Stator losses = 1 kW

Slip = 3% (= 0.03)

Mechanical power developed: Rotor input = stator output = stator input - stator losses

=60 -1= 59 kW

Now mechanical power developed = (1-s) rotor input = (1 - 0.03) x 59 = 57.23 kW.

UNIT-II

4. **a) Derive the torque equation of three phase induction motor. [5M]**

Let the rotor at standstill have per phase induced e.m.f. E_2, reactance X_2 and resistance R_2. Then under running conditions at slip s,

$$\text{Rotor e.m.f./phase, } E'_2 = sE_2$$

$$\text{Rotor reactance/phase, } X'_2 = sX_2$$

$$\text{Rotor impedance/phase, } Z'_2 = \sqrt{R_2^2 + (sX_2)^2}$$

$$\text{Rotor current/phase, } I'_2 = \frac{E'_2}{Z'_2} = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$\text{Rotor p.f., } \cos\phi'_2 = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

The equation of torque, T

$$Torque \propto \Phi I'_2 \cos\Phi'_2$$

$$\propto \phi \times \frac{s\,E_2}{\sqrt{R_2^2 + (s\,X_2)^2}} \times \frac{R_2}{\sqrt{R_2^2 + (s\,X_2)^2}}$$

$$\propto \frac{\phi\, s\, E_2\, R_2}{R_2^2 + (s\,X_2)^2}$$

$$= \frac{K\,\phi\, s\, E_2\, R_2}{R_2^2 + (s\,X_2)^2}$$

$$= \frac{K\; s\, E_2^2\, R_2}{R_2^2 + (s\,X_2)^2} \qquad (\;E_2 \propto \phi)$$

constant $K = \frac{3}{2\pi n_s}$

Where n_s is synchronous speed in r. p. s,

$n_s = N_s / 60$.

So, finally the equation of torque becomes,

$$T = \frac{3}{2\pi n_s} \times \frac{sE_2{}^2R_2}{R_2{}^2 + (sX_2)^2}$$

4 b) Interpret the V/F speed control method of induction machine. [5M]

The synchronous speed is given by.

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

Thus by controlling the supply frequency smoothly, the synchronous speed can be controlled over a wide range. This gives smooth speed control of an induction motor.

It is very important to note that if speed control is to be achieved by changing frequency, the supply voltage should also simultaneously be changed. This is because if the supply frequency is reduced keeping the applied voltage constant, the flux is increased ($V=4.44\O_m fT$). If flux is increased, this may result into saturation of stator and rotor cores. Core-losses will increase and cause reduction in the efficiency. On the other hand, if the frequency is increased, flux will decrease, thereby reducing the torque developed.

$$\O m = \frac{1}{4.44T} \times \left(\frac{V}{f}\right)$$

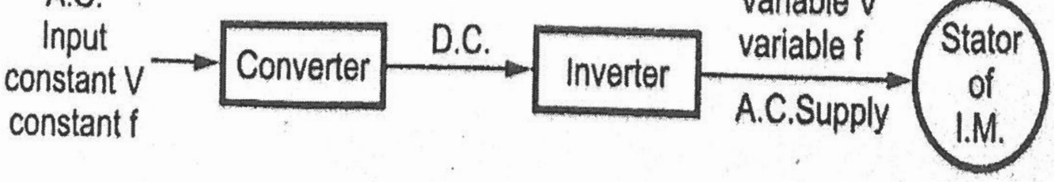
Hence it is necessary to maintain air gap flux constant when supply frequency f is changed.

To achieve this, it can be seen from the above expression that along with f, V also must be changed so as to keep (V/f) ratio constant.

Therefore, that the frequency changing device should change frequency and voltage simultaneously as a direct ratio. That is, if frequency is increased, the supply voltage must also be increased and if the frequency is decreased the supply voltage must also be decreased proportionately.

This ensures constant air gap flux giving speed control without affecting the performance of the motor. Hence this method is called V/f control.

Hence in this method, the supply to the induction motor required is variable voltage variable frequency supply and can be achieved by an electronic scheme using converter and inverter circuitry. The scheme is shown in the Fig.



The normal supply available is constant voltage constant frequency a.c. supply. The converter converts this supply into a d.c. supply. This d.c. supply is then given to the inverter. The inverter is a device which converts d.c. supply, to variable voltage variable frequency a.c. supply which is required to keep V/f ratio constant. By selecting the proper frequency and maintaining V/f constant, smooth speed control of the induction motor is possible.

5. **Predetermine the efficiency of the three phase induction machine and examine the performance parameters with the procedure to draw the circle diagram. [10 M]**

Procedure to draw the Circle Diagram

By using the data obtained from the no load test and the blocked rotor test, the circle diagram can be drawn using the following steps

Step 1: Take reference phasor V as vertical (Y-axis)

Step 2: Select suitable current scale such that diameter of circle is about 20 cm.

Step 3: From no load test, I_0 and Φ_0 are obtained. Draw vector I_0, lagging V by angle Φ_0 . This is line OO' as shown in the Fig.

Step 4: Draw horizontal line through extremity of I_0 i.e O', parallel to horizontal axis.

Step 5: Draw the current I_{SN} calculated from I_{SC} with the same scale, lagging V by angle Φ_{SC} , from the origin O. This is phasor OA as shown in the Fig.

Step 6: Join O'A. the line O'A is called Output line.

Step 7: Draw a perpendicular bisector of O'A. Extend it to meet horizontal line drawn from O' and let it be at point C. This is the centre of the circle.

Step 8: Draw the circle, with C as a centre and radius equal to O'C This meets the horizontal line drawn from O' at B as shown in the Fig.

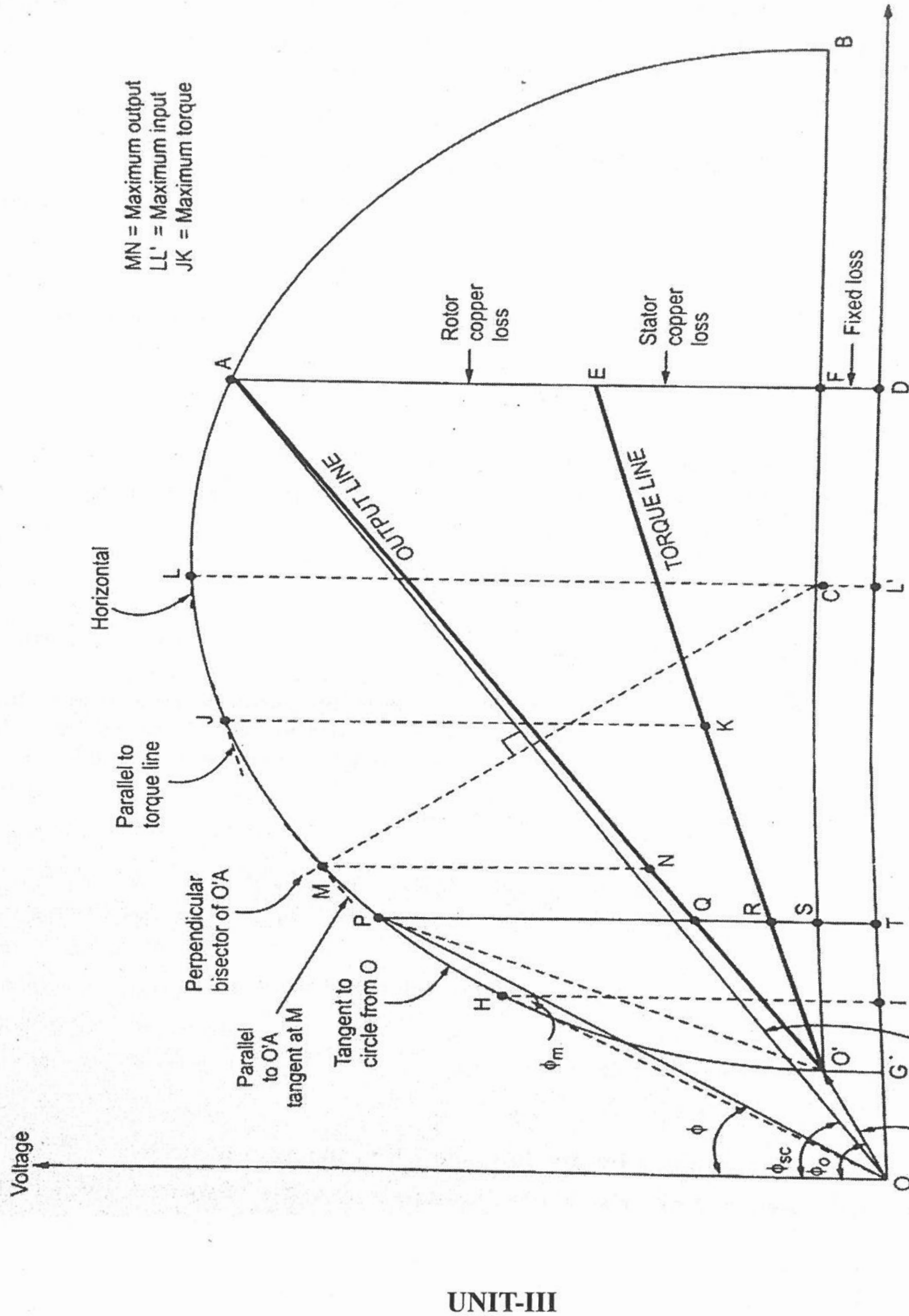
Step 9: Draw the perpendicular from point A on the horizontal axis, to meet O'B line at F and meet horizontal axis at D.

Step 10: Torque line: The torque line separates stator and rotor copper losses

Let the motor is taking a current OP as shown in fig.

Using the power scale and various distances, the values of the performance parameters can be obtained as,

1. Total motor input = PT × Power scale
2. Fixed loss = ST × Power scale
3. Stator copper loss = SR × Power scale
4. Rotor copper loss = QR × Power scale
5. Total loss = QT × Power scale
6. Rotor output = PQ × Power scale
7. Rotor input = PQ + QR = PR × Power scale
8. Slip $s = \dfrac{\text{rotor Cu loss}}{\text{rotor input}} = \dfrac{QR}{PR}$
9. Power factor $\cos\phi = \dfrac{PT}{OP}$
10. Motor efficiency $= \dfrac{\text{output}}{\text{input}} = \dfrac{PQ}{PT}$



UNIT-III

6. **Explain the double field revolving theory and infer the construction and working principle of single phase induction motor. [10 M]**

Double field revolving theory:

According to this theory, any alternating quantity can be resolved into two rotating components which rotate in opposite directions and each having magnitude as half of the maximum magnitude of the alternating quantity.

In case of single phase induction motors, the stator winding produces an alternating magnetic field having maximum magnitude of Φ_{1m}.

According to double revolving field theory, consider the two components of the stator flux, each having magnitude half of maximum magnitude of stator flux i.e. (Φ_{1m} / 2). Both these components are rotating in opposite directions at the synchronous speed N_s which is dependent on frequency and stator poles.

Let Φ_f is forward component rotating in anticlockwise direction while Φ_b is the backward component rotating in clockwise direction. The resultant of these two components at any instant gives the instantaneous value of the stator flux at that instant. So resultant of these two is the original stator flux.

The Fig. shows the stator flux and its two components Φ_f and Φ_b. At start both the components are shown opposite to each other in the Fig.(a). Thus, the resultant $\Phi_R = 0$. This is nothing but the instantaneous value of stator flux at start. After 90^0, as shown in the Fig. (b), the two components are rotated in such a way that both are pointing in the same direction. Hence the resultant Φ_R is the algebraic sum of the magnitudes of the two components.

So $\Phi_R = (\Phi_{1m} / 2) + (\Phi_{1m} / 2) = \Phi_{1m}$. This is nothing but the instantaneous value of the stator flux at $\theta = 90^0$ as shown in the Fig. (c). Thus, continuous rotation of the two components gives the original alternating stator flux.

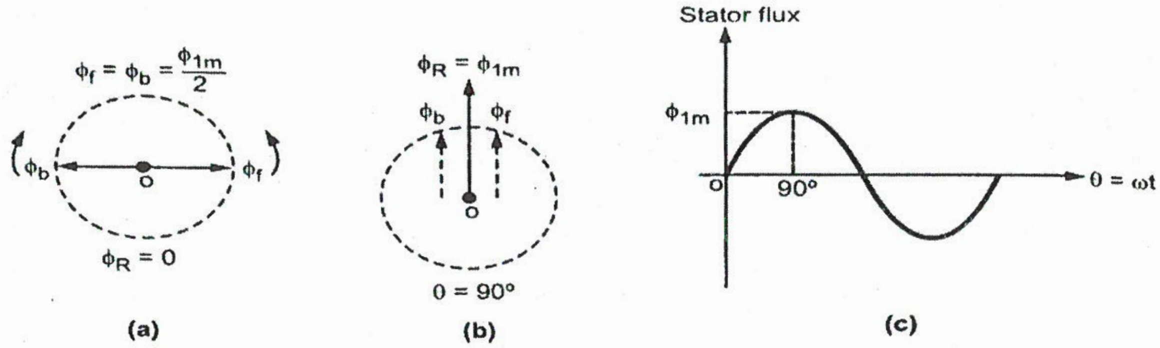


Fig. Stator flux and its two components

Both the components are rotating and hence get cut by the rotor conductors. Due to cutting of flux, e.m.f gets induced in rotor which circulates rotor current. The rotor current produces rotor flux. This flux interacts with forward component Φ_f to produce a torque in one particular direction say anticlockwise direction. While rotor flux interacts with backward component Φ_b to produce a torque in the clockwise direction. So if anticlockwise torque is positive then clockwise torque is negative.

At start these two torques are equal in magnitude but rotate opposite in direction. Each torque tries to rotate the rotor in its own direction. Thus net torque experienced by the rotor is zero at start. And hence the single phase induction motors are not self starting.

Construction of Single Phase Induction Motors:

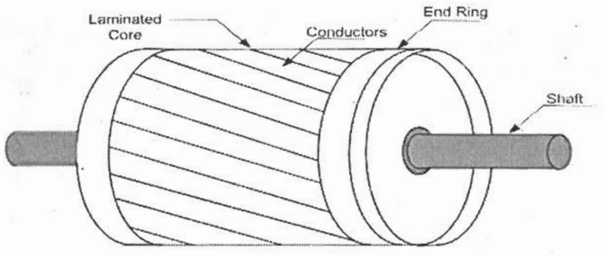
Single phase induction motor has basically two main parts, one rotating and other stationary. The stationary part in single phase induction motors is called **stator** while the rotating part is called **rotor**.

The stator has laminated construction, made up of stampings. The stampings are slotted on its periphery to carry the winding called stator winding or main winding. This is excited by a single phase a.c. supply. The laminated construction keeps iron losses to minimum. The stampings are made up of material like silicon steel which minimises the hysteresis loss. The stator winding is wound for certain definite number of poles means when excited by single phase a.c supply, stator produces the magnetic field which creates the effect of certain definite number of poles. The number of poles for which stator winding is wound, decides the synchronous speed of the motor. The synchronous speed is denoted as N, and it has a fixed relation with supply frequency f and number of poles P. The relation is given by

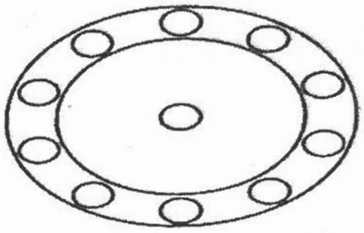
$$N = 120(f/ P)$$

The induction motor never rotates with the synchronous speed but rotates at a speed which is slightly less than the synchronous speed.

The rotor construction is of **squirrel cage type**. In this type, rotor consists of copper or aluminium bars, placed in the slots The bars are permanently shorted at both the ends with the help of conducting rings called end rings The entire structure looks like cage hence called squirrel cage rotor The construction and symbol is shown in the Fig.



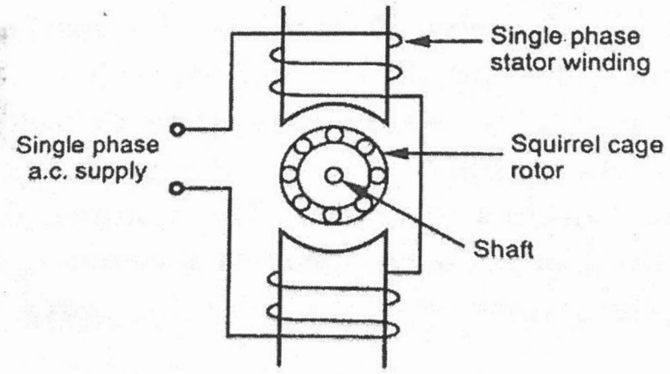
(a) Cage type structure



(b) Symbolic representation

As the bars are permanently shorted to each other, the resistance of the entire rotor is very very small. The air gap between stator and rotor is kept uniform and as small as possible. The main feature of this rotor is that it automatically adjusts itself for same number of poles as that of the stator winding

The schematic representation of two pole single phase induction motor is shown in the Fig .



Working Principle: For the motoring action, there must exist two fluxes which interact with each other to produce the torque In dc motors, field winding produces the main flux while d.c supply given to armature is responsible to produce armature flux. The main flux and armature flux interact to produce the torque.

In the single phase induction motor, single phase ac supply is given to the stator winding. The stator winding carries an alternating current which produces the flux which is also alternating in nature. This flux is called main flux. This flux links with the rotor conductors and due to transformer action e.m.f. gets induced in the rotor. The induced emf drives current through the rotor as rotor circuit is closed circuit. This rotor current produces another flux called rotor flux required for the motoring action. Thus, second flux is produced according to induction principle due to induced e.m.f. hence the motor is called induction motor.

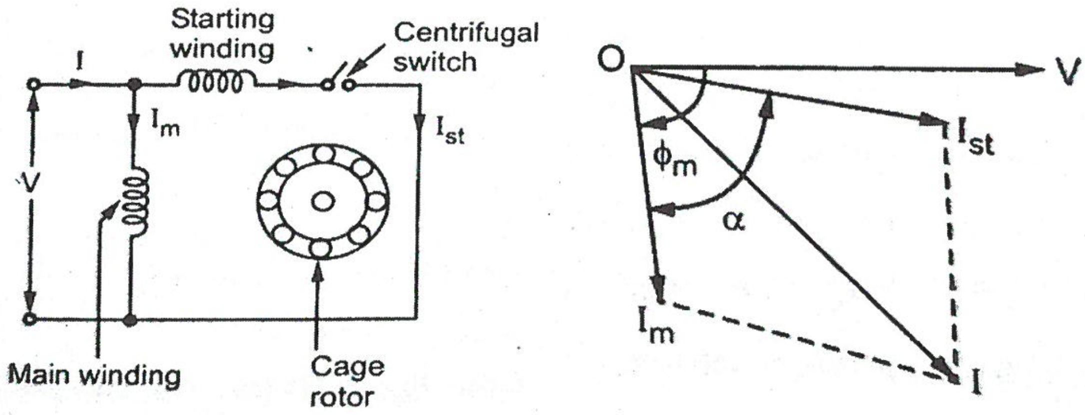
7. **Illustrate the operation of split phase and shaded pole induction machine with its characteristics.** [10 M]

Split Phase Induction Motor:

This type of motor has single phase stator winding called main winding. In addition to this, stator carries one more winding called auxiliary winding or starting winding. The auxiliary winding carries a series resistance such that its impedance is highly resistive in nature. The main winding is inductive in nature.

Let I_m = Current through main winding and I_{st} = Current through auxiliary winding

As main winding is inductive, current I_m lags voltage V by a large angle Φ_m while I_{st} is almost in phase in V as auxiliary winding is highly resistive. Thus, there exists a phase difference of α between the two currents and hence between the two fluxes produced by the two currents. This is shown in the Fig (a). The resultant of these two fluxes is a rotating magnetic field. Due to this, the starting torque, which acts only in one direction is produced.

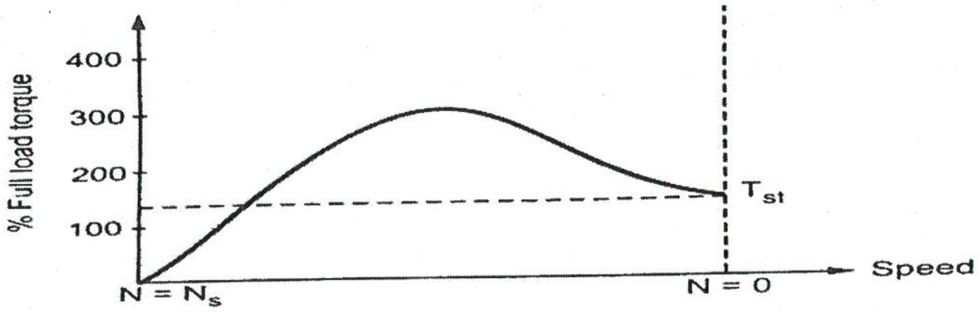


(a) Circuit diagram (b) phasor diagram

Fig. Split phase induction motor

The auxiliary winding has a centrifugal switch in series with it. When motor gathers a speed upto 75 % of the synchronous speed, centrifugal switch gets opened mechanically and in running condition auxiliary winding remains out of the circuit. So motor runs only on stator winding. So auxiliary winding is designed for short time use while the main winding is designed for continuous use. As the current I_m and I_{st} are splitted from each other by angle α at start the motor is commonly called split phase motor.

The torque-speed characteristics of split phase motors is shown in the Fig.



Shaded Pole Induction Motor:

This type of motor consists of a squirrel cage rotor and stator consisting of salient poles i.e. projected poles. The poles are shaded i.e. each pole carries a copper band on one of its unequally divided part called **shading band**. Fig. shows 2 pole shaded pole Induction motor.

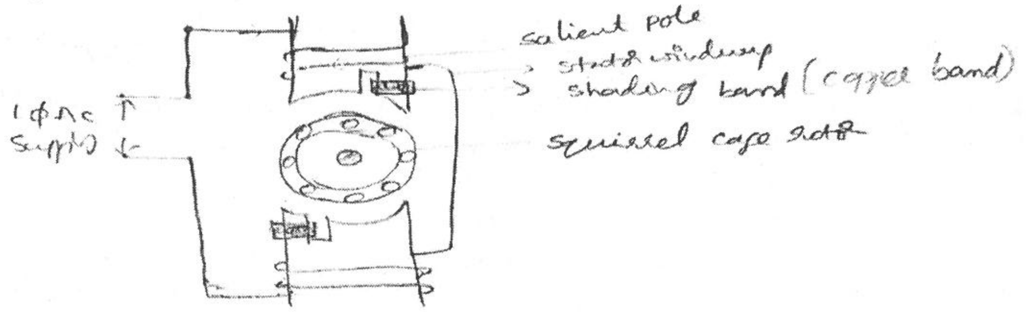


Fig (a) 2-pole shaded pole Induction Motor

When single phase ac supply is given to the stator winding, due to shading provided to the poles, a rotating magnetic field is generated.The production of rotating magnetic field can be explained as below:

The current carried by the stator winding is alternating and produces alternating flux. The waveform of the flux is shown in the Fig (a). The distribution of this flux in the pole area is greatly influenced by the role of copper shading band. Consider the three instants say t_1, t_2 and t_3 during first half cycle of the flux as shown, in the Fig.(a).

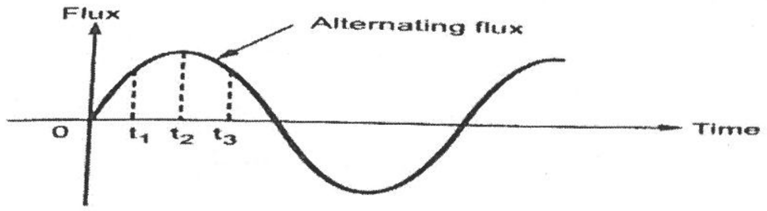


Fig. (a) Waveform of stator flux

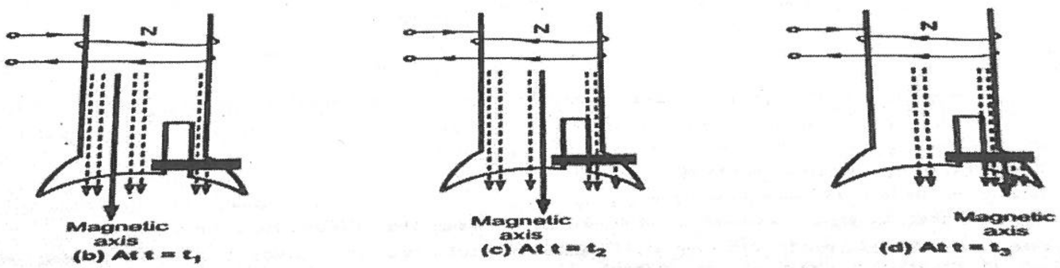


Fig. 1. Production of rotating magnetic field in shaded pole motor

At instant **t = t₁**, rate of rise of current and hence the flux is very high. Due to the transformer action, large e.m.f gets induced in the copper shading band. This circulates current through shading band as it is short circuited, producing its own flux. According to lenz's law, the direction of this current is so as to oppose the cause i.e. rise in current. Hence shading ring flux is opposing to the main flux. Hence there is crowding of flux in nonshaded part while weakening of flux in shaded part. Overall magnetic axis shifts in nonshaded part as shown in the Fig 1(b).

At instant **t = t₂**, rate of rise of current and hence the rate of change of flux is almost zero as flux almost reaches to its maximum value. So $d\Phi/dt = 0$. Hence there is very little induced emf in the shading ring. Hence the shading ring flux is also negligible, hardly affecting the distribution of the main flux. Hence the main flux distribution is uniform and magnetic axis lies at the centre of the pole face as shown in the Fig 1(c).

At instant **t = t₃**, the current and the flux is decreasing. The rate of decrease is high which again induces a very large e.m.f in the shading ring. This circulates current through the ring which produces its own flux. Now direction of the flux produced by the shaded ring current is so as to oppose the cause which is decrease in flux. So, it opposes the decrease in flux means its direction is same as that of main flux, strengthening it. So, there is crowding of flux in the shaded part as compared to nonshaded part. Due to this the magnetic axis shifts to the middle of the shaded part of the pole. This is shown in the Fig 1(d).

This sequence keeps on repeating for negative half cycle too. Consequently, this produces an effect of rotating magnetic field, the direction of which is from nonshaded part of the pole to the shaded part of the pole. Due to this, motor produces the starting torque and starts rotating. The starting torque is low which is abut 40 to 50% of the full load torque for this type of motor. The torque speed characteristics is shown in the Fig

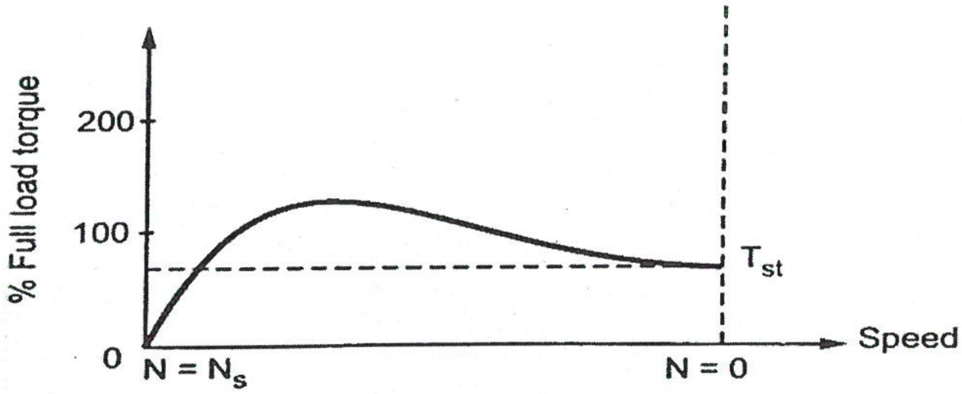


Fig. Torque-speed characteristics of shaded pole motor

UNIT-IV

8. **Explain the construction and working principle of Synchronous generator and infer the difference between the two rotors. [10M]**

Construction of Alternator: An alternator has 3-phase winding on the stator and a d.c. field winding on the rotor.

Stator:

- It is the stationary part of the machine and is built up of sheet-steel laminations insulated from each other having slots on its inner periphery to hold the armature windings.
- The core is laminated to reduce the eddy current losses and is made up of steel to minimize hysteresis loss.

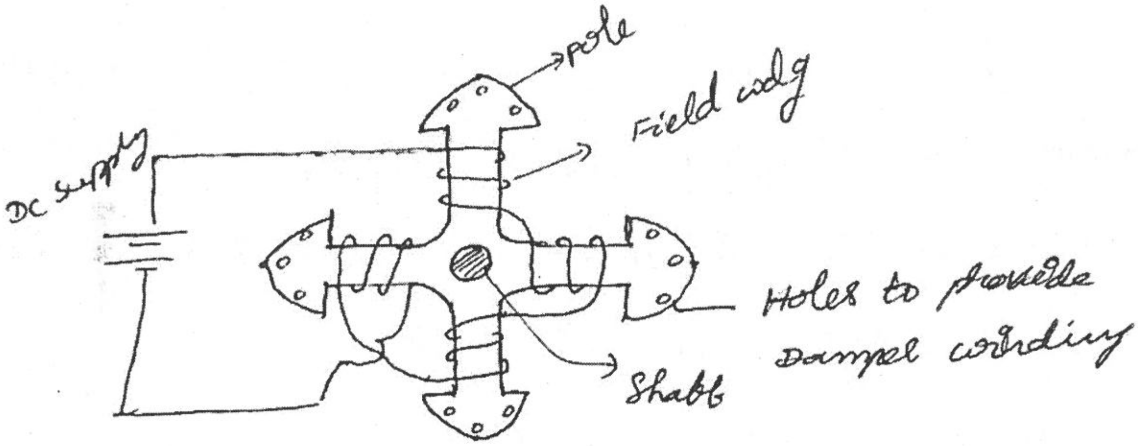
Rotor:

The rotor carries the field winding which is supplied with direct current through two slip rings by a separate d.c. source (called exciter).
Rotor construction is of two types, namely;

- (i) Salient (or projecting) pole type
- (ii) Non-salient (or cylindrical) pole type

(i) Salient (or projecting) pole type

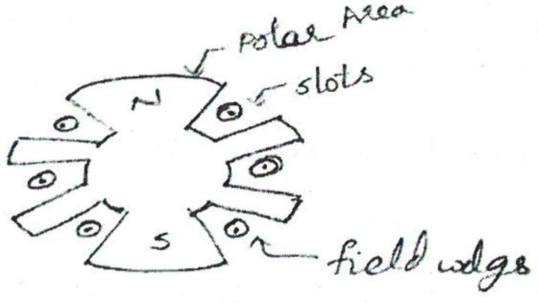
- ➢ In this type, salient or projecting poles are mounted on a large circular steel frame which is fixed to the shaft of the alternator as shown in Fig.



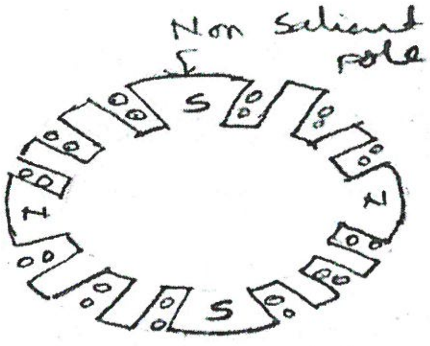
- ➢ The individual field pole windings are connected in series in such a way that when the field winding is energized by the d.c. exciter, adjacent poles have opposite polarities.
- ➢ Low and medium-speed alternators (120-400 r.p.m.) such as those driven by diesel engines or water turbines have salient pole type rotors.
- ➢ Since a frequency of 50 Hz is required, we must use a large number of poles on the rotor of slow-speed alternators. Low-speed rotors always possess a large diameter to provide the necessary space for the poles. Consequently, salient-pole type rotors have large diameters and short axial lengths.

(ii) Non-salient (or cylindrical) pole type:

- ➢ In this type, the rotor is made of smooth solid forged-steel radial cylinder having a number of slots along the outer periphery.
- ➢ The field windings are embedded in these slots and are connected in series to the slip rings through which they are energized by the d.c. exciter.
- ➢ The regions forming the poles are usually left unslotted as shown in Fig. It is clear that the poles formed are non-salient i.e., they do not project out from the rotor surface.



2 - pole



4 - pole

- High-speed alternators (1500 or 3000r.p.m.) are driven by steam turbines and use non-salient type rotors.
- Since steam turbines run at high speed and a frequency of 50Hz is required, we need a small number of poles on the rotor of high-speed alternators (also called turboalternators).
- The Cylindrical type rotors are designed for 2 poles or 4 poles turbo alternators running at 3000 r.p.m for a 2-pole machine or 1500 r.p.m. for a 4-pole machine for a frequency of 50Hz.
- The Cylindrical type rotor has small diameter and long axial length, such a construction limits the centrifugal forces.

Working principle of Synchronous generator

- The rotor winding is energized from the d.c. exciter and alternate N and S poles are developed on the rotor. When the rotor is rotated by a prime mover, the stator or armature conductors are cut by the magnetic flux of rotor poles. Consequently, e.m.f. is induced in the armature conductors due to electromagnetic induction.

9. The following data were obtained for the OCC of a 10 MVA, 13 kV, 3 Phase, 50 Hz, Y connected synchronous generator:

Field current (A)	50	75	100	125	150	162.5	200	250	300
O.C voltage (kV)	6.2	8.7	10.5	11.8	12.8	13.2	14.2	15.2	15.9

An excitation of 100 A causes the full loads current to flow during the short circuit test. The excitation required giving the rated current at zero pf and total voltage is 290 A.
(i) Calculate the adjusted synchronous reactance of the machine.
(ii) Calculate the leakage reactance of the machine assuming the resistance to be negligible. Determine the excitation required when the machine supplies full load at 0.8 pf lagging by using the leakage reactance and drawing the MMF phasor diagram. What is the voltage regulation of the machine? Also calculate the voltage regulation for this loading using the adjusted synchronous reactance. Compare and comment upon the results. **[10M]**

Solution : 10 MVA, 13 kV, 50 Hz, star connection

$$I_a(\text{rated}) = \frac{VA}{\sqrt{3}V_L} = \frac{10\times10^6}{\sqrt{3}\times13\times10^3} = 444 \text{ A}$$

a) Draw O.C.C. and S.C.C. as shown in the Fig.

Note that in graph **line values** of V_{oc} are used.

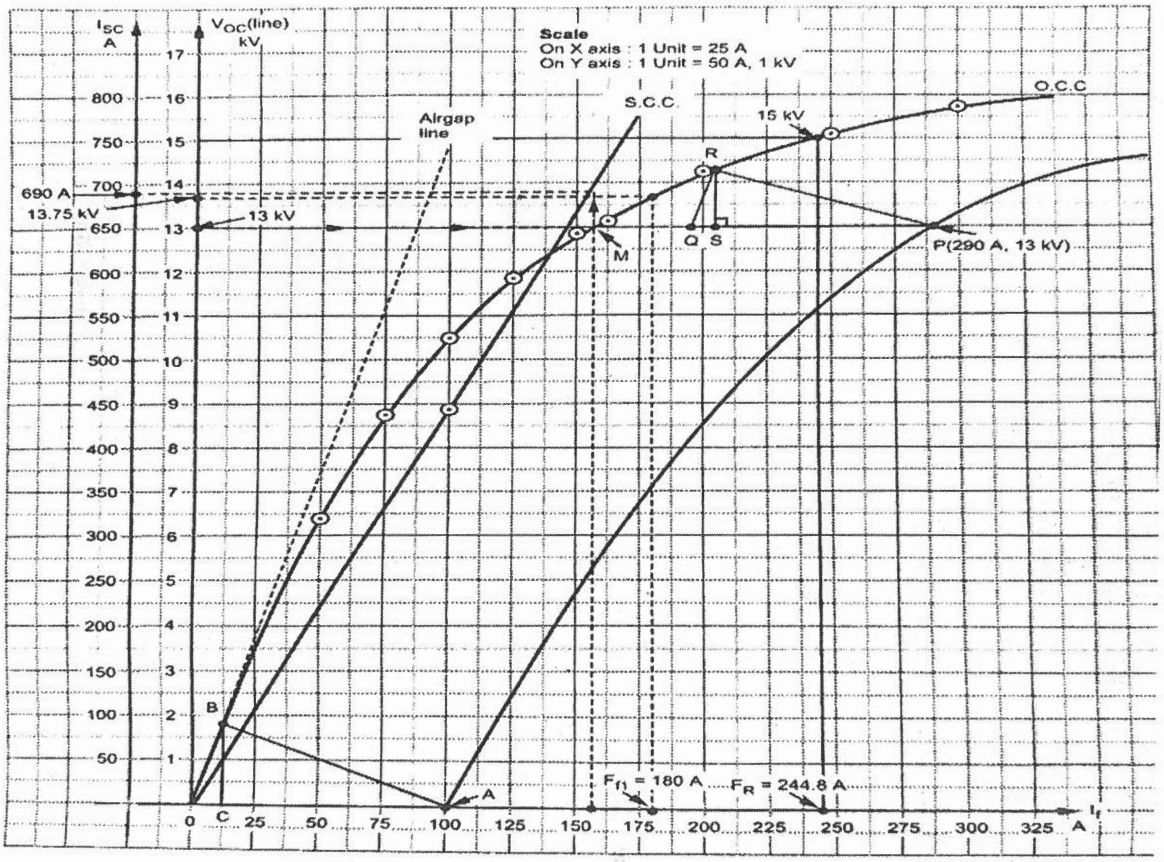
For rated voltage of 13 kV, calculate short circuit current from S.C.C. Corresponding to 13 kV on O.C.C. shown by point M, the short circuit current is I_{SC} = **690 A** from graph.

$$\therefore \quad X_S \text{ (adjusted)} = \left.\frac{V_{ph}(\text{rated})}{I_{sc}}\right|_{\substack{\text{If corresponding to} \\ \text{Vrated on O.C.C.}}}$$

$$\therefore \quad X_S = \frac{\left(\frac{13\times10^3}{\sqrt{3}}\right)}{690} = \mathbf{10.877\ \Omega}$$

b) To find the leakage reactance, the potier triangle method must be used.

Plot the O.C.C. and location of point P corresponding to ZPF at rated current. The point P is (290 A, 13 kV). This is shown in the Fig. Mark point A corresponding to I_f = 100 A for circulating rated I_{sc}. Draw line PQ = OA parallel to OA from P and locate point Q. From Q, draw line parallel to air line which intersects O.C.C. at R. Join PR. The triangle PQR is the potier triangle. Draw a line RS perpendicular from R on PQ. The length RS gives the voltage drop due to the armature leakage reactance i.e. IX_L.



$$\therefore \quad l(RS) = (I_{aph})_{FL}\, X_L$$

From graph, $l(RS) = 1.2 \text{ kV} = 1200 \text{ V}$ (line value)

$$\therefore \quad X_L = \frac{(1200/\sqrt{3})}{(I_{aph})_{FL}} = \frac{1200/\sqrt{3}}{444} = \mathbf{1.56\ \Omega}$$

c) The length PS gives I_f necessary to overcome armature reaction.

$\therefore \quad l(PS) = F_{AR} = 3.6 \text{ cm} = \mathbf{90\ A}$ ...from graph

Now $\cos\phi = 0.8$ lagging

Find E_{1ph} by adding vectorially $(I_{aph}\, X_{Lph})$ to V_{ph}.

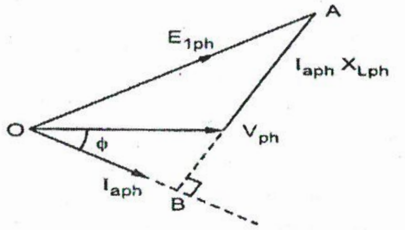


Fig. 3.61

Consider triangle OAB shown in the phasor diagram.

$$\therefore \quad E_{1ph}^2 = (V_{ph}\cos\phi)^2 + (V_{ph}\sin\phi + I_{aph}\, X_{Lph})^2$$

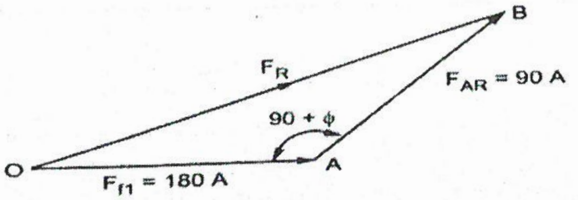
$$\therefore \quad E_{1ph}^2 = \left(\frac{13\times10^3}{\sqrt{3}}\times0.8\right)^2 + \left(\frac{13\times10^3}{\sqrt{3}}\times0.6+444\times1.56\right)^2$$

$$\therefore \quad E_{1ph} = 7940.494 \text{ V}$$

$$\therefore \quad E_1 \text{ (line)} = \sqrt{3}\times7940.494 = 13.7533 \text{ kV}$$

From graph of O.C.C., field curent corresponding to E_1(line) = 13.7533 kV is $F_{f1} = \mathbf{180\ A}$

Add vectorially F_{f1} and F_{AR} as shown in the Fig. 3.62.



Using cosine rule for the triangle OAB with

$$\phi = \cos^{-1} 0.8 = 36.86^\circ$$

$$\therefore \quad (F_R)^2 = (F_{f1})^2 + (F_{AR})^2 - 2\, F_{f1}\, F_{AR}\cos(F_{f1} \wedge F_{AR})$$

$$= (180)^2 + (90)^2 - 2\times180\times90\times\cos(90^\circ + 36.86^\circ) = 59940$$

$$\therefore \quad F_R = \mathbf{244.8\ A}$$

From O.C.C., corresponding voltage to $F_R = 244.8$ A is given by,

$E = 15$ kV (line) ...from graph

$$\therefore \quad E_{ph} = \frac{15\times10^3}{\sqrt{3}} = 8.6602 \text{ kV}$$

$$\therefore \quad \%R = \frac{E_{ph}-V_{ph}}{V_{ph}}\times100 = \frac{8.6602\times10^3 - \dfrac{13\times10^3}{\sqrt{3}}}{\dfrac{13\times10^3}{\sqrt{3}}}\times100 = \mathbf{15.38\ \%}$$

V.R at adjusted synchronous reactance

$$E_{ph}^2 = (V_{ph}\cos\phi)^2 + (V_{ph}\sin\phi + I_{aph}X_s)^2$$

$$= \left(\frac{13\times10^3}{\sqrt{3}}\times0.8\right)^2 + \left(\frac{13\times10^3}{\sqrt{3}}\times0.6 + (444)(10.877)\right)^2$$

$$= 123,094,397$$

$$E_{ph} = 11095$$

$$V.R = \frac{E_{ph}-V_{ph}}{V_{ph}}\times100 = \frac{11095-7505}{7505}\times100 = \frac{3590}{7505}\times100$$

$$= 47.8\,\%.$$

Compare and Comment upon results

⇒ The synchronous reactance method gives voltage regulation value higher than the actual value.

⇒ The Z.P.F method gives voltage regulation value approximatelly actual value.

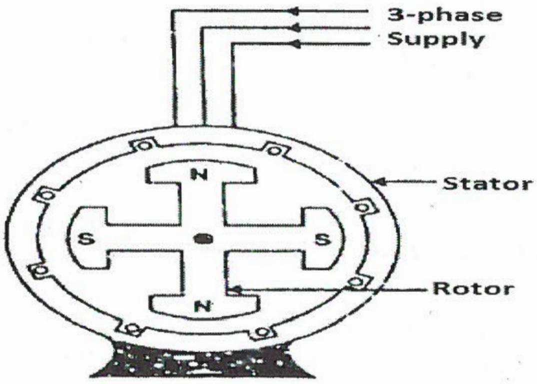
10. a) Explain the construction and working principle of Synchronous Motor. [5 M]

Construction a synchronous motor

A synchronous motor is a machine that operates at synchronous speed and converts electrical energy into mechanical energy. It is fundamentally an alternator operated as a motor. Like an alternator, a synchronous motor has the following two parts:

(i) A stator which houses 3-phase armature winding in the slots of the stator core and receives power from a 3-phase supply.

(ii) A rotor that has a set of salient poles excited by direct current to form alternate N and S poles. The exciting coils are connected in series to two slip rings and direct current is fed into the winding from an external exciter mounted on the rotor shaft.



An important drawback of a synchronous motor is that it is not self-starting and auxiliary means have to be used for starting it.

Working principle of Synchronous Motor.

(i) Consider a 3-phase synchronous motor having two rotor poles N_R and S_R. Then the stator will also be wound for two poles N_S and S_S. The motor has direct voltage applied to the rotor winding and a 3-phase voltage applied to the stator winding. The stator winding produces a rotating field which revolves round the stator at synchronous speed Ns= (120 f/P). The direct (or zero frequency) current sets up a two-pole field which is stationary so long as the rotor is not turning. Thus, we have a situation in which there exists a pair of revolving armature poles (i.e., N_S - S_S) and a pair of stationary rotor poles (i.e., N_R - S_R).

(ii) Suppose at any instant, the stator poles are at positions A and B as shown in Fig 4.2 (a). It is clear that poles N_S and N_R repel each other and so do the poles S_S and S_R. Therefore, the rotor tends to move in the anticlockwise direction. After a period of half-cycle (or ½ f = 1/100 second), the polarities of the stator poles are reversed but the polarities of the rotor poles remain the same as shown in Fig 4.2 (b). Now S_S and N_R attract each other and so do N_S and S_R. Therefore, the rotor tends to move in the clockwise direction. Since the stator poles change their polarities rapidly, they tend to pull the rotor first in one direction on and then after a period of half-cycle in the other. Due to high inertia of the rotor, the motor fails to start.

Hence, a synchronous motor has no self-starting torque i.e., a synchronous motor cannot start by itself.

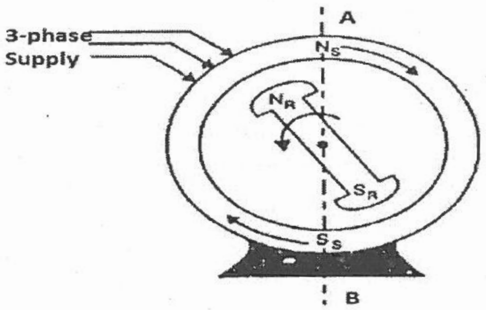


Fig: 4.2 (a)

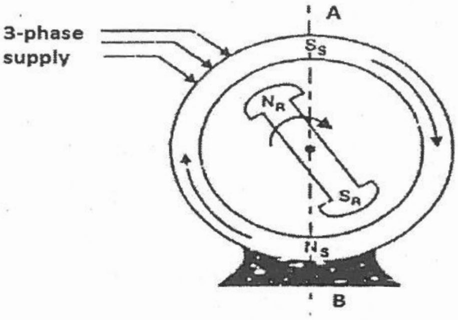


Fig: 4.2 (b)

If the rotor poles are rotated by some external means at such a speed that they interchange their positions along with the stator poles, then the rotor will experience a continuous unidirectional torque.

(i) Suppose the stator field is rotating in the clockwise direction and the rotor is also rotated clockwise by some external means at such a speed that the rotor poles interchange their positions along with the stator poles.

(ii) Suppose at any instant the stator and rotor poles are in the position shown in Fig 4.3(a). It is clear that torque on the rotor will be clockwise. After a period of half-cycle, the stator poles reverse their polarities and at the same time rotor poles also interchange their positions as shown in Fig 4.3 (b). The result is that again the torque on the rotor is clockwise. Hence a continuous unidirectional torque acts on the rotor and moves it in the clockwise direction. Under this condition, poles on the rotor always face poles of opposite polarity on the stator and a strong magnetic attraction is set up between them.

This mutual attraction locks the rotor and stator together and the rotor is virtually pulled into step with the speed of revolving flux (i.e., synchronous speed).

(iii) If now the external prime mover driving the rotor is removed, the rotor will continue to rotate at synchronous speed in the clockwise direction because the rotor poles are magnetically locked up with the stator poles. It is due to this magnetic interlocking between stator and rotor poles that a synchronous motor runs at the speed of revolving flux i.e., synchronous speed.

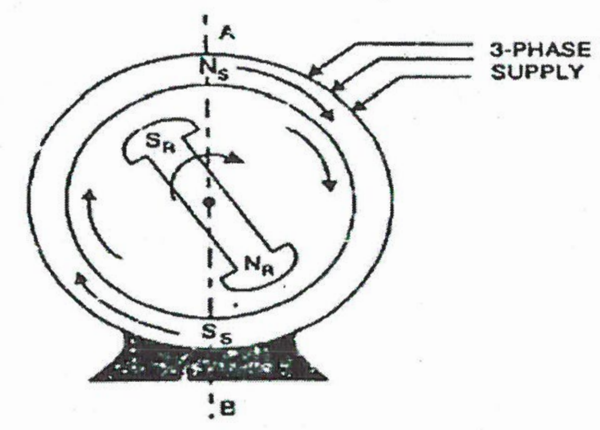


Fig: 4.3 (a)

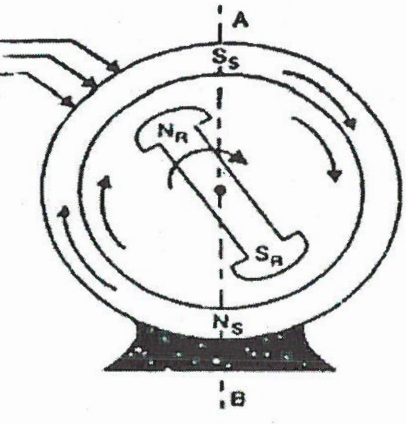


Fig: 4.3 (b)

10 b) Explain the variation of current and power factor of a synchronous motor with excitation. [5 M]

One of the most important features of a synchronous motor is that by changing the field excitation, it can be made to operate from lagging to leading power factor. Consider a synchronous motor having a fixed supply voltage and driving a constant mechanical load. Since the mechanical load as well as the speed is constant, the power input to the motor ($=3\ VI_a\cos\Phi$) is also constant. This means that the in-phase component $I_a \cos \Phi$ drawn from the supply will remain constant. If the field excitation is changed, Excitation e.m.f E_b also changes. This results in the change of phase position of I_a w.r.t. V and hence the power factor $\cos\phi$ of the motor changes. Fig. shows the phasor diagram of the synchronous motor for different values of field excitation. Note that extremities of current phasor I_a lie on the straight-line AB.

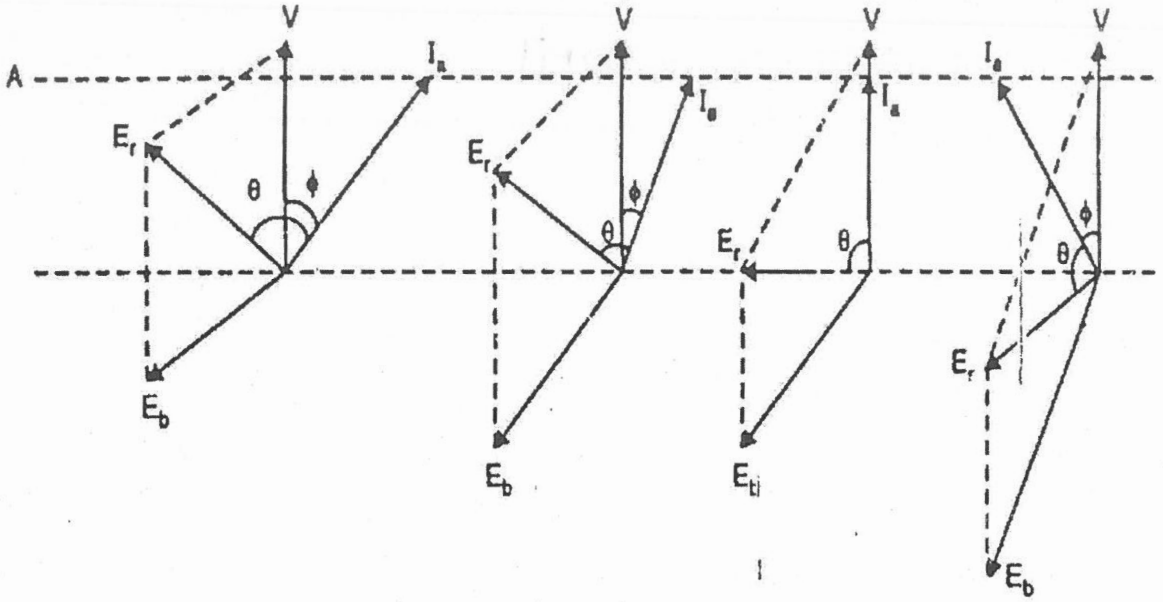
(i) Under excitation

The motor is said to be under-excited if the field excitation is such that $E_b < V$. Under such conditions, the current I_a lags behind V so that motor power factor is lagging as shown in Fig: (i). Since $E_b < V$, the net voltage E_r is decreased and turns clockwise. As angle $\theta(= 90°)$ between E_r and I_a is constant, therefore, phasor I_a also turns clockwise i.e., current I_a lags behind the supply voltage. Consequently, the motor has a lagging power factor.

(iI) Normal excitation

The motor is said to be normally excited if the field excitation is such that $E_b = V$. This is shown in Fig: (ii). Note that the effect of increasing excitation (i.e., increasing E_b) is to turn the phasor E_b and hence I_a in the anti-clockwise direction i.e., I_a phasor has come closer to phasor V. Therefore, power factor increases though still lagging. Since input power ($3\ V\ Ia \cos \Phi$) is unchanged, the stator current I_a must decrease with increase in power factor.

Suppose the field excitation is increased until the current is in phase with the applied voltage V, making the power factor of the synchronous motor unity [see Fig: (iii)]. For a given load, at unity power factor, the resultant E_r and, therefore, I_a are minimum.



$E_b < V$
Under excitation
(*i*)

$V = E_b$
Normal excitation
(*ii*)

$E_b > V$
Unity p.f.
(*iii*)

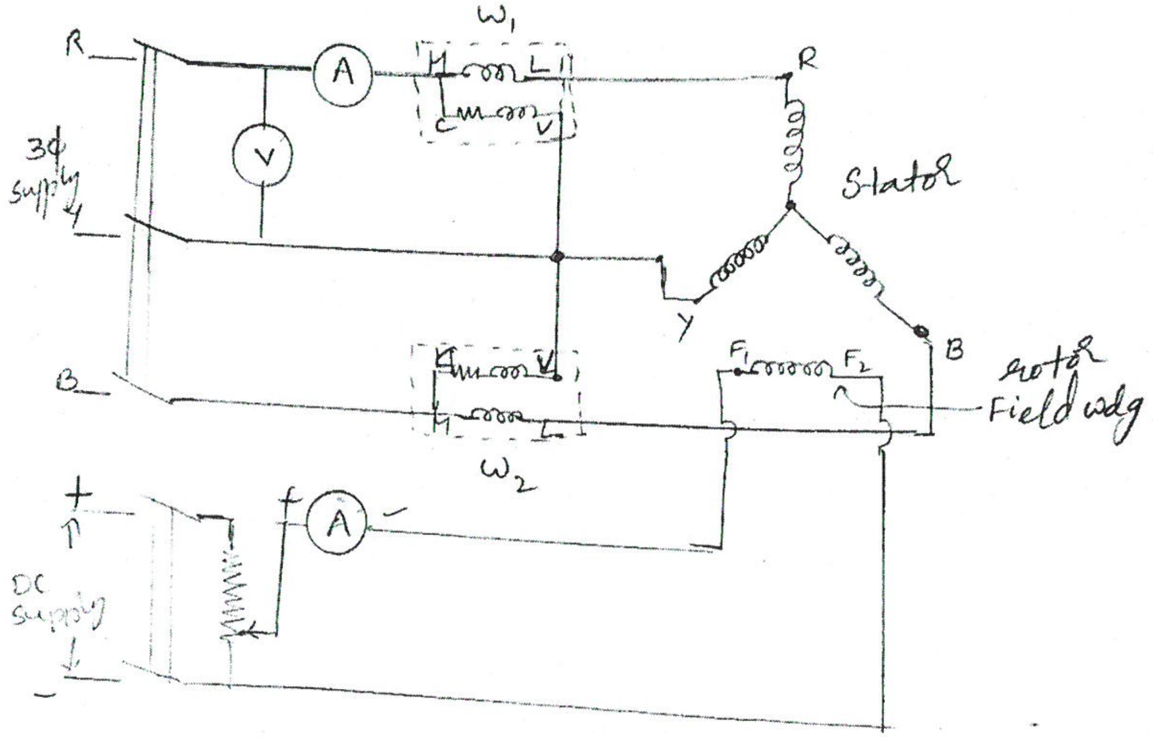
$E_b > V$
Over-excitation
(*iv*)

(iii) Over excitation

The motor is said to be overexcited if the field excitation is such that $E_b > V$. Under-such conditions, current I_a leads V and the motor power factor is leading as shown in Fig:(iv). Note that E_r and hence I_a further turn anti-clockwise from the normal excitation position. Consequently, I_a leads V.

11. **Explain the procedure for constructing 'V' curves and Inverted 'V' curves of Synchronous motor.** [10M]

Experimental setup to obtain V & Λ curves



- Fig shows an experimental setup to obtain V and inverted V [Λ] curves of synchronous motor.

- Stator is connected to 3φ supply through wattmeter and ammeter. the two wattmeter method is used to measure input power of motor.

- The ammeter is reading line current which is same as armature current.

- A rheostat in a potential divider arrangement is used in the field circuit.

- By controlling the voltage by rheostat, the field current can be changed. Hence motor can be subjected to variable excitation condition to note down the readings.

observation table :-

S. No.	I_L	I_f	ω_1	ω_2	$\cos\phi$ (P.f)

→ The power factor can be obtained as

$$\cos\phi = \cos\left\{\tan^{-1}\left[\frac{\sqrt{3}(\omega_1-\omega_2)}{\omega_1+\omega_2}\right]\right\}$$

- The graph can be plotted from this ~~result~~ observation table.
  - → I_a Vs I_f → V curve
  - → $\cos\phi$ Vs I_f → Inverted V-curve.
- The entire procedure can be repeated for various load conditions to obtain family of V-curves and Inverted V curves.

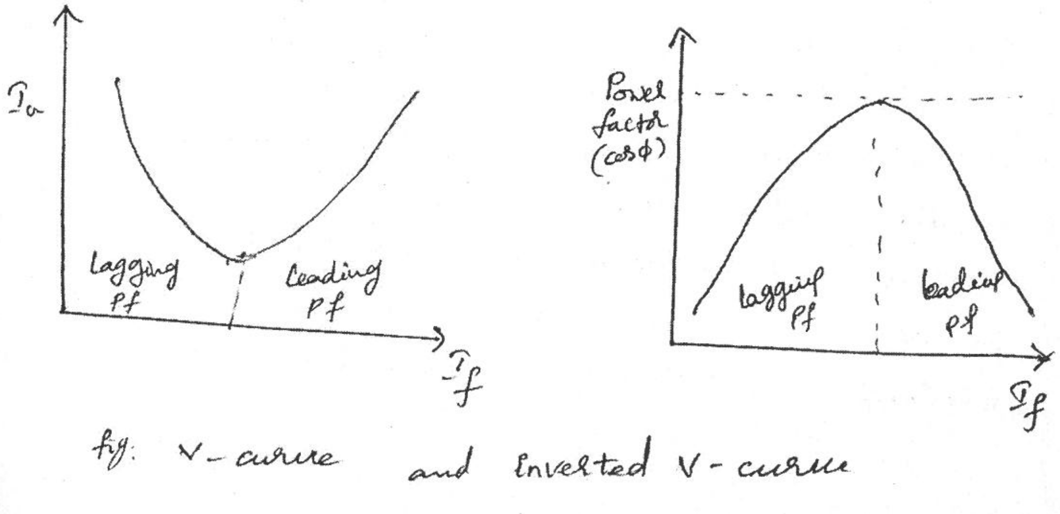


fig: V-curve and Inverted V-curve