Synchronous motor

Unit II

Introduction

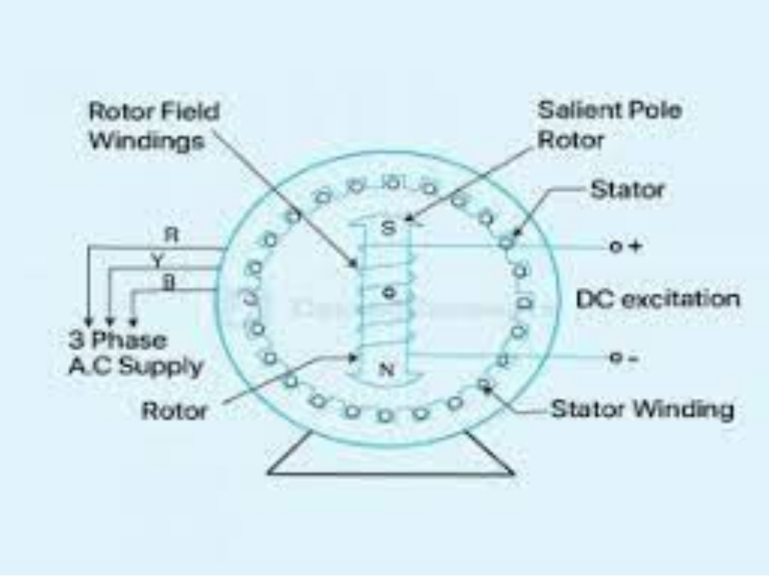
- Synchronous motors are widely used in the industry for high-precision applications. This motor runs at constant speed and it does not depend on the torque acting on it. So it has a constant-speed torque characteristic. The efficiency of synchronous motor is around 90%–93%
- Synchronous motor is a doubly fed motor
- three-phase power is given to the stator while the rotor is fed from a DC source for excitation of the field winding

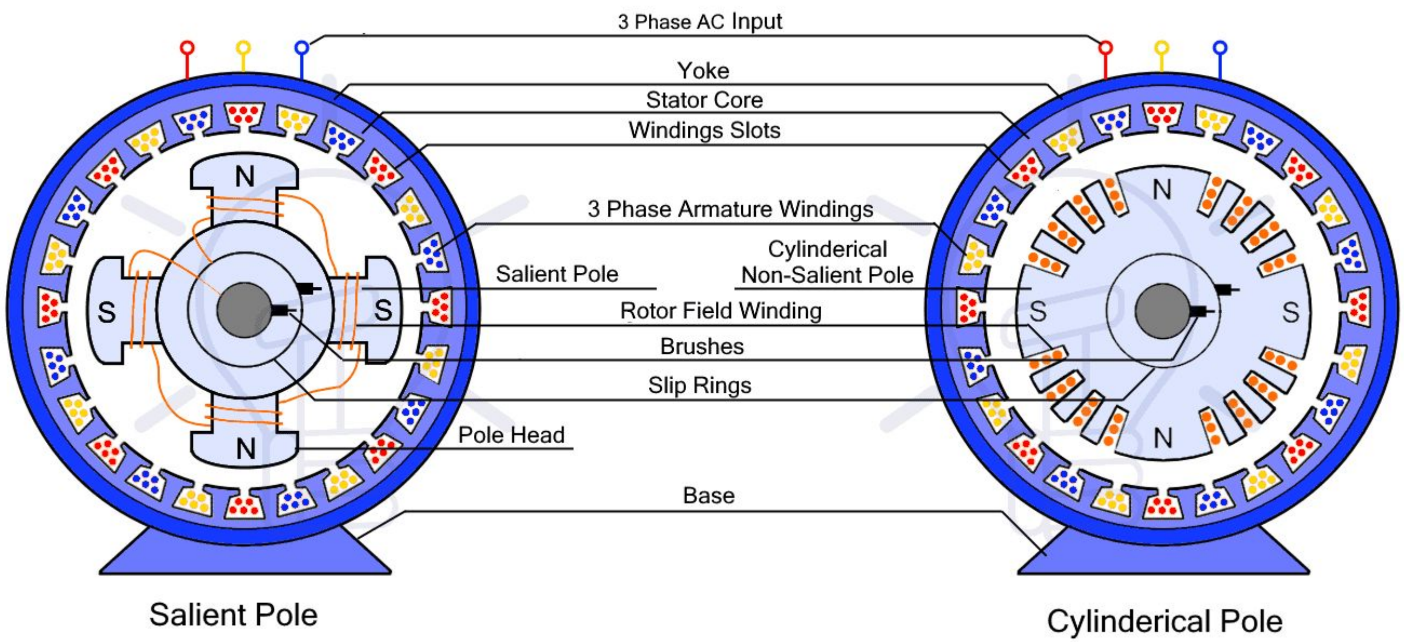
Construction

- There is no constructional difference between synchronous motor and synchronous generator
- The stator has a laminated core with slots to hold the three-phase windings.

• Rotor holds the field winding. The rotor can be of salient-pole type or cylindrical type.

• Synchronous motor is likely to hunt and so damper windings are also provided in the rotor poles.





Construction of Synchronous Motor

Principle of operation

- When a three phase-supply is given to the stator of the synchronous motor, it produces a rotating magnetic flux of constant magnitude, rotating at synchronous speed.

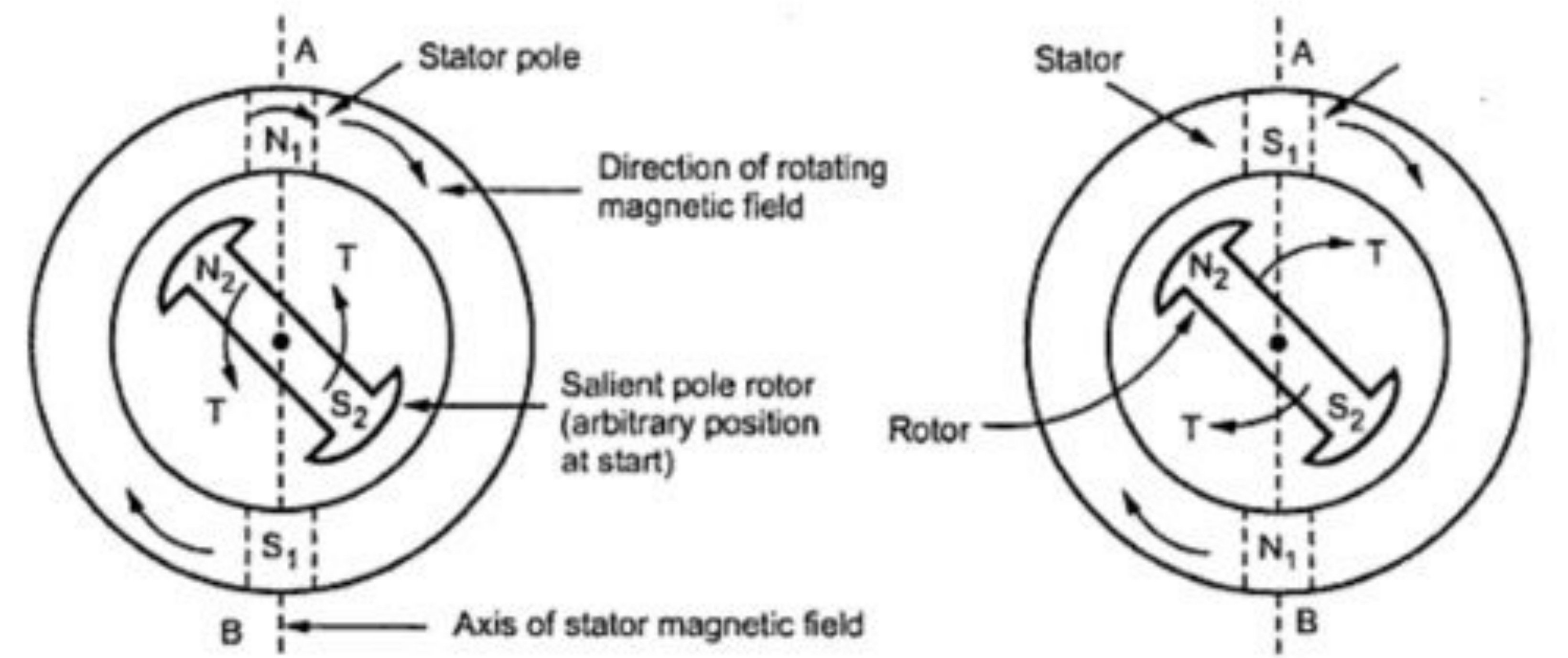
•DC supply on the rotor will also produce a flux of constant magnitude.

• A three phase synchronous motor is not self-starting.

• If the rotor of the synchronous motor is rotated by some external means at the start.

- there will be a continuous force of attraction between the stator and the rotor.
- This is called magnetic locking.

• Once this stage is reached, the rotor pole is dragged by the revolving stator field and thus the rotor will continue to rotate


A
Stator pole
N1
Direction of rotating
magnetic field
N2
T
T
S2
Salient pole rotor
(arbitrary position
at start)
S1
B
Axis of stator magnetic field
Stator
A
S1
N2
T
Rotor
T
S2
N1
B

- https://youtu.be/JC73hjt6Plw

STARTING METHODS FOR SYNCHRONOUS MOTOR

- The different methods that are generally followed to start the synchronous motor are
- i) By using a pony motor (Small induction motor)
- ii) By using a damper winding
- iii) By using DC motor
- iv) Starting as an induction motor

starting methods….

- By using a pony motor (Small induction motor)
- It could be either 3 phase induction motor or DC shunt motor
- In this method, the rotor of the synchronous motor is brought to its synchronous speed with the help of an external induction motor. This external motor is called the pony motor.
- No DC excitation applied initially.
- It rotates at speed very close to its synchronous speed, and then we give the DC excitation.
- After some time when magnetic locking takes place supply to the external motor is cut off.
- Since the load is not connected to the synchronous motor before synchronizing, the starter motor has to overcome the inertia of synchronous motor at no load.
- The rating of the starter motor is much smaller than the rating of synchronous motor

Starting methods-By using a damper winding

- The motor is equipped with a squirrel case winding, to start it as an induction motor.
- The damper windings are provided on the pole face slots in the fields of rotor.
- These windings are short-circuited at both ends with the help of end rings, thus forming a squirrel-cage system.
- When the synchronous motor is started as a slip-ring induction motor, the three ends of the windings are connected to an external resistance in series through slip-rings.
- Initially, when the rotor is not rotating, the relative speed between damper winding and rotating air gap flux is large and an emf is induced in it which produces the required starting torque.
- Now, when a three-phase supply is given to the stator of a synchronous motor, it will start as a three-phase induction motor.
- The motor accelerates until it reaches slightly below synchronous speed.
- As the motor approaches synchronous speed, the DC excitation is applied to the field windings.
- As speed approaches synchronous speed, emf and torque are reduced and finally when magnetic locking takes place; torque also reduces to zero.

POWER ANGLE OF SYNCHRONOUS MOTOR

- The synchronous motor rotates at synchronous speed. But increase in shaft load causes the rotor magnet to change its angular position with respect to the rotating flux of the stator by an electrical angle δ. This angle is called the power angle or load angle or torque angle.

Hunting in Synchronous Motor

- At no-load, the magnetic axis of the stator and rotor coincides as the load angle $\delta = 0$.
- However, when the motor is loaded, the rotor axis lags the stator axis by an angle δ.
- If the load is suddenly changed, the rotor will not immediately attain its equilibrium position but pass beyond it producing more torque than required.
- The rotor will now swing in the opposite direction to reduce the load angle.
- This periodic swing of the rotor to either side before stopping at the equilibrium position is called Hunting of the rotor.

Causes of Hunting in Synchronous Motor

- 1. Sudden change in load
- 2. Sudden change in field current
- 3. A load containing harmonic torque
- 4. Fault in supply system.

Effects of Hunting in Synchronous Motor

- 1. It may lead to loss of synchronism.
- 2. It produces mechanical stresses.
- 3. Increases machine loss and causes temperature rise.
- 4. Causes greater surges in current and power flow

Reduction of Hunting in Synchronous Motor

- i) By using damper winding:

  Damper winding damps out hunting by producing torque opposite to slip of rotor. The magnitude of damping torque is proportional to the slip speed.

- ii) By using Flywheels:

  By providing large and heavy flywheel to the prime mover, its inertia can be increased, which in turn, helps in maintaining the rotor speed constant.

Effect of Increased Load with Constant Excitation

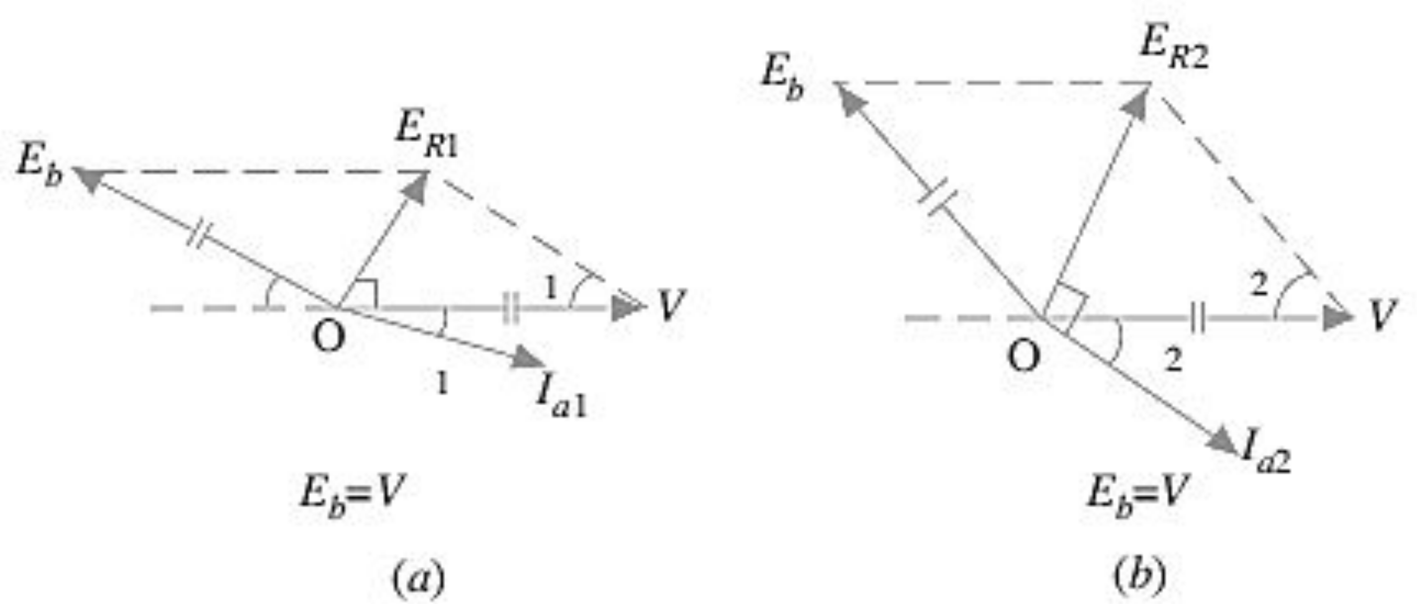


Fig 1: Normal Excitation

- With normal excitation, $E_b = V$,
- with under excitation, $E_b < V$ and
- with over-excitation, $E_b > V$.
- Whatever the value of excitation, it would be kept constant during our discussion. It would also be assumed that Ra is negligible as compared to X_S so that phase angle between E_R and I_a i.e., $\theta = 90^0$.

Normal Excitation

- Fig. 1. (a) shows the condition when motor is running with light load so that (i) torque angle α_1 is small (ii) so E_{R1} is small (iii) hence I_{a1} is small and (iv) φ_1 is small so that cos φ_1 is large.
- Now, suppose that load on the motor is increased as shown in Fig. 1 (b). For meeting this extra load, motor must develop more torque by drawing more armature current. Unlike a d.c. motor, a synchronous motor cannot increase its I_a by decreasing its speed and hence E_b because both are constant in its case.

- 1. Rotor falls back in phase i.e., load angle increases to α_2 as shown in Fig. 1 (b),
- 2. The resultant voltage in armature is increased considerably to new value E_{R2},
- 3. as a result, I_{a1} increases to I_{a2}, thereby increasing the torque developed by the motor,
- 4. φ_1 increases to φ_2, so that power factor decreases from cos φ_1 to the new value cos φ_2. Since increase in I_a is much greater than the slight decrease in power factor, the torque developed by the motor is increased (on the whole) to a new value sufficient to meet the extra load put on the motor. It will be seen that essentially it is by increasing its Ia that the motor is able to carry the extra load put on it.

- A phase summary of the effect of increased load on a synchronous motor at normal excitation is shown in Fig. 2 (a) It is seen that there is a comparatively much greater increase in I_a than in φ

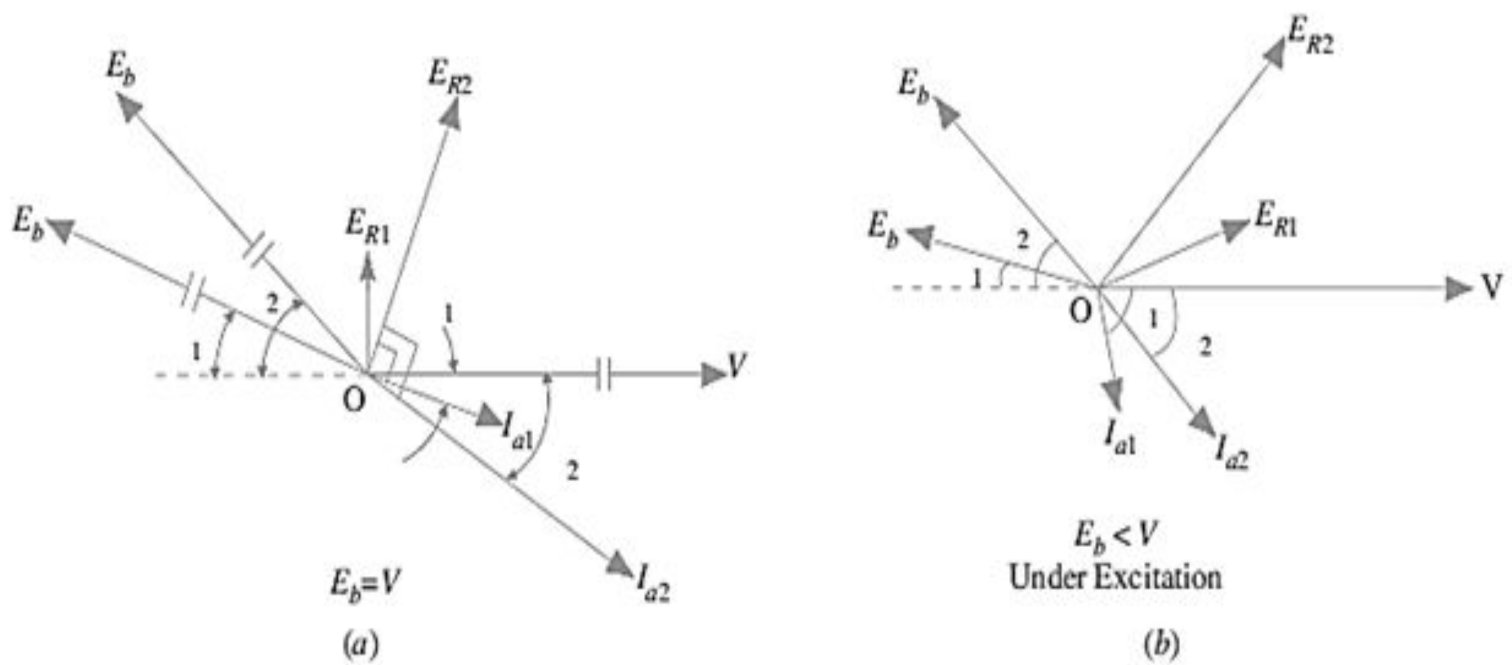
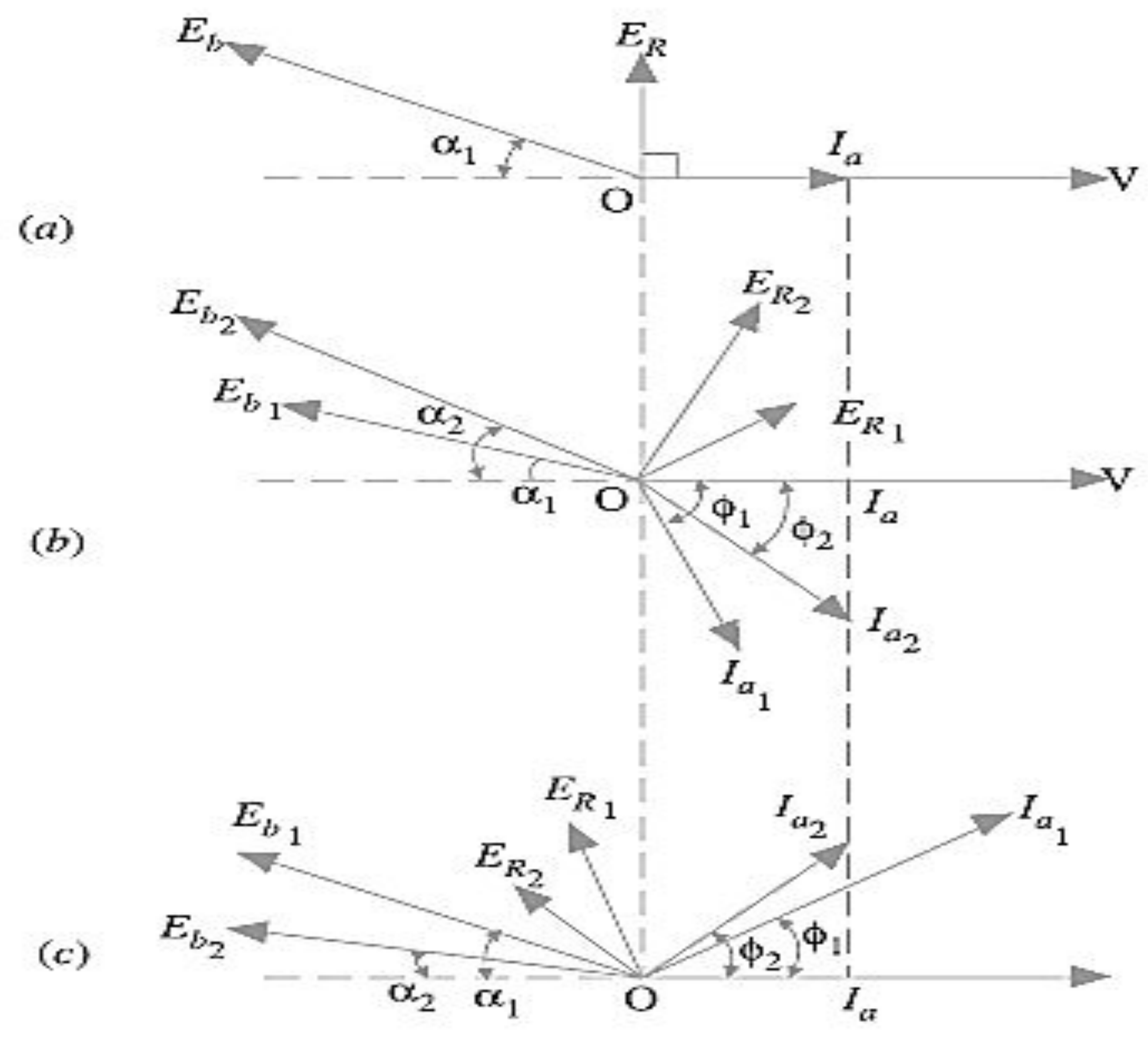


Fig: 2 Phasor Diagram normal excitation & under excitation

Effect of Changing Excitation on Constant Load



- As shown in Fig. (a), suppose a synchronous motor is operating with normal excitation ($E_b = V$) at unity p.f. with a given load.
- If R_a is negligible as compared to X_S, then I_a lags E_R by 90º and is in phase with V because p.f. is unity.
- The armature is drawing a power of $V.I_a$ per phase which is enough to meet the mechanical load on the motor.
- Now, let us discuss the effect of decreasing or increasing the field excitation when the load applied to the motor remains constant.

(a) Excitation Decreased

- As shown in Fig. (b), suppose due to decrease in excitation, back e.m.f. is reduced to Eb1 at the same load angle α_1.
- The resultant voltage E_{R1} causes a lagging armature current Ia1 to flow.
- Even though I_{a1} is larger than Ia in magnitude it is incapable of producing necessary power VIa for carrying the constant load because I_{a1} cos φ_1 component is less than I_a
- Hence, it becomes necessary for load angle to increase from α_1 to α_2.
- It increases back e.m.f. from E_{b1} to E_{b2} which, in turn, increases resultant voltage from E_{R1} to E_{R2}.
- Consequently, armature current increases to I_{a2} whose in-phase component produces enough power (VI_{a2} cos φ_2) to meet the constant load on the motor.

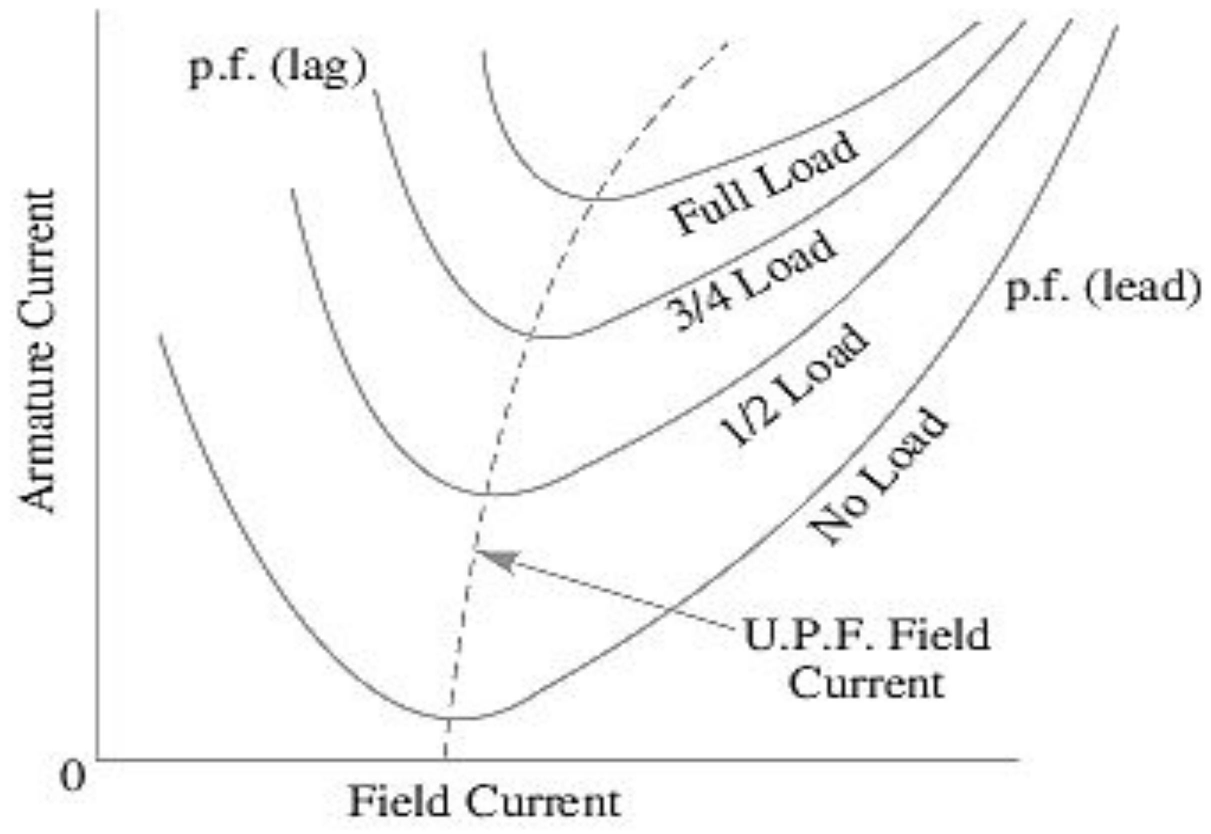
(b) Excitation Increased

- The effect of increasing field excitation is shown in Fig. (c)
- where increased E_{b1} is shown at the original load angle α_1.
- The resultant voltage E_{R1} causes a leading current I_{a1} whose in-phase component is larger than I_a.
- Hence, armature develops more power than the load on the motor.
- Accordingly, load angle decreases from α_1 to α_2 which decreases resultant voltage from E_{R1} to E_{R2}.
- Consequently, armature current decreases from I_{a1} to I_{a2} whose in-phase component $I_{a2} \cos \varphi_2 = I_a$.
- In that case, armature develops power sufficient to carry the constant load on the motor.
- Hence, we find that variations in the excitation of a synchronous motor running with a given load produce variations in its load angle only.

- From the above discussion, it is concluded that
- if the synchronous motor is under-excited, it has a lagging power factor.
- As the excitation is increased, the power factor improves till it becomes unity at normal excitation.
- Under such conditions, the current drawn from the supply is minimum.
- If the excitation is further increased (i.e., over excitation), the motor power factor becomes leading.
- Note. The armature current (Ia) is minimum at unity p.f and increases as the power factor becomes poor, either leading or lagging.

'V' Curves in Synchronous motor

- It is clear from above discussion that if excitation is varied from very low (under excitation) to very high (over excitation) value, then current Ia decreases, becomes minimum at unity p.f. and then again increases. But initial lagging current becomes unity and then becomes leading in nature.
- The V-curves of a synchronous motor show how armature current varies with its field current when motor input is kept constant. These are obtained by plotting a.c. armature current against d.c. field current while motor input is kept constant and are so called because of their shape (Fig. 1).


p.f. (lag)
Armature Current
Full Load
3/4 Load
1/2 Load
No Load
p.f. (lead)
U.P.F. Field
Current
0
Field Current

Inverted 'V' Curves

- As against this, if the power factor (cos ϕ) is plotted against field current (If), then the shape of the graph looks like an inverted V. Such curves obtained by plotting p.f. against If, at various load conditions are called Inverted V-curves of synchronous motor.