MODULE III
Synchronous Motor

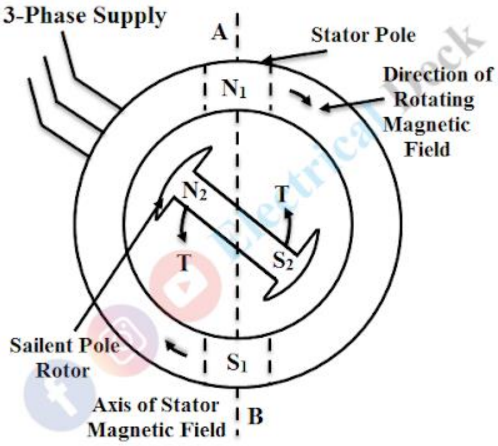
- It is a constant speed motor
- Can be operated under lagging ,leading, and unity power factor
- Not self starting
- Need both AC and DC supply
- Also called double excitation motor
- Runs either at synchronous speed or not at all

Construction of synchronous motor

There is no constructional difference between synchronous motor and alternator. In synchronous motor salient pole rotor is used.

Working of synchronous motor

- When three phase supply is applied to stator, a rotating magnetic field produced.
- The speed of rotating magnetic field is called synchronous speed (Ns)
- Consider a 2 pole synchronous motor,



N1 & S1 – North and South pole of stator

N2 & S2 - North and South pole of rotor

Fig 1

- When N1 and N2 are at position A and S1 and S2 at position B. They repel each other
- Rotor tries to rotate in anticlockwise direction.

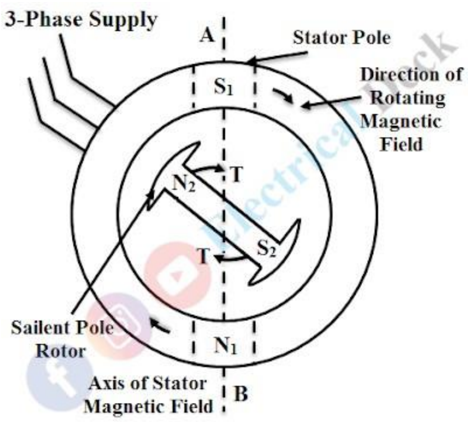


Fig 2

- In fig 2, stator pole position changed.
- N1 is at position B and S1 is at A
- N1 attracts S2 and S1 attracts N2
- Rotor tries to rotate in clockwise direction.
- So torque is not unidirectional
- Due to large inertia of rotor, it does not respond quickly with the change in torque.
- Therefore, synchronous motor is not self-starting.
- When rotor is rotated to synchronous speed by external starting methods, rotor and stator poles magnetically locked and continue to run in synchronous speed.

Starting methods of synchronous motor

1.Using Pony Motor

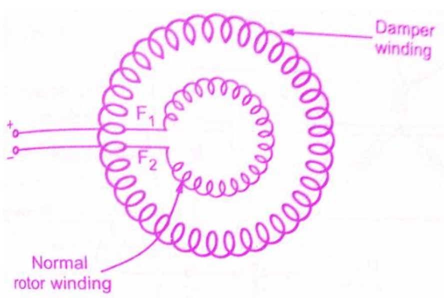
- A small induction motor is called pony motor.
- Pony motor is coupled to the synchronous motor which bring the rotor of synchronous motor to synchronous speed.
- Then switch on DC supply to rotor
- Rotor pole lock with rotating magnetic field and rotates in synchronous speed
- Once rotor attains synchronous speed, pony motor can be decoupled.

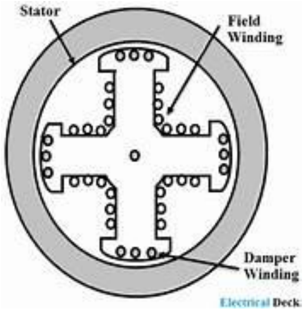
2. Using small DC machine

- A dc machine is coupled to the synchronous motor
- The DC machine works as a dc motor initially and bring the synchronous motor in to synchronous speed.
- When achieve Ns, DC machine works as a dc generator and supply dc to the rotor of synchronous motor.

3.Using Damper winding

- Damper winding consists of low resistance copper bars
- Damper windings are short-circuited at the ends and form as a squirrel cage winding.
- It is placed in the pole faces of salient poles
- When three phase supply is applied, rotating magnetic field is produced which induce current in the damper winding
- And the motor starts as a squirrel cage induction motor.
- When motor approaches synchronous speed dc supply is given to rotor
- Rotor poles and stator poles interlocked and motor runs at synchronous speed
- When motor is running at synchronous speed, there is no emf induced in damper winding





Hunting in synchronous motor

- The phenomenon is oscillation of the rotor about its equilibrium or steady state position in synhronous machine is called hunting
- When the motor is running at a particular load with load angle δ_1 , If load changed δ_2 also changed.
- But due to the inertia of rotor it can not move smoothly to new δ_2 angle position
- Thus rotor oscillates about new load angle position δ_2. This is called hunting.

Causes of hunting

- Sudden change in load
- Sudden change in excitation
- When fault occur in system

Effects of hunting

- Lead to loss of synchronism
- Large mechanical stress may develop in rotor shaft.
- Losses and temperature increases

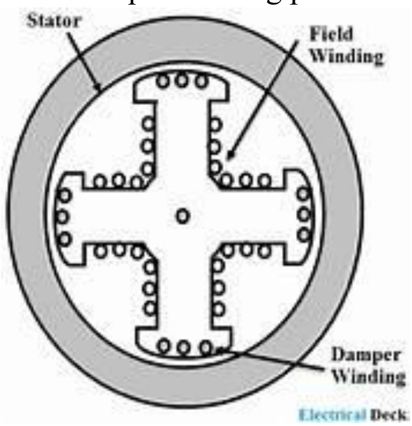
Methods to eliminate hunting.

a. **Using flywheels**

- Prime mover provided with large and heavy flywheel
- It increases inertia of prime mover and maintains rotor speed constant

b. **Using damper winding**

- Damper winding consists of low resistance copper bar
- Damper windings are short-circuited at the ends and form as a squirrel cage winding.
- When 3 phase supply is given to stator, rotating flux cuts damper winding and an emf is induced
- This emf opposes the oscillation of rotor
- Thus damper winding prevents hunting.



Different torques in synchronous motor

1. **Starting torque**
   Torque produced at the time of starting of synchronous motor is called starting torque
2. **Running torque**
   Torque produced at running condition of synchronous motor is called starting torque
3. **Pull in torque**
   The amount of torque required for synchronous motor to pull into synchronism.
   Synchronism is achieved by rotating the rotor in same of stator speed or synchronous speed.
4. **Pull out torque**
   It is the maximum torque developed by the synchronous motor with out pulling out of synchronism.
   Pull out torque is also called breakdown torque
   Its value is 1.5 to 3 times the full load torque.

Effect of load on synchronous motor

(a) **Change in load with constant excitation**

We know that V = Eb + Ia Zs

Where V = Applied voltage to motor , Eb = Back emf

Ia= Armature current, Zs= Synchronous impedance

Case 1

When motor is on no load and assume no losses (ideal case)

- Here V=Eb
- So Ia=0
- δ = 0

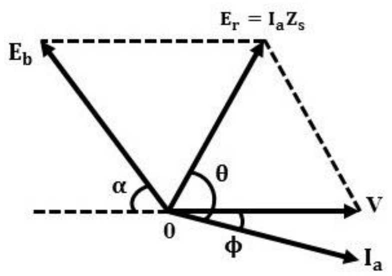
Case 2 : When motor is on load (Practical case)

- There is losses in practical case.
- Eb falls back by angle δ ,called load angle
- Ia ,δ are not equal to zero and V ≠ Eb

Case 3 : When motor is on load

- When motor is loaded, the rotor pole tends fall back by angle. Hence Eb also falls back by δ

- That is when motor loaded δ also changes
- Eb depends on field excitation.
- δ can vary upto 90 degree
- . If motor loaded beyond 90 degrees motor will pull out of synchronism.

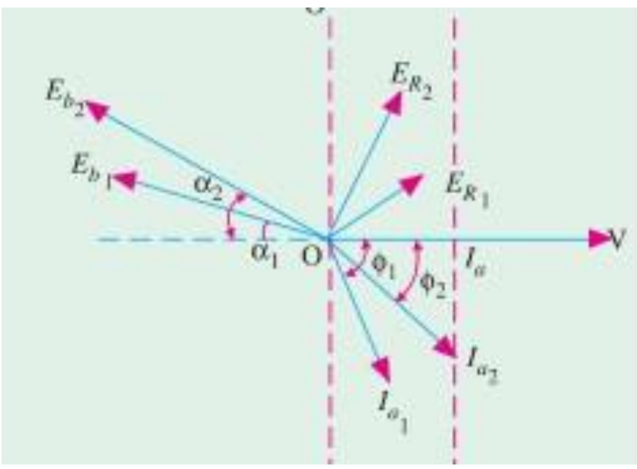


Change in excitation with constant load

- By changing the field excitation of synchronous motor it can operate from lagging to leading power factor
- By keeping load constant, input supply voltage is constant, power input to the motor √3 VI Cos ϕ also constant

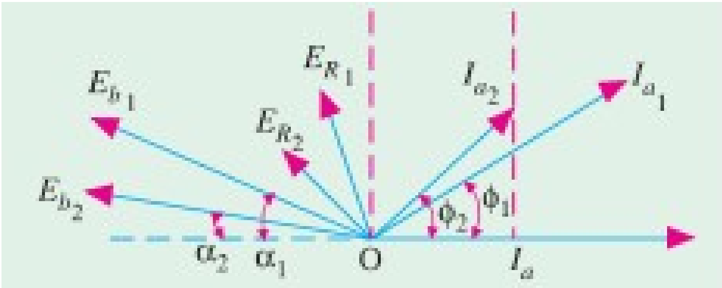
(a)When Excitation decreased

- When excitation is decrease, Back emf is reduced
- The resultant voltage ER1 causes a lagging current flow
- If load angle is increased to α2 , back emf also changed to Eb2 and resultant voltage to ER2
- So armature current increased to Ia2 to meet the constant load

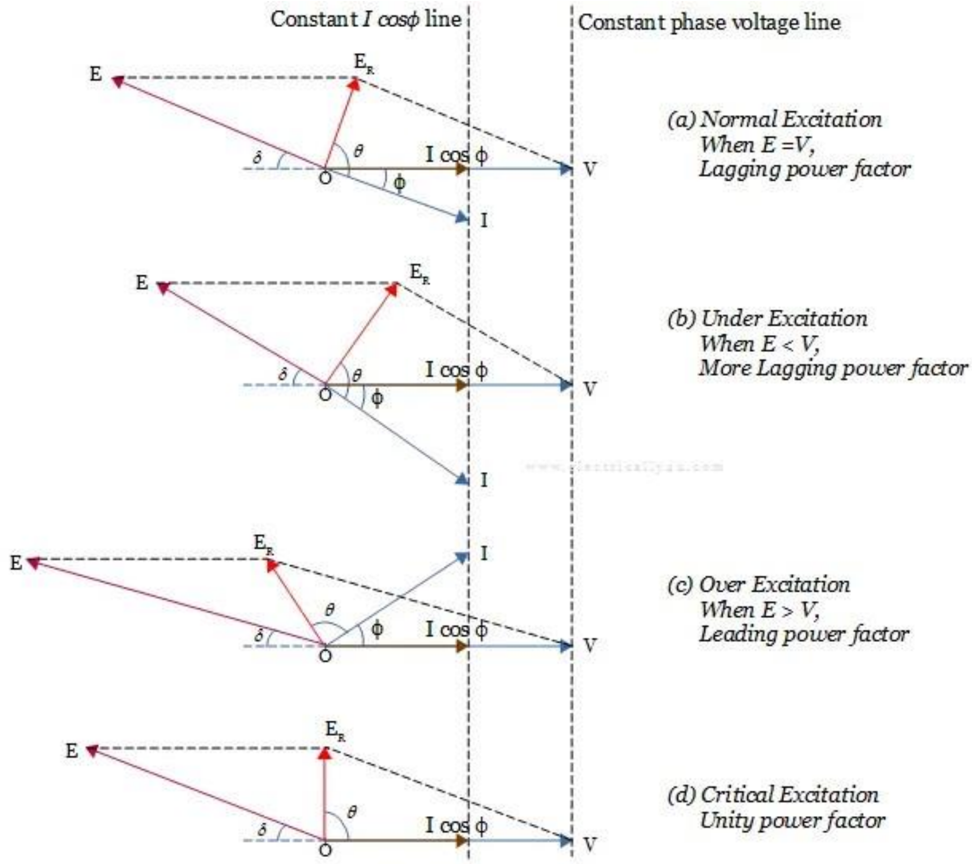


(b) When excitation increases

- When excitation increase back emf increases
- The resultant current causes a leading current flow
- If load angle is decreased from α1 to α2 , back emf also changed to Eb2 and resultant voltage to ER2
- So armature current decreased to Ia2 to meet the constant load



<u>Effect of change in excitation on armature current and power factor</u>



(a) **Normal Excitation**

- Here Eb = V.
- E_R - vector difference Eb of & V.
- The armature current I lags behind $E_R$by an angle θ .
- Now the armature current I will lag behind input voltage V by a small angle ϕ .
- Motor runs on lagging power factor.

(b) **Under excitation**

- Here Back emf Eb < applied V.

- E_R- vector difference of Eb & V.
- The armature current I lags behind E_R by an angle θ
- The armature current I will more lag behind input voltage V by a small angle ϕ .
- Here the motor runs on more lagging pf.

(C) Over excitation

- Here Eb > V.
- E_R - vector difference Eb of & V.
- The armature current I lags behind E_R by an angle θ.
- The armature current I will lead input voltage V by small angle ϕ
- Motor runs on leading power factor.

(d)Critical excitation

- Eb is slightly higher than V
- Here Armature current I and V are in phase
- Angle between E_R and V is 90 degree
- Motor runs on unity power factor.

Power developed by synchronous motor

Power developed by synchronous motor

$$P_m = \frac{E_b V}{X_s}\cos(90-\alpha) - \frac{E_b^2}{X_s}\cos 90^0$$

$$P_m = \frac{E_b V}{X_s}\sin\alpha$$

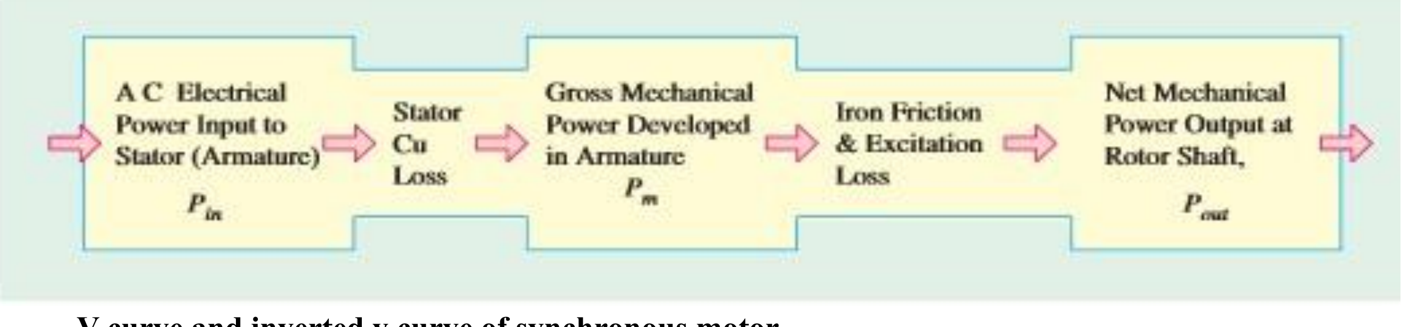
Eb – Back emf

V- Applied voltage

Xs – Synchronous reactance

α – load angle

Power flow diagram of synchronous motor

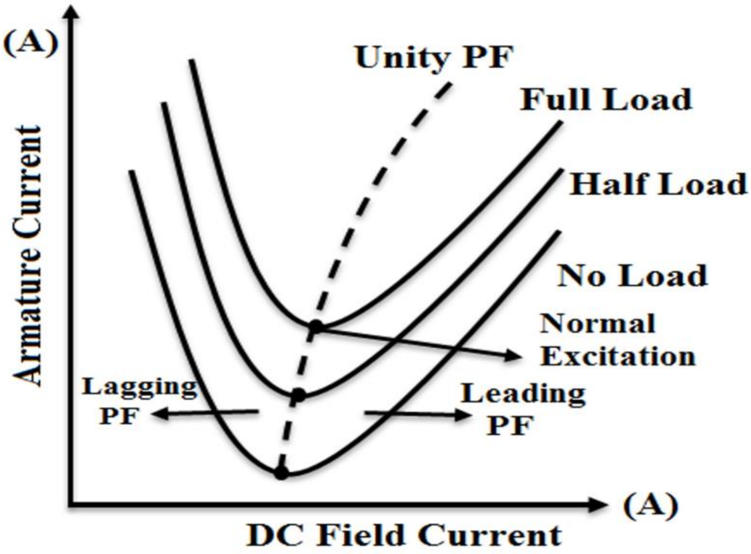


V curve and inverted v curve of synchronous motor

V curve

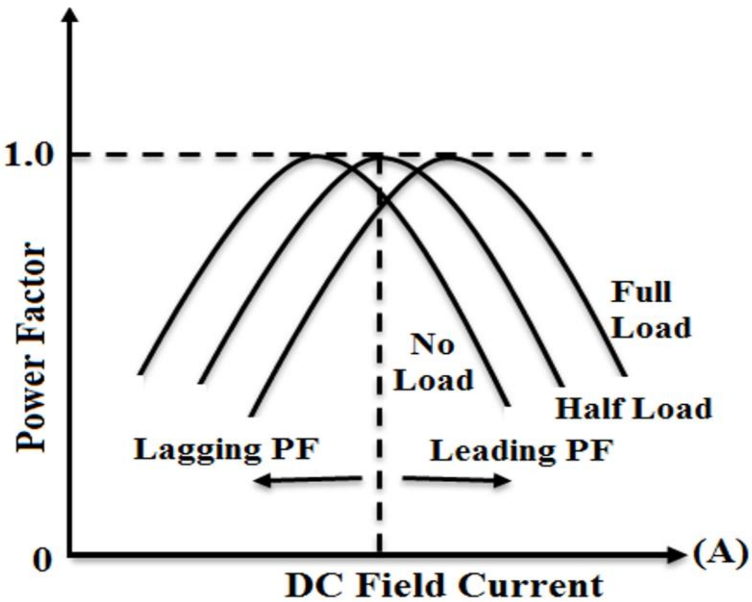
- V curve is a plot of the armature current versus field current for different constant loads.
- The shape of these curves is similar to the letter "V", they are called V curve of synchronous motors.
- Assume the motor is running at constant load.
- If the field current is increased from small value, the armature current decreases until the minimum value where motor operates at UPF

- In this region, the motor operates at a lagging power factor.
- If the field current is increased further, the armature current increases and the motor starts operating at the leading power factor



Inverted V curve

- **Inverted V curve** is a plot of power factor versus field current for different constant loads.
- The shape of these curves is similar to the letter "inverted V" they are called inverted V curve of synchronous motor
- The motor is running at constant load.
- If the field current is increased from small value, the power factor changes from lagging to unity power factor.
- If the field current is increased further, the power factor reduces and the motor starts operating at leading power factor.

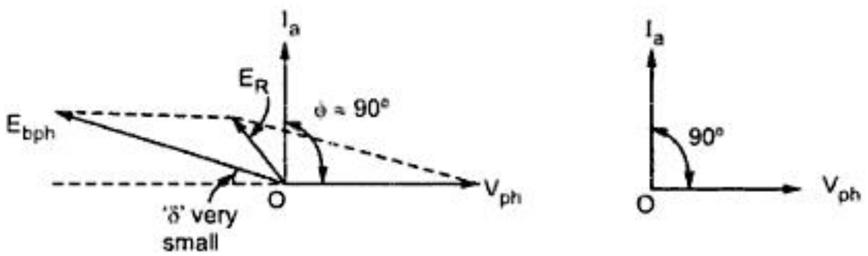


Comparison between synchronous and induction motor

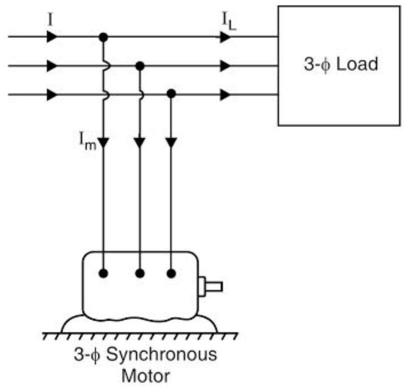
Basic difference	**Synchronous Motor**	**Induction motor**
Type of excitation	Double excitation motor	Single excitation motor
Supply	Stator winding is supplied with AC and field winding is suppled with DC	Stator winding is supplied with AC
Speed	Runs at synchronous speed	Always runs less than synchronous speed
Starting	Not self starting	Self starting
Operation	Can be operated from lagging to leading power factor by changing excitation	Operated at only lagging power factor
Efficiency	More efficient than induction motor of the same output & voltage rating	Efficiency is less than that of the synchronous motor of the same output & voltage rating
Cost	Higher than induction motor	Less than synchronous motor

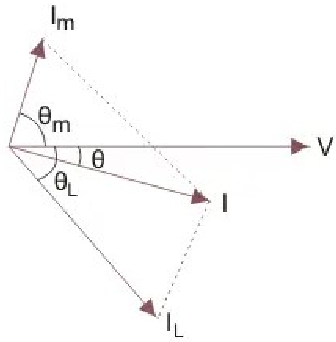
Synchronous condensers

- An over excited synchronous motor that runs on no load is called synchronous condensers.
- It draws leading current
- Used for power factor improvement.
- If this motor is on no load condition, where load angle ‘δ’ is small & Eb > V
- The PF angle will increase nearly to 90 degrees.
- So, this motor runs with approximately zero leading PF condition



- Consider a power system where loads are lagging nature (ie, more no of induction motors are used).
- If we are connecting a synchronous condenser to this system, it takes leading current Im by an angle θm.
- I is the resultant current
- Power factor of the system is improved.





Applications of synchronous motor

- Used in power houses and substations to improve the power factor.
- It can be used as a frequency changer
- Used to improve voltage regulation of transmission lines.
- synchronous motors (above 600 r.p.m.)are suited for loads where constant speed is required such as centrifugal pumps, belt-driven reciprocating compressors, blowers, line shafts, rubber and paper mills etc.
- Used in robotics actuators, ball mills