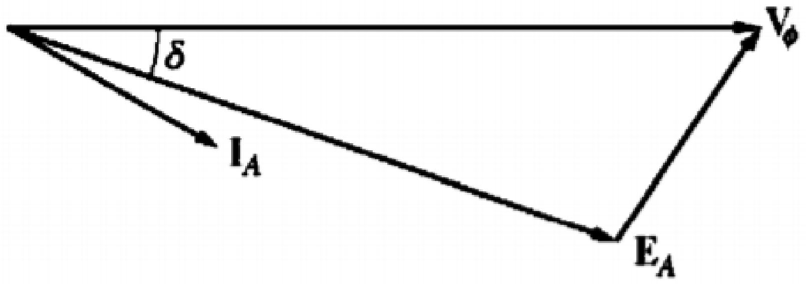
EEE363

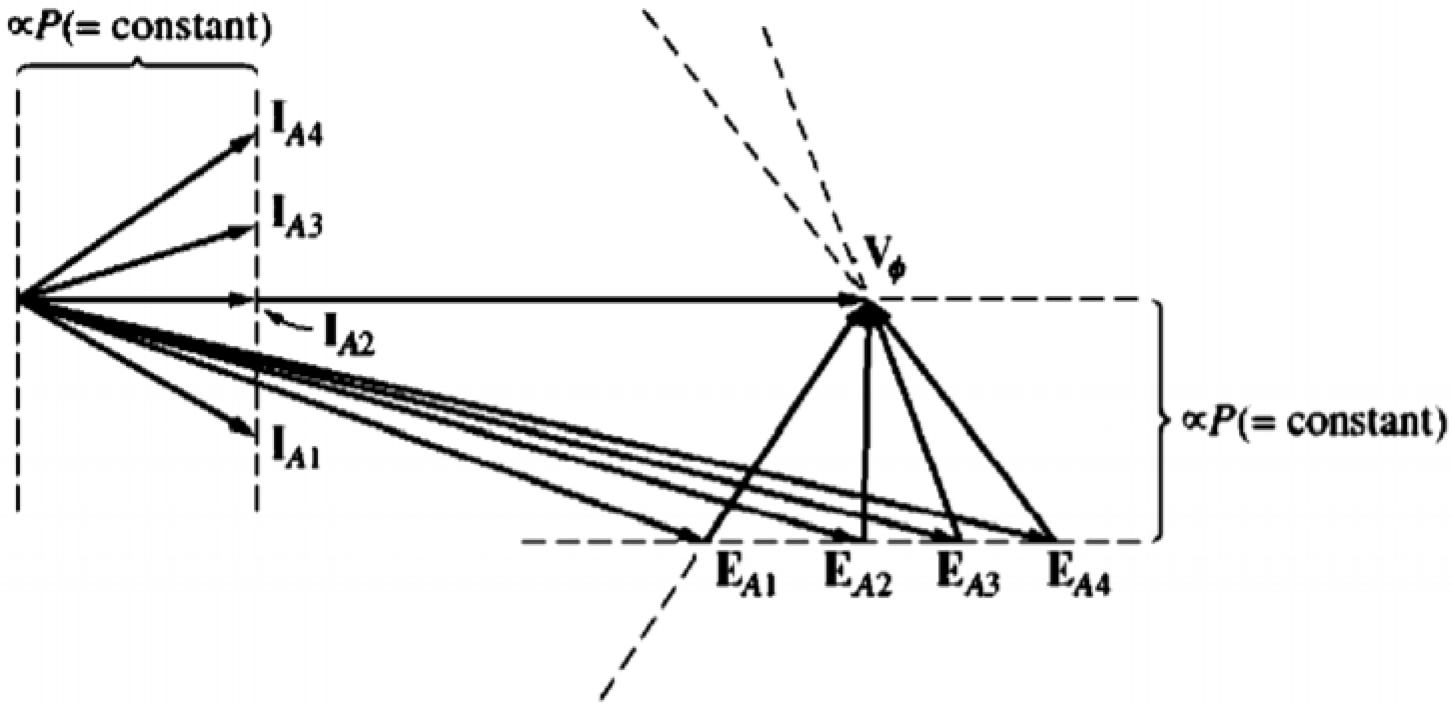
Electrical Machines

Lecture # 20

Dr Atiqur Rahman

Effect of Field current change

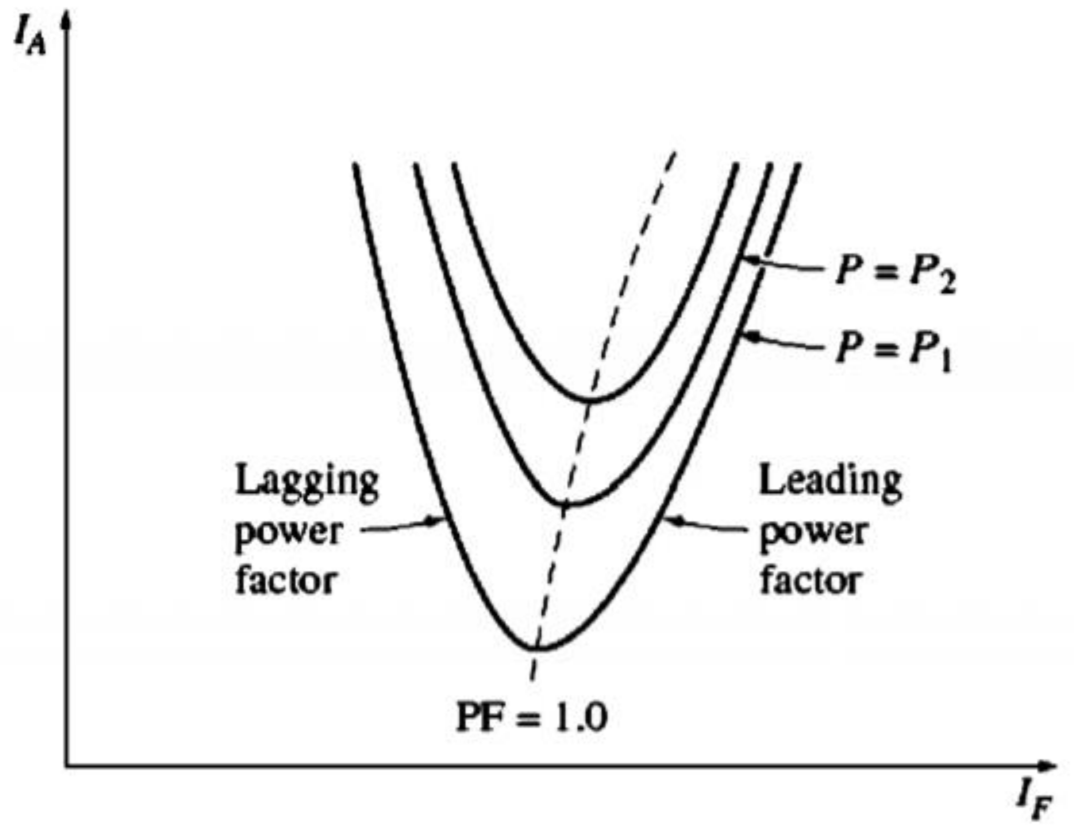




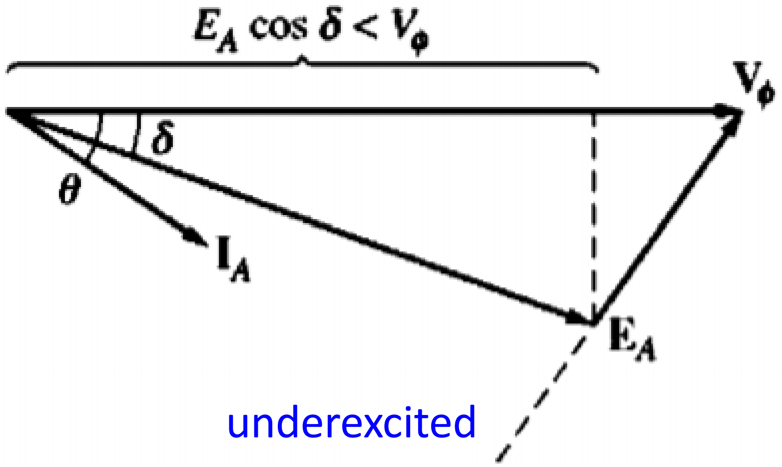
- ✓ Notice that as the value of E_A increases, the magnitude of the armature current I_A first decreases and then increases again.
- ✓ At low E_A, the armature current is lagging, and the motor is an inductive load.
- ✓ As the field current is increased further, the armature current becomes leading, and the motor becomes a capacitive load.

Synchronous motor ‘V’ curves

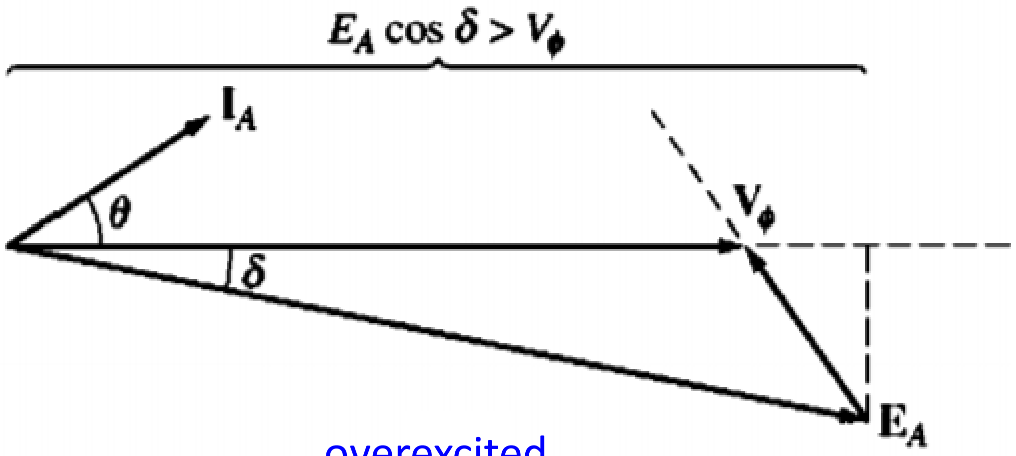
- A plot of I_A versus I_f for a synchronous motor is called a synchronous motor V curve.
- For field currents less than the value giving minimum I_A, the armature current is lagging, consuming Q.
- For field currents greater than the value giving the minimum I_A, the armature current is leading, supplying Q to the power system.



Over/Under-excited mode



underexcited



overexcited

✓ In order to enable the synchronous motor to supply reactive power to the system it must operate in overexcited mode.

Numerical problems

Example 6.1 and 6.2

Problem # 1

Example 6–1. A 208-V, 45-kVA, 0.8-PF-leading, Δ-connected, 60-Hz synchronous machine has a synchronous reactance of 2.5 Ω and a negligible armature resistance. Its friction and windage losses are 1.5 kW, and its core losses are 1.0 kW. Initially, the shaft is supplying a 15-hp load, and the motor's power factor is 0.80 leading.

(a) find the values of $\mathbf{I}_A$, I_L, and $\mathbf{E}_A$. *(b)* Assume that the shaft load is now increased to 30 hp.

(c) Find $\mathbf{I}_A$, I_L, and $\mathbf{E}_A$ after the load change. What is the new motor power factor?

Initially, the motor's output power is 15 hp. This corresponds to an output of

$$P_{\text{out}} = (15\text{ hp})(0.746\text{ KW/hp}) = 11.19\text{ kW}$$

$$P_{\text{in}} = P_{\text{out}} + P_{\text{mech loss}} + P_{\text{core loss}} + P_{\text{elec loss}} \quad = 11.19\text{ kW} + 1.5\text{ kW} + 1.0\text{ kW} + 0\text{ kW} = 13.69\text{ kW}$$

Since the motor's power factor is 0.80 leading, the resulting line current flow is

$$I_L = \frac{P_{\text{in}}}{\sqrt{3}\,V_T\cos\theta} \quad = \frac{13.69\text{ kW}}{\sqrt{3}(208\text{ V})(0.80)} = 47.5\text{ A}$$

and the armature current is $I_L/\sqrt{3}$, with 0.8 leading power factor, which gives $\mathbf{I}_A = 27.4\angle 36.87°\text{ A}$

Problem # 1

$$\mathbf{E}_A = \mathbf{V}_\phi - jX_S\mathbf{I}_A = 208\angle 0° \text{ V} - (j2.5\ \Omega)(27.4\angle 36.87° \text{ A}) = 208\angle 0° \text{ V} - 68.5\angle 126.87° \text{ V}$$

$$= 249.1 - j54.8 \text{ V} = 255\angle -12.4° \text{ V}$$

After the load changes, the electric input power of the machine becomes

$$P_{\text{in}} = P_{\text{out}} + P_{\text{mech loss}} + P_{\text{core loss}} + P_{\text{elec loss}} = (30 \text{ hp})(0.746 \text{ kW/hp}) + 1.5 \text{ kW} + 1.0 \text{ kW} + 0 \text{ kW}$$

$$= 24.88 \text{ kW}$$

From the equation for power in terms of torque angle, it is possible to find the magnitude of the angle.

$$P = \frac{3V_\phi E_A \sin\delta}{X_S} \Rightarrow \delta = \sin^{-1}\frac{X_S P}{3V_\phi E_A} = \sin^{-1}\frac{(2.5\ \Omega)(24.88 \text{ kW})}{3(208 \text{ V})(255 \text{ V})} = \sin^{-1} 0.391 = 23°$$

$$\mathbf{I}_A = \frac{\mathbf{V}_\phi - \mathbf{E}_A}{jX_S} = \frac{208\angle 0° \text{ V} - 255\angle -23° \text{ V}}{j2.5\ \Omega} = \frac{103.1\angle 105° \text{ V}}{j2.5\ \Omega} = 41.2\angle 15° \text{ A}$$

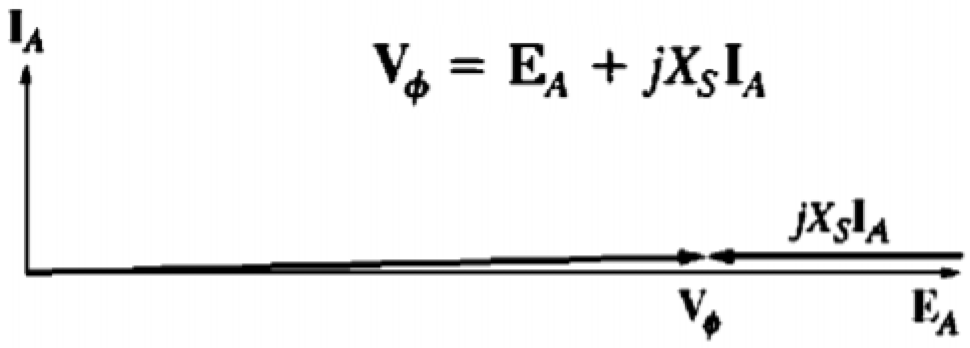
and I_L will become $\quad I_L = \sqrt{3}I_A = 71.4 \text{ A}$

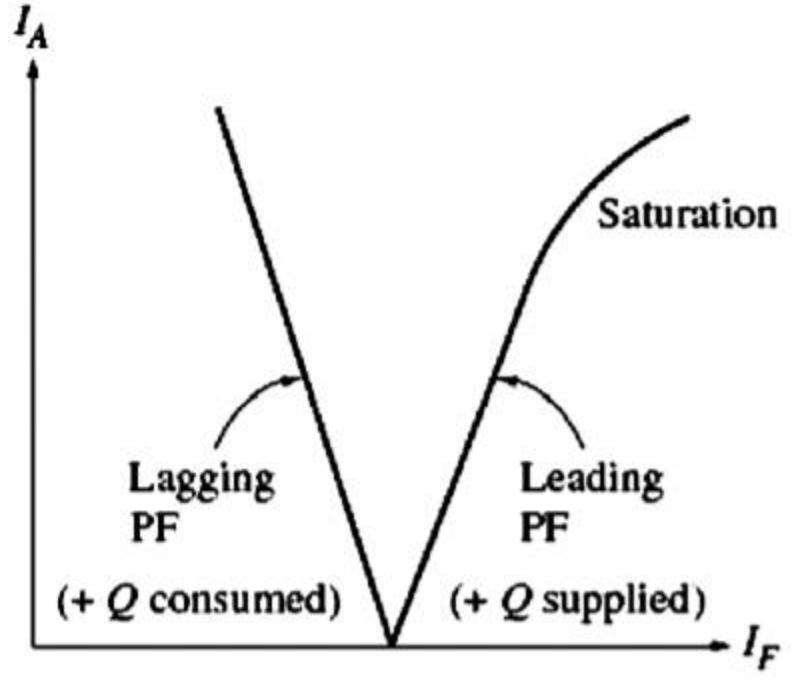
The Synchronous Capacitor or Synchronous Condenser

A synchronous motor designed only for supplying reactive power is called Synchronous capacitor. Some synchronous motors used to be sold specifically for power-factor correction.

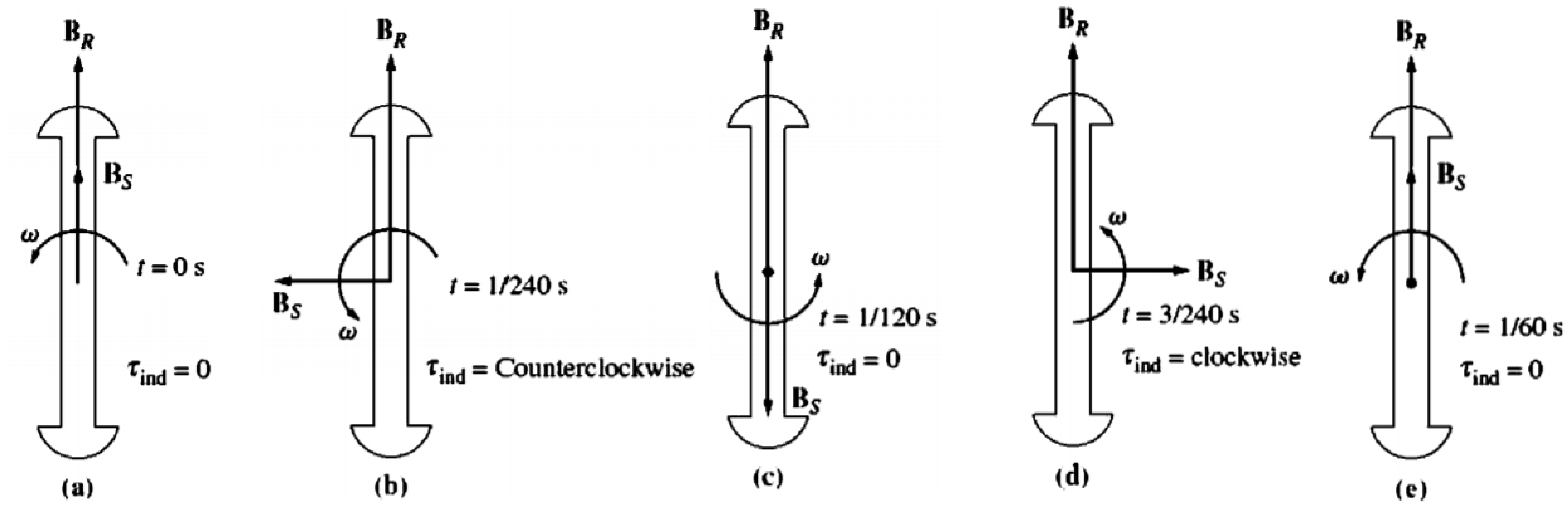
These machines had shafts that did not even come through the frame of the motor- no load could be connected to them.

Since there is no power (very small) being drawn from the motor, the distances proportional to power ($E_A\ sin\delta$ or $I_A cos\theta$) are close zero.





Starting of synchronous motor



$$\tau_{ind} = k\mathbf{B}_R \times \mathbf{B}_S$$

Starting of synchronous motor

The following techniques can be employed to start a synchronous motor:

1. *By reducing the speed of the stator magnetic field*

2. *By using an external prime move.*

3. *By using damper windings or amortisseur windings*

Induction Motor

Operation principle

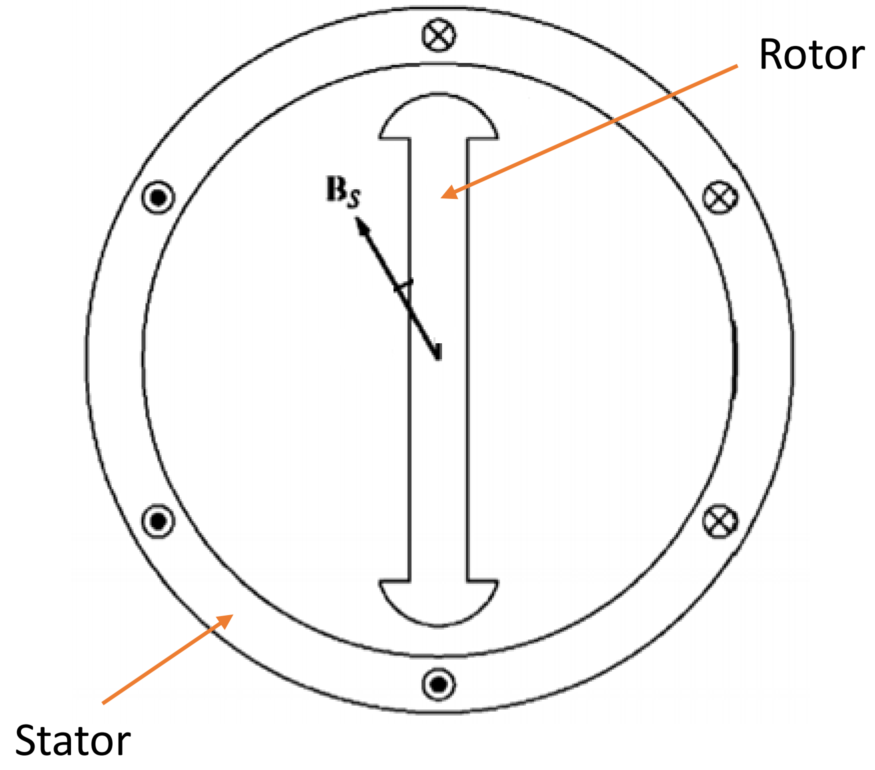
If a 3φ supply is applied to the stator it produces a rotating magnetic field which sweeps past the rotor surface and so cuts the rotor conductors.

Therefore, an emf is induced in the rotor conductor and its direction is given by the Fleming's Right hand rule.

A current flows in the rotor circuit whose direction, as given by the Lenz's rule, is such as to oppose the very cause producing it.

In this case, the cause which produces the rotor currents the relative speed between the rotating flux of the stator and the stationary rotor conductor.

Hence, to reduce the relative speed the rotor starts to rotate in the same direction.



Slip

In fact, rotor never succeeds in catching the speed of stator field.

If it really did so, there would be no relative speed and thus no induced emf and torque.

That is why rotor runs at a speed which is always smaller than the speed of stator field (n_{sync}).

Slip speed $$\boxed{n_{\text{slip}} = n_{\text{sync}} - n_m}$$

n_{slip} = slip speed of the machine

n_{sync} = speed of the magnetic fields

n_m = mechanical shaft speed of motor

Slip $$\boxed{s = \frac{n_{\text{sync}} - n_m}{n_{\text{sync}}}(\times\ 100\%)} \Rightarrow \boxed{n_m = (1 - s)n_{\text{sync}}} \quad \boxed{\omega_m = (1 - s)\omega_{\text{sync}}}$$

Rotor current frequency

$$\boxed{n_s = \frac{120 f_e}{P}}$$

$$\boxed{n_s - n_m = \frac{120 f_r}{P}}$$

f_r is rotor current frequency

f_e is supply frequency

$$\frac{f_r}{f_e} = \frac{n_s - n_m}{n_s} = \mathrm{s} \Rightarrow f_r = s.f_e$$