

Induction Motor

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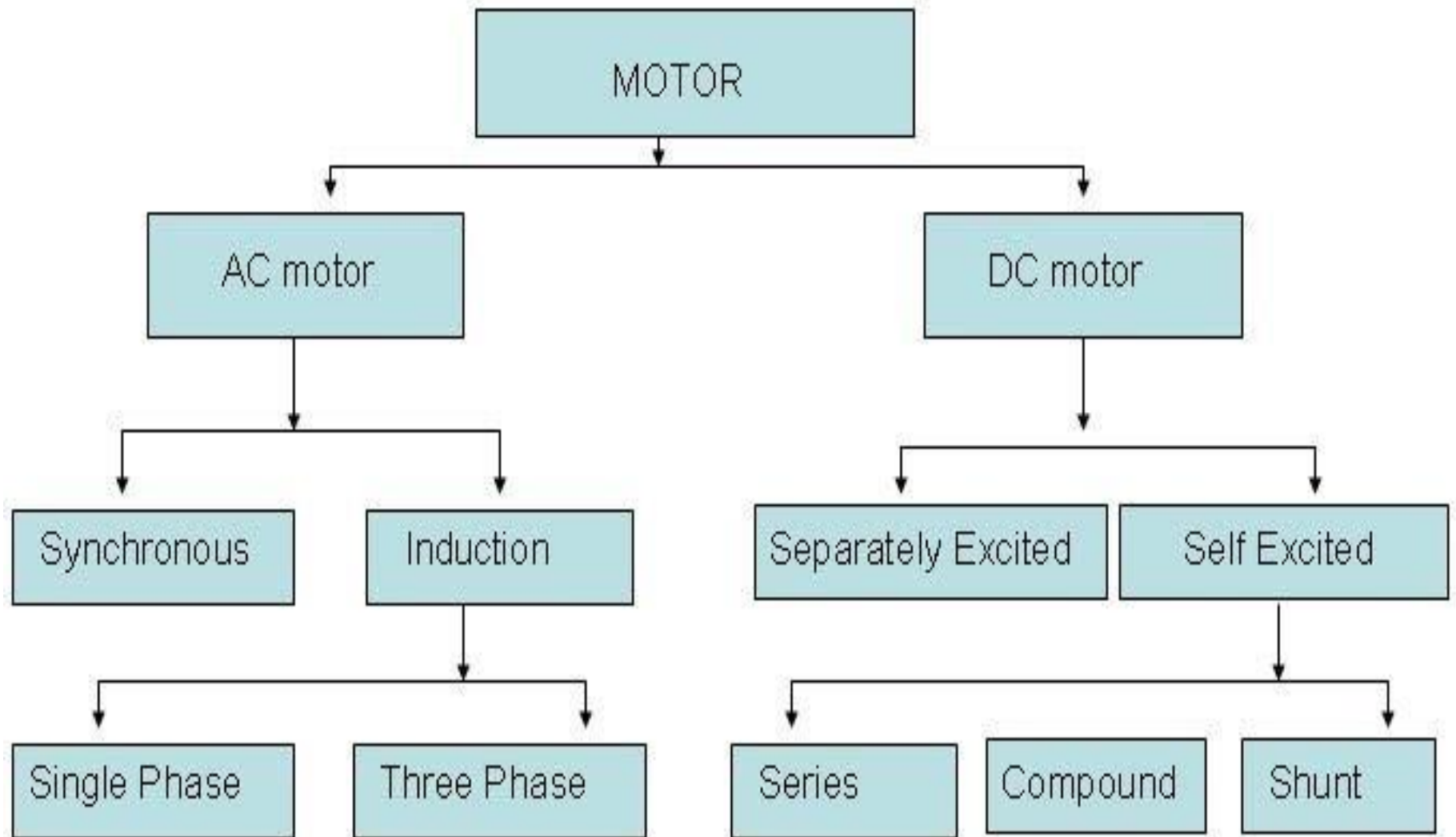
Introduction

- Three-phase induction motors are the most common and frequently encountered machines in industry
 - simple design, rugged, low-price, easy maintenance
 - wide range of power ratings: fractional horsepower to 10 MW
 - run essentially as constant speed from no load to full load
 - Its speed depends on the frequency of the power source
 - not easy to have variable speed control
 - requires a variable-frequency power-electronic drive for optimal speed control

- **Why induction motor (IM)?**

- –Robust; No brushes. No contacts on rotor shaft
- –High Power/Weight ratio compared to Dc motor
- –Lower Cost/Power
- –Easy to manufacture
- –Almost maintenance-free, except for bearing and other mechanical parts

Classification of Motor

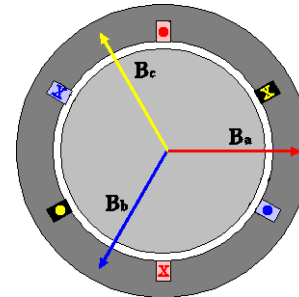


Rotating Magnetic Field

- Balanced three phase windings, i.e. mechanically displaced 120 degrees from each other, fed by balanced three phase source
- A rotating magnetic field with constant magnitude is produced, rotating with a speed

$$n_{sync} = \frac{120 f_e}{P} \text{ rpm}$$

P is the no. of poles and n_{sync} is called the synchronous speed in rpm (revolutions per minute)

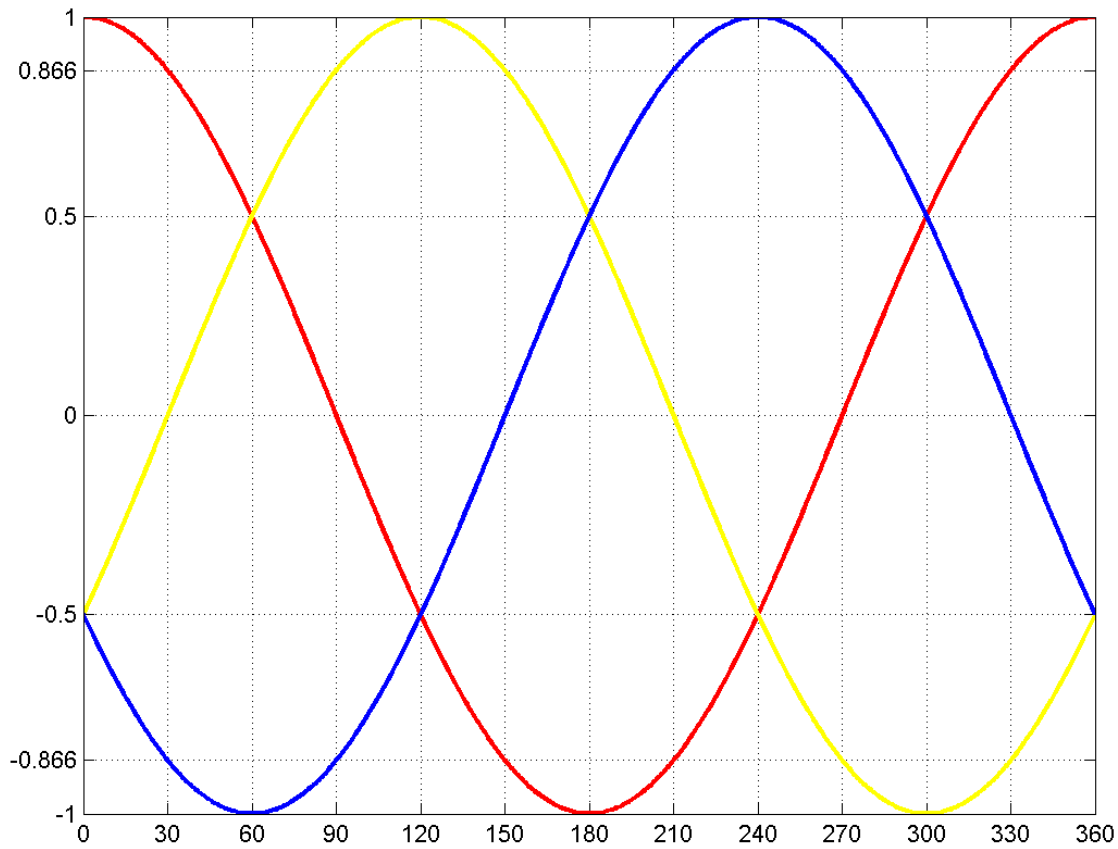


Where f_e is the supply frequency and rpm

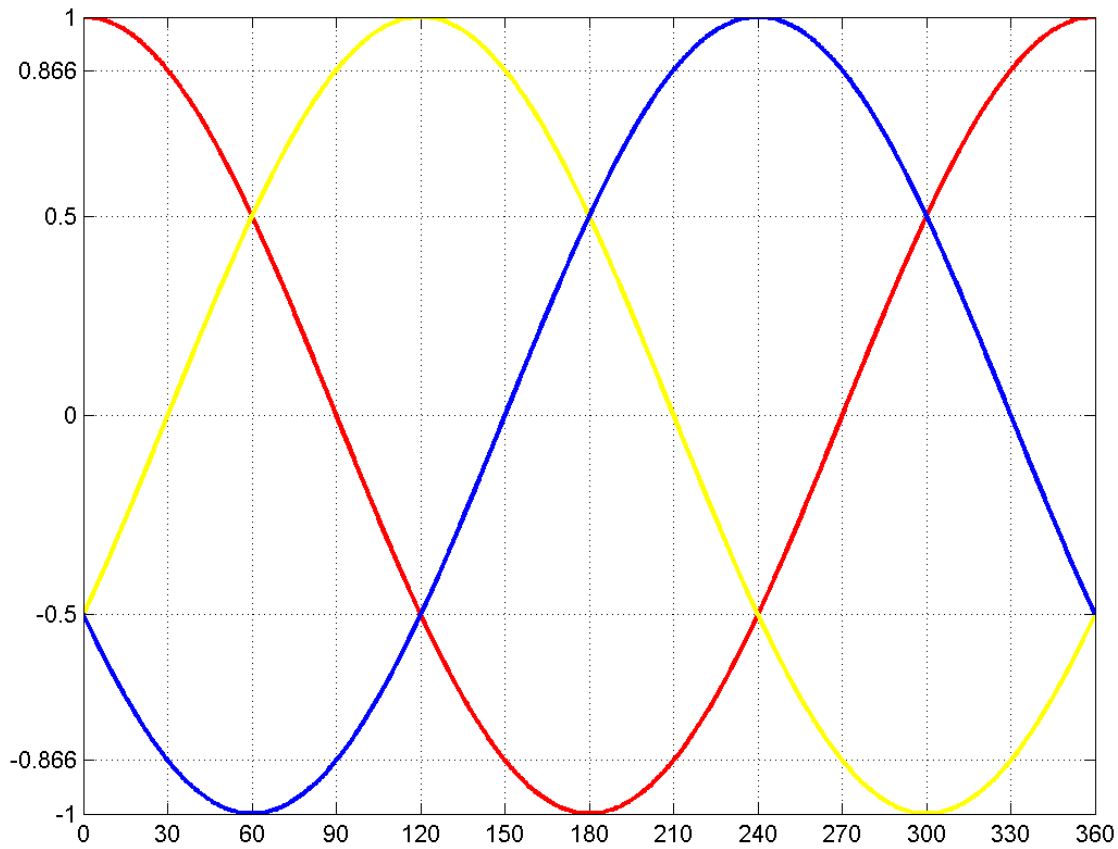
Synchronous speed

P	50 Hz	60 Hz
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600

Rotating Magnetic Field



Rotating Magnetic Field



Rotating Magnetic Field

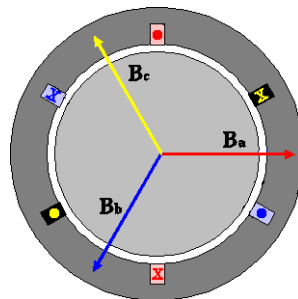
$$B_{net}(t) = B_a(t) + B_b(t) + B_c(t)$$

$$= B_M \sin(\omega t) \angle 0^\circ + B_M \sin(\omega t - 120^\circ) \angle 120^\circ + B_M \sin(\omega t - 240^\circ) \angle 240^\circ$$

$$= B_M \sin(\omega t) \hat{\mathbf{x}}$$

$$- [0.5 B_M \sin(\omega t - 120^\circ)] \hat{\mathbf{x}} - \left[\frac{\sqrt{3}}{2} B_M \sin(\omega t - 120^\circ) \right] \hat{\mathbf{y}}$$

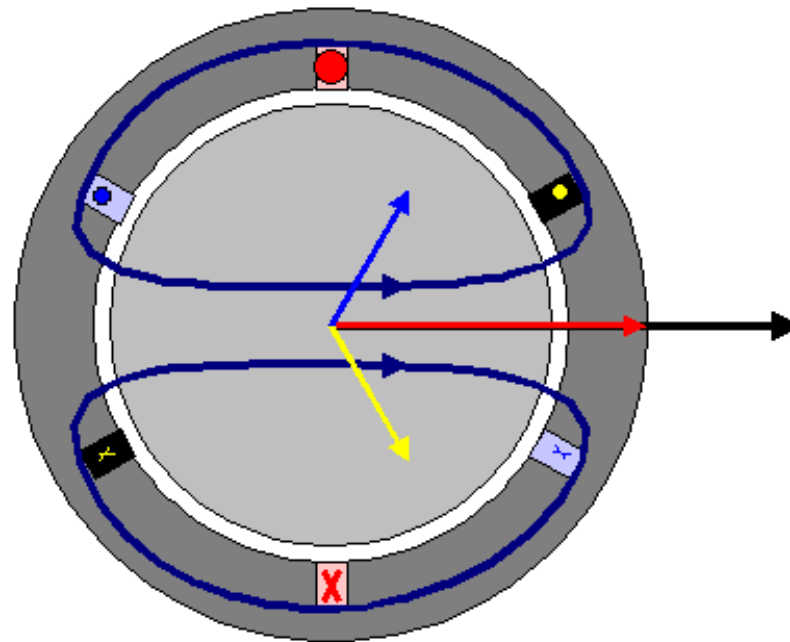
$$- [0.5 B_M \sin(\omega t - 240^\circ)] \hat{\mathbf{x}} + \left[\frac{\sqrt{3}}{2} B_M \sin(\omega t - 240^\circ) \right] \hat{\mathbf{y}}$$



Rotating Magnetic Field

$$\begin{aligned} B_{net}(t) &= [B_M \sin(\omega t) + \frac{1}{4} B_M \sin(\omega t) + \frac{\sqrt{3}}{4} B_M \cos(\omega t) + \frac{1}{4} B_M \sin(\omega t) - \frac{\sqrt{3}}{4} B_M \cos(\omega t)] \hat{\mathbf{x}} \\ &\quad + [-\frac{\sqrt{3}}{4} B_M \sin(\omega t) - \frac{3}{4} B_M \cos(\omega t) + \frac{\sqrt{3}}{4} B_M \sin(\omega t) - \frac{3}{4} B_M \cos(\omega t)] \hat{\mathbf{y}} \\ &= [1.5 B_M \sin(\omega t)] \hat{\mathbf{x}} - [1.5 B_M \cos(\omega t)] \hat{\mathbf{y}} \end{aligned}$$

Rotating Magnetic Field



Principle of operation

- This rotating magnetic field cuts the rotor windings and produces an induced voltage in the rotor windings
- Due to the fact that the rotor windings are short circuited, for both squirrel cage and wound-rotor, and induced current flows in the rotor windings
- The rotor current produces another magnetic field
- A torque is produced as a result of the interaction of those two magnetic fields

$$\tau_{ind} = k B_R \times B_s$$

Where τ_{ind} is the induced torque and B_R and B_s are the magnetic flux densities of the rotor and the stator respectively

Induction motor speed

At what speed will the IM run?

Can the IM run at the synchronous speed, why?

- If rotor runs at the synchronous speed, which is the same speed of the rotating magnetic field, then the rotor will appear stationary to the rotating magnetic field and the rotating magnetic field will not cut the rotor. So, no induced current will flow in the rotor and no rotor magnetic flux will be produced so no torque is generated and the rotor speed will fall below the synchronous speed
- When the speed falls, the rotating magnetic field will cut the rotor windings and a torque is produced

Induction motor speed

- So, the IM will always run at a speed **lower** than the synchronous speed
- The difference between the motor speed and the synchronous speed is called the *Slip*

$$n_{slip} = n_{sync} - n_m$$

Where n_{slip} = slip speed

n_{sync} = speed of the magnetic field

n_m = mechanical shaft speed of the motor

The Slip

$$s \equiv \frac{n_{sync} - n_m}{n_{sync}}$$

Where s is the *slip*

Notice that : if the rotor runs at synchronous speed

$$s = 0$$

if the rotor is stationary

$$s = 1$$

Slip may be expressed as a **percentage** by multiplying the above eq. by 100, notice that the slip is a ratio and doesn't have units

Induction Motors and Transformers

- Both IM and transformer works on the principle of induced voltage
 - Transformer: voltage applied to the primary windings produce an induced voltage in the secondary windings
 - Induction motor: voltage applied to the stator windings produce an induced voltage in the rotor windings
 - The difference is that, in the case of the induction motor, the secondary windings can move
 - Due to the rotation of the rotor (the secondary winding of the IM), the induced voltage in it does not have the same frequency of the stator (the primary) voltage

Disadvantages

- Essentially a “fixed-speed” machine
- Speed is determined by the supply frequency
- To vary its speed need a variable frequency supply