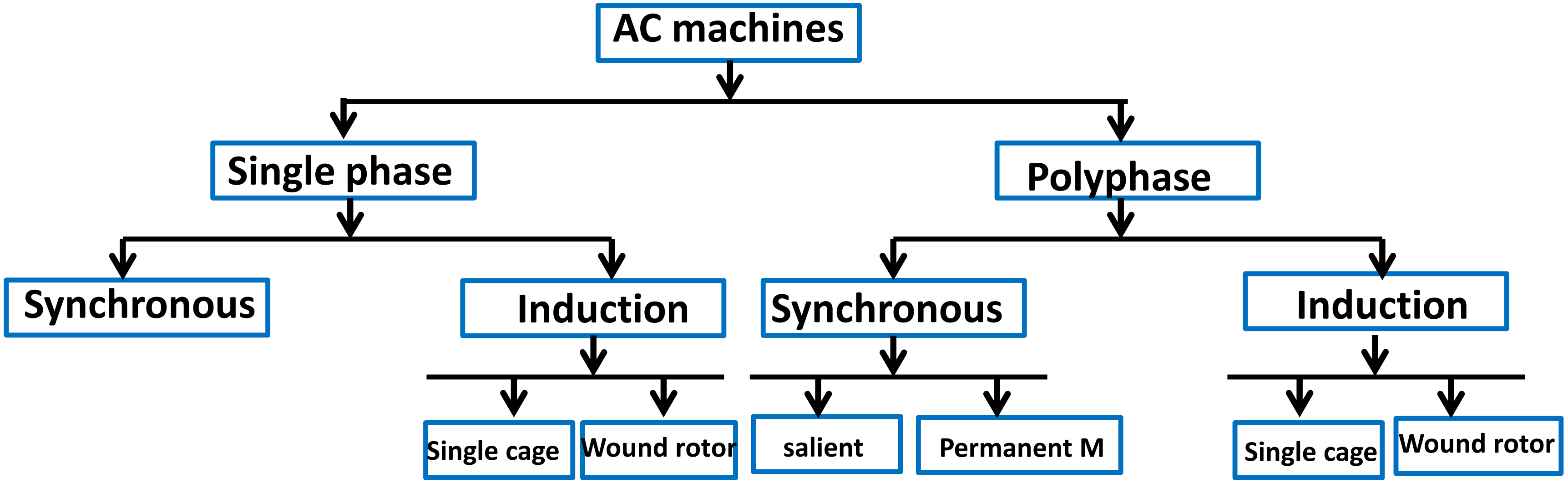
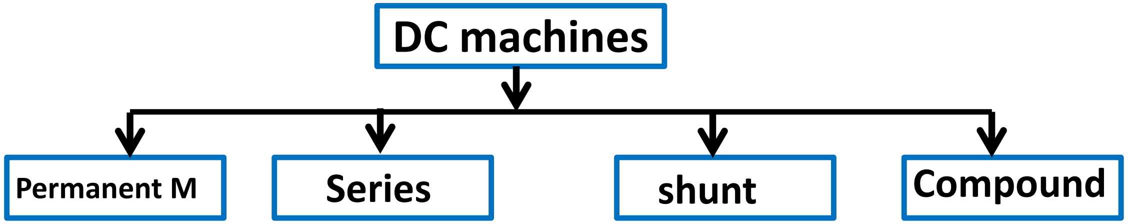
Classification of electrical machines





CHAPTER FOUR

Induction machines

Learning outcomes

- ✓ Understand the basic theories of induction machine
- ✓ Understand how squirrel-cage and wound rotor three-phase induction motors operate
- ✓ Know about the function and operation of motor starters
- ✓ Know about a range of industrial applications
- ✓ Describe the construction of a three-phase induction motor.
- ✓ Discuss torque, speed, efficiency and power factor characteristics of three-phase motors

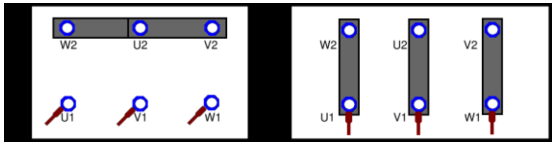
Construction

An induction motor has two main parts

A stationary stator

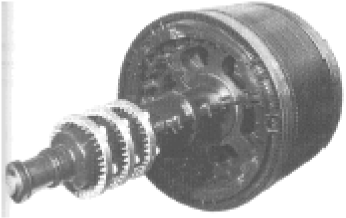
- ✓ Consisting of a steel frame that supports a hollow, cylindrical core
- ✓ Core, constructed from stacked laminations (why?), having a number of evenly spaced slots, providing the space for the stator winding

An induction machine can be Star- or Delta -connected:



<u>A revolving rotor</u>

wound-rotors



squirrel-cages

Synchronous speed

$$N_{syn} = \frac{60 \times f_{syn}}{p}$$

p	1	2	3	4	5	6
N_{sync}	3000	1500	1000	750	600	500

Slip

$$s = \frac{N_{syn} - N_{mech}}{N_{syn}} \times 100\%$$

the mechanical shaft speed

$$N_{mech} = (1 - s) \times N_{syn}$$

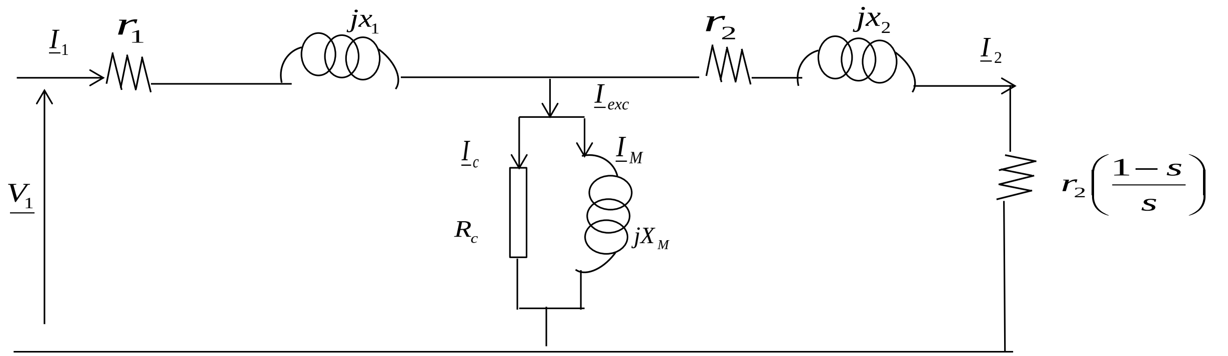
the rotor frequency (Hz)

$$f_r = \frac{p \times (N_{syn} - N_{mech})}{60} = \frac{p \times s \times N_{syn}}{60} = s \times f_{syn}$$

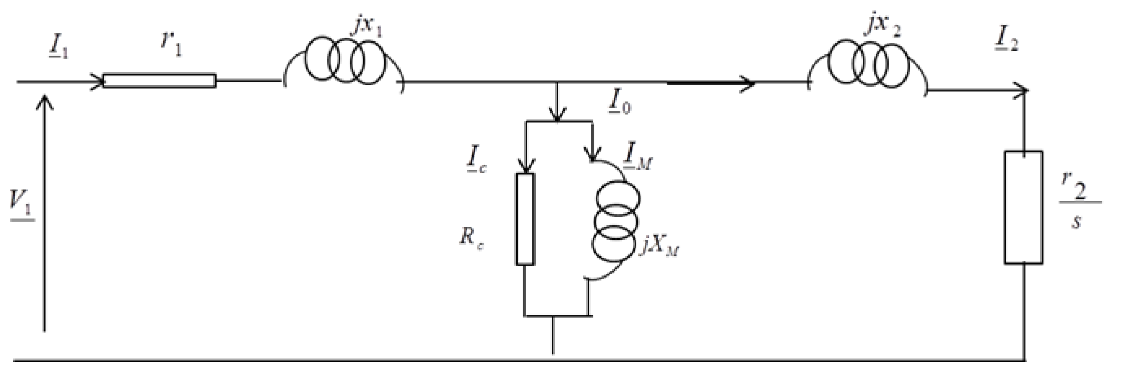
Torque

$$T_{load} = \frac{P_{out}}{\Omega_{mech}} (Nm)$$

Equivalent Circuit



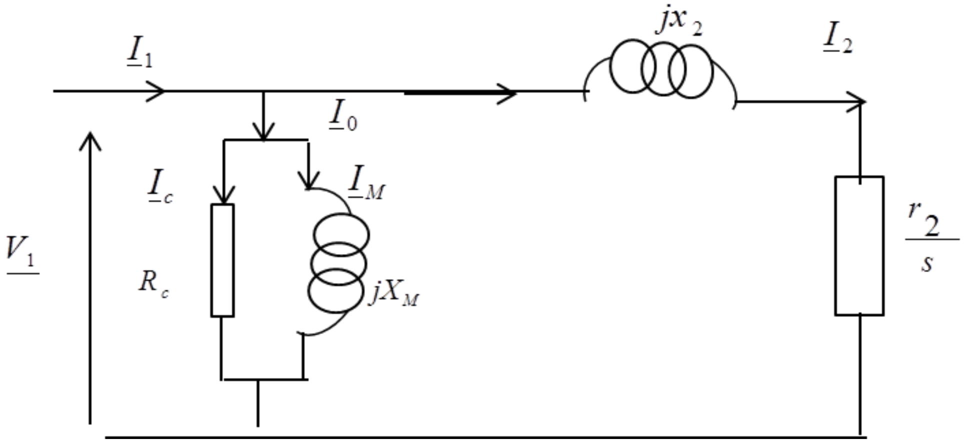
We can draw the IM equivalent circuit as follows:



Where

$$\frac{r_2}{s} = r_2 + \frac{1-s}{s} r_2$$

If we neglect r_1 and x_1 then the equivalent circuit becomes as follows:



Now we can calculate the rotor current as:

$$\underline{V_1} = \left(\frac{r_2}{s} + jx_2 \right) \times \underline{I_2}$$

$$\underline{I_2} = \frac{\underline{V_1}}{\left(\frac{r_2}{s} + jx_2 \right)}$$

$$P_{dev} = 3 \times \frac{r_2}{s} \times (I_2)^2$$

<u>Torque relations</u>

$$T_{dev} = \frac{P_{dev}}{\Omega_{syn}} \rightarrow \Omega_{syn} = \frac{\omega_{syn}}{p}$$

$$T_{dev} = \frac{3p}{\omega_{syn}} \times \frac{r_2}{s} \times (I_2)^2$$

Or

$$\left|\underline{I_2}\right| = \frac{\left|\underline{V_1}\right|}{\sqrt{\left(\left(\frac{r_2}{s}\right)^2 + \left(x_2\right)^2\right)}}$$

Therefore

$$T_{dev} = \frac{3p}{\omega_{syn}} \times \frac{V_1^{\,2}}{\left(\frac{r_2}{s}\right) + \left(\frac{g\left(x_2\right)^2}{r_2}\right)}$$

1. If $s << 1$

$$T_{mech} \cong \frac{1}{\omega_{syn}} \times \frac{V_T^2}{r_2} \times s$$

2. If $s_0 = \frac{r_2}{x_2}$

$$T_{\max} = \frac{3p}{\omega_{syn}} \frac{V_1^2}{2 \times x_2}$$

3. If $s_{start} = 1$

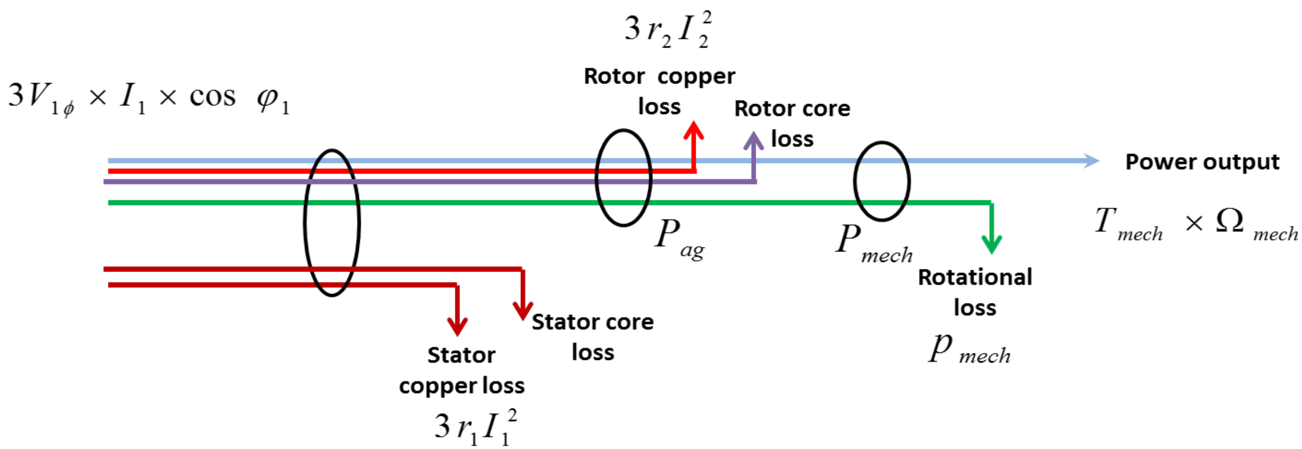
$$T_{start} = \frac{3p}{\omega_{syn}} \times \frac{V_1^2}{r_2 + \left(\frac{(x_2)^2}{r_2} \right)}$$

4. If $\frac{r_2}{s} >> x_2$

$$T_{em} = K \times \left(N_{syn} - N_{mec} \right)$$

$$K = \frac{90}{\pi \times r_2 \times N_{syn}} \times V_1^2$$

The power-flow diagram of induction motor



$$P_{in} = 3r_1 I_1^2 + p_{stat-core} + P_{ag}$$

$$P_{ag} = 3r_2 I_1^2 + p_{rot-core} + p_{mech} + P_{out}$$

P_{ag} is air gap power

$$P_{in} = 3 \times V_{1\phi} \times I_1 \times \cos\varphi_1$$

$$p_{r1} = 3 \times r_1 \times I_1^2$$

$$p_{r2} = 3 \times r_2 \times I_2^2 = s \times P_{ag} = \frac{s}{(1-s)} P_{mech}$$

$$P_{ag} = P_{mech} + p_{r2}$$

$$P_{mech} = P_{out} + p_{friction}$$

$$P_{in} = p_{r1} + p_{core} + P_{ag} = p_{r1} + p_{core} + p_{r2} + p_{friction} + P_{out}$$

The Efficiency

$$\eta = \frac{P_{out}}{P_{in}}$$

Exercise 1

1) A 1500 W,400 V, 50 Hz, three-phase induction motor has 4 poles, a nominal speed of 1440-rpm, and a power factor of 0.77 and an efficiency of 80%. Calculate:

a) The synchronous speed in RPM and in rad/sec and slip of this motor.
b) The output torque in Nm.
c) The current drawn by the motor at nominal speed and load.
d) The apparent power and reactive power.
e) The losses

Solution

a) The synchronous speed in RPM and in rad/sec and slip of this motor.

$$N_{syn} = \frac{60 \times f}{p} = \frac{60 \times 50}{2} = 1500 RPM \qquad \Omega_{syn} = 2\pi \frac{N_{syn}}{60} = 157{,}07 rad/\sec$$

$$s = \frac{N_{syn} - N_{mec}}{N_{syn}} = \frac{1500 - 1440}{1500} = 4\%$$

b) The output torque in Nm.

$$T = \frac{P_{out}}{\Omega_{mec}} (Nm) = \frac{1500 \times 60}{2\pi \times 1440} = 9{,}94 Nm$$

c) The current drawn by the motor at nominal speed and load.

$$\eta = \frac{P_{out}}{P_{in}} \rightarrow P_{in} = \frac{P_{out}}{\eta} = \frac{1500}{0{,}8} = 1875W$$

$$P_{in} = \sqrt{3}(UI\cos\varphi) = \sqrt{3}(400 \times I \times 0{,}77) = 1875W$$

$$I = \frac{1875}{\sqrt{3}(400 \times 0{,}77)} = 3{,}5A$$

d) The apparent power and reactive power.

$$S_{in} = \sqrt{3}(UI) = \sqrt{3}(400 \times 3{,}5) = 2424{,}87VA$$

$$Q_{in} = \sqrt{S_{in}^2 - P_{in}^2} = 1537{,}65VAR$$

e) The losses

$$\sum p = P_{in} - P_{out} = 1875 - 1500 = 375W$$

Exercise 2

A 208-V, 10hp, four poles, 50 Hz, Y-connected induction motor has a full-load slip of 5 percent

1. What is the synchronous speed of this motor?
2. What is the rotor speed of this motor at rated load?
3. What is the rotor frequency of this motor at rated load?
4. What is the shaft torque of this motor at rated load?

Answer

1. What is the synchronous speed of this motor?

$$N_{syn} = \frac{60 \times f_{syn}}{p} = \frac{60 \times 50}{2} = 1500 rpm$$

2. What is the rotor speed of this motor at rated load?

$$N_{mech} = (1 - s) \times N_{syn} = (1 - 0{,}05) \times 1500 = 1425 rpm$$

3. What is the rotor frequency of this motor at rated load?

$$f_r = s \times f_{syn} = 0{,}05 \times 50 = 2{,}5 Hz$$

4. What is the shaft torque of this motor at rated load?

$$T_{load} = \frac{P_{out}}{\Omega_{mech}} = \frac{10 \times 746}{2\pi \frac{1425}{60}} \cong 50 Nm$$

Review

Q1. Why is the ac induction motor used more often than other types?

R1. They are simple and inexpensive to make.

Q2. The speed of the rotor is always somewhat less than the speed of the rotating field. What is the difference called?

R2. Slip

Q3. What determines the amount of slip in an induction motor?

R3. Load

Q4. What type of ac motor is most widely used?

R4. Single-phase induction motor

Q5. How do split-phase induction motors become self-starting?

R5. By using combinations of inductance and capacitance to apply out-of phase currents in starting windings

Q6. Why are shaded-pole motors used to drive only very small devices?

R6. They have very weak starting torques


The End