LECTURE 3

Equivalent Circuit of Induction Machines

V_1 – stator voltage, per phase ($V_1 = V_{LL} / \sqrt{3}$)

R_1, R_2 – stator and rotor winding resistance

$X_1 = 2\pi f_1 L_1$ – stator leakage reactance

$X_2 = 2\pi f_1 L_2$ – rotor leakage reactance

R_c – resistance representing core loss, per phase

X_m – magnetizing reactance, per phase

N_1, N_2 – effective number of turns of stator and rotor windings.

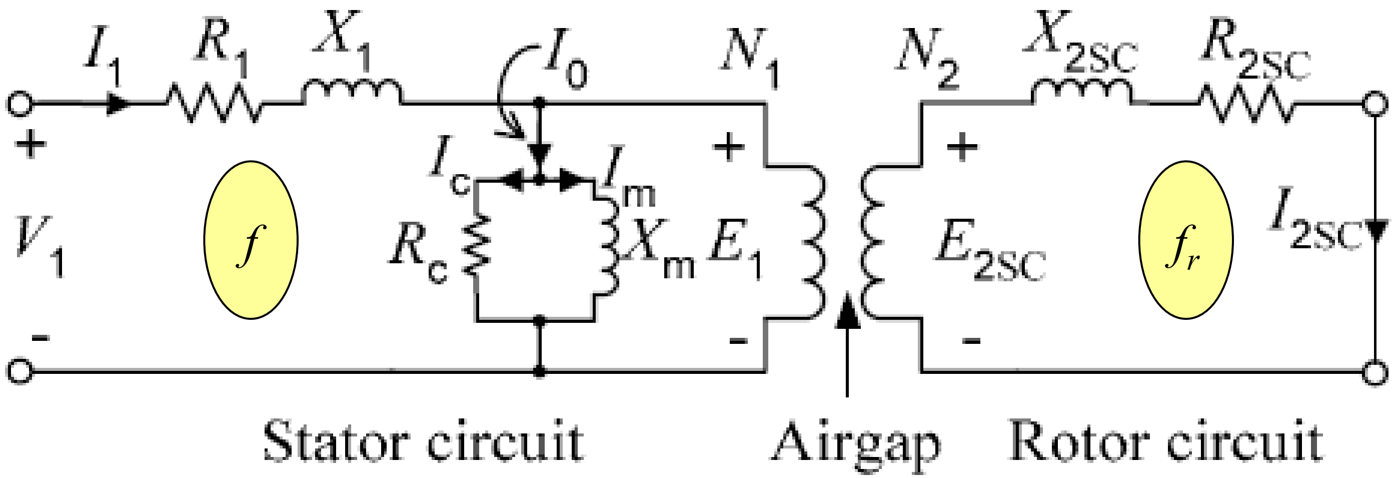
$E_1 = 4.44 f_1 N_1 \Phi$, where Φ is flux per pole

$E_2 = 4.44 f_1 N_2 \Phi$

Equivalent Circuit of Induction Machines

- **Step2 Rotor winding is shorted**

  (Under normal operating conditions, the rotor winding is shorted. The slip is *s*)

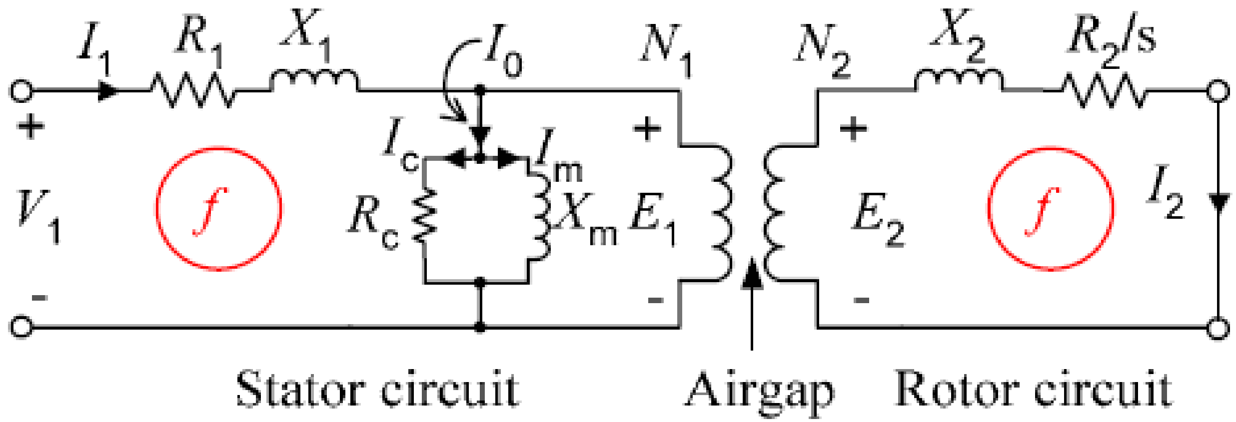


- Note: the frequency of E_2

is $f_r = sf$ because rotor is rotating.

Equivalent Circuit of Induction Machines

- **Step3 Eliminate f_2**

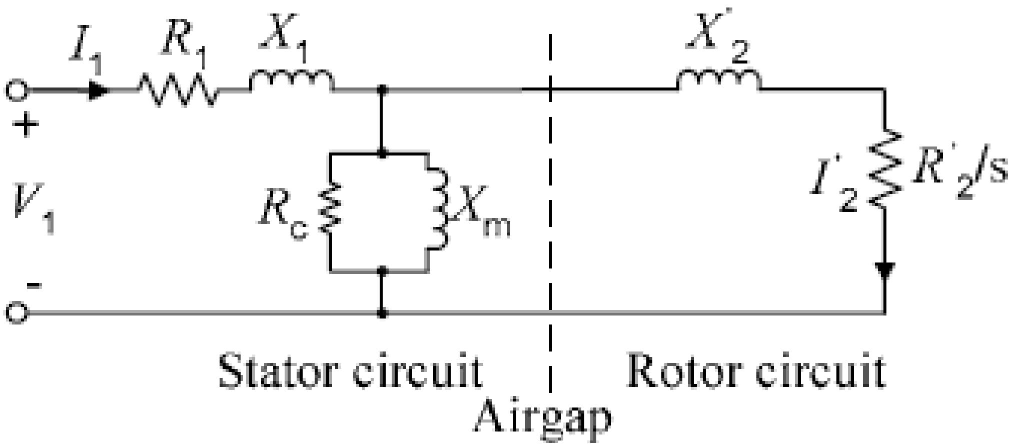


Keep the rotor current same:

$$I_{2sc} = \frac{E_{2sc}}{R_{2sc} + jX_{2sc}} = \frac{sE_2}{R_2 + jsX_2} = \frac{E_2}{\frac{R_2}{s} + jX_2} = I_2$$

Equivalent Circuit of Induction Machines

- **Step 4 Referred to the stator side**



$$X_2' = a^2 X_2,$$

$$R_2' = a^2 R_2,$$

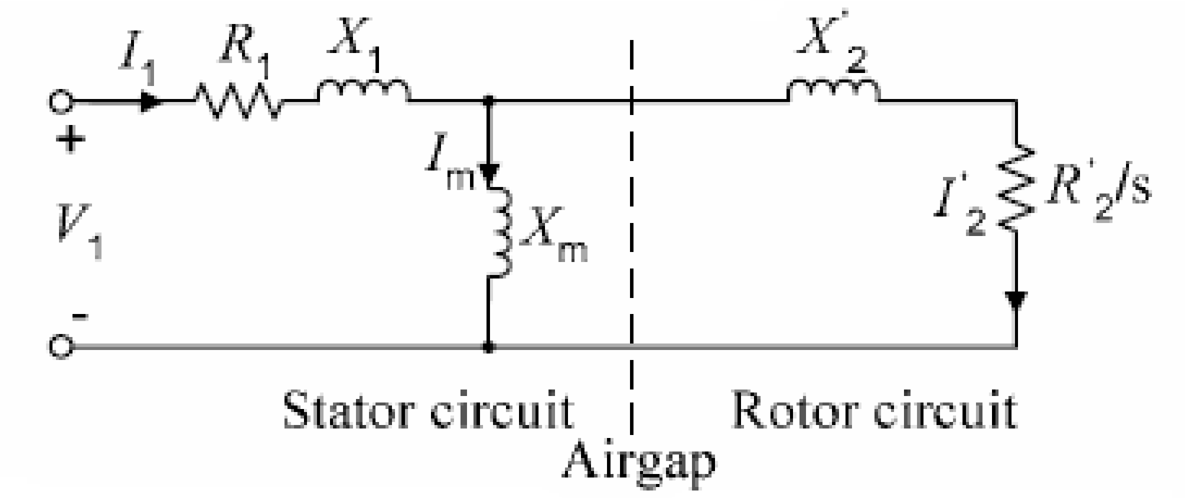
$$I_2' = \frac{1}{a} I_2,$$

$$\text{where } a = \frac{N_1}{N_2}$$

- Note:
  - X'_2 and R'_2 will be given or measured. In practice, we do not have to calculate them from above equations.
  - Always refer the rotor side parameters to stator side.
  - R_c represents core loss, which is the core loss of stator side.

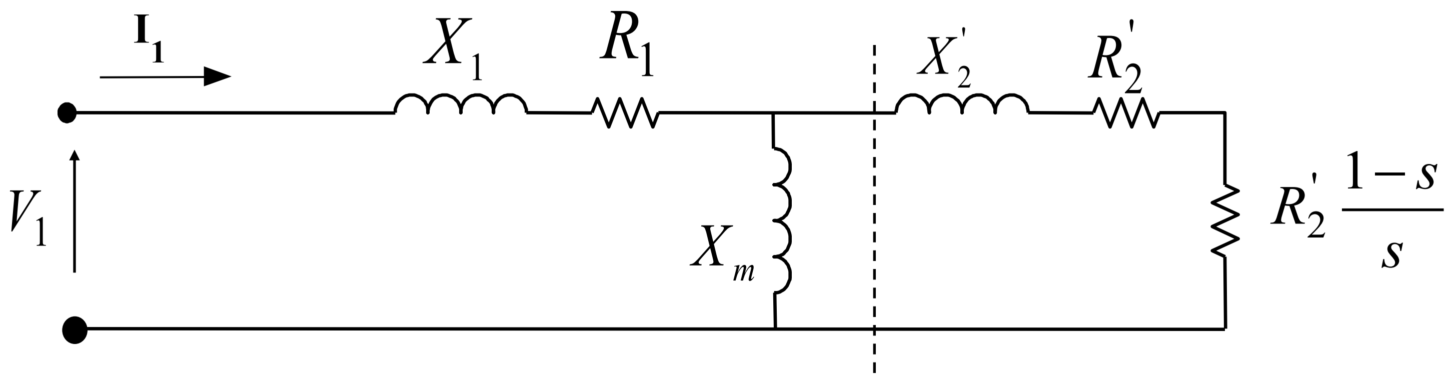
Equivalent Circuit of Induction Machines

- **IEEE recommended equivalent circuit**



Equivalent Circuit of Induction Machines

- **IEEE recommended equivalent circuit**



Note: $\frac{R_2}{s}$ **can be separated into 2 PARTS**

$$\frac{R_2}{s} = R_2 + \frac{R_2(1-s)}{s}$$

- **Purpose : to obtain the developed mechanical**

Power Flow Diagram

$$\sqrt{3} V_s I_s \cos\theta$$

$$1hp = 746W$$

P_{in} (Motor)

P_{in} (Stator)

P_{in} (Rotor)

$P_{air\ Gap}$ (P_{ag})

$$3 I_R'^2 \frac{R_R'}{s}$$

$P_{developed}$

$P_{mechanical}$

$P_{converted}$ (P_m)

$$3 I_R'^2 R_R' \left(\frac{1-s}{s} \right)$$

P_{out}, P_o

$P_{stator\ copper\ loss}$, (P_{scu})

$$3 I_s^2 R_s$$

$P_{core\ loss}$ (P_c)

$$3 \left(\frac{V_{RM}}{R_c} \right)^2$$

$P_{rotor\ copper\ loss}$ (P_{rcu})

$$3 I_R'^2 R_R'$$

$P_{windage,\ friction,\ etc}$ (P_μ - Given)

Torque-Equation

- Torque, can be derived from power equation in term of mechanical power or electrical power.

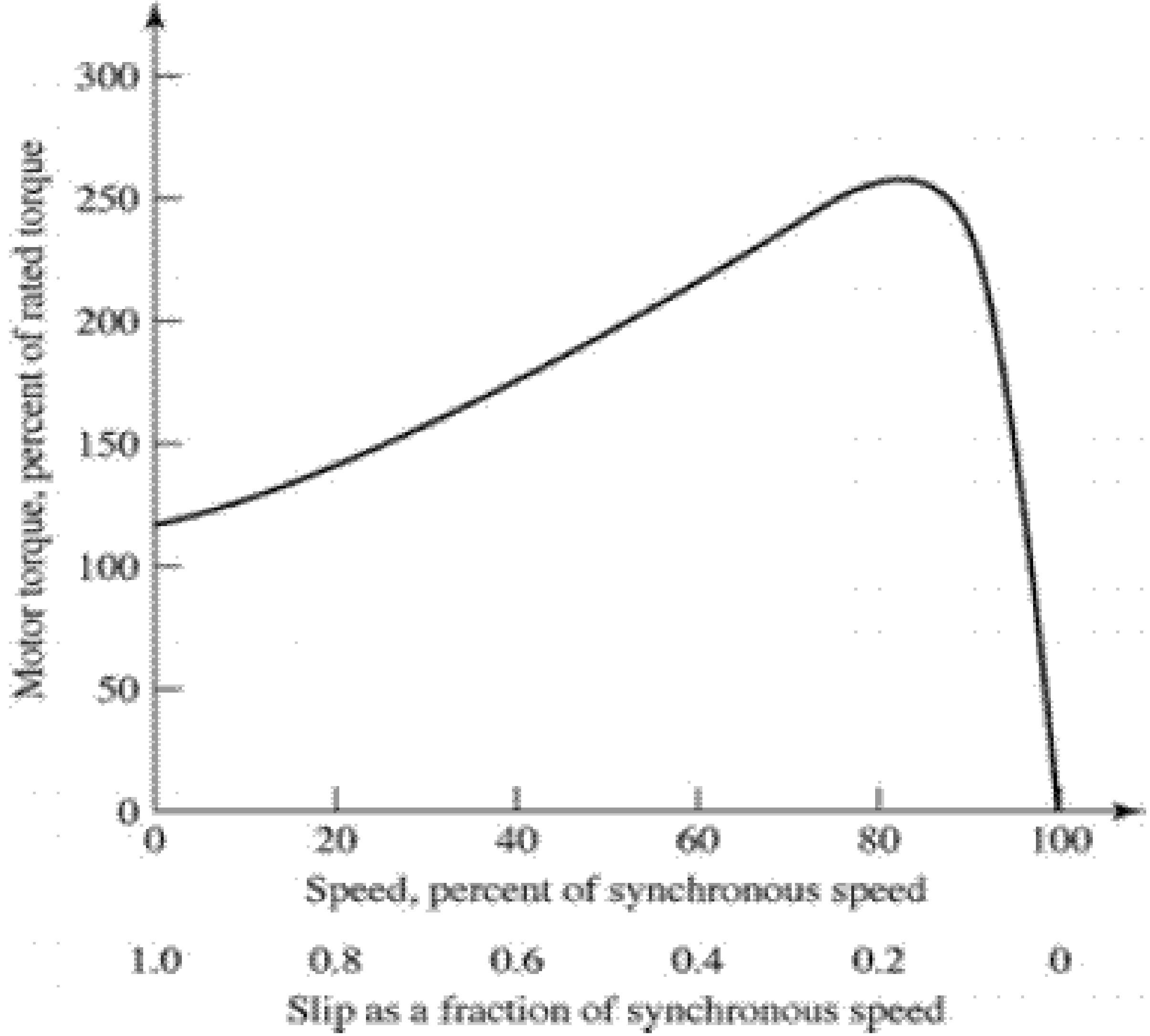
$$Power, P = \omega T, where\ \omega = \frac{2\pi n}{60} (rad/s)$$

$$Hence, T = \frac{60P}{2\pi n}$$

$$Thus,$$

$$Mechanical\ Torque, T_m = \frac{60P_m}{2\pi n_r}$$

$$Output\ Torque, T_o = \frac{60P_o}{2\pi n_r}$$


Motor torque, percent of rated torque
300
250
200
150
100
50
0
0
20
40
60
80
100
Speed, percent of synchronous speed
1.0
0.8
0.6
0.4
0.2
0
Slip as a fraction of synchronous speed