

Induction Motors

(1)

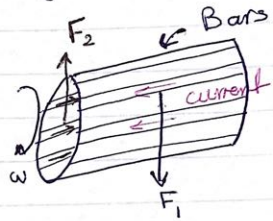
Video

- Self starting motor , No need for external Dc source

Composites:

- 1- Rotor
- 2- Stator

- we use squirrel cage as in synchronous motor when induced voltage will cause a current passing in the Bars which cause a force to be generated $\rightarrow$ Torque is generated



- No maintenance needed and has long working life

Slides:

Induction machine: rotor voltage is induced in rotor windings

- No need for:
 - 1- physical wires
 - 2- Dc field current
- Rarely used as generator: always consumes reactive power / low PF / not stand alone

Main difference between an induction motor and a Synchronous motor

1. No current supplied in induction motors
- 2.
3. Speed of rotor and stator are the same in synchronous motor. In induction motor speed of rotor is less than speed of stator

Difference between them is called Slip

Slip

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

↙ Speed of magnetic field ↘ mechanical shaft speed

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

can be $s = \frac{n_{sync} - n_m}{n_{sync}} \times 100\%$

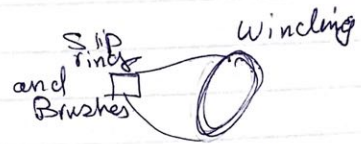
measured or calculated $(n_m) = (1-s)n_{sync}$ ↙ can be calculated

if Rotor rotates at Synchronous speed $s=0$
rotor is stationary $s=1$
All normal motor speeds $0 < s < 1$

• Rotor construction

1. Squirrel cage: consists of a series of conducting bars laid into slots, shorted at either end by large shorting rings
2. Wound rotor: It has 3-phase windings usually Y connected and windings ends are connected via slip rings on the rotor shaft

Rotor windings are shorted through brushes riding on the slip rings



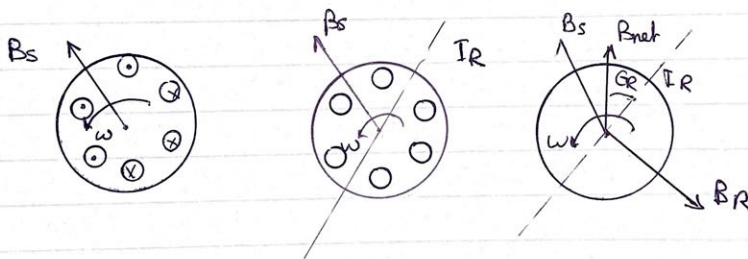
- In squirrel cage Resistance is constant But in wound rotor I can control it by connecting an external resistance to it

But it needs maintenance

Basic Induction motor concept : Torque

$B_s \rightarrow$ induced voltage $\rightarrow I_R$ (lagging) $\rightarrow B_R$
 $\rightarrow$ Torque

- Speed of stator magnetic field $= n_{sync} = \frac{120 f_e}{P}$



$$T_{ind} = K \vec{B}_{net} \times \vec{B}_r = K B_{net} B_r \sin \delta$$

Is there upper limit to the motor's speed?

Yes!

- If Rotor Speed = Stator speed ($V_{relative} = 0$)
 No e_{ind} , No I_R , No B_R , No T , Rotor slows down due to friction
- It can never reach synchronous speed

Electrical frequency on the Rotor

(حسابات تردد في دائرة كير في الجال)

- When Rotor is locked: - (eind max)

$$\omega_m = 0 \rightarrow s = 1 \rightarrow f_r = s f_e = f_e$$

(حساب تردد في دائرة كير في الجال)

- When Rotor is Rotating: - (eind = 0)

$$\omega_m \neq 0 \rightarrow s = 0 \rightarrow f_r = 0$$

→ Generally: $f_r = s f_e$ constant

$$0 < s < 1, \quad 0 < n_m < n_{syn}$$

→ Also:

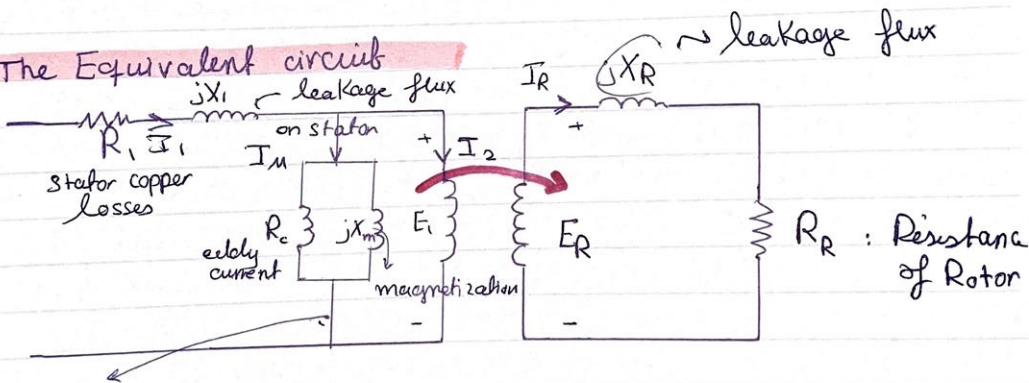
$$f_r = \frac{P}{120} (n_{syn} - n_m)$$

Note:

- Slip value is given by the manufacturer

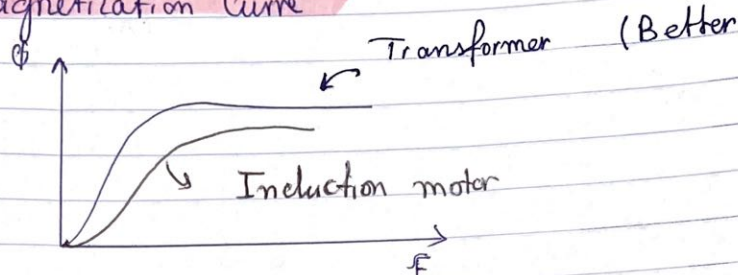
- n_m can be measured using encoder or Tacho generator

The Equivalent circuit



- Excitation Branch is on stator or Rotor but Preferably we take it on stator (Represents for Both S and R)

Magnetization Curve



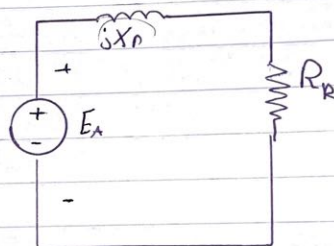
Turns Ratio (a)

- For wound rotor type: $a = \frac{N_1}{N_2}$
- For squirrel cage: (No windings) : a_{eff}

► Taking Secondary side

$$E_r = S E_s \leftarrow = E_i$$

$0 < S < 1$



at $S=1$ $E_{r \max} = E_{r0}$

so $E_r = S E_{r0}$

$$I_r = \frac{S E_{r0}}{R_r + S j X_{r0}} = S \frac{E_{r0}}{\frac{R_r}{S} + j X_{r0}}$$

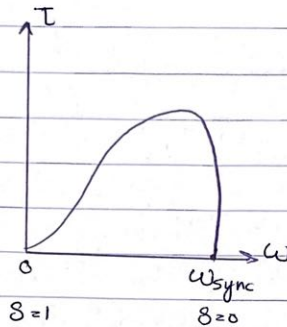
For inductance :

$$jX_r = j 2\pi f_r L = j 2\pi L (S f_e) = j S X_{r0}$$

so $jX_r = S jX_{r0}$

Note that:

- At very low slips, $R_r/s \gg X_{r0}$: I_r varies linearly with s
- At very high slips, $X_{r0} \gg R_r/s$: I_r approaches steady state value



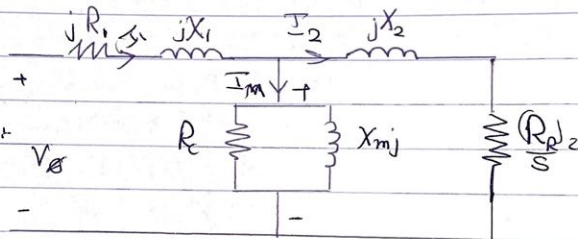
Now Back to a_{eff}

$$Z_R = \frac{R_r}{s} + jX_r$$

Single phase

$$Z_R' = a_{eff} (Z_R)$$

And circuit becomes:

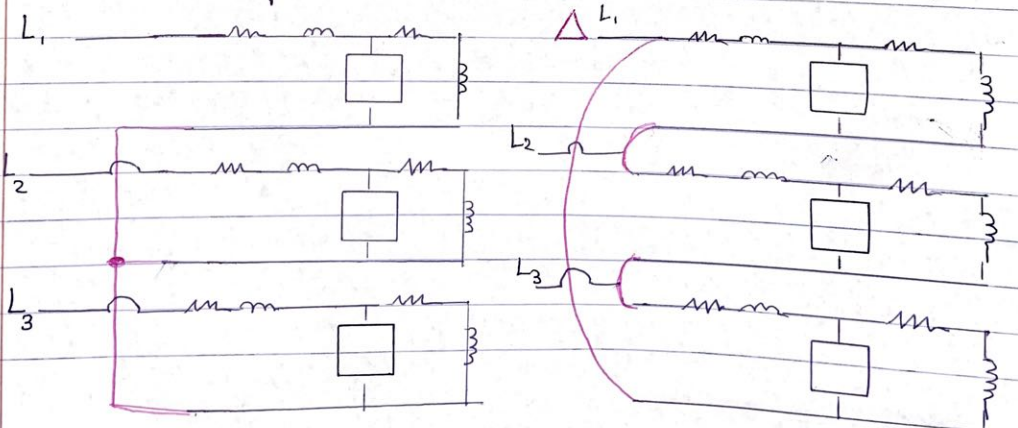


$$I_2 = a_{eff} I_1$$

The model we use

$$Z_{eq} = \left[\left(\frac{R_r}{s} + jX_r \right) \parallel (R_s + jX_s) \right] \rightarrow R_{eq} + jX_{eq}$$

For three phase connection



Power flow diagram

$$P_{in} = \sqrt{3} V_L I \text{ PF} = 3 V_{\phi} I_{\phi} \text{ PF}$$

CL: copper losses

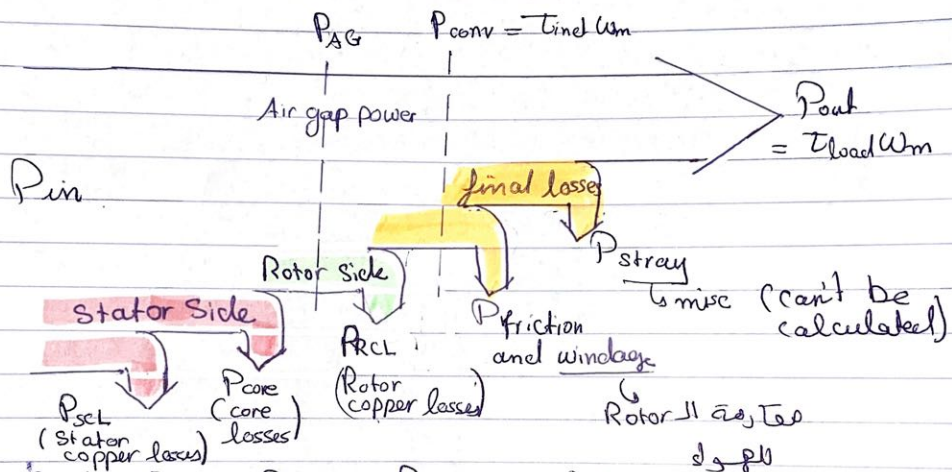
at Stator

Voltage given is always $R_{2/k} \frac{V_{LL}}{I}$

$$P_{scl} = 3 I_1^2 R_1$$

$$P_{RCL} = 3 I_2^2 R_2 = 3 P_{AG}$$

not over 5



$$\bullet P_{AG} = P_{in} - P_{SCL} - P_{Re} = 3I_2^2 \frac{R_2}{S}$$

$$\bullet P_{\text{conv}} = 3I_2^2 R_2 \left(\frac{1-s}{s} \right) = P_{\text{AG}} - P_{\text{RCL}} = (1-s) P_{\text{AG}}$$

- Rotational losses = $P_{\text{core}} + P_{\text{misc (stray)}} + P_{\text{F&W}}$

- $P_{core} = 3 E_1^2 G_c :$

$$G_C = \frac{1}{R_C}$$

$$P_{AG} = W_{syn} T_{ind}$$

$$P_{conv} = W_m T_{ind}$$

$$\text{So } T_{ind} = \frac{P_{AG}}{W_{syn}} = \frac{P_{conv}}{W_m}$$

This is not constant

- We use this since W_{syn} is constant