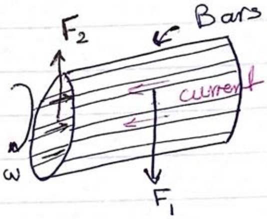
Induction Motors

Video

- Self starting motor, No need for external Dc source

Composites:-
1- Rotor
2- Stator

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



- No maintenanc 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

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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

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

n_m → mechanical shaft speed

n_{sync} → speed of magnetic field

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

$S = \frac{n_{sync} - n_m}{n_{sync}} \times 100\%$

- If Rotor rotates at Synchronous Speed $S=0$
- rotor is Stationary $S=1$
- All normal motor speeds $0 < S < 1$

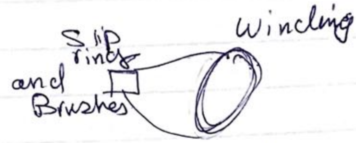
can be measured or calculated $n_m = (1-S) n_{sync}$ → can be calculated

- 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



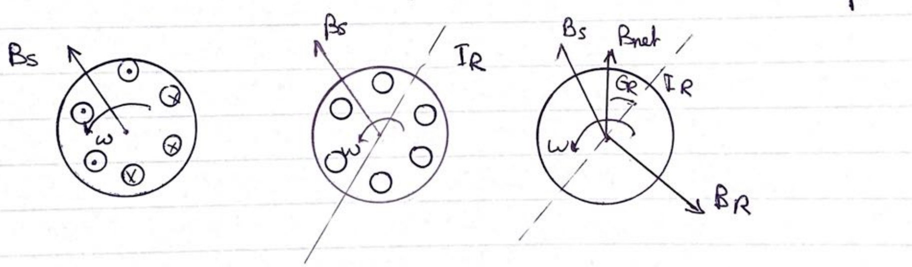
- In squirrel cage Resistance is constant But in wound rotor I can control it by connecting an external resistance to it

But it needs maintanance

Basic Induction motor concept : Torque

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

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



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

Is there upper limit to the motor's speed?
Yes!

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

Electrical frequency on the Rotor

(لأنه ثابت مدامه بتحرك فاكل تقطيع خطوط المجال

- When Rotor is locked:- (e_{ind} max)

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

  لا يوجد تقطيع خطوط المجال

- when Rotor is Rotating:- ($e_{ind} = 0$)

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

→ Generally: $\boxed{f_r = S f_e}$ ← f_e constant

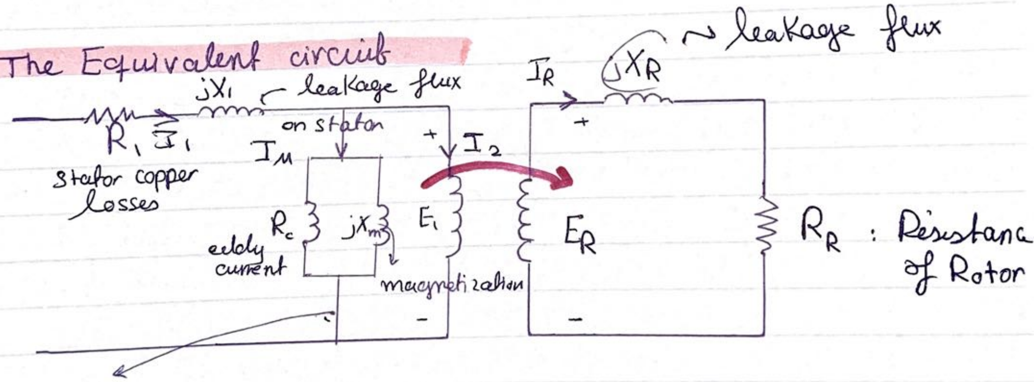
$0 < S < 1$, $0 < n_m < n_{syn}$

→ Also: $\boxed{f_r = \frac{P}{120}(n_{syn} - n_m)}$

Note:

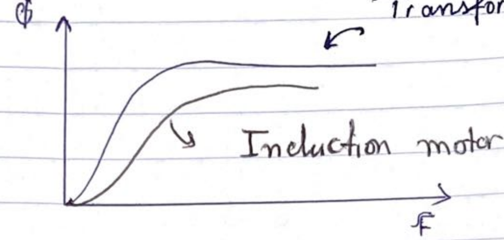
- Slip value is given by the manufactur
- n_m can be measured using encoder or Taco generator

The Equivalent circuit



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

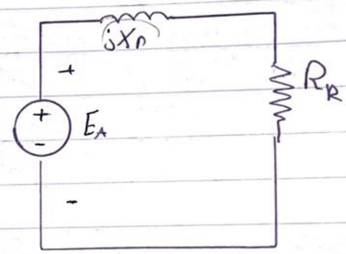
Magnetization Curve



Turns Ratio (a)

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

▶ Taking Secondary Side



$E_r = S E_s$ ($E_s = E_1$), $0 < S < 1$

at $S = 1$ $\quad E_{r\,max} = E_{ro}$

so $\boxed{E_r = S E_{ro}}$

$$I_R = \frac{S E_{ro}}{R_r + S j X_{ro}} = S \frac{E_{ro}}{\frac{R_r}{s} + j X_{ro}}$$

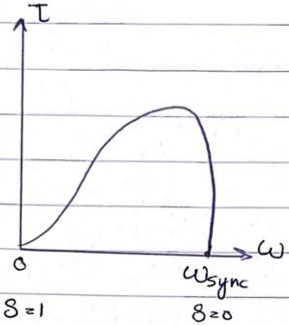
for inductance :

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

so $\boxed{jX_r = S j X_{ro}}$

Note that:

- At very low slips $R_R/S \gg X_{R_0}$: I_R varies linearly with S
- At very high slips, $X_{R_0} \gg R_R/S$: I_R approaches steady state value



Now Back to a_{eff}

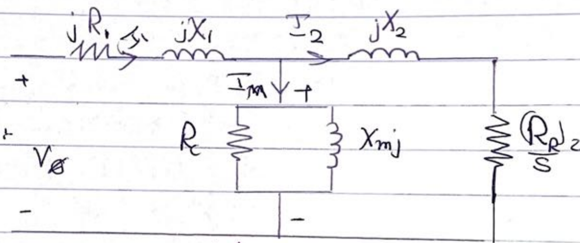
$Z_R = \frac{R_R}{S} + jX_R$

$Z_R' = a_{eff}^2 (Z_R)$

And circuit becomes:

$I_2 = a_{eff} I_1$

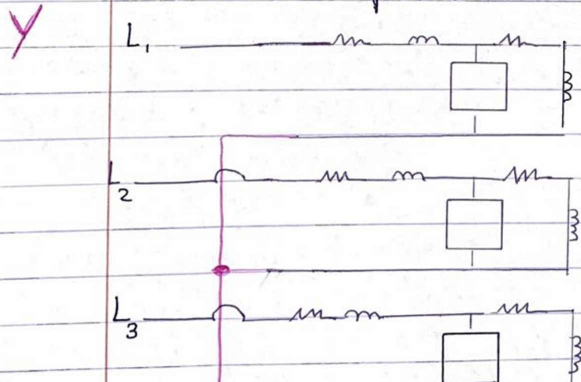
Single Phase

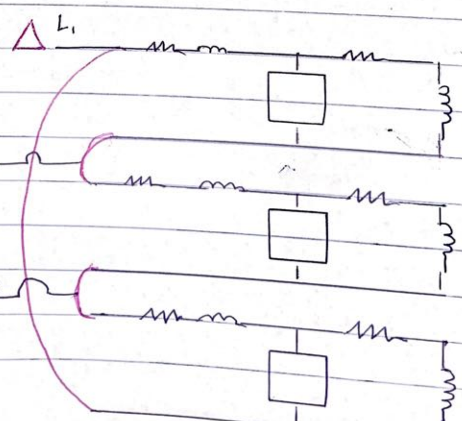


The model we use

$Z_{eq} = \left[\left(\frac{R_2}{S} + X_2 j\right) // (R_c // X_m j)\right] + R_1 + X_1 j$

For three phase connection





Power flow diagram

CL : copper losses

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

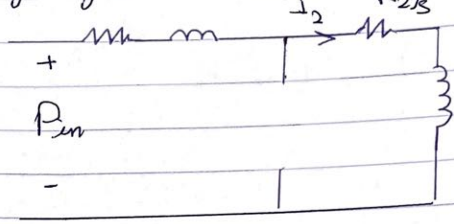
at stator

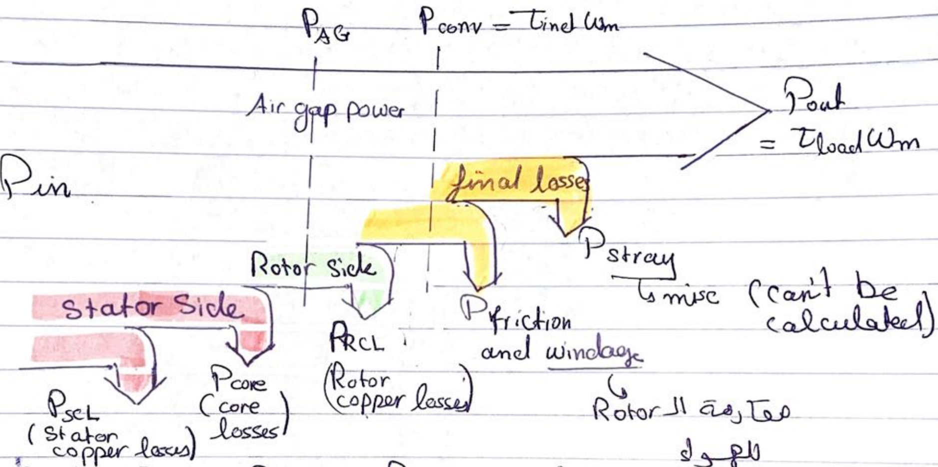
Voltage given is always V_{LL}

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

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

not over s





- $P_{AG} = P_{in} - P_{SCL} - P_{core} = 3 I_2^2 \frac{R_2}{S}$
- $P_{conv} = 3 I_2^2 R_2 \left(\frac{1-S}{S}\right) = P_{AG} - P_{RCL} = (1-S) P_{AG}$
- Rotational losses $= P_{core} + P_{misc}$ (stray) $+ P_{F\&W}$
- $P_{core} = 3 E_1^2 G_c$:

$G_c = \frac{1}{R_c}$

$$P_{AG} = \omega_{syn} \boxed{\tau_{ind}}$$

$$P_{conv} = \omega_m \boxed{\tau_{ind}}$$

So $\boxed{\tau_{ind} = \frac{P_{AG}}{\omega_{syn}} = \frac{P_{conv}}{\omega_m}}$ → ω_m: This is not constant

- We use this ($\frac{P_{AG}}{\omega_{syn}}$) since ω_{syn} is Constant