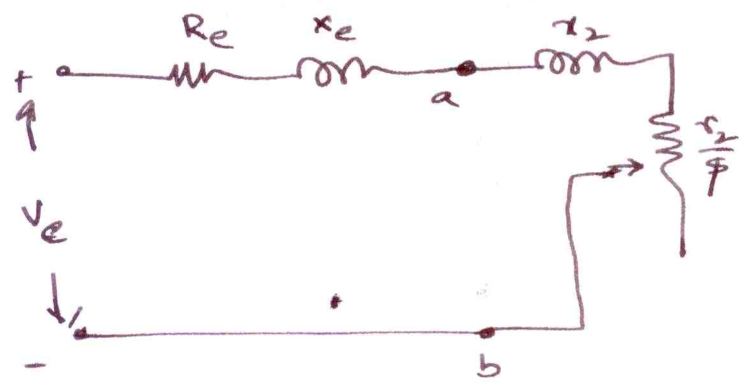
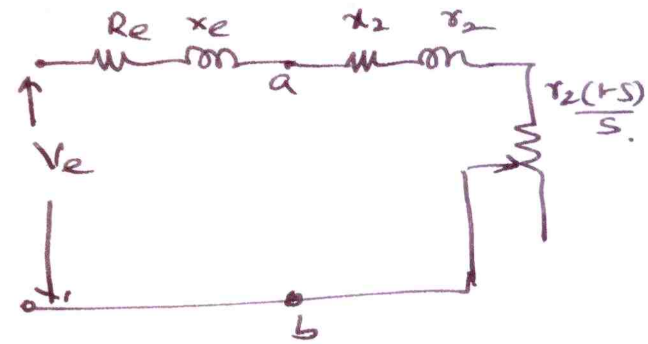
Torque - Slip characteristics:





$$\bar{V}_e = \frac{V_1 (j x_\phi)}{r_1 + j(x_1 + x_\phi)}, \quad \bar{Z}_e = \frac{(r_1 + j x_1)(j x_\phi)}{r_1 + j(x_1 + x_\phi)}$$

For most induction motors

$$x_1 + x_\phi \ggg r_1$$

$$\therefore \quad \bar{V}_e = \frac{V_1 x_\phi}{x_1 + x_\phi}, \quad \bar{Z}_e = \frac{r_1 x_\phi}{X_1} + j\frac{x_1 x_\phi}{X_1}$$

where $X_1 = x_1 + x_\phi$

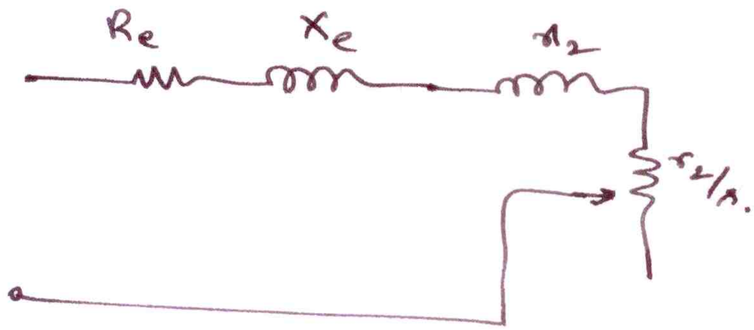
$$\bar{I}_2 = \frac{\bar{V}_e}{\left(R_e + \frac{r_2}{s}\right) + j(x_2 + x_e)}$$

$$T_e = \frac{m}{\omega_s} \cdot \frac{V_e^2}{\left(R_e + \frac{r_2}{s}\right)^2 + (x_2 + x_e)^2} \cdot \frac{r_2}{s} \rightarrow (\mathrm{Nm})$$

$$T_e = \frac{K_t}{\left(R_e + \frac{r_2}{s}\right)^2 + X^2} \cdot \frac{r_2}{s}; \quad \text{where } K_t = \frac{m V_e^2}{\omega_s}$$

$$X = x_2 + x_e.$$

Maximum internal Torque:- (T_{em})



Torque is maximum when $\frac{I_2^2 r_2}{s}$ is maximum.

→ use maximum power x^r theorem.

$$\frac{r_2}{s_{mT}} = \sqrt{R_e^2 + (X_e + x_2)^2} = \sqrt{R_e^2 + x^2}$$

$\boxed{x = x_e + x_2}$

Slip at which maximum torque occurs is

$$s_{mT} = \frac{r_2}{\sqrt{R_e^2 + x^2}}.$$

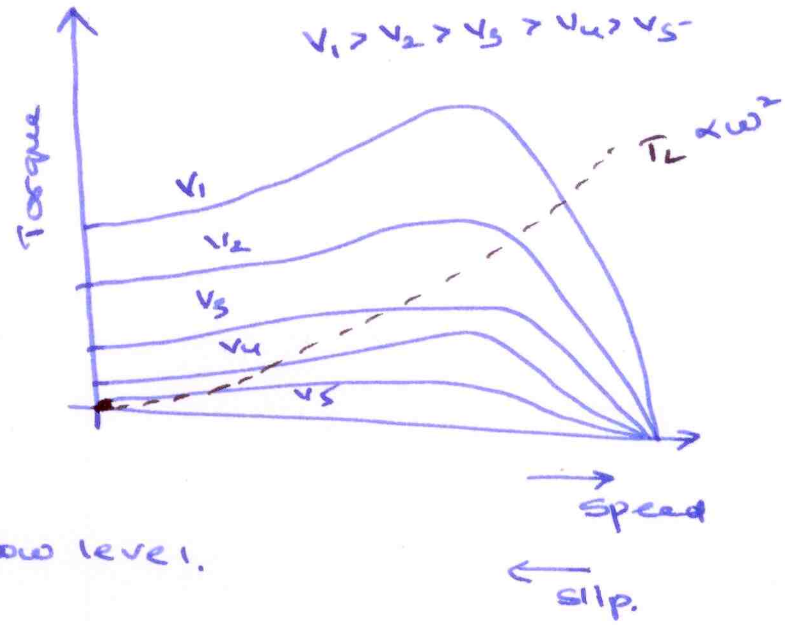
$$\therefore \quad T_{em} = \frac{K_t \cdot \sqrt{R_e^2 + x^2}}{\left[R_e + \sqrt{R_e^2 + x^2}\right]^2 + x^2}$$

$$= \frac{K_t}{2\left[R_e + \sqrt{R_e^2 + x^2}\right]}$$

Slip at which maximum torque occurs is directly proportional to "r_2" but the maximum torque is independent of "r_2".

Speed control of Induction Motor.

① Variable voltage constant frequency



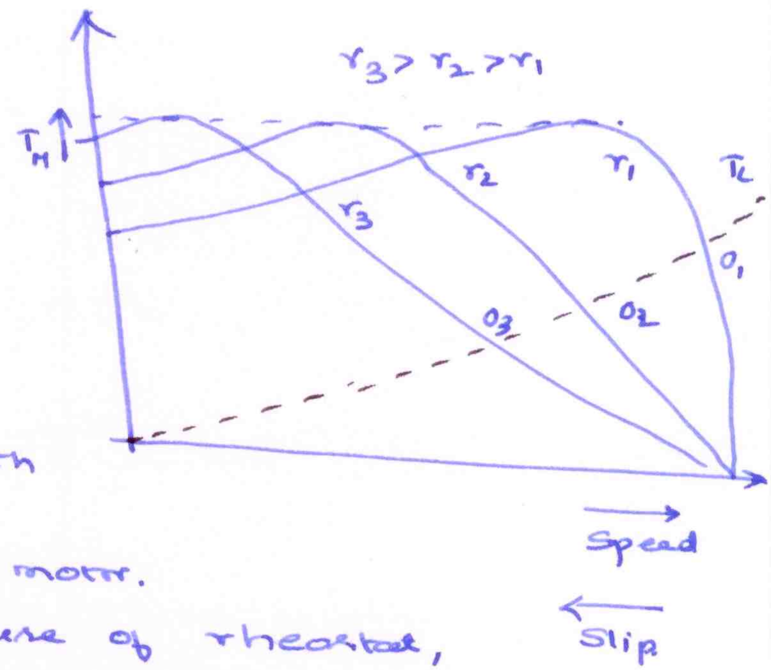
→ when voltage is reduced,
 → voltage across X_ϕ is reduced
  → magnetizing flux reduces.
  → Torque is reduced

→ at light loaded conditions ~~too~~ the flux need not be at rated level.

→ Power factor improves at low level.

→ Soft starting methods.

② Rotor resistance control



→ Slip at which max torque occurs is dependent on rotor resistance

→ Max torque is independent of rotor resistance

→ Starting torque increases with rotor resistance

→ Only possible with slip ring motor.

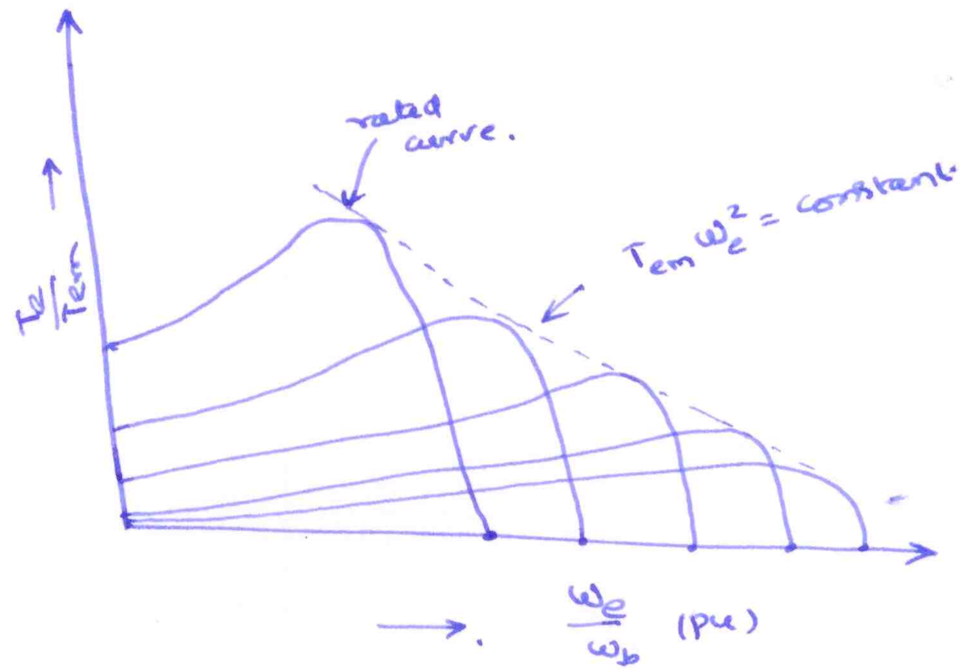
→ Not very efficient because of rheostat, also operation at high slip leads to more dissipation.

③ Pole changing method.

$$N_s = \frac{120 f}{P}.$$

④ Constant voltage Variable frequency.
(High frequency).

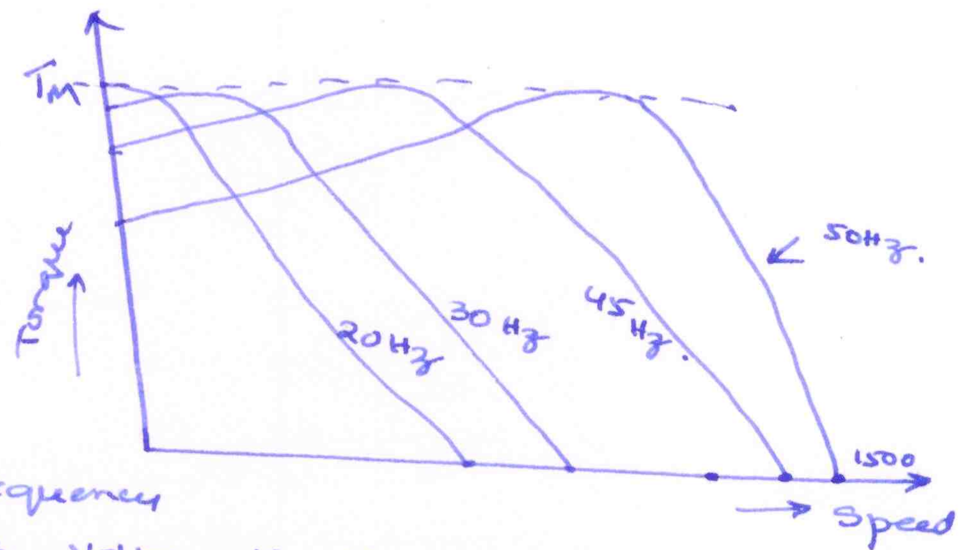
- airgap flux, rotor current decreases ↑
- Machine behaves like a 'dc' series motor in variable frequency mode of operation.



⑤ Variable Voltage Variable Frequency:
Constant V/Hz operation

$E = 4.44 N \phi_m f$

N: number of turns per phase.
ϕ_m: Maximum flux in air gap.
f: frequency.



To reduce speed frequency can be reduced. If voltage is kept constant, and frequency is reduced, "ϕ_m" core may saturate.

∴ E/f is generally maintained constant.

→ The maximum torque remains constant.
→ In VVVF drive, ~~slip~~ efficiency is high.
→ The machine has low starting torque at base frequency, but it is possible to get maximum torque at starting.
→ To maintain sufficient torque at "low speeds", it is required to give voltage boost.