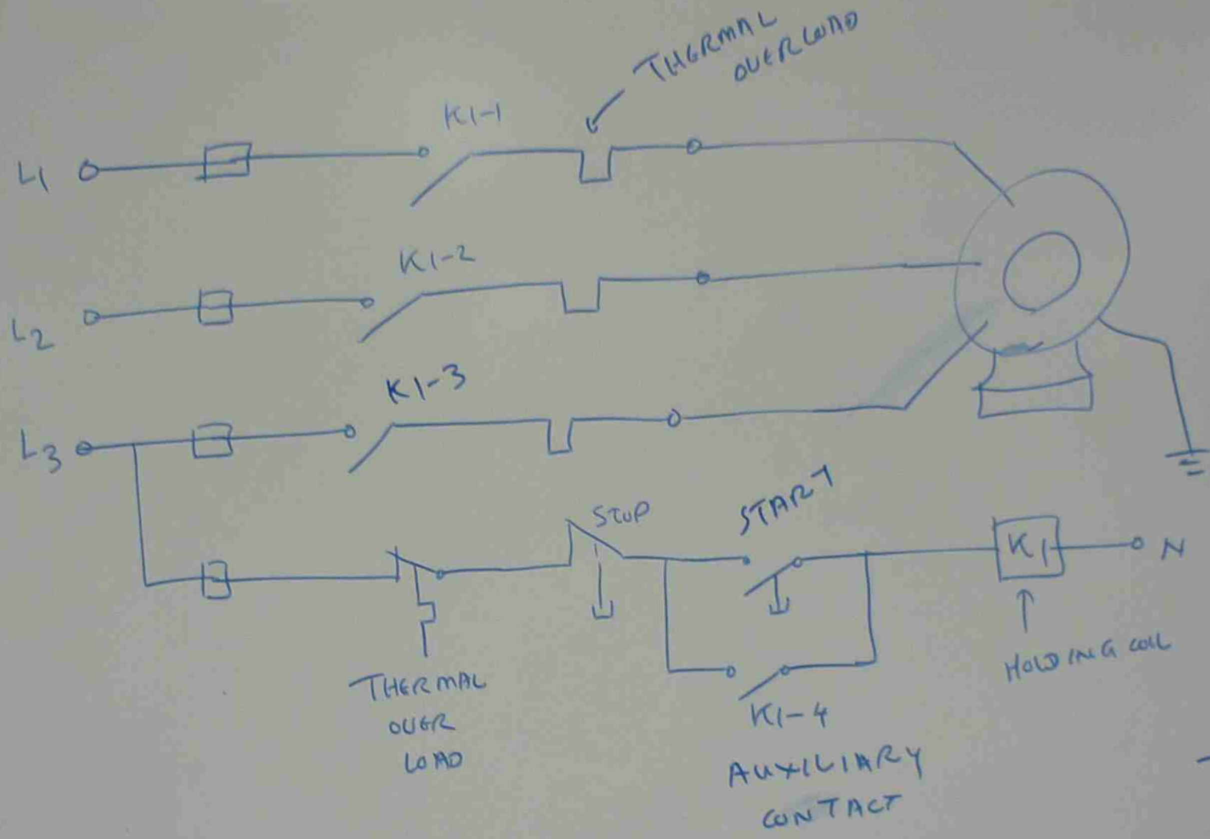
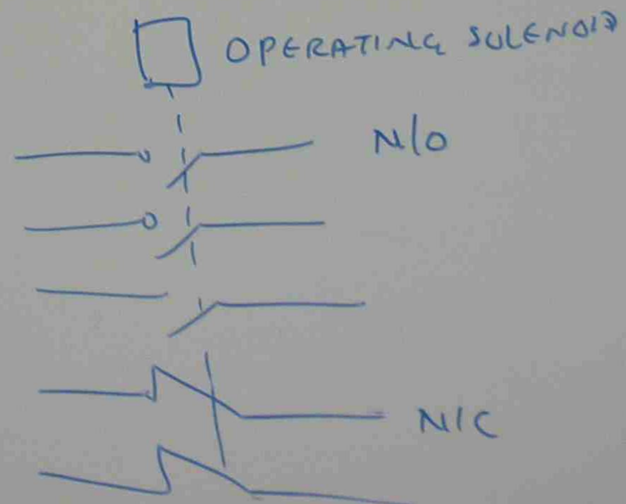


CURRENT $\propto$ VOLTAGE

TORQUE $\propto$ (VOLTAGE)^2

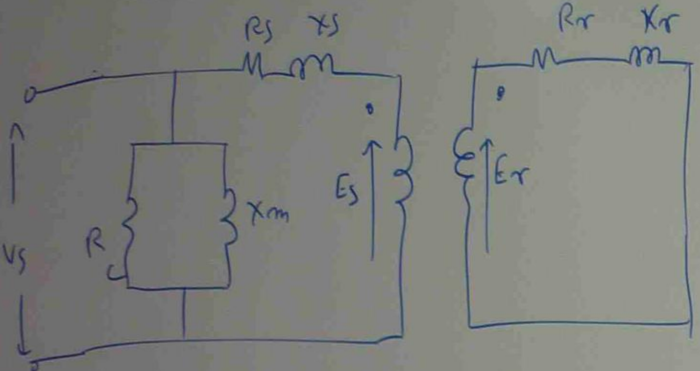
CONTACTORS



LOCKED ROTOR CURRENT $= \dfrac{1}{0.5} \times$ MEASURED CURRENT

LOCKED ROTOR TORQUE $= \dfrac{1}{(0.5)^2} \times$ MEASURED TORQUE

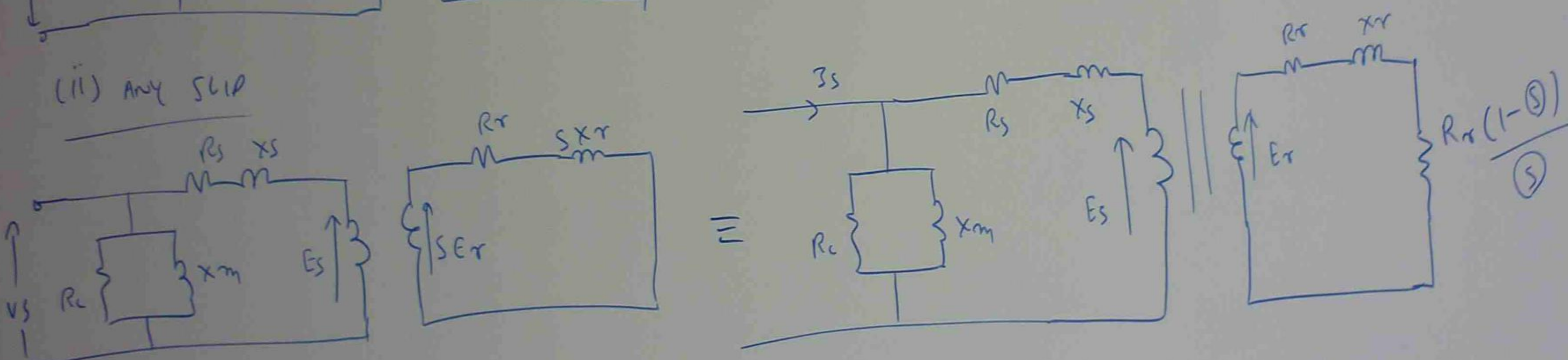
(i) STAND STILL



$$I_r = \frac{S\,E_r}{R_r + jS X_r} = \frac{E_r}{\frac{R_r}{S} + jX_r} = \frac{E_r}{(R_r + jX_r) + R_r\left(\frac{1-S}{S}\right)}$$

I_r = ROTOR WINDING CURRENT

(ii) ANY SLIP



ANY SLIP

S = SLIP

E_s = STATOR VOLTAGE

E_r = ROTOR VOLTAGE

R_c = CORE RESISTANCE

X_m = CORE INDUCTIVE REACTANCE

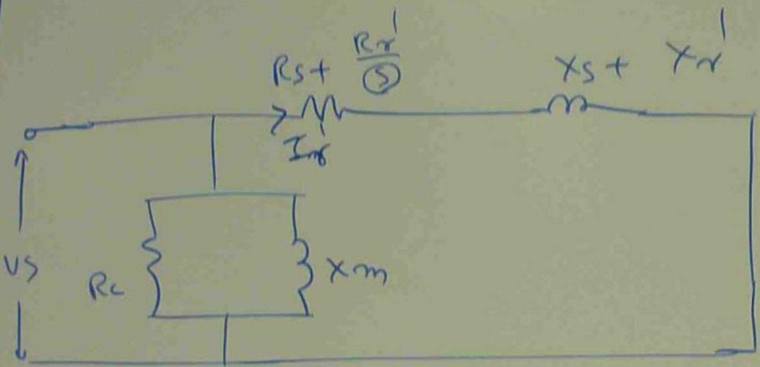
R_r = ROTOR WINDING RESISTANCE

X_r = ROTOR WINDING INDUCTIVE REACTANCE

R_s = STATOR WINDING RESISTANCE

X_s = STATOR WINDING INDUCTIVE REACTANCE

OVER ALL EQUIVALENT CIRCUIT



$$\frac{R_r'}{S} = (\text{TURN RATIO})^2 \times \frac{R_r}{S}$$

$$X_r' = (\text{TURN RATIO})^2 \times X_r$$

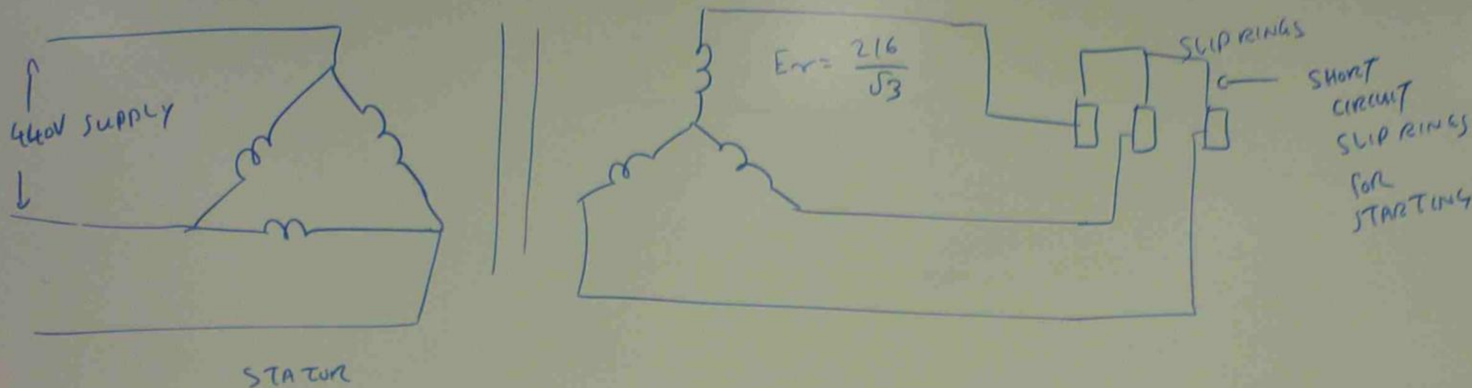
$$\text{TURN RATIO} = \frac{\text{STATOR TURNS / PHASE}}{\text{ROTOR TURNS / PHASE}}$$

$$I_r' = \frac{V_s}{\sqrt{\left(R_s + \frac{R_r'}{S}\right)^2 + \left(X_s + X_r'\right)^2}}$$

Ex 20

A 440V 4 pole 3ϕ 50 Hz SLIP RING INDUCTION MOTOR HAS IT'S WINDING MESH (Δ) CONNECTED AND IT'S ROTOR WINDING STAR CONNECTED. THE STANDSTILL VOLTAGE MEASURED BETWEEN SLIP RINGS WITH THE ROTOR OPEN CIRCUIT IS 216V. THE STATOR RESISTANCE / PHASE IS 0.6Ω AND THE STATOR REACTANCE / PHASE IS 3Ω. THE ROTOR RESISTANCE / PHASE IS 0.05Ω AND ROTOR REACTANCE / PHASE IS 0.25Ω. CALCULATE THE ROTOR CURRENT AND STATOR CURRENT WHEN SLIP RINGS ARE SHORT CIRCUITED TO START THE MOTOR.

CALCULATE ROTOR POWER FACTOR AND STATOR POWER FACTOR.



$$\text{TURN RATIO} \quad k_s = \frac{E_s/ph}{E_r/ph} = \frac{440}{216/\sqrt{3}} = \frac{440}{126} = 3.49$$

$$I_r = \frac{E_r/ph}{R_r + j\,s\,x_r} = \frac{E_r/ph}{\frac{R_r}{s} + j\,x_r} = \frac{E_r/ph}{\sqrt{\left(\frac{R_r}{s}\right)^2 + x_r^2}} = \frac{126}{\sqrt{\left(\frac{0.05}{1}\right)^2 + (0.25)^2}} = 504 \text{ Amp}$$

ROTOR CURRENT

$$\text{STATOR CURRENT} = I_r' = \frac{V_s/ph}{\sqrt{\left(R_s + \frac{R_r'}{s}\right)^2 + \left(x_s + x_r'\right)^2}} = \frac{440}{\sqrt{(0.6 + 0.609)^2 + (3 + 3.045)^2}}$$

$$= 71.42 \text{ Amp}$$

$R_s = 0.6\,\Omega$

$x_s = 3\,\Omega$

$$\frac{R_r'}{s} = k_s^2 \times \frac{R_r}{s} = 3.49^2 \times \frac{0.05}{1} = 0.609\,\Omega$$

$$x_r' = k_s^2 \times x_r = 3.49^2 \times 0.25 = 3.045$$

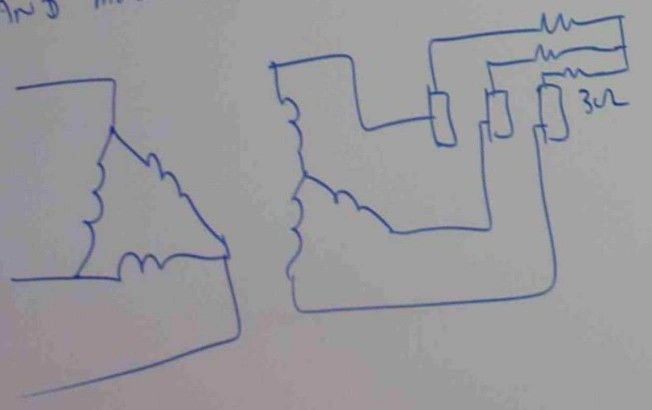
$$\text{STATOR P.F} = \cos\left(\tan^{-1}\frac{X_s + X_r'}{R_s + \frac{R_r'}{S}}\right)$$

$$= \cos\left(\tan^{-1}\frac{3 + 3.045}{0.6 + 0.609}\right)$$

$$= \cos\tan^{-1} 5$$

$$= \cos 78.6 = 0.196 \text{ LAGGING}$$

EX 21 IN ABOVE PROBLEM, CALCULATE ROTOR CURRENT AND STATOR CURRENT WHEN SLIP RINGS ARE CONNECTED TO 3Ω EXTERNAL RESISTANCE AND MOTOR IS RUNNING AT 0.03 SLIP



ROTOR CURRENT

$$I_r = \frac{E_r}{\sqrt{\left(\frac{R_r}{S} + R_{EXT}\right)^2 + (X_r)^2}}$$

$$= \frac{126}{\sqrt{\left(\frac{0.05}{0.3} + 3\right)^2 + (0.25)^2}}$$

$$= 39.6 \text{ Amp}$$

$$\text{ROTOR PF} : \cos\tan^{-1}\frac{X_r}{\frac{R_r}{S} + R_{Ext}}$$

$$= \cos\tan^{-1}\frac{0.25}{3.166} = 0.996 \text{ LAGGING}$$

$$\text{STATOR PF} = \cos\tan^{-1}\frac{X_s + X_r'}{R_s + K_s^2\left(\frac{R_r}{S} + R_{Ext}\right)}$$

$$= \cos\tan^{-1}\frac{(3.045 + 3)}{0.6 + 3.49^2\left(\frac{0.05}{0.3} + 3\right)}$$

$$= \cos\tan^{-1} 0.154$$

$$= \cos 8.77$$

$$= 0.988 \text{ LAGGING}$$

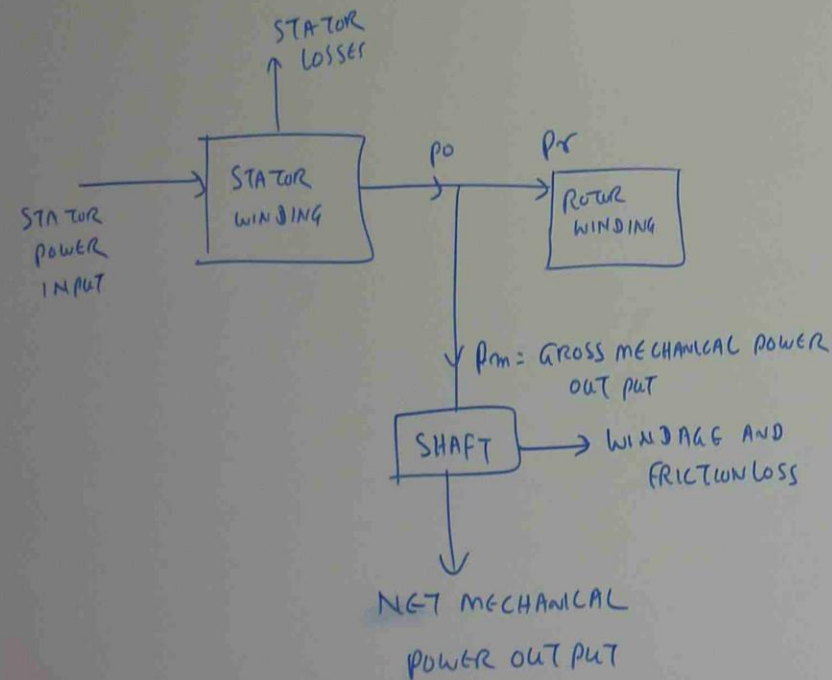
$$\text{STATOR CURRENT} = I_r' = \frac{V_s/ph}{\sqrt{\left(R_s + K_s^2\left(\frac{R_r}{S} + R_{Ext}\right)\right)^2 + (X_s + X_r')^2}}$$

$$I_r' = \frac{440}{\sqrt{\left(0.6 + 3.49^2\left(\frac{0.05}{0.3} + 3\right)\right)^2 + \left(3 + 3.49^2 \times 0.25\right)^2}}$$

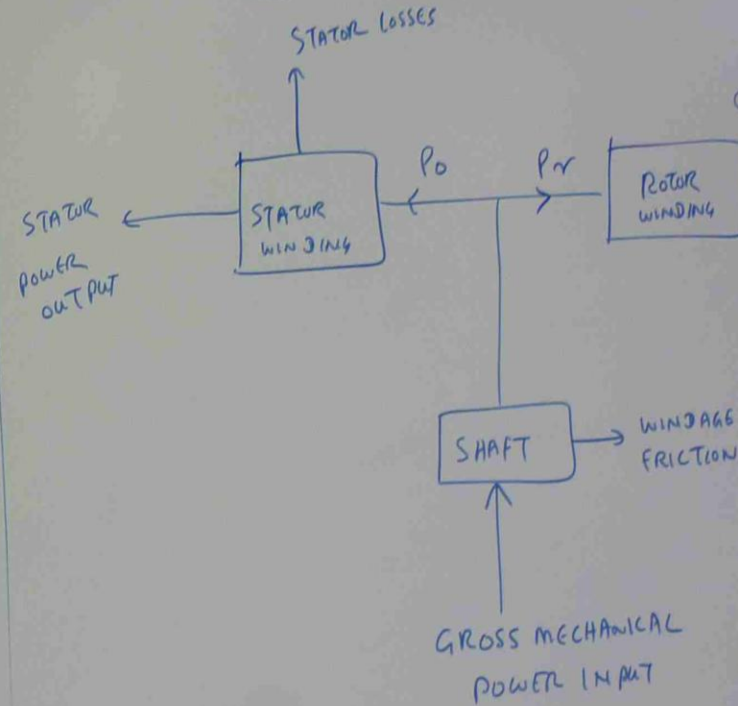
$$= 11.11 \text{ Amp}$$

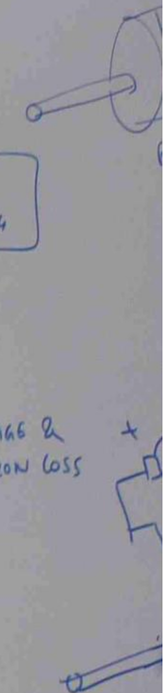
POWER TRANSFER IN INDUCTION MACHINE

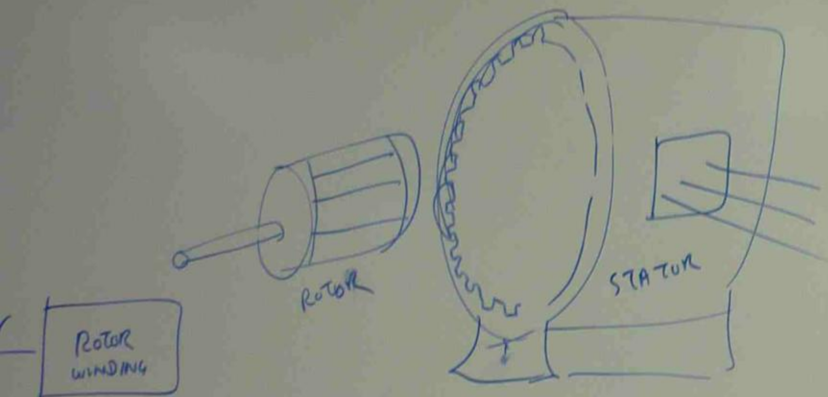
MOTOR MODE



GENERATOR MODE

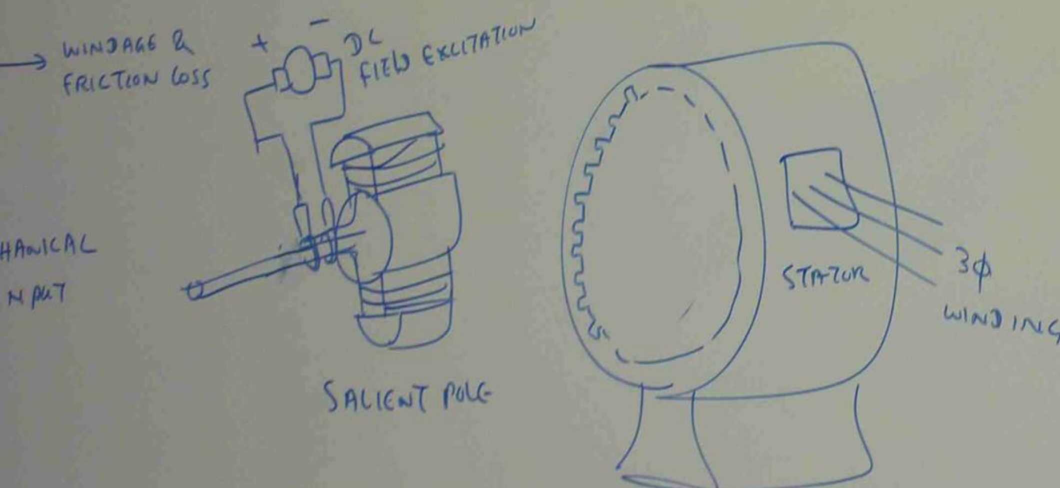






INDUCTION MACHINE

(INDUCTION MOTOR)



SYNCHRONOUS GENERATOR

SYNCHRONOUS MOTOR

FOR MOTOR CASE (3ϕ)

POWER ABSORBED BY IDEAL STATOR WINDING $P_0 = 3 E_S I_r' \cos\phi_r$

POWER DISSIPATED IN THE ROTOR CIRCUIT $= 3 S E_r I_r \cos\phi_r$

<OR>

$3 S E_S I_r' \cos\phi_r$

MECHANICAL POWER $(P_m) = P_0 - P_r$

$= P_0 - S P_0$

$P_m = P_0 (1 - S)$

POWER DISSIPATED IN ROTOR RESISTANCE $= 3 I_r^2 R_r \left(\frac{1-S}{S}\right)$

ROTOR CIRCUIT POWER LOSS $= 3 (I_r')^2 R_r'$

POWER ABSORBED BY IDEAL STATOR WINDING $= 3 (I_r')^2 \frac{R_r'}{S}$

GROSS MECHANICAL POWER OUTPUT = $P_{m} = 3\left(I_r^{1}\right)^2 R_r \left(\frac{1-s}{s}\right)$

GROSS TORQUE DEVELOPED $T = \frac{3}{2\pi n_r}\left(I_r^{1}\right)^2 R_r^{1} \left(\frac{1-s}{s}\right)$

$n_o = \frac{f}{P/2}$ n_r = ROTOR SPEED (RPM) = $(1-s)$ ROTOR SPEED AT NO LOAD

$n_r = (1-s)\, n_s$

s = SLIP

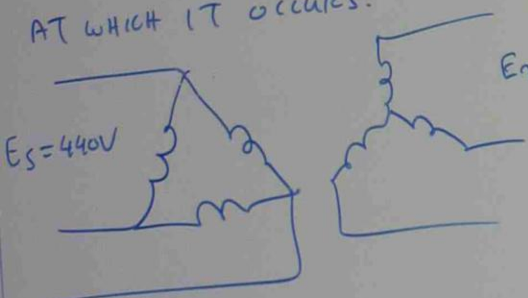
ANY TORQUE → $T = \frac{3 V_s^2}{4\pi n_o} \frac{s R_r^{1}}{\left[\left(s R_s + R_r^{1}\right)^2 + s^2\left(X_s + X_r^{1}\right)^2\right]}$

MAXIMUM TORQUE → $T_{MAX} = \frac{3 V_s^2}{4\pi n_o} \times \frac{s}{\left(s R_s + R_r^{1}\right)}$

SLIP AT MAXIMUM TORQUE $S_m = \frac{R_r^{1}}{\sqrt{R_s^2 + \left(X_s + X_r^{1}\right)^2}}$

Ex (22)

A 440V 4poles 3φ 50Hz SLIP RING INDUCTION MOTOR HAS IT'S STATOR WINDING DELTA CONNECTED AND ROTOR WINDING STAR CONNECTED. THE STANDSTILL VOLTAGE MEASURED BETWEEN SLIP RINGS WITH THE ROTOR OPEN CIRCUITED IS 218V. THE STATOR RESISTANCE PER PHASE IS 0.6Ω AND THE STATOR REACTANCE PER PHASE IS 3Ω. THE ROTOR RESISTANCE PER PHASE IS 0.05Ω AND THE ROTOR REACTANCE PER PHASE IS 0.25Ω. CALCULATE THE MAXIMUM TORQUE AND THE SLIP AT WHICH IT OCCURS.



$$E_r(ph) = \frac{218}{\sqrt{3}} = 126V$$

$$K_t = \frac{E_s(ph)}{E_r(ph)} = \frac{440}{126} = 3.49$$

$$R_r' = K_t^2 \times R_r = 3.49^2 \times 0.05 = 0.61\Omega$$

$$X_r' = K_t^2 \times X_r = 3.49^2 \times 0.25 = 3.05\Omega$$

$$S_m = \frac{R_r'}{\sqrt{R_s^2 + (X_s + X_r')^2}} = \frac{0.61}{\sqrt{0.6^2 + (3+3.05)^2}} = 0.1$$

$$n_0 = \frac{f}{P/2} = \frac{50}{4/2} = \frac{50}{2} = 25$$

$$T_{max} = \frac{3V_s^2}{4\pi n_0} \frac{s R_r'}{\sqrt{(s R_s + R_r')^2 + s^2 (X_s + X_r')^2}}$$

$$= \frac{3 \times 440^2 \times 1 \times 0.61}{4 \times 3.1416 \times 25 \sqrt{(1 \times 0.6 + 0.61)^2 + 1^2 (3 + 3.05)^2}}$$

$$= 277 \text{ N-m}$$