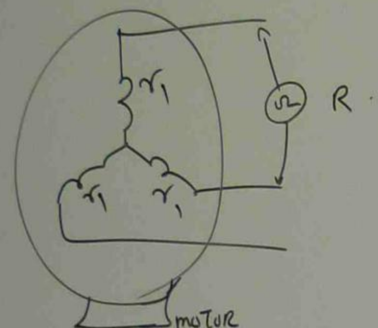
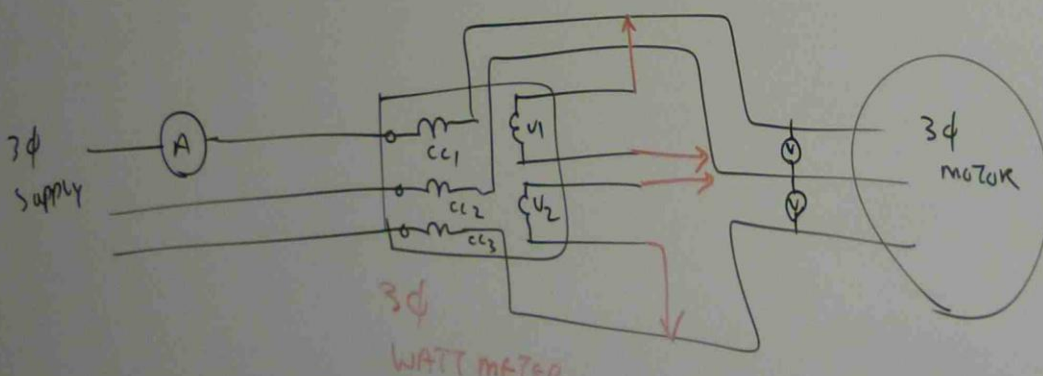
TESTS TO DETERMINE THE EQUIVALENT CIRCUIT OF 3ϕ MOTOR

NO LOAD TEST ⟶ TO DETERMINE MAGNETIZING REACTANCE AND CORE RESISTANCE

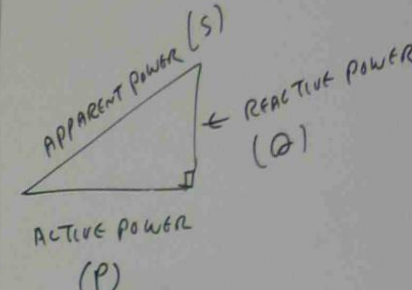


$$r_1 = \frac{R}{2}$$



RUN THE MOTOR AT NO LOAD

- MEASURE RATED LINE TO LINE VOLTAGE (E_{NL}
- MEASURE NO LOAD CURRENT (I_{NL})
- MEASURE TOTAL 3ϕ POWER (P_{NL})



APPARENT POWER AT NO LOAD $= S_{NL}$

ACTIVE POWER AT NO LOAD $= P_{NL}$

REACTIVE POWER AT NO LOAD $= Q_{NL}$

3ϕ WATTMETER READING $= P_{NL}$

DETE

R_m

$R_m =$

$X_m =$

R

R AT NO LOAD

TED LINE TO LINE VOLTAGE (E_{NL})

LOAD CURRENT (I_{NL})

AL 3ϕ POWER (P_{NL})

REACTIVE POWER (Q)

$= S_{NL}$

$= P_{NL}$

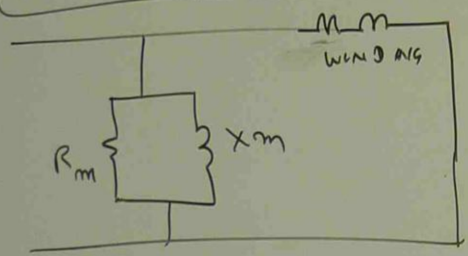
$= Q_{NL}$

NETOR ING $= P_{NL}$

$$S_{NL} = \sqrt{3}\, E_{NL}\, I_{NL}$$

$$Q_{NL} = \sqrt{S_{NL}^2 - P_{NL}^2}$$

DETERMINATION OF CORE RESISTANCE & REACTANCE



R_m = CORE RESISTANCE

X_m = CORE INDUCTIVE REACTANCE

$$R_m = \frac{E_{NL}^2}{\text{WINDAGE + FRICTION + IRON LOSS}}$$

AT NO LOAD

TOTAL NO LOAD ACTIVE POWER (P_{NL}) = COPPER LOSS IN WINDING + (WINDAGE + FRICTION + IRON LOSS)

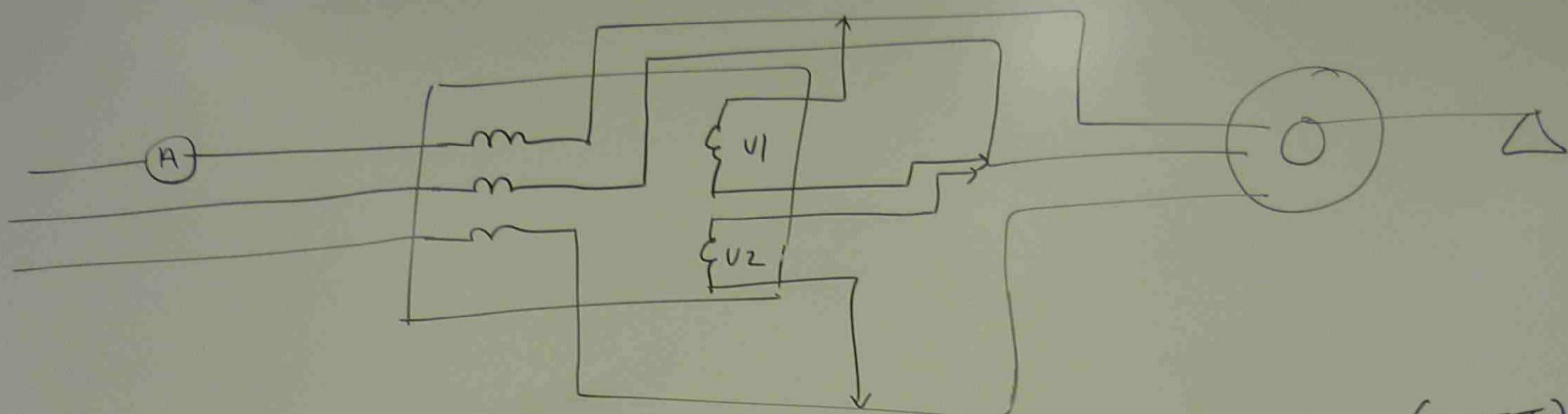
WINDAGE + FRICTION + IRON LOSS = P_{NL} − COPPER LOSS IN WINDING

$= P_{NL} - 3 I_{NL}^2\, r$

$$X_m = \frac{E_{NL}^2}{Q_{NL}}$$

DETERMINATION OF WINDING RESISTANCE AND REACTANCE

LOCKED ROTOR TEST



3ϕ WATT METER READING = P_{LF} (LOCKED ROTOR ACTIVE POWER) (WATT)

E_{LF} = LOCKED ROTOR VOLTAGE

I_{LF} = LOCKED ROTOR CURRENT

S_{LF} = LOCKED ROTOR APPARENT POWER (VA) $= \sqrt{3}\, E_{LF} I_{LF}$

Q_{LF} = LOCKED ROTOR REACTIVE POWER (VAR)

$$Q_{LF} = \sqrt{S_{LF}^2 - P_{LF}^2}$$

$$\underset{\text{WINDING REACTANCE}}{X} = \frac{Q_{LF}}{3 I_{LF}^2}$$

$$\underset{\text{WINDING RESISTANCE}}{r_2} = \frac{P_{LF}}{3 I_{LF}^2} - r$$

Pb A NO LOAD TEST CONDUCTED ON A 30 HP, 835 RPM 440V 3ϕ 60 HZ SQUIRREL CAGE INDUCTION MOTOR YIELD THE FOLLOWING RESULTS.

NL

NO LOAD VOLTAGE (LINE TO LINE) = 440V

NO LOAD CURRENT = 14 A

NO LOAD POWER = 1470 W

RESISTANCE MEASURED BETWEEN TWO TERMINALS = 0.5Ω

LF THE LOCKED ROTOR TEST CONDUCTED AT REDUCED VOLTAGE GAVE THE FOLLOWING RESULTS.

LOCKED ROTOR VOLTAGE (L–L) = 163V

LOCKED ROTOR POWER = 7200W

LOCKED ROTOR CURRENT = 60 A

DETERMINE THE EQUIVALENT CIRCUIT OF THE MOTOR

NO LOAD TEST

$$r_1 = \frac{R}{2} = \frac{0.5}{2} = 0.25\Omega$$

$E_{NL} = 440V$, $I_{NL} = 14A$, $P_{NL} = 1470W$

$$S_{NL} = \sqrt{3}\, E_{NL} I_{NL} = 1.7321 \times 440 \times 14 = 10669\ VA$$

$$Q_{NL} = \sqrt{S_{NL}^2 - P_{NL}^2} = \sqrt{10669^2 - 1470^2} = 10586\ VAR$$

r

$$X_m = \frac{E_{NL}^2}{Q_{NL}} = \frac{440^2}{10586} = 18.3\Omega$$

$$R_m = \frac{E_{NL}^2}{P_{NL} - 3 I_{NL}^2 r_1} = \frac{440^2}{1470 - 3\times 14^2 \times 0.25} = 146\Omega$$

<u>Locked rotor test</u>

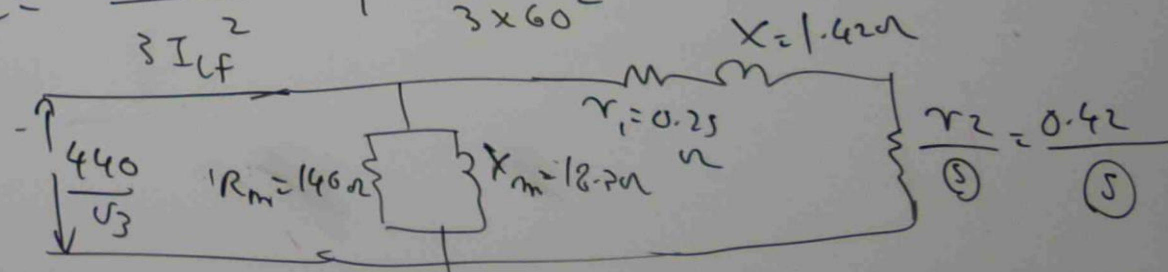
$$S_{LF} = \sqrt{3}\, E_{LF}\, I_{LF} = 1.7321 \times 60 \times 163 = 16939\ \text{VA}$$

$$P_{LF} = 7200\ \text{WATT}$$

$$Q_{LF} = \sqrt{S_{LF}^2 - P_{LF}^2} = \sqrt{16939^2 - 7200^2} = 15333\ \text{VAR}$$

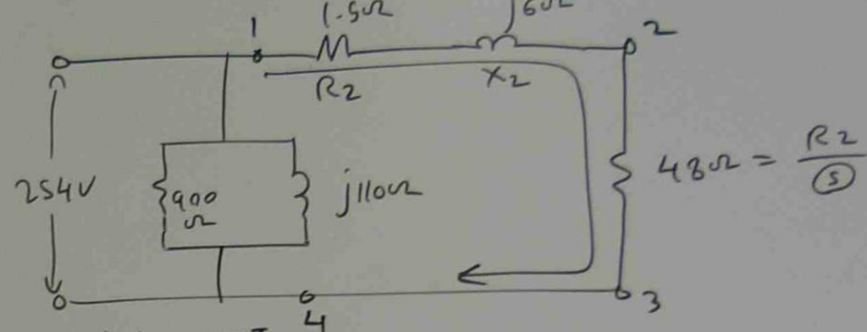
$$X = \frac{Q_{LF}}{3 I_{LF}^2} = \frac{15333}{3\times 60^2} = 1.42\Omega$$

$$r_2 = \frac{P_{LF}}{3 I_{LF}^2} - r_1 = \frac{7200}{3\times 60^2} - 0.25 = 0.42\Omega$$



CALCULATING TORQUE, LINE CURRENT, POWER, POWER FACTOR, SLIP AND EFFICIENCY FOR THE MOTOR USING EQUIVALENT CIRCUIT PARAMETERS FOR GIVEN LOAD

Ex 29



STATOR COPPER LOSS = 44 WATT

CALCULATE (a) ACTIVE POWER DELIVERED TO ROTOR

(b) MECHANICAL POWER INPUT TO SHAFT

(c) STATOR POWER INPUT

(d) INPUT CURRENT AND P.F

(e) IF WINDAGE & FRICTION LOSS IS 70 WATT

FIND OUTPUT TORQUE AND EFFICIENCY

SPEED = 1854 RPM.

$R_{1234} = 1.5 + 48 = 49.5\,\Omega$

$$Z_{1234} = \sqrt{R_{1234}^2 + X^2}$$

$$= \sqrt{49.5^2 + 6^2} = 49.86\,\Omega$$

$$I_{1234} = \frac{V}{Z_{1234}} = \frac{254}{49.86} = 5.09 \text{ Amp.}$$

(a) ACTIVE POWER DELIVERED TO ROTOR $= I^2 \dfrac{R_2}{S}$

$$= 5.09^2 \times 48$$

$$= 1243.5 \text{ WATT}$$

COPPER LOSS

(b) MECHANICAL POWER INPUT TO SHAFT $= (I^2 R \text{ loss in rotor}) +$ ACTIVE POWER DELIVERED TO ROTOR

$$= I^2 R_2 + 1243.5$$

$$= (5.09)^2 \times 1.5 + 1243.5 = 1282.36 \text{ WATT}$$

(c) STATOR

(d)

7

(c) STATOR POWER INPUT = CORE LOSS + STATOR COPPER LOSS + MECHANICAL POWER INPUT TO SHAFT

$$= \frac{(\text{TERMINAL VOLTAGE})^2}{\text{CORE RESISTANCE}} + 44 + 1282.3$$

$$= \frac{(254)^2}{900} + 44 + 1282.3$$

$$= 1398.04 \text{ WATT}$$

(d) INPUT CURRENT = $\dfrac{\text{TOTAL APPARENT POWER}}{\text{SUPPLY VOLTAGE}}$

$$\text{TOTAL APPARENT POWER} = \sqrt{\text{ACTIVE POWER}^2 + \text{REACTIVE POWER}^2}$$

ACTIVE POWER ↕ STATOR POWER INPUT

REACTIVE POWER ↕ $\dfrac{(\text{SUPPLY VOLTAGE})^2}{\text{CORE REACTANCE}}$

UE POWER
LIVERED TO
OTOR

1282.35 WATT

ACTIVE POWER = STATOR POWER INPUT = 1398.04 W

$$\text{REACTIVE POWER} = \frac{(\text{SUPPLY VOLTAGE})^2}{\text{CORE REACTANCE}} = \frac{(254)^2}{110} = 586 \text{ VAR}$$

$$\text{TOTAL APPARENT POWER} = \sqrt{1398.04^2 + 586^2} = 1515.8 \text{ VA}$$

$$\text{INPUT LINE CURRENT} = \frac{\text{APPARENT POWER}}{\text{SUPPLY VOLTAGE}} = \frac{1515.8}{254} = 5.96 \text{ Amp}$$

$$\text{POWER FACTOR (PF) of motor} = \frac{\text{ACTIVE POWER}}{\text{APPARENT POWER}} = \frac{1398.04}{1515.8} = 0.922 \text{ LAGGING}$$

(e) $\text{POWER OUTPUT TO SHAFT} = \text{ACTIVE POWER DELIVERED TO ROTOR} - \text{WINDAGE \& FRICTION LOSS}$

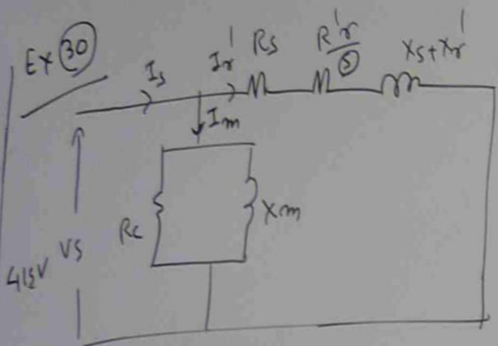
$$= 1243.5 - 70 = 1173.5 \text{ WATT}$$

$$\text{SHAFT TORQUE} = \frac{9.55 \times \text{POWER OUTPUT TO SHAFT}}{\text{SPEED}}$$

$$= \frac{9.55 \times 1173.5}{1854} = 6.04 \text{ N-m}$$

$$\text{EFFICIENCY} = \frac{\text{OUTPUT POWER TO LOAD}}{\text{INPUT ELECTRICAL POWER}} \times 100 = \frac{1173.5}{1398.04} \times 100 = 83.9\%$$

Ex 30



IN THE APPROPRIATE EQUIVALENT CIRCUIT OF ONE PHASE OF A 3ϕ MESH CONNECTED INDUCTION MOTOR SHOWN IN FIGURE. $V_S = 415V$, $R_c = 250\Omega$, $R_S = 0.1\Omega$, $R_r' = 0.2\Omega$, $X_m = 25\Omega$, $X_S + X_r' = 1\Omega$. DETERMINE THE INPUT CURRENT, POWER FACTOR, INPUT POWER AND EFFICIENCY IF THE FULL LOAD SLIP IS 0.03 WHEN THE MACHINE IS CONNECTED TO A 3ϕ, 415V, 50HZ SUPPLY

$$Z_S = \sqrt{\left(R_S + \frac{R_r'}{s}\right)^2 + (X_S + X_r')^2} \angle \tan^{-1} \frac{(X_S + X_r')}{\left(R_S + \frac{R_r'}{s}\right)}$$

$$= \sqrt{\left(0.1 + \frac{0.2}{0.03}\right)^2 + (1)^2} \angle \tan^{-1} \frac{1}{0.1 + \frac{0.2}{0.3}}$$

$$= 6.83 \angle 8.4 \ \Omega$$

$$I_r' = \frac{V_S}{Z_S} = \frac{415}{6.83 \angle 8.4} = 60.76 \angle -8.4 \text{ Amp}$$

WINDING CURRENT

$$I_m = \frac{V_S}{R_c} - j\frac{V_S}{X_m} = \frac{415}{250} - j\frac{415}{25} = 1.66 - j16.6 \text{ Amp.}$$

CORE CURRENT

$$\bar{I}_S = \bar{I}_r' + \bar{I}_m = 60.76 \angle -8.4 + 1.66 - j16.6 \text{ Amp}$$

$$= 60.76(\cos(-8.4) + j\sin(-8.4)) + 1.66 - j16.6$$

$$= 60.1 - j8.87 + 1.66 - j16.6$$

$$= 61.76 - j25.47 = \sqrt{61.76^2 + 25.47^2} \angle -\tan^{-1}\frac{25.47}{61.76} = 66.75 \angle -22.4 \text{ A}$$

Δ $I_{ph} = 66.75$ Amp, $I_{LINE} = \sqrt{3} I_{ph} = 1.7321 \times 66.75 = 115.6$ Amp.

$$\text{MECHANICAL POWER OUTPUT} = 3(I_r')^2 \times R_r' \times \frac{(1-s)}{s}$$

$$= 3 \times 60.76^2 \times 0.2 \times \frac{(1-0.03)}{0.03} = 71100 \text{ WATT}$$

$$\text{INPUT POWER TO MOTOR} = \sqrt{3} EI\cos\phi = 1.7321 \times 415 \times 115.6 \times \cos(-22.4)$$

$$= 76822 \text{ WATT}$$

$$\text{EFFICIENCY} = \frac{\text{OUTPUT}}{\text{INPUT}} \times 100 = \frac{71100}{76822} \times 100 = 92.55\%$$

Ex 31

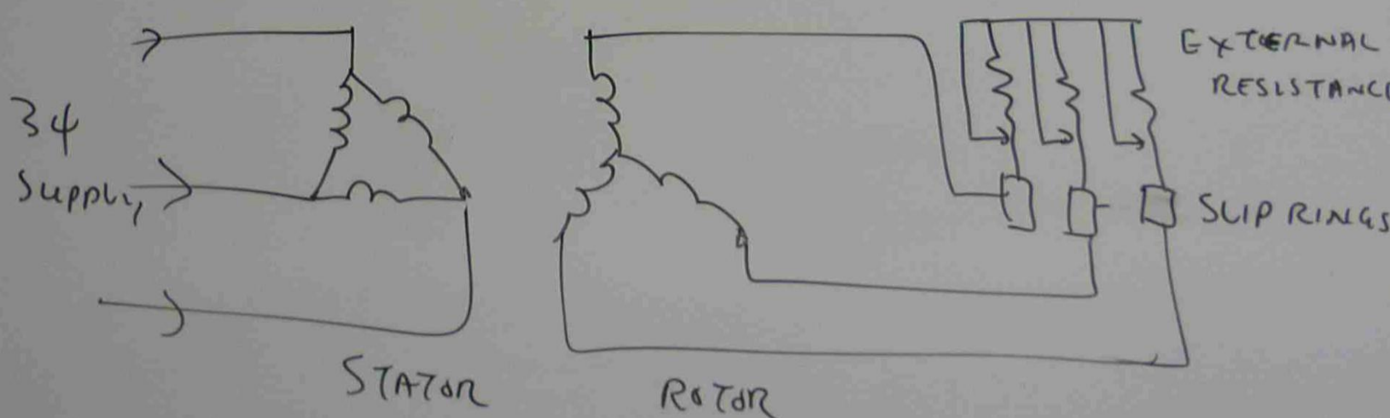
AN 8 POLE 50HZ 3ϕ SLIP RING INDUCTION MOTOR HAS A TOTAL LEAKAGE IMPEDANCE $(2 + j5.4)\Omega$ PER PHASE REFERRED TO THE STATOR

THE STATOR RESISTANCE PER PHASE IS 1.1Ω.

WHEN 415V IS APPLIED TO MESH CONNECTED STATOR WINDING, THE VOLTAGE BETWEEN ANY PAIR OF OPEN CIRCUITED SLIP RING TO WHICH THE STAR CONNECTED ROTOR WINDING IS CONNECTED IS 239V.

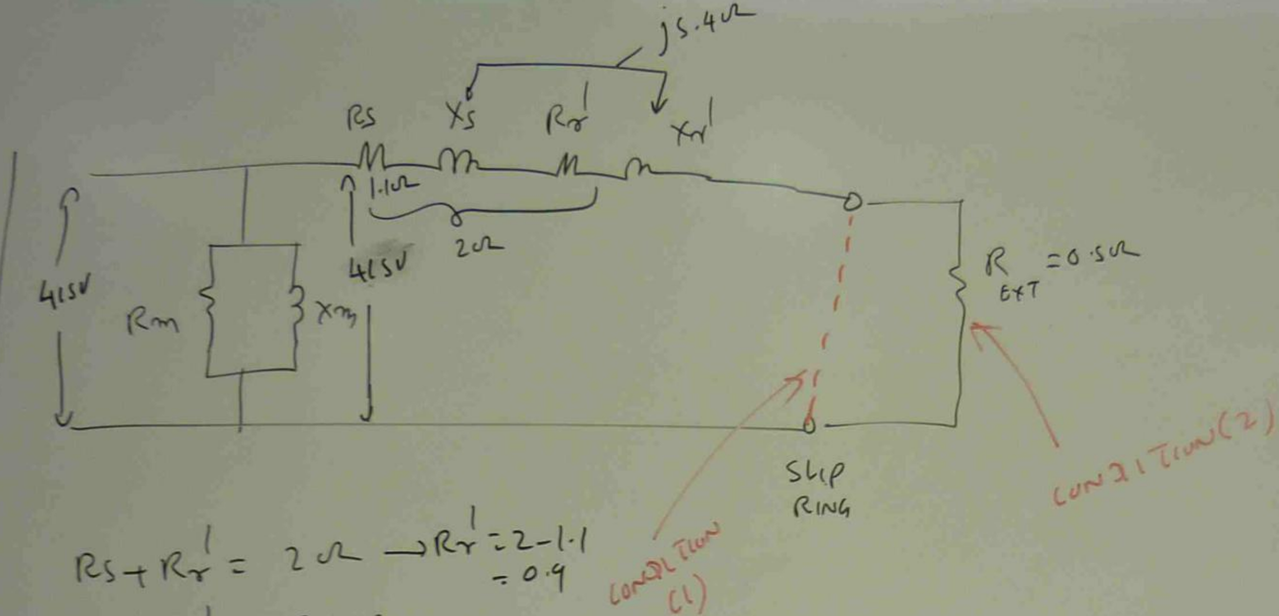
(a) WHEN SLIP RINGS ARE SHORT CIRCUITED, THE SLIP IS 0.04, CALCULATE TORQUE

(b) WHEN SLIP RINGS ARE CONNECTED TO EXTERNAL RESISTOR 0.5Ω/ph, SLIP IS 0.05, CALCULATE TORQUE



TORQUE

/ph,



$R_s + R_r' = 2\,\Omega \rightarrow R_r' = 2 - 1.1 = 0.9$

$X_s + X_r' = 5.4\,\Omega$

$$T = \frac{3 V_s^2}{2\pi n} \times \frac{s R_r'}{(s R_s + R_r')^2 + s^2 (X_s + X_r')^2}$$

$n = n_s(1 - s)$

$n_s = \frac{120 f}{p} = \frac{120 \times 50}{8} = 750$

$n = 750(1 - 0.04) = 750 \times 0.96 = 720\,\text{Rpm}$

$$T = \frac{3 \times 415^2}{2 \times 3.1416 \times 720}\left(\frac{0.04 \times 0.9}{(0.04 \times 1.1 + 0.9)^2 + 0.04^2 \times (5.4)^2}\right)$$

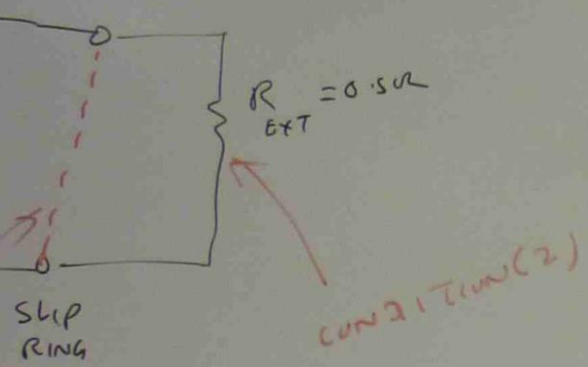
$$= 114.2 \times \frac{0.036}{(0.891 + 0.0466)}$$

$$= \frac{114.2 \times 0.036}{0.9376} = 4.38\,N$$

SLIP RINGS ARE

$$T = \frac{3 V_s^2}{2\pi n} \times \frac{(\ldots}{(s\ldots}$$

$$= \frac{3 \times 415^2}{2 \times 3.1416 \times 750(1-0\ldots}$$



$$+ S^2 (X_s + X_r')^2$$

$$T = \frac{3\times 415^2}{2\times 3.1416\times 720}\left(\frac{0.04\times 0.9}{(0.04\times 1.1+0.9)^2 + 0.04^2\times(5.4)^2}\right)$$

$$= 114.2 \times \frac{0.036}{(0.891 + 0.0466)}$$

$$= \frac{114.2\times 0.036}{0.9376} = 4.38\,N$$

SLIP RINGS ARE CONNECTED TO 0.5Ω

$$T = \frac{3V_s^2}{2\pi n} \times \frac{S(R_r' + R_{LOAD})}{(S R_s + R_r' + R_{LOAD})^2 + S^2(X_s + X_r')^2}$$

$$= \frac{3\times 415^2}{2\times 3.1416\times 750(1-0.05)} \times \frac{0.05(0.9+0.5)}{(0.05\times 1.1+0.9+0.5)^2 + 0.05^2(5.4)^2}$$

$$= \frac{115.4\times 0.07}{(1.455)^2 + 0.0729}$$

$$= \frac{115.4\times 0.07}{2.899}$$

$$= 2.78\,N$$

Ex 31

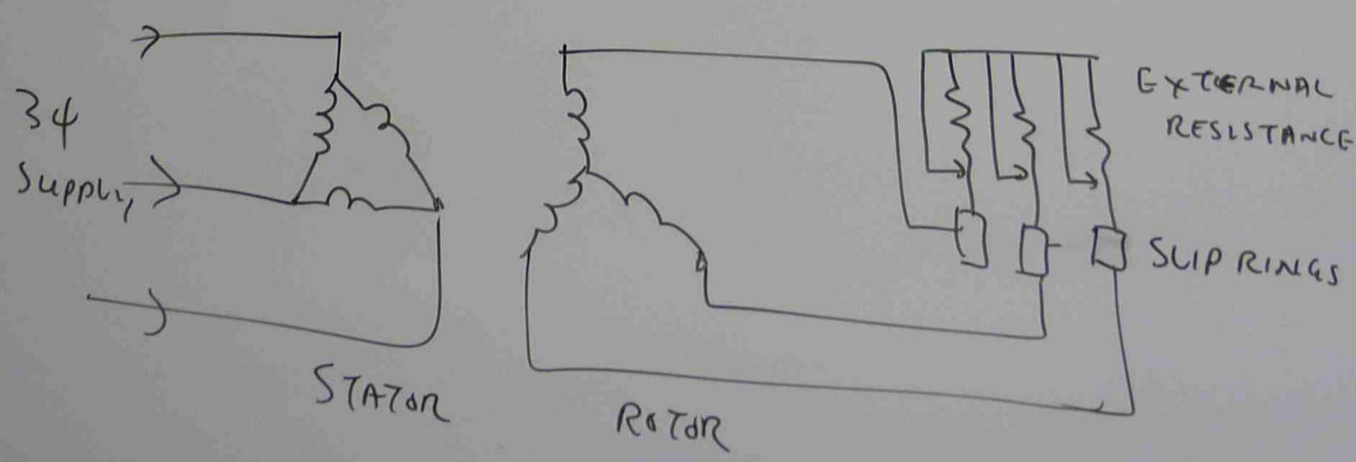
AN 8 POLE 50HZ 3ϕ SLIP RING INDUCTION MOTOR HAS A TOTAL LEAKAGE IMPEDANCE $(2 + j\,5.4)\,\Omega$ PER PHASE REFERRED TO THE STATOR

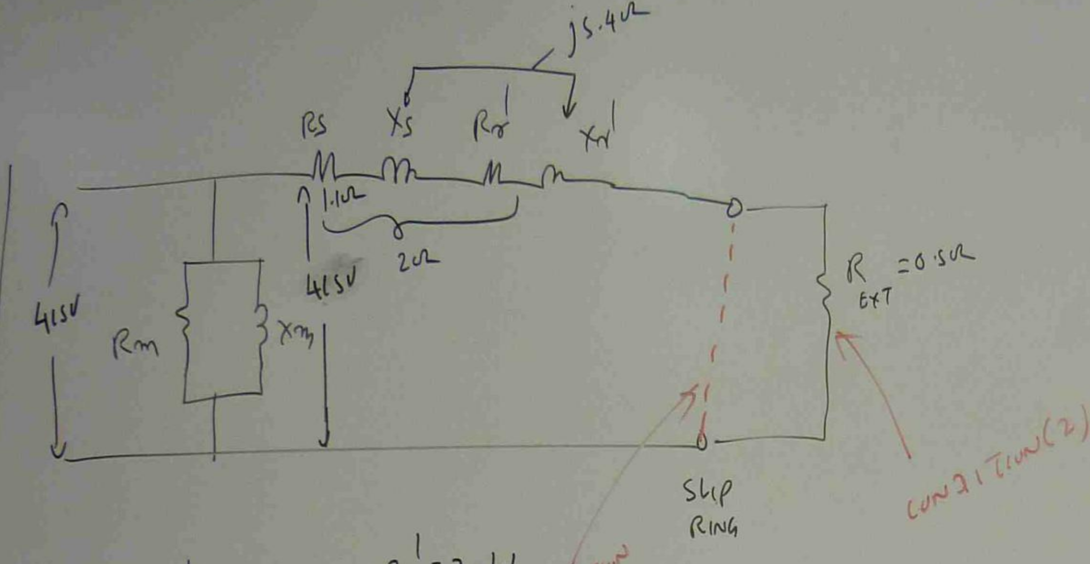
THE STATOR RESISTANCE PER PHASE IS $1.1\,\Omega$.

WHEN 415V IS APPLIED TO MESH CONNECTED STATOR WINDING, THE VOLTAGE BETWEEN ANY PAIR OF OPEN CIRCUITED SLIP RING TO WHICH THE STAR CONNECTED ROTOR WINDING IS CONNECTED IS 239V.

(a) WHEN SLIP RINGS ARE SHORT CIRCUITED, THE SLIP IS 0.04, CALCULATE TORQUE

(b) WHEN SLIP RINGS ARE CONNECTED TO EXTERNAL RESISTOR $0.5\,\Omega$/ph, SLIP IS 0.05, CALCULATE TORQUE





$R_s + R_r' = 2\Omega \rightarrow R_r' = 2 - 1.1$
$= 0.9$

$X_s + X_r' = 5.4\Omega$

$$T = \frac{3 V_s^2}{2\pi n} \times \frac{s R_r'}{(s R_s + R_r')^2 + s^2 (X_s + X_r')^2}$$

$n = n_s(1 - s)$

$n_s = \frac{120 f}{P} = \frac{120 \times 50}{8} = 750$

$n = 750(1 - 0.04) = 750 \times 0.96 = 720\ Rpm$

$$T = \frac{3 \times 415^2}{2 \times 3.1416 \times 720}\left(\frac{0.04 \times 0.9}{(0.04 \times 1.1 + 0.9)^2 + 0.04^2 \times (5.4)^2}\right)$$

$$= 114.2 \times \frac{0.036}{(0.891 + 0.0466)}$$

$$= \frac{114.2 \times 0.036}{0.9376} = 4.38\ N$$

SLIP RINGS ARE CONNECTED TO 0.5Ω

$$T = \frac{3 V_s^2}{2\pi n} \times \frac{s (R_r' + R_{LOAD})}{(s R_s + R_r' + R_{LOAD})^2 + s^2 (X_s + X_r')^2}$$

$$= \frac{3 \times 415^2}{2 \times 3.1416 \times 750(1 - 0.05)} \times \frac{0.05(0.9 + 0.5)}{(0.05 \times 1.1 + 0.9 + 0.5)^2 + 0.05^2 (\ldots}$$

$$= \frac{115.4 \times 0.07}{(1.455)^2 + 0.0729}$$

$$= \frac{115.4 \times 0.07}{2.899}$$

$$= 2.78\ N$$

Ex 32

A SINGLE PHASE 230V 4 POLES 50HZ, 0.5 KW INDUCTION MOTOR GAVE THE FOLLOWING TEST RESULTS.

LOCKED ROTOR TEST = 60V, 1.5 A, PF 0.6 LAGGING

NO LOAD TEST = 230V, 0.535A, pf 0.174 LAGGING

DETERMINE THE APPROPRIATE EQUIVALENT CIRCUIT OF THE MACHINE.

FIND ALSO THE TORQUE DEVELOPED, THE POWER OUTPUT, INPUT CURRENT AND POWER FACTOR WHEN THE MACHINE RUNS WITH A SLIP OF 0.05.

LOCKED ROTOR TEST

$S_{LF} = E_{LF} \times I_{LF} = 60 \times 1.5 = 90\ VA$

$P_{LF} = E_{LF} \times I_{LF} \times PF = 60 \times 1.5 \times 0.6 = 54\ WATT$

$Q_{LF} = \sqrt{S_{LF}^2 - P_{LF}^2} = \sqrt{90^2 - 54^2} = 72\ VAR$

$X = \dfrac{Q_{LF}}{3 I_{LF}^2} = \dfrac{72}{3 \times 1.5^2} = 10.66\,\Omega$

$r_2 = \dfrac{P_{LF}}{3 I_{LF}^2} - r_1 = \dfrac{54}{3 \times (1.5)^2} - 0 = 8\,\Omega$

NO LOAD TEST

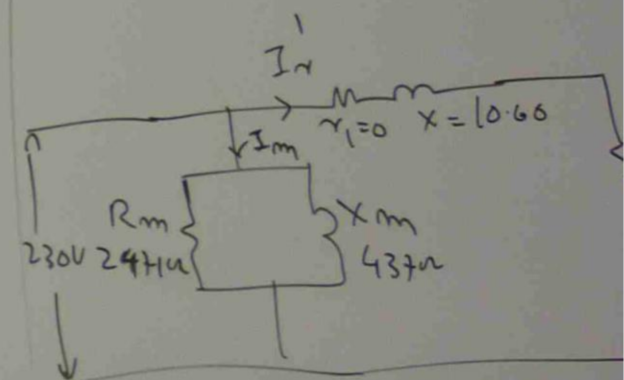
$S_{NL} = E_{NL} \times I_{NL} = 2$

$P_{NL} = E_{NL} \times I_{NL} \times PF =$

$Q_{NL} = \sqrt{S_{NL}^2 - P_{NL}^2} =$

$X_m = \dfrac{E_{NL}^2}{Q_{NL}} = \dfrac{230^2}{121}$

$R_m = \dfrac{E_{NL}^2}{P_{NL} - 3 I_{NL}^2 r_1}$



MOTOR

RENT

S.

MECHANICAL OUTPUT

NO LOAD TEST

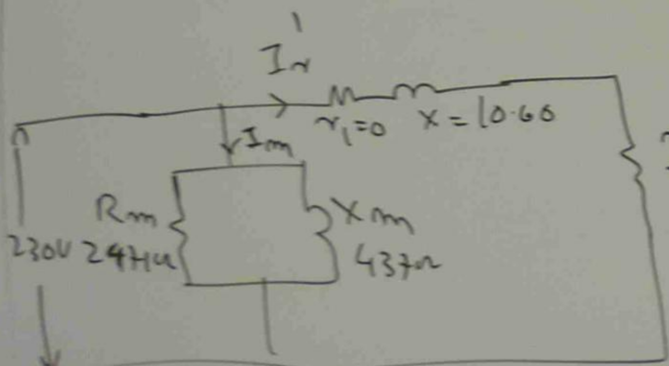
$$S_{NL} = E_{NL} \times I_{NL} = 230 \times 0.535 = 123 \text{ VA}$$

$$P_{NL} = E_{NL} \times I_{NL} \times PF = 230 \times 0.535 \times 0.174 = 21.4 \text{ WATT}$$

$$Q_{NL} = \sqrt{S_{NL}^2 - P_{NL}^2} = \sqrt{123^2 - 21.4^2} = 121 \text{ VAR}$$

$$X_m = \frac{E_{NL}^2}{Q_{NL}} = \frac{230^2}{121} = 437\,\Omega$$

$$R_m = \frac{E_{NL}^2}{P_{NL} - 3 I_{NL}^2 r_1} = \frac{230^2}{21.4 - 3 \times (0.535)^2 \times 0} = 2471\,\Omega$$



$$\frac{r_2}{s} = \frac{8}{s}$$

$$I_r' = \frac{230}{\sqrt{\left(R_s + \frac{R_r'}{s}\right)^2 + \left(X_s + X_r'\right)^2}}$$

$$= \frac{230}{\sqrt{\left(0 + \frac{8}{0.05}\right)^2 + \left(10.66\right)^2}}$$

$$\tan^{-1} \frac{10.66}{8/0.05}$$

$$= 1.434 \angle -3.81 \text{ Amp}$$

T =

I

TO CARRY THE SECOND LOAD IN STARTING, MOTOR ROTOR RESISTANCE MUST BE CHANGED & NEW CHARACTERISTICS CURVE IS TO BE ACHIEVED.

THE OPERATING POINT BEYOND THE ORIGINAL CURVE WILL CREATE UNSTABILITY.

AT WORST MOTOR WILL FOLLOW THE RUN AWAY CURVE.

MOTOR OPERATES FLUCUTING BETWEEN STABLE & UNSTABLE IS CRAWLING WHICH IS THE EARLY SIGN OF RUN AWAY.

INDUCTION MOTOR CHARACTERISTICS UNDER VARIOUS LOAD CONDITIONS

AT THE RATED FREQUENCY

SLIP (S), TORQUE (T), LINE VOLTAGE (E), MOTOR RESISTANCE (R)

ARE RELATED TO MOTOR CONSTANT

$$K = \frac{S\ E^2}{T\ R}$$

$$K = \frac{S_1\ E_1^2}{T_1\ R_1} = \frac{S_2\ E_2^2}{T_2\ R_2} = \frac{S_3\ E_3^2}{T_3\ R_3} = \cdots$$

S

S_{NE}

S_{OL}

T_{N}

T_{O}

SISTANCE (R)

ONCE WE KNOW THE CHARACTERISTICS OF A MOTOR FOR GIVEN LOAD CONDITION, WE CAN PREDICT SPEED, TORQUE, POWER FOR OTHER LOADS.

$$S_{NEW} = S_{OLD} \left[\frac{T_{NEW}}{T_{OLD}} \right] \left[\frac{R_{NEW}}{R_{OLD}} \right] \left[\frac{E_{OLD}}{E_{NEW}} \right]^2$$

S_{NEW} = NEW SLIP

S_{OLD} = OLD SLIP

T_{NEW} = NEW TORQUE

T_{OLD} = OLD TORQUE

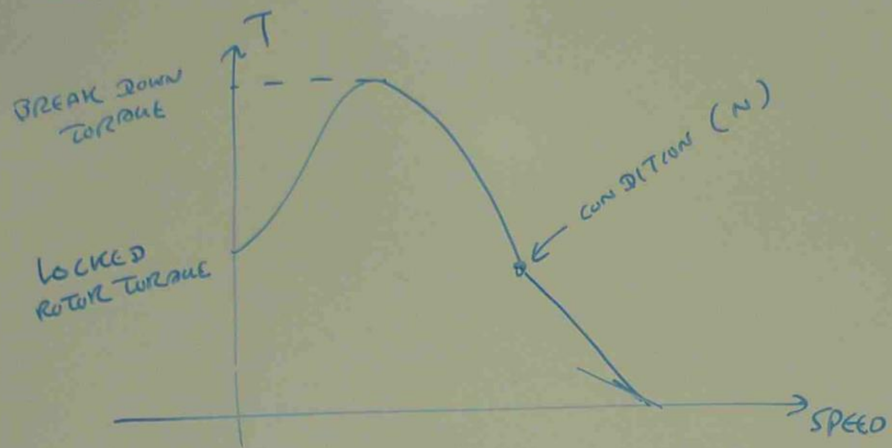
R_{NEW} = NEW ROTOR RESISTANCE

R_{OLD} = OLD ROTOR RESISTANCE

E_{old} = OLD ROTOR VOLTAGE

E_{NEW} = NEW ROTOR VOLTAGE

TORQUE - SPEED CURVE



EX 33 A 3 PHASE, 208 V INDUCTION MOTOR HAVING A SYNCHRONOUS SPEED OF 1200 RPM RUNS AT 1140 RPM WHEN CONNECTED TO A 215 V LINE AND DRIVING A CONSTANT TORQUE LOAD. CALCULATE THE SPEED IF THE VOLTAGE INCREASES TO 240V.

$N_S = 1200$ RPM

$N = 1140$ RPM

$$S_1 = \frac{N_S - N}{N_S} = \frac{1200 - 114}{1200}$$

$$= 0.05$$

$E_1 = 215$ V

$E_2 = 240$ V

$S_2 = ?$ → NEW SPEED.

$$k = \frac{S E^2}{TR}$$

$$\frac{S_1 E_1^2}{T_1 R_1} = \frac{S_2 E_2^2}{T_2 R_2}$$

$T_1 = T_2$, $R_1 = R_2$

$$\frac{0.05 \times 215^2}{\cancel{T_1}\ \cancel{R_1}} = \frac{S_2 \times 240^2}{\cancel{T_2}\ \cancel{R_2}}$$

$$S_2 = \frac{0.05 \times 215^2}{240^2}$$

$$= 0.04$$

$$\text{NEW SPEED} = [1 - S_2] \times N_S$$

$$= [1 - 0.04] \times 1200$$

$$= 1152 \text{ RPM}$$

HOT | COLD

ROTOR RESISTANCE

Ex 34 A 3ϕ 8 POLE INDUCTION MOTOR DRIVING A COMPRESSOR RUNS AT 873 RPM, IMMEDIATELY AFTER IT IS CONNECTED TO A FIXED 460V, 60 HZ LINE. THE INITIAL COLD ROTOR TEMPERATURE IS 23°C. THE SPEED DROPS TO 864 RPM AFTER THE MACHINE HAS RUN FOR SEVERAL HOURS.

CALCULATE (a) THE HOT ROTOR RESISTANCE IN TERM OF THE COLD RESISTANCE

(b) THE APPROPRIATE HOT TEMPERATURE OF THE ROTOR BARS, KNOWING THEY ARE MADE OF COPPER.

$$N_S = \text{SYNCHRONOUS SPEED} = \frac{120 f}{P} = \frac{120 \times 60}{8} = 900 \text{ RPM}$$

$N_1 = 873$ RPM

$N_2 = 864$ RPM

$$S = \frac{N_S - N_r}{N_S}, \quad S_1 = \frac{900 - 873}{900} = 0.03$$

$$S_2 = \frac{900 - 864}{900} = 0.04$$

COLD → $R_1 = ?$ $R_2 = ?$ ← HOT

$$\frac{R_2}{R_1} = ?$$

$$T_1 = T_2$$

$$K = \frac{S E^2}{TR}$$

$$\frac{S_1 E_1^2}{T_1 R_1} = \frac{S_2 E_2^2}{T_2 R_2}$$

$$\frac{0.03 \times 460^2}{\cancel{T_1} \times R_1} = \frac{0.04 \times 460^2}{\cancel{T_2} \times R_2}$$

$$\frac{0.03}{R_1} = \frac{0.04}{R_2}$$

$$\frac{R_2}{R_1} = \frac{0.04}{0.03} = 1.33$$

COPPER

$$\boxed{t_2 = \frac{R_2}{R_1}(234 + t_1) - 234}$$

$$t_2 = 1.333(234 + 23) - 234$$

$$= 108°C$$

Ex 35

A 3ϕ 4 POLE WOUND ROTOR INDUCTION MOTOR HAS A RATING OF 110 KW, 1760 RPM, 2.3 KV, 60 HZ. THREE EXTERNAL RESISTANCES OF 2Ω ARE CONNECTED IN STAR (WYE) ACROSS THE ROTOR SLIP RINGS. UNDER THESE CONDITIONS, THE MOTOR DEVELOPS A TORQUE OF 300 N-m AT A SPEED OF 1000 RPM.

(a) CALCULATE THE SPEED FOR A TORQUE OF 400 N-m

(b) CALCULATE THE VALUE OF EXTERNAL RESISTANCES SO THAT THE MOTOR DEVELOPS 10 KW AT 200 RPM.

Ex (35)

A 3ϕ 4 POLE WOUND ROTOR INDUCTION MOTOR HAS A RATING OF 110 KW, 1760 RPM, 2.3 KV, 60 HZ. THREE EXTERNAL RESISTANCES OF 2Ω ARE CONNECTED IN STAR (WYE) ACROSS THE ROTOR SLIP RINGS. UNDER THESE CONDITIONS, THE MOTOR DEVELOPS A TORQUE OF 300 N-m AT A SPEED OF 1000 RPM.

(a) CALCULATE THE SPEED FOR A TORQUE OF 400 N-m

(b) CALCULATE THE VALUE OF EXTERNAL RESISTANCES SO THAT THE MOTOR DEVELOPS 10 KW AT 200 RPM.

$T_1 = 300$ N-m $\qquad T_2 = 400$ N-m

$N_1 = 1000$ RPM $\qquad N_2 = ?$

$$N_s = \frac{120f}{P} = \frac{120 \times 60}{4} = 1800 \text{ RPM}$$

$$S_1 = \frac{N_s - N_{r1}}{N_s} = \frac{1800 - 1000}{1800} = 0.444$$

$S_2 = ?$

ASSUME

$E_1 = E_2$

$R_1 \text{ I } R_2$

$$K = \frac{S E^2}{T R}$$

$$\frac{S_1 E_1^2}{T_1 R_1} = \frac{S_2 E_2^2}{T_2 R_2}$$

$$\frac{0.444 \times \cancel{E_1^2}}{300 \times \cancel{R_1}} = \frac{S_2 \cancel{E_2^2}}{400 \times \cancel{R_2}}$$

$$S_2 = \frac{0.444 \times 400}{300}$$

$$= 0.592$$

$$N_{r(2)} = (1 - S) N_s$$

$$= (1 - 0.592) \times 1800$$

$$= 734.4 \text{ RPM}$$

(b) 10 kW, 200 RPM

$$\underset{(N\text{-}m)}{T} = \frac{9.55 \times \text{POWER (WATT)}}{\text{RPM}}$$

$$T = \frac{9.55 \times 10{,}000}{200}$$

$$= 478 \text{ N-m}$$

$$\text{SLIP} = \frac{N_s - N_r}{N_s} = \frac{1800 - 200}{1800} = 0.89$$

$R_1 = 2\Omega$, $T_1 = 300$ N-m, $S_1 = 0.444$ $E_1 = E_2$

$R_2 = ?$ $T_2 = 478$ N-m $S_2 = 0.89$

$$K = \frac{S E^2}{T R}$$

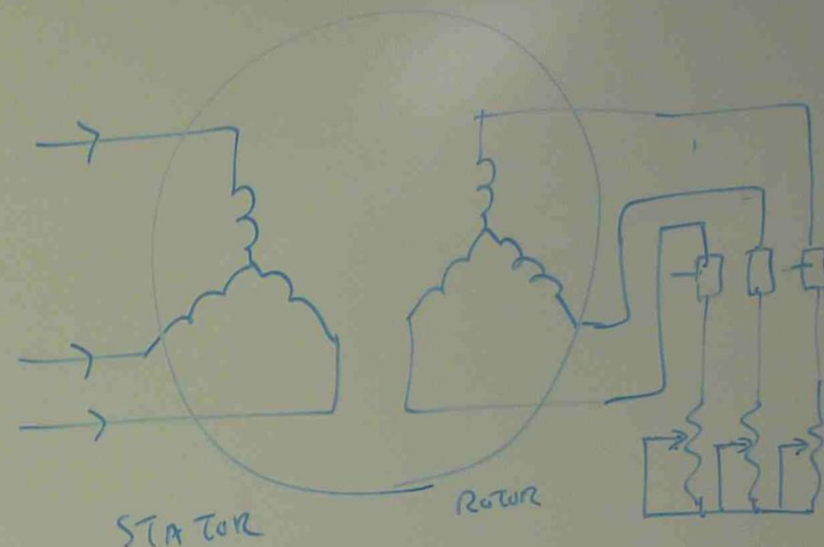
$$\frac{S_1 E_1^2}{T_1 R_1} = \frac{S_2 E_2^2}{T_2 R_2}$$

$$\frac{0.444 \times \cancel{E_1^2}}{300 \times 2} = \frac{0.89 \times \cancel{E_2^2}}{478 \times R_2}$$

$$R_2 = \frac{0.89 \times 300 \times 2}{0.444 \times 478}$$

$$= 2.53\,\Omega$$

E_2



WOUND ROTOR INDUCTION MOTOR

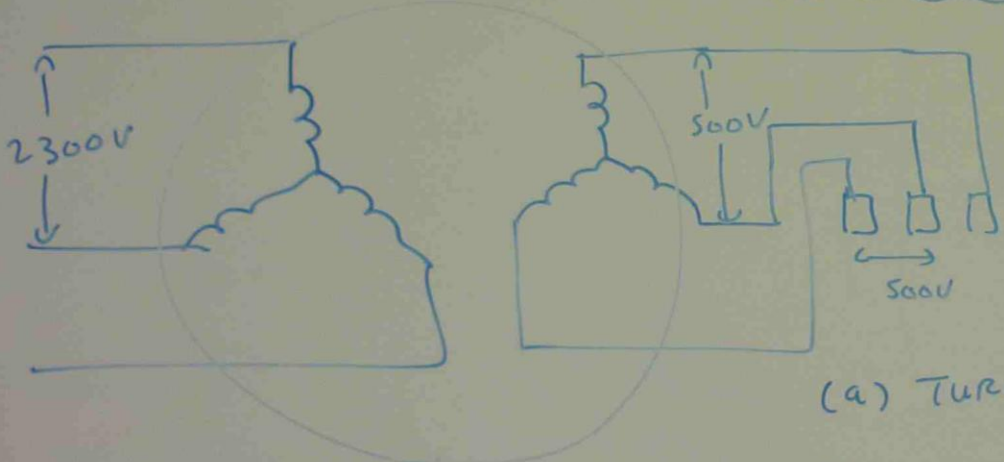
BY ADJUSTING THE ROTOR EXTERNAL RESISTANCE, THE SPEED AND TORQUE OF WOUND ROTOR INDUCTION MOTOR CAN BE REGULATED.

Ex 36 A 3ϕ WOUND ROTOR INDUCTION MOTOR HAS A RATING OF 150 HP (110 kW), 1760 RPM 2.3 kV, 60 HZ. UNDER LOCKED ROTOR CONDITION, THE OPEN CIRCUIT ROTOR VOLTAGE BETWEEN THE SLIP RING IS 500 V. THE ROTOR IS DRIVEN BY A VARIABLE SPEED DC MOTOR.

CALCULATE (a) THE TURN RATIO OF THE STATOR TO ROTOR WINDING

(b) THE ROTOR VOLTAGE AND FREQUENCY WHEN THE ROTOR IS DRIVEN AT 720 RPM IN THE SAME DIRECTION AS THE REVOLVING FIELD.

(c) THE ROTOR VOLTAGE AND FREQUENCY WHEN THE ROTOR IS DRIVEN AT 720 RPM OPPOSITE TO THE REVOLVING FIELD.



WOUND ROTOR MOTOR

ALL SLIP RINGS ARE TO BE SHORT CIRCUITED SO THAT MOTOR CAN START.

(a) TURN RATIO $= \frac{V_1}{V_2} = \frac{2300}{500} = 4.6$

(b) ROTOR VOLTAGE AT 720 RPM $=$ SLIP $\times E_2$ (STAND STILL)

f_r = ROTOR FREQUENCY AT ANY RPM

f_s = STATOR FREQUENCY

$f_r = \text{SLIP} \times f_s$

1760 RPM $\longrightarrow$ 1800 RPM

$$N = \frac{120 f}{P}$$

$$1800 = \frac{120 \times 60}{P} = P = 4$$

$$\text{SLIP} = \frac{N_S - N_m}{N_S}$$

$$= \frac{1800 - 720}{1800} = 0.6$$

ROTOR VOLTAGE AT 720 RPM = SLIP × E_2 STANDSTILL

$$= 0.6 \times 500 = 300\,V$$

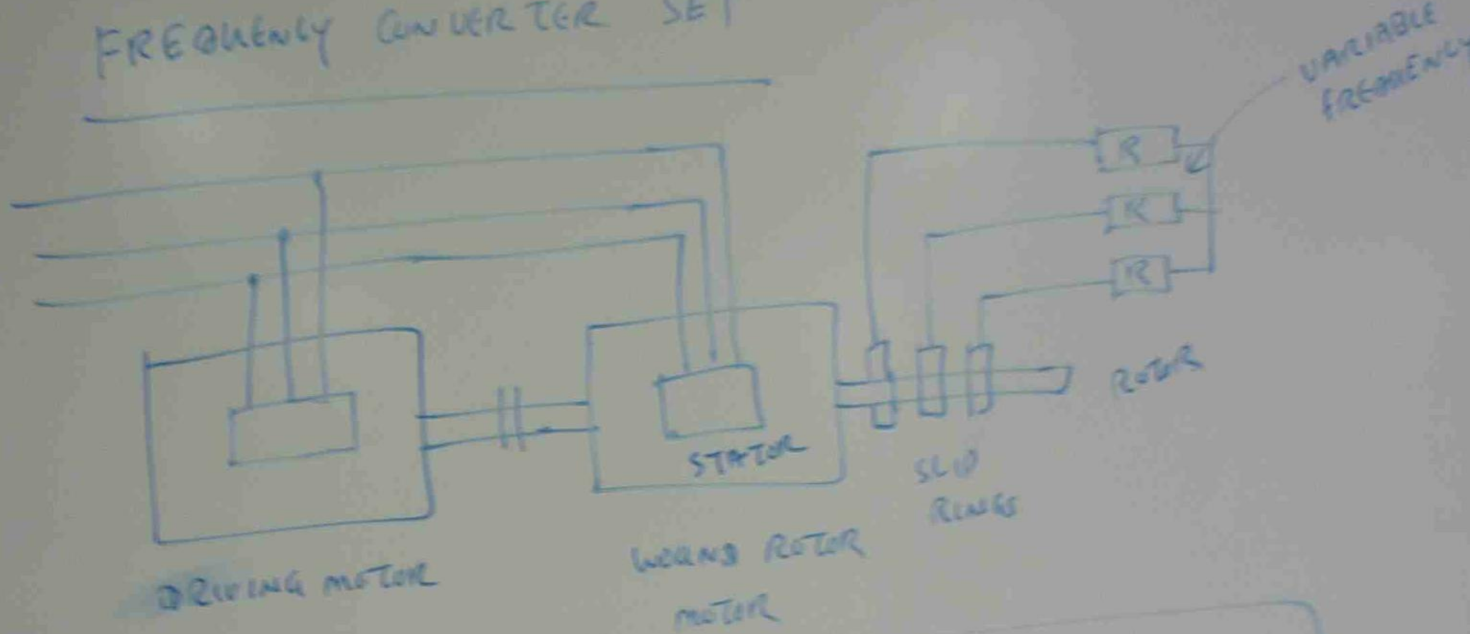
$$f_r = S f_S = 0.6 \times 60 = 36\,Hz$$

(c) $$\text{SLIP} = \frac{N_S - N_r}{N_S} = \frac{1800 - (-720)}{1800} = 1.4$$

$$S E_2 = 1.4 \times 500 = 700\,V$$

$$f_r = S f_S = 1.4 \times 60 = 84\,Hz$$

FREQUENCY CONVERTER SET



POWER TRANSFERRED FROM STATOR TO ROTOR OF WOUND ROTOR MOTOR = $\frac{\text{POWER GENERATED}}{\text{SLIP}}$

IABLE
QUENCY

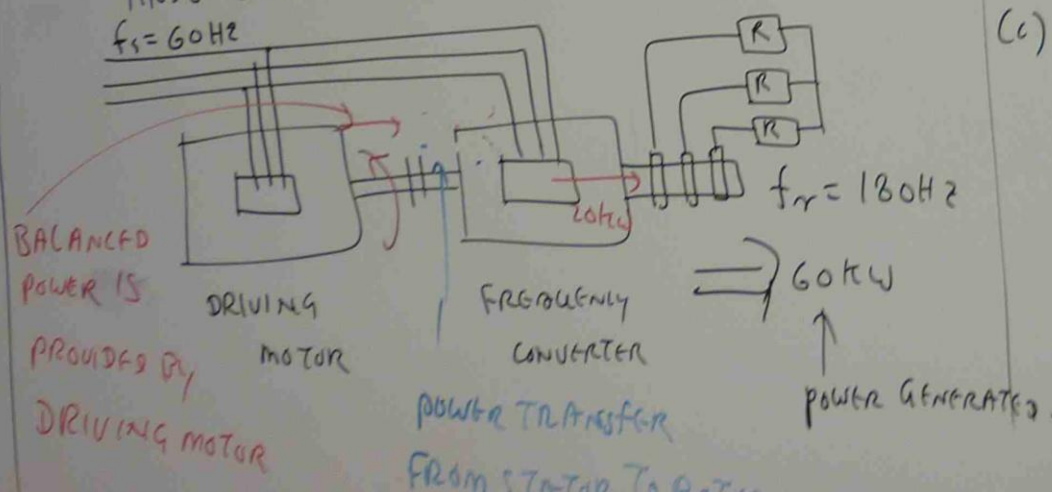
EX 37 WE WISH TO USE A 30 KW, 880 RPM, 60HZ WOUND ROTOR MOTOR AS A FREQUENCY CONVERTER TO GENERATE 60 KW AT AN APPROXIMATE FREQUENCY OF 180 HZ. IF THE SUPPLY LINE FREQUENCY IS 60 HZ, CALCULATE THE FOLLOWINGS.

(a) THE SPEED OF THE INDUCTION MOTOR THAT DRIVES THE FREQUENCY CONVERTER

(b) THE ACTIVE POWER DELIVERED TO THE STATOR OF THE FREQUENCY CONVERTER

(c) THE POWER OF THE INDUCTION MOTOR (M)

(d) WILL THE FREQUENCY CONVERTER OVER HEAT UNDER THESE CONDITIONS.



POWER TRANSFERRED FROM STATOR TO ROTOR OF WOUND ROTOR MOTOR $= \dfrac{\text{POWER GENERATED}}{\text{SLIP}}$

$$f_r = s\, f_s$$

$$180 = s \times 60 \longrightarrow s = \frac{180}{60} = 3$$

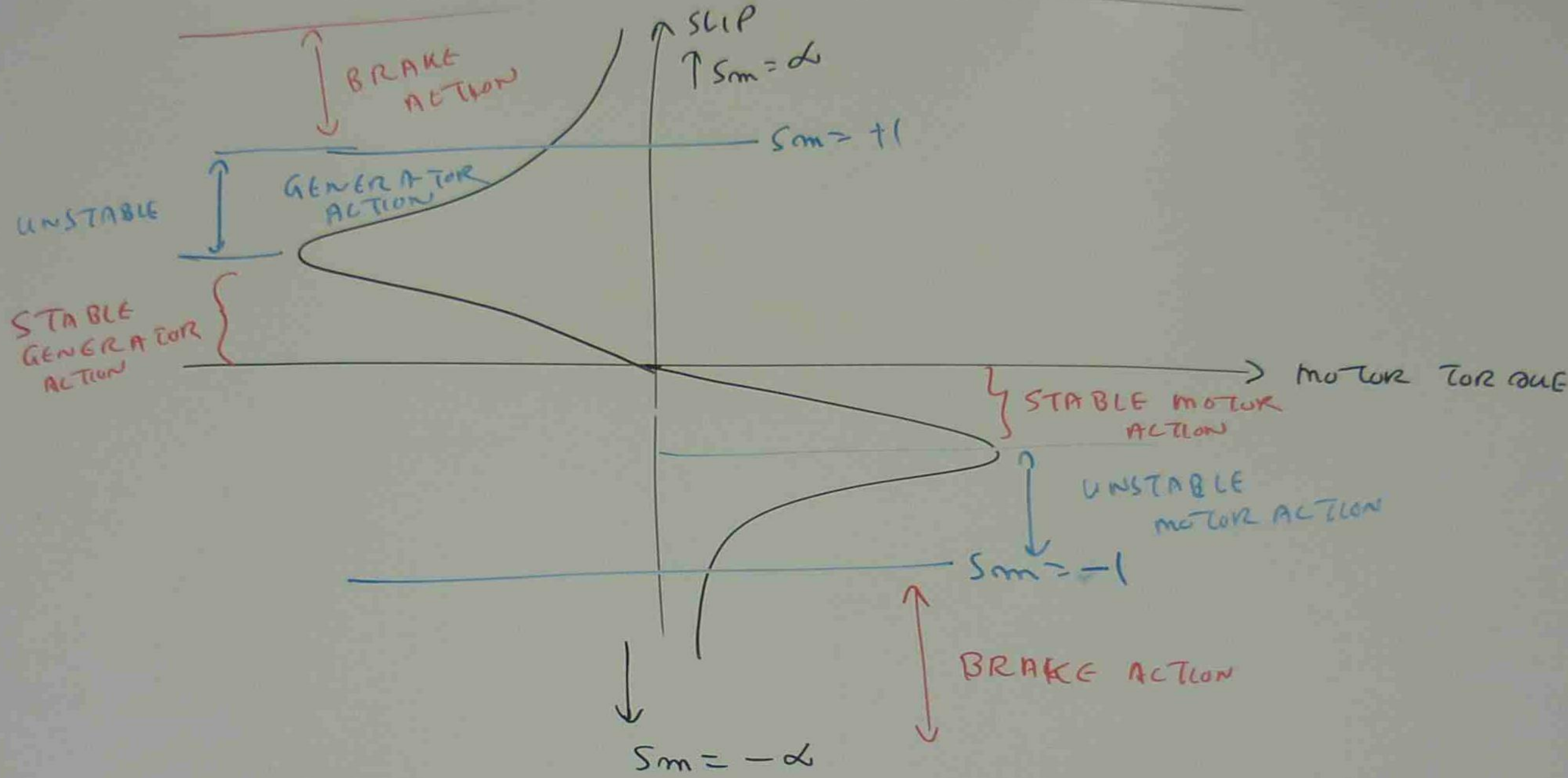
(b) POWER TRANSFERRED FROM STATOR TO ROTOR $= \dfrac{60}{3} = 20\text{kW}$

(c) DRIVING MOTOR POWER = POWER GENERATED − POWER TRANSFERRED FROM STATOR TO ROTOR

$$= 60 - 20 = 40\text{kW}$$

(d) IT WILL BE OVER HEATED

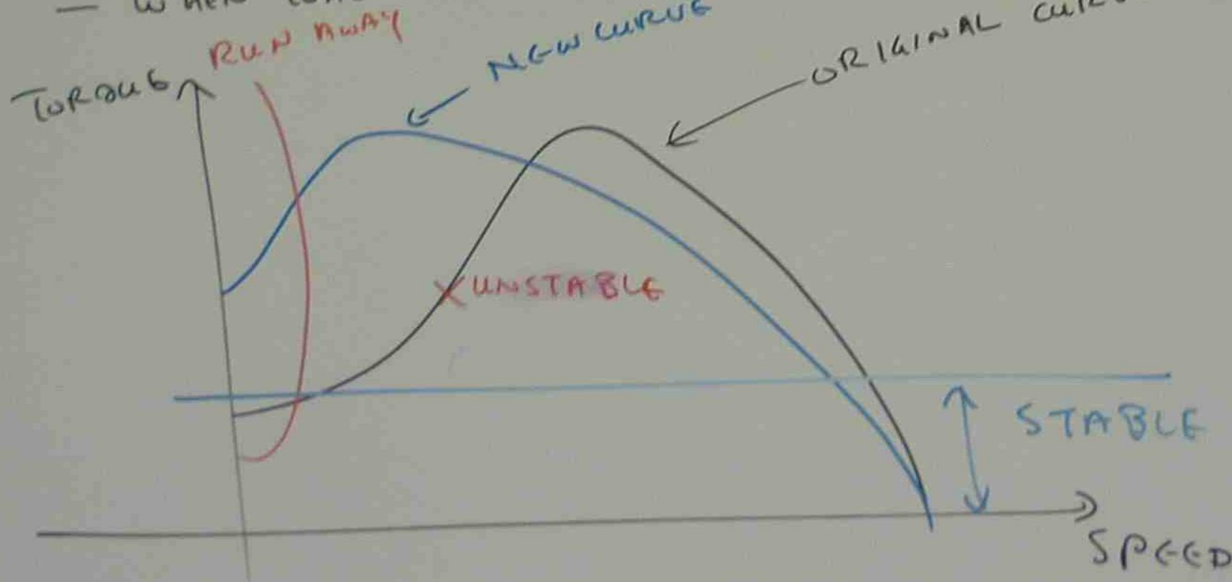
SLIP TORQUE CHARACTERISTICS of INDUCTION MACHINE



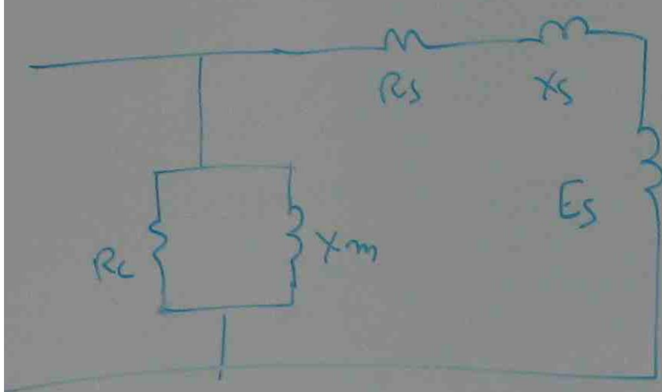
STABILITY AND CRAWING

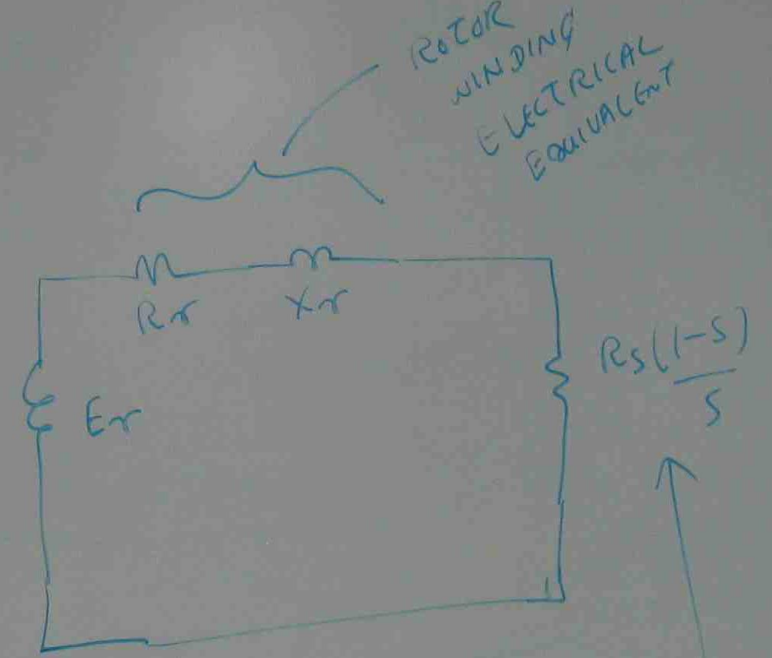
STABILITY

- STARTING TORQUE IS GREATER THAN LOAD TORQUE
- ACCELERATION AT ANY SPEED $\propto$ TORQUE DIFFERENCE
- WHEN THE ACCELERATION IS ZERO $\longrightarrow$ STEADY SPEED IS OBTAINED
  $\downarrow$
  STABLE OPERATING POINT.
- WHEN LOAD TORQUE EXCEEDS DRIVING TORQUE $\rightarrow$ DECELERATION



MODIFIED CIRCUIT





$$I_r = \frac{E_r}{(R_r + jX_r) + R_r\left(\frac{1-s}{s}\right)}$$