

Induction Motor Revision (for Mr-II)

Yildirm ictig - Induction Motors Q-17.

⇒ A 380-V line-to-line 3-phase, 50 Hz. 4-pole Y machine whose torque-speed characteristics can be approximated as.

$$T_m = k \cdot s = \frac{3 V_1^2}{r_2' w_s} \cdot s \text{ where } r_2' = 1 \Omega/\text{phase.}$$

is used to drive a load at precisely constant speed of 1500 rpm. The torque versus speed requirement of the load is given as $T_L = (w_r + 10) \text{ Nm}$

a) Propose a method of speed control for this purpose. Explain your reasoning. Draw the block diagram and calculate the value(s) of the controller variables.

b) Calculate the operating slip of the motor

c) Give an order of magnitude (estimate) for the motor under these conditions.

d) What is the minimum value of starting torque the motor must produce in order to be able to drive the motor-load combination. Explain

$$a) T_m = k \cdot s = \frac{3U_1^2}{r_2' \cdot w_s} \cdot s \quad \text{Why?}$$

$$T_e \approx \frac{3 \cdot U_1^2}{w_s} \cdot \frac{(r_2')^2}{(r_1 + r_2')^2 + (x_1 + x_2')^2} \cdot \left(\frac{r_2'}{s}\right)$$

if $s \approx r_2'/s \gg r_1, (x_1 + x_2')$

$$T_e = \frac{3}{w_s} \frac{U_1^2}{(r_2'/s)^2} \cdot \left(\frac{r_2'}{s}\right) = \underbrace{\frac{3U_1^2}{w_s \cdot r_2'}}_k \cdot s$$

Suitable control $\Rightarrow V/f =$ only method to run at sync speed.

$$T_e = T_L @ 1500 \text{ rpm} \Rightarrow w_r = \frac{1500 \cdot 2\pi}{60} = 157 \text{ rad/s.}$$

$$T_e = T_L = w_r + 10 = \underline{\underline{167 \text{ Nm}}}$$

$$T_e = \frac{3U_1^2}{w_s \cdot r_2'} \cdot s \quad w_s = ? \quad U_1 = ?$$

Constant (V/f)

N_1	f
380/13	50
4.4 fe	fe

$$167 = \frac{3 \cdot \left(\frac{220}{50}\right)^2 \cdot w_s^2}{w_s \cdot r_2'} \cdot s$$

$$\frac{w_s - w_r}{w_s}$$

$$167 = \frac{3 \cdot \left(\frac{220}{50}\right)^2 \cdot 45^2}{w_s \cdot r_2'} \cdot \frac{w_s - w_r}{w_s}$$

$\frac{U_1}{V_1}$	$\frac{w_s}{2\pi f}$
220	$\frac{50}{(P/2)}$
$\left(\frac{220}{50}\right) \cdot (w_s)$	(mech. sync speed.)

$$w_s - w_r = 28.4$$

$$w_s = 28.4 + \frac{1500}{60} \cdot 2\pi$$

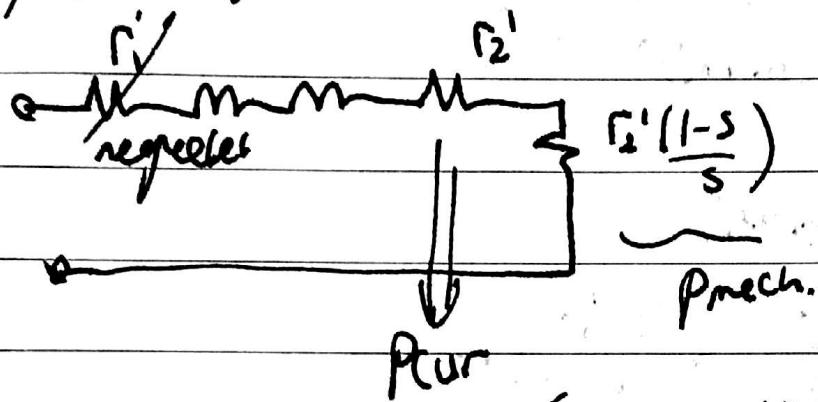
rotor rotates at 1500 rpm

$$w_s = 185.5 \text{ rad/s} \Rightarrow f_s = 59 \text{ Hz}$$

$$V_1 = 259.6 \text{ V} \Rightarrow V_{eff} = \underline{\underline{450 \text{ V}}}$$

$$b) s = \frac{\omega_s - \omega_r}{\omega_s} = \frac{28,4}{185,5} = 0,153$$

c) efficiency estimation



$$\frac{r_1' (1-s/s)^{\text{mech}}}{r_2' (s/s)} \approx \text{eff} \approx 1-s$$

$$\text{eff} = 95,2$$

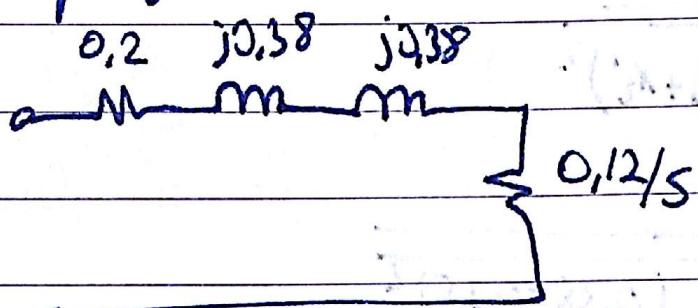
$$d) \omega_s = 0 \Rightarrow T_{\text{mech}} = 0 \text{ Nm}$$



Ahmet Demeli Induction Machine Q.6-5

6-pole $215\sqrt{3}$ V, Y-connected 60 Hz, 3-phase induction

\Rightarrow Lifting at constant load $\Rightarrow 160 \text{ Nm}$



$$n_s = 6 \text{ pole } \quad \frac{n_s}{s} = n_s = 1200 \text{ rpm}$$

$$w_s = 2\pi \cdot \frac{1200}{60} = 40\pi$$

$$= 125,66 \text{ rad/s}$$

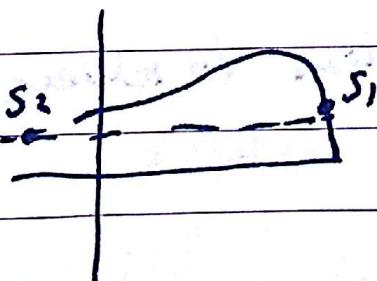
$$\text{2) } T = 160 \text{ Nm} \Rightarrow T = \frac{3V_1^2}{w_s \cdot (r_1 + r_2'/s)^2 + (x_1 + x_2')^2} \cdot \frac{s}{s}$$

$$T = \frac{3 \cdot 215^2}{125,66 \cdot (0,2 + \frac{0,12}{s})^2 + (0,76)^2} \cdot \frac{0,12}{s} = 160$$

$$0,618s^2 - 0,78s + 0,0144 = 0$$

$$s_1 = 0,0187 \Rightarrow \text{stable}$$

$$s_2 = 1,244 \Rightarrow \text{unstable}$$



$$n_r = (1-s) \cdot 1200$$

$$n_r = 1177,6 \text{ rpm}$$

$$n_r = 1178 \text{ rpm}$$

Linear torque

$$T = \frac{3V_1^2}{w_s \cdot r_2'} \cdot s$$

$$= \frac{3 \cdot 215^2}{125,66 \cdot 0,12} \cdot s = 160$$

$$s = 0,0174$$

$$n_r = 1179 \text{ rpm}$$

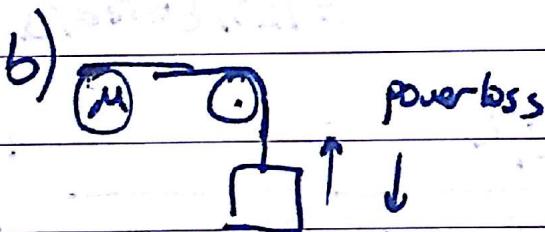
2) slip at max torque = ?

$$S_{\max T} \Rightarrow P_{\max} / P_{gap}$$

$$S_{\max T} = \frac{r_2'}{\sqrt{r_1^2 + (x_1 + x_2')^2}}$$

$$= \frac{0,12}{\sqrt{0,2^2 + (0,38 + 0,38)^2}}$$

$$S_{\max T} = 0,153$$

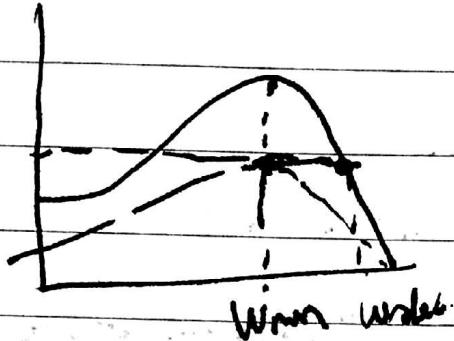


i) if $s < 1,244$ first stops $n \rightarrow 0$, then free fall plugging

if applied at start decelerating the moves in the upward direction, accelerates and reaches the initial operating point.

ii) if $s > 1,224$ $s \rightarrow \infty$ continue accelerating (falling down)

c) Minimum voltage when lifting the load to achieve minimum speed.



$$S_{max} T = 0,153$$

$$\frac{3V_1^2}{\omega s \left((r_1 + r_2'/s)^2 + (x_1 + x_2')^2 \right)} \frac{r_2'}{s} = 160$$

$$\frac{3 \cdot V_1^2}{125,66 \left(\frac{0,2 + 0,12}{0,153} \right)^2 + (0,76)^2} \frac{0,12}{0,153} = 160$$

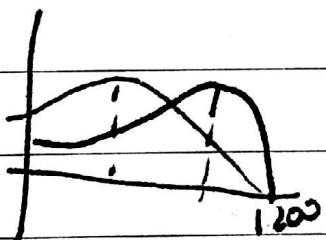
$\eta r = \eta s (1-s)$

$= 1200 \cdot (1 - 0,153)$
 $= 1016 \text{ rpm}$

$$V_1 = 115 \text{ V}$$

$S_{max} T$ doesn't change with varying voltage.

d) With this new voltage, if we need to reduce the speed to 600 rpm. What should be the value of the external resistance.



$$S = 0,5 \quad V_1 = 115 \text{ V}$$

$$R_{2t} = r_2' + R_{ext}$$

$$S_{max} T = 0,153 = \frac{r_{2t}'}{\sqrt{r_1^2 + (x_1 + x_2')^2}}$$

$$r_{2t}' = 0,5 (\sqrt{0,2^2 + 0,76^2})$$

$$r_{2t}' = 0,393$$

$$r_{ext} = 0,273 \text{ } \underline{\Omega}$$

$$r_{ext} = 0,273$$

$$r_{2t}' = 0,273 + 0,12 = 0,393$$

$$S_{max} T = \frac{0,623 - 0,393}{\sqrt{0,623^2 + (0,78)^2}} \frac{0,2}{0,2}$$

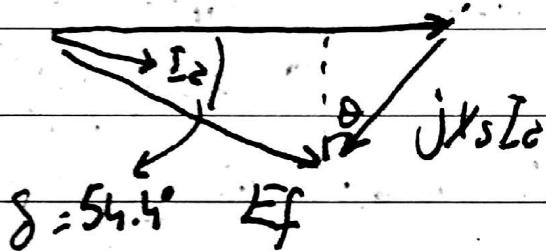
Recitation - Synchronous Machines

Yildiz University Solved Problems CH-3-Q8.

\Rightarrow 3-phase Y-connected, 6.9kV L-L, 50Hz, synchronous motor. $X_s = 95 \Omega/\text{ph}$.

Q) I_a , pf if it is supplying 700kW power. and the power angle is 54.4° .

$$V_f = \frac{6.9k}{\sqrt{3}} = 3983V.$$



$$P = 3V_f \cdot I_a \cdot \cos(\theta)$$

$$= 3 \cdot 3983 \cdot I_a \cdot \cos(54.4^\circ) = 700kW$$

$$I_a \cdot \cos(\theta) = 58.6 A$$

$$\tan(54.4^\circ) = \frac{X_s I_a \cdot \cos \theta}{V_f - X_s I_a \sin \theta}$$

$$(V_f - X_s I_a \sin \theta) = \frac{95 \cdot 58.6}{\tan(54.4^\circ)} = 3983$$

$$X_s I_a \sin \theta = 0 \Rightarrow \sin(\theta) = 0$$

$$\cos(\theta) = 1 \Rightarrow \text{unity pf}$$

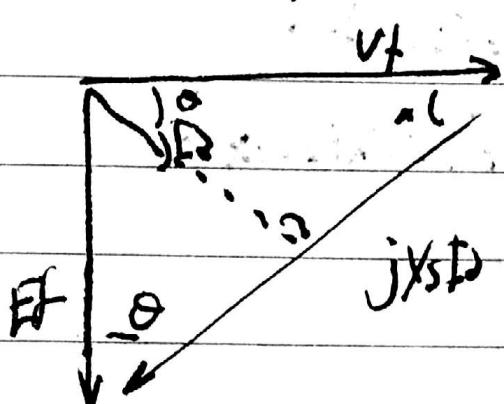
$$I_a = 58.6 A$$

$$E_f = \sqrt{(58.6 \cdot 95)^2 + 3983^2}$$

$$E_f = 6845V$$

b) Max power the motor can deliver.

$$P_{max} \Rightarrow \delta = 90^\circ$$



E

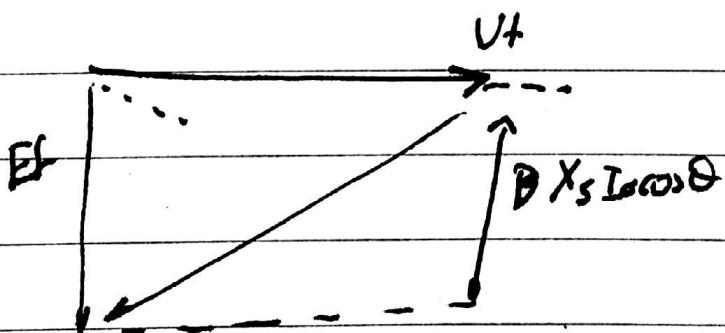
$$\sqrt{X_s^2 + 6845^2} = \sqrt{6845^2 + 3983^2}$$

$$X_s I_a = 7920$$

$$I_a = \frac{7920}{95} = 83.36 A$$

$$\cos(\theta) = \frac{6845}{7920} = 0.864 \text{ lagging.}$$

c) What should be the ^{without} increase in field current to supply 1MW?



$$P = 3V_f I_a \cos\theta = 1 \text{ MW}$$

$$I_a \cos\theta = 83.66$$

$$E_f \sin(\delta) = X_s I_a \cos\theta$$

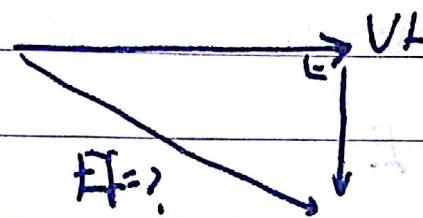
$$E_f \sin(\delta) = 7948$$

7948

$$\frac{7948}{6845} = 1.16 \Rightarrow \% 16 \text{ increase in } I_f.$$

\uparrow 16% increase

d)



$$3VtI_a \cos\theta = 1.000.000$$

$$I_a = 83.68 A$$

$$Ef = \sqrt{3983^2 + (95 \cdot 83.68)^2}$$

$$Ef = \underline{\underline{8892 V}}$$

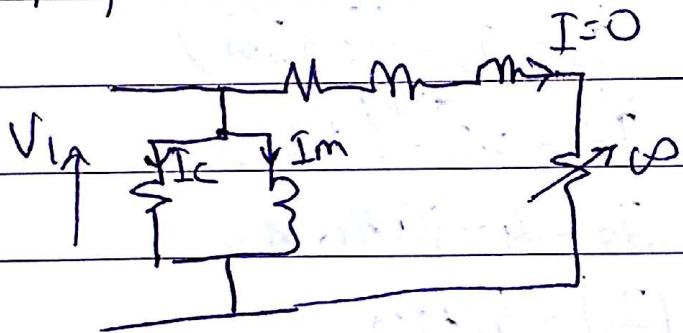
EE362 - MT2 Q3] 2004 (Recitation 2)

3-ph, 4 pole Y connected, 208V (line-to-line) induction motor is run under no load conditions and the following data are obtained:

$$I_1 = 1,562 \text{ A}$$

$$P_{\text{in}} = 432 \text{ W}$$

2) Find the core loss resistance (R_c) and magnetizing impedance (X_m)



$$P_{\text{core}} = \frac{3V_1^2}{R_c}$$

$$432 = \frac{3 \cdot 120^2}{R_c}$$

$$R_c = 100 \Omega$$

$$\begin{aligned} S_{\text{ph}} &= V_{\text{ph}} \cdot I_{\text{ph}} \\ &= 120 \cdot 1,562 \\ &= 187,44 \text{ VA} \end{aligned}$$

$$I_c = \frac{120}{100} = 1,2 \text{ A}$$

$$I_0 = \sqrt{I_c^2 + I_m^2}$$

$$1,562 = \sqrt{(1,2)^2 + I_m^2}$$

$$I_m = 1 \text{ A}$$

$$I_m = \frac{V}{X_m} \Rightarrow X_m = 120 \Omega$$

$$\begin{aligned} Q &= 120 \text{ VAR} \\ Q &= \frac{V^2}{X_m} \Rightarrow X_m = 120 \Omega \end{aligned}$$

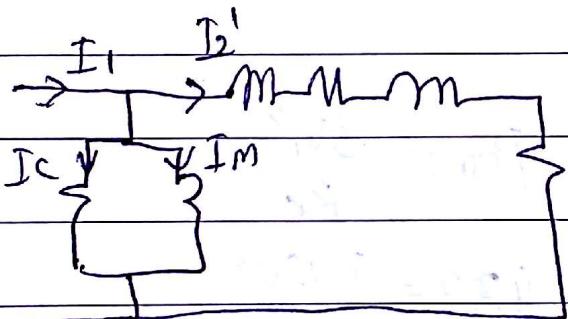
Now, the motor is run under 8.73 Nm load, and it is found that it draws 5.5A, 0.944 pf lagging, and the slip is measured as $s=0.05$. The stator phase AC resistance is measured as 1.2Ω

\Rightarrow find the other parameters of the equivalent circuit.

Assume ($X_1 = X_2'$)

$$\cos(\theta) = 0.944 \text{ lagging } |I| = 5.5 \text{ A}$$

$$(\vec{I}_1 = 5.2 - j1.86 \text{ A})$$



$$\vec{I}_2' = \vec{I}_1 - (\vec{I}_c + \vec{I}_m)$$

$$\vec{I}_2' = 5.2 - (1.2 - j)$$

$$I_2' = 4 - j0.86 \text{ A}$$

$$(I_2) = 4.07 \text{ A}$$

$$8.73 = \frac{3}{ws} \frac{(4.07)^2 \cdot r_2'}{0.05}$$

eff power

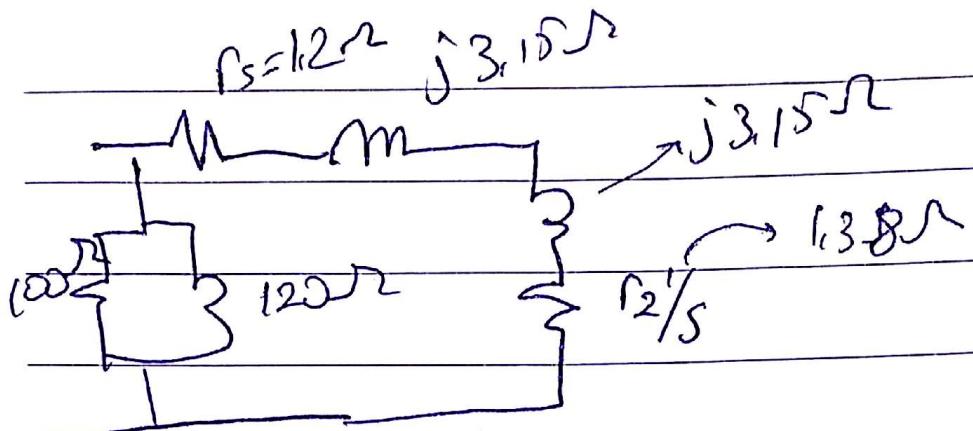
$$r_2' = 1.38 \Omega \quad I = \frac{V}{Z} \quad Z = \frac{120}{4.07} = 29.5 \Omega$$

$$29.5 = \sqrt{\left(1.2 + \frac{1.38}{0.05}\right)^2 + (X_1 + X_2')^2}$$

$$X_1 + X_2' = 6.30 \Omega$$

$$X_1 = X_2' = 3.15 \Omega$$

$$R_s = 12\Omega \quad j3.15\Omega$$



b) Calculate the voltage level required to keep the flux constant at 150Hz

Assume ($V/f = E/f$)

$$50\text{Hz} \Rightarrow 120\text{Vph}$$

$$150\text{Hz} \Rightarrow 360\text{Vph} \Rightarrow \underline{\underline{509\text{V}}}$$

c) Is the inverter capable of giving voltage?

No, flux weakening need to be applied