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Induction Motor Recitation (for MT-II)

Yildirim Üçtuğ - 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:

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

is used to drive a load at precisely constant speed of 1500 rpm. The torque versus speed requirement of the load is given as $T_L = (\omega_r + 10)$ 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) $T_m = k.s = \frac{3V_1^2}{r_2'.w_s}.s$ Why=?

$$T_e \approx \frac{3}{w_s} \cdot \frac{V_1^2}{\left(r_1+\frac{r_2'}{s}\right)^2+(X_1+X_2')^2} \cdot \left(\frac{r_2'}{s}\right)$$

if $s \approx 0$ $r_2'/s >> r_1, (X_1+X_2')$

$$T_e = \frac{3}{w_s} \frac{V_1^2}{(r_2'/s)^2} \cdot \left(\frac{r_2'}{s}\right) = \underbrace{\frac{3V_1^2}{w_s . r_2'}}_{k} . s$$

Suitable control ⇒ V/f ⇒ only method to run at synch speed.

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

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

$T_e = \frac{3V_1^2}{w_s . r_2'} . s$ $w_s=?$ $V_1=?$

Constant (V/f)

V_l	f
$380/\sqrt{3}$	50
$4.4 f_e$	f_e

V_1	w_s
V_1	$\frac{2\pi f}{(P/2)}$
220	50π
$\left(\frac{220}{50\pi} w_s\right)$	(w_s) ← mech. synch speed.

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

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

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

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$w_s - w_r = 28.4$

rotor rotates at 1500 rpm

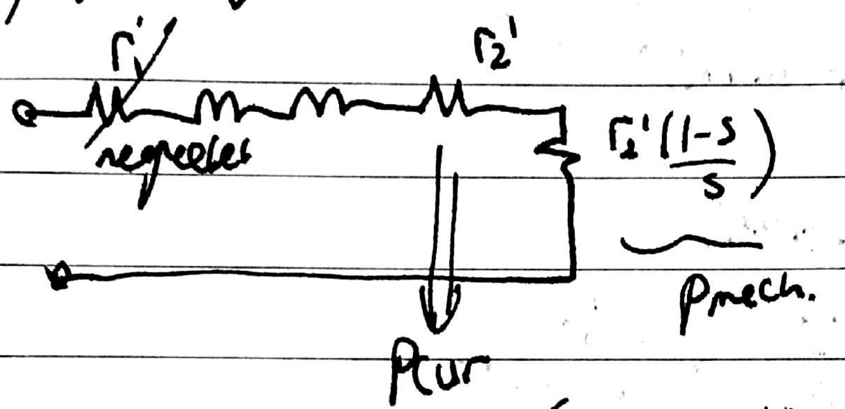
$w_s = 28.4 + \frac{1500}{60}.2\pi$

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

$V_1 = 259.6V ⇒ V_{LL} = \underline{450V}$

b) $s = \frac{\omega_s - \omega_r}{\omega_s} = \frac{28.4}{185.5} = \underline{0{,}153}$

c) efficiency estimation



$$\frac{\cancel{I_2^2}\,(1-s/s)^{mech}}{\text{air gap}\ \cancel{I_2^2}\,(r_2'/s)} \simeq \text{eff} \approx 1-s$$

eff = %$\underline{84{,}7}$

d) $\cancel{\omega_s} = 0 \Rightarrow T_{mech} = 10\,Nm.$

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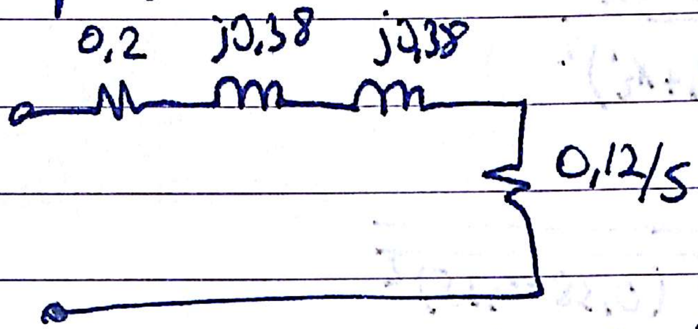
Ahmet Rumeli Induction Machine Q 6-5

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

⇒ Lifting at constant load ⇒ 160 Nm



n_s ⇒ 6 pole ~~w_s~~ = $n_s = 1200$ rpm

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

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

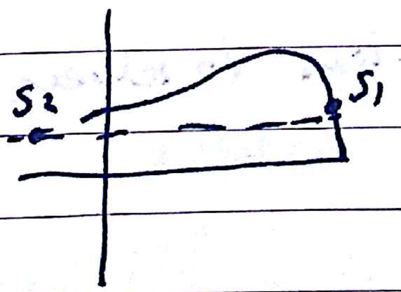
a) $T = 160 Nm$ ⇒ $T = \dfrac{3V_1^2}{w_s \cdot \left[(r_1 + r_2'/s)^2 + (X_1 + X_2')^2 \right]} \cdot \dfrac{r_2'}{s}$

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

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

$s_1 = 0{,}0187$ ⇒ stable

$s_2 = 1{,}244$ ⇒ unstable



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

~~$n_r = 1177{,}6$ rpm~~

$n_r = 1178$ rpm

Linear torque

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

$$= \frac{3 \cdot 215^2}{125.66 \cdot 0{,}12} \cdot s = 160$$

$$s = 0{,}0174$$

$n_r = 1179$ rpm

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a) slip at max torque = ?

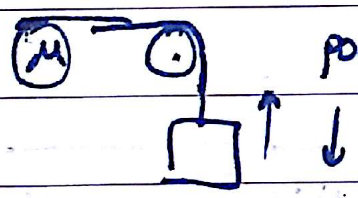
$S_{max\,T} \Rightarrow Max\ P_{gap}$

$$S_{max,T} = \frac{r_2'}{\sqrt{r_1^2 + (X_1 + X_2')^2}}$$

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

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

b)



power loss

i) $s < 1{,}244$ plugging | before powering first stops $n \to 0$, then free fall

if applied at start decelerating then moves in the upward direction, accelerates and catches 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.

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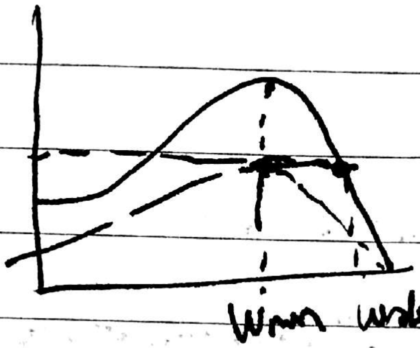


T

$S_{maxT} = 0{,}153$

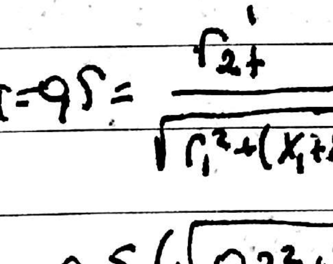
$$\frac{3V_1^2}{\omega_s\left((r_1+r_2'/s)^2+(X_1+X_2')^2\right)}\cdot\frac{r_2'}{s} = 160$$

$$\frac{3.V_1^2}{125.66\left(\left(0{,}2+\frac{0{,}12}{0{,}153}\right)^2+(0{,}76)^2\right)}\cdot\frac{0{,}12}{0{,}153} = 160$$

$n_r = n_s(1-s)$
$= 1200.(1-0{,}153)$
$= 1016\,rpm$

$\underline{U_1 = 115\,V}$ S_{maxT} 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 ressistance.



$S = 0{,}5$ $U_1 = 115\,V$

$R_{2t} = r_2' + R_2'ext$

$$S_{maxT} = 0{,}5 = \frac{r_{2t}'}{\sqrt{r_1^2+(X_1+X_2')^2}}$$

$r_{2t}' = 0.5\left(\sqrt{0{,}2^2+0{,}76^2}\right)$

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

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

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

$r_{2t}' = 0{,}273 + 0{,}12 = \cancel{0{,}473}$ $0{,}393$

$$S_{maxT} = \frac{\cancel{0{,}473}\ 0{,}393}{\sqrt{\cancel{0{,}473}^2+(0{,}78)^2}}$$

0,2

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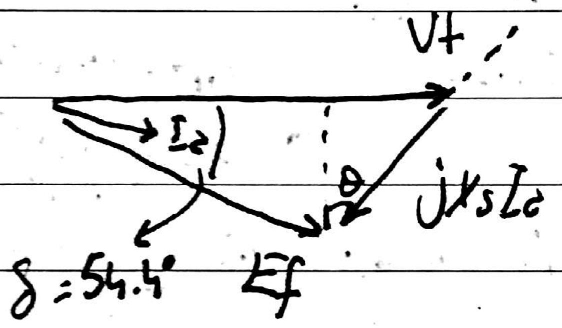
Recitation- Synchronous Machines

Yildirim Üctug solved Problems CH-3-Q8.

⇒ 3-phase Y-connected 6.9kV l-l. 50Hz. synchronous motor. $X_s = 95\ \Omega/ph$.

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



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

$$P = 3V_t \cdot I_a \cdot \cos(\theta).$$

$$= 3.\ 3983.\ I_a \cdot \cos(\theta) = 700k.$$

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

$$\tan(54.4°) = \frac{X_s\ I_a \cdot \cos\theta}{V_t - X_s I_a \sin\theta}$$

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

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

$\cos(\theta) = 1 \Rightarrow$ unity pf

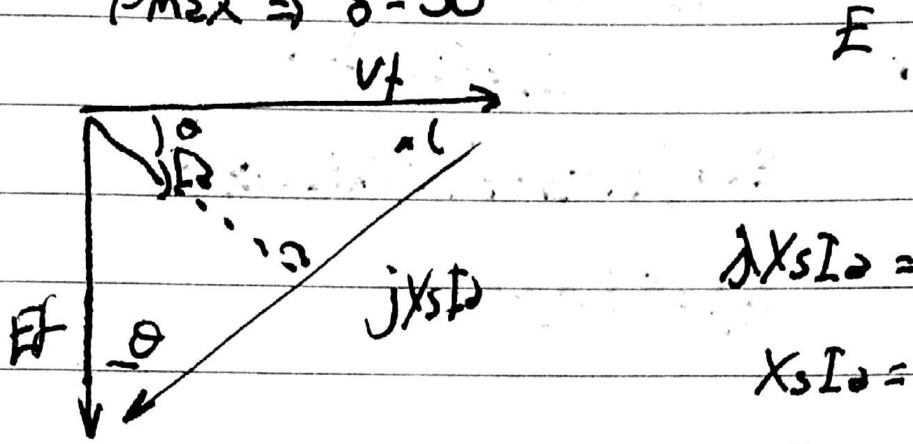
$$I_a = 58.6\ A$$

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

$$E_f = 6845V$$

b) Max power this motor can deliver.

$P_{max} \Rightarrow \delta = 90°$



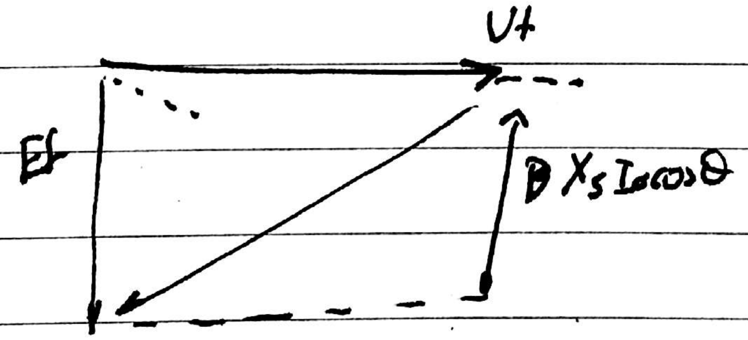
$jX_sI_a = \sqrt{6845^2 + 3983^2}$

$X_sI_a = 7920$

$I_a = \frac{7920}{95} = 83,36A$

$\cos(\theta) = \frac{6845}{7920} = 0,864$ lagging.

c) What should be the ^minimum^ increase in field current to supply 1MW?



$P = 3V_t I_a\cos\theta = 1MW$

$I_a\cos\theta = 83.66$

$E_f\sin(\delta) = X_sI_a\cos\theta$

$E_f\underbrace{\sin(\delta)}_{1} = 7948$

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

$\uparrow$ old value

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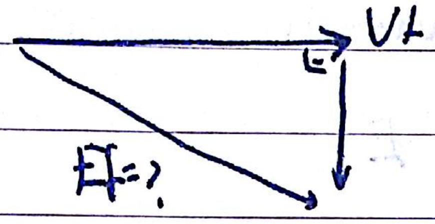
d)



$$3V_t I_a \cos\theta = 1.000.000$$

$$I_a = 83.68\,A$$

$$E_f = \sqrt{3988^2 + (95 \times 83.68)^2}$$

$$\underline{E_f = 8892\,V}$$