Grade:	24 /30

University of Jordan — Faculty of Engineering & Technology — Electrical Engineering Department

EE471: Electrical Machines II — Second Exam — Second Semester 2015-2016 — 4/04/2016 — Time: 15:00 - 16:30 pm

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Question # 1 (3 marks)

An induction motor develops 15kW to a load at a speed of 2950 rpm. Find

1.1	the frequency of the stator current and number of poles	f = 50 Hz P = 2 poles
1.2	the motor's slip s.	s = 1.667 %
1.3	the developed torque in the motor in N.m under these conditions.	T_d = 48.55 Nm
1.4	the operating speed of the motor if its torque is doubled.	n_m = rpm
1.5	the power that will be supplied by the motor when the torque is doubled.	P_d = kW

$$n_s = \frac{120(50)}{2} = 3000 \approx 2950$$

$$s = \frac{n_s - n_m}{n_s}$$

$$T_d = \frac{P_d}{\omega_m} = \frac{15K}{308.9}, \quad \omega_m = \frac{2\pi n_m}{60} = 308.9 \text{ rad/s}$$

$$= 48.5$$

$$T_{d2} = 97 \text{ N.m}$$

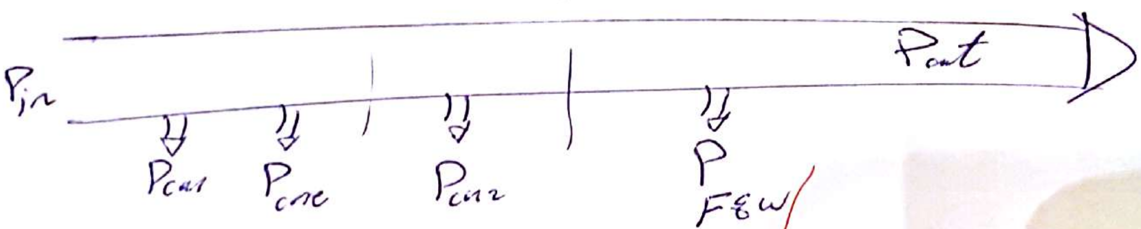
$$s = \frac{n_s - n_m}{n_s} =$$

$$n_m = (1-s) n_m$$

Question # 2 (4 marks) → $n_s = 1800$ rpm

A 480-V, 4 pole, 60 Hz, 50-hp, three phase induction motor is drawing 60A at 0.85 PF lagging. The stator copper losses are 2 kW, and the rotor copper losses are 700 W. The friction and windage losses are 600 Wand the core losses are 1800 W. Draw the IM power flow diagram and find the following quantities:

2.1	The input power P_{in}	P_{in} = 42.4	kW
2.2	The air-gap power P_g	P_g = ~~40.4~~ 38.6	kW
2.3	The power developed P_d	P_d = ~~39.7~~ 37.9	kW
2.4	The output horse power P_{out}	P_{out} = ~~53~~ 50	hp
2.5	The efficiency of the motor η	%η = 87.97 %	
2.6	The motor speed n_m	n_m = 1767.6	rpm
2.7	The torque developed T_d	T_d = 204.77	Nm
2.8	The output torque T_{out}	T_{out} = 201.5	Nm



$P_{in} = \sqrt{3}\, V_L I_L \cos\theta = 42400$ W

$P_g = P_{in} - P_{cu1} - P_{core}$ 42400 − 2000 − 1800 = ~~40400 W~~ 38600

~~$P_{dev} = P_g - P_{cu2}$ = 40400 − 700 = 39700~~ 37900 W

~~$P_{out} = P_{dev} - P_{F\&W}$ = 39700 −~~

P_{out} = 37.9 kW − ~~600~~ 0.6 = 37300 W

$P_{out} = \frac{37300}{746} = 50$ hP, $\eta = \frac{P_{out}}{P_{in}}$

$n_m = (1-s)\, n_s$ ⇒ $P_d = (1-s) P_g$ ⇒ s = 0.018 = 1.8%

$T_d = \frac{P_g}{\omega_s} = \frac{38600}{188.5}$ $\omega_m = (1-s)\omega_s$ = 185.107

$T_{out} = \frac{P_{out}}{\omega_m} = \frac{37300}{185.107}$

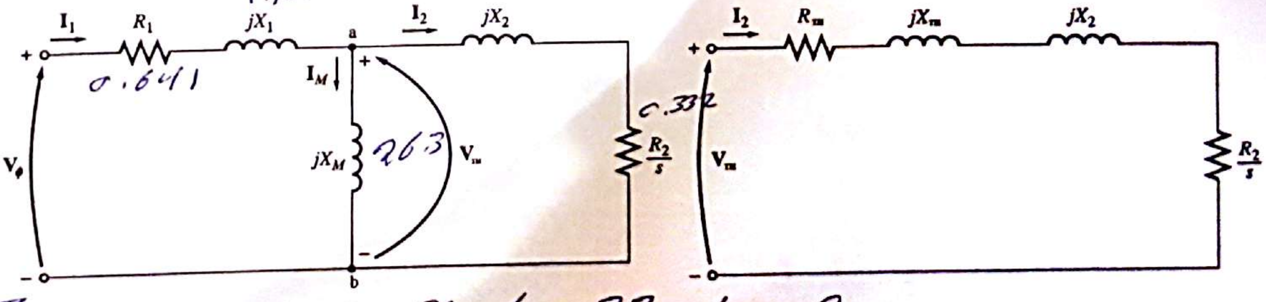
Question # 3 (10 marks) → $n_s = 1800$

A 460-V, 25-hp, 60 Hz, four-pole, Y-connected wound-rotor induction motor has the following impedances in ohms per phase referred to the stator circuit:

$R_1 = 0.641\Omega$ $R_2 = 0.332\Omega$ $X_1 = 1.106\ \Omega$ $X_2 = 0.464\ \Omega$ $X_M = 26.3\ \Omega$

The core loss is lumped in with the rotational losses. The total rotational losses are 1100 W and are assumed to be constant. For a rotor slip of 2.2 percent at the rated voltage and rated frequency, use the IEEE motor equivalent circuit to find the motor's

3.1	synchronous speed n_s rotor speed n_m	n_s = 1800 n_m = 1760.4	rpm rpm
3.2	magnitude of stator current $\|I_1\|$ and PF_1 at the above slip	$\|I_1\|$ = 18.9 PF = 0.833 lag	A
3.3	Thévenin's equivalent voltage V_{Th} and Thévenin's equivalent impedance Z_{Th}	V_{Th} = 254.8∠1.34 Z_{Th} = 1.22∠61.2	V Ω
3.4	magnitude of rotor current $\|I_2\|$ and PF_2 at the above slip	$\|I_2\|$ = 16.17∠-4.2 PF = 0.997 lag	A
3.5	converted power P_{conv} and airgap power P_g	P_{cov} = 11.576 P_g = 11.837	kW kW
3.6	developed torque T_d load torque T_L	T_d = 62.79 T_L = 56.83	Nm Nm
3.7	the starting torque of this motor T_{st} magnitude of rotor starting current $\|I_{2st}\|$	T_{st} = ~~0.237~~ → 114.14 $\|I_{2st}\|$ =	Nm A
3.8	the maximum torque of this motor T_{max} the speed at maximum torque n_{Tmax}	T_{max} = 234.9 n_{Tmax} = 1440	Nm rpm
3.9	the new maximum torque of the motor T_{maxnew} and the speed at which the maximum torque now occur, if the rotor resistance is doubled, n_{Tmax}	T_{maxnew} = 234.9 n_{Tmax} = 1080	Nm rpm
3.10	the new starting torque of the motor T_{stnew} if the rotor resistance is doubled, T_{stnew}	T_{stnew} = 191.1	Nm
3.11	Plot the *T-Speed* c/c for both cases.		



$I_L = 18.9 \angle -33.6$ A

$V_{Th} = V_\phi = 265 \dfrac{j26.3}{j26.3 + j1.106 + 0.641} = 254.8\angle 1.34°$

$Z_{Th} = \ // = 1.22\angle 61.2$

$$|I_2| = \frac{V_{Th}}{Z_{Th} + \frac{R_2'}{s} + jX_2}$$

$$P_{conv} = 3 (I_2')^2 R_2' \left(\frac{1-s}{s}\right)$$

$$P_g = 3 (I_2')^2 \frac{R_2'}{s}$$

$$T_d = \frac{P_g}{\omega_s} = \frac{11837}{188.5} = 62.79$$

$$T_L = \frac{P_{out}}{\omega_m}$$

0.58 + j1.07

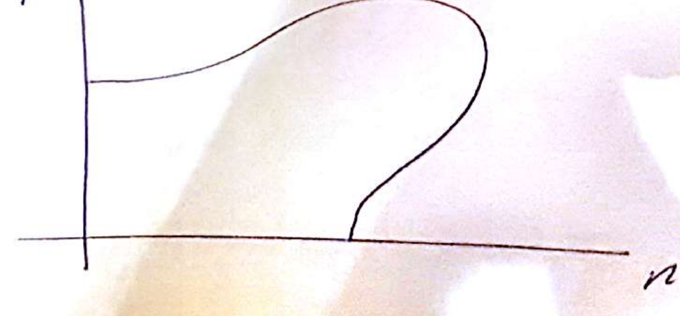
$$T_d\Big|_{st} = \frac{3 V_{th}^2}{\omega_s} \frac{R_2'}{(R_{th} + R_2')^2 + (X_{th} + X_2')^2}$$

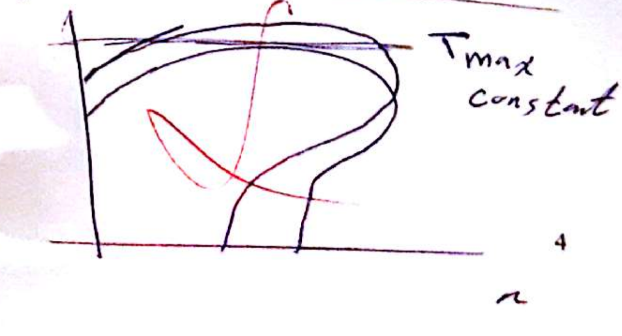
$$T_{max} = \frac{3V^2}{2\omega_s} \frac{1}{\left[R_{th} + \sqrt{R_{th}^2 + (X_{th} X_2')^2}\right.}$$

$$S_{max} = \frac{R_2'}{\sqrt{R_1^2 + X_{eq}^2}} = 0.2$$

$n_n =$

$S_{max} = 0.4$





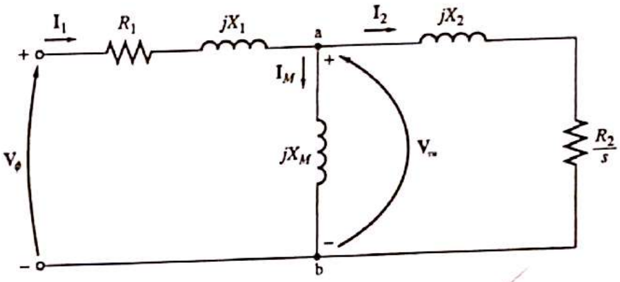
Question # 4 (8 marks) (8

The following test data were taken on a 7.5-hp, four-pole, 208-V, 60-Hz, **design A**, Y-connected IM having a rated current of 28 A. Find the parameters (R_1, X_1, R_2, X_2, and X_M) of the IEEE model of the IM and the rotational power loss P_{rot}.

DC Test		No-load Test (f = 60 Hz)			Locked-rotor Test (f = 15 Hz)		
V_{DC}	I_{DC}	V_{nl}	I_{nl}	P_{nl}	V_{Bl}	I_{Bl}	P_{Bl}
13.6 V	**28.0 A**	**208 V**	**8.17 A**	**420 W**	**25 V**	**27.9 A**	**920 W**

Division of blocked-rotor reactance for NEMA-design motors

	A, D	B	C	Wound Rotor
X_1	$0.5X_{BR}$	$0.4X_{BR}$	$0.3X_{BR}$	$0.5X_{BR}$
X_2	$0.5X_{BR}$	$0.6X_{BR}$	$0.7X_{BR}$	$0.5X_{BR}$



R_1 =	0.24	Ω
R_2 =	0.15	Ω
X_1 =	0.68	Ω
X_2 =	0.68	Ω
X_M =	~~371.9~~ → 13.86	Ω
P_{rot} =	371.9	W

① DC

$R_1 = \frac{1}{2}\frac{13.6}{28} = 0.24$

② Blocked ($s = 1$)

$Z_B = \frac{25/\sqrt{3}}{27.9} = 0.52\ \Omega$

$R_{eq} = \frac{920/3}{27.9^2} = 0.39\ \Omega$

$R_{eq} = R_1 + R_2$

$X_{BL}\big|_{15Hz} = \sqrt{Z^2 - R^2} = 0.34\ \Omega$

$X_B\big|_{60Hz} = 4(0.34) = 1.36\ \Omega = (X_1 + X_2')$

③ No-load ($s = 0$)

$P_{nl} = 3I^2R_1 + P_{rot}$

$S_{nl} = 2943.3$

$Q = 2913.25 = 3I^2(X_1 + X_m)$

$X_1 + X_m = 14.54 \rightarrow X_m =$

Question # 5 (5 marks)

$n_1 = 1800$ ② $S_{FL} = 5\%$

A 460-V 100-hp four-pole Δ-connected 60-Hz three-phase induction motor has a full-load slip of 5 %, and efficiency of 92 %, and a power factor of 0.87 lagging. At start-up, the motor develops 1.9 times the full-load torque but draws 7.5 times the rated current at the rated voltage. This motor is to be started with a reduced voltage starter. Find

5.1	The full-load torque T_{FL}.	T_{FL} = 416.43 Nm
5.2	The full-load current I_{FL}.	I_{FL} = ~~67.5∠-29.5~~ A → 116.9 ∠-29.5
5.3	the starting voltage V_{st} that would reduce the starting torque until it equals the rated torque of the motor	V_{st} = 333.7 V_L ~~192.6~~ Oph-value
5.4	the motor starting current I_{st} drawn from the supply at the reduced voltage.	I_{st} = 161.18 A
5.5	the new starting T_{st} torque if the motor is started at rated voltage using a 50 Hz source	T_{st} = Nm

$T_{FL} = \frac{T_{st}}{1.9}$, $T_{st} = 1.9\ T_{FL}$

$\eta = \frac{P_{out}}{P_{in}} = \frac{0.92}{1} = \frac{74.57}{?}$ ⟹ $P_{in} = 81.05$ kW

$T_{dFL} = \frac{P_d}{\omega_m}$ = ~~416.4~~ ③

$I_{L-L} = 116.9 \angle -29.5$ A

67.5

~~$\frac{T_{FL}}{T_{st}} = \left(\frac{V_2}{V_1}\right)^2$~~

~~$\frac{V_2}{V_1} = \sqrt{\frac{1}{1.9}}$ ⟹ $V_2 = \ldots$ = 333~~