University of Jordan Faculty of Engineering & Technology Electrical Engineering Department
EE471: Electrical Machines II Second Exam Second Summer 2016-2017 9/7/2017 Time: 14:00-15:00

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*Q # 1 (5)	Q # 2 (6)	Q # 3 (7)	Q # 4 (4)	Q # 5 (3)	GRADE
3.5	4	7	1.5	3	21 ~~19~~ /25

Question # 1 (5 marks) **ABET Outcome *h* Assessment** **SHOW YOUR CALCULATIONS**

A small industrial plant has a total electrical load of 500 kVA at 0.60 PF lagging. A 100 hp water pump is to be installed. A synchronous motor operating at 0.60 PF leading is selected to drive the pump. Neglect all losses in the synchronous motor. Draw the power triangles for the load, motor and source, and then calculate

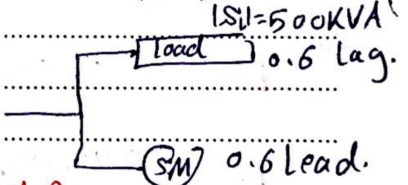
1 hp = 746 W

a.	the total real and reactive powers supplied by the source before installing the pump.	P_s = 300 kW	①
		Q_s = 400 kVAR	
b.	the real and reactive powers taken by the the pump.	P_m = ~~7.46~~ kW	74.6
		Q_m = ~~9.95~~ kVAR	99.5
c.	the total real and reactive powers supplied by the source after installing the pump.	P_s = 307.46 kW	
		Q_s = 390.05 kVAR	①
d.	the overall (combined) system power factor, $PF_{overall}$.	$PF_{overall}$ = 0.6184 lead [✓ lag]	

0.5

$P_s = |S| pf = 300 KW$.

$Q_s = |S| \sin(\cos^{-1} 0.6) = 400 KVAR$.



$P_m = P_{in} = P_{out} = \cancel{7.46 KW}$ 74.6 KW

$Q_m = \frac{P}{pf} \sin(\cos^{-1} 0.6) = \cancel{9.95 KVAR}$ -99.5 KVAR

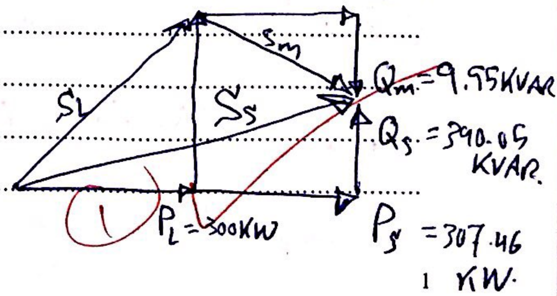
$P_{in} = P_{out} = 100 \times 746$
$= 7.46 KW$.

$P_s = 300K + 7.46K = 307.46 KW$.

$Q_s = 400K - 9.95K = 390.05 KVAR$.

$S_s = 496.66 \angle 51.8° KVA$.

$\Rightarrow pf = \cos(51.8°)$
$= 0.6184$



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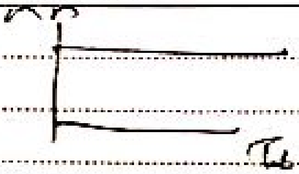
Question # 2 (6 marks) **SHOW YOUR CALCULATIONS**

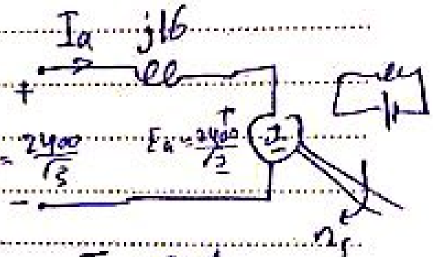
A 3-phase, 2400 V, 60 Hz, four pole, Y-connected synchronous motor has a per phase synchronous reactance X_s of 16 Ω and negligible armature resistance. The excitation is adjusted so that the induced voltage is 2400 V. The motor drives a load connected to its shaft, and the stator current is 80 A. **Draw the phasor diagram** and calculate

a.	the developed torque at the above load condition	T_d = 1564.43 Nm
b.	the motor's power factor	PF = 0.8868 lead [✓ lag]
c.	the new motor's speed, if the load is doubled.	N_s = 900 rpm
d.	the maximum torque the machine can develop	T_{dmax} = 1909.81 Nm

1800 rpm



$I_a = \frac{V_t - E_a}{jX_s}$



$|I_a|^2 = \frac{|V_t|^2 + |E_a|^2 - 2|V_t||E_a|\cos\delta}{|X_s|^2}$

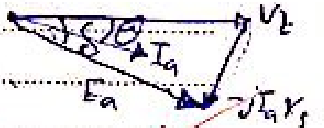
$I_a = 80A$

$(16)^2 (80)^2 = \frac{2400^2}{3} + \frac{2400^2}{3} - \frac{2(2400)^2}{3}\cos\delta$

$\cos\delta = 0.5773 \Rightarrow \boxed{\delta \simeq 55^\circ}$

so

$P_d = \frac{3 V_t E_a}{X_s}\sin\delta = \frac{(2400)^2}{16}\sin 55 =$



$P_d = 294394.7$ ~~Nm~~ $W \Rightarrow n_s = \frac{120}{4}(60) = 1800\,rpm$

$\omega_s = \frac{2\pi}{60}(1800) = 188.5\,rad/s.$

$\tau_d = \frac{P_d}{\omega_s} = \boxed{1564.4}\,N.m.$

$P_d = \sqrt{3} V_t I_L pf$

$P_d = 294394.7 = \sqrt{3}\,(2400)(80)\,pf \Rightarrow \boxed{pf = 0.8868}$ Lagging.

$\theta_I = -27.5^\circ$

$\tau \propto \frac{1}{N_s} \Rightarrow$ reduced to half.

$P_{max} = \frac{3 V_t E_a}{X_s} = \frac{(2400)^2}{16} = 360000\,W$

$\tau_{max} = \frac{360000}{188.5} = 1909.81\,N.m.$

Question # 3 (7 marks) **SHOW YOUR CALCULATIONS**

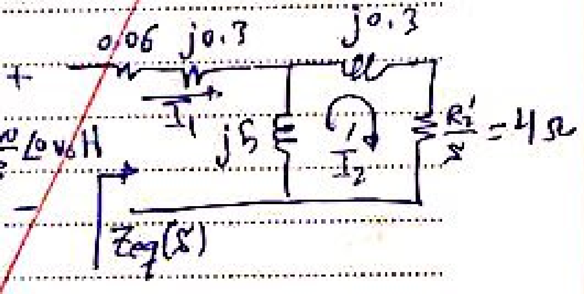
Consider a three phase, 100 hp, 400 V, Y-connected, 4 pole, 60 Hz induction motor. The equivalent circuit parameters are:

$$R_1 = 0.06\,\Omega,\ R_2' = 0.08\,\Omega,\ X_1 = 0.3\,\Omega,\ X_2' = 0.3\,\Omega,\ X_m = 5\,\Omega$$

The motor drives its load at a slip $\boxed{S = 0.02}$. Calculate

a.	the magnitude of the motor's armature current	$\lvert I_a \rvert$ =	70.65	A
b.	the motor's power factor	PF =	0.712	lead [✓ lag]
c.	the magnitude of the rotor's current	$\lvert I_2 \rvert$ =	53.16	A
d.	the developed torque at the above load condition	T_d =	179.9	Nm
e.	the maximum developed torque	T_{dmax} =	640.13	Nm

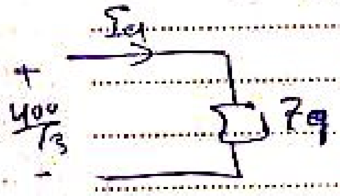
using IEEE model:



$Zeq(s) = (0.06 + j0.3) + (j5) // (4 + 0.3j)$

$Zeq = 2.33 + j2.29\ \Omega$

$= 3.27 \angle 44.6°\ \Omega$



$\Rightarrow I_a = \frac{400/\sqrt{3}}{3.27 \angle 44.6} = \underline{70.6} \angle{-44.6°}\ A$

$Pf = \cos 44.6 = 0.712$

$I_2' = I_1 * \frac{j5}{j5 + 4 + j0.3} = \underline{53.16} \angle{-7.6°}\ A.$

$P_d = 3 |I_2'|^2 \cdot \frac{(1-s)}{s} R_2' = 3(53.16)^2 * \frac{1-0.02}{0.02} * 0.08 = 33.23 KW$

$T_d = \frac{P_d}{\omega_m} = \frac{33.233K}{2\pi\left(\frac{1764}{60}\right)} = 179.9\ \underline{N.m}$

$n_m = (1-s) n_s = (1-0.02) * \frac{120}{4}(60) = 1764$

$$T_{d\,max} = \frac{3|V_1|^2}{2\omega_s} \cdot \frac{1}{R_1 + \sqrt{R_1^2 + X_{eq}^2}} = \frac{\cancel{3}(400)^2}{2\omega_s} * \frac{1}{0.06 + \sqrt{0.06^2 + 0.6^2}}$$

$\omega_s \rightarrow 188.5$

$T_{max} = 640.13 N.m$

Question # 4 (4 marks) **SHOW YOUR CALCULATIONS**

A three-phase, 400 V, 50 Hz, 6-pole wound-rotor induction motor drives a constant torque load at a speed of 950 rpm when the rotor terminals are short-circuited. It is required to reduce the speed of the motor to 850 rpm by inserting external resistances R'_{ext} in the rotor circuit. The rotor winding resistance $R'_2 = 0.2\ \Omega$ per phase and the rotational losses are negligible. Draw the speed-torque characteristics before and after adding the external resistance, and determine approximately

a.	the value of the external resistance.	$R'_{ext} =$	4.8	Ω
b.	the motor's developed torque	$T_d =$	1145.92	Nm

$n_{m_1} = 950$ rpm ; Need $n_{m_2} = 850$ rpm $\Rightarrow R'_{ext} = ??$

$n_s = 1000$ rpm ; $\boxed{R_2' = 0.2}$

$S_1 = \frac{1000-950}{1000} = 0.05$

$S_2 = \frac{n_s - n_{m_2}}{n_s} = \boxed{0.15}$

$P_{out} = P_d$

$P_d = (1-S)P_g$

$P_{cu_2} = S P_g$

$P_g = ?$

with R_{ext}:

$$\tau_d = \frac{3|V_1|^2}{\omega_s} \cdot \frac{R_2' + R_{ext}}{\left(R_1 + \frac{R_2' + R_{ext}}{S}\right)^2 + X_{eq}^2}$$?!

τ @ $S = 0.05$

$$\tau = \frac{400^2}{2\pi \times \frac{1000}{60}} \times \frac{0.05}{0.2} = 381.97\ \text{N.M}$$

Approximate use:

$$\tau_{d_1} = \frac{3|V_1|^2}{\omega_s} \cdot \frac{S}{R_2'} \Rightarrow \tau_d = \frac{3\left(\frac{400}{\sqrt{3}}\right)^2}{2\pi \times \frac{1000}{60}} \cdot \frac{0.15}{0.2} = \boxed{1145.92}$$

T_{d_2}

$\Rightarrow P_d = \omega_m \tau_d = 2\pi \frac{850}{60}(1145.92) = 102\ KW = P_{out}$

$P_g = \frac{P_d}{1-S} =$

$$\tau_d = \frac{3|V_1|^2}{\omega_s} \cdot \frac{S}{R_2' + R_{ext}} \Rightarrow R_2' + R_{ext} = \frac{(1145.92) \times \omega_s}{3|V_1|^2 S}$$

$R_2' + ~~R_{ext} = 5~~$ $\Rightarrow \boxed{R_{ext} = 4.8\ \Omega}$ 0.4

$\frac{S_1}{R_2} = \frac{S_2}{R_2 + R_{ext}}$

$0.05/0.2 = \frac{0.15}{0.2 + R_{ext}}$

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Question # 5 (3 marks) **SHOW YOUR CALCULATIONS**

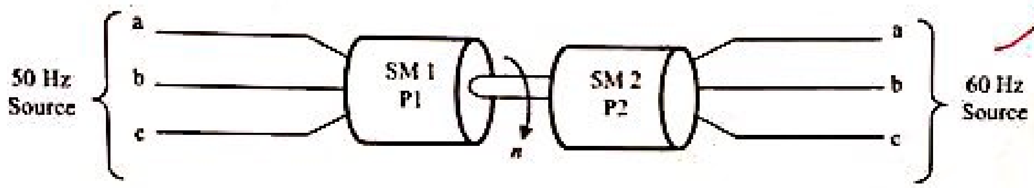
A pair of synchronous machines (SM) on the same shaft, may be used to generate power at 60 Hz from a given power source at 50 Hz as shown below. SM1 has P1 number of poles while SM2 has P2 number of poles. Determine for this type of operation,

a. the mode operation of SM1 and SM2 (Generator/Motor).

b. the minimum number of poles P_1 and P_2.

c. the shaft-speed in rpm, n.

SM1: Motor.
SM2: Generator.
P_1 = 10 poles.
P_2 = 12 poles
n = 600 rpm.



SM1 ⇒ will have an electrical input
so it will give an output mechanical
so it is $\boxed{\text{Motor.}}$

SM2 ⇒ will have ~~a~~ ~~m~~mechanical input
& give an output electrical
so it is $\boxed{\text{Generator}}$.

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

SM1: @ 50Hz ⇒ 10 poles.
SM2: @ 60Hz ⇒ 12 poles.

⇓

$n_s = 600$ rpm

	n_s (rpm).	
P	50	60
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600

$\boxed{Q_1}$

$P_s = |S|\,pf = 300KW.$

$Q_s = |S| \sin(\cos^{-1} 0.6) = 400KVAR.$

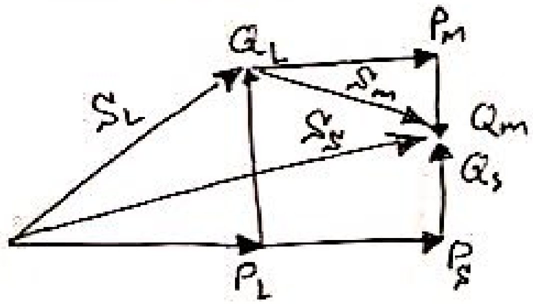
$P_m = P_{in} = P_{out} = 74.6\ KW.$

$Q_m = \frac{P}{pf} \sin(\cos^{-1} 0.6) = -99.5KVAR.$

$P_s = 300K + 74.6K = 374.6KW.$

$Q_s = 400K - 99.5K = 300.5KVAR.$

$S_s = 480.2 \angle 38.7^\circ \Rightarrow pf = \cos(38.7) = 0.78$ lagging.



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$\boxed{Q_4}$

$n_{m_1} = 950$ rpm.
$n_s = 1000$ rpm.
$n_{m_2} = 850$ rpm.

$\Rightarrow$

$S_1 = 0.05$
$S_2 = 0.15$

$$\tau_d = \frac{3|V|^2}{\omega_s} \cdot \frac{S}{R_2'} = \frac{400^2}{2\pi * \frac{1000}{60}} * \frac{0.05}{0.2} = \boxed{381.97}\ N.m.$$

$$\tau_{d_1} = \tau_{d_2} \Rightarrow \cancel{\frac{3|V_2|^2}{\omega_s}} \cdot \frac{S_2}{R_2' + R_{ext}} = \cancel{\frac{3|V_1|^2}{\omega_s}} \cdot \frac{S_1}{R_2'}$$

$$\frac{0.15}{0.2 + R_{ext}} = \frac{0.05}{0.2} \Longrightarrow \boxed{R_{ext} = 0.4\ \Omega}$$