34/40

**Grade:** 17/20

| University of Jordan | Faculty of Engineering & Technology | Electrical Engineering Department |
|---|---|---|
| EE471: Electrical Machines II | First Exam / Second Semester 2015-2016 | 15/3/2016 / Time: 1 Hour |



**Student Name:** [illegible] **Student ID#:** [illegible] **Serial #:** 38

**Question # 1 (10 Points)**

Two identical 3-ph, Y-connected alternators (A and B) are connected in parallel and deliver a total load of 2.5 MW at 11 kV and a power factor of 0.866 lagging. Each generator has a per phase synchronous reactance $X_s = 10\ \Omega$ and a negligible armature resistance. The induced voltage ($E_{aA}$) and the power angle ($\delta_A$) of **generator *A*** are adjusted to 12.5 kV and 6.26°, respectively. Determine for **generators *A* and *B*** the following

a. The load current $I_L$

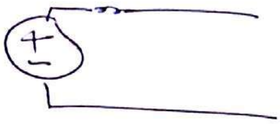
b. The real output power $P_A$ and $P_B$

c. The armature current $I_A$ and $I_B$

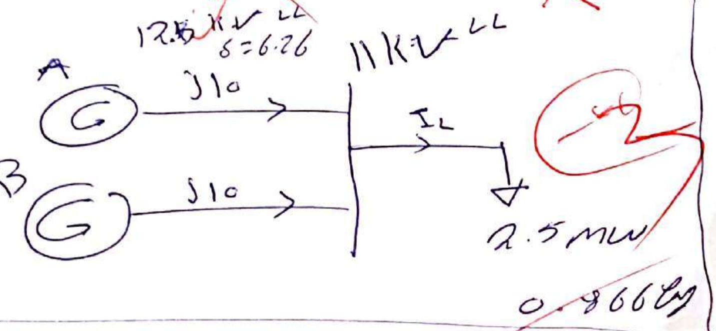
d. The power factor $PF_A$ and $PF_B$ and indicate lead or lag.

e. The reactive output power $Q_A$ and $Q_B$

f. The induced voltage ($E_{aB}$) and the power angle ($\delta_B$) of **generator *B***



| | | | |
|---|---|---|---|
| $I_L = 151 \angle -30°$ A | | $PF_A = 0.713$ | $PF_B = 0.992$ |
| $P_A = 1585.4$ kW | $P_B = 914.7$ kW | $Q_A = 1558.8$ kVAR | $Q_B = 113.93$ kVAR |
| $I_A = 116.67 \angle -44.5$ | $I_B = 48.38 \angle 7.1$ | $E_{aB} = 6309.34$ V | $\delta_B = 4.36°$ |



$I_L = \frac{2.5M}{\sqrt{3}\ 11k \cdot 0.866} = 151.5 \angle -30$

$\bar{I}_A = \frac{\frac{12.5k}{\sqrt{3}} \angle 6.26 - \frac{11k}{\sqrt{3}} \angle 0}{j10} = 116.67 \angle -44.5$

$\bar{I}_B = \bar{I}_L - \bar{I}_A = 48.38 \angle 7.1$

$\bar{E}_e = V_t \angle 0 + \bar{I}_a (jX_s)$

$=$

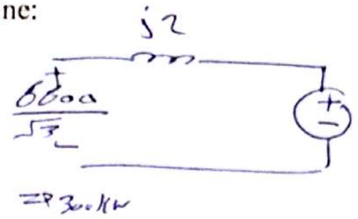
$P_A = \sqrt{3}\, V_L\, I_L \cos\theta$

$Q_A = \sqrt{3}\, V_L\, I_L \sin\theta$

$P = \frac{3 V_t E_a}{X_s} \sin\delta_B$

**Question # 2-a (13 points)**

A 6600-V, 50-Hz, 4-pole, 3-phase, Y-connected synchronous motor takes 300 kW at 0.6 PF lagging. The motor has a synchronous reactance $X_s$ of 2 Ω/phase, negligible armature resistance $R_a$ and rotational power loss $P_{rot}$ (friction, windage and core losses) of 30 kW. Determine:




a. The motor synchronous speed $n_s$,
b. The armature current $I_a$,
c. The induced voltage $E_a$ and torque angle $\delta$,
d. The reactive power absorbed/supplied by the motor $Q_m$,
e. The developed power $P_d$, and developed torque $T_d$,
f. The output horse power $P_{out}$, and the motor efficiency $\%\eta$,
g. The maximum torque the motor can develop $T_{dmax}$,
h. The motor's armature current $I_a$, reactive power $Q_m$ and power factor $PF$ when the motor develops its maximum torque.

$3 I_a^2 R_a$

| | | |
|---|---|---|
| $n_s$ = 1500 rpm | $I_a$ = 43.7∠-53.1° A | $E_a\angle\delta$ = 3740.9∠-0.8° V |
| $Q_m$ = 399.48 kVAR | $P_d$ = 298.540 kW | $T_d$ = 1900 N.m |
| $P_{out}$ = 268.54 kW | $\%\eta$ = 89.95 % | $T_{dmax}$ = 136122 N.m |
| $I_a$ = 2670.9∠-45.5 | $Q_m$ = 21777.310 kVAR | $PF$ = 0.700 lead/(lag) |

(11.5) (0.5)

**Question # 2-b (5 points)** 1 hp = 746 W

$I_{a2} = 1.2 I_{a1}$, $|E_{a2}| = 1.2|E_{a1}|$

If the induced voltage $E_a$ of the machine of Question # 2-a is increased by 20% and the power input to the motor remains the same, i.e. 300 kW, find:

a. The new induced voltage $E_a$ and power angle $\delta$,
b. The new values of armature current $I_a$, reactive power $Q_m$ and the power factor $PF$,
c. The new maximum developed torque $T_{dmax}$.

(-0.5)

$P_1 = P_2 = \frac{3 V_t E_{a1}}{X_s} \sin\delta_1 = \frac{3 V_t E_{a2}}{X_s} \sin\delta_2$

| | | |
|---|---|---|
| $E_a\angle\delta$ = 4489∠-0.668° | | |
| $I_a$ = 340∠85° A | $Q_m$ = 3871.931 kVAR | $PF$ = 0.087 (lead)/lag |
| $T_{dmax}$ = 163344.4 N.m | | |

(4.5)

$I_a = \frac{300k}{\sqrt{3} V\, PF}$

$E_a \angle\delta = \bar{V_t} - \bar{I_a}(jX_s)$
$= 3740.9 \angle -0.8°$

$Q_m = \sqrt{3} V_L I_L \sin\theta$

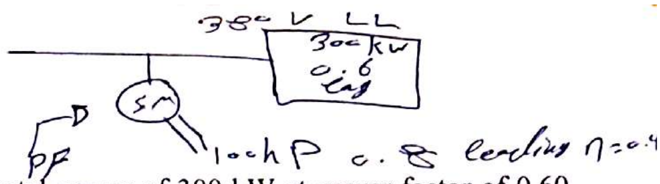
$P_d = \frac{3 V_t E_a}{X_s} \sin\delta_1$

$P_{cu} = 3 I_a^2 R_a = 0$

$\eta = \frac{P_{out}}{P_{in}}$

$T_{dmax} = \frac{3 V_t E_a}{\omega_s X} \Big|_{\delta = 90°}$

$\bar{I_a} = \frac{\frac{6600}{\sqrt{3}}\angle 0 - 3740.9\angle -90}{j2}$

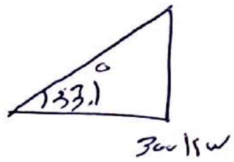



**Question # 3 (7 points) ABET outcome 'h' Assessment**

In an industrial plant, a 3-phase Y-connected load takes a total power of 300 kW at power factor of 0.60 lagging from a 380-V, 3-phase source. A synchronous motor supplying 100 hp and operating at 0.8 power factor leading and having an efficiency of 90% is added to the plant.

Determine

a. The reactive and apparent powers of taken by the load $Q_L$ and $S_L$
b. The real, reactive, and apparent powers of taken by the motor $P_m$, $Q_m$ and $S_m$
c. The overall real, reactive, and apparent powers supplied by the system $P_s$, $Q_s$ and $S_s$
d. The magnitudes of load current, motor current, and system current $I_L$, $I_m$, and $I_s$
e. The over all system power factor $PF_s$.
f. Is the motor under- or over-excited.




**Draw the power triangles to illustrate your solution.**

| | | |
|---|---|---|
| $Q_L$ = 399.5 kVAR | $S_L$ = 499.6 kVA | |
| $P_m$ = 82.85 kW | $Q_m$ = 62.14 kVAR | $S_m$ = 103.56 kVA |
| $P_s$ = 382.85 kW | $Q_s$ = 461.64 kVAR | $S_s$ = 599.73 kVA |
| $I_L$ = 759∠-53.1 A | $I_m$ = 157.3∠+36.9° A | $I_s$ = 775.2∠-41° A |
| $PF_{overall}$ = 0.754 lead (lag) | | |

$100\,hp = P_{out} = 74.57\ kW$, $\eta = 0.9 = \frac{P_{out}}{P_{in}}$

$P_{in} = 82.85\,K$

$I_L = \frac{P_{3\phi}}{\sqrt{3}\,V_L\,PF}$

$Q_L = P\tan\phi$

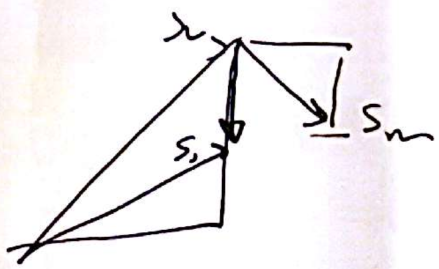
$S_L = \sqrt{P^2 + Q^2}$

$P_s = P_L + P_m$

$Q_s = Q_L \mp Q_m$

$S_s = S_L + S_m$

$I = \frac{S_{3\phi}}{\sqrt{3}\,V_{LL}}$

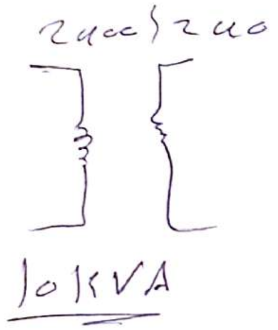


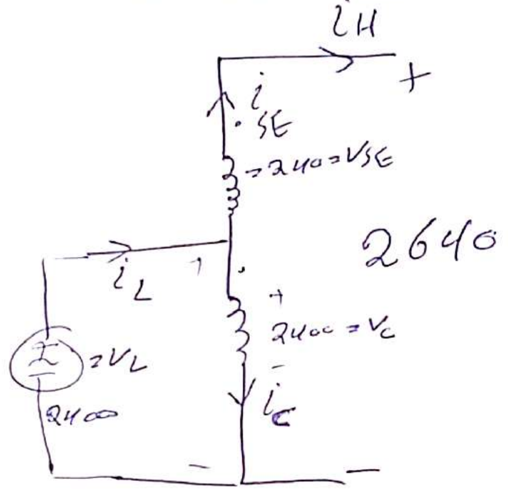
8.5

**Question #4 (10 marks)** **SHOW YOUR CALCULATIONS**

A 10-kVA, 60-Hz, 2400—240-V distribution transformer is reconnected for use as a step-up autotransformer with a 2640-V output and a 2400-V input. Draw the connection diagram and determine:

a. the rated primary current $I_L$ and secondary current $I_H$ when connected as an autotransformer.
b. the advantage factor, $A_f$.
c. the apparent-power rating $S_{I/O}$ when connected as an autotransformer.
d. power transferred by induction $S_{ind}$ and conduction $S_{cond}$.




$2640 = V_H$

| | | |
|---|---|---|
| $I_L$ = | 45.87 | A |
| $I_H$ = | 41.7 A | A |
| $A_f$ = | 11 | |
| $S_{I/O}$ = | 110080 | kVA |
| $S_{ind}$ = | ~~10k~~ 10000 = Sw | kVA |
| $S_{cond}$ = | 100080 | kVA |

$i_H = i_{SE}$

$i_L = i_{SE} + i_C$

$V_L = V_C$

$V_H = V_C + V_{SE}$

$110080 = S_{IO}$

$110080$

~~$V_L I_L = S_w \Rightarrow I_L = \frac{S_w}{V_L} = 4.17\,A$~~

~~$I_H = I_{SE} = \frac{S_w}{V_{SE}} = 41.67\,A$~~

~~$A_f = \frac{S_{IO}}{S_w}, S_{IO} =$~~

$I_{SE} = \frac{10k}{240} = 41.7\,A = I_H$

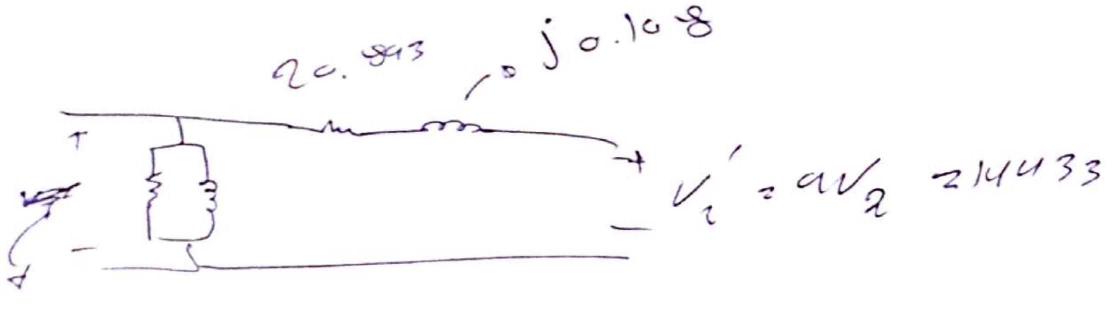
$\Rightarrow i_L = 45.87\,A$

$i_C = 4.17\,A$

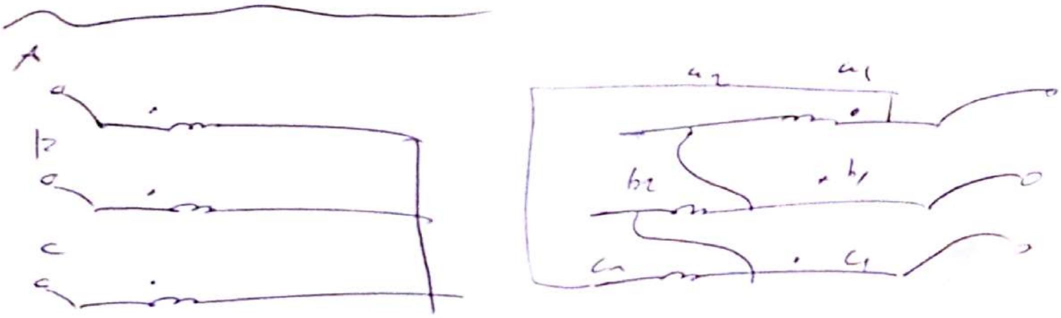
$S_{IO} = 110080 \Rightarrow A_f = \frac{S_{IO}}{S_w} = 11$

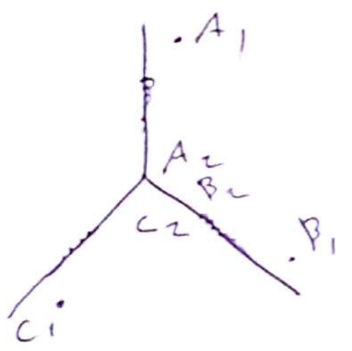
$S_{in} = S_w$

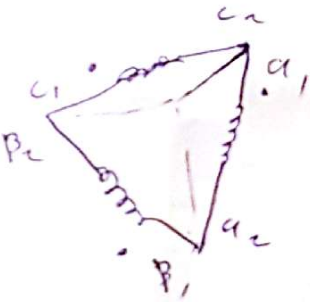
$S_{con} = S_{IO} - S_w$


20.893
j 0.108
+
-
$V_1' = aV_2 = 14433$

14433


A
B
C
a2
a1
b2
b1
c2
c1


A1
A2
B2
C2
B1
C1


c2
a1
c1
b2
a2
b1

$Y_n d1$