University of Jordan	School of Engineering	Electrical Engineering Department
EE471: Electrical Machines II	First Exam 2nd Summer Session 2016-2017	Wed.: 2/8/2017 Time: 1 Hour

Student Name: **Student ID#:** **Serial #:**

Q # 1 (4)	Q # 2 (4)	Q # 3 (4)	Q # 4 (6)	Q # 5 (7)	GRADE
4	4	4	6	7	25/25

Question # 1 (4 marks) **ABET Outcome *h* Assessment**

Due to the increasing cost of building new power stations, increasing cost of fuel and pollution reduction, many countries including Jordan thought of many alternatives to meet the maximum demand. Mention four alternatives to the classical (conventional) power generation to avoid the above constraints and to meet the maximum demand.

1. Building Renewable Energy power Plants such as wind and PV
2. Interconnection with other countries
3. using high efficient devices
4. Building nuclear power station

Question # 2 (4 marks) **SHOW YOUR CALCULATIONS**

The open-circuit, short-circuit and DC test data for a 3-phase, Y-connected, 50 kVA, 240 V, 60-Hz synchronous alternator are

Open-Circuit Test	Short-Circuit Test	DC-Resistance Test
$I_f = 20$ A	$I_f = 20$ A	$I_{dc} = 52.80$ A
$V_{Loc} = 240$ V	$I_{Lsc} = 115.65$ A	$V_{dc} = 10.35$ V

Determine based on machine ratings

a.	the armature resistance, R_a in pu (Assume the effective armature resistance $R_a = 1.2\times R_{dc}$)	$R_a = 0.102$	pu
b.	the synchronous impedance, Z_s in pu	$Z_s = 1.04$	pu
c.	the synchronous impedance, X_s in pu	$X_s = 1.035$	pu

Solution:

$$R_{dc} = \frac{1}{2}\frac{V_{dc}}{I_{dc}} = \frac{1}{2}\times\frac{10.35}{52.8} = \frac{0.196}{2} = 0.098\Omega \Rightarrow R_a = 1.2\times R_{dc} = 1.2\times 0.098 = 0.1176\,\Omega$$

$$Z_s = \frac{V_{oc}}{I_{sc}} = \frac{240/\sqrt{3}}{115.65} = 1.1981\,\Omega \qquad \Rightarrow X_s = \sqrt{Z_s^2 - R_s^2} = \sqrt{1.1981^2 - 0.1176^2} = 1.1923\,\Omega$$

$$Z_b = \frac{V_b^2}{S_b} = \frac{(0.240)^2}{0.05} = 1.152\,\Omega$$

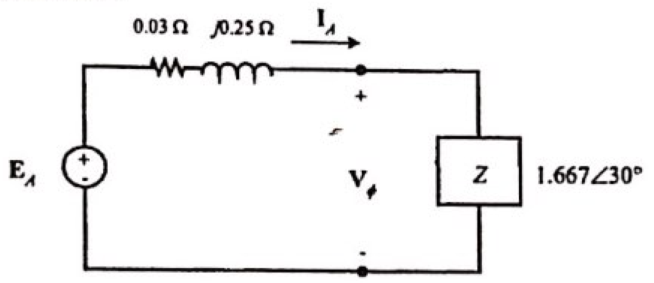
$$R_a = \frac{R_a}{Z_b} = \frac{0.1176}{1.152} = 0.102\ pu \quad ,Z_s = \frac{Z_s}{Z_b} = \frac{1.1981}{1.152} = 1.04\ pu \qquad X_s = \frac{X_s}{Z_b} = \frac{1.1923}{1.152} = 1.035\ pu$$

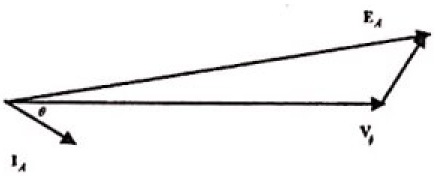
Question # 3 (4 marks) **SHOW YOUR CALCULATIONS**

A 480-V, 200-kVA, 0.8-PF-lagging, 60-Hz, two-pole, Y-connected synchronous generator has a synchronous reactance of 0.25 Ω and an armature resistance of 0.03 Ω. At 60 Hz, its friction and windage losses are 6kW, and its core losses are 4kW. Assume that the field current of the generator has been adjusted to a value of 4.5 A (so that the open-circuit terminal voltage of the generator will be about 477 V). If the generator is connected to a Δ-connected load with an impedance of $5\angle 30^{\circ}$ Ω per phase, find

a.	the magnitude of the *L-L* terminal voltage	$V_t =$	433	V
b.	the efficiency of the generator	$\eta =$	89.01	%

Solution:





The magnitude of the phase current flowing in this generator is

$$I_A = \frac{E_A}{|R_A + jX_S + Z|} = \frac{275\text{ V}}{|0.03 + j0.25 + 1.667\angle 30°|} = \frac{275\text{ V}}{1.829\ \Omega} = 150\text{ A}$$

Therefore, the magnitude of the phase voltage is

$$V_\phi = I_A Z = (150\text{ A})(1.667\ \Omega) = 250\text{ V}$$

and the terminal voltage is

$$V_T = \sqrt{3}\,V_\phi = \sqrt{3}\,(250\text{ V}) = 433\text{ V}$$

$$P_{out} = 3 \times V_t \times I_a \times \cos(\theta) = 3 \times 250 \times 150 \times \cos(30°) = 97.4\ kW$$

$$P_{cu} = 3 \times I_a^2 \times R_a = 3 \times 150^2 \times 0.03 = 2.025\ kW$$

$$P_{in} = P_{out} + P_{cu} + P_{F\&W} + P_{core} = (97.425 + 2.025 + 6 + 4)k = 109.45\ kW$$

$$\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{97.425}{109.45} \times 100 = 89.01\%$$

Question # 4 (6 marks) **SHOW YOUR CALCULATIONS**

A 100-MVA, 12.5-kV, 0.80-PF-lagging, 50-Hz, two-pole, Y-connected synchronous generator has a synchronous reactance $X_s = 1.716\ \Omega$ and an armature resistance $R_A = 0.0187\ \Omega$.

1. Calculate for rated conditions

a.	the magnitude of the *L-L* generated voltage and the power angle	$E_a =$	23.54	kV
		$\delta =$	27.6	o
b.	the % voltage regulation	$\%VR =$	88.3	%
c.	the real and reactive power delivered by the generator	$P_{FL} =$	80	MW
		$Q_{FL} =$	60	MVAR
d.	the applied mechanical torque assuming all losses are ignored	$T_{m.} =$	255	kNm

2. Draw the phasor diagram for rated conditions.

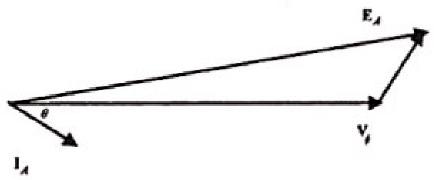
Solution:

a. The speed of the generator prime-mover n_s is

$$n_m = n_s = \frac{120f}{P} = \frac{120\times 50}{2} = 3000\ rpm \qquad \omega_s = \frac{2\pi n_s}{60} = \frac{2\pi\times 3000}{60} = 100\pi = 314\ rad/s$$

The phase voltage V_φ is,

$$V_\varphi = \frac{V_{LL}}{\sqrt{3}} = \frac{12{,}500}{\sqrt{3}} = 7217V.$$



The phase current I_A is,

$$I_L = \frac{S_{3\varphi}}{\sqrt{3}V_{LL}} \frac{100\times 10^6\ VA}{\sqrt{3}\times 12.5\times 10^3\ V} = 4619\ A$$

The power is 0.8 lagging, the power factor angle θ is $\theta = \cos^{-1}(0.8) = 36.9^\circ$, So $\bar{I}_A = 4619\angle -36.9^\circ\ A$

The internal generated voltage E is,

$$\bar{E}_a = \bar{V}_\varphi + (R_A + jX_s)\cdot \bar{I}_A = 7217\angle 0^\circ + (0.0187 + j1.716)\times 4619\angle -36.9^\circ$$

$\bar{E}_a = 13{,}590\angle 27.6^\circ\ V\ (13.59\angle 27.6^\circ\ kV)$ **The power angle δ is $\delta = 27.6^\circ$.**

b. The % voltage regulation (VR) at full-load and 0.8 PF lagging is

$$VR = \frac{V_{nl} - V_{FL}}{V_{FL}}\times 100 = \frac{E - V_{FL}}{V_{FL}}\times 100 = \frac{13590 - 7217}{7217}\times 100 = 88.3\%$$

c. The output real power of the generator P_{out} is

$$P_{FL} = S_{3\varphi}\times\cos(\theta) = S_{3\varphi}\times PF = 100\times\cos(36.9^\circ) = 100\,MVA\times 0.8 = 80\ MW$$

The output reactive power of the generator Q_{out} is

$$Q_{FL} = S_{3\varphi}\times\sin(\theta) = 100\,MVA\times\sin(36.9^\circ) = 100\,MVA\times 0.6 = 60\ MVAR$$

d. The applied mechanical torque T_m is

$$T_m = \frac{P_{in}}{\omega_s} = \frac{P_{out}}{\omega_s} = \frac{80\times 10^6\ MW}{100\pi} = 255\ kN.m$$

Question # 5 (7 marks) **SHOW YOUR CALCULATIONS**

A 3-phase Y-connected synchronous generator is rated 120 MVA, 13.8 kV, 0.85 PF lagging, and 60 Hz. Its synchronous reactance is 0.7 Ω, and its resistance may be ignored. If the generator is connected to to13.8 kV distribution grid, find

a.	the % voltage regulation at rated conditions	$\%VR =$	28.8	%
b.	the power developed by the generator	$P_d =$	101.84	MW
c.	the magnitude of the *L-L* terminal voltage and apparent power ratings of this generator if it were operated at 50 Hz with the same armature and field losses as it had at 60 Hz	$V_t =$	11.5	kV
		$S_{rated} =$	100	MVA
d.	the % voltage regulation of the generator at 50 Hz	$\%VR =$	28.8	%

Solution:

The rated armature current is

$$I_A = I_L = \frac{S}{\sqrt{3}\,V_T} = \frac{120\text{ MVA}}{\sqrt{3}(13.8\text{ kV})} = 5020\text{ A}$$

The power factor is 0.85 lagging, so $\mathbf{I}_A = 5020\angle -31.8^\circ\text{ A}$. Therefore, the internal generated voltage is

$$\mathbf{E}_A = \mathbf{V}_\phi + R_A\mathbf{I}_A + jX_S\mathbf{I}_A$$

$$\mathbf{E}_A = 7967\angle 0^\circ + j(0.7\ \Omega)(5020\angle -31.8^\circ\text{ A})$$

$$\mathbf{E}_A = 10{,}260\angle 16.9^\circ\text{ V}$$

The resulting voltage regulation is

$$\text{VR} = \frac{10{,}260 - 7967}{7967} \times 100\% = 28.8\%$$

$$P_d = \frac{3\times V_t \times E_a}{X_s}\sin(\delta) = \frac{3\times 7{,}967 \times 10{,}260}{0.7}\sin(16.9^\circ) = \mathbf{101.8389}\ MW$$

If the generator is to be operated at 50 Hz with the same armature and field losses as at 60 Hz (so that the windings do not overheat), then its armature and field currents must not change. Since the voltage of the generator is directly proportional to the speed of the generator, the voltage rating (and hence the apparent power rating) of the generator will be reduced by a factor of 5/6.

$$V_{trated} = \frac{50}{60}\times 13.8\ kV = 11.5\ kV \qquad S_{rated} = \frac{50}{60}\times 120\ MVA = 100\ MVA$$

Also, the synchronous reactance will be reduced by a factor of 5/6. $X_s = \frac{50}{60}\times 0.7\ \Omega = \mathbf{0.583\ \Omega}$

At 50 Hz rated conditions, the armature current would be

$$I_A = I_L = \frac{S}{\sqrt{3}\,V_T} = \frac{100\text{ MVA}}{\sqrt{3}(11.5\text{ kV})} = 5020\text{ A}$$

The power factor is 0.8 lagging, so $\mathbf{I}_A = 5020\angle -31.8^\circ\text{ A}$. Therefore, the internal generated voltage is

$$\mathbf{E}_A = \mathbf{V}_\phi + R_A\mathbf{I}_A + jX_S\mathbf{I}_A$$

$$\mathbf{E}_A = 6640\angle 0^\circ + j(0.583\ \Omega)(5020\angle -31.8^\circ\text{ A})$$

$$\mathbf{E}_A = 8550\angle 16.9^\circ\text{ V}$$

The resulting voltage regulation is

$$\text{VR} = \frac{8550 - 6640}{6640}\times 100\% = 28.8\%$$

Because voltage, apparent power, and synchronous reactance all scale linearly with frequency, the voltage regulation at 50 Hz is the same as that at 60 Hz.