## ECE 325, Fall 2016, Final Exam

Name
The test has 110 points in total.

Problem 1 (45 points, 3 points each): True or False? (Reasons are NOT required)
a. True of false for each statement about a 6-pole squirrel-cage induction motor excited by a 3-phase, 60 Hz AC source?

1) Under the no load condition, its rotor has a speed of $1200 \mathrm{r} / \mathrm{min}$ at a steady state

False
2) To reverse the direction of the revolving magnetic field, we may interchange any two of lines $A, B$ and C .
True
3) When the motor has a negative slip, it operates as a generator supplying both active power and reactive power to the source.

> False
4) When the rotor is locked, both the current and torque are much higher than the values under the full-load condition.

False
5) If its rotor resistance is increased, the rotor speed will have more variation when the torque changes from the no-load torque to the breakdown torque. True
b. True or false for each statement about synchronous machines?

1) Steam turbine generators usually adopt salient-pole rotor synchronous machines operating at high speeds in 1800-3600 r/min

## False

2) When a synchronous generator has a sudden load current change, the reactance of its equivalent circuit drops to a lower value but eventually goes back to the value of the synchronous reactance. True
3) A synchronous condenser is synchronous machine running at no-load and its main purpose is to absorb or deliver reactive power by changing its excitation True
4) For a synchronous generator delivering both active and reactive powers to an infinite bus, an increase of its mechanical torque can increase the delivered active and reactive powers.

False
5) For the same generator as 4), an increase of its exciting current can increase the delivered active and reactive powers.
True
c. True or false for these statements about the 4-quadrant DC-to-DC converter shown in the figure?

1) Switches Q1-Q4 may be IGBTs, GTOs, MOSFETs or Thyristors.

False
2) It is called a 4-quadrant converter because both $E_{\mathrm{A}}$ and $E_{\mathrm{B}}$ change between $-E_{\mathrm{H}}$ and $+E_{\mathrm{H}}$

False

3) Q1 and Q2 can never be closed at the same time to avoid a short-circuit across the source but may both open for a very brief time
True
4) If the duty cycle of Q 2 is 0.4 , the average voltage $E_{\mathrm{LL}}$ must be negative

## False

5) When this converter is used as a DC-to-AC sine wave converter with PMW, the duty cycle of Q1 varies at a frequency much higher than the switching frequency of Q 1 . True

Problem 2 ( 25 points): A wye-connected squirrel-cage motor having a synchronous speed of $900 \mathrm{r} / \mathrm{min}$ is connected to a $600 \mathrm{~V}, 60 \mathrm{~Hz}, 3-$ phase line. It has the equivalent circuit per phase as shown in the figure. If it operates at a speed of $870 \mathrm{r} / \mathrm{min}$, answer or calculate the following:
a. Does it operate as a generator or motor?
b. The active power transmitted to the rotor

c. The rotor $I^{2} R$ losses
d. The total mechanical power and torque delivered to the load, ignoring the windage and friction losses
e. The total complex power supplied from the 3-phase line
f. Its efficiency
a.
$s=\left(n_{s}-\mathrm{n}\right) / n_{s}=(900-870) / 900=0.0333 \quad 2$,
$R_{2} / \mathrm{s}=1 / 0.0333=30 \Omega>0$
Motor
b.
$\left|E_{\mathrm{g}}\right|=600 / 1.73=346.4 \mathrm{~V} \quad 2$,
$\left|I_{1}\right|=\left|E_{\mathrm{g}}\right| /|30+1+\mathrm{j} 5|=346.4 / 31.4=11.03 \mathrm{~A}$
$P_{r}=\left|I_{1}\right|^{2} R_{2} / s=3651 \mathrm{~W}$
c
$P_{j r}=\left|I_{1}\right|^{2} R_{2}=121.7 \mathrm{~W}$
d
$P_{m 3 p}=3\left(P_{r}-P_{j r}\right)=10588 \mathrm{~W}$
$T_{m 3 p}=9.55 \times P_{m} / n=116.2 \mathrm{~N} \cdot \mathrm{~m}$
e
$\mathrm{Z}_{\mathrm{m}}=1 /\left(1 / \mathrm{j} \mathrm{X}_{\mathrm{m}}+1 / \mathrm{R}_{\mathrm{m}}\right)=9.9+\mathrm{j} 99 \Omega \quad 1$,
$S_{1 \mathrm{p}}=E_{\mathrm{g}} I_{1}{ }^{*}+\left|E_{\mathrm{g}}\right|^{2} / Z_{\mathrm{m}}{ }^{*}=3893 \mathrm{~W}+\mathrm{j} 1809$ var $\quad 2$,
$S_{3 \mathrm{p}}=3 S_{1 \mathrm{p}}=\quad 11,678 \mathrm{~W}+\mathrm{j} 5,426$ var $\quad 2^{\prime}$
f
$\eta=P_{m 3 p} / P_{e 3 p}=90.7 \%$

Problem 3 (20 points): Consider the equivalent circuit per phase of a synchronous generator connected to an infinite bus:
synchronous reactance $X_{\mathrm{S}}=1 \Omega$
infinite bus voltage $E=11 \mathrm{kV}$
excitation voltage $E_{\mathrm{o}}=10 \mathrm{kV}$
torque angle $\delta=30^{\circ}$
Calculate the following for one phase:
a. The active power output

b. The maximum active power output
c. The line current $I$
d. Does the infinite bus absorb or supply reactive power? How much?
e. The load power factor, leading or lagging?
f. Draw the phasor diagram for one phase about $E_{\mathrm{o}}, E, I$ and $E_{\mathrm{x}}$
a.
$P=E_{0} E \sin \left(30^{\circ}\right) / X_{\mathrm{s}}=55 \mathrm{MW} \quad 3$,
b.
$P_{\max }=E_{0} E / X_{\mathrm{s}}=110 \mathrm{MW} \quad 3$,
c.
$I=\left(E_{0} \angle 30^{\circ}-E\right) /\left(j X_{\mathrm{s}}\right)=5.52 \angle 25.08^{\circ} \mathrm{kA} \quad 3^{\prime}$
d.
$S=E I^{*}=55 \mathrm{MW}-\mathrm{j} 25.7 \mathrm{Mvar}$
$\mathrm{Q}=-25.7$ Mvar 2'
Supply $\quad 1$ '
e.
$\mathrm{PF}=\cos \left(25.08^{\circ}\right)=0.906 \quad 2^{\prime}$
Leading $\quad 1$,
f.
$E_{\mathrm{x}}=\mathrm{j} X_{\mathrm{s}} I=5.52 \angle 115.08^{\circ} \mathrm{kV} \quad 1$,
4 phasors: $\quad 1$ ' x 4


Problem 4 (20 points): The 2-quadrant DC-to-DC converter shown in the figure has a switching frequency $=10 \mathrm{kHz}$ and a duty cycle $D=0.2$ for S 1 .
a. Determine the average value and actual direction of the DC current $I_{\mathrm{L}}$
b. Determine the ON time $T_{\mathrm{a}}$ of switch S 1 and the ON time $T_{\mathrm{b}}$ of switch S 2
c. Determine the peak-to-peak ripple superposed on current $I_{\mathrm{L}}$ and draw the waveform of $I_{\mathrm{L}}$ for one cycle

a.
$E_{\mathrm{L}}=D E_{\mathrm{H}}=0.2 \times 100=20 \mathrm{~V} \quad 2$,
$I_{\mathrm{L}}=(20-30) / 2=-5 \mathrm{~A} \quad 2$,
From 5 to $1 \quad 2$,
b.

The duration of one cycle
$T=1 / f=1 / 10000=100 \mu \mathrm{~s} \quad 2$ '
S1 is closed for $T_{\mathrm{a}}=0.2 \times 100=20 \mu \mathrm{~s} \quad 2^{\prime}$
S 2 is closed for $T_{\mathrm{b}}=80 \mu \mathrm{~s} \quad 2^{\prime}$
c.

Since $I_{\mathrm{L}}$ is from 5 to $1, I_{\mathrm{a}}<I_{\mathrm{b}}$
Assume S 2 is closed
$I_{\mathrm{b}}-I_{\mathrm{a}}=\left(E_{45}+E_{52}\right) T_{\mathrm{b}} / L=(-5 \times 2+30) \times 80 \times 10^{-6} /\left(10 \times 10^{-3}\right)=0.16 \mathrm{~A}$
or
$I_{\mathrm{b}}-I_{\mathrm{a}}=\left(\mathrm{E}_{\mathrm{H}}-E_{45}-E_{52}\right) T_{\mathrm{a}} L=(100+5 \times 2-30) \times 20 \times 10^{-6} /\left(10 \times 10^{-3}\right)=0.16 \mathrm{~A} \quad 2^{\prime}$
$I_{\mathrm{b}}=5.08 \mathrm{~A} \quad 2^{\prime}$
$I_{\mathrm{a}}=4.92 \mathrm{~A} \quad 2^{\prime}$
Figure 2,


