

# EE152 F13 Midterm 1

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Name: (please print)   **Solution**  

In recognition of and in the spirit of the Stanford University Honor Code, I certify that I will neither give nor receive unpermitted aid on this exam.

Signature: \_\_\_\_\_

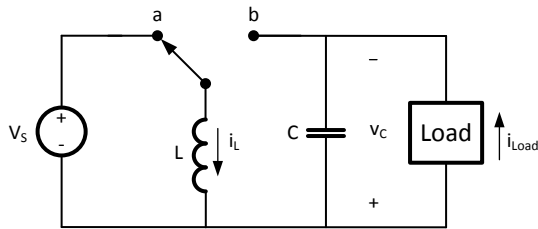
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**You may not, collaborate in any manner on this exam. This exam is open notes, open book. You have 90 minutes to complete the exam. Please do all of your work on the exam itself. Attach any additional pages as necessary.**

**Before starting, please check to make sure that you have all 6 pages.**

<b>1</b>		<b>20</b>
<b>2</b>		<b>20</b>
<b>3</b>		<b>20</b>
<b>4</b>		<b>20</b>
<b>5</b>		<b>20</b>
<b>Total</b>		<b>100</b>

## Problem 1 [20 Points]



Consider the switching converter shown in the Figure above operating with a switching cycle time of  $t_{cy}$ .

- (a) [10 Points] What is the relationship between output voltage  $V_C$  and input voltage  $V_S$  as a function of the duty factor of the switch in position **a**  $D_a$  in the periodic steady state.

*To give volt-second balance across the inductor we must have:*

$$D_a V_S = (1 - D_a) V_C$$

*Note the polarity on  $V_C$*

- (b) [10 Points, 5 Points Each] Write expressions for the change in inductor current  $\Delta I$  and the change in capacitor voltage  $\Delta V$  over one cycle when not in the periodic steady state.

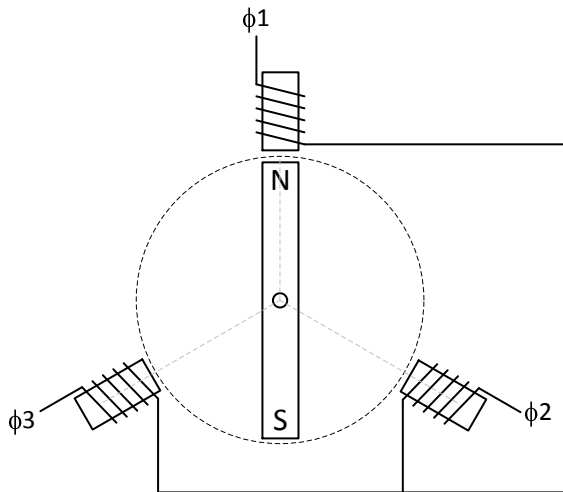
*The change in inductor current is the volt-dutyfactor imbalance multiplied by  $t_{cy}/L$ .*

$$\Delta I = (t_{cy}/L) (D_a V_S - (1 - D_a) V_C)$$

*The capacitor integrates this current less the load current.*

$$\Delta V = (t_{cy}/C) (I_L - I_{Load})$$

## Problem 2 [20 Points]



Suppose you have a 3-phase brushless permanent magnet motor (as shown above) with motor constant  $K_M = 1 \text{ Vs/rad}$  for which the drive to  $\phi 3$  has become disconnected. Assuming that you drive  $\phi 1$  and  $\phi 2$  with appropriate sine waves of current with peak amplitude of 1A, write an expression for the torque of this motor as a function of  $\theta$ . Assume that you have an explicit return from the common point of the windings so that the current to  $\phi 1$  and  $\phi 2$  can be controlled independently.

The current for phases 1 and 2 are

$$i_1 = \sin(\theta)$$

$$i_2 = \sin(\theta - 120)$$

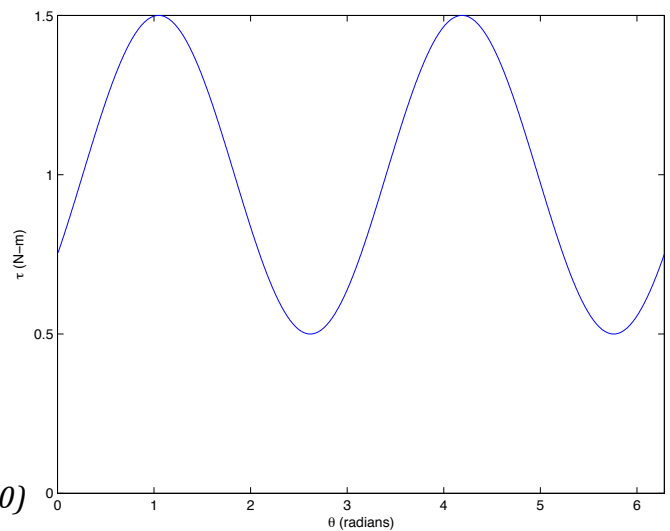
The torque for each phase is

$$t_1 = K_M i_1 \sin(\theta) = K_M \sin^2(\theta)$$

$$t_2 = K_M i_2 \sin(\theta - 120) = K_M \sin^2(\theta - 120)$$

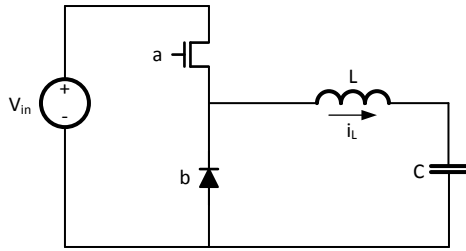
Summing gives

$$\tau = K_M (\sin^2(\theta) + \sin^2(\theta - 120)) = \sin^2(\theta) + \sin^2(\theta - 120)$$



This is plotted at right. You can see its just the steady 1.5 N-m torque one would expect less the contribution of the disconnected third phase.

### Problem 3 [20 points]



Consider the buck converter shown above operating in the periodic steady state with  $V_{in} = 12V$ ,  $V_C = 1V$ ,  $I_L = 30A$ , and a 200kHz switching frequency  $f_{cy}$ . Suppose the MOSFET has an  $R_{on}$  of  $5m\Omega$  and switches with a linear current ramp of  $1A/ns$  for both turn-on and turn-off. Assume that the capacitance on the source of the MOSFET is negligible. Also assume that the diode, inductor, and capacitor are ideal and that ripple current is negligible. Compute the switching loss and conduction loss of this converter.

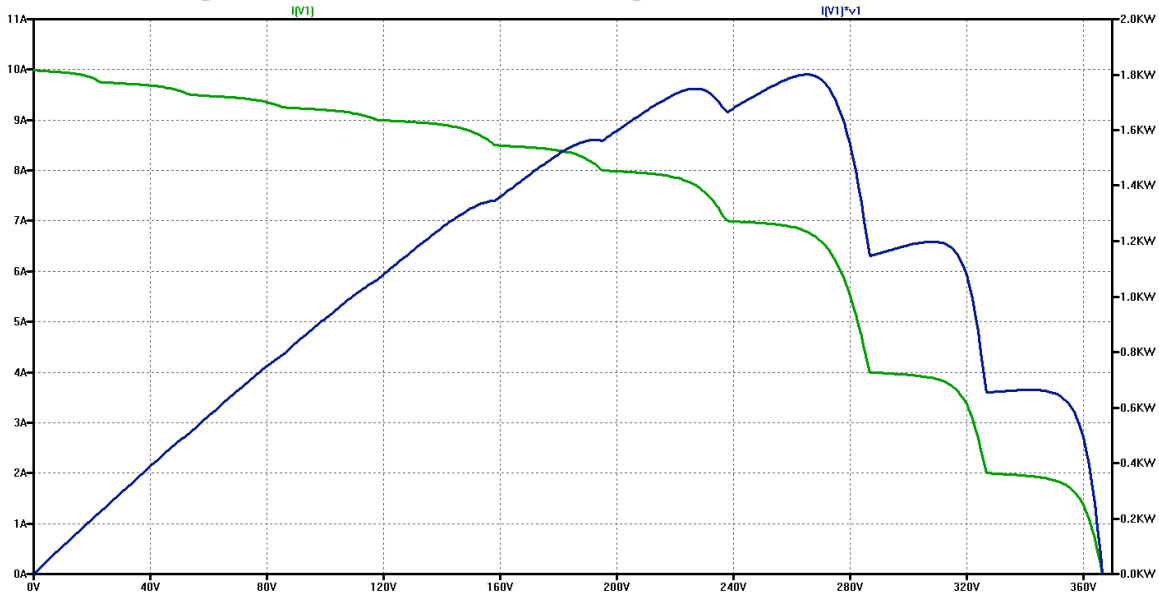
*The MOSFET has a conduction loss of  $(30A)^2(.005\Omega) = 4.5W$  but only when it is on, which is  $1/12$  the time, so the actual conduction loss is  $4.5/12 = 0.375W$ .*

*During turn-on the full 12V drops across the MOSFET until the current ramp reaches 30A at 30ns, then the voltage falls instantly – since there is no capacitance and the diode is ideal. So the turn-on energy is  $(0.5)(12V)(30A)(30ns) = 5.4\mu J$  at 200kHz this gives a turn-on power of 1.08W*

*During turn-off, as soon as the MOSFET current drops below 30A the voltage at the source of the MOSFET drops instantly putting the full voltage across the MOSFET during the entire current ramp. Thus the turn-off loss is the same as the turn on loss at  $5.4\mu J$  and 1.08W.*

*Total switching loss is 2.16W and total losses are 2.54W for this 30W converter giving an efficiency of 92%*

### Problem 4 [20 Points, 5 Points Each]



A string of 10 PV modules has the I-V (left axis) and P-V (right axis) curves shown above. Which of the following statements above this string of modules are true? (Mark each as T or F)

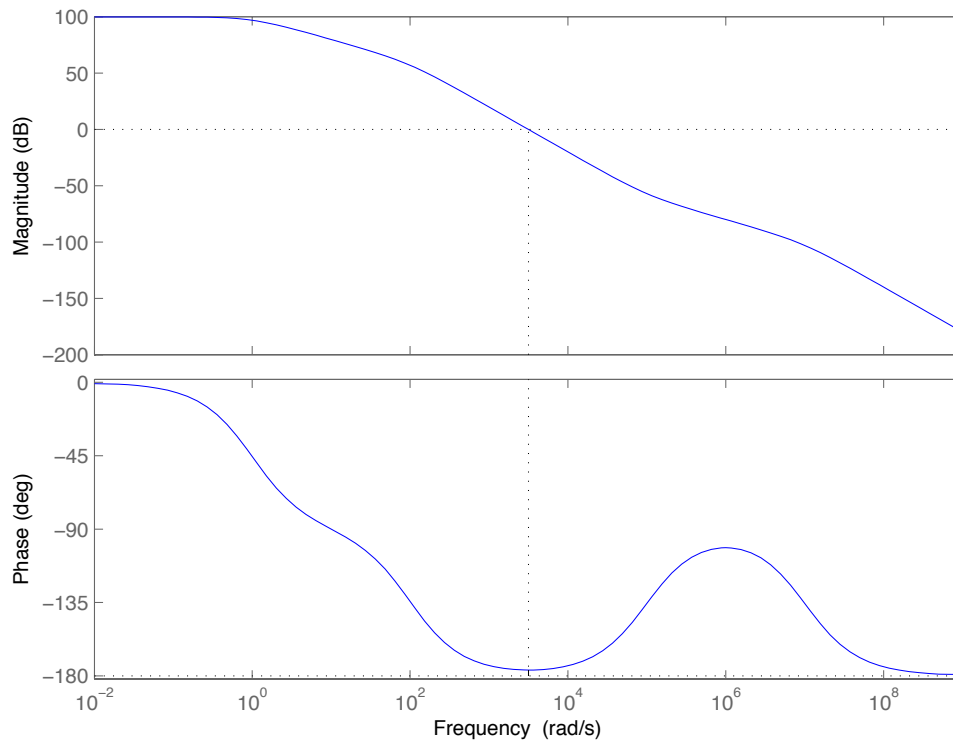
(a) The maximum power point (MPP) occurs at the open-circuit string voltage.  
*False, the power at this point is zero since no current is flowing.*

(b) The maximum power point (MPP) occurs at the short-circuit string current.  
*False, the power at this point is also zero since there is no voltage across the array.*

(c) The maximum power point occurs at about 265V.  
*True.*

(d) The maximum power point can be found via a hill-climbing algorithm starting from the open-circuit voltage.  
*False, a hill-climbing or gradient search algorithm will get stuck at the first local maximum.*

## Problem 5



You have a plant plus controller with the open-loop frequency response as shown in the Bode plot above. Suppose you close a feedback loop around this system. Answer the following questions about the resulting system:

(a) Is the system adequately damped, i.e., will any ringing after an abrupt transition die out in at most a cycle or two? (yes/no)

*No, the phase margin at unity gain is only a few degrees.*

(b) At what frequency in (rad/s) will any ringing occur?

*About  $3 \times 10^3$  rad/s. This is the unity-gain frequency which is about half way from  $10^3$  to  $10^4$  on a log scale.*

(c) At what frequency in (rad/s) are the poles and zeros of this system?

*Poles at 1, 100, and  $10^7$  this is where the magnitude slope decreases.*

*One zero at  $10^5$ . This is where the magnitude slope increases.*

(d) Which of the following will increase the phase margin, and hence the damping of the system (circle all that will):

- i) Increase the DC gain by 100 (40dB). (True)
- ii) Decrease the DC gain by 100 (40dB). (True)
- iii) Move the first zero up by three decades. (False)
- iv) Move the first zero down by three decades. (True)

*Increasing or decreasing the DC gain will move the unity gain point up or down by 10x moving this point out of the minimum it is currently in and hence increasing phase margin.*

*Moving the zero up by 3 decades doesn't help. Its already above the unity-gain frequency.*

*Moving the zero down by 3 decades puts it on top of the second pole – cancelling this pole and keeping the phase at -90 until well past unity gain.*