Tampere University

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Exam of the course *DEE-33106 Switched-mode converters*, 5 cr.

Please answer all of the **five (5)** questions. The use of calculator is allowed. Please answer in Finnish or English.

Question 1: Answer TRUE or FALSE (+0.5 for correct, -0.5 for incorrect, 0 for empty, total max 8 p.)

a. In steady state sum of ampere-seconds in capacitor is zero during one switching period
b. In a given circuit increasing the inductor value decreases current ripple
c. Unit of inductance (H) can also be presented in SI units as Vs/A
d. Ideal capacitor would create an ideal current source
e. Converter goes from CCM to DCM when load resistance increases significantly
f. Capacitor parasitic inductance starts to dominate the impedance value on very high frequencies
g. Mosfet is controlled by voltage signal to transistor gate
h. Ceramic capacitors have higher ESR then electrolyte capacitors
i. Inductor AC losses can be calculated if numbers of turns and switching frequency are known
j. Doubling switching frequency doubles the switching losses in transistor
k. Faster transistor rise time causes less current harmonics
l. Capacitor has both AC and DC losses
m. When inductor is saturated, inductance value decreases with increasing current
n. Power factor correction means having more accurate square waves
o. Normally it is best to build tailored control mechanism instead of using existing ICs
p. EMC immunity means that device is not emitting electromagnetic waves

Question 2 (6 p.)

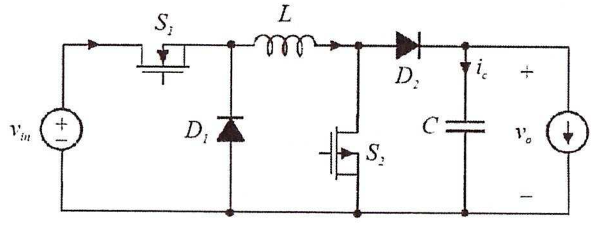

Figure 1: A non-inverting buck-boost converter

Fig. 1 shows a non-inverting buck-boost converter, which can be operated at three different modes: boost, buck-boost, and buck.

Mode 1: The switch S_2 is constantly OFF and switch S_1 is operated normally with duty ratio D.
Mode 2: The switch S_1 is constantly ON and switch S_2 is operated normally with duty ratio D.
Mode 3: The switches are operated together with duty ratio D (that is, both switches either conduct or not conduct in unison)

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Draw on-time and off-time circuits for each operation mode (2 pts)

a) Define symbolically the conversion ratio $M(D)$ from input to output voltage for each operation mode (2 pts)
b) Identify the operation modes (1 pts)
c) Briefly discuss the downsides of using this converter topology (1 pts)

Question 3 (6 p.)

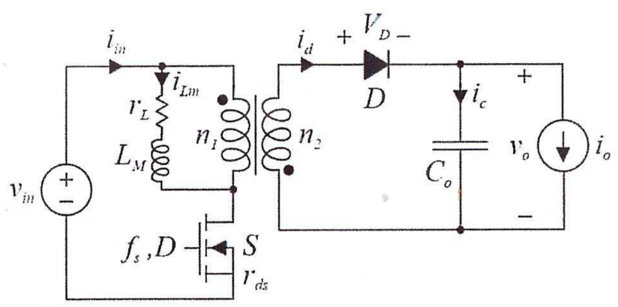


Figure 2: A non-ideal flyback converter

$V_{in} = 340$ V $\quad V_o = 60$ V $\quad f_s = 10$ kHz $\quad I_o = 2.5$ A

$V_D = 0.7$ V $\quad r_{ds} = 100$ mΩ $\quad r_L = 100$ mΩ $\quad n = \frac{n_2}{n_1} = 0.26$

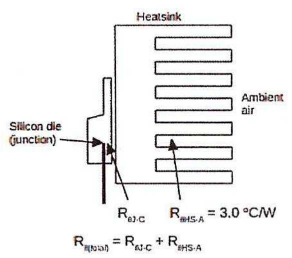
Fig. 2 shows a flyback converter with non-ideal magnetizing inductor, switch, and diode. The transformer and capacitor can be assumed ideal. Take the diode voltage drop, switch resistance and inductor resistance into account in calculations.

a) Calculate the voltage over the transistor during off-time (1 pts)
b) Solve the duty ratio and average inductor current (3 pts)
c) Design output capacitor so that the output voltage peak-to-peak ripple is 5 V (2 pts)

Question 4 (6 p.)

A boost converter (such as one used in a PFC stage) is designed with the following parameters:

Input voltage	325 V DC
Input current	10.0 A DC
Output voltage	420 V DC
f_{sw}	100 kHz
V_{gs}	10V
$t_{ambient}$	50 °C
Diode heatsink R_{th}	3.0 °C/W



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Following components are used (datasheets included, please check carefully per component!):

MOSFET	IPW65R045C7
Diode	IDH16G65C5
Inductor	500 uH
Output capacitor	1500uF, 450V electrolytic

a) Calculate MOSFET and diode conduction losses in worst case
b) Calculate other types of diode losses, and diode die temperature, worst case
c) After a failed EMC test, you have to add gate resistance Rg=10ohms. Calculate MOSFET switching loss.

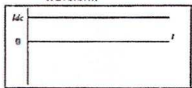
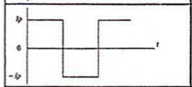
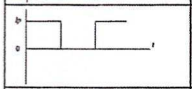
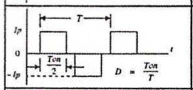
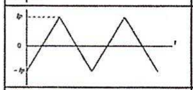
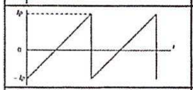
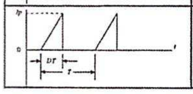
Question 5 (6 p.)

a) Explain in sufficient detail how inductor works in switched mode converters. Include picture(s) and equations of basic principles and describe also coupled inductor.
b) You have been asked to design a dc-dc converter for a small solar installation where a battery system would be charged. Describe the strategy on how to make a usable switch mode converter. What needs to be taken into account?

HELP for the exam

Second order equation solution: $ax^2 + bx + c = 0 \rightarrow x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

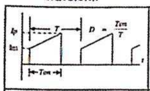
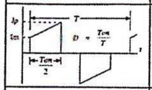
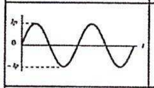
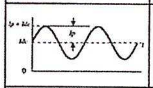
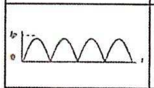
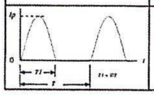
Appendix A - Waveform Formulas

Waveform	Irms	Idc	Iac(rms)
	Idc	Idc	0
	Ip	0	Ip
	$Ip\sqrt{D}$	DIp	$Ip\sqrt{D(1-D)}$
	$Ip\sqrt{D}$	0	$Ip\sqrt{D}$
	$Ip\sqrt{\frac{1}{3}}$	0	$Ip\sqrt{\frac{1}{3}}$
	$Ip\sqrt{\frac{1}{3}}$	0	$Ip\sqrt{\frac{1}{3}}$
	$Ip\sqrt{\frac{D}{3}}$	$\frac{D}{2}Ip$	$Ip\sqrt{\frac{D}{3}\left(1-\frac{3}{4}D\right)}$

$$I_{dc}^2 + I_{ac(rms)}^2 = I_{rms}^2$$

APPENDICES

Appendix A - Waveform Formulas

Waveform	Irms	Idc	Iac(rms)
	$\sqrt{D\left(Ip \times Im + \frac{1}{3}(Ip-Im)^2\right)}$	$\frac{D(Ip+Im)}{2}$	$\sqrt{Irms^2 - Idc^2}$
	$\sqrt{D\left(Ip \times Im + \frac{1}{3}(Ip-Im)^2\right)}$	0	$\sqrt{D\left(Ip \times Im + \frac{1}{3}(Ip-Im)^2\right)}$
	$\frac{Ip}{\sqrt{2}}$	0	$\frac{Ip}{\sqrt{2}}$
	$\sqrt{Idc^2 + \frac{1}{2}Ip^2}$	Idc	$\frac{Ip}{\sqrt{2}}$
	$\frac{Ip}{\sqrt{2}}$	$\frac{2}{\pi}Ip$	$Ip\sqrt{\frac{1}{2}-\frac{4}{\pi^2}}$
	$Ip\sqrt{\frac{D}{2}}$	$\frac{2D\,Ip}{\pi}$	$Ip\sqrt{\frac{D}{2}-\left(\frac{2D}{\pi}\right)^2}$