DR. ÖZGÜR ÜSTÜN 23 . 11 . 2012

INDUSTRIAL APPLICATIONS OF POWER ELECTRONICS

2012 – 2013 FALL

MIDTERM EXAM

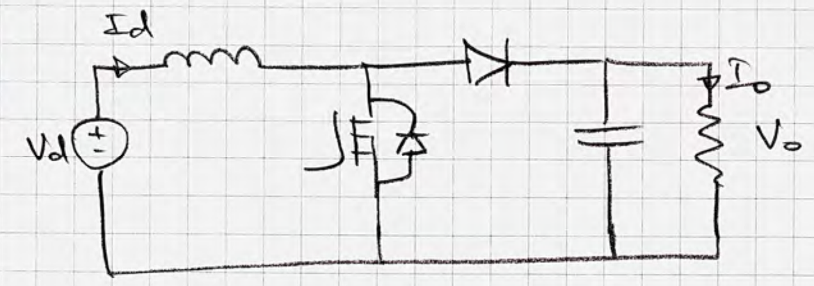
QUESTIONS

1. Some concepts which are related with SMPS circuits are given. Briefly explain "PWM", "duty cycle", "switching frequency", "CCM", "DCM", "output voltage ripple" and "inductor volt-second balance".
2. What is magnetically coupled SMPS? What is the purpose of these circuits? Briefly explain the magnetizing inductor phenomena and indicate the importance of magnetizing inductor for a flyback converter.
3. Sketch the circuit schema of the boost converter and explain the operation principle. Sketch sub-circuits for CCM operation, and develop the expressions for voltage conversion ratio, peak inductor current and average switch current.
4. Boost converter is convenient for photovoltaic applications. A resistive load of 15Ω is supplied by a CCM operating boost converter whose input source is a photovoltaic module with 45V and 5A. Switching frequency of the converter is 75kHz.
   a. Assuming the ideal conditions, calculate the power this converter.
   b. Calculate the output voltage and required duty cycle.
   c. Calculate the inductor value for 0,25A peak-to-peak inductor current.
   d. Plot the capacitor current and find the output voltage ripple for 150µF capacitor value.
5. An electronic circuit which operates at 5V and draws a current of 10A is supplied by a 12V battery through a buck converter. The converter is wanted to be operate at DCM. Switching frequency of the converter is given as 35kHz.
   a. What is the critical inductor value for this converter?
   b. Select an inductor value and calculate duty cycle.
   c. Plot the capacitor current and calculate the capacitor value to obtain $\Delta v_o = 0{,}025V$.
6. A forward converter with tertiary winding is supplied by 20V source and a 10Ω resistive load is given. Turns ratio of the transformer is $N_1/N_2/N_3 = 3/13/1$. Magnetizing inductor is 10mH.
   a. Sketch the principal circuit schema and indicate the importance of magnetizing inductor and the tertiary winding.
   b. What is the maximum duty cycle of this converter? Find the output voltage for D_{max}.
   c. Calculate the maximum and minimum filter inductor current for L = 330µH.
   d. Plot the magnetizing inductor current and input current of the converter.

GOOD LUCK !

IAPE Midterm Exam Solution (23.11.2012)

3)

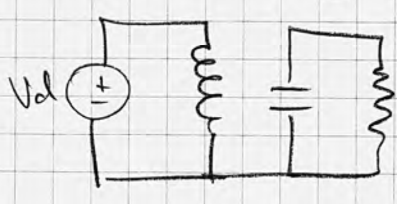


Mosfet ON → inductor stores energy, capacitor feeds the load.

Mosfet OFF → stored energy is transferred to output.

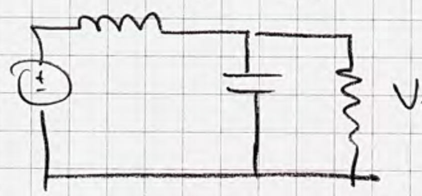
Sub-circuit 1

$D \cdot T_s$



Sub-circuit 2

$(1-D)\,T_s$



Applying IVSB (inductor Volt second Balance)

$$V_d \cdot D \cdot T_s + (V_d - V_o)(1-D)\,T_s = 0$$

$$V_d D + V_d + V_o D - V_d \cdot D - V_o = 0.$$

$$\frac{V_o}{V_d} = \frac{1}{1-D}.$$

Average inductor current is $I_L = I_d$

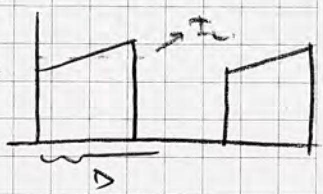
$$I_{L,max} = I_d + \frac{\Delta i_L}{2} = I_d + \frac{V_d D}{2 L f_s}$$

$$I_{L,min} = I_d - \frac{\Delta i_L}{2} = I_d - \frac{V_d D}{2 L f_s}$$

$$\Delta i_L = \frac{V_d}{L} \cdot D \cdot T_s$$

Average switch current

$I_M =$



$$I_M = I_L \cdot D$$

$$= I_d \cdot D.$$

GIPTA

4) PV supplies 45V @ 5A.

a) $P_{in} = P_o = 45 \cdot 5 = 225 W$

b) $R = 15 \Omega$ $\quad P_o = \frac{V_o^2}{R} \Rightarrow \quad V_o = \sqrt{P_o \cdot R} = 58,1 V.$

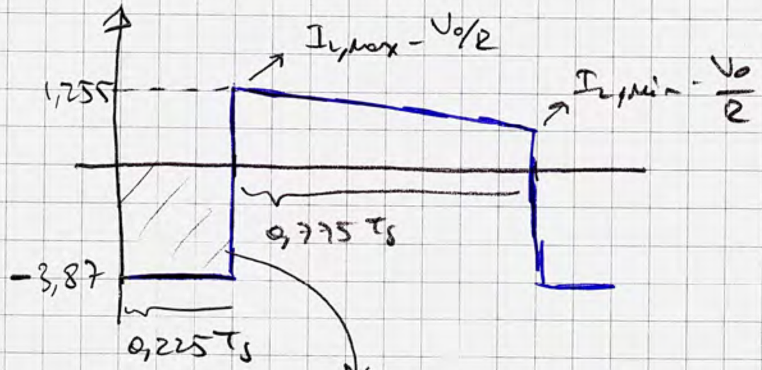
$$\frac{V_o}{V_d} = \frac{1}{1-D} \Rightarrow D = 1 - \frac{V_d}{V_o} = 1 - \frac{45}{58,1} = 0,225$$

c) $\Delta i_L = 0,25$ $\quad \Delta i_L = \frac{V_d \cdot D}{L \cdot f_s} \Rightarrow L = \frac{V_d \cdot D}{\Delta i_L \cdot f_s} = \frac{45 \cdot 0,225}{0,25 \cdot 75000}$

$$= 540 \mu H.$$

d) Subcircuit 1 $\rightarrow$ $i_C = -V_o/R$

Subcircuit 2 $\rightarrow$ $i_C = i_L - V_o/R.$



$$\Delta Q = i_C \cdot \Delta t = \frac{3,87 \cdot 0,225}{75000} = 11,61 \mu C$$

$$C = \frac{\Delta Q}{\Delta V_o} \Rightarrow \Delta V_o = \frac{\Delta Q}{C} = \frac{11,61 \mu C}{150 \mu F} = 0,077 V$$

$$= 77 mV.$$

5) Electronic Load 5V @ 10A $\Rightarrow$ $R = 0{,}5$

Buck Converter is used; (DCM operation)

a) $L_{crit} = \dfrac{R(1-D)}{2 f_s}$ $\quad D = V_o/V_d = 5/12 = 0{,}417$

$$= \frac{0{,}5\,(1-0{,}417)}{2 \cdot 35000} = 4{,}17\mu H$$

b) L must be selected less than L_{crit} for DCM operation;

$L = 3\mu H$ (selected)

$$K = \frac{2 L f_s}{R} = \frac{2 \cdot 3\mu \cdot 35000}{0{,}5} = 0{,}42$$

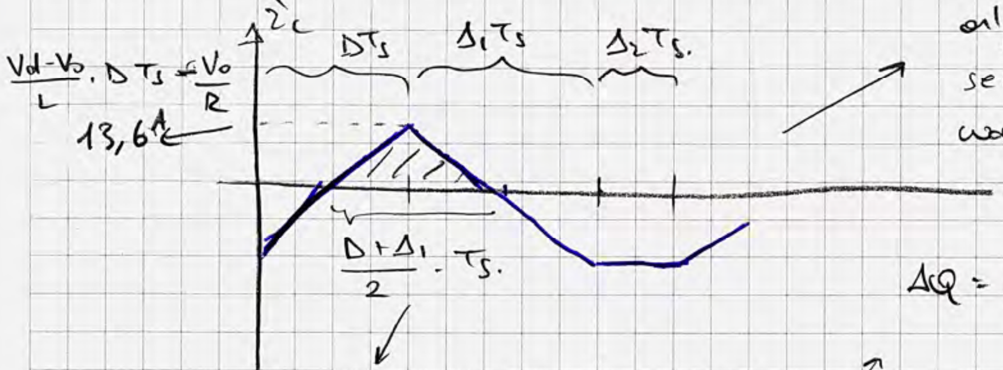
$$D = \sqrt{\frac{K}{\left(\frac{V_d}{V_o}\right)\left(\frac{V_d}{V_o}-1\right)}} = \sqrt{\frac{0{,}42}{\left(\frac{12}{5}\right)\left(\frac{7}{5}\right)}} = 0{,}354$$

$$\Delta_1 = \frac{D}{2}\left(\sqrt{1+\frac{4K}{D^2}}-1\right) = 0{,}495$$

c) Sub-circuit 1 $\rightarrow$ $i_c = i_L - V_o/R$

Sub-circuit 2 $\rightarrow$ $i_c = i_L - V_o/R$

Sub-circuit 3 $\rightarrow$ $i_c = -V_o/R$.



only positive or negative sections are calculated, in this waveform it is easier to calculate positive part.

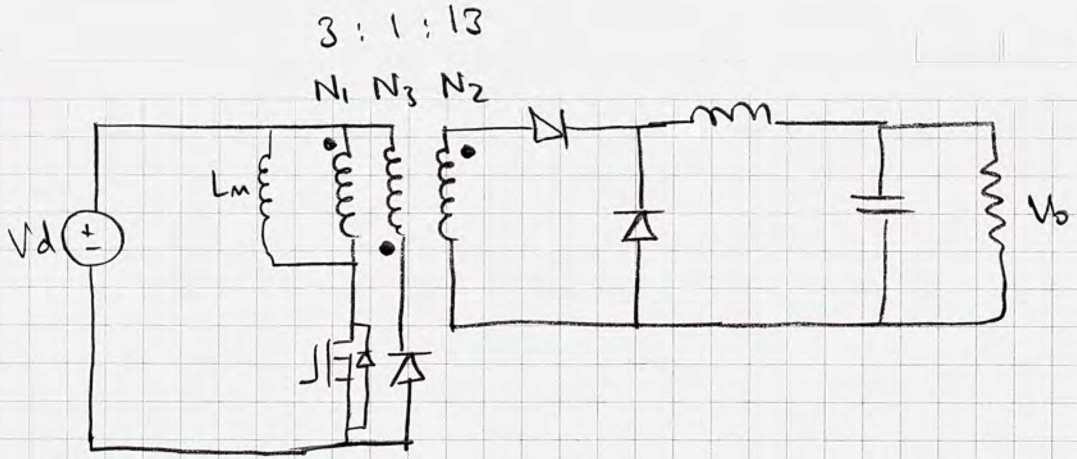
$$\frac{0{,}354 + 0{,}495}{2} \cdot \frac{1}{35000} = 12{,}13\mu s.$$

$$\Delta Q = \frac{12{,}13\mu \cdot 13{,}6}{2} = 82{,}484\mu C$$

$$C = \frac{\Delta Q}{\Delta V_o} = \frac{82{,}484\mu}{0{,}025} = 3{,}3mF$$

GIPTA

6) a)



b) $D_{max} = \frac{N_1}{N_1 + N_3} = \frac{3}{3+1} = \frac{3}{4} = 0{,}75$

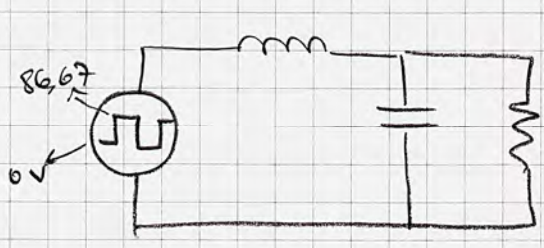
This duty cycle can't be greater than 0,75 because this is the limit time for resetting the Lm (magnetizing inductor)

$V_o = V_d \cdot \frac{N_2}{N_1} \cdot D = 20 \cdot \frac{13}{3} \cdot 0{,}75 = 65V.$

c) For this part, forget about the input side; output side of a forward converter is a "Buck Converter"

MOSFET is ON → reflected secondary voltage $= \frac{20}{3} \cdot 13 = 86{,}67V$

MOSFET is OFF → " " " $= 0V.$



$\langle i_L \rangle = I_L = \frac{V_o}{R} = \frac{65}{10} = 6{,}5A.$

$\Delta i_L = \frac{(86{,}67-65)}{L} \cdot D \cdot T_s = \frac{21{,}67}{400\mu} \cdot 0{,}75 \cdot \frac{1}{150000}$

$= 0{,}27 A.$

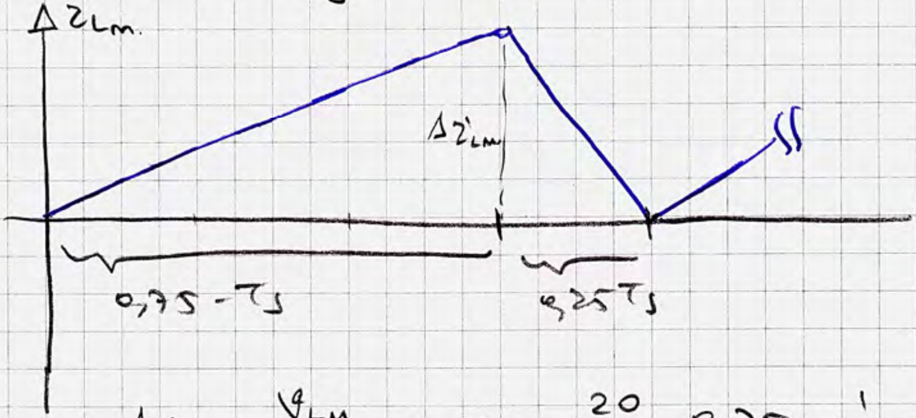
$I_{L,max} = 6{,}5 + \frac{0{,}27}{2} = 6{,}635A.$

$I_{L,min} = 6{,}5 - \frac{0{,}27}{2} = 6{,}365A.$

d) For magnetizing inductor;

$v_{LM} = 20V$ (MOSFET is ON)

$v_{LM} = -Vd \cdot \frac{N1}{N3} = -\frac{20 \cdot 3}{1} = -60V$ (MOSFET is OFF)



$\Delta i_{LM} = \frac{v_{LM}}{L} \cdot D \cdot T_s = \frac{20}{10m} 0,75 \cdot \frac{1}{150000} = 0,01A.$