ELEC-E8417 Switched-Mode Power Supplies **Exam 27.5.2020**

ONLINE EXAM

Question 1

In a Buck converter output voltage U_o = 5 V, supply voltage U_d = 40 V, output power P_o = 5 W, and switching frequency f_s = 50 kHz. Output filter components (L and C) are so large that output current of the converter is ideal dc. Harmonic currents of the supply voltage source are limited, and the switching frequency component can in maximum be 0,2 mA. What is the maximum allowed resonance frequency of the input filter?

Question 2

In a Flyback converter output voltage U_o = 5 V, supply voltage 12 V $\leq U_d \leq$ 24 V, output power 6 W $\leq P_o \leq$ 60 W, switching frequency f_s = 200 kHz, and N_1:N_2 = 1. Calculate the maximum value of the magnetizing inductance of the Flyback transformer so that the converter is always in the complete demagnetization area.

Question 3

In a Forward converter output voltage U_o = 12 V, supply voltage 210 V $\leq U_d \leq$ 325 V, output power 15 W $\leq P_o \leq$ 50 W and switching frequency f_s = 50 kHz. The transformer is built from ferrite 3C8 with ETD 34 core. Its volume is 7640 mm^3, effective area 97,1 mm^2 and the smallest surface area of the core is $A_{c,min}$ = 86,6 mm^2. Copper filling factor is assumed to be 0,6 and saturation flux density at 100 ºC is 0,32 T. Calculate the number of turns in the transformer when demagnetization winding $N_3 = N_1$. Remanence flux density can be assumed to be zero. Primary inductance of the transformer is 10 mH, calculate the needed airgap length.

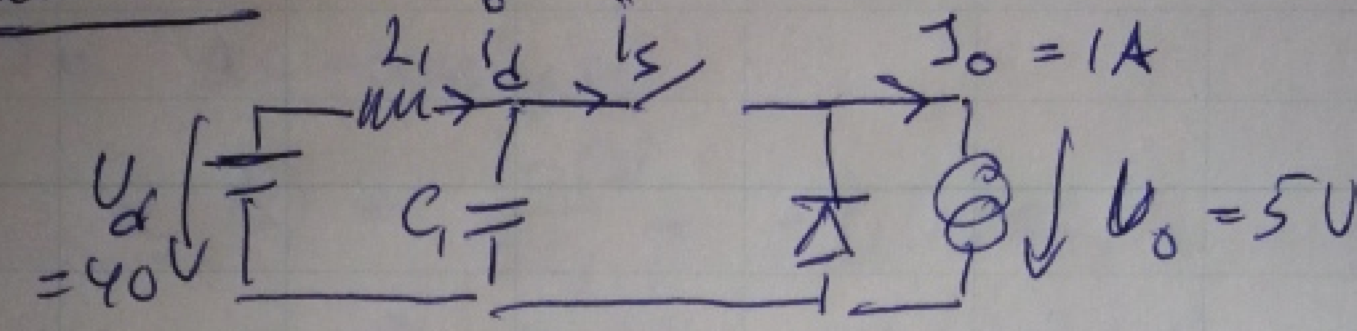
Question 4

Efficiency is important in switched mode power supplies. One part of the losses are the switching losses of the power semiconductor devices. What kind of methods can be used to reduce the losses created by these switches in SMPS.

Question 5

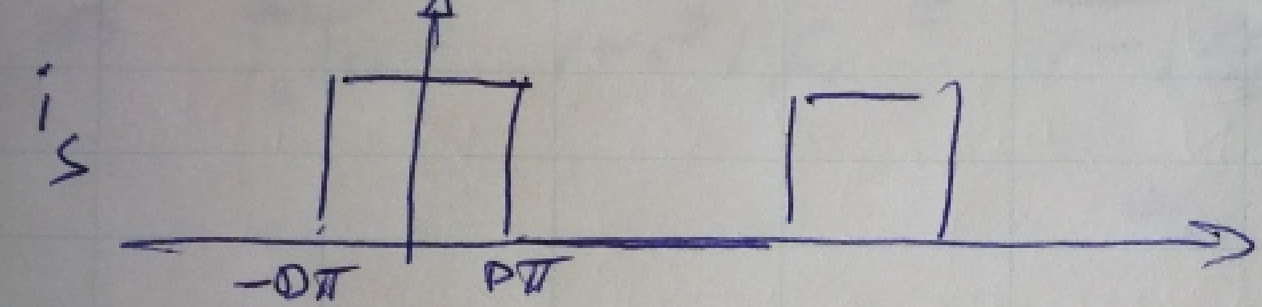
What kind of methods can be used to implement current-mode control in SMPS? What are the advantages of current-mode control when compared to the voltage-mode control (PWM duty ratio control)?

Question 1



$$U_0 = D\,U_d \Rightarrow D = \frac{5}{40} = 0{,}125$$

Current from the supply U_d depends on the switch current i_s

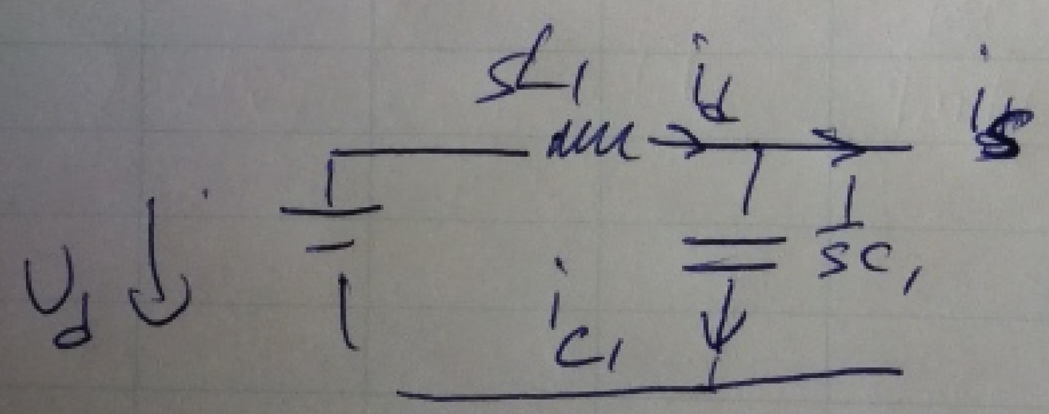


Fourier series of i_s

$$i_s(x) = D I_0 + \frac{2 I_0}{\pi} \sum_{n \geq 1}^{\infty} \frac{1}{n} \sin(n D \pi) \cos(n x)$$

Largest value is $n = 1$

$$\hat{i}_{d1} = \frac{2 I_0}{\pi} \sin(D\pi) = 0{,}243\,A$$



In ac-analysis

$$u_d(s) = \frac{i_{C1}(s)}{sC_1} = -i_d(s)sL_1$$

$$\Rightarrow i_{C1}(s) = -i_d(s)s^2L_1C_1$$

For currents

$$i_d(s) = i_s(s) + i_{C1}(s) = i_s(s) - i_d(s)s^2L_1C_1$$

$$\Rightarrow \frac{i_d(s)}{i_s(s)} = \frac{1}{1+s^2L_1C_1} = \frac{1}{1-\left(\frac{\omega}{\omega_{01}}\right)^2}$$

$$\omega_{01} = \frac{1}{\sqrt{LC}}$$

For the absolute values of $h=1$

$$\frac{\hat{i}_{d1}}{\hat{i}_{s1}} = \left|\frac{1}{1-\left(\frac{\omega}{\omega_{01}}\right)^2}\right| = \frac{1}{\left(\frac{\omega}{\omega_{01}}\right)^2-1}$$

$$\omega_{01} = \omega_s \sqrt{\frac{1}{1+\frac{\hat{i}_{s1}}{\hat{i}_{d1}}}} \approx 8998 \text{ rad/s}$$

Question 2

In exercise 7, question 2 it has been shown that in the demagnetizing area of Flyback

$$\frac{V_o}{V_d} = D\sqrt{\frac{R}{2L_m f_s}} \quad \text{where } R = \frac{V_o}{I_o}$$

In CCM of Flyback

$$\frac{V_o}{V_d} = \frac{N_2}{N_1} \cdot \frac{D}{1-D} \qquad D = \frac{1}{\frac{N_2}{N_1}\frac{V_d}{V_o} + 1}$$

and in the borderline both comply

$$D\sqrt{\frac{R}{2L_m f_s}} = \frac{N_2}{N_1} \cdot \frac{D}{1-D}$$

$$\Rightarrow L_m = \frac{R(1-D)^2}{2f_s} \quad \text{when } N_2 = N_1$$

Highest value of L_m is obtained with highest load $R = \frac{5}{12}$ [illegible]. However, with duty cycle it is a bit different. If we calculate with D_{min} (V_d max) then L_m would be too larger and it would not be DCM with V_{dmin}

$$D_{max} = \frac{1}{\frac{12}{5}+1} = 0{,}29 \text{ and } L_m \approx 0{,}52 \mu H$$

Question 3

In forward converter duty ratio is limite due to the demagnetization time needed.

$$D_{max} = \frac{1}{1+\frac{N_3}{N_1}} = \frac{1}{2}$$

In forward magnetization is only in one quadrant and therefore

$$\Delta B_{max} = \frac{B_{sat}}{2}$$

Here input voltage can change and saturation should not occur even with the highest voltage ⇒

$$B_{ac} = \frac{B_{sat}}{2} \cdot \frac{V_{d\,min}}{V_{d\,max}} = \frac{0,32}{2} \cdot \frac{210}{325} = 0,103\,T$$

$$v = N\frac{d\phi}{dt} \Rightarrow N = v\frac{dt}{d\phi} = \frac{V_1\,D\,T_s}{2\,A_{min} \cdot B_{ac}} \qquad V_1 = V_{d\,min}$$

$$\approx 117,7 \Rightarrow N_1 = 118$$

In Forward convertor $\frac{V_o}{V_d} = \frac{N_2}{N_1} D$

$$\Rightarrow N_2 = \frac{V_o}{V_d} \cdot \frac{N_1}{D} = \frac{12}{210} \cdot \frac{118}{0,5} = 13,5 = 14$$

$$L = \frac{N^2}{\mathcal{R}} \quad \text{where} \quad \mathcal{R} = \frac{l}{\mu A} \quad \text{and}$$

with airgap

$$\mathcal{R} = \mathcal{R}_m + \mathcal{R}_g = \frac{l_e}{\mu A_c} + \frac{l_g}{\mu_0 A_g} = \frac{N^2}{L}$$

$$\Rightarrow l_g = \frac{N^2 \mu_0 A_e}{L} - \frac{l_e}{\mu_r} \qquad A_g \approx A_e$$

$A_e = 97{,}1\ mm^2$, $N = 118$, $l_e = \frac{V_e}{A_e} = \frac{7640}{97{,}1}\ mm$

$L = 10\ mH$

$\mu_0 = 4 \cdot \pi \cdot 10^{-7}\ H/m$

μ_r = realitive pearmeability of 3C8 which was not given in the paper but can be as in Exercise 11

$$\mu = \mu_r \mu_0 = 5{,}58 \cdot 10^{-3} \frac{Vs}{Am} \Rightarrow \mu_r = 4440$$

$$\Rightarrow l_g \approx 0{,}15\ mm$$