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AALBORG UNIVERSITET
Energy

Study number: 2013 70 14	Programme: EPSH/PED/WPS
Evaluation subject: High Voltage Engineering and Design of Switch Mode Converters Friday 27 January at 9:30-13:30	

Please write your study no. on all pages. Do not write your name as your evaluation is anonymous!

Total number of pages, including this page: 10

Please, only write on one side of the papers that you hand in.

NB! Your paper must be easy to read. If this is not the case, your paper may be evaluated as "not passed".

All usual aids are allowed (notes, books, tables, calculator and PC). You are not allowed to communicate amongst each other or with the outside world which means that the use of mobile phone, Wi-Fi, internet, email is not allowed.

You are allowed to take the examination questions with you. But you are NOT allowed to take them with you if you leave the room before the examination has ended.

[redacted]

Problem 1:

1) it is given by $\eta = \frac{C_1}{C_1+C_2} = \frac{1}{1+C_2/C_1}$ (Setup b)

that the higher value for C_2 the more efficient the generator is.
~~therefore~~ we always design it to be much bigger than C_2 Z
Otherwise, lower efficiency is obtained.
and also C_1 must be big enough to be able to supply the load

2) $C_1 = 20 \cdot 10^{-9}F$ and $C_2 = 2 \cdot 10^{-9}F$
A standard switching impulse is the 250/2500 μs impulse (T_1/T_2)
From table in book this impulse has

$\frac{1}{\alpha_1} = 2877\ \mu s$ ✓ $\qquad \frac{1}{\alpha_2} = 104\ \mu s$ ✓

$\Updownarrow \qquad\qquad\qquad \Updownarrow$

$\alpha_1 = 347{,}584\ \frac{1}{s} \qquad \alpha_2 = 9615{,}4\ \frac{1}{s}$

so $R_1 = \frac{1}{2C_2}\left[\left(\frac{1}{\alpha_1}+\frac{1}{\alpha_2}\right) - \sqrt{\left(\frac{1}{\alpha_1}+\frac{1}{\alpha_2}\right)^2 - \frac{4(C_1+C_2)}{\alpha_1\alpha_2 C_1}}\right] = \underline{\underline{57{,}4\,k\Omega}}$

$R_2 = \frac{1}{2(C_1+C_2)}\left[\left(\frac{1}{\alpha_1}+\frac{1}{\alpha_2}\right) + \sqrt{\left(\frac{1}{\alpha_1}+\frac{1}{\alpha_2}\right)^2 - \frac{4(C_1+C_2)}{\alpha_1\alpha_2 C_1}}\right] = \underline{\underline{130{,}2\,k\Omega}}$

[redacted]

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Problem 1:

3) $V(t) = \frac{V_0}{k}\left(\frac{1}{\alpha_2-\alpha_1}\right)\left(e^{-\alpha_1 t} - e^{-\alpha_2 t}\right)$

$V_0 = 50kV$

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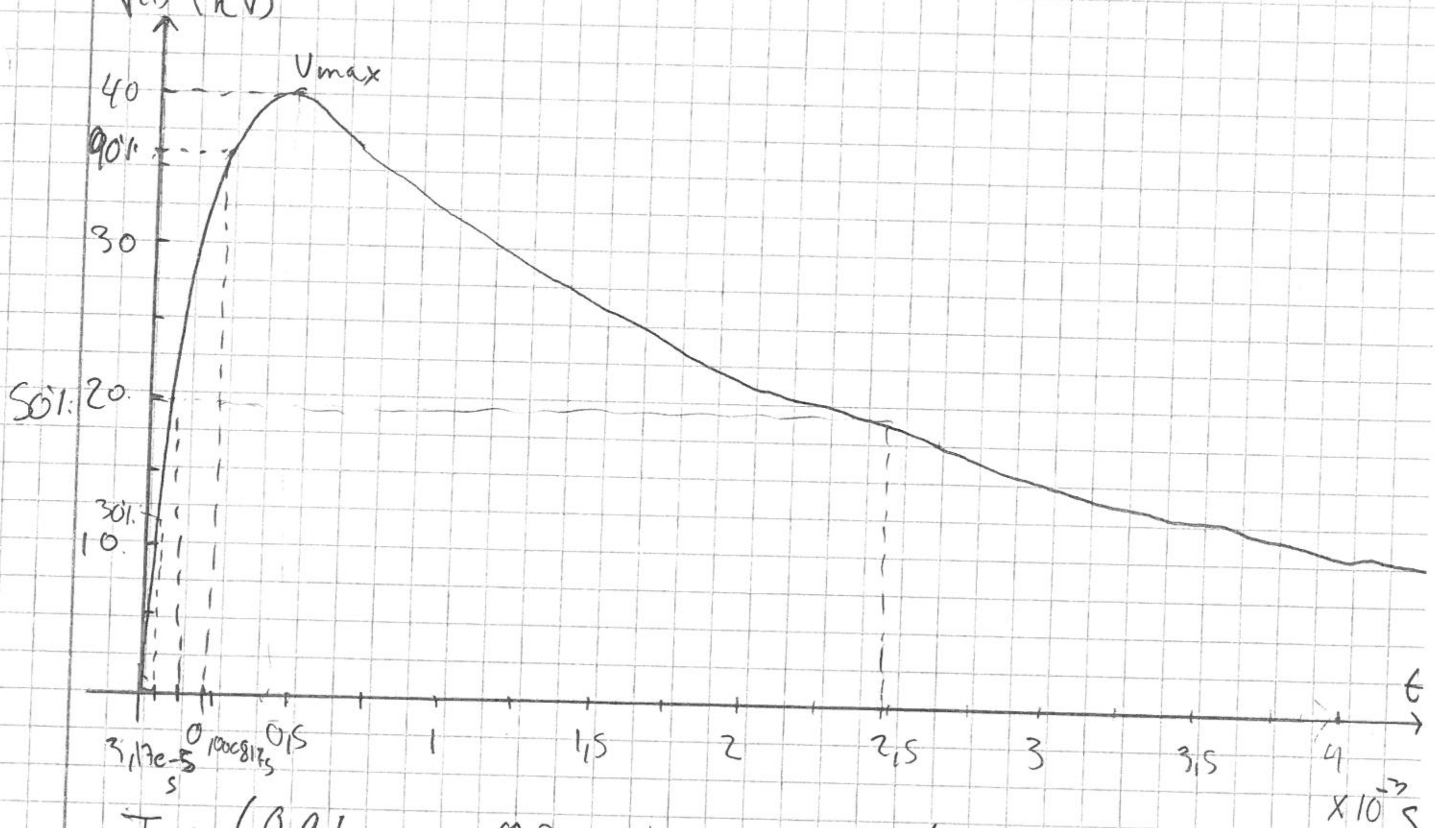
$k = R_1 \cdot C_2 = 1{,}148 \cdot 10^{-4}$ so:

$\underline{V(t) = 46982 \cdot \left(e^{-347{,}584t} - e^{-9615{,}4t}\right)}$



$T_1 = (0{,}9t_{max} - 0{,}3t_{max}) \cdot 1{,}67$ t_{max}: when $V(t) = V_{max}$

T_2 is the time when at falling it reaches $0{,}5 \cdot V_{max}$

$V_{max} = 40kV$ $0{,}9 \cdot V_{max} \Rightarrow t_{0,9} = 0{,}000184s$

$0{,}3V_{max} \Rightarrow t_{0,3} = 3{,}173 \cdot 10^{-5}s$

$\underline{T_1 = 2{,}5 \cdot 10^{-4}s}$ which is within ±20% off 250µs so ok!

$T_2 = \underline{2{,}3 \cdot 10^{-3}s}$ ± 60% of 2500µs So ok!

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Exercise 2:

1) Choose DC since insolation under DC, the voltage on the insulator will be dependend on the resistivity. resistivity is opposite of conductivity, so DC current is ok! [redacted]

2) So $R = \frac{500V}{20 \cdot 10^{-9} A} = 2{,}5 \cdot 10^{10} \Omega$

and $L = 2 \cdot 10^{-3} m$, $A = 80 \cdot 10^{-3} m \cdot 80 \cdot 10^{-3} m$
$= 0{,}0064 \, m^2$

So $\rho = R \cdot \frac{A}{L} = \underline{\underline{8 \cdot 10^{10} \, \Omega \cdot m}}$ [redacted]

3)

$\varepsilon_{oil} = 2$ $\varepsilon_{dielectric} = 4$ $d_{tank} = 10 \cdot 10^{-3} m$

$d_{diel} = 2 \cdot 10^{-3} m$

$U = 18 kV$

before inserting dielectric:

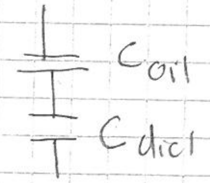
$C_{oil} = \varepsilon \cdot \frac{A}{d} = 2 \cdot \frac{1}{10 \cdot 10^{-3} m} \cdot A$ [redacted]

$Q = C_{oil} \cdot U = 200 \cdot A \cdot 18 \cdot 10^{3} V = 3600 \, kC \cdot A$

$E = \frac{Q}{\varepsilon_{oil} \cdot A} = \frac{3600 \cdot 10^{3} \, C \cancel{A}}{2 \cdot \cancel{A}} = \underline{\underline{1800 \frac{kV}{m}}}$ ✓

now

after inserting:



$\Rightarrow \frac{V_{oil}}{V_{diel}} = \frac{\varepsilon_{diel}}{\varepsilon_{oil}} = 2 \Leftrightarrow$

$V_{oil} = 2 \cdot V_{diel}$

So: $U_{oil} + U_{diel} = 18 \cdot 10^{3} V$

$\Downarrow$

$2 V_{diel} + V_{diel} = 18 \cdot 10^{3} V \Leftrightarrow V_{diel} = 600 kV$

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Exercise 2:

3) $V_{diel} = 600 kV$

$$C_{diel} = 4 \cdot \frac{1}{2 \cdot 10^{-3} m} A = 2000 \cdot A$$

$$E = \frac{Q_{diel}}{\varepsilon \cdot A} = 5400 \frac{kV}{m}$$

increse E field, due to the fact that the capacitance increases when dielectric is put in the medium. [redacted]

4) $C_x = C_N \cdot \frac{R_4}{R_3} = 37{,}2 \cdot 10^{-12} F \cdot \frac{652 \Omega}{2412 \Omega} = 1{,}002 \cdot 10^{-11} C$

$P = \omega \cdot C_x \cdot \tan\delta \cdot U^2$ (assome power frequency 50Hz)

$= 2\pi 50 \cdot 1{,}002 \cdot 10^{-10} C \cdot 0{,}006 \cdot (200 \cdot 10^3 V)^2 = \underline{7{,}55W}$ ✓

Exercise 3

1) q_0 is the aparent charge but it cannots be equal to the amount of charge locally involved in the PD since it cannot be measured directly. [redacted]

2) X-axis: complete cycle of the applied voltage [redacted]

Y-axis: PD charge magnitude (detected magnitudes)

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3) PD's are located at zero crossing of voltage therefore this must be internal PD's (also considering high $V = 30kV$

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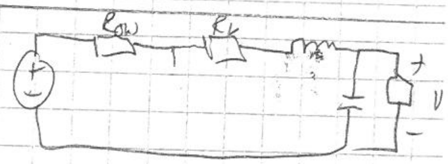
Exercise 3

[redacted]

4) Tells us something about the quality of the dielectric.
if internal PD's are present this means small blisters or cavities in the dielectric → very fast current if breakdow
→ degrade the quality of dielectric if happens repeadetly

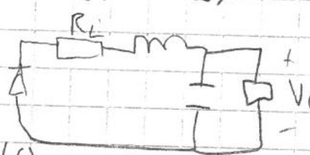
Exercise 4



A) When switch is ON:

$V_L(t) = V_g(t) - i_L \cdot (R_{ON} + R_L) - V_0(t)$

Switch off:



$V_L = -V_0(t) - V_D \cdot i(t) - R_L \cdot i_L(t)$ So:

averanging inductanor voltage gives (1 T_s):

$\langle V_L(t) \rangle_{T_s} = [\langle V_g(t) \rangle - \langle i_L(t) \rangle \cdot (R_{ON} + R_L) - \langle V_0(t) \rangle] \cdot D$

$- [\langle V_0(t) \rangle + V_D + \langle i_L(t) \rangle \cdot R_L] \cdot (1-D) = 0$ ← Volt-sec-balance (Steady State)

$\Updownarrow$ $D = \dfrac{V_0 + V_D + I_L \cdot R_L}{V_g - I_L(R_{ON} + R_L) + V_0 + I_L \cdot R_L}$ $I_L = I_0$ So:

$D = \dfrac{5V + 0{,}4V + 20A \cdot 0{,}04\Omega}{12V - 20A \cdot (0{,}04\Omega + 0{,}12\Omega) + 0{,}4V + 20A \cdot 0{,}04\Omega} = \underline{\underline{0{,}62}}$

$m_1 = \dfrac{V_{LON}}{L} = \dfrac{V_g - I_0 \cdot (R_{ON} + R_L) - V_0}{L} = \underline{\underline{3{,}167 \cdot 10^5}}$

$m_2 = \dfrac{V_{Loff}}{L} = \dfrac{-V_0 - V_D - I_0 \cdot R_L}{L} = \underline{\underline{-5{,}167 \cdot 10^5}}$

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Exercise 4:

B) again ON, off stages!

Q_{ON}: $V_L(t) = V_g(t) - I_L(t)(R_{ON} + R_L) - V_o(t)$

$i_C(t) = i_L(t) - \frac{V_o(t)}{R_o}$, $i_g(t) = i_L(t)$

Q_{off}: $V_L(t) = -V_o(t) - V_D - i_L(t) \cdot R_L$

$i_C(t) = i_L(t) - \frac{V_o(t)}{R}$, $i_g(t) = 0$

<u>Inductor</u>: linearize and pertubate:

$\langle x(t) \rangle = X + \hat{x}$; don't write $\hat{x}(t)$ due to ease:

$$V_L + \hat{v}_L = (D + \hat{d})\left[V_g + \hat{V}_g - (I_L + \hat{i}_L)(R_{ON} + R_L) - V_o - \hat{V}_o\right]$$

$$D' \atop (1-D)-\hat{d} \quad - (D' - \hat{d}) \cdot \left[V_o + \hat{V}_o + V_D + (I_L + \hat{i}_L) R_L\right]$$

AC: $\hat{x} \cdot \hat{y} \to 0$, $X \to 0$ so

$$\hat{V}_L = D \cdot \hat{V}_g - D \cdot \hat{i}_L (R_{ON} + R_L) - D \cdot \hat{V}_o + \hat{d} V_g - \hat{i}_L (R_{ON} + R_L) \hat{d}$$
$$- \hat{d} V_o - D' \hat{V}_o - D' \hat{i}_L R_L + \hat{d} V_o + V_D \hat{d} + \hat{d} I_L R_L$$

I'm not gonna reduce it :)

<u>Capacitor</u>: is equal in both ON and off

so: $\langle i_C \rangle = \langle i_L \rangle - \frac{\langle V_o \rangle}{R_o}$

$\Updownarrow$

$$I_C + \hat{i}_C = I_L + \hat{i}_L - \frac{V_o + \hat{V}_o}{R_o}$$

AC: $\hat{i}_C = \hat{i}_L - \frac{\hat{V}_C}{R_O}$

Input current:

$\langle i_g \rangle = \langle i_L \rangle \cdot D \iff I_g + \hat{i}_g = (I_L + \hat{i}_L) \cdot (D + \hat{d})$

$\iff$ AC: $\hat{i}_g = \hat{i}_L D + I_L \hat{d}$

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Exercise 4

c) Stable operation is $|\alpha| < 1$ so for

$M_a = 0,3\,M_2$

$$\alpha = -\frac{1-\frac{m_a}{m_2}}{\frac{D'}{D}+\frac{m_a}{m_2}} = -\frac{1-\frac{0,3m_2}{m_2}}{\frac{D'}{D}+\frac{0,3m_2}{m_2}} = -\frac{0,7}{\frac{1}{D}-0,7}$$

This means that stable operation is for $\underline{\underline{D < \frac{5}{7} \approx 0,71}}$

for $M_a = 0,5\,m_2$

$$\alpha = -\frac{1-\frac{0,5m_2}{m_2}}{\frac{D'}{D}+\frac{0,5m_2}{m_2}} = -\frac{0,5}{\frac{1}{D}-0,5}$$

[redacted]

meaning that stable operation for

$\underline{\underline{D < 1}}$ (all D)

d) we have: $G_{vc} = \frac{\hat{v}_o(s)}{\hat{i}_{control}}$ so:

$$\hat{i}_c(s) = \hat{i}_L(s) - \frac{v_o(s)}{R} \iff \hat{i}_L(s) = \left(sC + \frac{1}{R}\right)\cdot\hat{v}_o(s)$$

$$\iff \frac{\hat{v}_o(s)}{\hat{i}_L(s)} = \frac{\hat{v}_o(s)}{\hat{i}_{control}} = \underline{\underline{\frac{1}{sC+\frac{1}{R}} = G_{vc}}}$$

[redacted]

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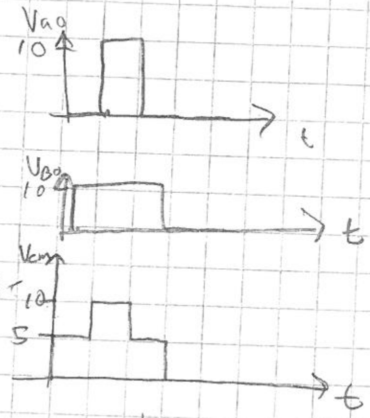
Exercise 5):

if i have V_{AO}

V_{BO}

then common mode is:



$$V_{cm} = \frac{V_{AO} + V_{BO}}{2}$$

- this is not good since it can destroy bearings in motor.
- Depending on the PWM signal it can Create high Leakage currents which are the bearing currents in the motor The common mode voltage will give varying frequency component ⇒ not good in motor applications ⇒ hot spots in bearings
- So Switching actions will cause current pulses at the input of power supply. as see above, the V_{cm} has rectangular Waveforms, and for high freq. $\frac{dv}{dt}$ and $\frac{di}{dt}$ is very Short ⇒ harmonics

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a) $V_o = D \cdot V_g \cdot n \Leftrightarrow$ $\quad n = \frac{N_s}{N_p}$

$$D = \frac{V_0}{V_g \cdot n} = \frac{12V}{400V \cdot \frac{1}{8}} = \underline{\underline{0,6}}$$

b) $P = U_o \cdot I_o \Leftrightarrow I_o = \frac{70W}{12V} = 5,833A$

$$R_L = \frac{U_o}{I_o} = \frac{12U}{5,833A} = \underline{\underline{2,06\ \Omega}}$$

c) $\Delta I_{o,pa} = I_o \cdot 0,01 \quad 0,0583\ A$

$$\Delta I_{o,pp} = 2 \cdot \Delta I_{o,pa} = 0,1166\ A$$

$$T_{sw} = \frac{1}{100 \cdot 10^3 Hz} = 1 \cdot 10^{-5} s \quad \text{so}$$

$$L_o = \frac{V_0}{\Delta I_{L,pp}} \cdot (1-D) \cdot T_s = \frac{12}{0,1166A} \cdot (1-0,6) \cdot 1 \cdot 10^{-5} s$$

$$= \underline{\underline{4,12 \cdot 10^{-4} H}}$$

d) bode is plottet in matlab:

reading $G_{vd0} = 52\ dB$

again measuring on bode plot in matlab gives $G_{vd}(1000 \cdot 2\pi \frac{rad}{s}) = 49,1 dB$

$$G_{vd-\omega c} = 49,1 dB$$

$$G_{vd} = \frac{400}{4,1 \cdot 10^{-8} s^2 + 0,0002 \cdot s + 1}$$

To get W_c as cross over then gain of G_{vc-0} should be $G_{vc-0} = \underline{\underline{-49,1 dB}}$ which is:

$$|G_{vc-0}| = 10^{\frac{-49,1}{20}} = \underline{\underline{0,0035}}$$

↑ quite high gain

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[redacted]