exam

EPSH1/PED1/WPS1
2011
November 2011/CLB/SMN

Department of
ENERGY TECHNOLOGY
E.T.
Aalborg University

Written examination in

High Voltage Engineering and Design of Switch Mode Converters

Tuesday 17th January 2011

09.00 – 13.00 (4 hours)

Please provide sufficient text description and reference to textbook and equations so your method of solution is clear and easy to follow. Statements and results will only give credit if explained thoroughly.

Both exercises in HV and SMC individually have to be passed in order to pass the course. This means that at least 50 % of both the HV exercise and the SMC exercise have to be correctly answered.

The HV exercise and the SMC exercise have the same weight.

Exercise 1 (High Voltage)

Students' pursuing the Masters at Department of Energy Technology at AAU wants to perform testing of power system equipment regarding lightning overvoltage.

For this purpose a group of students wants to design and construct a setup in the HV laboratory in order to test specific equipment. During this the following questions arises, which are to be answered at this examination.

A single stage impulse generator, type b with a maximum output peak impulse voltage V_{max} = 300 kV should be designed. Already chosen components are: Discharge capacitance C_1 = 10 nF, load capacitance C_2 = 1,2 nF, discharge resistance R_2 = 9500 Ω

Temperature in the HV laboratory is 18°C and air pressure p = 1022 hPa

a) Draw a single line diagram of the impulse voltage generator and explain the components and the mode of operation. Why is type b normally preferred?

b) Calculate the value of the front resistance R_1 for a standard lightning impulse 1,2/50 µs

c) Draw the impulse voltage generated by the impulse generator for a charging voltage of V_0 = 250 kV using a sufficient number of calculated points of the curve V(t). Determine, on the basis of this curve graphically front time T_1 and time to half T_2 and the efficiency η.

d) Calculate (by equations) maximum voltage V_{max} and time to reach maximum voltage t_{max} and efficiency η and compare to results from c)

e) The generator is tested with negative polarity in the HV lab and the peak voltage is sought measured with a 25 cm sphere gap. The gap flashed over for a gap length of 80 mm. What was the peak value of the impulse voltage measured (include accuracy of the sphere gap)?

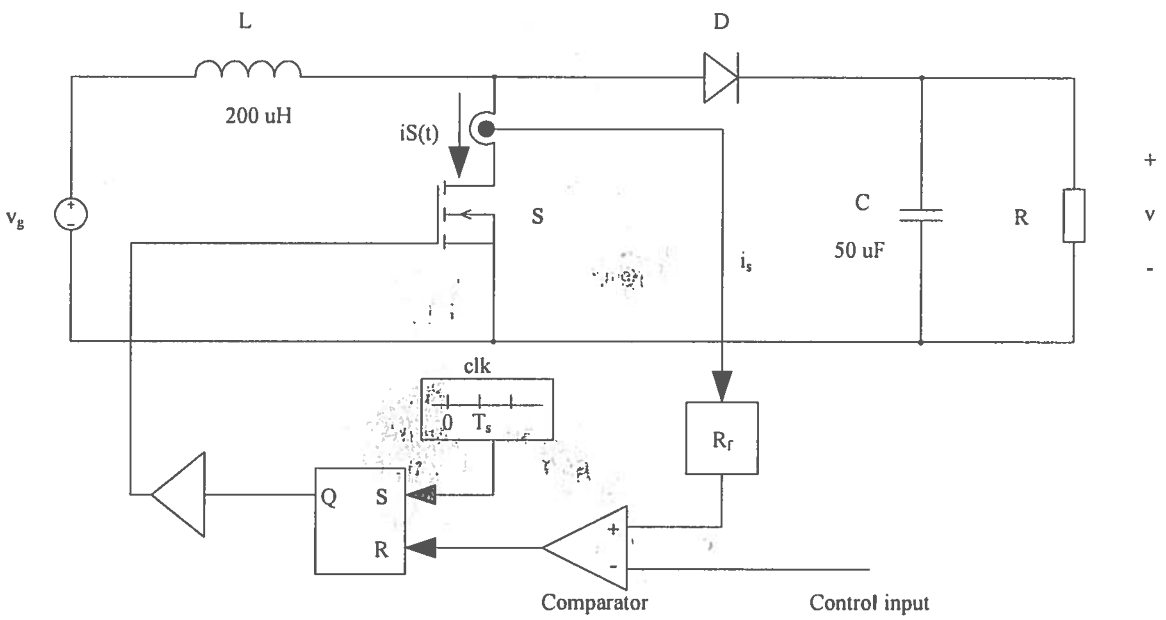
f) Now the students want to record the impulse waveform by means of a resistive voltage divider and an oscilloscope. A resistive divider is constructed with the following data: Diameter d = 10 cm, length l = 100 cm standing on a 10 cm high foot on the floor. Resistance is R = 50 kΩ. In order to assess the transfer characteristics of the divider the students assumes that the divider can be seen as a first-order system with a truly exponential rise. On the basis of this assumption, please calculate the response time T of this divider.

g) Finally the students are ready for testing in the HV lab ☺ By means of the oscilloscope they measure a peak voltage of 218 kV for a front chopped lightning impulse with chopping time T_c = 0,3 µs. What was the actual peak voltage at the test object ?

GOOD LUCK ☺

Exercise 2 (Switch mode)

Current Programmed Control of Boost converter, operation steady-state.



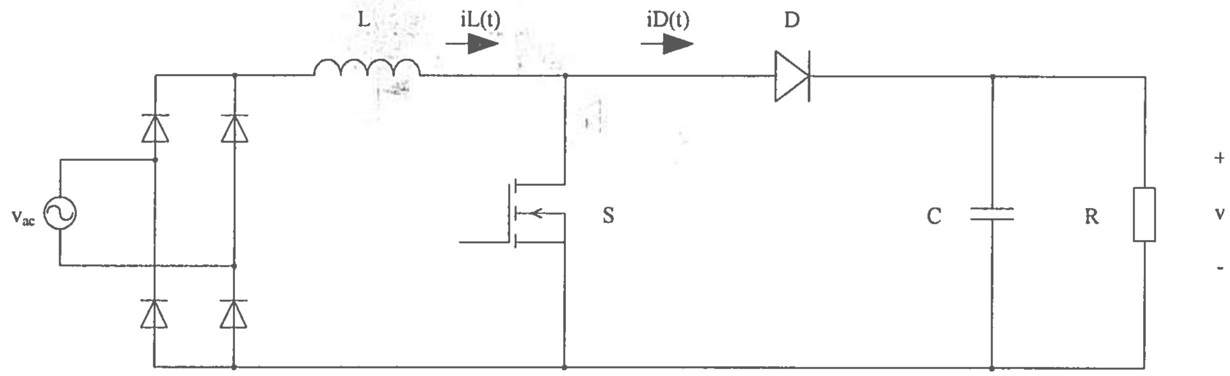
$T_s = 10\ \mu s$ $R = 20\ \Omega$ $V_g = 20$ V $V = 100$ V $R_f = 1\ \Omega$

Assume ideal components (=> no power loss in power conversion)

a) Calculate the average current of the switch S.

b) Add a stabilizing ramp and calculate the minimum slope of the artificial ramp m_a that will give stability.

Design a boost converter,



Specification:

Output voltage	390 V
Output power	500 W
Rms input voltage	230 V
Efficiency	0.95
Fundamental frequency	50 Hz
Switching frequency	100 kHz

In question a, b assume converter operate in CCM and switching frequency ripple current in L is very small – so small you may ignore it.

a) For one fundamental period sketch the current of iL(t) label the axis.

b) For one switching period sketch the current of iD(t) assume the average current is 1 A and the duty-cycle of S is 25 %. Label the axis

c) Calculate the value of the emulated resistance R_e.

d) For what values of L is the converter operating in DCM?

e) Sketch the low frequency waveform of the ripple voltage found in the output voltage v. The ripple voltage waveform for one fundamental period of the line voltage must be shown. Label the axis.

HV 2011 exam

a) See figure 2.25 and explanation.
type b has higher efficiency η

b) eq (2.38) yields $\underline{R_1 = 378{,}3\ \Omega}$

c) (2.26) $v(t) = \frac{V_0}{k} \frac{1}{(\alpha_2 - \alpha_1)} \left[e^{-\alpha_1 t} - e^{\alpha_2 t} \right]$

$k = 378 \cdot 1{,}2 \cdot 10^{-9} = 454 \cdot 10^{-9}$

$\frac{1}{(\alpha_2 - \alpha_1)} = 4{,}074 \cdot 10^{-7}$

$v = \frac{250 \cdot}{454 \cdot 10^{-9}} \cdot 4{,}074 \cdot 10^{-7} = 224{,}5\ kV$

$v(t) = 224{,}5 \left(e^{-14663 \cdot t} - e^{-2469136 \cdot t} \right)$

afl. $V_{max} = 216\ kV$ $30\% = 65\ kV \Rightarrow 1{,}38 \cdot 10^{-7}$
$90\%\ 195\ kV \Rightarrow 8{,}49 \cdot 10^{-7}$

so 50 $T_1 = 1{,}67 \cdot (8{,}49 - 1{,}38) \cdot 10^{-7} = \underline{1{,}18\ \mu s}$

$\underline{T_2 = 49{,}3\ \mu s}$ legge på graf aflest.

$\eta = \frac{216}{250} = \underline{0{,}864}$

②

d) (2.29) $t_{max} = \dfrac{\ln(\alpha_2/\alpha_1)}{(\alpha_2 - \alpha_1)}$

$t_{max} = \dfrac{\ln\left(\frac{1}{0.405\cdot10^{-6}} \Big/ \frac{1}{68.2\cdot10^{-6}}\right)}{\frac{1}{0.405\cdot10^{-6}} - \frac{1}{68.2\cdot10^{-6}}} = \underline{\underline{2.09\,\mu s}}$

Passer med graf

$V_{max} = 224.5\left(e^{-14663\cdot2.09\cdot10^{-6}} - e^{-2469136\cdot2.09\cdot10^{-6}}\right)$

$V_{max} = \underline{\underline{216,4}}\ kV$ passer!

(2.34) $\eta = \dfrac{C_1}{C_1 + C_2} = \dfrac{10\cdot10^{-9}}{10\cdot10^{-9} + \ldots} = \underline{\underline{0.89}}$

e) tabell 9.3 : 23 ⇒ V_{50} = 206 kV

(3.2) $\delta = \dfrac{p}{p_0}\,\dfrac{273+t_0}{273+t} = \dfrac{1022}{1013}\,\dfrac{273+20}{273+18} = 1,016$

δ = RAD tabell 3.5 : 85 ⇒ k_d = 1,00

(3.1) $V_d = k_d \cdot V_{d0} = 1,00 \cdot 206 = \underline{\underline{206\ kV}}$

p. 87 usikkerhet ± 3% ⇒

$\underline{\underline{V_d = 206 \pm 6\ kV}}$

(3)

7) (3.33) p. 126

$$C_e \approx \frac{2\pi\varepsilon l}{\ln\frac{1.15\,l}{d}} = \frac{2\pi\cdot 8.85\cdot10^{-12}\cdot 1.00}{\ln\frac{1.15\cdot 1.00}{2.1}} = \underline{\underline{22.8\,pF}}$$

p. 152 first-order only [illegible] $\Rightarrow$

$$\tau = T = \frac{R\cdot C_e}{6} = \frac{50000\cdot 22.8\cdot10^{-12}}{6} = \underline{\underline{190\,ns}}$$

9) (3.53) p. 139

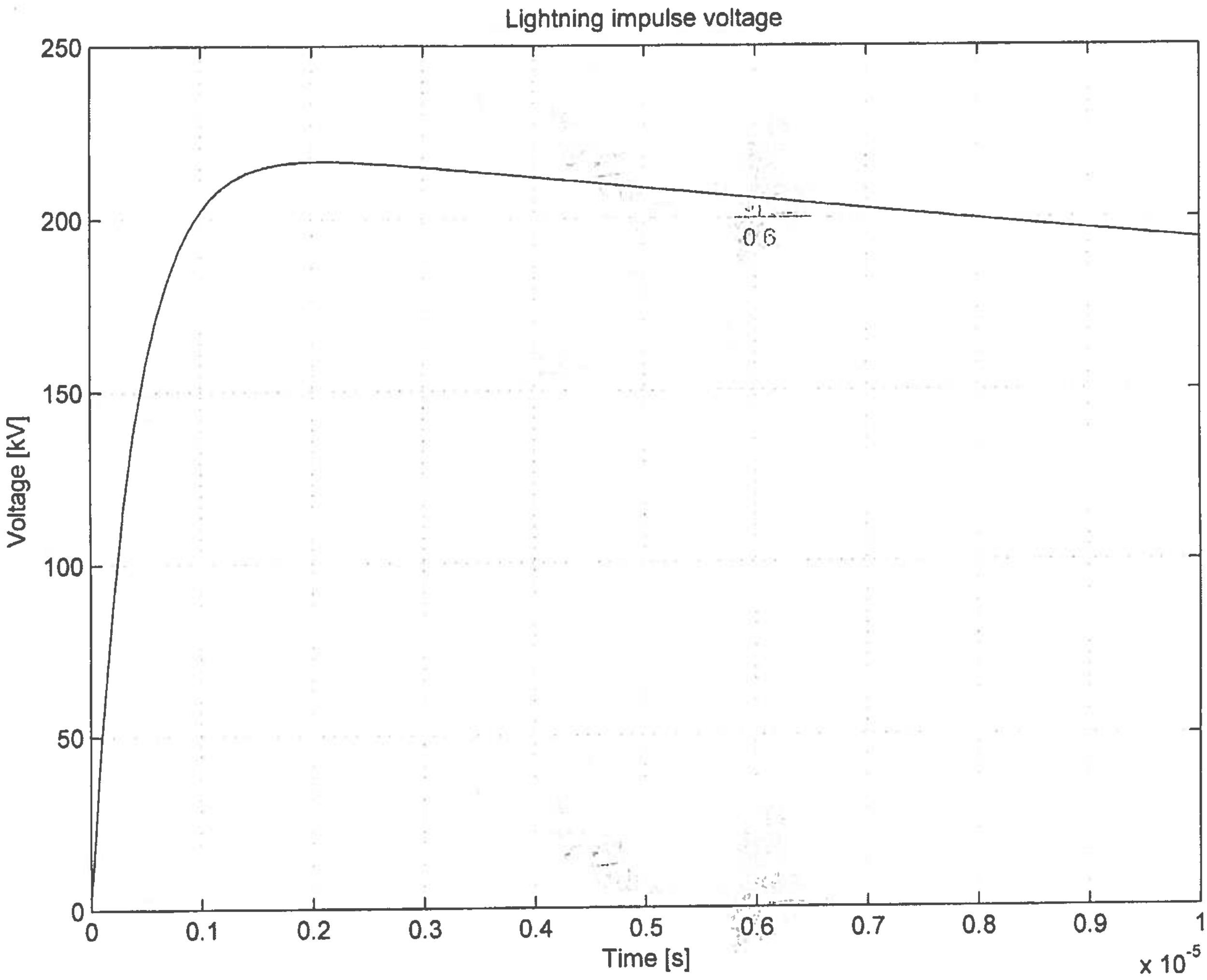
$$\delta = \frac{\Delta V}{S\cdot T_c} = \frac{T}{T_c}$$

$$\delta = \frac{190\cdot10^{-9}}{300\cdot10^{-9}} = 0.632,\quad S = {}^{218}/_{0.3} = 727\ {}^{kV}/_{\mu s}$$

$$\Delta V = \delta\cdot S\cdot T_c = 0.632\cdot 727\cdot 0.3 = 138\,kV$$

So [illegible] voltage $= V_{max} + \Delta V = 218 + 138$

$= \underline{\underline{356\,kV}}$



Lightning impulse voltage
Voltage [kV]
Time [s]
x 10^-5
0
50
100
150
200
250
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1