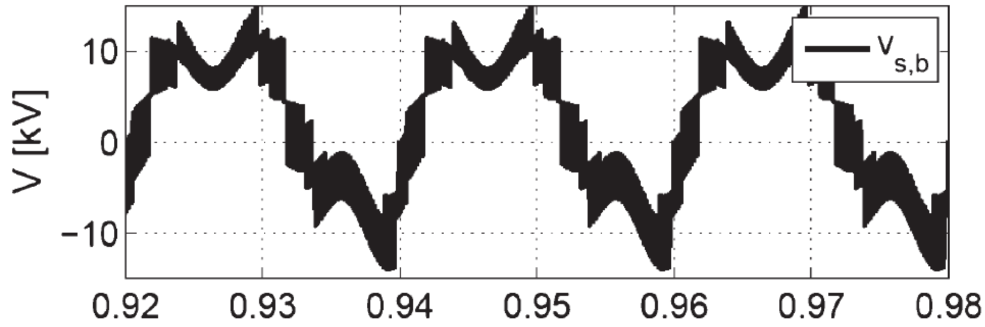
KTH Electrical Engineering

Examination in **POWER ELECTRONICS** (EJ2300)
Tuesday, 7th January 2014, 08:00 – 13:00 (Questions 09:00, 10:30, and 12:00)
Exam responsible: Hans-Peter Nee, 070 – 695 34 70

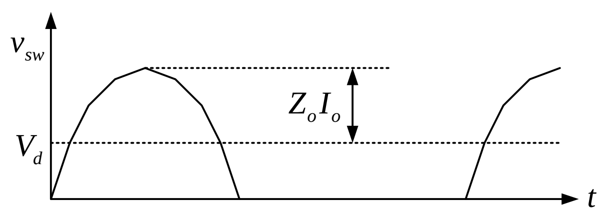
Permitted aid: Calculator, mathematical handbook, and three-phase paper.
The requirement to pass is 15 points. Problems 1–5 give 3 points each and problems 6–8 give 5 points each.
For full marks, the solutions have to be readable and *the line of thought has to be recognizable*!
Do not forget to scale axes of graphs!
Only one problem per paper! (Because different persons will mark different problems!)

1. In the figure below, a plot of the output voltage waveform of a high-voltage inverter is shown. The horizontal axis represents the time in seconds. Determine (approximately) the frequency of the fundamental component of the waveform.



2. The maximum permissible duty ratio of the forward converter is given by $D_{\max} = \dfrac{1}{1 + N_3 / N_1}$, where N_1 and N_3 are the numbers of turns in two of the windings of the transformer. What happens if the duty ratio is increased above this value?
If the value of N_3 is small compared to N_1, high values of $D_{\max}$ can be achieved. Is this choice associated with any drawback?

3. A ZVS resonant-switch dc-dc converter has a voltage wavefrom across the switch as shown in the figure below. The angular resonance frequency is given by $\omega_0 = 1/\sqrt{L_r C_r}$. A design engineer is given the task to reduce the maximum voltage across the switch without changing the resonance frequency. What can the engineer do if $Z_0 = \sqrt{L_r / C_r}$?

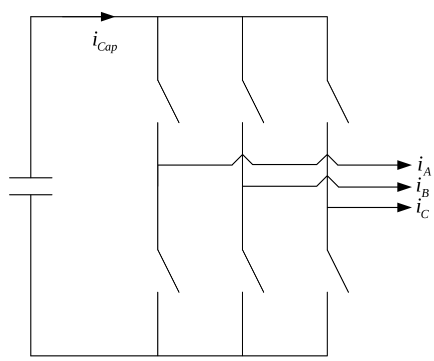


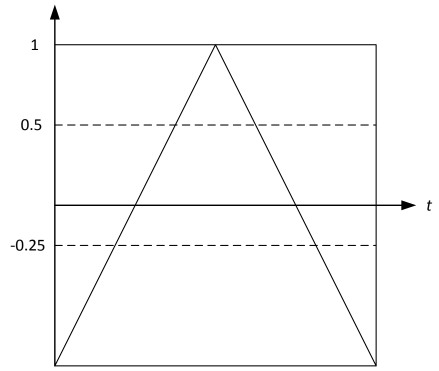
4. A three-phase diode rectifier has a completely smooth load current of 75 A. Calculate the output voltage if the supply voltage is 400 V/50 Hz, and the commutation inductance is 1 mH.

5. The unfiltered output voltage of a dc-dc converter has a dc-component of 48 V and a 180 kHz symmetrical square wave component with the RMS-value 48 V. Calculate the RMS-value of the output voltage.

6. A three-phase switch-mode inverter for reactive power compensation is only connected to a capacitor on the dc side (see the left figure below). In the right figure below, the triangular carrier and the reference voltages for the three phases during one switching cycle are shown. The reference value for phase A is 0.5 and the reference values of the other two phases are both -0.25. The output voltages from the inverter are generated in the common way when using sinusoidal PWM. During this switching cycle, the current in phase A is 100 A and in the other two phases the currents are – 50 A (with respect to the definitions in the left figure below).

   Draw the waveform of i_{Cap} and calculate the average value during the switching cycle.





7. A 400 V/50 Hz three-phase system is loaded with an ideal three-phase diode rectifier having a completely smooth output current of 50 A. An ideal three-phase thyristor converter is connected in parallel with the diode rectifier. The output current of the thyristor converter is also 50 A and completely smooth, but the output power of the thyristor converter is zero.

a) Draw the waveforms of the input currents to the two converters and the the sum of the two currents. (2p)

b) Calculate the power factor for the total load. (3p)

8. A single-phase diode rectifier bridge is fed from the 230 V/50 Hz line. The load consists of an inductor (1,0 H) and a resistor (10 Ω).

a) Calculate the peak-to-peak ripple in the output current assuming that the voltage across the resistor is constant. (3p)

b) Draw the waveforms of the ripple components of both the output voltage and output current. The drawing must be made with care such that the slopes and extreme values are reasonably right in various points. (2p)

Solutions

1. Using the grid in the figure, it is easily found that the fundamental cycle time is 0,02 s. This corresponds to a fundamental frequency of 50 Hz.

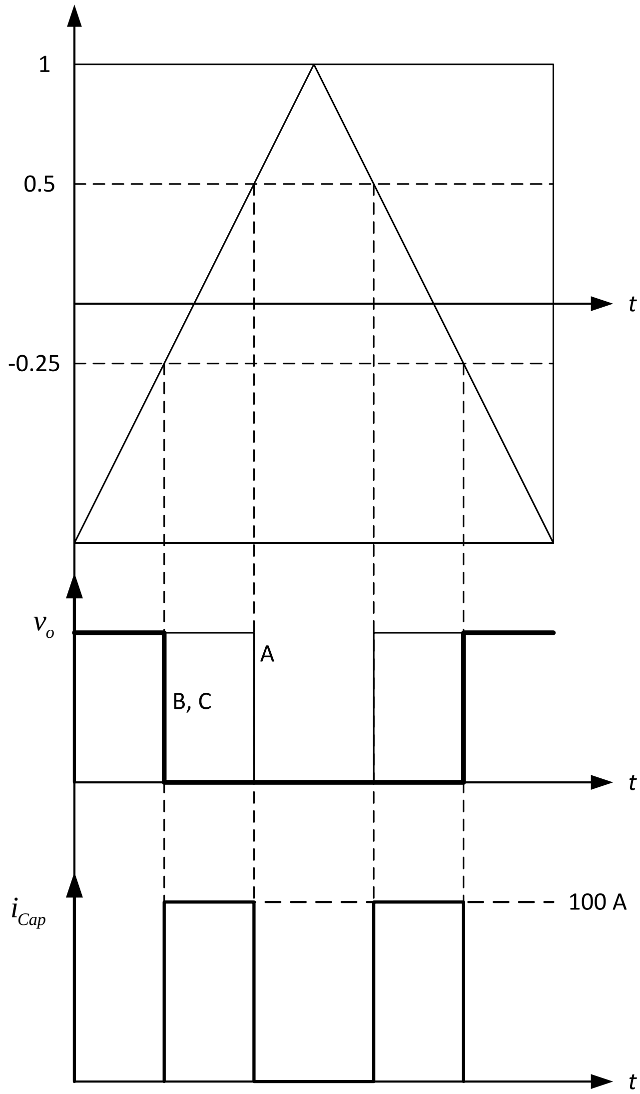
2. Zero-voltage switching is preferable at high switching speeds because of the stray capacitance of the switch. If zero-current switching is used the voltage across the switch might have to change abruptly. This means that the stray capacitance of the switch has to be charged or discharged abruptly. This can only be achieved with a high current spike with associated losses. The energy of the stray capacitance may, for instance, be dissipated in the switch at turn-on.

3. One way to proceed is to reduce Z_0, but this has to be done without changing ω_0.
If the product of L_r and C_r is kept constant, ω_0 will remain unchanged.
So, if L_r is reduced and C_r is increased such that the product is still constant, Z_0 can be reduced without changing ω_0. With a reduced value of Z_0, the maximum voltage across the switch will be reduced. Comment: A drawback with this method is that the minimum output current in order to stay in soft-switching operation is increased. Therefore, this method only works if the current never goes low.

4. $$V_d = 1{,}35 \cdot V_{LL} - \frac{3}{\pi} \cdot \omega \cdot L_s \cdot I_d = 1{,}35 \cdot 400 - \frac{3}{\pi} \cdot 2\pi 50 \cdot \frac{75}{1000} = \underline{518\text{ V}}$$

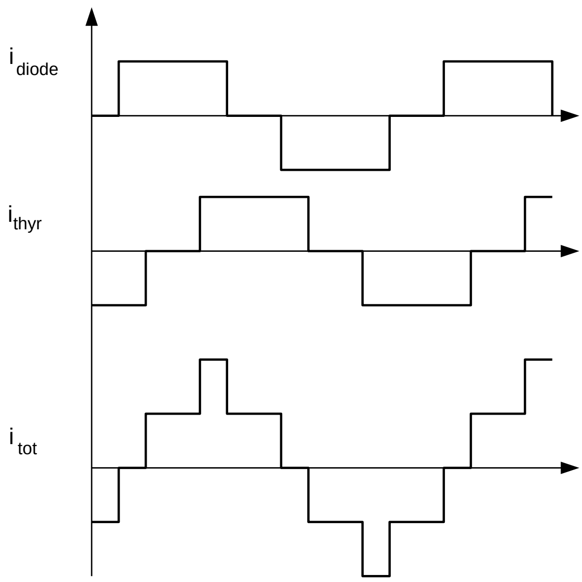
5. $V_{RMS} = \sqrt{48^2 + 48^2} = \underline{68\text{ V}}$

6. The capacitor has a current only if at least two output voltages are different. When all three output voltages are identical, the capacitor is disconnected. Using this, i_{Cap} can be drawn.



By studying the drawing, the average value of i_{Cap} is found to be 37.5 A.

7. a)



7.b) $P.F. = \dfrac{P}{3 \cdot V_s \cdot I_s}$

$$I_s = \sqrt{\frac{1}{T} \cdot \left(\frac{2}{3} \cdot T \cdot 50^2 + \frac{1}{6} \cdot T \cdot 100^2 \right)} = \sqrt{\frac{2}{3} \cdot 50^2 + \frac{1}{6} \cdot 100^2} = 57{,}735 \text{ A}$$

Only the diode rectifier consumes active power. This active power equals the output power of the diode rectifier.

$$P = 1{,}35 \cdot V_{LL} \cdot I_d = 1{,}35 \cdot 400 \cdot 50 = 27000 \text{ W}$$

$$P.F. = \frac{27000}{3 \cdot 230 \cdot 57{,}735} = \underline{0{,}68}$$

8. a) The mean value of the output voltage is

$$V_d = \frac{1}{\pi} \cdot \int_{-\pi/2}^{\pi/2} \hat{v}_s \cos(\alpha) \mathrm{d}\alpha = \frac{2\hat{v}_s}{\pi}$$

During the time when the instantaneous voltage is higher than the mean value, the current will increase monotonically. This means that the peak-to-peak ripple can be calculated by integration during this time. The instantaneous output voltage equals the mean value two times per 100 Hz-cycle.

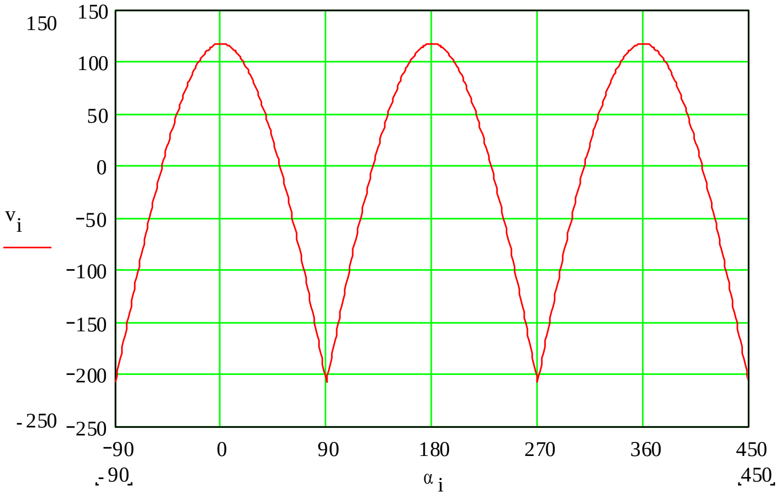
$$\hat{v}_s \cos(\alpha) = \frac{2\hat{v}_s}{\pi} \Rightarrow \alpha_0 = \pm 50.46°$$

$$\Delta I_d = \frac{1}{L} \int_{-50{,}46°}^{50{,}46°} \hat{v}_s \cos(\omega t) dt = \frac{1}{L} \cdot \frac{\hat{v}_s}{\omega} \cdot 2 \cdot \sin(50{,}46°) = \underline{1{,}6 \text{ A}}$$

b) The output voltage ripple is given by

$$\Delta v = \hat{v}_s \cos(\omega t) - \frac{2}{\pi} \cdot \hat{v}_s$$

The current ripple is obtained in the same way as in a)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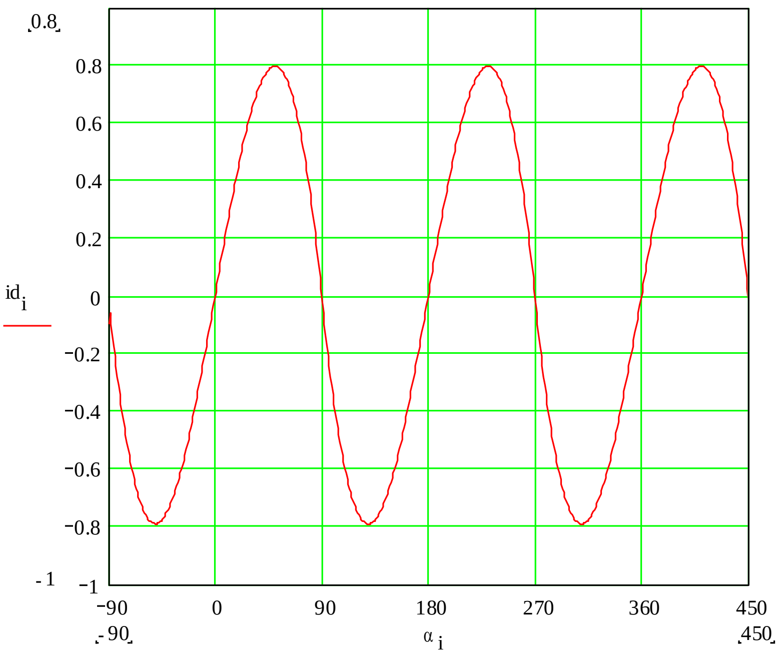
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