Midterm Exam **ENM060 Power Electronic Converters - Solutions**
Wednesday November 26, 2014

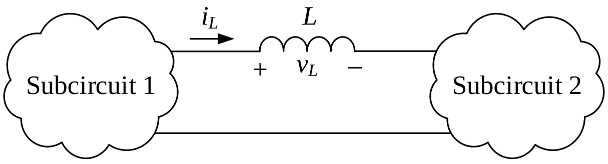
Lecturer: Andreas Karvonen, tel. 031-7721642 or 0709-524924
Help: CTH approved calculator (Casio FX82, Texas TI30, Sharp EL531)
Solutions: Will be posted on the course webpage (2014-11-26).
Mark list: Handed out 2014-12-03 at 15:15 in ML11
Pick-up of Exam Handed out 2014-12-03 at 15:15 in ML11

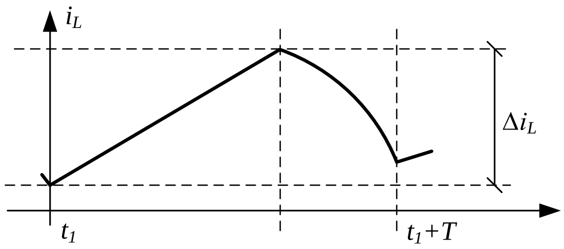
Each question is connected to a lecture (1 to 8). The bonus points are rewarded as follows:

-2p:	0-4p
+1p:	5-14p
+2p:	15-19p
+3p:	20-25p

---

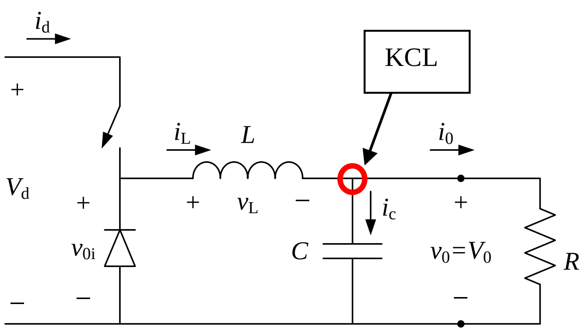
1. **For the system below, draw the resulting inductor voltage and comment if the system is operating in steady-state. (3p)**





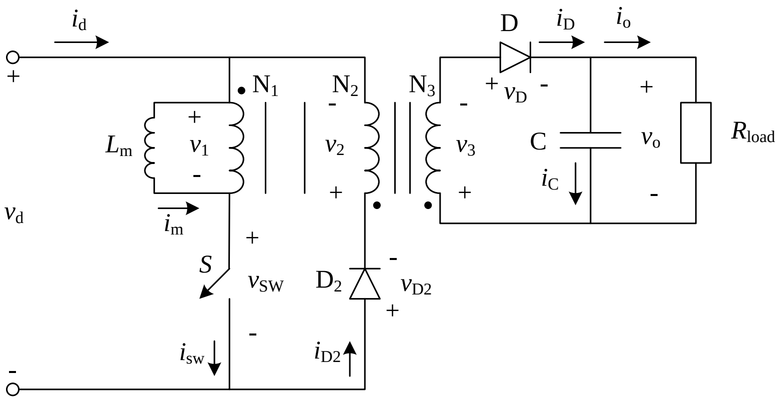
2. **Draw the ideal *iv*-characteristics (i_D as a function of v_D) for a low voltage and a high voltage diode. Also, draw the equivalent circuits when the diodes are conducting. (4p)**

3. **Apply kirchoffs current law on the marked node and draw the resulting currents (i_0, i_c and i_L). Assume that the output voltage is constant and that the converter is operating in discontinuous conduction mode (DCM). (3p)**

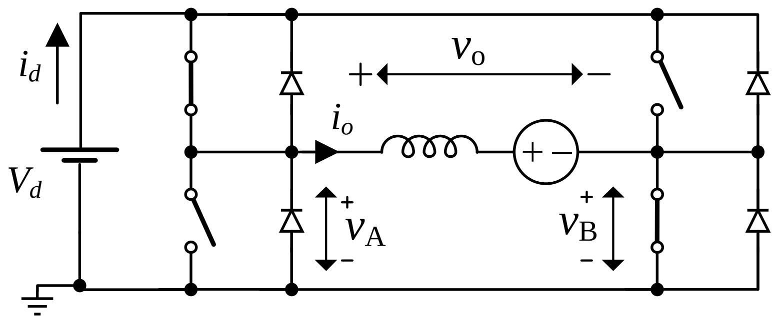


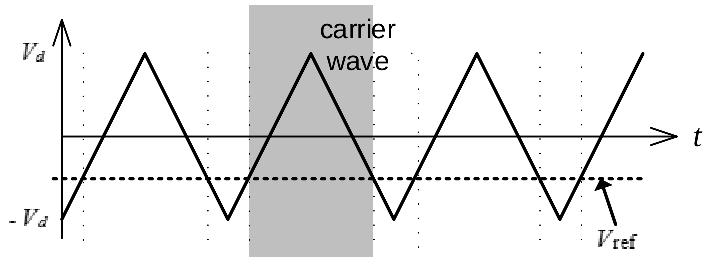
4. **For a boost converter, derive an expression of the ratio between the input and output voltage when it is operating in continuous conduction mode (CCM). (3p)**

5. **The flyback converter below has a protective winding (N_2) and the total turns ratio of the transformer $(N_1\!:\!N_2\!:\!N_3)$ is $(1\!:\!2\!:\!1)$. Draw the resulting switch voltage (v_{sw}) with D=0.3 if the converter is operating without any load ($R_{load}=\infty$). (4p)**

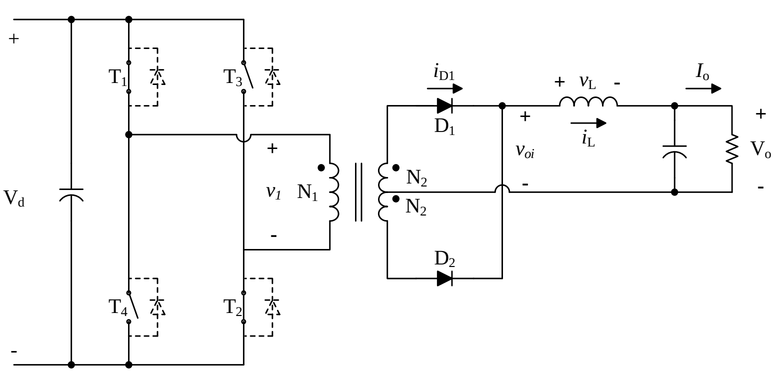


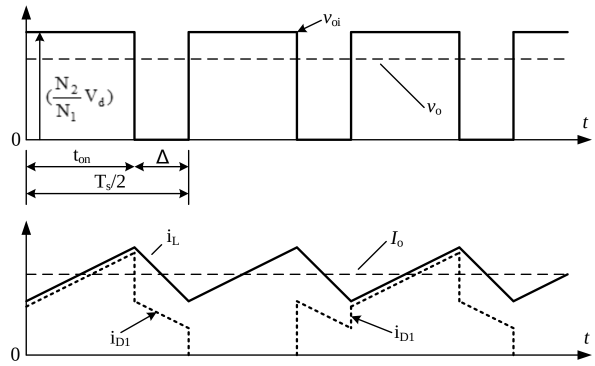
6. **The H-bridge converter below is operating with a bipolar switching pattern an output current that is negative during the entire switching period. Draw the resulting input (i_d) and output (i_o) current and draw the current path during the shaded time interval. (3p)**



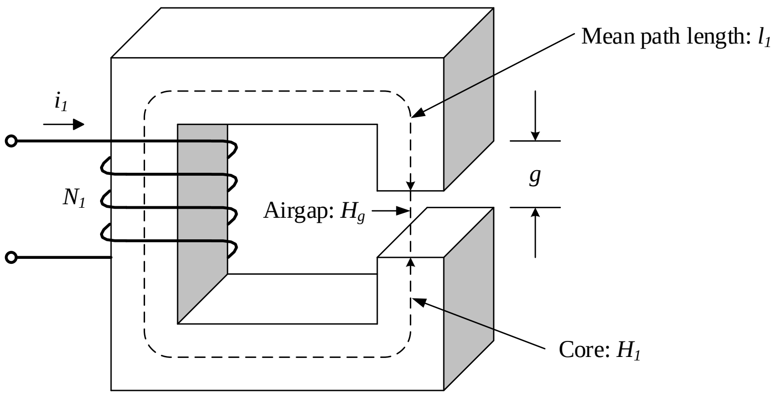


7. **The fullbridge DC/DC converter below is realized with a real (non-ideal) transformer. Why must there be anti-parallel diodes connected over each switch? Explain and exemplify with e.g. a current arrow. (2p)**





8. **On the magnetic core depicted below, a coil is wound on one side. If an air gap is introduced in the core, how is the *BH*-loop affected? Explain with a suitable equation/expression and visualize in a *BH*-plot. (3p)**



Formulas for Examination in Power Electronic Converters (ENM060)

Table 3-1 Use of Symmetry in Fourier Analysis

Symmetry	*Condition Required*	a_h and b_h
Even	$f(-t) = f(t)$	$b_h = 0 \quad a_h = \frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\, d(\omega t)$
Odd	$f(-t) = -f(t)$	$a_h = 0 \quad b_h = \frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\, d(\omega t)$
Half-wave	$f(t) = -f(t + \frac{1}{2}T)$	$a_h = b_h = 0$ for even h $a_h = \frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\, d(\omega t)$ for odd h $b_h = \frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\, d(\omega t)$ for odd h
Even quarter-wave	Even and half-wave	$b_h = 0$ for all h $a_h = \begin{cases} \frac{4}{\pi}\int_0^{\pi/2} f(t)\cos(h\omega t)\, d(\omega t) & \text{for odd } h \\ 0 & \text{for even } h \end{cases}$
Odd quarter-wave	Odd and half-wave	$a_h = 0$ for all h $b_h = \begin{cases} \frac{4}{\pi}\int_0^{\pi/2} f(t)\sin(h\omega t)\, d(\omega t) & \text{for odd } h \\ 0 & \text{for even } h \end{cases}$

Definition of RMS-value:

$$F_{RMS} = \sqrt{\frac{1}{T}\int_{t_o}^{t_o+T} f(t)^2 dt}$$

Definition of RMS-value with Fourier-series:

$$F_{RMS} = \sqrt{F_0^2 + \sum_{n=1}^{\infty} F_n^2} = \sqrt{\left(\frac{a_0}{2}\right)^2 + \sum_{n=1}^{\infty}\left(\frac{\sqrt{a_n^2 + b_n^2}}{\sqrt{2}}\right)^2}$$

$$\sin^2(\alpha) + \cos^2(\alpha) = 1$$

$$\sin(\alpha+\beta) = \sin(\alpha)\cos(\beta) + \cos(\alpha)\sin(\beta) \qquad \sin(\alpha-\beta) = \sin(\alpha)\cos(\beta) - \cos(\alpha)\sin(\beta)$$

$$\cos(\alpha+\beta) = \cos(\alpha)\cos(\beta) - \sin(\alpha)\sin(\beta) \qquad \cos(\alpha-\beta) = \cos(\alpha)\cos(\beta) + \sin(\alpha)\sin(\beta)$$

$$\sin(\alpha)\sin(\beta) = \frac{1}{2}\left(\cos(\alpha-\beta) - \cos(\alpha+\beta)\right) \qquad \sin(\alpha)\cos(\beta) = \frac{1}{2}\left(\sin(\alpha-\beta) + \sin(\alpha+\beta)\right)$$

$$\cos(\alpha)\cos(\beta) = \frac{1}{2}\left(\cos(\alpha-\beta) + \cos(\alpha+\beta)\right)$$

$$\int \sin(ax)dx = -\frac{1}{a}\cos(ax), \quad \int x\sin(ax)dx = \frac{1}{a^2}\left(\sin(ax) - ax\cos(ax)\right), \quad \int \cos(ax)dx = \frac{1}{a}\sin(ax)$$

$$\int x\cos(ax)dx = \frac{1}{a^2}\left(\cos(ax) + ax\sin(ax)\right)$$

$$PF = \frac{P}{S} = \frac{V_s I_{s1}\cos\phi_1}{V_s I_s}, \quad DPF = \cos\phi_1, \quad \%THD_i = 100\frac{I_{dis}}{I_{s1}} = 100\frac{\sqrt{I_s^2 - I_{s1}^2}}{I_{s1}} = 100\sqrt{\sum_{h\neq 1}\left(\frac{I_{sh}}{I_{s1}}\right)^2}$$

Electromagnetics

$$e = \frac{d}{dt}\psi \qquad \psi = N\phi \qquad \phi = BA \qquad R = \frac{l}{A\mu_r\mu_0} \qquad L = \frac{\Psi}{i}$$

$$NI = R\phi = mmf \qquad N\phi = LI \qquad L = A_L N^2 \qquad W = \frac{1}{2}LI^2$$

Simpson's rule

Let $f(x)$ be a polynomial of maximum third degree, this means

$$f(x) = a_1 + a_2 x + a_3 x^2 + a_4 x^3$$

For this function the integral can be calculated as

$$\frac{1}{T}\int_{t_0}^{t_0+T} f(x)dx = \frac{1}{6}\left(f(t_0) + 4f(t_0 + \frac{T}{2}) + f(t_0 + T)\right)$$