Examination	**ENM060 Power Electronic Converters**
Date and time	Tuesday April 5th, 2016, 14:00 – 18:00
Responsible Teacher:	Andreas Henriksson, tel. 0709-524924
Authorised Aids:	Chalmers-approved calculator (Casio FX82..., Texas Instruments Ti-30... and Sharp EL-W531...)
Grades:	U, 3, 4 or 5. (The limit for a 3 on the exam is 20p, a 4 is 30p and 5 is 40p. The maximum number of points is 50.)
Solutions:	Course webpage (Ping-Pong), April 6th 2016
Review of Exam	May 2nd and May 4th, 12:00-13:00. Fredrik Lamms Room. Division of Electric Power Engineering (1st floor). From May 5th 2016, the exams can be picked-up at the exam office, Department of Energy and Environment. Location: EDIT building, Maskingränd 2, 3Ö (east) floor, room 3434A. Opening hours during semesters: Monday-Friday 12:30-14:30

Observe that the questions are not arranged in any kind of order.

On the last pages there are some formulas that can be used in the examination. Always assume steady-state conditions in all tasks unless otherwise stated.

Please, read through the exam before you start.

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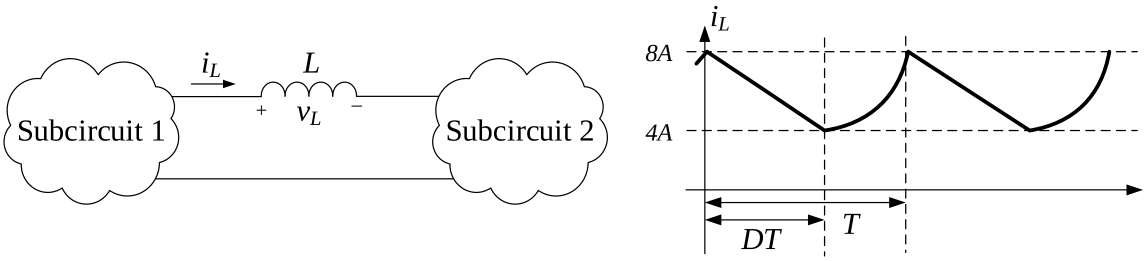
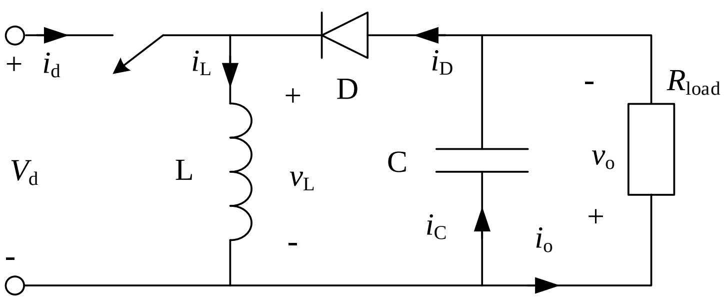
1) For the circuit below with $T = 30\mu s$ and $D = 0.6$, sketch the resulting voltage and calculate the inductance needed if the voltage applied over the inductor during $0 < t < DT$ is $12V$. (3p)



2) For the buck/boost converter below, <u>derive</u> an expression for the ratio between the input and output voltage if the converter is operating in CCM. (3p)

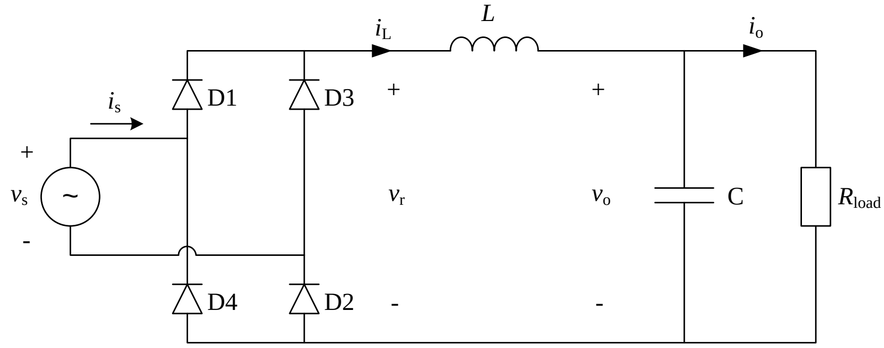


3) **The buck/boost converter in (2) is used with the circuit parameters and operating conditions below. Draw the resulting capacitor current (i_C), <u>apply Simpsons</u> formula and calculate the maximum power dissipation in the output capacitor if $R_{ESR} = 45m\Omega$. (5p)**

$V_d = 20V \quad V_o = 30V \quad L = 40\mu H \quad f_s = 80kHz \quad C_o = 330\mu F \quad I_o = 1A\ to\ 7A$

4) **For the buck/boost converter in (2), calculate the lowest value of the inductance (L) required to keep the converter operation in continuous conduction mode (CCM) for the entire operating region. (4p)**

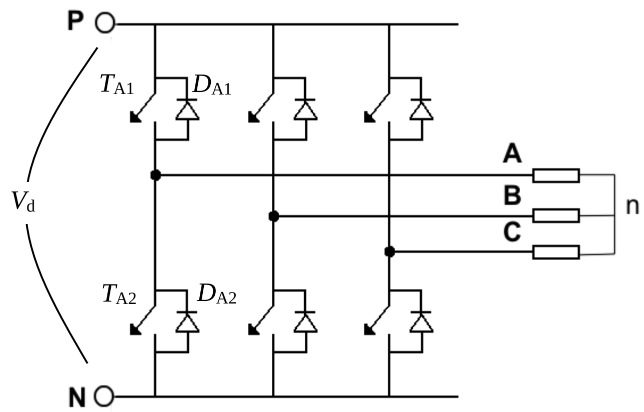
5) **The single-phase diode rectifier shown below is connected to an AC-voltage of 230V, 50Hz with a negligible inductance (source inductance). A DC-side inductance (L) is connected between the rectifier output and the filter capacitor (C). The DC-side inductance can not be considered infinite (L=10mH) but the filter capacitor can be assumed to be very large. Calculate the output voltage for a continuous inductor current (i_L). (3p)**



6) **For the diode rectifier in (5), the current that flows through the DC-side inductance (i_L) will consist of a DC-component and a superimposed AC-component. Draw the waveforms of $v_r(t)$, $v_o(t)$ and $i_L(t)$ at the limit which $i_L(t)$ becomes discontinuous. No calculations are needed, just typical waveforms. (3p)**

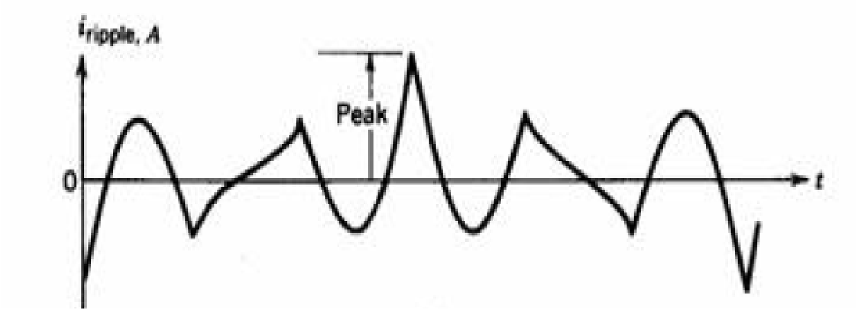
7) **For the diode rectifier in (5), the current that flows through the DC-side inductance (i_L) will consist of a DC-component and a superimposed AC-component. As the load resistance decreases or increases, the current can be either continuous or discontinuous. Calculate the load resistance value (R_{load}) at the limit below which i_L(t) becomes discontinuous. (5p)**

8) **The three phase inverter below is operated in square wave mode and the fundamental frequency component of the AC-side voltage is 50Hz. Plot the phase potentials of each leg (v_{AN}, v_{BN}, v_{CN}), the phase voltage over the load (v_{An}) and the resulting line to line voltage (v_{AB}). (4p)**

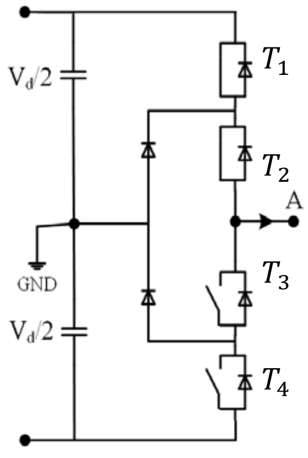


9) **The three-phase inverter in (8) is loaded with a purely resistive load ($R_A = R_A = R_A = 5\Omega$) and with $V_d = 340V$. Determine the RMS-value of the fundamental component of the phase current (i_A). (4p)**

10) **The load is replaced with an inductance and a voltage source (back-EMF) instead. The voltage from the back-EMF is sinusoidal shaped and in phase with the fundamental frequency output voltage which gives a resulting current as depicted below. For one leg and one period, sketch the phase voltage (v_{An}) and the back-EMF. Also, draw the current through phase leg A and the current through each diode (D_{A1}, D_{A2}) and each valve (T_{A1}, T_{A2}) (5p)**

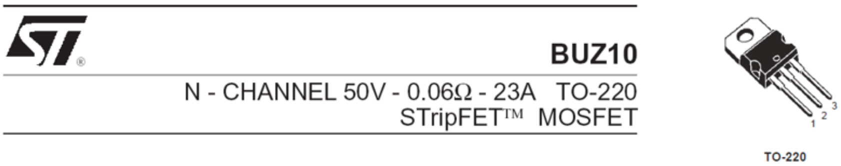


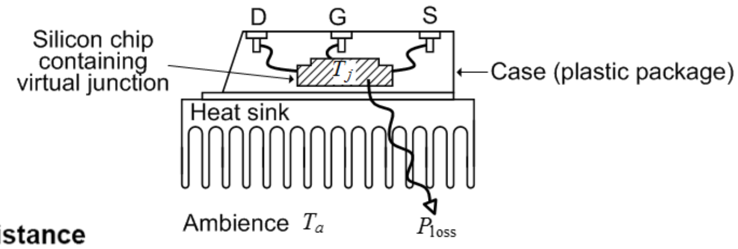
11) **You replace the standard 2-level inverter in (8) with a 3-level neutral point diode clamped (NPC) inverter instead, see phase leg below. Draw the resulting mid-point voltages ($v_{AGND}, v_{BGND}, v_{CGND}$) and the resulting voltage (v_{An}) that is applied over a *y*-connected load (phase voltage) for the 3-level inverter. Assume that upper and lower part of the phase leg (T_1, T_2 or T_3, T_4) is turned on for 150° and that the midpoint switches (T_2, T_3) are turned on for 30°. What is the benefit of using a multi-level inverter? (4p)**



$$v_{An} = \frac{2}{3} v_{AGND} - \frac{1}{3}(v_{BGND} + v_{CGND})$$

12) **For the component below, calculate the resulting chip temperature if the component is mounted on a heat sink with $R_{\Theta SA} = 12.3K/W$, the power dissipation is 3.4W and the ambient temperature is $T_A = 25°C$. If the component is used in an environment where it is exposed to many thermal cycles it will eventually break down. Due to which mechanism will it break down? (3p)**

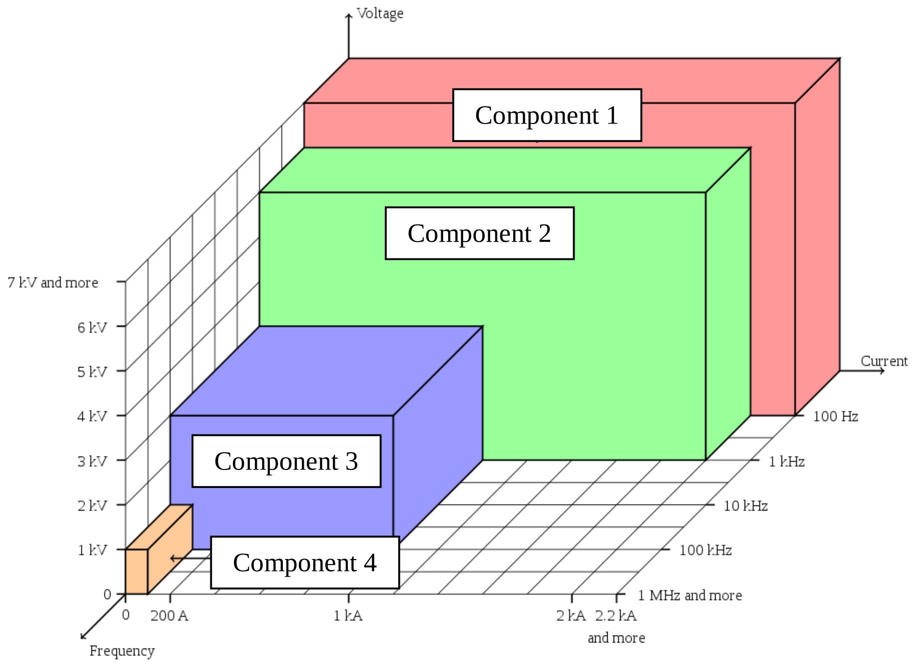




Thermal Resistance

	Parameter	Typ.	Max.	Units
$R_{\theta JC}$	Junction-to-Case	—	1.0	°C/W
$R_{\theta CS}$	Case-to-Sink, Flat, Greased Surface ④	0.50	—	
$R_{\theta JA}$	Junction-to-Ambient④	—	62	
$R_{\theta JA}$	Junction-to-Ambient (PCB mount)⑤	—	40	

13) **In the diagram below, state which component that is typically used in each power range. Why can't high power components be used with a high switching frequency? (4p)**



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:

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

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

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

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

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

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

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

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

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

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

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