Examination	**ENM061 Power Electronic Converters**
Date and time	Saturday January 13th, 2018, 14:00 – 18:00
Teacher responsible:	Mebtu Beza/Zeyang Geng, tel. +46317721617
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 grade of 3, 4 and 5 on the exam are 20, 30, and 40 pts., respectively. The maximum number of points in the exam is 50.)

The questions are not arranged in any kind of order and a formula sheet is attached in the last page.

For those of you, who want the result of this exam to be reported to ENM60 (a previous version of the course), please write the course code 'ENM060' on the cover of the exam answer sheet. All others who sit for the ENM061 exam should write the course code 'ENM061' as expected.

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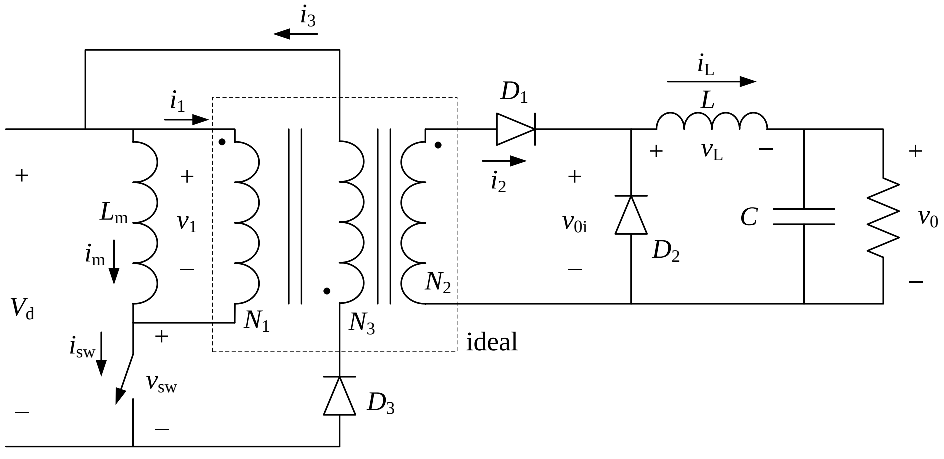
1) Briefly answer the following questions. ***(6 pts.)***

(a) What are the advantages and disadvantages of a switch-mode power supply over a corresponding linear power supply? ***(2 pts.)***

(b) What are the possible sources of power losses in a realistic MOSFET and how does these losses affect the life time of the MOSFET? ***(2 pts.)***

(c) Isolated DC/DC converters can be grouped based on the type of transformer core excitation. Give one example each for a converter with unipolar core excitation and bipolar core excitation. Motivate also the advantage of bipolar excitation over the unipolar excitation? ***(2 pts.)***

2) The isolated 3-winding forward converter with $N_1{:}N_2{:}N_3 = 1{:}1{:}0.5$ shown below which basically is derived from a buck converter operates with an output voltage (V_o) of 15V and an output power (P_o) of 50 W for an input voltage (V_d) of 25V and a switching frequency (f_{sw}) of 20 kHz. ***(8 pts.)***



(a) Calculate the inductance (L) in order to obtain the peak-to-peak current ripple in the inductor to be 10% of the average output current. ***(2 pts.)***

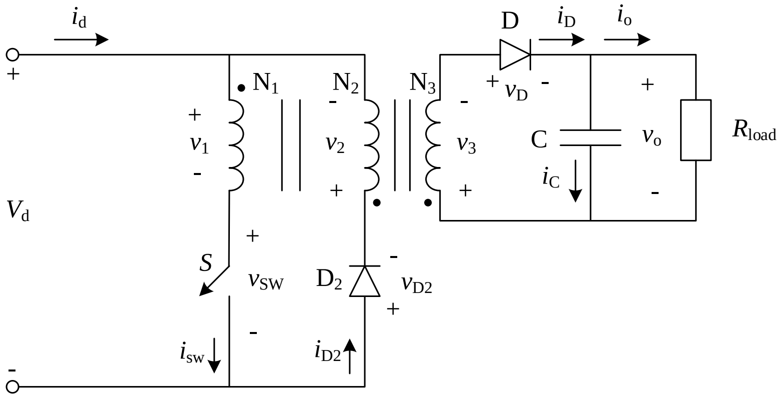
(b) Using the result in part (a), plot the inductor and capacitor current waveforms. Show the important points clearly. ***(2 pts.)***

(c) Using the capacitor current plotted in part (b), calculate the minimum capacitance (C) in order to limit the maximum peak-to-peak output voltage ripple to 1% of the average output voltage. ***(2 pts.)***

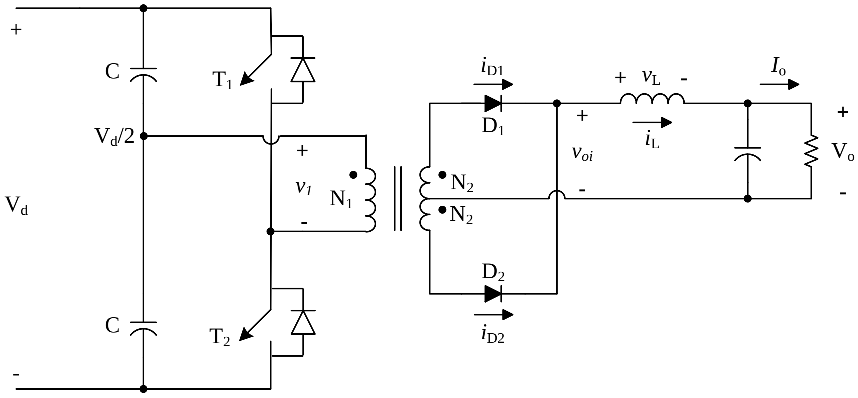
(d) Roughly sketch the waveforms for i_1, i_3, i_m and v_{sw} for one switching cycle. ***(2 pts.)***

3) **The flyback converter below has a protective winding (N_2) with the total turns ratio of the transformer as $N_1: N_2: N_3 = 1: 2: 2$ and input voltage $V_d = 20V$. The switching frequency $f_{sw} = 20kHz$, the duty cycle $D = 0.3$ and the mutual inductance $L_m = 100\mu H$.** ***(10 pts.)***

(a) For $R_{load} = 20\Omega$, calculate the average output voltage V_o and sketch the waveforms for v_{sw}, i_d and i_D. [*Hint: you have to first decide if the converter is operating in continuous or discontinuous conduction mode*] ***(4 pts.)***
(b) For the case of no load connected to the output, calculate the average output voltage V_o and sketch the waveforms for v_{sw}, i_d and i_D. ***(4 pts.)***
(c) What is the difference in the transformer core used in a flyback and a forward converter and motivate the reason for the difference? ***(2 pts.)***

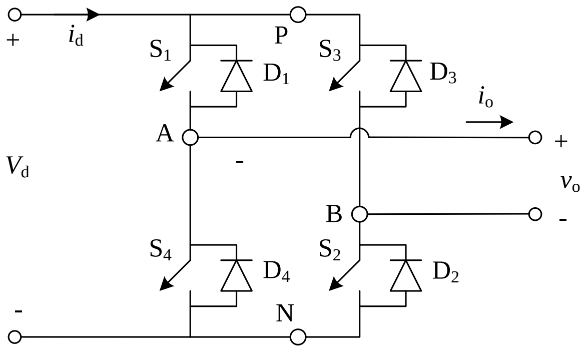


4) **For a half-bridge DC/DC converter shown below operating in continuous conduction mode (CCM),** ***(4 pts.)***



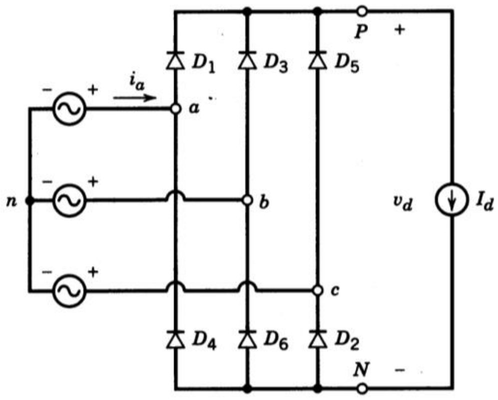
(a) Roughly sketch the waveforms for i_L, i_{D1} and i_{D2} for one switching cycle. ***(2 pts.)***
(b) Derive the expression for the output to input voltage ratio (V_o/V_d). ***(2 pts.)***

5) **For the single-phase inverter shown below with an input voltage $V_d = 300V$,** ***(10 pts.)***



(a) For a square-wave operation, plot the output voltage waveform and calculate the magnitude of the fundamental component as well as the total harmonic distortion. ***(3 pts.)***
(b) If a purely inductive load is connected to the output of the converter in square-wave operation, roughly sketch the output current for one fundamental cycle and show which switch/diode is conducting. ? ***(2 pts.)***
(c) For a square wave operation, which order of harmonics is present in the output ac-current and the input dc-current? Can you explain what the impact of using a 3-phase inverter on these harmonics is? ***(3 pts.)***
(d) What are the advantages and disadvantages of using a Pulse Width Modulation (PWM) operation instead of a square wave operation? ***(2 pts.)***

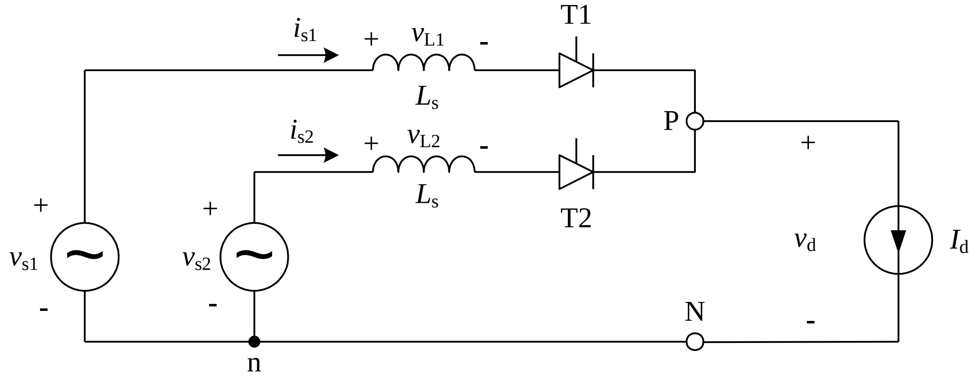
6) **The three-phase diode rectifier shown below is used with a current-stiff load with I_d = *15*A and a negligible source inductance. The system operates with a $50Hz$ balanced 3-phase source with RMS Line-to-Line voltage of *300*V.** *[use the attached dot paper in the last page of the exam paper if you prefer]* ***(6 pts.)***



(a) Plot the *phase a* source voltage and current. What is the input displacement power factor (DPF)? ***(2 pts.)***
(b) Plot the output voltage waveform and calculate its average value. ***(2 pts.)***
(c) If a source inductance results in a commutation angle of 10^o, plot the output voltage waveform and calculate the input DPF. ***(2 pts.)***

7) **For the thyristor rectifier circuit shown below, v_{s1} and v_{s2} are two sinusoidal with a peaк value of 187.8 V, a frequency of 50 Hz and a phase shift of 180^o. Assume that the source inductance (L_s) is 5 mH and that $I_d = 10A$ (current-stiff source). For a delay angle (α) of 45^o,** ***(6 pts.)***

(a) plot v_{s1}, i_{s1}, v_{s2}, i_{s2} and v_d. ***(3 pts.)***
(b) Calculate the commutation angle and the average value of V_d. How should the delay angle be selected to obtain a negative average voltage? ***(3 pts.)***



Formula sheet for the final exam of Power Electronic Converters (ENM061)

Fourier calculations

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:

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

Trigonometry

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

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

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

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

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

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

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

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

Electromagnetics

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

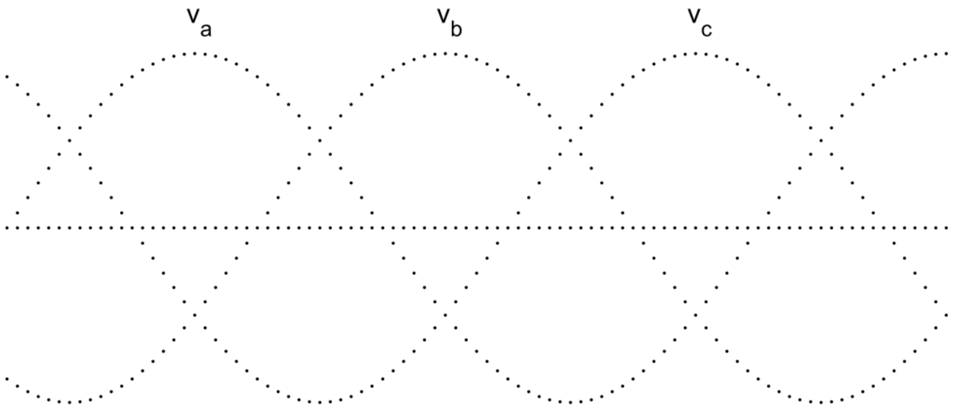
$$NI = R\phi = mmf \qquad N\phi = LI \qquad L = N^2/R \qquad W = \frac{1}{2}Li^2$$

Capacitor and inductor current-voltage relationship

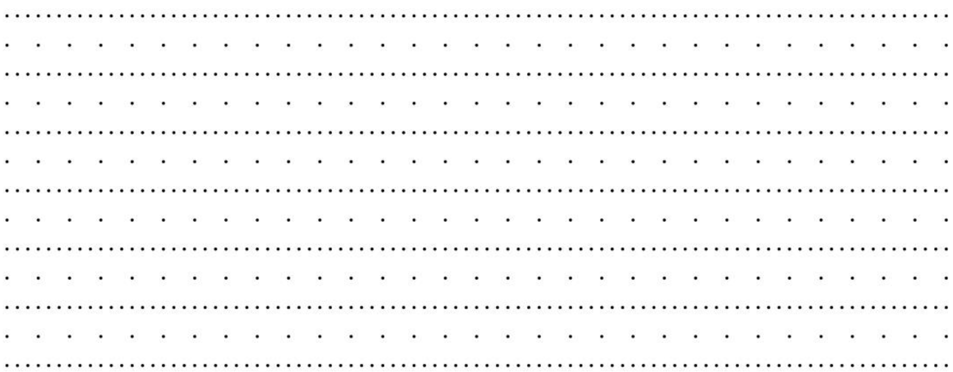
$$i_C = C\frac{dv_C}{dt} \qquad v_L = L\frac{di_L}{dt}$$

Dot paper for Question 6 (*give a page number and put this paper together with your answer sheets if you use it for your answers. The distance between the dots in the voltage plots is 5°.*)

1) Phase-voltage plot for part 6.a.



2) Phase-current plot for part 6.a.



3) Output dc-voltage plot for part 6.b and 6.c.