Examination	**ENM061 Power Electronic Converters**
Date and time	Wednesday April 4th, 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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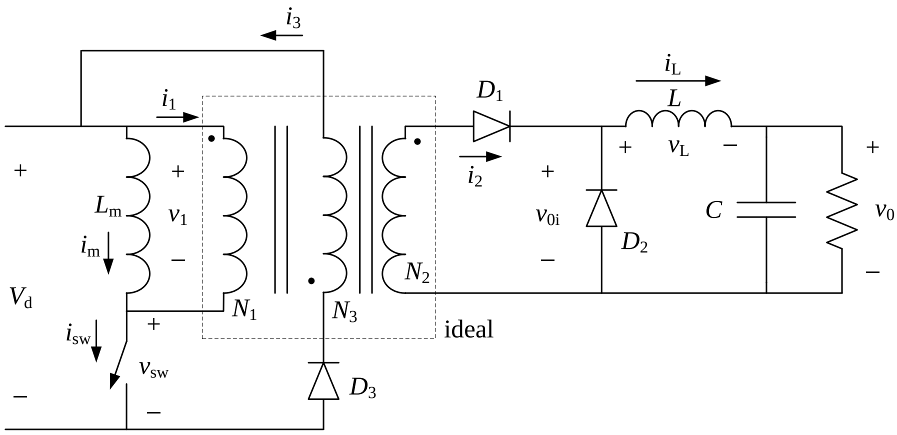
1) Briefly answer the following questions. ***(6 pts.)***

(a) What are the characteristic differences between a MOSFET and an IGBT? Consider conduction, switching and voltage blocking behaviours to explain the difference ***(3 pts.)***

(b) What is the difference in the transformer core used in a flyback, a forward and a half-bride DC/DC converters? What is the purpose of the transformer in these converters? ***(3 pts.)***

2) The forward converter with $N_1 : N_2 : N_3 = 1 : 1 : 1$ shown below operates with an output voltage (V_o) of 12V and an output power (P_o) of 48 W for an input voltage (V_d) of 20V and a switching frequency (f_{sw}) of 20 kHz. ***(10 pts.)***



(a) Calculate the inductance (L) in order to make the converter operate on the boundary between continuous and discontinuous conduction mode. ***(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 10% of the average output voltage. ***(2 pts.)***

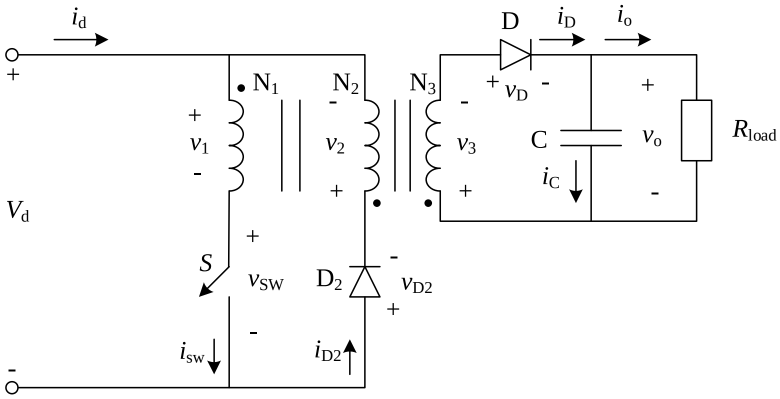
(d) What is the corner frequency of the low-pass filter for the converter? Are the inductance and capacitance values good enough to filter the switching harmonics in the output voltage? ***(2 pts.)***

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

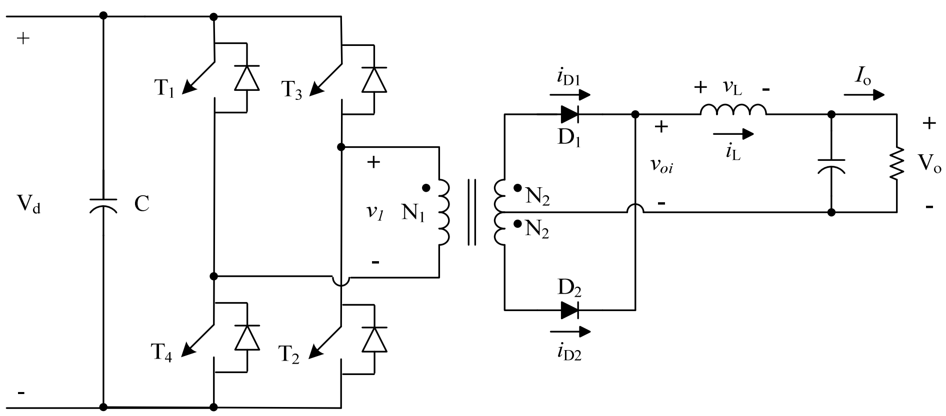
3) **The flyback converter below has a protective winding (N_2) with the total turns ratio of the transformer as $N_1 : N_2 : N_3 = 1 : 2 : 2$ and input voltage $V_d = 20V$. The switching frequency $f_{sw} = 20kHz$, the duty cycle $D = 0.3$ and the mutual inductance $L_m = 100\mu H$. *(8 pts.)***

(a) For $R_{load} = 40\Omega$, 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) The load resistance can influence the mode of operation of the converter. What is the maximum value of the load resistance (R_{load}) for the converter to operate in continuous conduction mode? ***(4 pts.)***



4) **For an isolated full-bridge DC/DC converter shown below operating in continuous conduction mode (CCM), (6 points)**



(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.)***

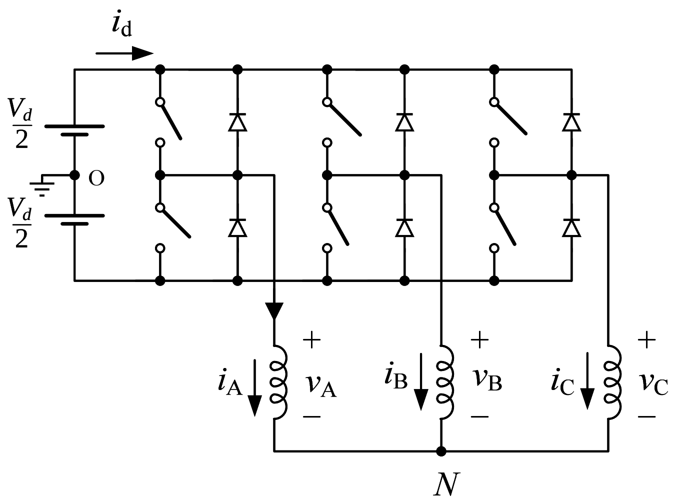
(c) What is the advantage and disadvantage of using the full-bridge converter instead of a half-bridge DC/DC converter? ***(2 pts.)***

5) **For the three-phase inverter shown below with an input voltage $V_d = 300\ V$, (9 points)**

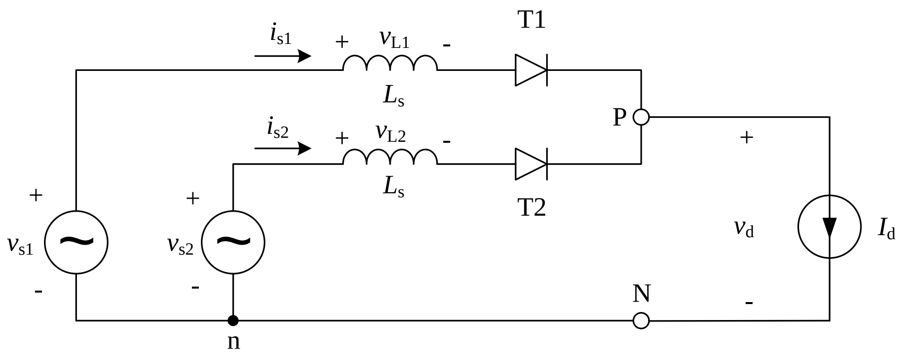
(a) For a square-wave operation, roughly plot the neutral-to-ground voltage, the phase-a voltage (v_A) and the phase-a current (i_A) for a balanced three-phase purely inductive load for one fundamental cycle. ***(3 pts.)***

(b) Can you predict the magnitude of the average dc-side current (I_d) and which order of harmonics are significant in the dc current i_d? What are the harmonic components if a PWM operation is used instead? ***(3 pts.)***

(c) Calculate the magnitude of the maximum fundamental voltage of $v_{A(1)}$ in the linear region using PWM operation and the square-wave operation? ***(3 pts.)***

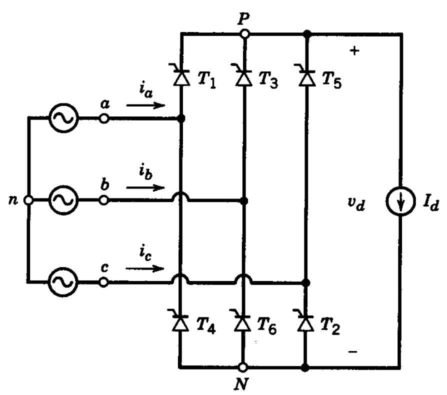


6) For the diode rectifier circuit shown below, v_{s1} and v_{s2} are two sinusoidal with a peak value of 200 V, a frequency of 50 Hz and a phase shift of 180°. Assume that the source inductance (L_s) is 5 mH and that $I_d = 12\ A$ (current-stiff source). ***(5 pts.)***



(a) plot v_{s1}, i_{s1}, v_{s2}, and i_{s2}. ***(2 pts.)***
(b) plot v_d and calculate the average value. ***(3 pts.)***

7) The three-phase thyristor rectifier circuit shown below is used with a current-stiff load with I_d = *20*A and a negligible source inductance. The system operates with a $50Hz$ balanced 3-phase source and the peak value of of the phase voltage is *300* V. For a delay angle of 30°, *[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 v_d and calculate its average value. ***(3 pts.)***
(c) What is the impact of source inductance on the DPF and the output voltage v_d. ***(1 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

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

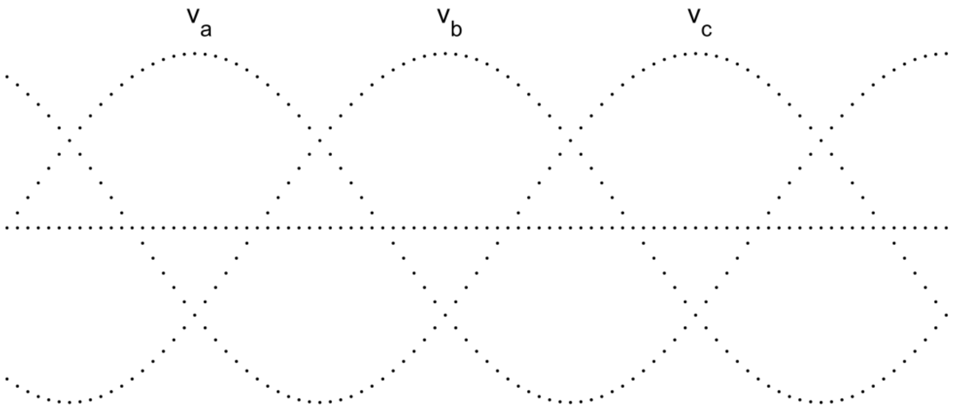
$$NI = R\phi = mmf \qquad N\phi = LI \qquad L = N^2/R \qquad W = \frac{1}{2}Li^2$$

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 7 (*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^o.*)

1) Phase-voltage plot for part 7.a.



2) Phase-current plot for part 7.a.

3) Output dc-voltage plot for part 7.b.