Examination	**ENM061 Power Electronic Converters**
Date and time	Tuesday August 22nd, 2017, 14:00 – 18:00
Teacher responsible:	Mebtu Beza, 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 3 on the exam is 20p, 4 is 30p and 5 is 40p. The maximum number of points is 50p.)

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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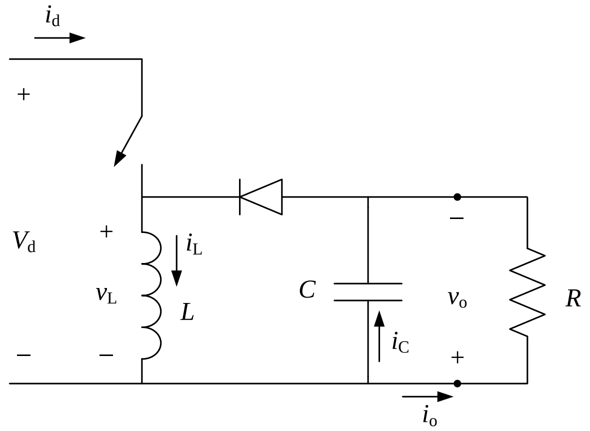
1) Briefly answer the following questions. (6 points)

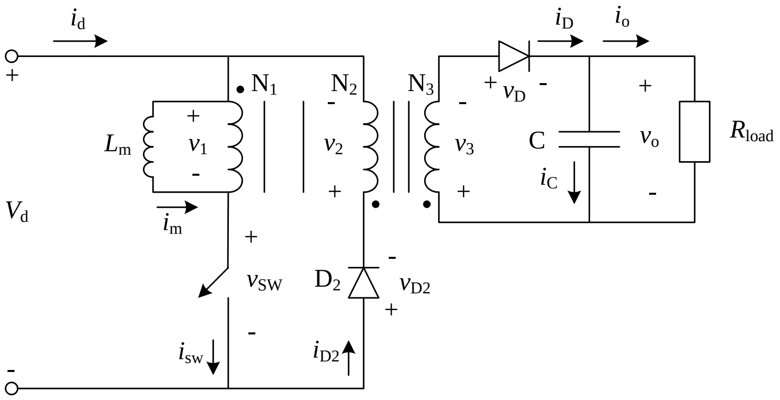
(a) What is the difference between a diode, a thyristor, a GTO and a MOSFET?
(b) What is the purpose of using an air-gap in the core of an inductor for DC/DC converter applications (please motivate your answer)?

2) The DC/DC converter with ideal components shown below operates with an output voltage (V_o) of 16V and an output power(P_o) of 64W for an input voltage (V_d) of 12V and a switching frequency (f_{sw}) of 20 kHz. (8 points)

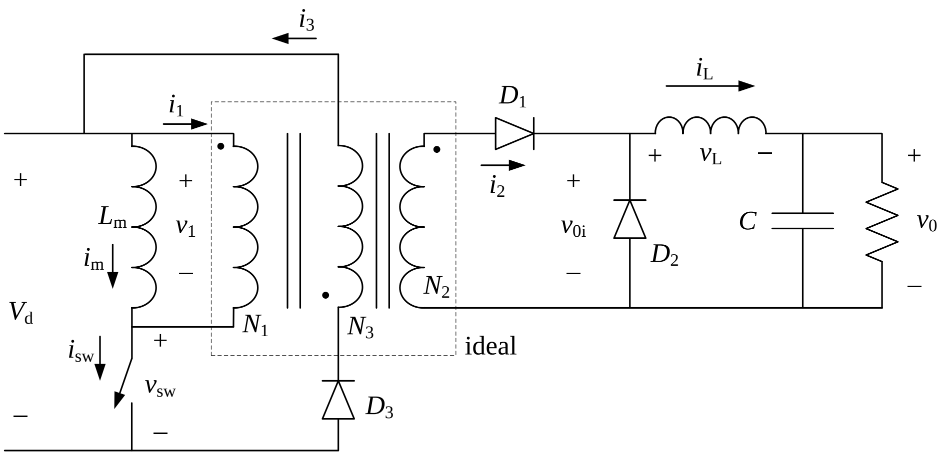


(a) Plot the ratio V_o/V_d versus the duty cycle D for both ideal and practical components in continuous conduction mode (CCM). From the result, can you identify the type of the DC/DC converter?
(b) Calculate the inductance (L) in order to obtain the peak-to-peak current ripple in the inductor to be 10% of the average output current.
(c) Using the result in part (b), plot the inductor and capacitor current waveforms. Show the important points clearly.
(d) Using the capacitor current plotted in part (c), calculate the minimum capacitance (C) in order to limit the maximum peak-to-peak output voltage ripple to 1% of the average output voltage.

3) **The flyback converter below has a protective winding (N_2) with the total turns ratio of the transformer given by $N_1:N_2:N_3 = 1:2:1$ and input voltage $V_d = 20V$. The switching frequency $f_{sw} = 20kHz$, the duty cycle $D = 0.3$ and the mutual inductance $L_m = 100\mu H$. For $R_{load} = 10\Omega$, 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*] (6 points)**

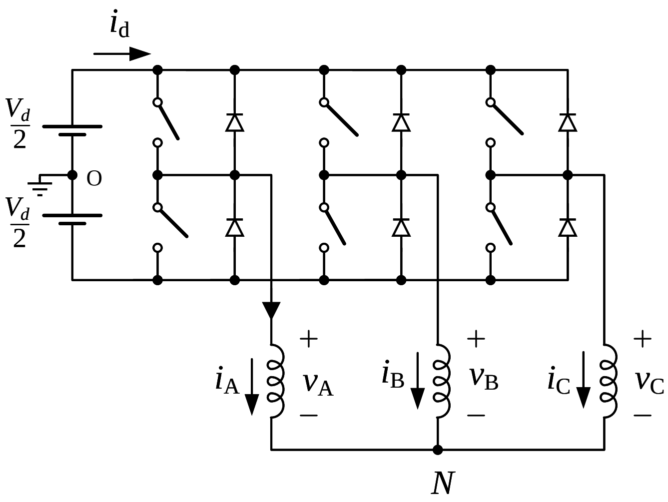


4) **For an isolated 3-winding forward converter operating in CCM, (10 points)**



(a) Roughly sketch the waveforms for i_L, i_1, i_2, i_3 and i_m for one switching cycle.
(b) Roughly sketch v_{0i} and derive the expression for the output to input voltage ratio (V_o/V_d).
(c) What is the purpose of the 3rd winding in the transformer?
(d) Roughly sketch the magnetic flux in the transformer and motivate what type of core should be selected for this converter?
(e) Describe the difference in the magnetic core used in the flyback converter and the forward converter?

5) **For the three-phase inverter shown below with an input voltage V_d, (10 points)**

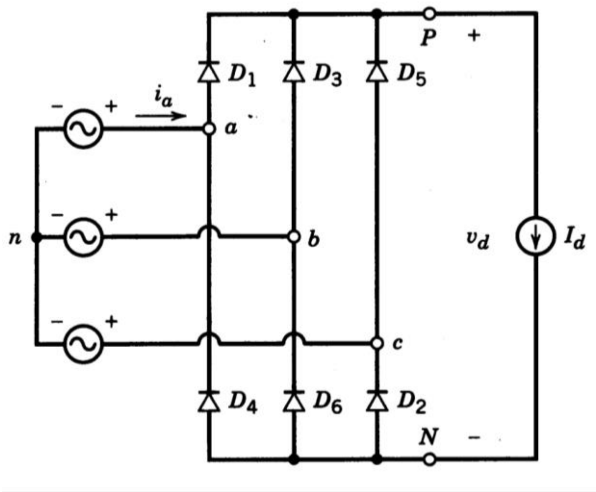


(a) For a square-wave operation, roughly plot the neutral-to-ground voltage, the phase voltages (v_A, v_B, v_C) and the phase currents (i_A, i_B, i_C) for a balanced three-phase purely inductive load for one fundamental cycle.

(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?

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

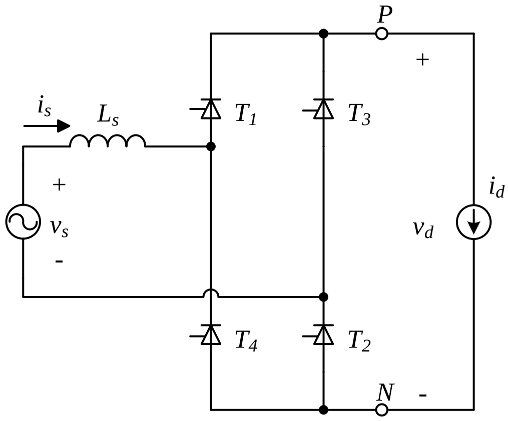
6) **The three-phase diode rectifier shown below is used with a current-stiff load with I_d = *10*A and a source inductance of 2mH. The system operates with a 50*Hz* balanced 3-phase source with RMS Line-to-Line voltage of *300*V. (5 points)**



(a) Plot the source voltage and current in phase a, and calculate the input displacement power factor (DPF)?

(b) Plot the output voltage waveform and calculate its average value.

7) **Consider the single-phase thyristor rectifier with a source inductance (L_s) of 5mH as shown below. The input is a sinusoidal voltage with peak value of 300V at a frequency of 50 Hz and the DC-side current (i_d) is constant at 20A. For a delay angle (α) of 30°, (5 points)**



(a) Plot the source current (i_s) and calculate the input displacement power factor (DPF).

(b) Plot the output voltage waveform (v_d) and calculate its average value (V_d).

Formula sheet for the Midterm 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

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