Examination **ENM061 Power Electronic Converters**

Date and time Wednesday April 24th, 2019, 14:00 – 18:00

Teacher responsible: Mebtu Beza/Zeyang Geng, mobile no. +46723850963

Authorised Aids: Chalmers-approved calculators

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.

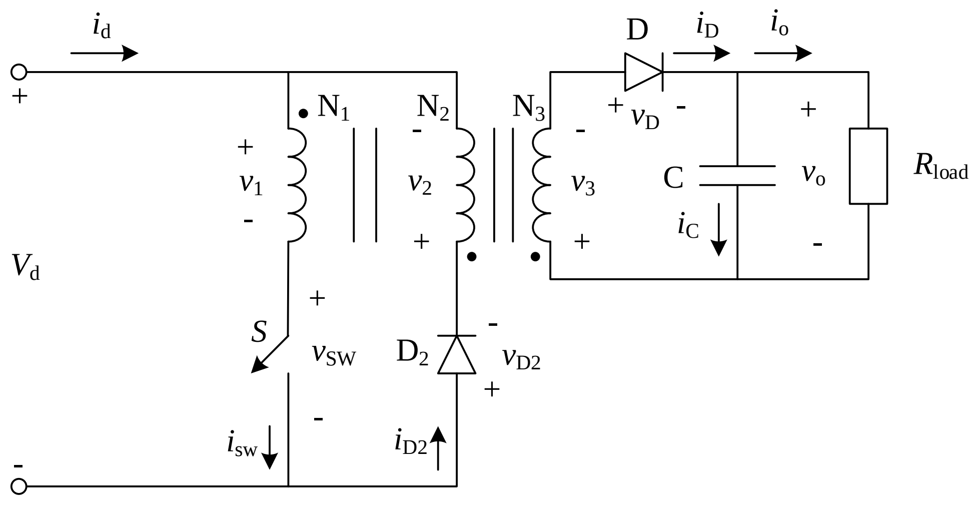
---

1) Briefly answer the following questions. ***(7 pts.)***

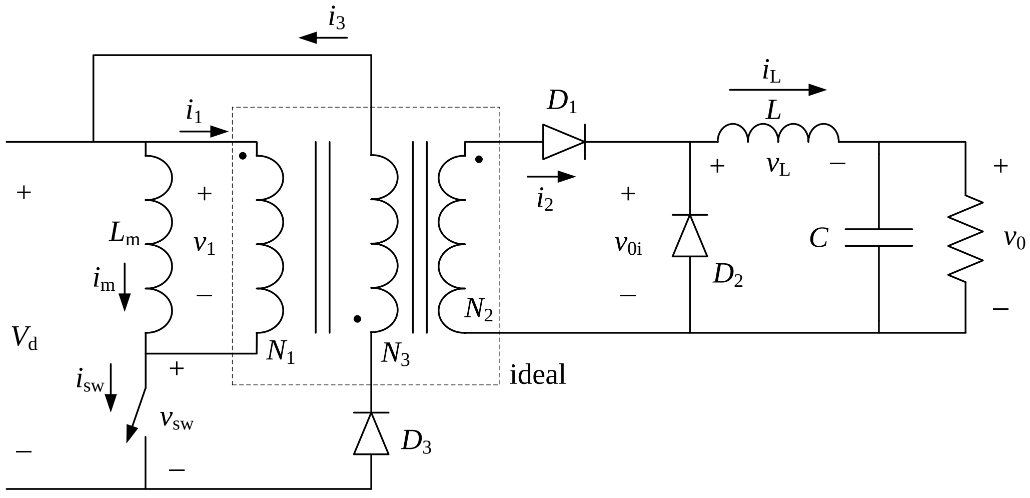
(a) In addition to increasing efficiency, why are power losses in switch-mode power converters important to consider? ***(2 pts.)***
(b) Plot the Steadystate voltage-current characteristic of a MOSFET and a thyristor. What are the basic operation differences between the two components? ***(3 pts.)***
(c) Describe how the use of an air-gap in an inductor increases the maximum saturating current and hence its operating range in DC/DC converters? ***(2 pts.)***

2) The flyback converter below has a protective winding (N_2) with the total turns ratio of the transformer as $N_1{:}N_2{:}N_3 = 0.5{:}1{:}1$ and input voltage $V_d = 25V$. The switching frequency $f_{sw} = 30kHz$, the duty cycle $D = 0.4$ and the mutual inductance $L_m = 120\mu H$. ***(7 pts.)***

(a) For $R_{load} = 15\Omega$ and 150Ω, calculate the average output voltage V_o. ***(4 pts.)***
(b) For case a, sketch the waveforms for v_{sw}, i_d and i_D. ***(3 pts.)***

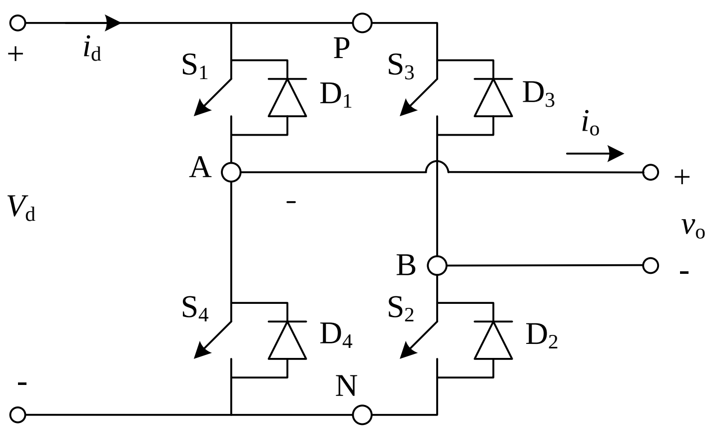


3) **The isolated 3-winding forward converter with $N_1 : N_3 : N_2 = 2 : 1 : 2$ shown below operates with an output voltage (V_o) of 20V and an output power(P_o) of 60 W for an input voltage (V_d) of 30V and a switching frequency (f_{sw}) of 30 kHz. *(11 pts.)***



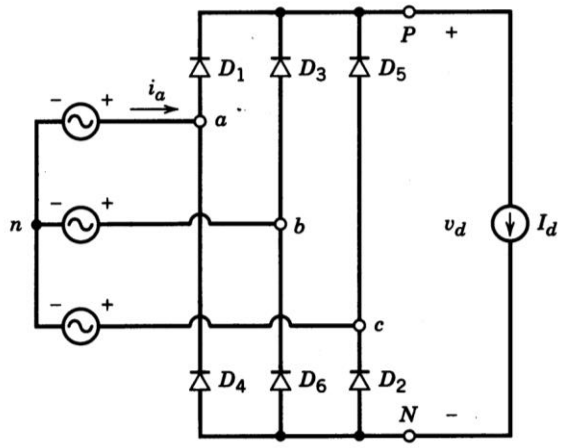
(a) Calculate the inductance (L) and the mutual inductance (L_m) in order to obtain the peak-to-peak inductor current ripple and magnetizing current ripple to be 15% and 1.5% of the average output current, respectively. ***(3 pts.)***
(b) Plot the inductor and capacitor current waveforms as well as i_1, i_3, i_m and v_{sw} for one switching cycle. Show the important points clearly. ***(4 pts.)***
(c) Calculate the minimum capacitance (C) in order to limit the maximum peak-to-peak output voltage ripple to 2% of the average output voltage. ***(2 pts.)***
(d) Calculate the corner frequency of the output filter and compare with the switching frequency if the requirement is met for good filtering. ***(2 pts.)***

4) **For the single-phase inverter shown below with an input voltage $V_d = 300V$, *(8 pts.)***



(a) 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? ***(4 pts.)***
(b) What are advantages and disadvantages of using square-wave operation? ***(2 pts.)***
(c) Using the inverter above, how can we improve the low-order harmonic content of the output voltage? ***(2 pts.)***

5) **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 *400*V.** ***(5 pts.)***



(a) Plot the source voltage and current in phase a. what is the input displacement power factor (DPF)? ***(2 pts.)***

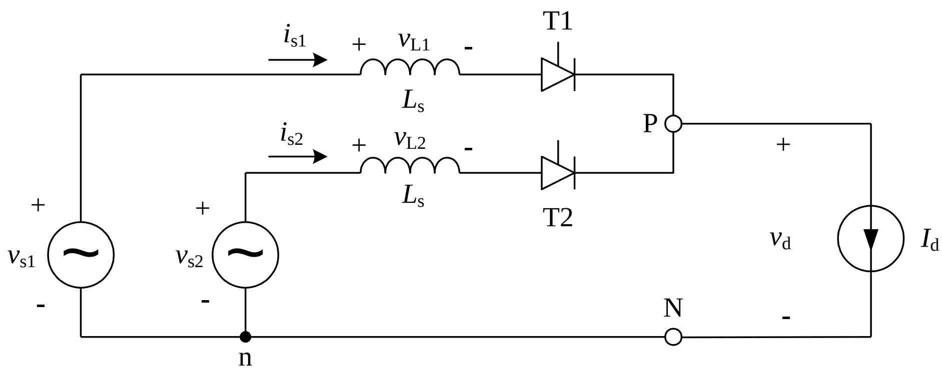
(b) Plot the output voltage waveform and calculate its average value. ***(3 pts.)***

6) **The thyristor rectifier circuit shown below is connected to the two-phases of a 50 Hz, 180 V (peak) voltage sources, v_{s1} and v_{s2} with a phase shift of 180°. Assume that the source inductance (L_s) is 5 mH and that $I_d = 15\ A$ (current-stiff source). For a delay angle (α) of** 30°, ***(8 pts.)***

(a) plot i_{s1}, i_{s2}, v_d and calculate the average value of V_d. ***(4 pts.)***

(b) Calculate the average value of V_d if the delay angle changes to 150°. ***(2 pts.)***

(c) plot i_{s1}, i_{s2}, v_d and calculate the average value of V_d if the thyristors are changed to diodes and the source inductances are negligible. ***(2 pts.)***



7) **A MOSFET of type IRF 640N is exposed to a continuous power dissipation of 2.5 W. The ambient temperature is 20°C. Without any heat sink or forced cooling, the junction-to-ambient thermal resistance is 62 °C/W.** ***(4 pts.)***

(a) Motivate if a heat sink is needed for a 150 °C maximum working temperature of the MOSFET? ***(2 pts.)***

(b) With a heat sink used, calculate the maximum junction-to-ambient thermal resistance to limit the junction temperature of the MOSFET below 100 °C. ***(2 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

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

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

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

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

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

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

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

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

Electromagnetics

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

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

Capacitor and inductor current-voltage relationship

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