Midterm Exam **ENM061 Power Electronic Converters**
Monday November 20, 2017

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Help: CTH approved calculator (Casio FX82, Texas TI30, Sharp EL531)

The bonus points are awarded as follows.

0: 0 – 4 pts.
1: 5 – 9 pts.
2: 10 – 14 pts.
3: 15 – 19 pts.
4: 20 – 25 pts.

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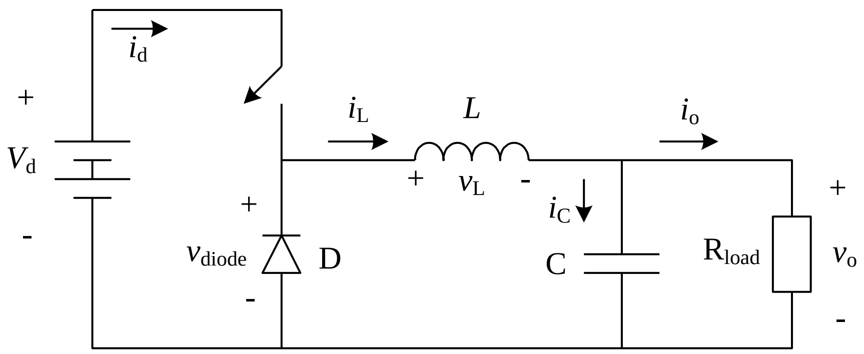
1. Briefly answer the following questions. (6 points)

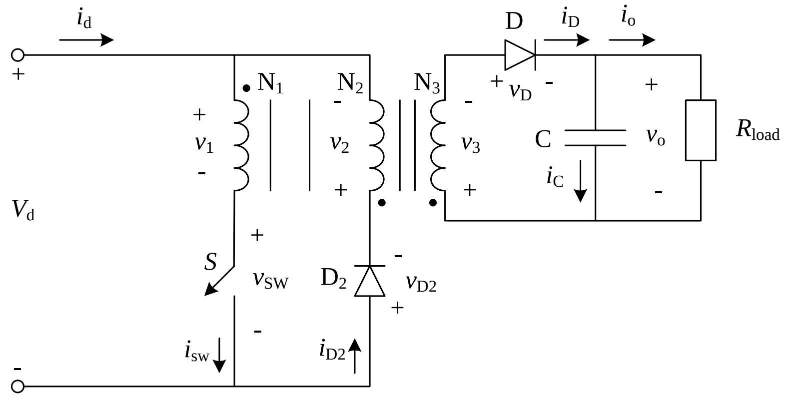
(a) What is the difference between a thyristor and a MOSFET in working principle and application?
(b) What does an equivalent-series-resistance (ESR) of a capacitor represent and why is it important?
(c) What are Fourier components in signals and why do we need to calculate them in power electronic circuits?

2. For a step-down converter with ideal components shown below, a constant output voltage (V_o) of 10 V is achieved by controlling the duty cycle D. The input voltage (V_d) is 20V, the switching frequency (f_{sw}) is 20 kHz, the inductance (L) is 100 μH, the capacitance (C) is 450 μF and the output power is 48 W. (10 points)



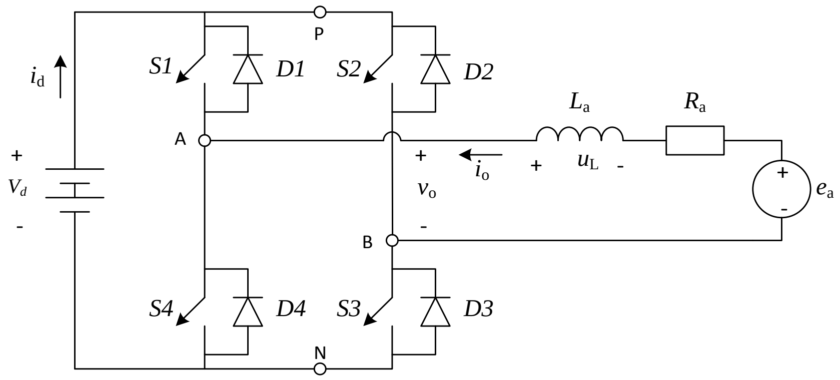
(a) Show that the converter is operating in CCM and calculate the duty cycle, D.
(b) Calculate the average output and input currents, I_o and I_d.
(c) Plot the capacitor current $i_C(t)$ and using the current plot calculate the output voltage ripple, Δv_o.
(d) What happens to the operation mode of the converter if the output power is reduced to ***8* W**.
(e) For the given switching frequency, how much should the corner frequency of the low-pass filter of the converter be? Are the chosen values of ***L*** and ***C*** satisfying the requirement?

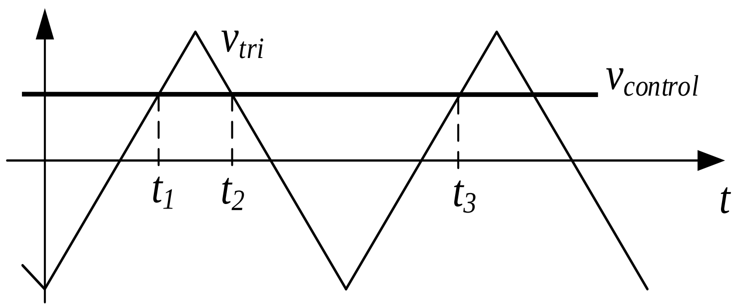
3. **The flyback converter below has a protective winding (N_2) with the total turns ratio of the transformer given by $N_1 : N_2 : N_3$ (4 points)**



For CCM and DCM operation with no current in winding N_2, derive the relationship between the output and input voltage (in terms of switching frequency f_{sw}, duty cycle D, mutual inductance L_m and load resistance R_{load}).

4. **The full-bridge DC/DC converter shown below uses a PWM bipolar voltage switching (i.e., When $v_{control} \geq v_{tri}$, *S1* & *S3* are on and *S2* & *S4* are off. When $v_{control} < v_{tri}$, *S2* & *S4* are on and *S1* & *S3* are off). For $\hat{V}_{tri} = V_d = 15V$, $v_{control} = 7.5V$ and $i_o = I_o = 5A$ (*observe the direction of the current*), (5 points)**





(a) Plot the output voltage waveform v_o and input current waveform i_d for $t_1 \leq t \leq t_3$.
(b) Calculate the average output voltage V_o and the average input current I_d.
(c) Which active components are conducting for the interval $t_1 \leq t \leq t_2$ and $t_2 \leq t \leq t_3$.

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

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

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

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

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

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

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

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

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

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

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