Midterm Exam **ENM061 Power Electronic Converters**
Monday November 21, 2016

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

The bonus points are awarded as follows.
0: 0 – 9 pts.
2: 10 – 19 pts.
4: 20 – 25 pts.

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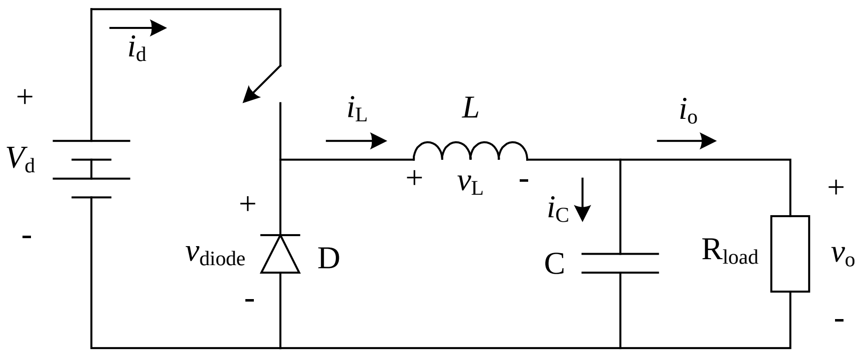
1. Briefly answer the following questions.(4 points)

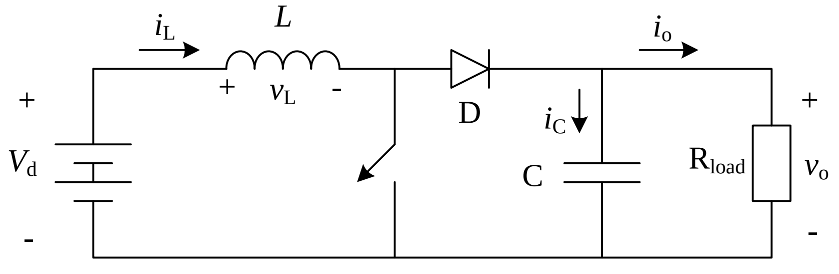
(a) What is the difference between a diode and a thyristor?
(b) What is the difference in application between a MOSFET and an IGBT?
(c) What does an equivalent-series-resistance (ESR) of a capacitor represent and why is it important?
(d) Explain the purpose of using isolation transformer in power electronic converters.

2. For a step-down converter with ideal components shown below, a constant output voltage (V_o) of 8V 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 500 μF and the output power is 50W. (6 points)

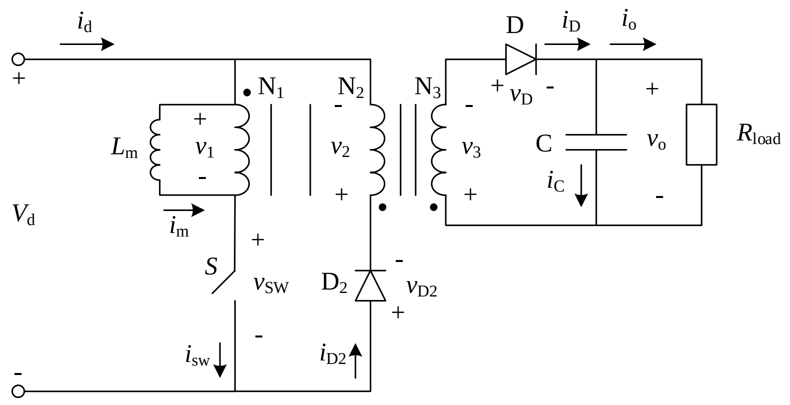


(a) Show that the converter is operating in CCM and calculate the duty cycle, D.
(b) Calculate the average output and input currents, I_o and I_d.
(c) Plot the capacitor current $i_C(t)$ and using the current plot calculate the output voltage ripple, Δv_o.

3. For a boost converter shown below and operating in CCM mode, derive the expression of the output voltage to input voltage ratio (V_o/V_d). Plot the ratio (V_o/V_d) as a function of the duty cycle (D) for the ideal and practical converter and explain the difference. (3 points)



4. **The flyback converter below has a protective winding (N_2) with the total turns ratio of the transformer given by $N_1 : N_2 : N_3 = 1 : 1 : 2$. (6 points)**

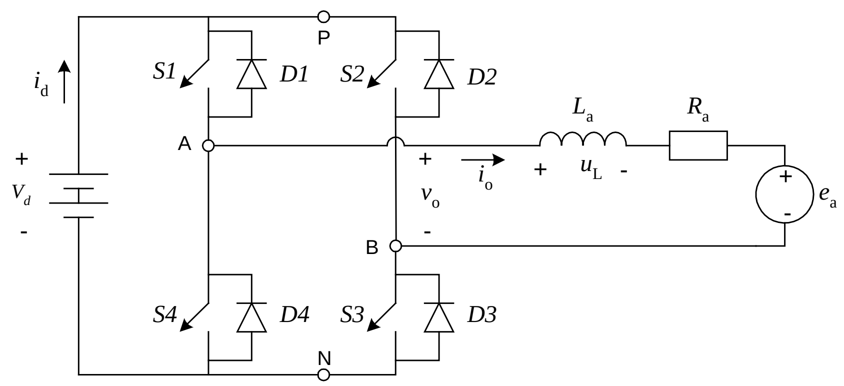


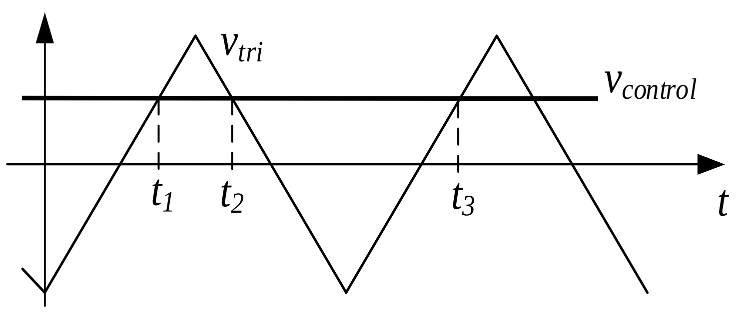
(a) For DCM operation with no current in winding N_2, derive the relationship between the output and input voltage (in terms of switching frequency f_{sw}, duty cycle D, mutual inductance L_m and load resistance R_{load}.

(b) For DCM operation and no current in winding N_2, roughly sketch the waveforms for v_1, i_m, i_d and i_D.

(c) Explain briefly how the winding N_2 limits the maximum output voltage for high value of R_{load}.

5. **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 $\hat{V}_{tri} = V_d = 20V, v_{control} = 10V$ and $i_o = I_o = 5A$, (6 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

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

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

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

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

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

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

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

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

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

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