ET4119 Electronic Power Conversion 2011/2012

Solutions 27 January 2012

1. In the single-phase rectifier shown below in Fig 1a., L_s = 1mH and I_d = 10A. The input voltage v_s has the pulse waveform shown in Fig 1b with the amplitude of 200V at 50Hz.

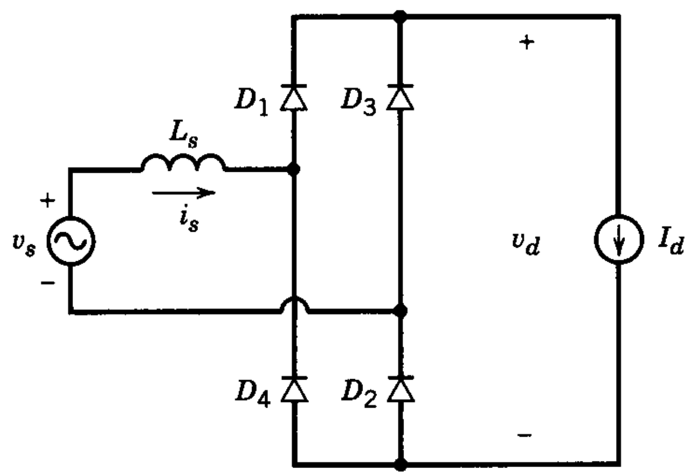


Figure 1a.

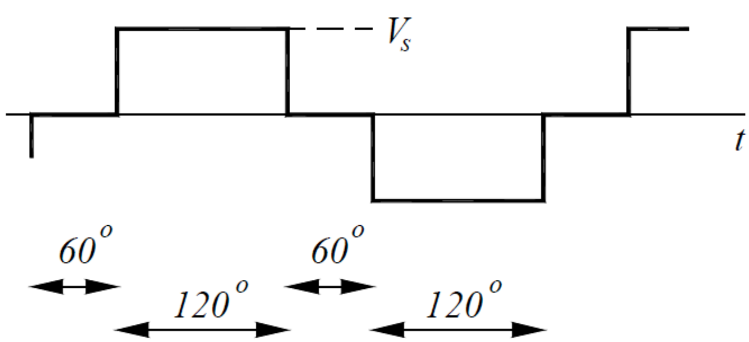
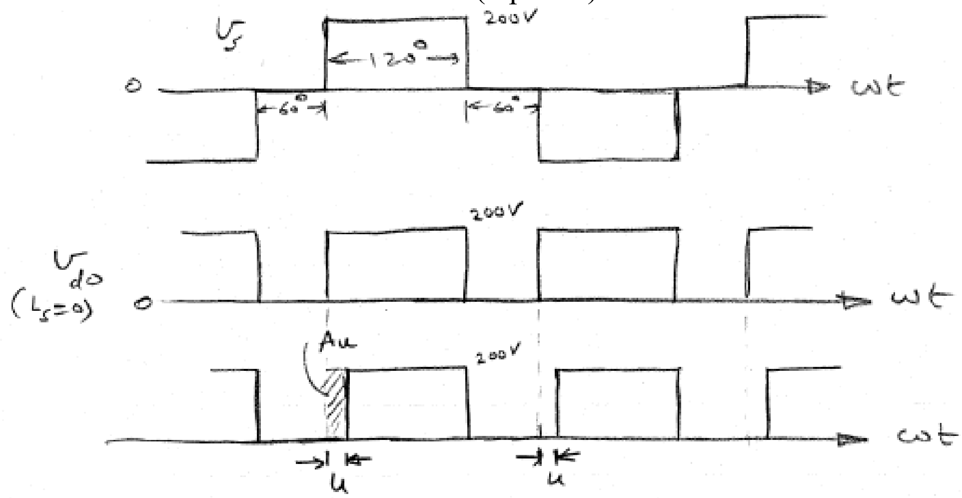


Figure 1b. Input voltage v_s

Solutions:

a. The relevant circuit waveforms are (5 points):



(5 points) Commutation interval *u* can be calculated as:

$$V_{do} = 200 \times \frac{120}{180} = 133.33\,V$$

$$A_u = 200\,u = 2\omega L_s I_d$$

$$u = \frac{2\omega L_s I_d}{200}\ \text{rad} = 0.0377\ \text{rad.}$$

b. The voltage v_d can be calculated as:

$$V_d = V_{do} - \frac{A_u}{\pi} = 133.33 - \frac{2\omega L_s I_d}{\pi} = 130.93\,V$$

c. The power delivered to the output circuit is given as:

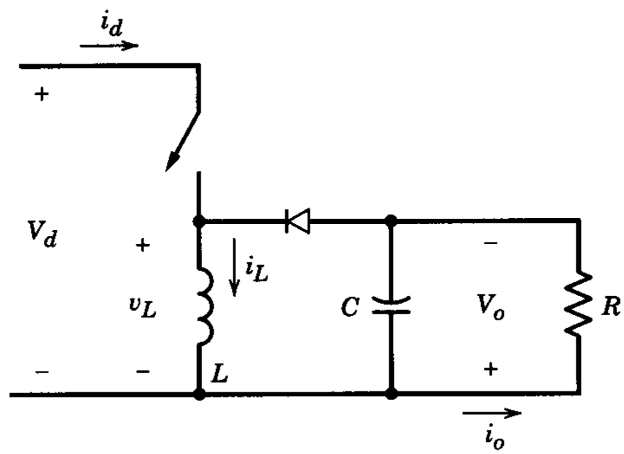
$$P_d = V_d I_d = 1309.3\,W$$

d. The voltage drop due to the commutation interval is:

$$\Delta V_d/V_d = A_u/\pi = 1.8\%$$

2. The ideal buck-boost converter is shown in figure below. The converter is operating in the continuous conduction mode (CCM). The converter's operating specifications are as follows:

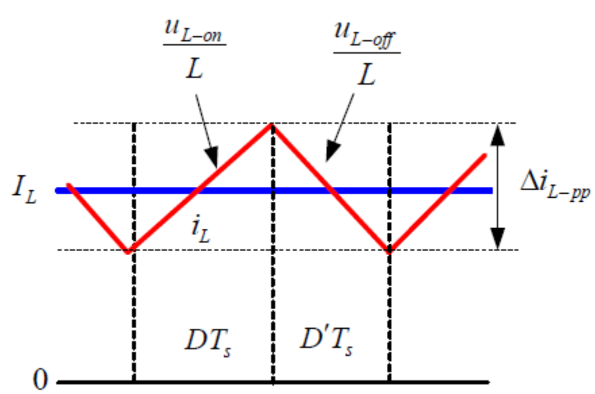
- input voltage $V_d = 30V$,
- output voltage V_o=20V
- load resistor R=4Ohm
- switching frequency f_s=40kHz.



Solutions:

a) See the book about Buck-boost converters

b)



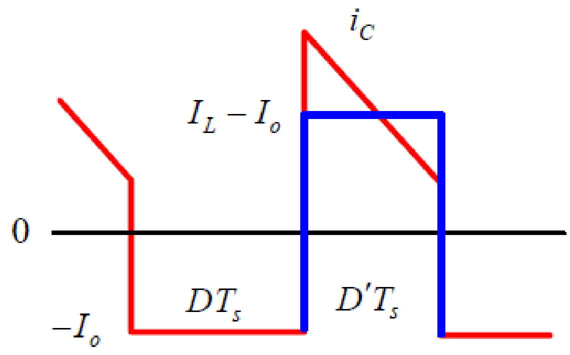
The peak-to-peak current ripple is given by:

$$\Delta i_{L-pp} = DT_s \cdot \frac{u_{L-on}}{L} = \frac{DT_s U_{in}}{L}$$

Which gives the inductance value:

$$L \geq \frac{DT_s U_{in}}{\Delta i_{L-pp}}$$

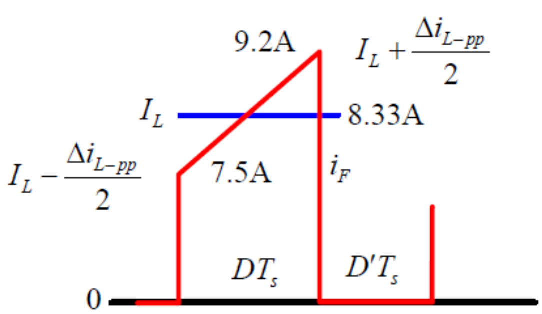
The figure below gives the capacitor current



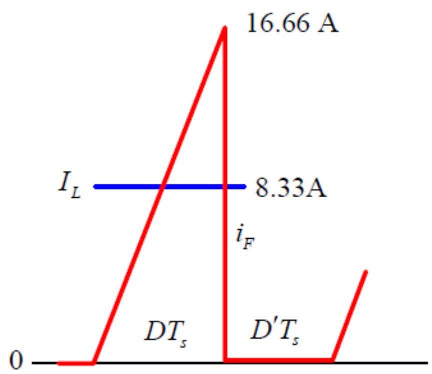
Hence the charge going into the capacitor/out of the capacitor in one switching cycle is:

$$\Delta Q = DT_s I_o . \rightarrow C \geq \frac{DT_s I_o}{\Delta u_{o-pp}}$$

c) CCM

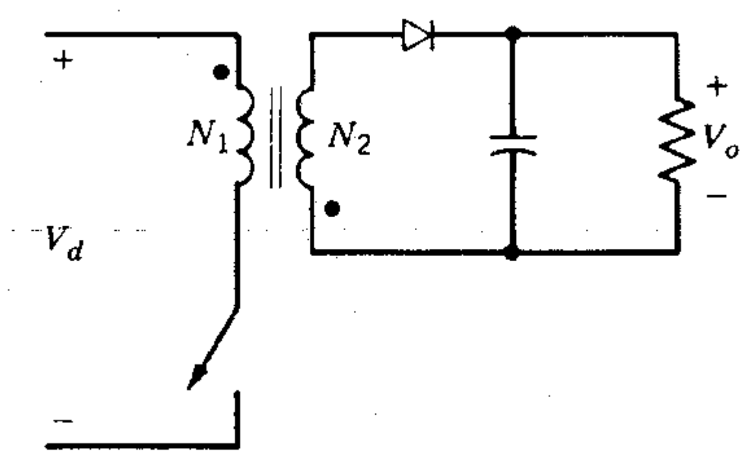


Boundary



3. Design a flyback converter operating in the discontinuous conduction mode with the following specifications:

- Input voltage $300V \le V_d \le 400V$ (nominal value 400V)
- Output power $0V \le P_o \le 50W$ (nominal value 50W)
- Output voltage $20V \le V_o \le 30W$ (nominal value 27V)
- Switching frequency f_s=50kHz
- Peak –to-peak voltage ripple ΔV_{0p_p}=20mV.



Solutions:

a) In BCM holds:

$$\frac{U_o + U_D}{U_{in}} = \frac{N_2}{N_1} \cdot \frac{D}{D'}$$

$$\frac{N_2}{N_1} = \frac{1 - D_{\max}}{D_{\max}} \cdot \frac{U_{omax} + U_D}{U_{inmin}} = \frac{0.52}{0.48} \times \frac{30V+1V}{300V} \approx \underline{0.112}$$

In BCM the peak magnetising current must equal twice the *average magnetizing current*. By applying the ampere-second balance to the output capacitor, we obtain that average current:

$$I_{LM} = \frac{1}{D'} \frac{N_2}{N_1} I_o$$

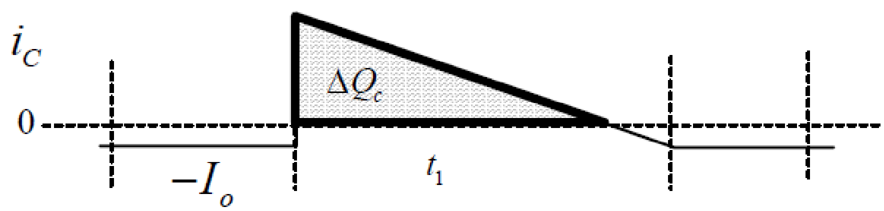
We know the peak magnetising current

$$i_{\mathrm{M,peak}} = \frac{U_{\mathrm{in}} D T_{\mathrm{s}}}{L_{\mathrm{M}}}$$

Combining the above equations:

$$i_{\mathrm{M,peak}} = 2 I_{\mathrm{LM}} \rightarrow \frac{U_{\mathrm{in}} D T_{\mathrm{s}}}{L_{\mathrm{M}}} = \frac{1}{D'} \frac{N_2}{N_1} I_{\mathrm{o}} \rightarrow L_{\mathrm{M}} = \frac{D D' U_{\mathrm{in}} T_{\mathrm{s}}}{2 \frac{N_2}{N_1} I_{\mathrm{o}}}$$

The following figure depicts the capacitor current waveform



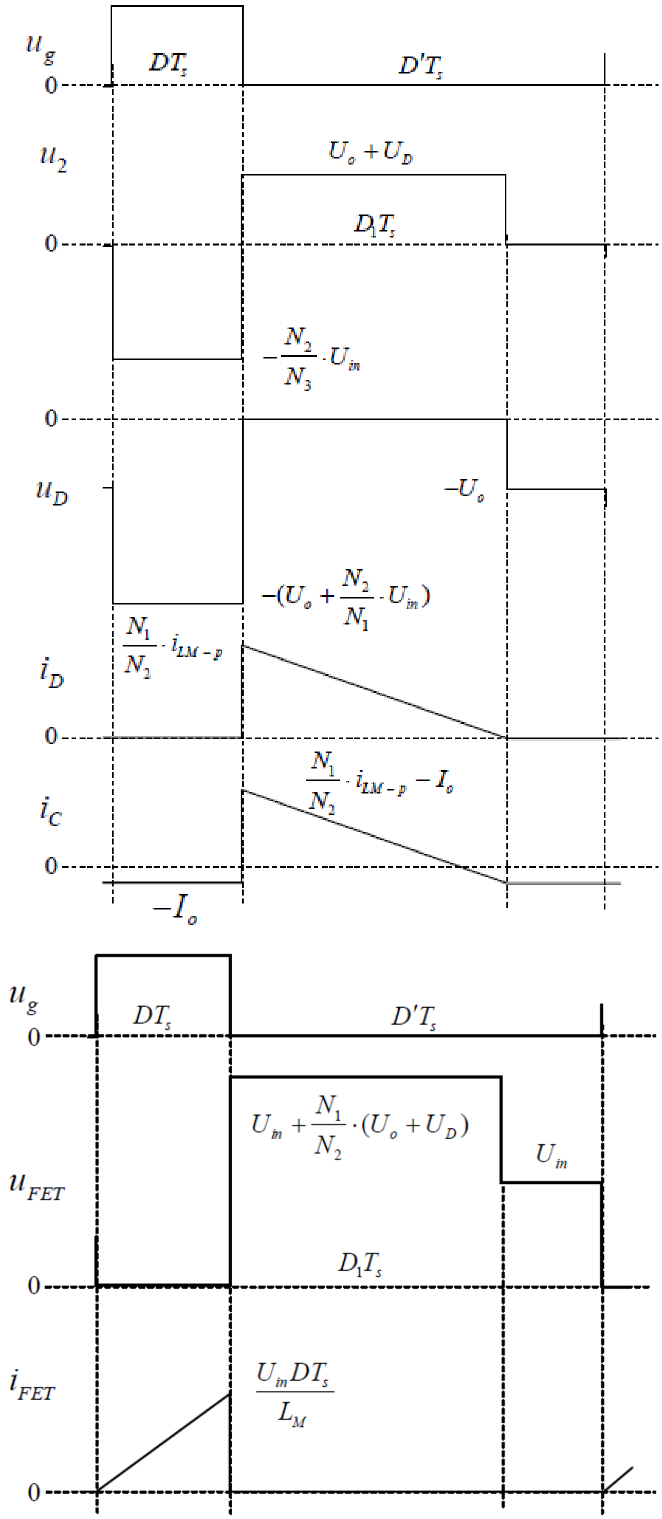
The peak capacitor current equals peak diode current minus the output current. The peak diode current equals the peak primary magnetising current multiplied by the turns ratio, as shown in figure. The falling slope of the diode/capacitor current is defined by the magnetizing inductance and its off-time voltage. Hence the time instant of t_1, at which the capacitor current crosses zero, can be given as follows:

$$t_1 = \left(\frac{N_2}{N_1}\right)^2 L_{\mathrm{M}} \frac{\frac{N_1}{N_2} i_{\mathrm{M,pk}} - I_{\mathrm{o}}}{U_{\mathrm{D}} + U_{\mathrm{o}}}$$

$$C = \frac{dQ}{du} = \frac{\Delta Q}{\Delta u_{\mathrm{o,pp}}} = \frac{1}{2} \frac{\frac{N_1}{N_2} i_{\mathrm{M,pk}} - I_{\mathrm{o}}}{\Delta u_{\mathrm{o,pp}}} t_1$$

The capacitance value should be chosen for each operating point and maximum value chosen.

b, c)



u_g
DT_s
$D'T_s$
0
u_2
$U_o + U_D$
D_1T_s
0
$-\frac{N_2}{N_3} \cdot U_{in}$
0
u_D
$-U_o$
$-(U_o + \frac{N_2}{N_1} \cdot U_{in})$
$\frac{N_1}{N_2} \cdot i_{LM-p}$
i_D
0
$\frac{N_1}{N_2} \cdot i_{LM-p} - I_o$
i_C
0
$-I_o$
u_g
DT_s
$D'T_s$
0
$U_{in} + \frac{N_1}{N_2} \cdot (U_o + U_D)$
U_{in}
u_{FET}
D_1T_s
0
i_{FET}
$\frac{U_{in}DT_s}{L_M}$
0

4. Figure 4 shows the inverter that contains a full-bridge voltage source converter.

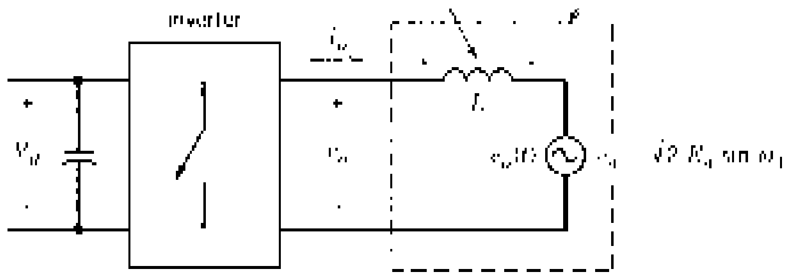


Figure 4

The output voltage v_0 of the inverter is obtained by unipolar voltage switching.

Given is further: $V_d = 350V$
$\omega_1 = 2\pi 50$
$L = 15$ mH
In the following questions 4.a and 4.b the ripple that is caused by the switching can be neglected.

Solutions:
a) See book – Eq (8-20)

b) See book page 214

c) The voltage across the inductor is given by $v_{ripple} = L \cdot \frac{di_{ripple}}{dt}$

$v_{ripple} = v_o - v_{o1}$ where v_o is the output voltage of the inverter and v_{o1} is the first harmonic (fundamental) of the output voltage.

$$i_{ripple}(t) = \frac{1}{L}\int_0^t v_{ripple}(t)d(t) = \frac{1}{L}\int_0^{t^*}(V_d - v_{o1})d(t)$$

Where $(0,t^*)$ is the time period in which the ripple voltage is larger than zero i.e. the inductor current increases. This is the case when v_o is V_d. v_{o1} is given by the input/output voltage ratio

$$v_{o1} = V_d(2 \cdot D_1 - 1)$$

And t^* is the time interval in the switching period where v_o is V_d, which is when $v_{AN}=V_d$ (which happens during D_1T_s) and $v_{BN}=0$ $(1-D_1)$, which $(2D_1-1)T_s/2$ (see Figure below)

$$i_{ripple}(t) = \frac{1}{L}\int_0^{\frac{2D_1-1}{2}} (V_d - V_d(2D_1-1))dt = \frac{1}{L}\int_0^{\frac{2D_1-1}{2}} (2V_d - 2V_d D_1)dt =$$

$$\frac{2V_d}{L}\int_0^{\frac{2D_1-1}{2}} (1-D_1)dt = \frac{V_d}{L}(1-D_1)\cdot(2D_1-1)$$

To find the maximum ripple, one needs to take the first derivative of the last expression, which gives D_1=3/4. If this is substituted in the above equation, the maximum ripple value is $V_d T_s/8L$.