ECE4643: Power Electronics

Assignment 3: Solution

Q1:

1.

2.

3.

4.

5.

Q2

A DC Buck converter has an input voltage of 50 V, and an output voltage of 25 V at a switching frequency of 100 kHz. If the load is 125 W, determine:

a) The duty cycle D.

The value of D can be determined using V_s and V_O as:

$$V_O = DV_s \Longrightarrow D = \frac{V_O}{V_s} = \frac{25}{50} = 0.5$$

b) The value of the ripple current in the inductor.

The value of the ripple current in the inductor Δi_L can be determined using the peak value of of the inductor current $I_1 = 6.25$ A and the average value of the load current I_O as:

$$I_1 = I_O + \frac{\Delta i_L}{2} \Longrightarrow \Delta i_L = 2\left(I_1 - I_O\right)$$

The average value of the load current I_O can be determined from V_O and the load power P_L as:

$$P_L = V_O I_O \Longrightarrow I_O = \frac{P_L}{V_O} = \frac{125}{25} = 5 \quad A$$

The value of Δi_L can be obtained as:

$$\Delta i_L = 2(6.25 - 5) = 2.5 \ \ A$$

c) The value of L to limit the peak inductor current to 6.25 A.

The value of the inductor L to limit the peak inductor current to 6.25 A, i.e. $I_1 = 6.25$ A can be determined using Δi_L as:

$$\Delta i_L = \frac{DV_S(1-D)T}{L} \Longrightarrow L = \frac{DV_S(1-D)}{f\Delta i_L} = \frac{0.5 \times 50(1-0.5)}{100 \times 10^3 \times 2.5} = 50 \ \mu H$$

d) The value of C to limit the output voltage ripple to 0.5%.

The value of the capacitor C to limit the voltage ripple to 0.5%, i.e. $\Delta v_O = 0.005$ can be determined as:

$$\Delta v_O = \frac{(1-D)V_O}{8LCf^2} \Longrightarrow C = \frac{(1-D)V_O}{8L\Delta v_O f^2} = \frac{(1-0.5) \times 25}{8 \times 50 \times 10^{-6} \times 0.005 \times (100 \times 10^3)^2} = 625 \ \ \mu F$$

Q3:

A DC boost converter has a supply voltage of 5 V, and an output voltage of 15 V to feed a load with 25 W. If the switching frequency is 300 kHz, determine:

a) The value of L that limit the minimum inductor current to 50$\%$ of the average current.

The average value of the load current I_O can be determined from V_O and the load power

P_L as:

$$P_L = V_O I_O \Longrightarrow I_O = \frac{P_L}{V_O} = \frac{25}{15} = 1.6667 \quad A$$

The minimum inductor current $I_2 = 0.5 I_O$, where:

$$I_2 = 0.5 I_O = I_O - \frac{\Delta i_L}{2} \Longrightarrow \Delta i_L = 2 \times 0.5 I_O = 2 \times 0.5 \times 1.6667 = 1.6667 A$$

The value of the inductor L can be determined using Δi_L as:

$$\Delta i_L = \frac{D V_S}{f L} \Longrightarrow L = \frac{D V_S}{f \Delta i_L}$$

The value of the duty cycle D can be determined using V_O and V_s as:

$$\frac{V_O}{V_s} = \frac{1}{1-D} \Longrightarrow \frac{15}{5} = \frac{1}{1-D} \Longrightarrow 1 - D = \frac{1}{3} \Longrightarrow D = \frac{2}{3} = 0.6667$$

The value of the inductor L can be evaluated as:

$$L = \frac{D V_S}{f \Delta i_L} = \frac{0.6667 \times 5}{300 \times 10^3 \times 1.66667} = 6.667 \ \mu H$$

b) The duty cycle D.

The value of the duty cycle D can be determined using V_O and V_s as:

$$\frac{V_O}{V_s} = \frac{1}{1-D} \Longrightarrow \frac{15}{5} = \frac{1}{1-D} \Longrightarrow 1 - D = \frac{1}{3} \Longrightarrow D = \frac{2}{3} = 0.6667$$

c) The minimum values of L and C to ensure the converter is in the continuous mode.

The minimum value of the inductor L_B can be determined as:

$$L_B = \frac{D(1-D)^2 R_L}{2f}; \quad R_L = \frac{V_O^2}{P_L} = \frac{15^2}{25} = 9 \quad \Omega$$

$$L_B = \frac{0.6667 \times (1-0.6667)^2 \times 9}{2 \times 300 \times 10^3} = 1.11 \quad \mu H$$

The minimum value of the capacitor C_B can be determined as:

$$C_B = \frac{D}{2fR_L} = \frac{0.6667}{2 \times 300 \times 10^3 \times 9} = 0.13 \quad \mu F$$

d) The value of current ripple in the inductor, and the value of the voltage ripple in the capacitor.

The value of Δi_L was determined as:

$$\Delta i_L = 2 \times 0.5 I_O = 2 \times 0.5 \times 1.6667 = 1.6667A$$

The value of Δv_O can be determined as:

$$\Delta v_O = \Delta v_C = \frac{I_O D}{fC} = \frac{1.66667 \times 0.66667}{300 \times 10^3 \times 10 \times C_B}$$

Please note that since the converter is in the continuous mode ($L > L_B$), then let $C = 10C_B = 1.3\ \mu$F.

$$\Delta v_O = \Delta v_C = \frac{1.66667 \times 0.66667}{300 \times 10^3 \times 1.3 \times 10^{-6}} = 2.85 \quad V$$

Q4

Design a Buck-boost DC converter to supply a load with 75 W at 50 V from a 40 V supply. The output voltage ripple $\Delta v_O \leq 1\%$. Specify the values of D, L, C, and switching frequency.

The duty cycle D can be determined using V_O and V_s as:

$$\frac{V_O}{V_s} = \frac{D}{1-D} \Longrightarrow \frac{50}{40} = \frac{D}{1-D} \Longrightarrow 1.25 - 1.25D = D \Longrightarrow D = \frac{1.25}{2.25} = 0.5556$$

The average value of the load current I_O can be determined using V_O and P_L as:

$$I_O = \frac{P_L}{V_O} = \frac{75}{50} = 1.5 \quad A$$

The value of the capacitor C can be determined using $\Delta v_C = \Delta v_O$ and the switching frequency f as:

$$\Delta v_C = \Delta v_O = \frac{DI_O}{fC} \Longrightarrow C = \frac{DI_O}{f\Delta v_O} = \frac{0.55556 \times 1.5}{0.01f}$$

Select $f = 250$ kHz.

$$C = \frac{0.55556 \times 1.5}{0.01 \times 250 \times 10^3} = 312 \ \ \mu F$$

In order to investigate the mode of operation, the value of C_B is determined and compared with C. The value of C_B is determined as:

$$C_B = \frac{DI_O}{2fV_O} = \frac{0.5556 \times 1.5}{2 \times 250 \times 10^3 \times 50} = 0.003 \ \ \mu F$$

Since $C > C_B$, the converter is in the continuous mode. The value of L can be determined using L_B as:

$$L_B = \frac{(1-D)V_O}{2fI_O} = \frac{(1-0.55556)50}{2 \times 250 \times 10^3 \times 1.5} = 29.63 \quad \mu H$$

Let $L = 5L_B = 150 \ \ \mu$H.

Q5

A DC flyback converter has an input of 24 V to supply an output with 40 W at 40 V. If the output voltage ripple is be limited to 0.5$\%$ and the ripple in the inductor current to 0.3$\%$ of the output average current, determine:

a) The duty cycle D, and switching frequency.

In this case, the flyback converter can be approximated by the function of the DC boost converter. The duty cycle D can be approximated using the boost converter input/output relationship as:

$$D = 1 - \frac{V_s}{V_O} = 1 - \frac{24}{40} = 0.4$$

For the switching frequency f, set $f = 150$ kHz.

b) The transformer turns ratio.

The turns ratio N_2/N_1 can be determined as:

$$\frac{N_2}{N_1} = \frac{V_O(1-D)}{DV_s} = \frac{40(1-0.4)}{0.4 \times 24} = 2.5$$

c) The value of L.

The value of L can be determined as:

$$L = \frac{V_s D}{f \Delta i_L}$$

The value of $\Delta i_L = 0.003 I_O$, which can be determined as:

$$\Delta i_L = 0.003 \times \frac{P_L}{V_O} = 0.003 \times \frac{40}{40} = 0.003 \times 1 = 0.003 \quad A$$

$$L = \frac{24 \times 0.4}{150 \times 10^3 \times 0.003} = 21.3 \quad mH$$

d) The value of C.

The value of C can be determined as:

$$C = \frac{DI_O}{f\Delta v_C} = \frac{0.4 \times 1}{150 \times 10^3 \times 0.005} = 533.33 \quad \mu F$$