Buck−Boost Converter (PE_buck_boost_3.sqproj)

Question: In the chopper circuit shown in Fig. 1, the switch (S) is switched at 10 kHz with a duty ratio (D) of 0.8. The circuit is operated in steady state and the circuit is at the boundary of continuous and discontinuous inductor current. If the switch S is an IGBT with a conduction drop of 0.5 V, find

(i) the required value of load resistance.

(ii) the approximate conduction loss in the switch.

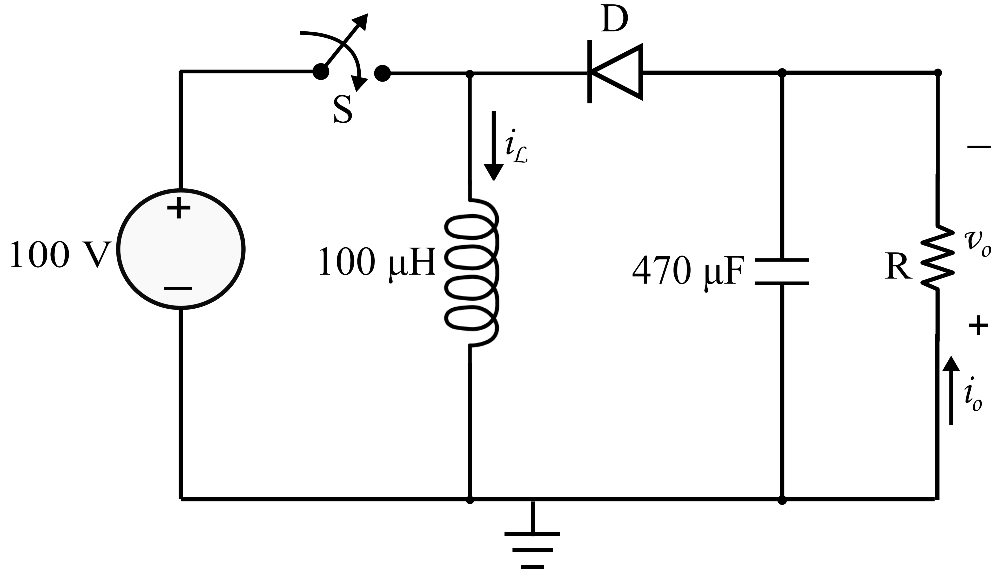

Figure 1: Buck−Boost converter

Solution :

Figs. 2 (a) and 2 (b) shows ON and OFF conditions of switch S, respectively.

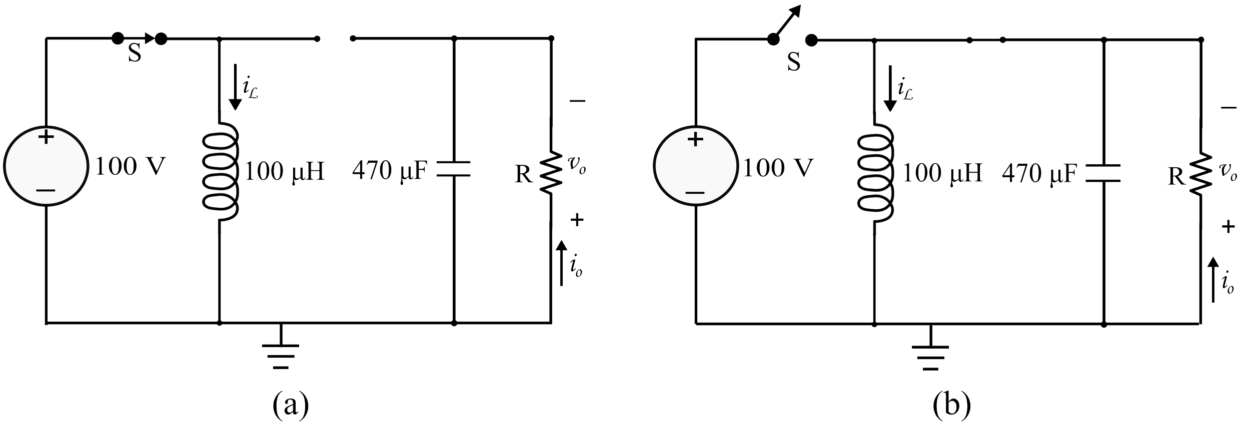

Figure 2: Buck–Boost converter circuit. (a) switch is ON, (b) switch is OFF

When the inductor current is just continuous, $I_L^{\text{avg}} = \dfrac{\Delta I_L}{2}$, where I_L^{avg} is the average inductor current and ΔI_L is the peak-to-peak ripple inductor current.

Operation : When the switch is ON $(0 < t < DT)$, the diode is reverse biased and the inductor stores energy. Alternatively, when the switch is off $(DT < t < T)$, the diode is forward biased and the inductor releases energy.

The circuit is operating under steady state, i.e., the energy stored in the inductor during the ON interval should be released during the OFF interval.

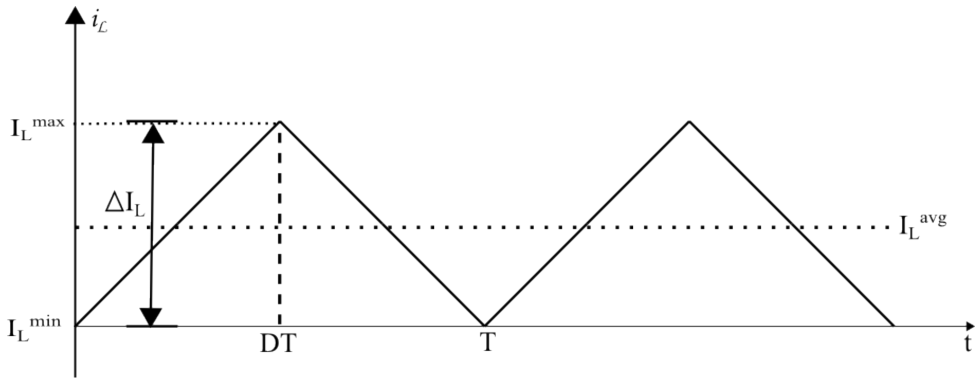

Figure 3: Inductor current waveform at the boundary of CCM and DCM mode

(i) When the switch is ON $(0 < t < DT)$, applying KVL gives

$$L\,\frac{d\,i_L}{dt} = V_{in} + 0.5\,i_L$$

Similarly, when the switch is OFF ($DT < t < T$), applying KVL gives

$$L\,\frac{d\,i_L}{dt} = -v_o$$

Applying the volt-sec balance equation,

$$\boxed{V_o = (V_{in} - 0.5)\Big(\frac{D}{1-D}\Big)}$$

$$\therefore V_o = (V_{in} - 0.5)\Big(\frac{D}{1-D}\Big) = \frac{(100-0.5)\times 0.8}{0.2} = 398\,\mathrm{V}$$

From Fig. 3, we can see that the peak-to-peak ripple inductor current is

$$\Delta I_L = I_L^{\max} - I_L^{\min}$$

At $0 < t < DT$, $\quad i_L(t) = \dfrac{V_{in}\times t}{L} + I_L^{min}$

At $t = DT$, $\quad i_L(t) = I_L^{\max}$

$$\therefore\ I_L^{\max} = \frac{V_{in}\,DT}{L} + I_L^{\min}$$

$$\boxed{\Delta I_L = \frac{V_{in}\,D}{L\,f}}$$

$$\therefore \Delta I_L = \frac{V_{in}\,D}{L\,f} = \frac{100\times 0.8}{(100\times 10^{-6})\times(10\times 10^{3})} = 80\,\mathrm{A} \quad , \quad I_L^{\mathrm{avg}} = \frac{\Delta\,I_L}{2} = \frac{80}{2} = 40\,A$$

When the switch is ON ($0 < t < DT$), applying KCL gives

$$C\,\frac{d\,v_o}{dt} + \frac{v_o}{R} = 0$$

Similarly, when the switch is OFF ($DT < t < T$), applying KCL gives

$$C\,\frac{d\,v_o}{dt} + \frac{v_o}{R} = i_L(t)$$

Applying the amp−sec balance equation,

$$\boxed{I_L^{\mathrm{avg}} = \frac{I_o}{1-D}}$$

$$\therefore I_o = 40\times(1-0.8) = 8\,\mathrm{A} \qquad ; \qquad R = \frac{V_o}{I_o} = 49.75\,\Omega$$

(ii) Applying power balance, $P_{out} = P_{in} + P_{loss}$

$\therefore V_o I_o + 0.5 I_{in} = V_{in} I_{in} \quad \Longrightarrow \quad I_{in} = \dfrac{V_o I_o}{(V_{in} - 0.5)} = \dfrac{398 \times 8}{99.5} = 32\text{A}$, where I_{in} is the average source current.

$$\therefore \text{Conduction loss in the switch} = 0.5\, I_{in} = 16\,\text{W}$$

SequelApp Exercises:

(1) In a buck−boost converter, if the switch has an on-state drop of 0.4 V and the switching frequency is 10 kHz, L is 100 μH and the duty ratio (D) is 0.6. The output voltage V_o is 50 V. Find the value of R that will make the inductor current just continuous.

(2) Also, find the switching loss (in W) in this case?

Verify your answer using SequelApp.