Buck Converter (`PE_buck_3.sqproj`)

Question: A buck converter feeding a variable resistive load is shown in the figure. The switching frequency is 100 kHz and the duty ratio is 0.6. The output voltage V_o is 36 V. Assume that all the components are ideal, and that the output voltage is ripple free.

(i) Find the value of R that will make the inductor current just continuous.

(ii) Find the average current through the diode.

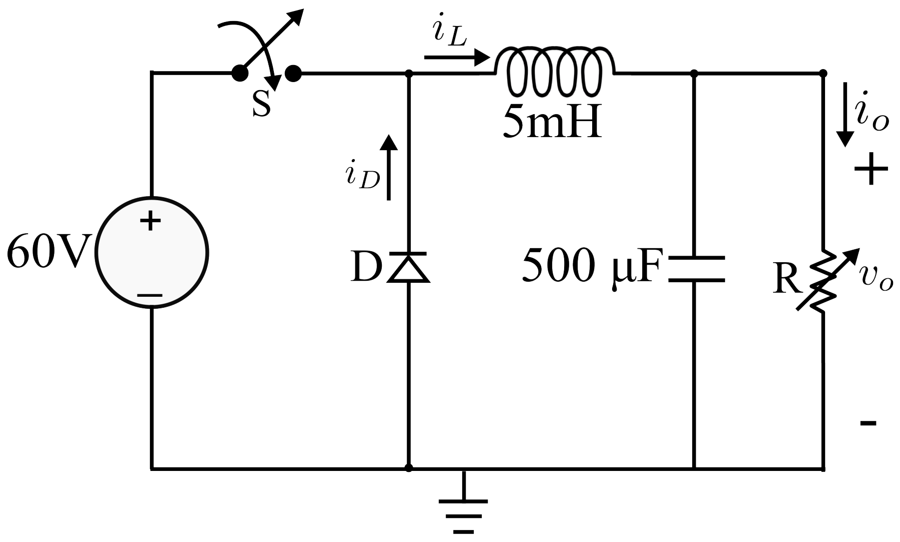

Figure 1: Buck converter

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

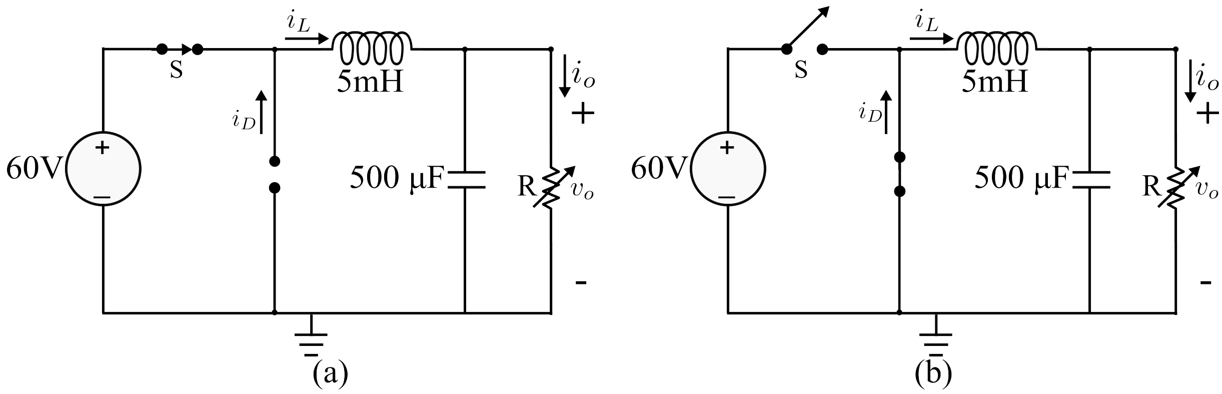

Figure 2: Buck converter circuit. (a) switch is ON, (b) switch is OFF.

When the inductor current is just continuous, i.e., at the boundary of continuous conduction mode (CCM) and discontinuous conduction mode (DCM), $I_L^{\text{avg}} = \dfrac{\Delta I_L}{2}$, 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 intervalas shown in Fig. 3..

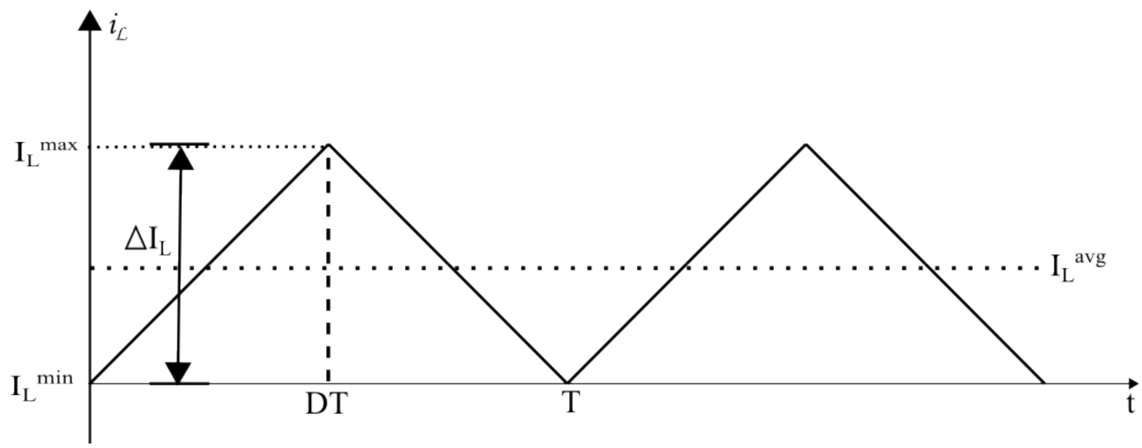

Figure 3: Inductor current waveform at the boundary of CCM and DCM mode

(i) From the Fig. 3, we can see that the peak to peak inductor current is

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

For $0 < t < DT$, $$i_L(t) = \frac{(V_{in} - V_o)\,t}{L} + I_L^{min}$$

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

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

$$\boxed{\Delta I_L = \frac{V_{in}\,D\,(1-D)}{L\,f}}$$

where, D is the duty cycle and f is the switching frequency of switch S.

$$\therefore\ \Delta I_L = \frac{60 \times 0.4 \times 0.6}{(5 \times 10^{-3}) \times (100 \times 10^{3})} = 0.0288\,A \quad , \quad I_L^{\text{avg}} = \frac{\Delta\, I_L}{2} = 0.0144\,A$$

The average current through a capacitor under steady state is zero.

$$\therefore\ I_L^{\text{avg}} = I_o$$

$$V_o = RI_o \implies R = \frac{V_o}{I_o} = 2500\,\Omega$$

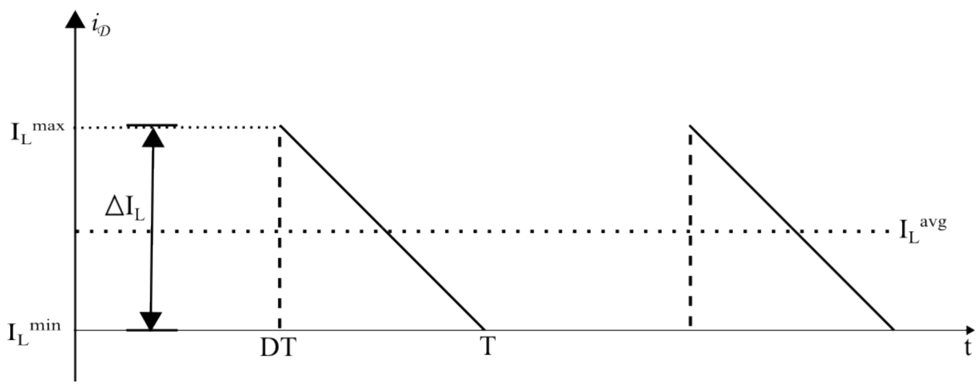

Figure 4: Diode current waveform

(ii) The diode current waveform is shown in Fig. 4. Average diode current is given by

$$I_D^{\text{avg}} = \frac{1}{T} \cdot \int_0^T i_D\,dt = \frac{1}{T} \cdot \int_{DT}^T i_D\,dt$$
$$= \frac{1}{T}\left(\frac{1}{2}\,(T - DT)\,I_L^{\max}\right) = 5.76\,\text{mA}$$

SequelApp Exercises:

1. A buck converter is feeding a resistive load of $R = 7.5\,\Omega$. The switching frequency is 100 kHz and the duty ratio is 0.5. The input voltage V_{in} is 15 V. Find the minimum value of inductance required to make the inductor current continuous.

Verify your answer using SequelApp.