Buck Converter (`PE_buck_1.sqproj`)

Question: Fig. 1(a) shows the circuit diagram of a chopper. The switch S in the circuit is switched such that the voltage V_D across the diode has the wave shape as shown in Fig. 1(b). The inductance and capacitance are sufficiently large to ensure continuous inductor current and capacitor voltage. If switch S and the diode are ideal, and source voltage is 50 V, find

(i) the average voltage across the load.

(ii) peak-to-peak ripple inductor current.

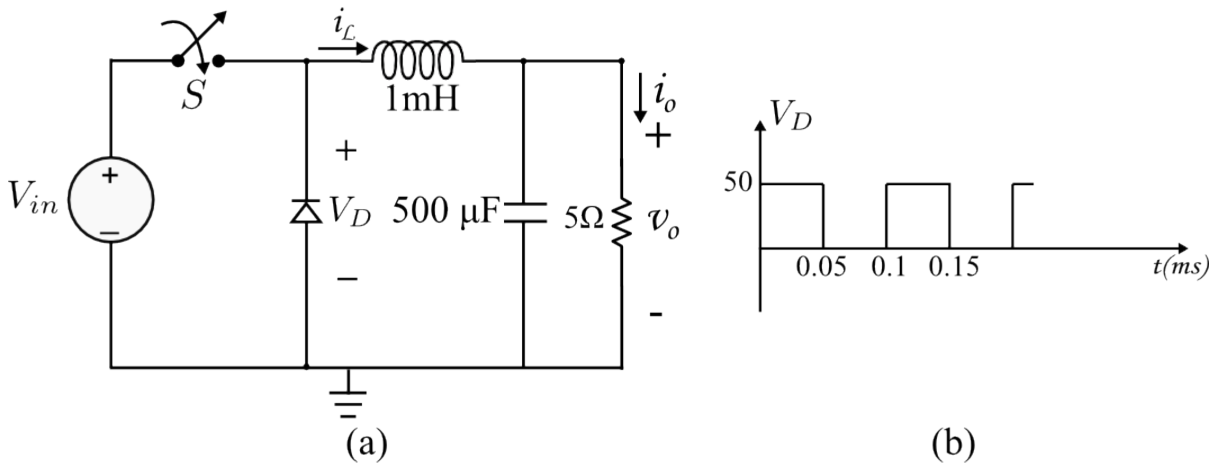

Figure 1: Buck converter .(a) Circuit diagram (b) Voltage across diode

Solution:

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

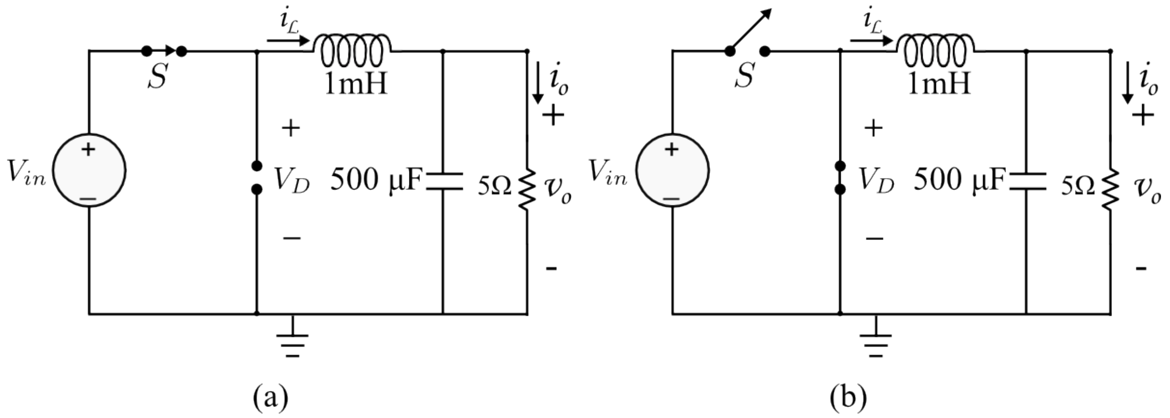

Figure 2: Buck converter circuit (a) switch is ON, (b) switch is OFF.

Operation : When the switch is ON ($0 < t < DT$), the diode is reverse biased and the inductor stores energy. Alternatively, if the inductor current is continuous, when the switch is OFF ($DT < t < T$), the diode is forward biased and the inductor releases energy as shown in Fig. 3.

We assume that 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.

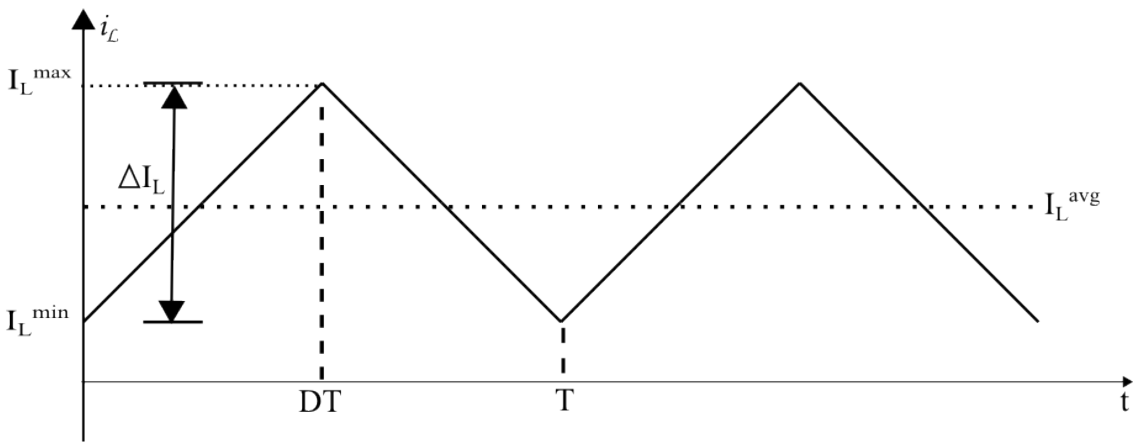

Figure 3: Inductor current waveform for continuous conduction

(i) When the switch is ON, applying KVL gives

$$L\,\frac{di_L}{dt} = V_{in} - v_o(t)$$

Similarly, when the switch is OFF, applying KVL gives

$$L\,\frac{di_L}{dt} = -v_o(t)$$

Applying the volt-sec balance equation,

$$\boxed{V_o = DV_{in}}$$

Duty cycle $(D)= \dfrac{T_{on}}{T_{\text{on}} + T_{\text{off}}} = 0.5 \qquad \therefore \text{V}_o = 25V$

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

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

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

At $t = DT$, $\qquad i_L = I_L^{\text{max}}$

where, V_o is the average voltage across the load. The voltage across the load is almost constant due to the smoothing capacitor. Hence instantaneous value (v_o) and average value (V_o) are considered as equal for inductor current calculations.

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

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

where f is is the switching frequency of switch (S). As seen from Fig 1.b, time-period of switch S is 0.1 msec and therefore frequency (f) is 10KHz.

$$\therefore\ \Delta I_L = 1.25A$$

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

SequelApp Exercises:

(1) If the inductance and resistance in Fig.1 are varied such that the peak-to-peak ripple inductor current $\Delta I_L = 3\,\text{A}$ and load current is $3\,\text{A}$, find the new inductance and resistance values, keeping all other circuit parameters same.

Verify your answer using SequelApp.