DC/DC Buck converter

Figure 2 (a) shows the circuit diagram of buck converter that use to step down the dc voltage. This is DC to DC converter. The circuit consists of switch (IGBT, MOSFET etc.) DC voltage, Inductor to stored energy, to filter ripple in DC Voltage capacitor is conncetd, diode and Load (R). Buck converter operates in two modes of operation.

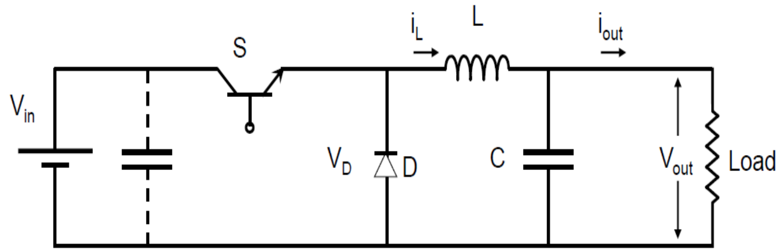

Fig.2 (a) Practical Buck converter circuit

Mode 1: The switch (IGBT, MOSFET, BJT) is turned 'ON'. As a result load is connected to battery voltage (Vin). During this period, capacitor stores energy from the input source. Inductor voltage can be obtained by applying KVL:

$$V_L = V_{in} - V_o \quad (1)$$

Mode 2: The switch is turned 'OFF'. The switch is turned off by removing gate pulse as shown in Fig.2 (b). Hence load is disconnected from the input supply. Now, inductor release its energy and hence current decreses as seen. The job of capacitor is to maintain constant voltage across the output. Inductor voltage by applying KVL:

$$V_L = -V_o \quad (2)$$

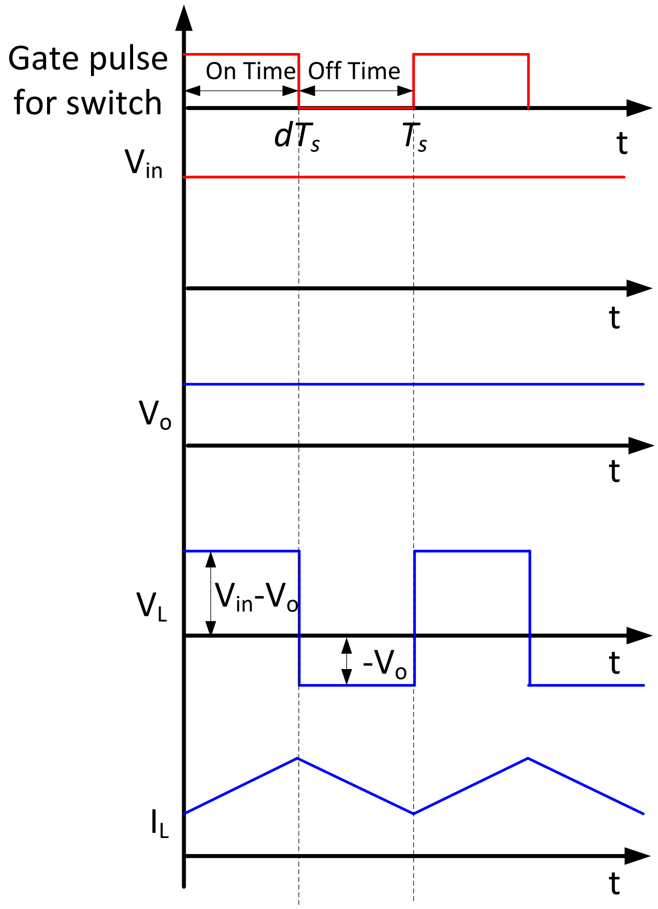

Fig. 2(b) Graphs of buck Converter: gate pulses, voltage and current waveforms

(b) During ON period of switch inductor current increses while during OFF period inductor current decreases. Average voltage Vo is obtained:

$$V_o = \frac{T_{ON}}{T_{ON}+T_{OFF}}V_{in} = \frac{T_{ON}}{T_s}V_{in} = dV_{in} \quad (3)$$

where *d* is the duty ratio is 'ON' time from the total sample time Ts.

The buck converter is used in low power electronic circuit. Battery charger is one of the famous application of buck converter [2].Laptop, USB power, small electronic gadgets power supply is generally consist of buck converter [3].

During ON time by applying KVL:

$$\frac{di_L}{dt} = \frac{V_{in} - V_0}{L} \tag{4}$$

The inductor current decreases during this period

$$\frac{I_{\max} - I_{\min}}{dT_s} = \frac{V_{in} - dV_{in}}{L}$$

$$\frac{I_{\max} - I_{\min}}{dT_s} = \frac{V_{in}}{L}(1-d)$$

$$I_{\max} - I_{\min} = \Delta I_L = \frac{V_{in}}{L}(1-d)dT_s \tag{5}$$

The above equation help us to select the inductor value. the current ripple will reduce by selecting proper value of L.

Now for voltage ripple, during on time:

$$i_c = \frac{-\Delta I_L}{2} + \Delta i_L \frac{t}{DT_S}$$

For off time: $i_c = \frac{\Delta I_L}{2} + \Delta i_L \frac{t - DT_s}{T_S - DT_S}$

$$\Delta V_0 = V_{c\_\max} - V_{c\_\max} = \frac{1}{c} \int_{dT_S/2}^{(1+d)T_S/2} i_c dt \Rightarrow \frac{1}{c} \Delta i_L \frac{T_S}{8}$$

$$\Delta V_0 = \frac{V_{in}}{8Lc}(1-d)dT_s^2 \tag{6}$$

The above equation helps to select the proper value of capacitor. The capacitor helps to reduce the voltage ripple present in output voltage.

(c)Design of buck converter:

$$V_{in} = 36V \qquad V_{out} = 12V \qquad f_{sw} = 100kHz$$
$$\Delta v_o = \mp 2\% \qquad \Delta i_L = 20\% \qquad I_o \le 10A$$

The duty ratio (d):

$$V_0 = dV_{in}$$

$$d = 12/36 = 0.33$$

let's take I_0= 8 Amp.

$$R = \frac{12}{8} = 1.5\Omega$$

Allowable current ripple is 20%.

$$\Delta I_L = 8 \cdot 0.2 = 1.6$$

$$\Delta I_L = \frac{V_{in}}{L}(1-d)dT_s$$

$$L = \frac{36}{1.6}(1-0.33)\cdot 0.33 \cdot 1 \cdot 10^{-5}$$
$$= 49.74uH$$

For continuous conduction [3] the value of R:

$R \le \frac{2L}{(1-d)T_S} \le 14.84$ This condition is satisfied.

Now for Capacitor (c):

$$\Delta V_0 = 12 \cdot 0.02 = 0.24$$

$$C = \frac{V_{in}}{8L\Delta V_0}(1-d)dT_s^2$$

$$C = \frac{36}{8 \cdot 49.74 \cdot 10^{-6} \cdot 0.24}(1-0.33)\cdot 0.33 \cdot (1\times 10^{-5})^2 = 8.33uF$$

(d) As seen in the calculation of size of L and size of C is the function of switching time Ts. As we increase the switching freqency the time Ts will decreased and hence the size of L and C will be decreased for a fixed input and output voltage level.

(e)Fig.2 (c) shows the simulink model of buck converter. The buck converter is developed to generate 12 V from the 36V input supply.

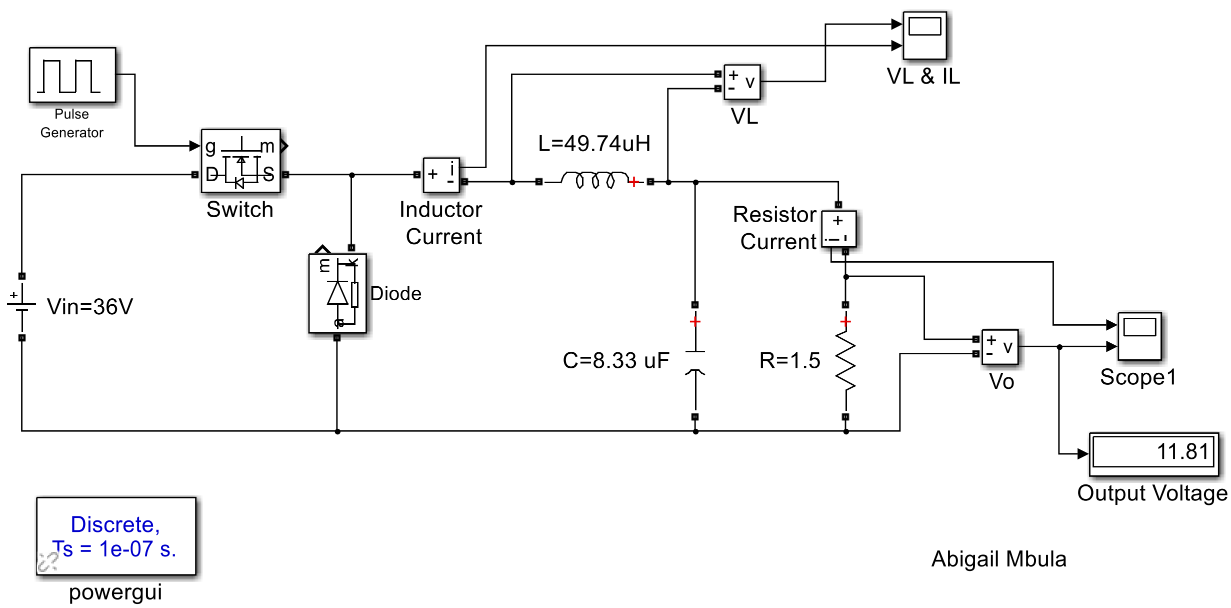

Fig.2(c) Simulink model of Buck converter

The simulation results are shown in Fig. 2(d). The output voltage is maintained 12 V and ripple content in output voltage is also as per the calculation (0.24V). The inductor current also varies from 7.1 A to 8.7 A as seen. Hence the current ripple is 1.6A and it is also match with the above calculation.

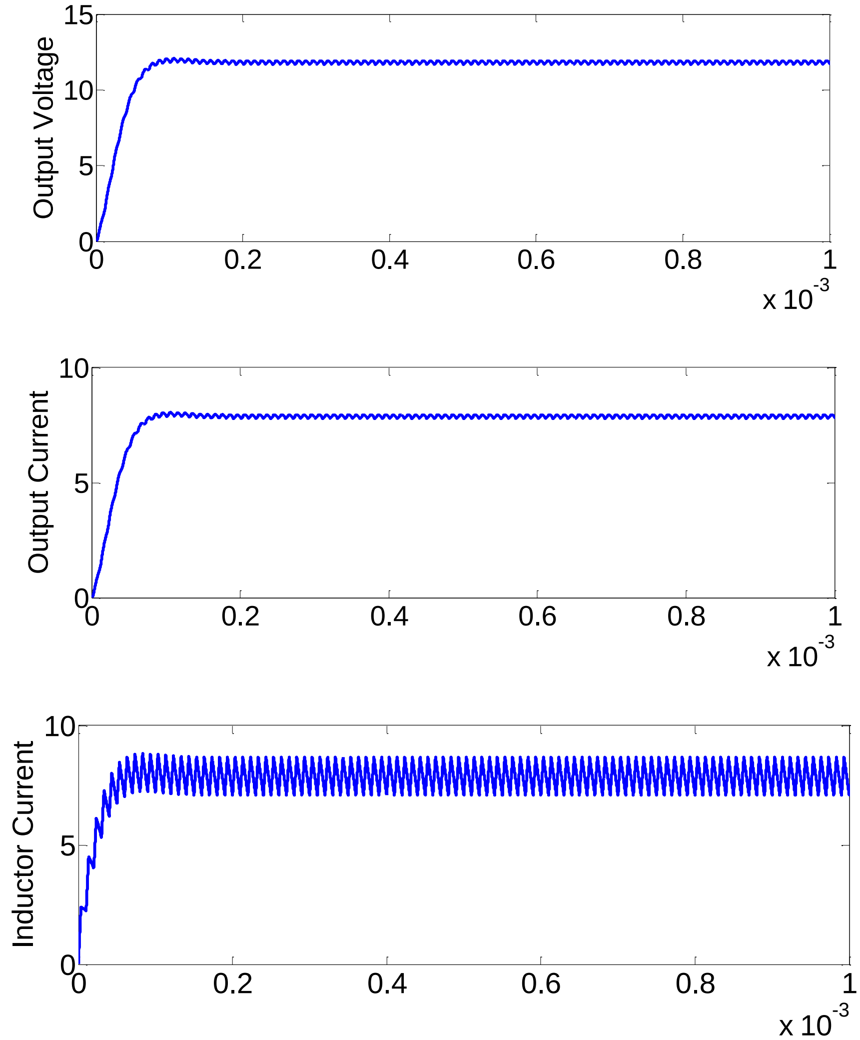

Fig.2(d) Simulation results of buck converter d=33%

(f) By reducing the duty cycle output voltage decreases to value 10.68 as shown

Calculation : $V_0 = dV_{in} = 0.3 \times 36 = 10.8$

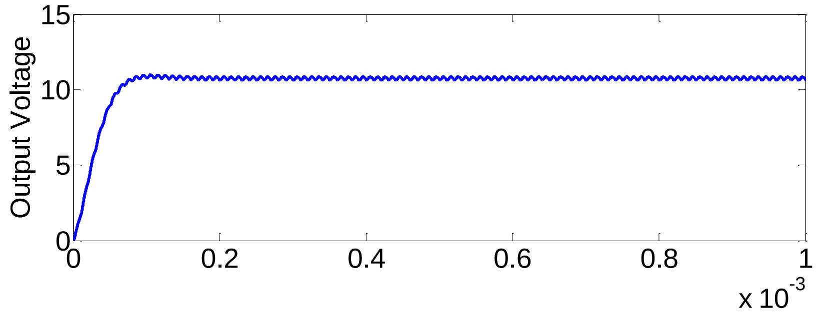

Fig.2(d) Simulation results of buck converter d=33%

By reducing the duty cycle output voltage decreases to value 12.84 as shown

Calculation : $V_0 = dV_{in} = 0.36 \times 36 = 12.96$

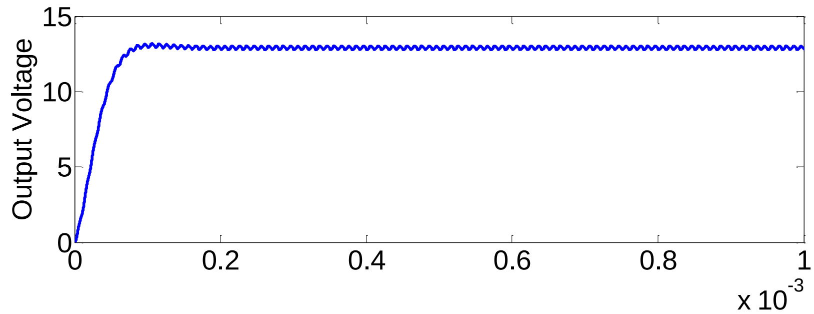

Fig.2(e) Simulation results of buck converter d=36%

The output voltage proportionally increase or decrease by increase or decrease the duty ratio.