Design of a Non-Ideal Buck-Boost Converter

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Abstract— DC-DC converters are nowadays employed in many applications of electrical and electronics equipments for converting DC voltages from one level to another. In this paper a buck boost converter is designed based on the given specifications and non-idealization of all the components used in the design is taking into considerations. Firstly formulas to be used in calculating the values of the components are derived, followed by calculating the component values and finally, simulation was carried out using Pspice simulation software to validate the operation of the buck boost converter circuit. The performance analysis, which includes the effect of non-idealization on key waveforms such as power output, voltage output and current are achieved and are discussed.

Index Terms— CCM, DC-DC Converter , Buck Boost, Non-idealities

1 INTRODUCTION

Basically, DC-DC converters are power electronics circuits designed for converting DC voltages from one level to another, often providing an output DC voltage that is regulated. These converters are employed in many electrical and electronic equipment. Examples include traction vehicles, mobile phones, computer power supplies and DC motor drives etc.. Isolated and non-isolated are two terms frequently used to describe DC-DC converter types. For the former, a transformer is used to eliminate the DC path between its input and output. For the latter, it has a DC path between its input and output. In addition, boost (*step up*), buck (*step down*) and buck boost (*step up or step down*) are the three basic converter topologies commonly used. The operation mode of these converters could either in discontinuous conduction mode (DCM) or continuous conduction mode (CCM) [1].

Literature reviews related to DC-DC power electronics converters are as follows. [2]proposed a DC/DC converter and at the same time defined power electronics associated with simple electrical networks. In 2010, [3] presented the designe and construction of a DC/DC boost, buck and buck boost converters. Furthermore, the experimental implementations of a proportional PI controller for these converters were successfully achieved. Other works associated with DC/DC power converters synthesis and control have been reported in [4, 5]. The main aim of this work is to design a buck-boost converter (non-isolated) with the consideration of all the non-idealities due to component and operating in CCM with following specification is designed;

- Input supply voltage: 80V to 110V
- Output Voltage: 19 V_{dc}
- Output Power: 750
- Output voltage ripple: <5%

The Non-Ideal Buck Boost Converter Circuit:

Figure (1) shows the equivalent circuit of the Buck Boost converter with non-ideal components.

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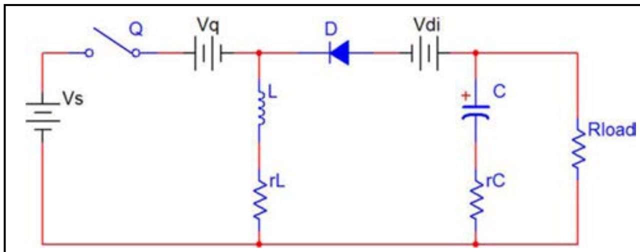

Fig. 1. Non-Ideak Bulk-Bulk Converter Circuit

The first stage in this design involves the derivation of formulas for the buck boost converter to consider the effect V_q , V_D and $r_{DC(ON)}$. Furthermore, calculations are made from the derived formulas to obtain the values circuit parameters (component) of the buck boost converter circuit as shown in Fig. (1). Then, Pspice software was used to carry out the simulation works in order to validate the performance and operation of the buck boost converter circuit. The analysis proceeds by examining important key waveform such as power, voltage and current by taking into accounts of all non-ideal components used in the design.

2 DERIVATION OF FORMULAR

a. *Analysis when the switch is closed [DT],*

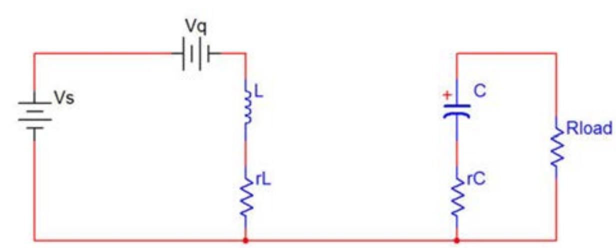

Fig. 2. Equivalent Circuit When Switch is closed.

As shown in fig. 2, when the switch is closed, by applying the Kirchhoff's voltage law, the voltage across the inductor is

$$V_L = V_s - V_q = L\frac{di_L}{dt}$$

$$\frac{di_L}{dt} = \frac{V_s - V_q}{L}$$

The rate of change of i_L is linear. Therefore, the inductor current will be;

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_s - V_q}{L}$$

$$(\Delta i_L)closed = \frac{(V_s - V_q)DT}{L} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

b. Analysis when the switch is open $[(1-D)T]$,

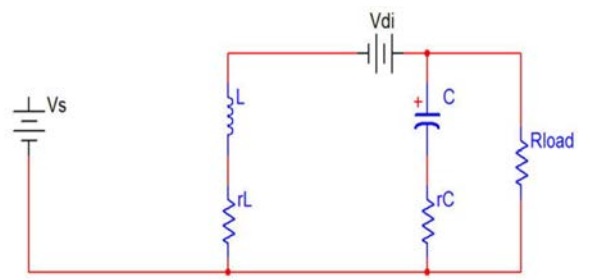

Fig. 3. Equivalent Circuit When Switch is Open.

As shown in fig. 2, when the switch is open, the diode becomes forward- biased. Therefore, in this condition the voltage across the inductor is

$$V_L = V_o - V_{di} = L\frac{di_L}{dt}$$

$$\frac{di_L}{dt} = \frac{V_o - V_{di}}{L}$$

Again, the rate of change of i_L is linear. Therefore, the change in inductor current is

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_o - V_{di}}{L}$$

$$(\Delta \boldsymbol{i_L})\boldsymbol{open} = \frac{(\boldsymbol{V_o} - \boldsymbol{V_{di}})(\boldsymbol{1} - \boldsymbol{D})\boldsymbol{T}}{\boldsymbol{L}} \ldots\ldots\ldots (\mathbf{2})$$

For steady state operation, the net of i_L must be equal to zero. Therefore, using equation (1) and (2)

$$(\Delta i_L)closed + (\Delta i_L)open = 0$$

$$V_o = \frac{-(V_s - V_q)D + V_{di}(1-D)}{1-D} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The duty cycle can be expressed as,

$$D = \frac{|V_o| + V_{di}}{V_s + |V_o| - V_q + V_{di}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Assume power input is equal to the power output and the power loss in the inductor. Therefore,

$$P_s = P_o + P_{rL}$$

$$V_s I_s = \frac{V_o^2}{R} + I_L^2 r_L$$

$$V_s I_L D = \frac{V_o^2}{R} + I_L^2 r_L$$

$$I_L^2 r_L - V_s I_L D + \frac{V_o^2}{R} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Rearranging equation (5) gives quadratic equation

$$I_L = \frac{V_s D \pm \sqrt{V_s^2 D^2 - 4r_L\left(\frac{V_o^2}{R}\right)}}{2r_c} \ldots\ldots\ldots\ldots.\ldots\ldots (6)$$

The minimum and maximum inductor current

$$I_{L(\max)} = \frac{V_s D \pm \sqrt{V_s^2 - 4r_L\left(\frac{V_o^2}{R}\right)}}{2r_L} + \frac{(V_s - V_q)DT}{L} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

$$I_{L(\min)} = \frac{V_s D \pm \sqrt{V_s^2 - 4r_L\left(\frac{V_o^2}{R}\right)}}{2r_L} - \frac{(V_s - V_q)DT}{L} \ldots\ldots\ldots\ldots (8)$$

For the minimum inductor, L_{min} to operate in continuous current mode (CCM), this can be obtained by setting I_{Lmin} to zero. By rearranging equation (8), therefore;

$$L_{min} = \frac{2r_L(V_s - V_q)DT}{V_s D \pm \sqrt{V_s^2 D^2 - 4r_L\left(\frac{V_o^2}{R}\right)}} \ldots\ldots\ldots\ldots (9)$$

The peak to peak voltage ripple can be calculated using $\Delta V_o, ESR = I_{L(\max)}\, r_c$ [6]

And, $R = \frac{V_o^2}{P_o}$

3 CALCULATION

The frequency was set to 50kHz and calculations are made using the derived formulas from section (1) to determine the duty cycle, D and the minimum induction value as shown in table 2 . The values of V_s and V_o are already specified in the objective. The value of V_q, r_L, r_c, and V_{di} is obtain from data sheet and is depicted in Table 1.

Since there are too many unknown, the value for the inductor and capacitor was chosen first with the value two times higher than the calculated value for the ideal buck-boost converter. The inductor and capacitor chosen are 11.5µH and

ISSN 2229-5518

4700µF. The value of the ripple can be calculated using the equation (7), (8) and (9).

TABLE 1
NON-IDEAL PARAMETER

Parameter	Values
Turn On Power Switch Voltage drop, V_q	1.70V
Diode Forward Voltage Drop, V_{di}	1.55V
Inductor series resistor, r_L	2.76mΩ (11.5µH)
Capacitor ESR, r_c	63.5µΩ (4700µF)

TABLE 2
DUTY CYCLE AND MINIMUM INDUCTOR NON-IDEAL BUCK-BOOST CONVERTER

Input Voltage, V_s	**110V**
Duty Cycle, D	0.1482
Inductor, L_{min}	6.946mH

TABLE 3
CALCULATION OF RIPPLE FACTOR USING CHOSEN CAPACITOR VLAUE (LET L=11.5 µH)

Input Voltage, V_s	110V
Average Inductor Current, I_L	42.456 A
Maximum Inductor Current, $I_{L(\max)}$	72.908 A
Maximum Peak to Peak Ripple Output Voltage, ΔV_{omax}	4.63
Maximum Output Ripple Voltage, r_{max}	0.023%

4 SIMULATION RESULT AND DISCUSSION

To determine the reliability of the circuit, the entire component is set to ideal during the simulation process. The 'Sbreak' rdson and vdson are both set to 1µΩ and 1µV respectively. The 'Dbreak' r'on' is also set to 1µΩ.

Table-4. Simulation result

Input Voltage, V_s	**110V**
Pulse Width, DT	2.964µs
Output Voltage, V_o	18.887V
Output Power, P_o	742W
Ripple Voltage, r	0.286%

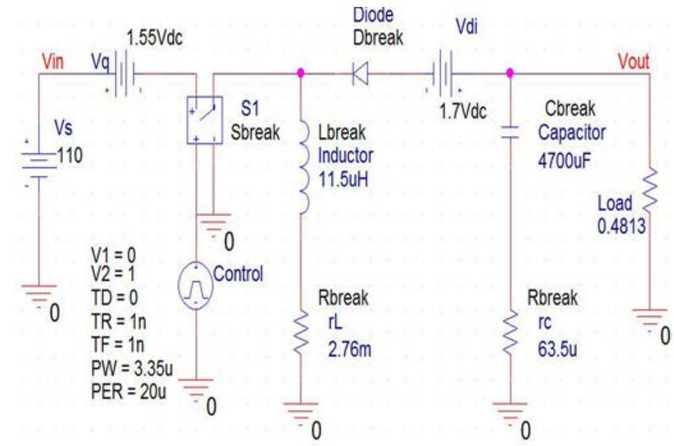

Fig. 4. Buck boost converter (with r_L and r_c) schematic diagram using Pspice software

It can be noticed in Figure 5, there is a significant power loss in the circuit which leads to a reduction in the output power, instead of 750W, 742W was obtained. The reduction in the output power is due to the resistive elements of rL and rc which is added in the circuit (rL and rc cannot be seen in practical circuit, they are only parasitic elements present in inductor and capacitors). Nevertheless, apart from that, power losses at the switch and diode also affect the output power. This leads to low efficiency. There is also a slight increment in the output voltage, instead of 19V, 20V was obtained. This may be as a result of r_L connected in series with the inductor, because the presence of r_L will affect the current flowing through the inductor.

Figure 6 shows the waveform of the inductor voltage (blue) and current (red). On the inductor voltage (blue) waveform, it can be noticed clearly, during ON state, the inductor takes the value of V_s, that is the supply voltage. During OFF state, it takes the values of V_o. For the inductor current (red) waveform, it can notice that the current flows continuously through the inductor in continuous current mode (CCM), this is an indication that the buck boost converter operates in CCM. This means that the current in the inductor always remains positive for the entire switching period.

It can be seen in figure 7 and 8, the peak current through the devices and the peak voltage of the devices are within an acceptable range for the diode and the switch to operate well in real life application. In addition, all the values have met the tolerable rating standard with that of the data sheet.

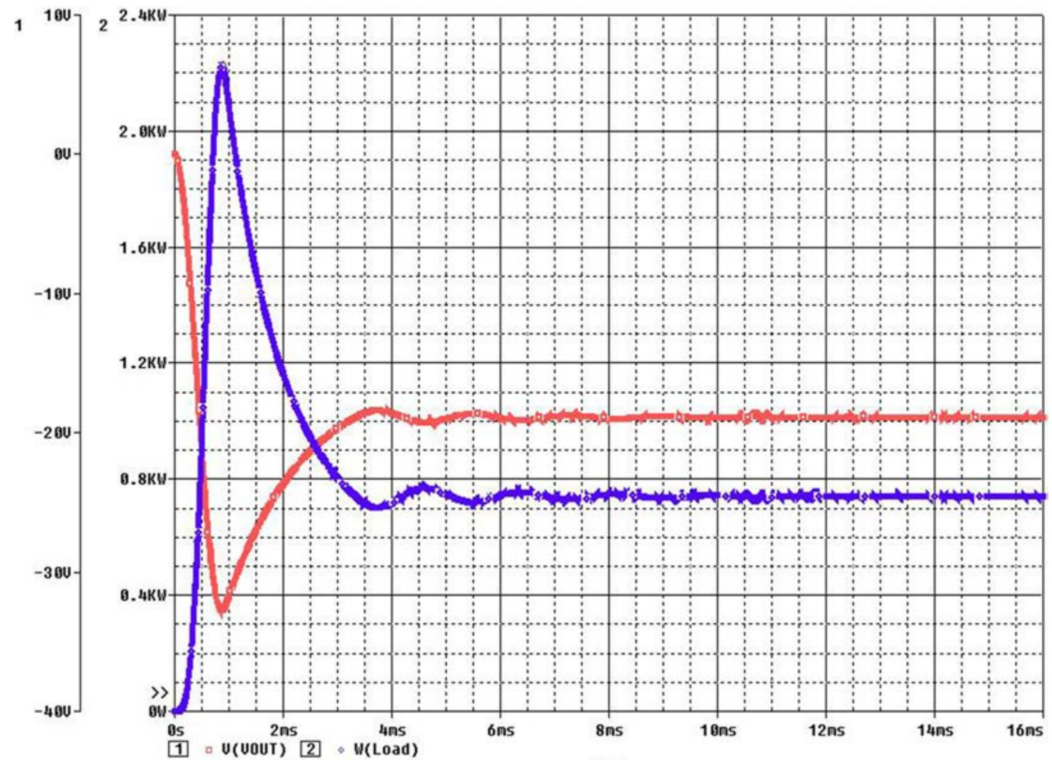

Fig. 5. Output Power (BLUE) and Output Voltage (RED) waveforms

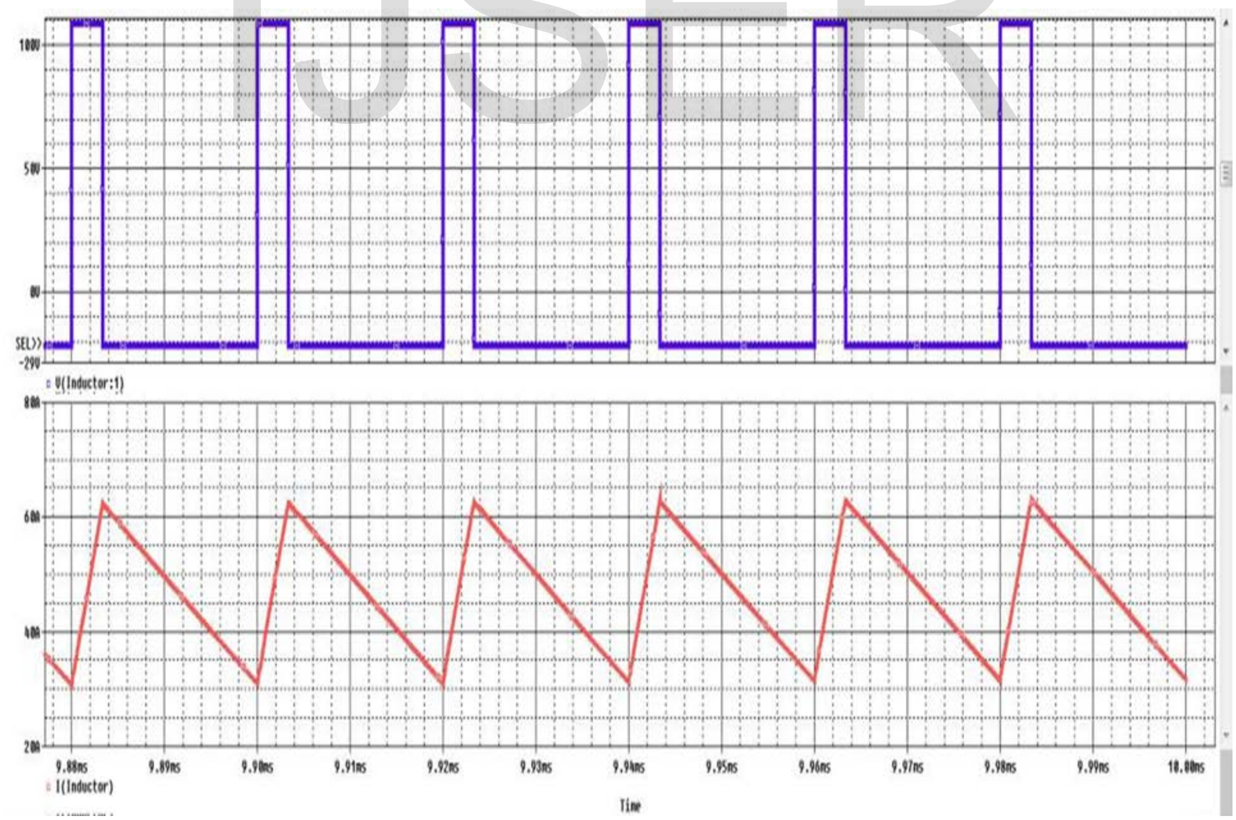

Fig. 6. Voltage Waveform (Blue) and Current Waveform (RED) of the Inductor

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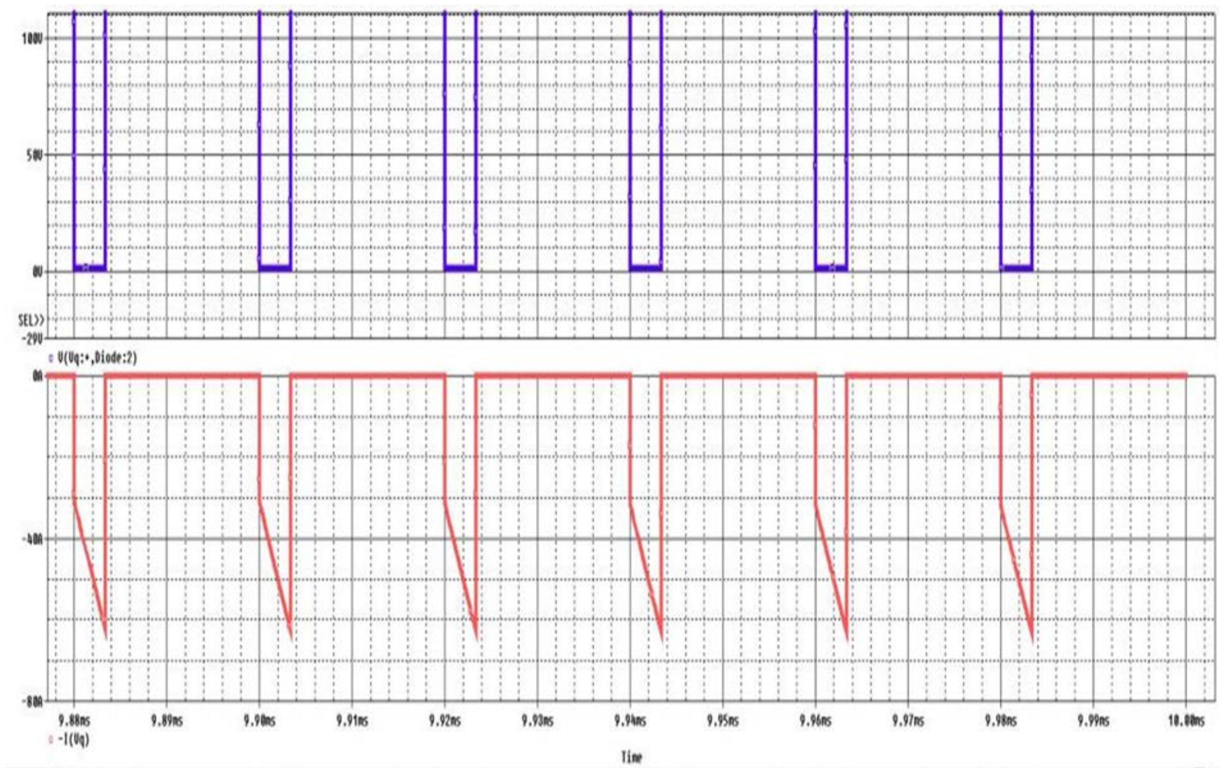

Fig. 7. Voltage Waveform (Blue) and Current Waveform (RED) of the Switch

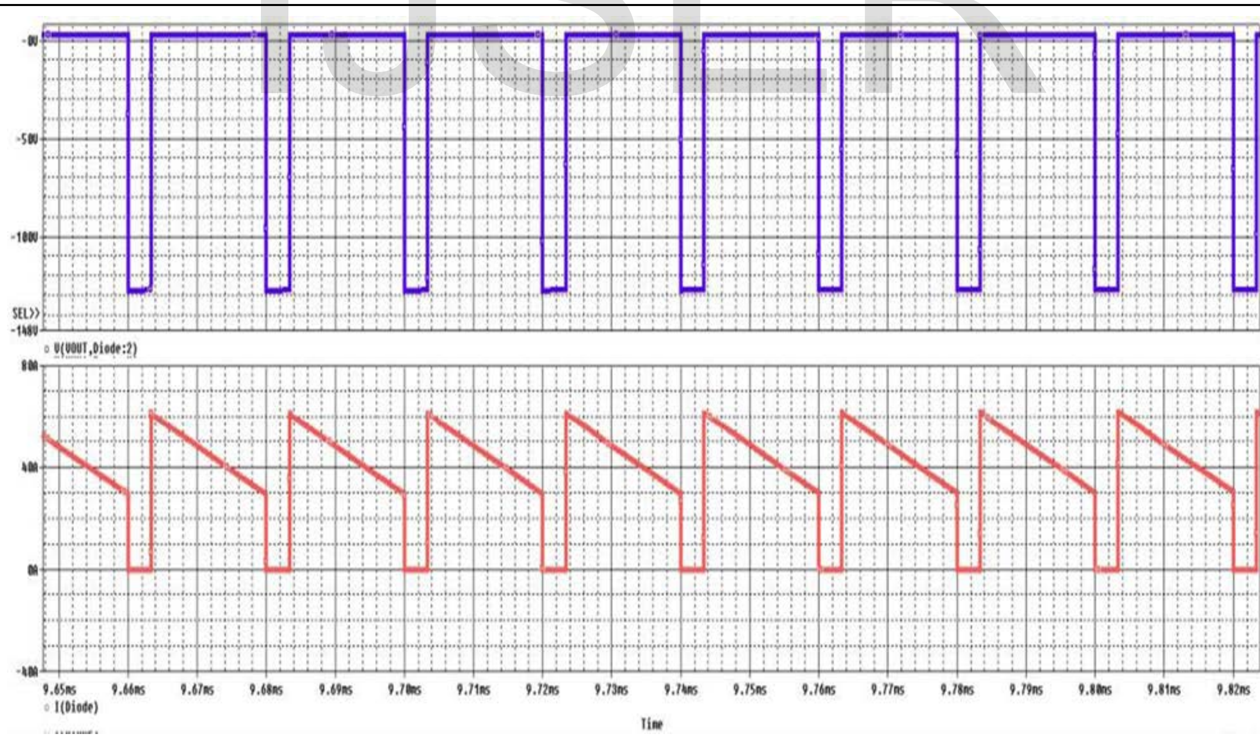

Fig. 8. Voltage Waveform (Blue) and Current Waveform (RED) of the Diode

5 CONCLUSION

The design specification which is to design a buck-boost converter with an output power of 750W, 19V output voltage and a voltage ripple of less 5% have been achieved and also the effect of non-idealities of components conforms with the simulation results obtained. Furthermore, the simulation shows that the derived equation concept can be used to determine the circuit parameters needed in designing a buck boost converter in real-life condition. This work will also serve as a guide to students to model and construct a practical circuit of their own choice.

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