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A Single Core Double Inductor Buck-Boost Converter with Positive Output Voltage

G. Kishor, M. Harsha Vardhan Reddy, R. Ramprasad, Syed Jaffer Vali

Abstract— ***The conventional Buck-Boost converter is used to step up or step down the voltage levels but with a negative output. Later on a transformer less buck boost converter is analyzed and designed to obtain a positive output voltage. This converter uses two separate cores for two inductors which increase the size of the converter and also the EMI is increased. So a new single core double inductor buck boost converter is analyzed and simulated to obtain the square times the conventional converter output and also with reduced EMI.***

Index Terms—Single core, Buck-Boost Converter, Transformer less.

1. INTRODUCTION

In general switched mode power supply is used in wide power applications like railways, aeronautics, X-ray units, industrial drives, communication systems and many other fields [1]. Many DC-DC converters have simple structure in which they can be used for different applications. Among so many converter topologies the buck boost converter has a special feature like obtaining high or low output voltage. Bust the basic converter topology is restricted to low power applications [2]. A leo converter with different structure is discussed which is used for high voltage gain and for high voltage gain and for high power applications. But this converter has limitations and has high complexity topology. Later on the isolated converters are introduced for high power applications with different transformer ratio. To obtain high voltage gain, additional components are required in quadratic converters which increases volume, cost and switching losses. The traditional buck boost converter had limitations like low voltage gain, negative output and discontinuous currents.

The non isolated converters like sepic, zeta and cuk converters also provide high and low level of outputs but have some limitations. A common ground converter is introduced to overcome the drawbacks in traditional converters with a high voltage gain. But this converter can only work for the duty ratio above 0.5. The KY converter discussed, has more advantages compared to other converters. So to realize the things and to meet the industrial needs a new converter is essential which overcome the drawbacks of all the basic converters.

In this paper a different transformer less single core buck boost converter is analyzed and discussed to obtain high voltage gain with a positive output voltage. This converter can be operated in a wide range. This converter provides the high and low output voltage by operating it with different duty ratios. This converter has a drawback that a separate core has to be used for two inductors. So some modifications had made to the converter and so a new converter with single core double inductor converter is discussed to provide the same high voltage gain with positive output.

2. STRUCTURE OF TRANSFORMER LESS CONVERTER

Fig.1 shows the conventional buck-boost converter which consists of a single inductor and a single switch. With the variation in the duty ratio the output voltage is varied. But this output voltage is negative. The limitation of this converter is, it is applicable for low power and low frequency applications. It exhibits low efficiency when operated in high frequency operations. The conventional buck-boost converter operations with the different duty ratios. The converter operates in buck mode when the duty ratio is below 0.5 and it operates in boost mode when the duty ratio is above 0.5. The output voltage of the buck boost converter is given as

$$V_0 = \frac{-D}{(1-D)} V_{IN} \qquad (1)$$

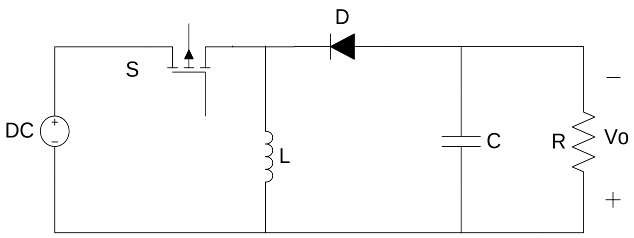

Fig.1 Conventional Buck-Boost converter

To overcome the limitation a transformer less buck-boost converter shown in Fig.2 is introduced which consists of two switches, twos diodes, two capacitors and two inductors. Here an additional switch is used to attain a maximum output voltage. Here the output voltage is square the times of the conventional converter and with a positive sign. The two switches are operated synchronously. The key waveforms of the converter are as shown in Fig.3.

The converter is operated in continuous conduction mode. The two switches are on for the on period and so the diodes are reversed biased. During this the two inductors gets

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charged and the capacitors get discharged. During the off period the switches are turned off and so the diodes get forward biased. The two inductors get discharged and the capacitors get charged.

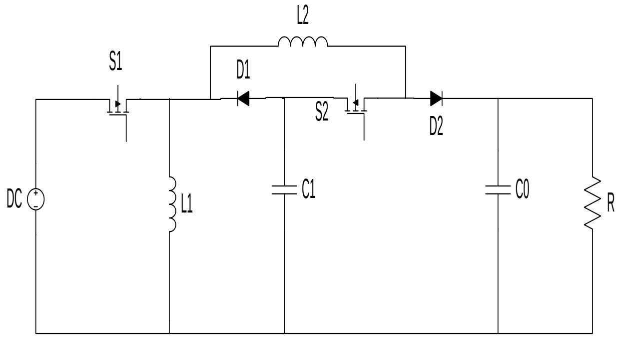

Fig.2 Transformer less Buck-Boost converter

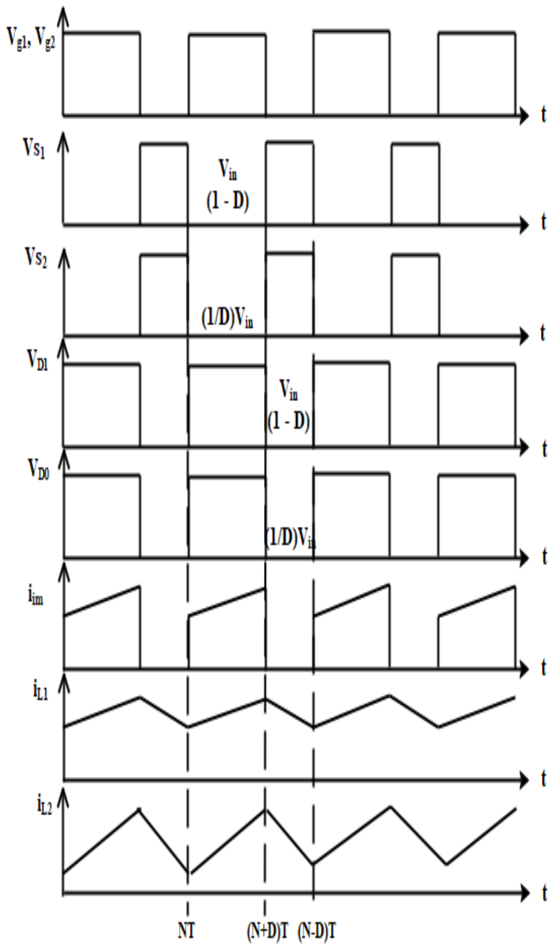

Fig.3 Key waveforms of Transformer less Buck-Boost converter

3. OPERATING MODES AND ANALYSIS

Transformer less buck-boost converter operates in two modes when operating in continuous conduction mode.

Mode 1: Fig. 4 represents the operation in mode 1. The switches are on during this mode and the diodes are off. L1 and L2 get magnetized and so the capacitors are discharged. At this stage the output is supplied from the capacitor. The interval for this mode is (NT < t < (N+D)T).

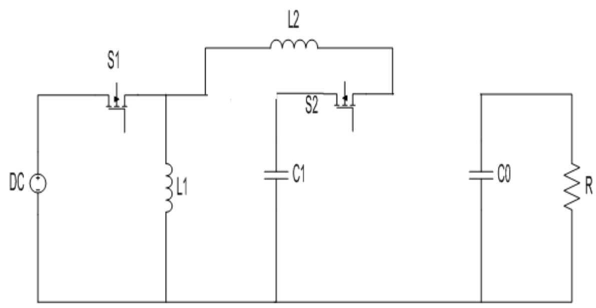

Fig.4 Mode 1 operation

The voltages across the inductors are

$V_{L1} = V_{IN}$ (2)

$V_{L2} = V_{IN} + V_{C1}$ (3)

Mode 2: Fig. 5 shows the mode 2 operation. During this mode the switch are off and the diodes are on. The two inductors L1 and L2 are demagnetized and so the capacitors are charged. At this stage the energy in the inductors is used to charge the capacitor. The interval for this mode is ((N+D)T < t < (N+1)T).

The voltages across the inductors are

$V_{L1} = -V_{C1}$ (4)

$V_{L2} = -(V_{C1} + V_0)$ (5)

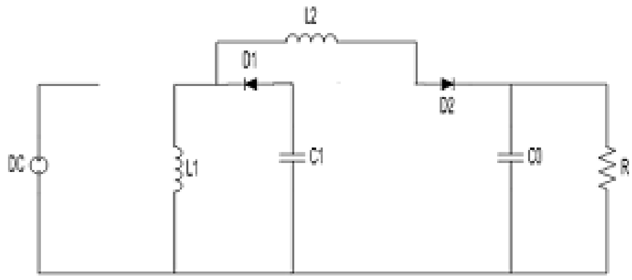

Fig.5 Mode 2 operation

Based on the volt-second balance equation the voltage across the capacitor is given as

$$V_{C1} = \frac{D}{(1-D)} V_{IN} \qquad (6)$$

Where D is the duty ratio.

By using the volt-second balance equation on inductor the output voltage is given as

$$V_0 = \left(\frac{D}{1-D}\right)^2 V_{IN} \qquad (7)$$

Based on this equation the output voltage is lesser than the input voltage when the converter duty ratio is below 0.5 and greater when duty ratio is greater than 0.5. In the similar way the current stress and the voltage stress of the switches can be evaluated for the proper analysis of the converter.

The current and voltage ripples of the inductor and capacitor is given as

$$\Delta i_{L1`} = \frac{V_{L1}}{L_1} DT_S \qquad (8)$$

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$$\Delta i_{L2} = \frac{V_{L2}}{L2} DT_S \quad (9)$$

$$\Delta V_{C1`} = \frac{\Delta Q}{C} \quad (10)$$

$$\Delta V_{C0`} = \frac{\Delta Q}{C} \quad (11)$$

4. SINGLE CORE DOUBLE INDUCTOR BUCK BOOST CONVERTER

Fig.6 shows the single core double inductor buck boost converter. Here the two inductors are placed on a single core.

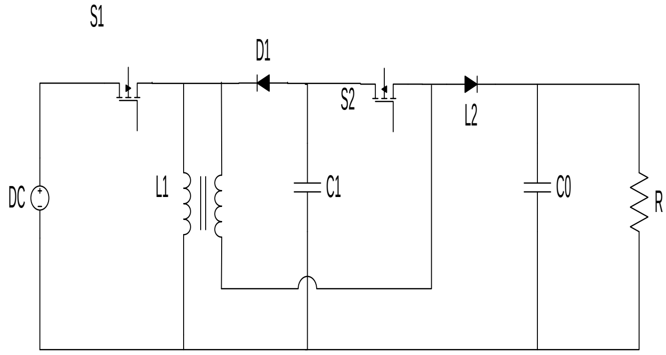

Fig.6 Single core double inductor buck boost converter

Fig.7 shows the equivalent model of directly coupled coils, in which Lk1 and Lk2 represent the leakage inductance, and Lm is the mutual inductance.

The relationships of the coupled inductors are

$$L_{k1} = L_1 - L_m$$
$$L_{k2} = L_2 - L_m \quad (12)$$
$$L_m = \alpha\sqrt{L_1 L_2}$$

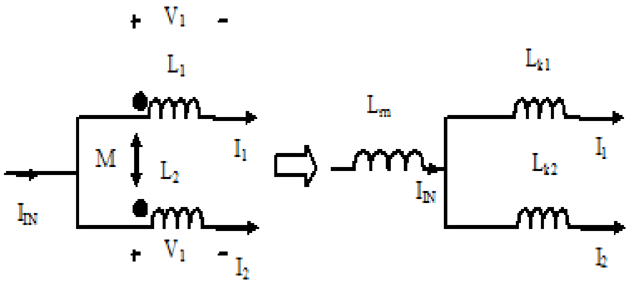

Fig.7 Equivalent model of coupled inductors

Where inductances of the two inductors mean as L1and L2, the coupling coefficient is α. For easy analisation, consider L1=L2=L and Lk1=Lk2=Lk. Assume the voltage across the coupled inductors L1, L2 is V1 and V2, respectively and it can be found as

$$V_1 = L_1 \frac{dI_1}{dt} + L_m \frac{dI_2}{dt}$$
$$V_2 = L_m \frac{dI_1}{dt} + L_2 \frac{dI_2}{dt} \quad (13)$$

After rearranging the equation (13)

$$V_1 - \frac{L_m}{L} V_2 = \left(L - \frac{L_m^2}{L} \right) \frac{dI_1}{dt}$$
$$V_2 - \frac{L_m}{L} V_1 = \left(L - \frac{L_m^2}{L} \right) \frac{dI_2}{dt} \quad (14)$$

The single core double inductor buck boost converter also maintains the same voltage gain same as the transformer less buck boost converter. The main advantage of this converter is reduced volume with increased efficiency. It reduces the board space.

5. RESULTS AND DISCUSSION

The conventional buck boost converter is simulated and the results are exhibited to study the performance of it. Table.1 shows the specifications of buck boost converter in buck mode of operation.

Table.1 Specifications of buck boost converter in buck mode

Input Voltage	12 V
Duty Ratio	0.25
Switching Frequency	25 KHz
Resistance R	3.2 Ω
Inductance L	150 μH
Capacitance C	220 μF

Fig.8 shows the pulse pattern given to the switch with a switching frequency of 25kHz. Fig.9 shows the output voltage which is negative and which is less than the input voltage. Fig.10 shows the output voltage ripple which maintains the ripple percentage of below 1% which is desirable. Fig.11 shows the current flowing through the inductor and which maintains a ripple percentage below 10%.

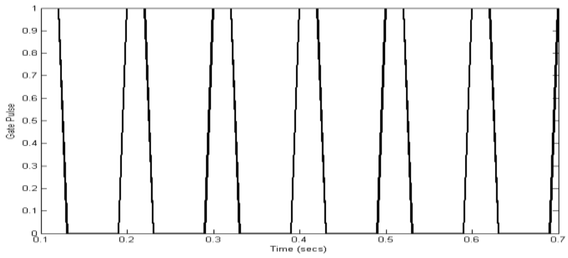

Fig.8 Pulse pattern given to switch

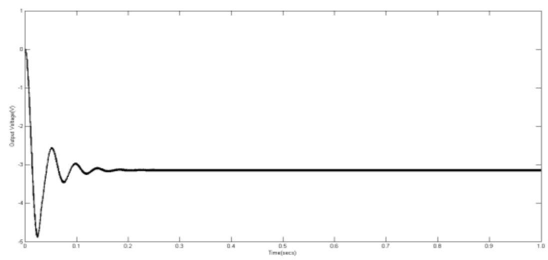

Fig.9 Output voltage

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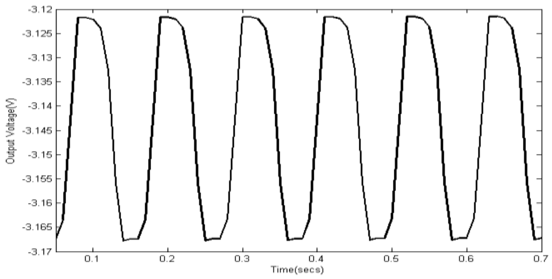

Fig.10 Output voltage ripple

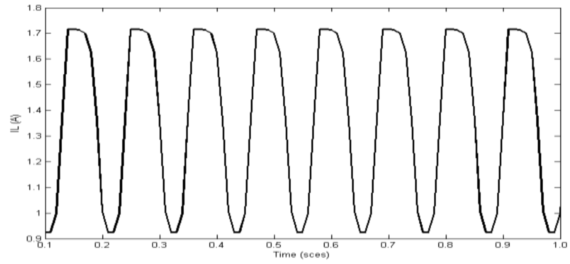

Fig.11 inductor current

With the specifications of buck boost converter in boost mode of operation with a duty ratio of 0.75.Fig.12 shows the pulse pattern given to the switch with a switching frequency of 25kHz. Fig.13 shows the output voltage which is negative and which is greater than the input voltage. Fig.14 shows the output voltage ripple which maintains the ripple percentage of below 1% which is desirable. Fig.15 shows the current flowing through the inductor and which maintains a ripple percentage below 10%.

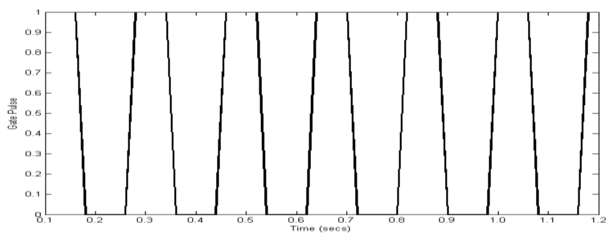

Fig.12 Switch Pulse pattern

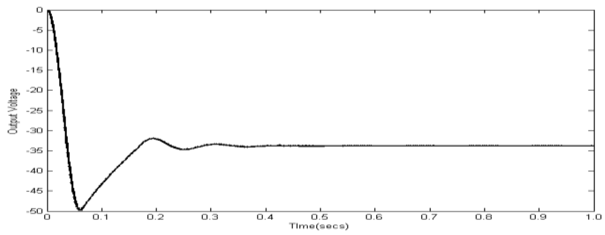

Fig.13 Output voltage

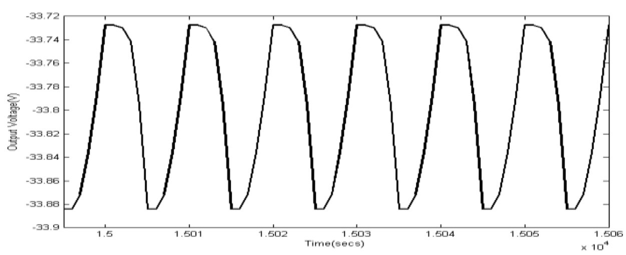

Fig.14 Output voltage ripple

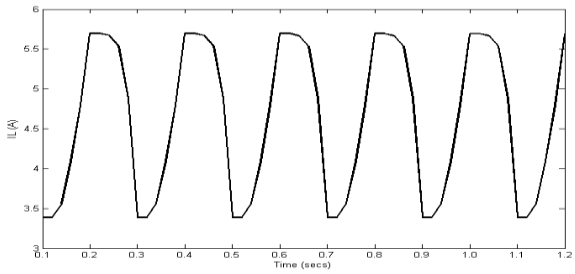

Fig.15 Inductor current

The transformer less buck boost converter is simulated and the results are analyzed in buck mode and boost mode of operation. Specifications for simulink model of a Transformer Less Buck-Boost Converter in Buck mode is as shown in Table.2.

Table.2 Specifications of Transformer less buck boost converter in buck mode

Input Voltage	18 V
Duty Ratio	0.4
Switching Frequency	20 KHz
Resistance R	30 Ω
Inductance L_1 and L_2	1 mH & 3 mH
Capacitance C_1 and C_0	10 μF & 20 μF

Fig.16 shows the pulse pattern given to the switch with a switching frequency of 20kHz. Fig.17 shows the output voltage which is positive and which is less than the input voltage. Fig.18 shows the output voltage ripple which maintains the ripple percentage of below 1% which is desirable. Fig.19 shows the current flowing through the inductor L1 and which maintains a ripple percentage below 10%. Fig.20 shows the current flowing through the inductor L2 and which maintains a ripple percentage below 10%.

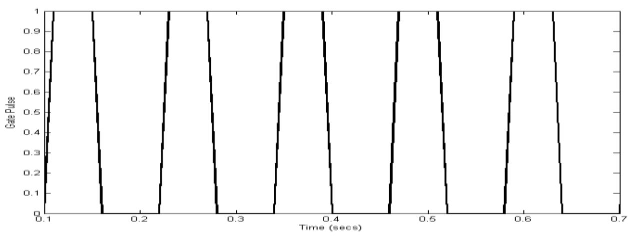

Fig.16 Pulse pattern given to switch

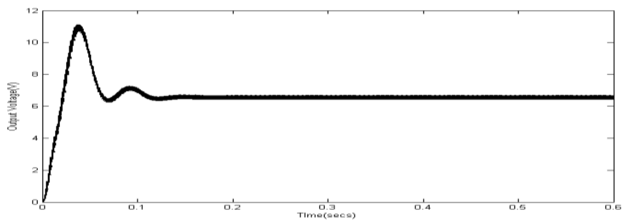

Fig.17 Output voltage

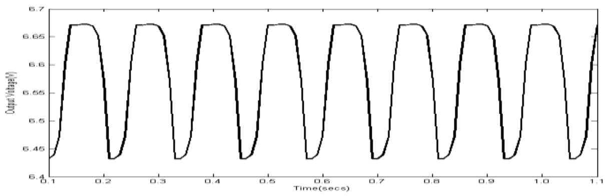

Fig.18 Output voltage ripple

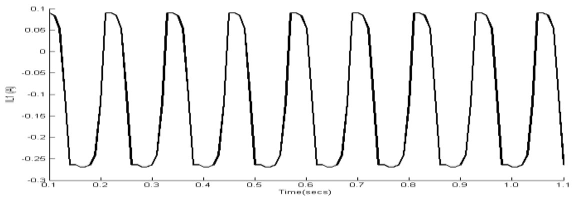

Fig.19 Inductor current through L1

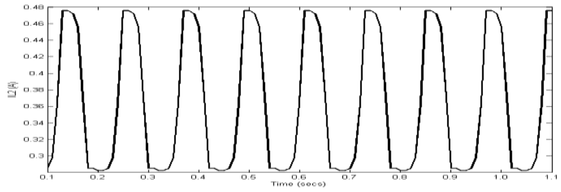

Fig.20 Inductor current through L2

With the same specifications and with a duty ratio of 0.6 the converter is simulated in boost mode and the results are as given below.

Fig.21 shows the pulse pattern given to the switch with a switching frequency of 20kHz. Fig.22 shows the output voltage which is positive and which is greater than the input voltage. Fig.23 shows the output voltage ripple which maintains the ripple percentage of below 1% which is desirable. Fig.24 shows the current flowing through the inductor L1 and which maintains a ripple percentage below 10%. Fig.25 shows the current flowing through the inductor L2 and which maintains a ripple percentage below 10%.

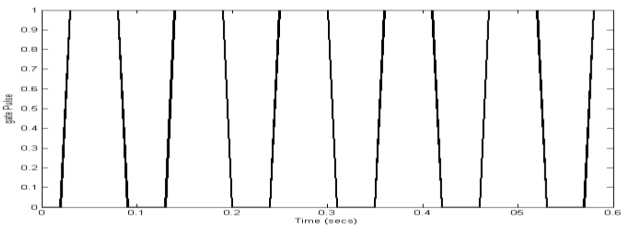

Fig.21 Pulse pattern given to switch

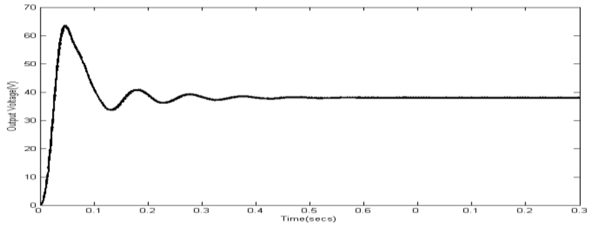

Fig.22 Output voltage

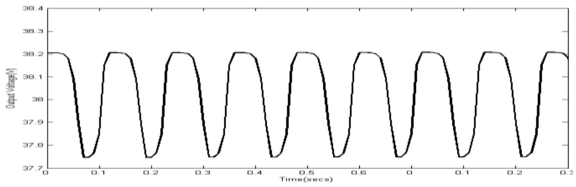

Fig.23 Output voltage ripple

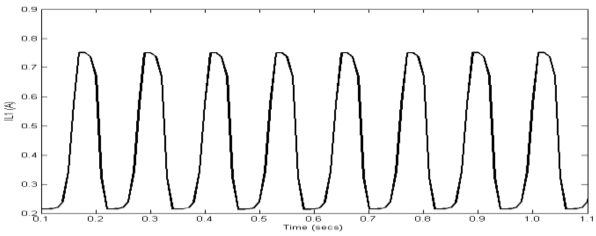

Fig.24 Inductor current through L1

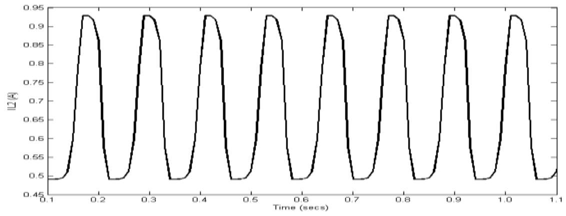

Fig.25 Inductor current through L2

Specifications for simulink model of Buck-Boost Converter with a single core inductor in Buck mode is as shown in Table.3.

Fig.26 shows the pulse pattern given to the switch with a switching frequency of 20kHz. Fig.27 shows the output voltage which is positive and which is less than the input voltage. Fig.28 shows the output voltage ripple which maintains the ripple percentage of below 1% which is desirable.

Table.3 Specifications of Single core buck boost converter in buck mode

Input Voltage	18 V
Duty Ratio	0.4
Switching Frequency	20 KHz
Resistance R	30 Ω
Inductance L_1 and L_2	1 mH & 3 mH
Capacitance C_1 and C_0	10 μF & 20 μF
Mutual inductance M	1.385 mH

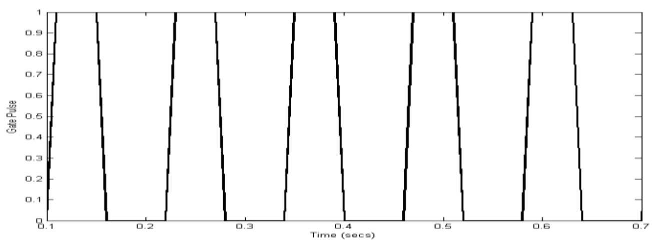

Fig.26 Pulse pattern given to switch

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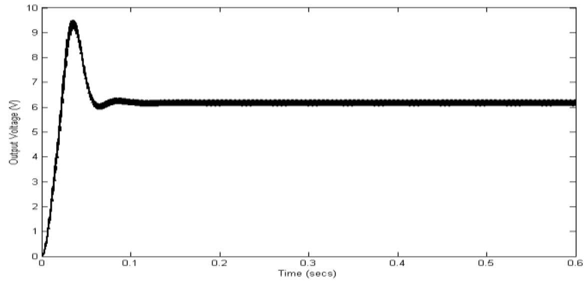

Fig.27 Output voltage

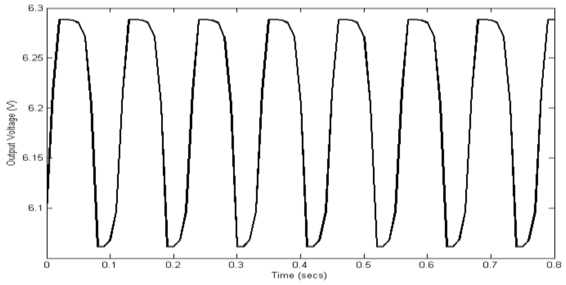

Fig.28 Output voltage ripple

Specifications for simulink model of Buck-Boost Converter with a single core inductor in Boost mode is same as previous but with duty ratio of 0.6.

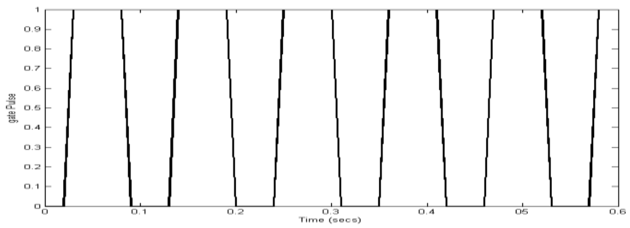

Fig.29 Pulse pattern given to switch

Fig.29 shows the pulse pattern given to the switch with a switching frequency of 20kHz. Fig.30 shows the output voltage which is positive and which is greater than the input voltage. Fig.31 shows the output voltage ripple which maintains the ripple percentage of below 1% which is desirable.

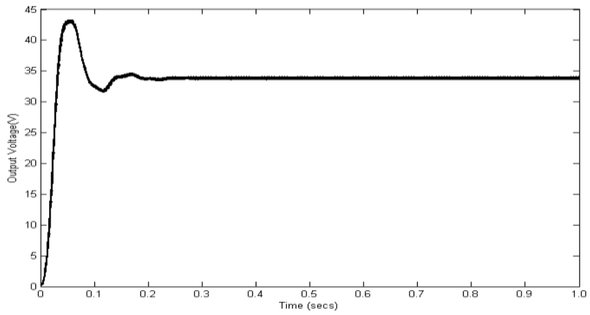

Fig.30 Output voltage

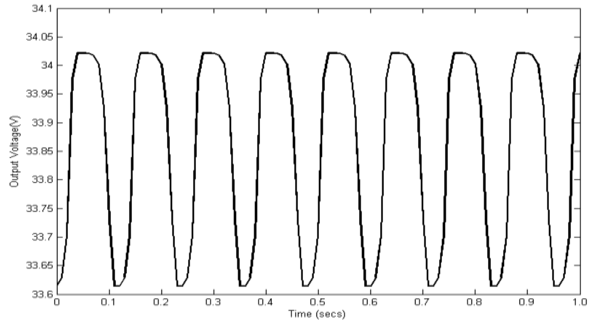

Fig.31 Output voltage ripple

The comparison of the three converters is as shown in Fig. 32. This shows that the single core double inductor buck boost converter produces the same output as transformer less buck boost converter but with a improved efficiency.

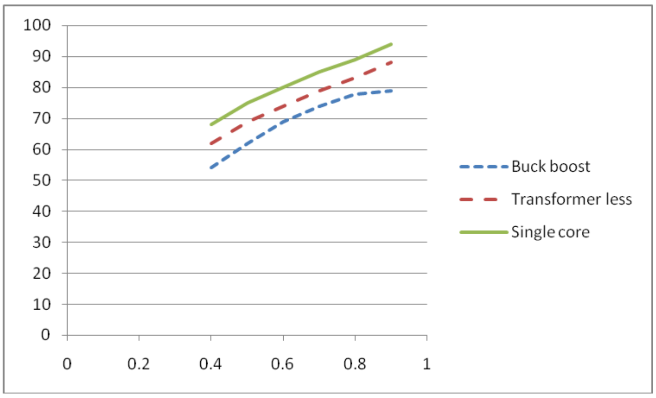

Fig.32 Comparison of converters

6. CONCLUSION

This paper had proposed a brief study on different configurations in buck boost converter topologies. A transformer less buck boost converter is analyzed and discussed to overcome the drawbacks of a conventional buck boost converter with high voltage gain. To obtain the same output with reduced size and volume a new single core double inductor buck boost converter is analyzed and discussed. A brief analysis and comparison with other converters are presented. From the theoretical and MATLAB simulation results it is proved that the two converters provides positive output voltage with high voltage gain.

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